Small Science Instruments: The Atmospheric Chemistry Experiment (ACE)

Peter Bernath

Department of Chemistry, University of York

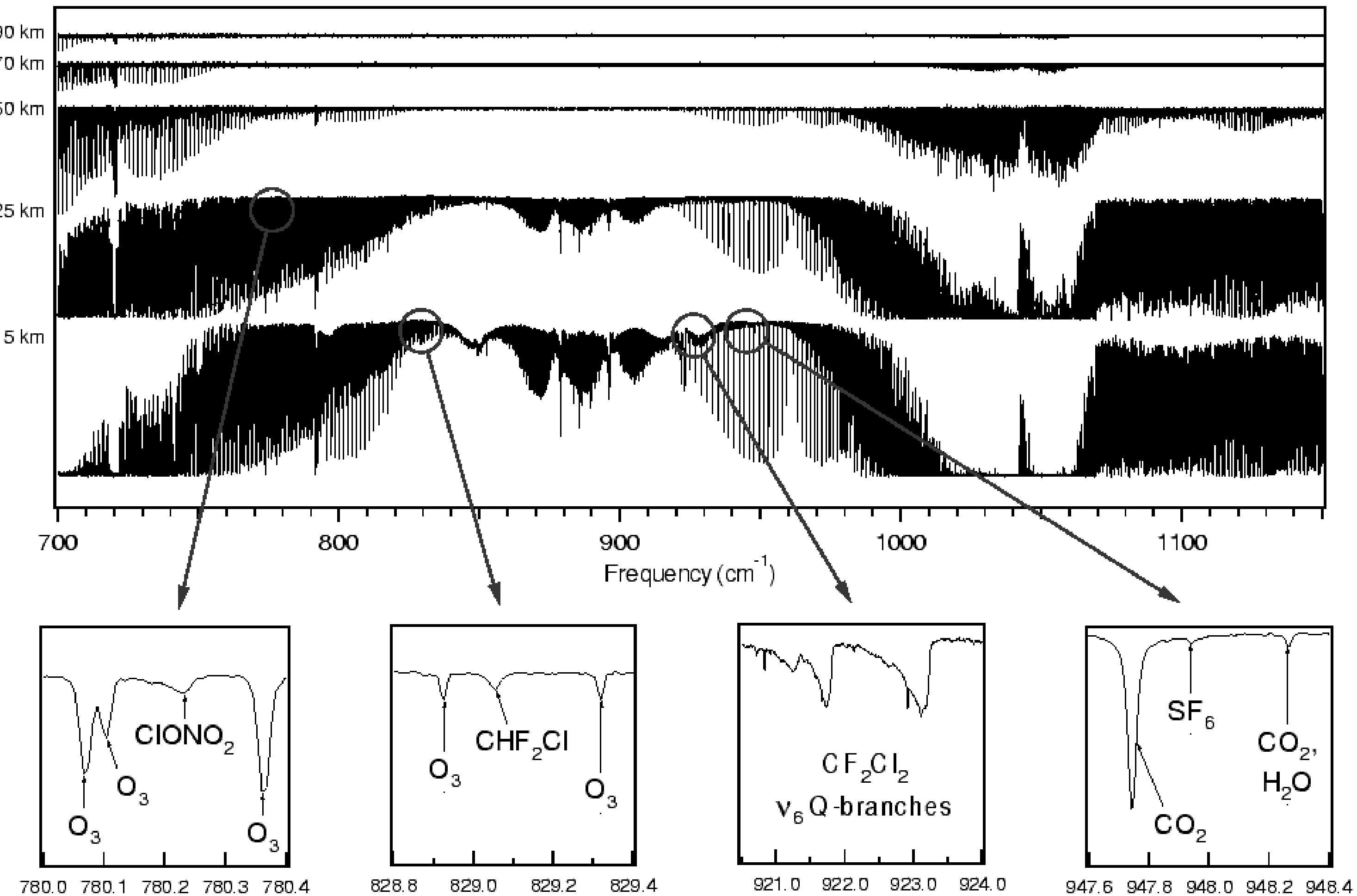
Heslington, York, UK

Inspiration:

ATMOS on Space Shuttle; Fourier transform infrared spectrometer (FTS) working in solar occultation; flights in 1985, 1992, 1993, 1994 (Farmer at conferences)

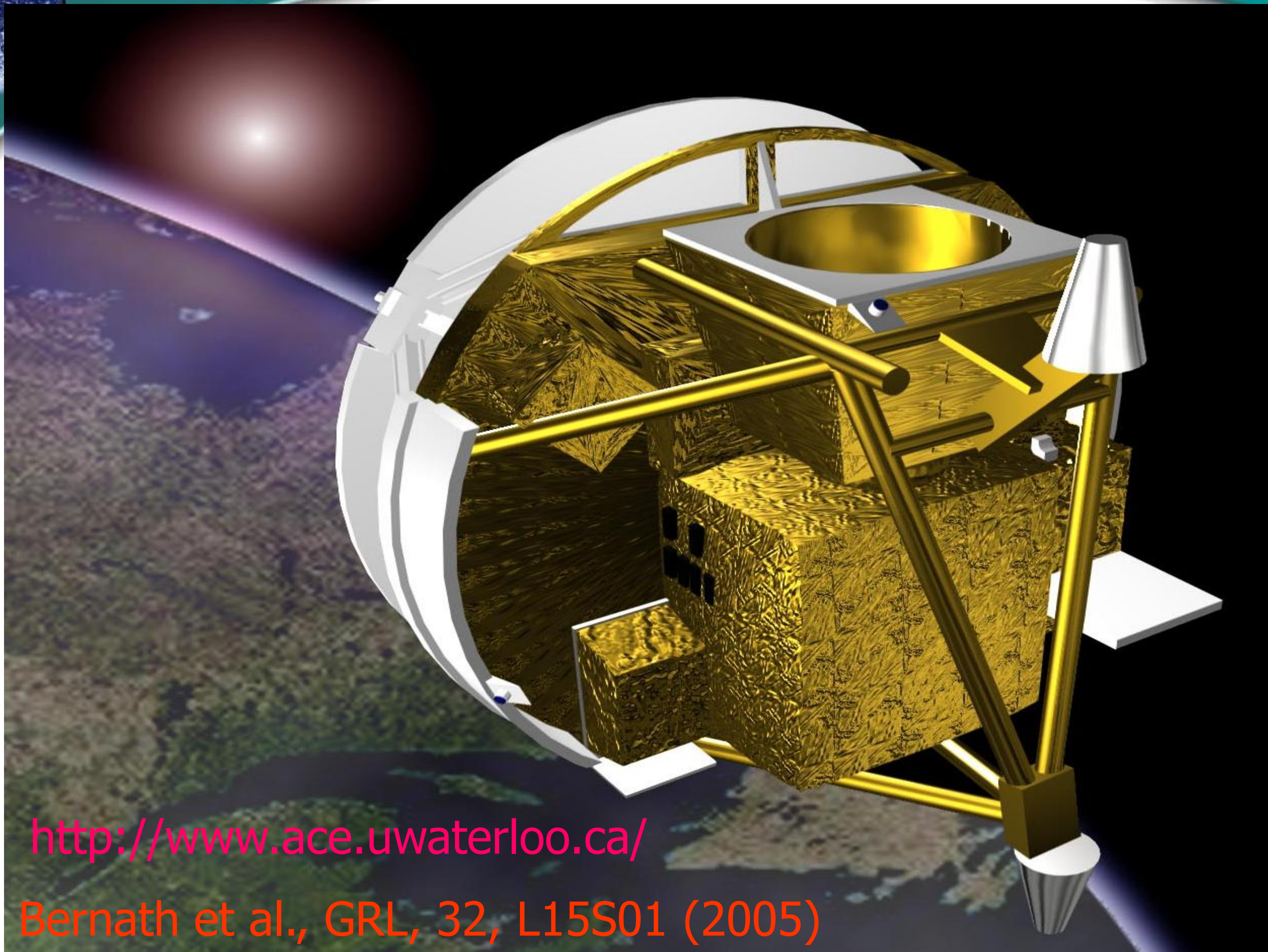
ATMOS IR FTS Spectra

Then:
1. Co-I on proposed NASA ATMOS follow-on
2. PI for a proposal to CSA for small IR nadir sounder (like IASI)
3. ACE



Infrared transmission at tangent altitudes between 15 and 90 km and between frequencies of 700 and 1100 cm-1 (recorded using the ATMOS interferometer onboard the space shuttle, Feb. 1992)

ACE Satellite



http://www.ace.uwaterloo.ca/

Bernath et al., GRL, 32, L15S01 (2005)

Instruments

- Infrared Fourier Transform Spectrometer (FTS) operating between 2 and 13 microns (750-4400 cm^{-1}) with a resolution of 0.02 cm^{-1}
- 2-channel visible/near infrared Imagers, operating at 0.525 and 1.02 microns (cf., SAGE II)
- UV / Visible spectrometer (MAESTRO) 0.4 to 1.03 microns, resolution ~1-2 nm (added after initial selection)

Central Canada- NE USA

Timeline ("faster, cheaper")

- July 1997 AO by CSA for SCISAT-1 (Astro or Atm Sci)
- Jan. 1998 Proposal to Canadian Space Agency (CSA)
- Apr. 1998 Start of Phase A (feasibility) for 3 proposals
- Oct. 1998 Presentations and selection of ACE
- Feb. 1999 Project kick-off (Phase B: preliminary design)
- Oct. 1999 FTS Preliminary Design Review (PDR) (Phase C start: detailed design)
- Feb. 2001 FTS/Imager Critical Design Review (CDR) (Phase D start: build)
- Sept. 2002 Spacecraft integration & test
- Mar. 2003 FTS Instrument test (Toronto)
- May 2003 Final integration (DFL, Ottawa) (AIT)(SRR)
- Aug. 2003 Launch and LEOP (launch & early orbit phase)
- Sept. 2003 Commissioning starts (Phase E: operations)
- Feb. 2004 Routine operations

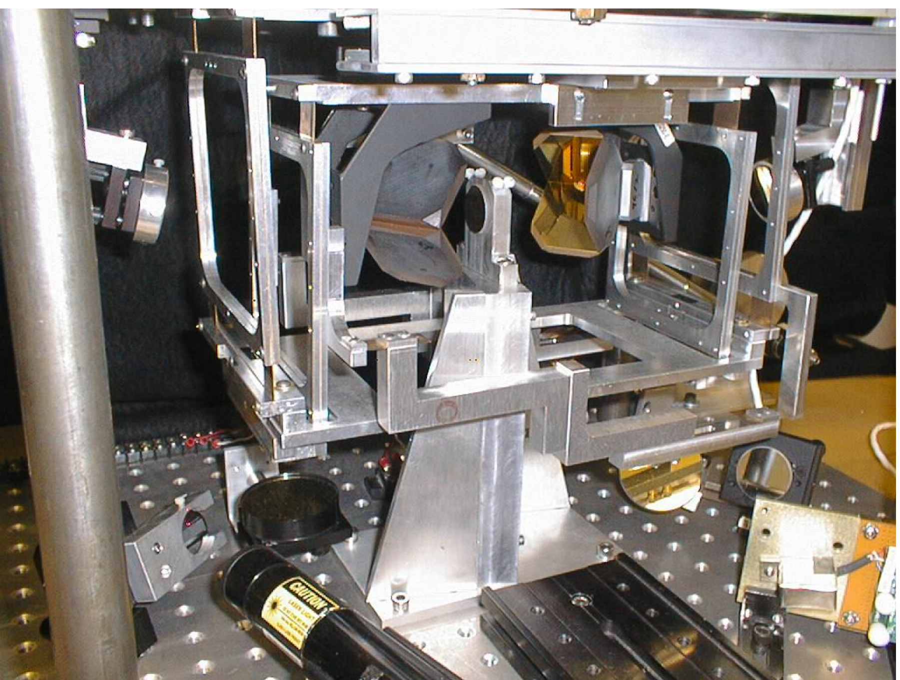
Mission had a nominal 2-year lifetime – sixth anniversary Aug. 2009.

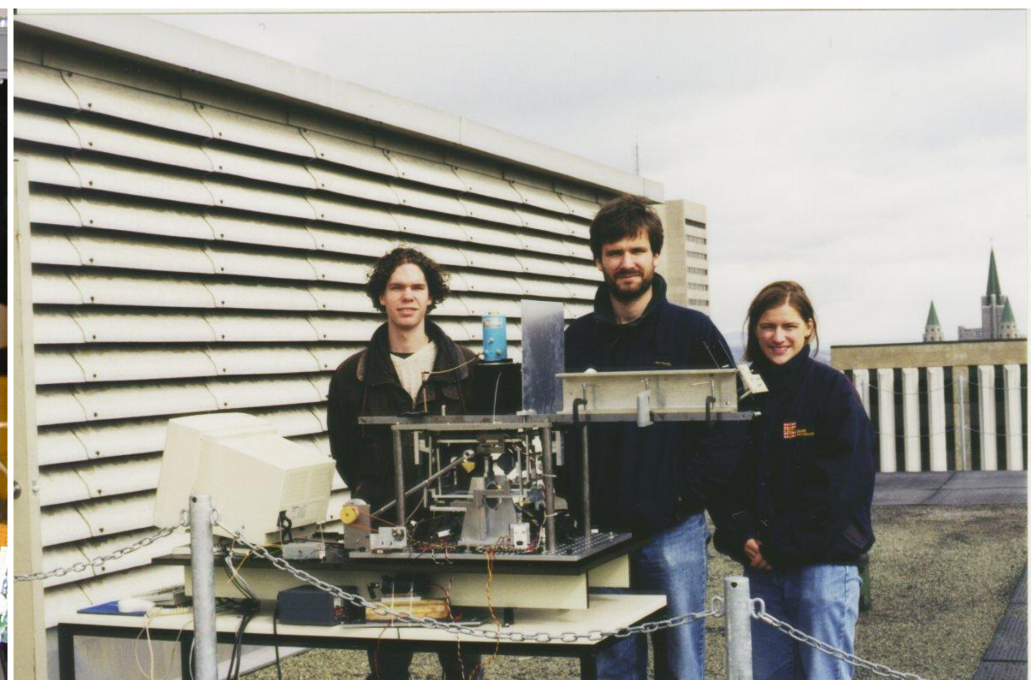
Key step: During Phase A engage the community in project. (Notice: no Pre-Phase-A studies!)

Phase A FTS Breadboard

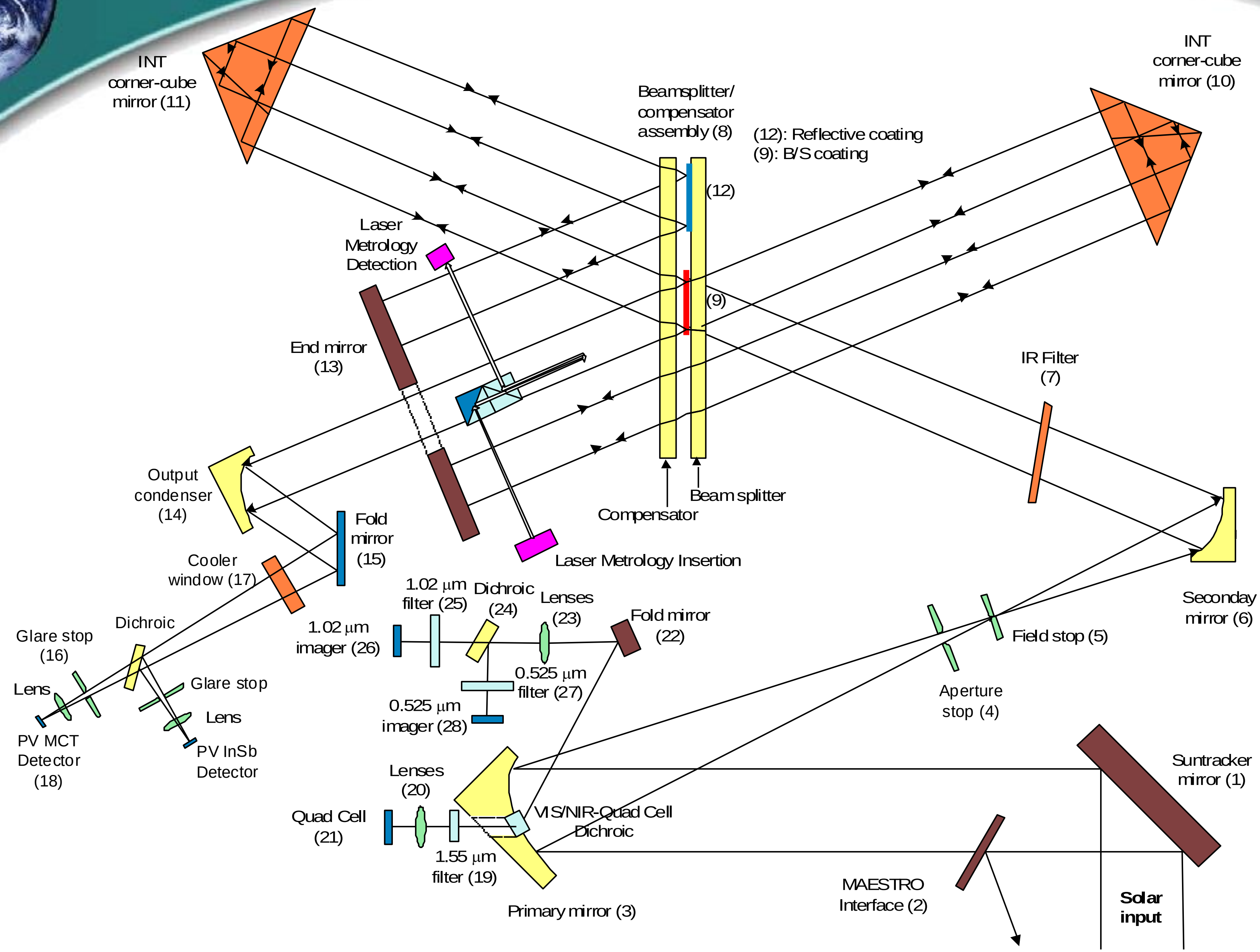
April 1999: Phase A (feasibility study) starts, but we were scientists and FTS users, not hardware designers.

1. Design work started at ABB-Bomem (our FTS industrial partner in Quebec City)
2. Possible prototype built by students of Pierre Tremblay (U. Laval); although their design was not used for flight, the breadboard was present at selection meeting in Oct. 1999

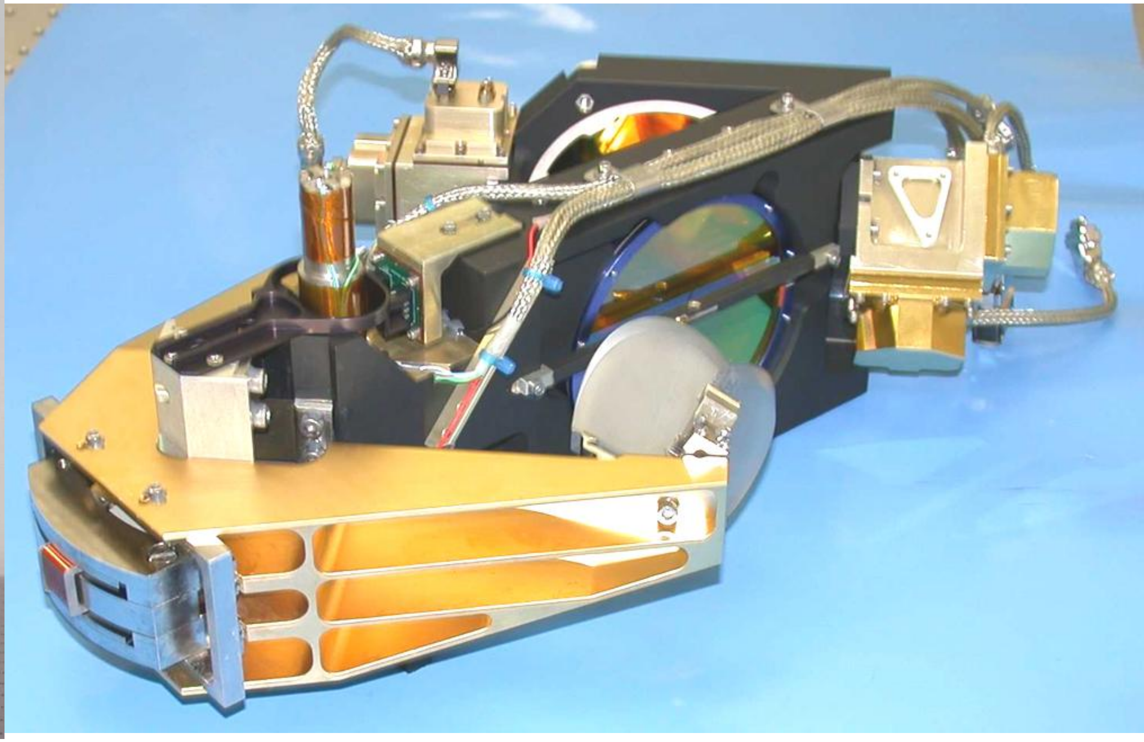




Optical Layout (ABB-Bomem, Quebec City)

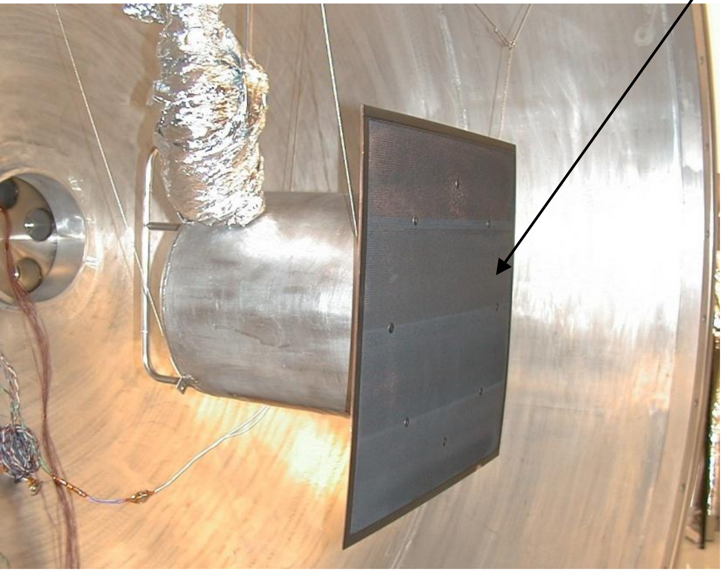


ACE-FTS (Flight Model)

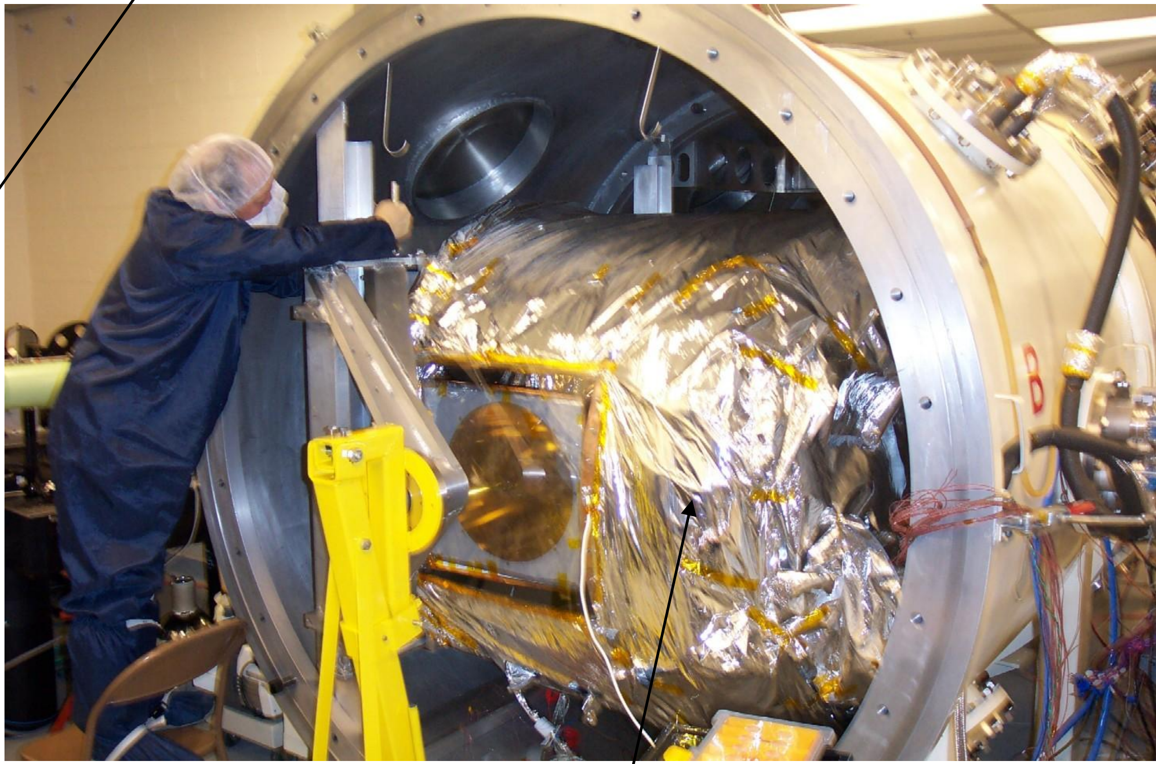


Testing the FTS (U. of Toronto)

Testing of flight hardware by graduate students and post-docs

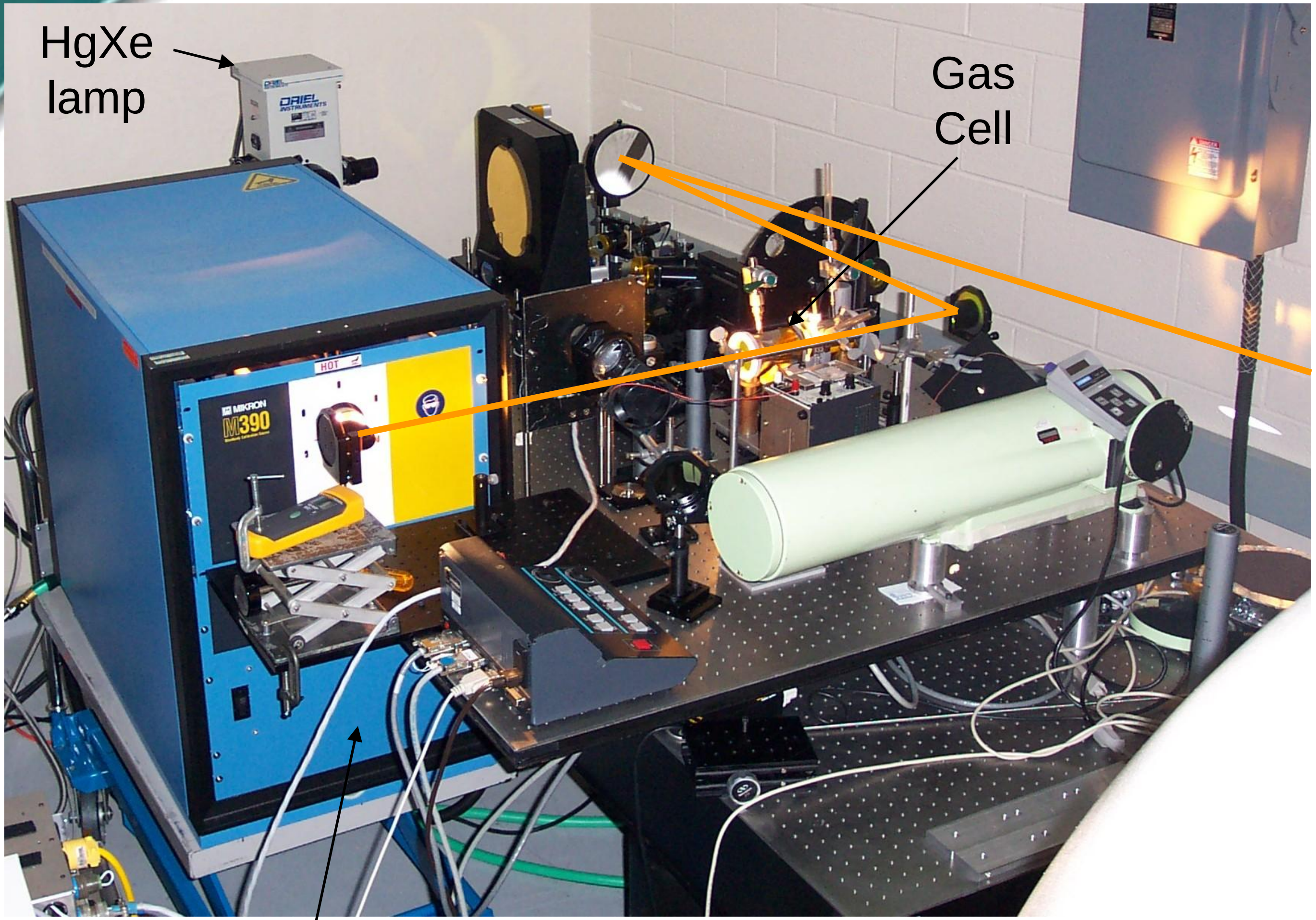


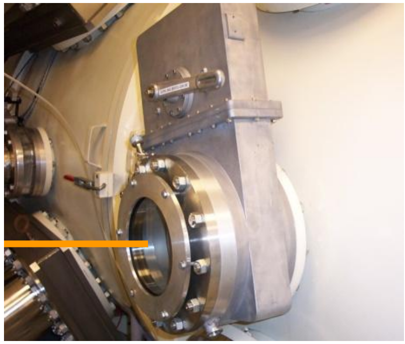
Detectors cooled to ~ 89 K by directing the FTS passive cooler at the liquid He-cooled target



Multi-layer insulation (MLI)

Gas Cell Measurements

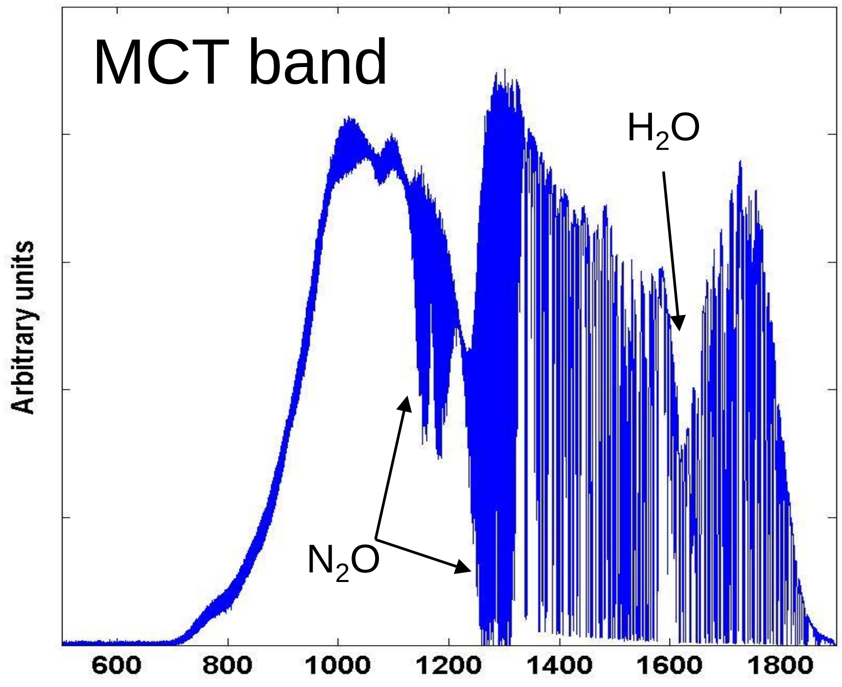


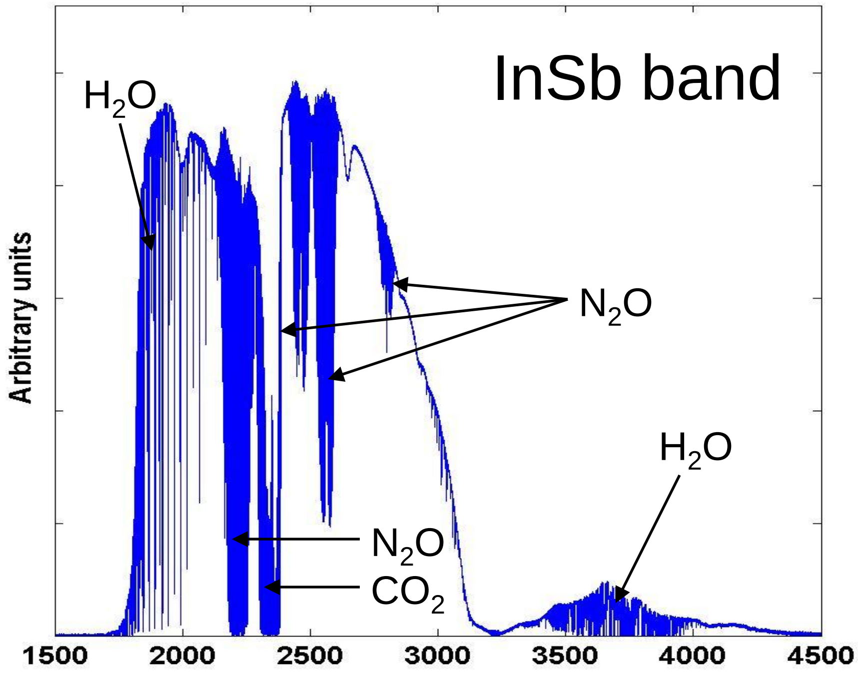


to TVAC Window

Gas Cell

ACE-FTS Test Data & Results



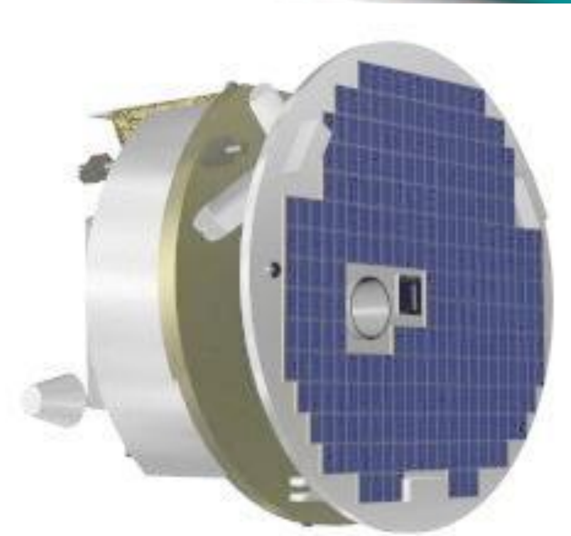


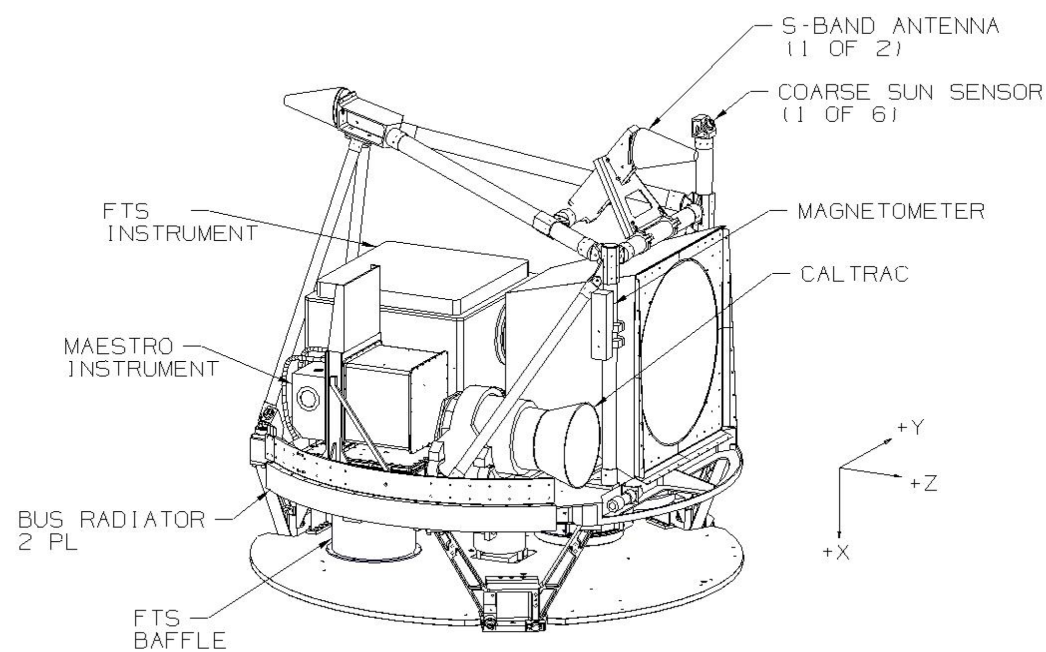
Detector 89 K, Instrument Nominal Temperature, ~12.0 Torr N_2O

Instrument test motto: "Test as you fly"

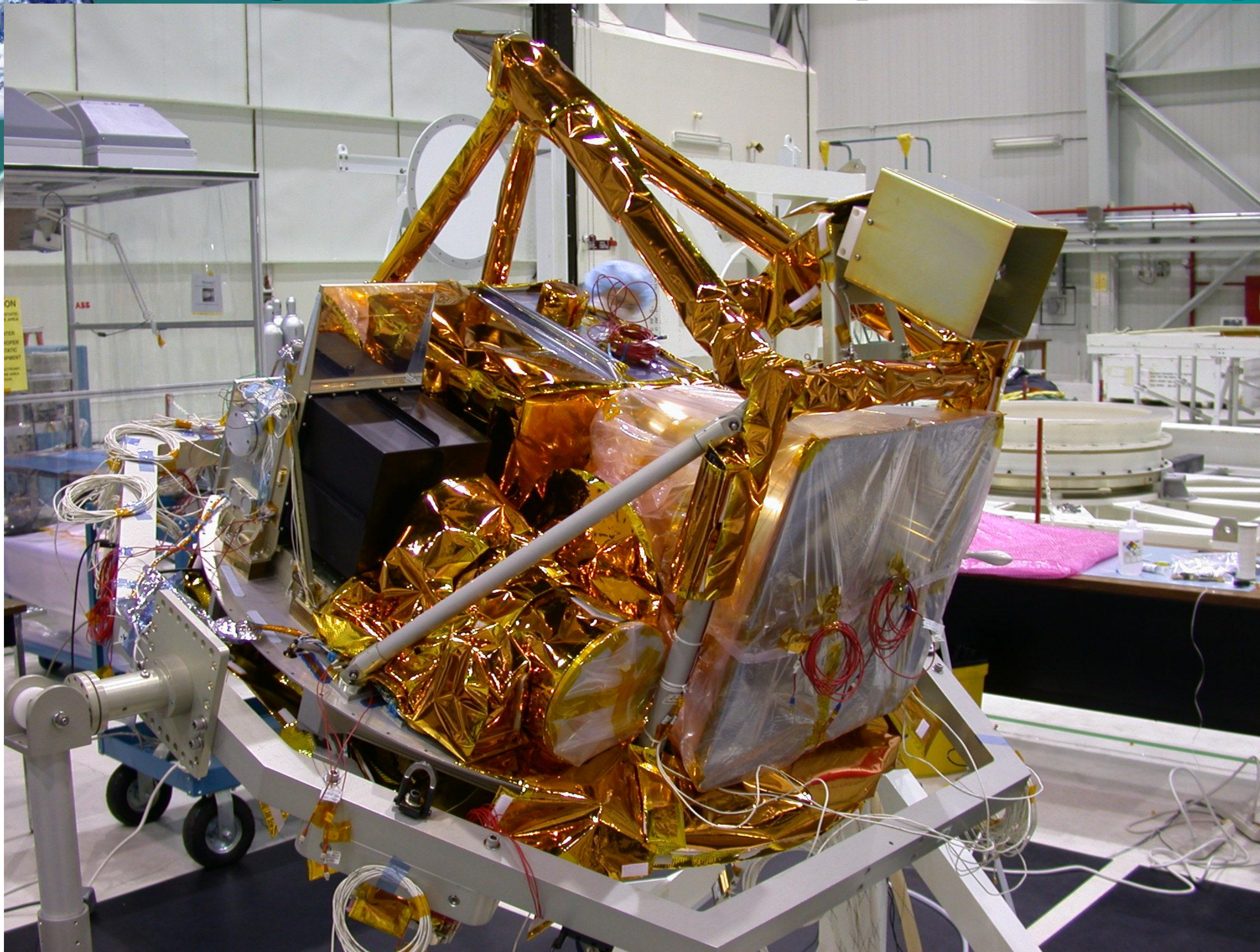
SCISAT-1 Spacecraft (Bristol Aerospace, Winnipeg)

Key Specifications	
Spacecraft diameter	112 cm
Spacecraft mass	152 kg
Pointing control: Pitch/yaw (3σ) Roll (3σ)	 ± 0.2º ± 0.7º
Pointing knowledge: Pitch/yaw Roll	 ± 0.1º ± 0.6º
Solar array EOL power	175 W
Spacecraft OA power	75 W
Bus reliability (2-yrs)	80 %
Mass memory	1.5 Gb



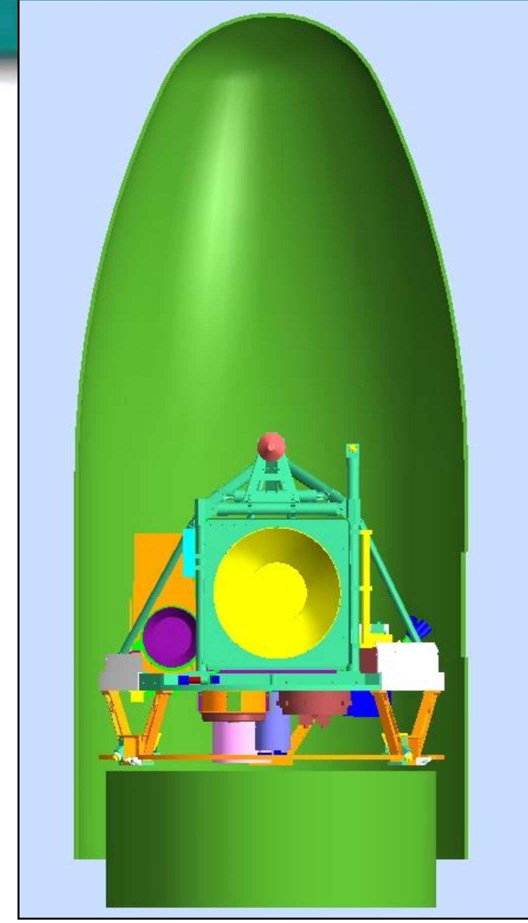


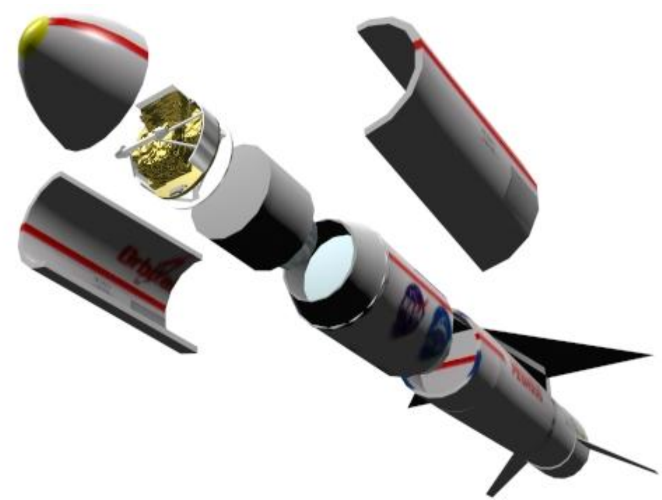
FTS Integration to S/C Bus (DFL Ottawa)



SCISAT-1 Launch

- Pegasus XL launch vehicle (provided by NASA)
- Launched from Vandenberg Air Force Base
- Nominal orbit of 650 km and 73.9° inclination
- Unpowered launch with S/C to roll slowly on orbit



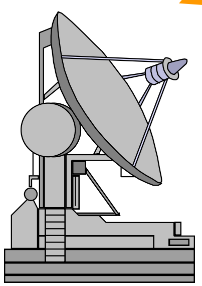


Integration of S/C to Pegasus Rocket

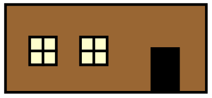
Pegasus XL Launch Vehicle

Ground Segment

SCISAT-1



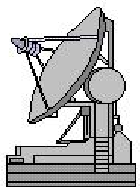
St. Hubert
- Primary Ground Station



University of Waterloo
- Science Operations Centre

Communications
- Downlink
  - S-band
  - CCSDS multiplexing
  - 40 kbps to 4 Mbps
  - 10^{-9} BER
- Uplink
  - S-band
  - CCSDS command protocol
  - 4 kbps

Tracking
- 2-way Doppler range-rate measurements



Saskatoon
- Secondary Ground Station

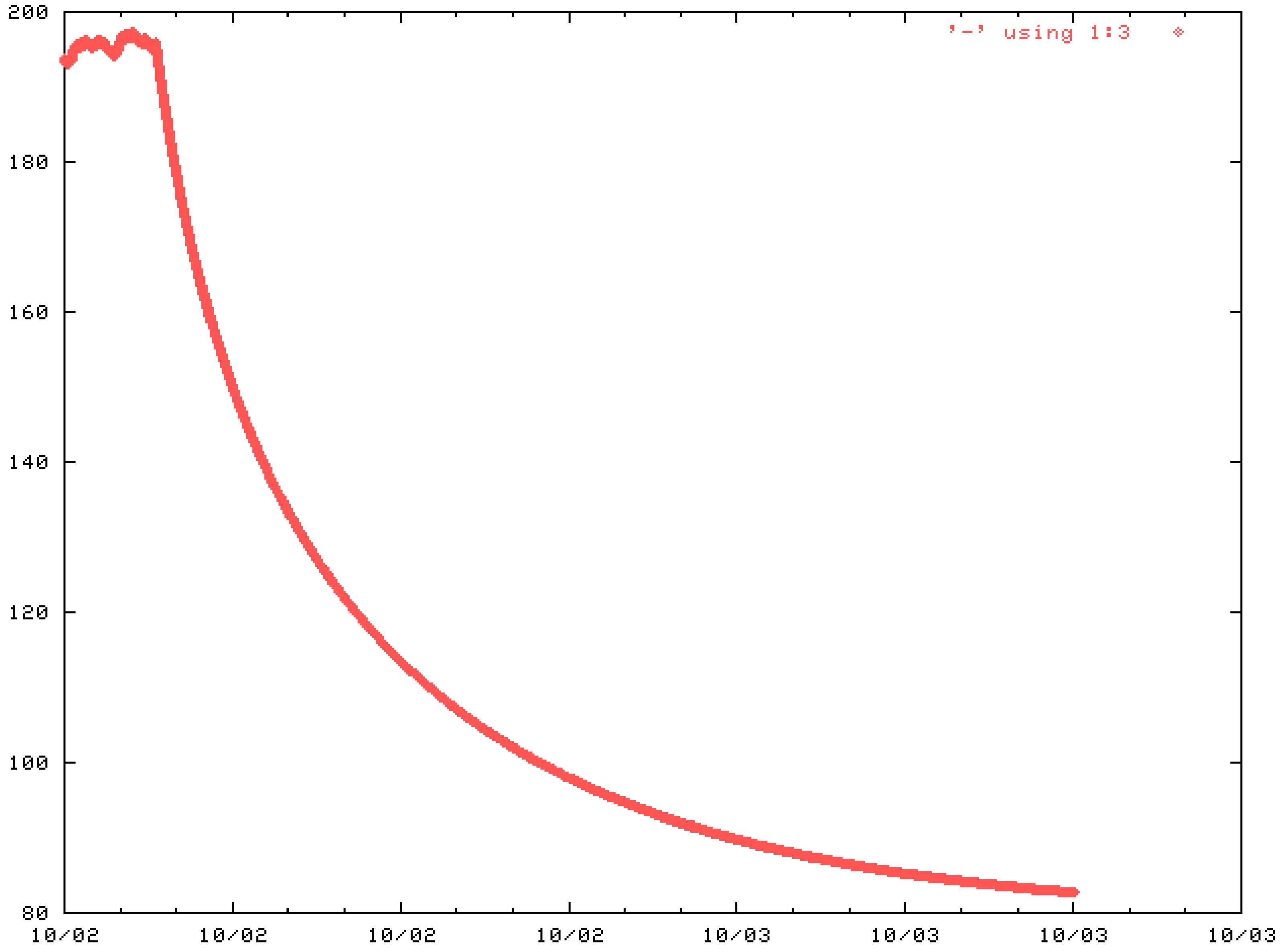
Fairbanks, USA

Alaska Satellite Facility (NASA)

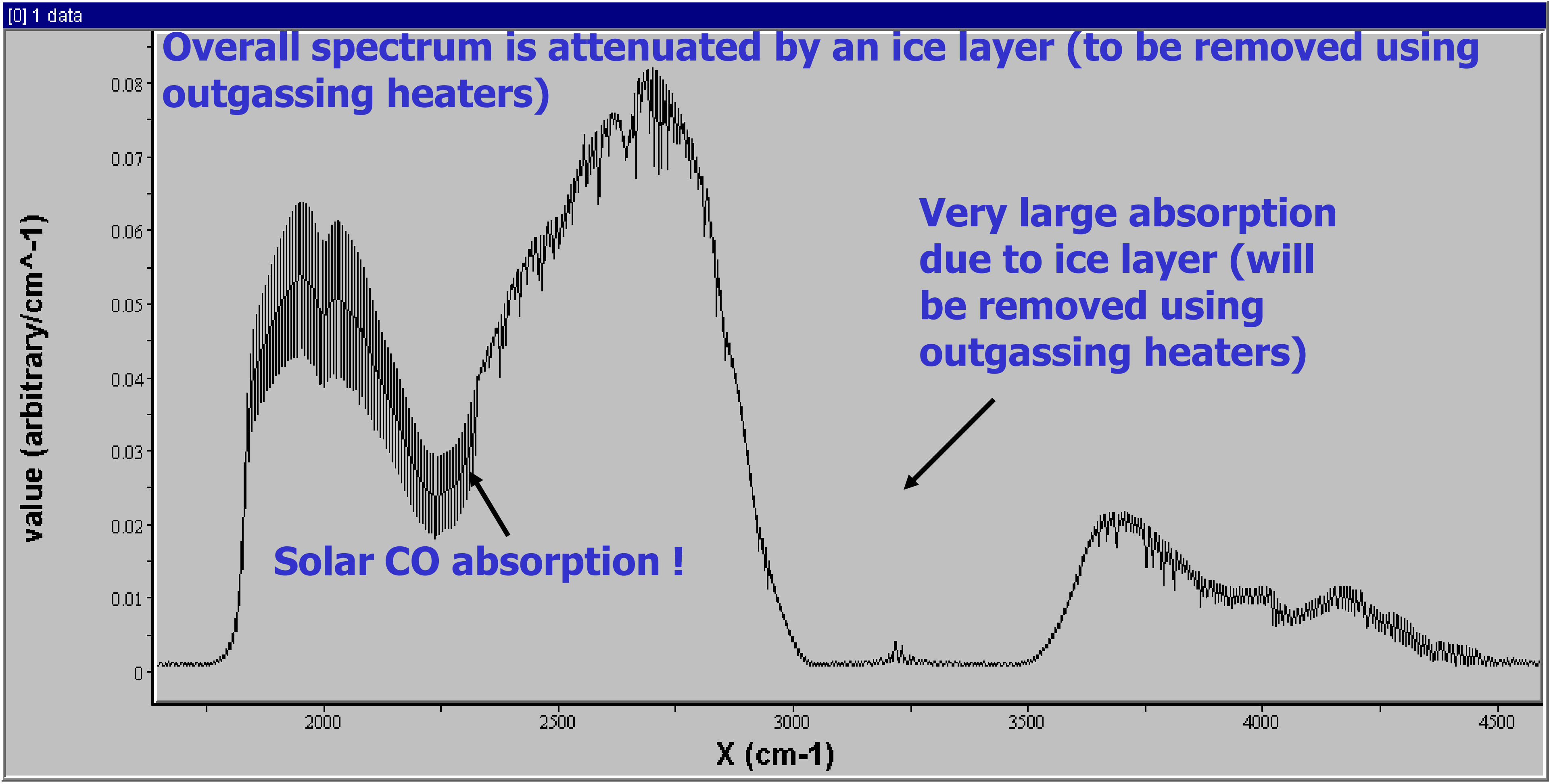
Kiruna, Sweden

ESA Satellite Station

FTS Detector Cool-Down-Oct. 2003 (roll control)

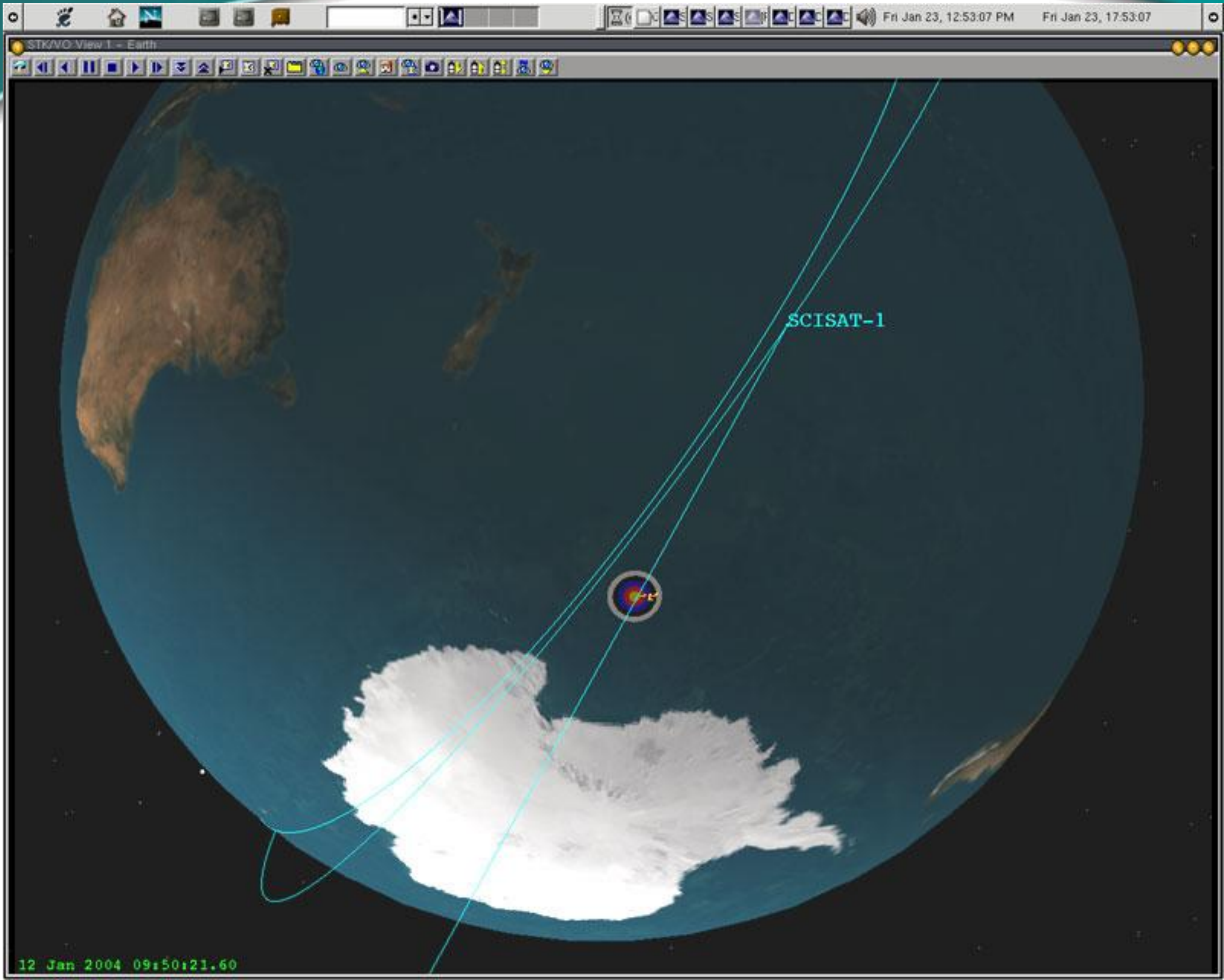


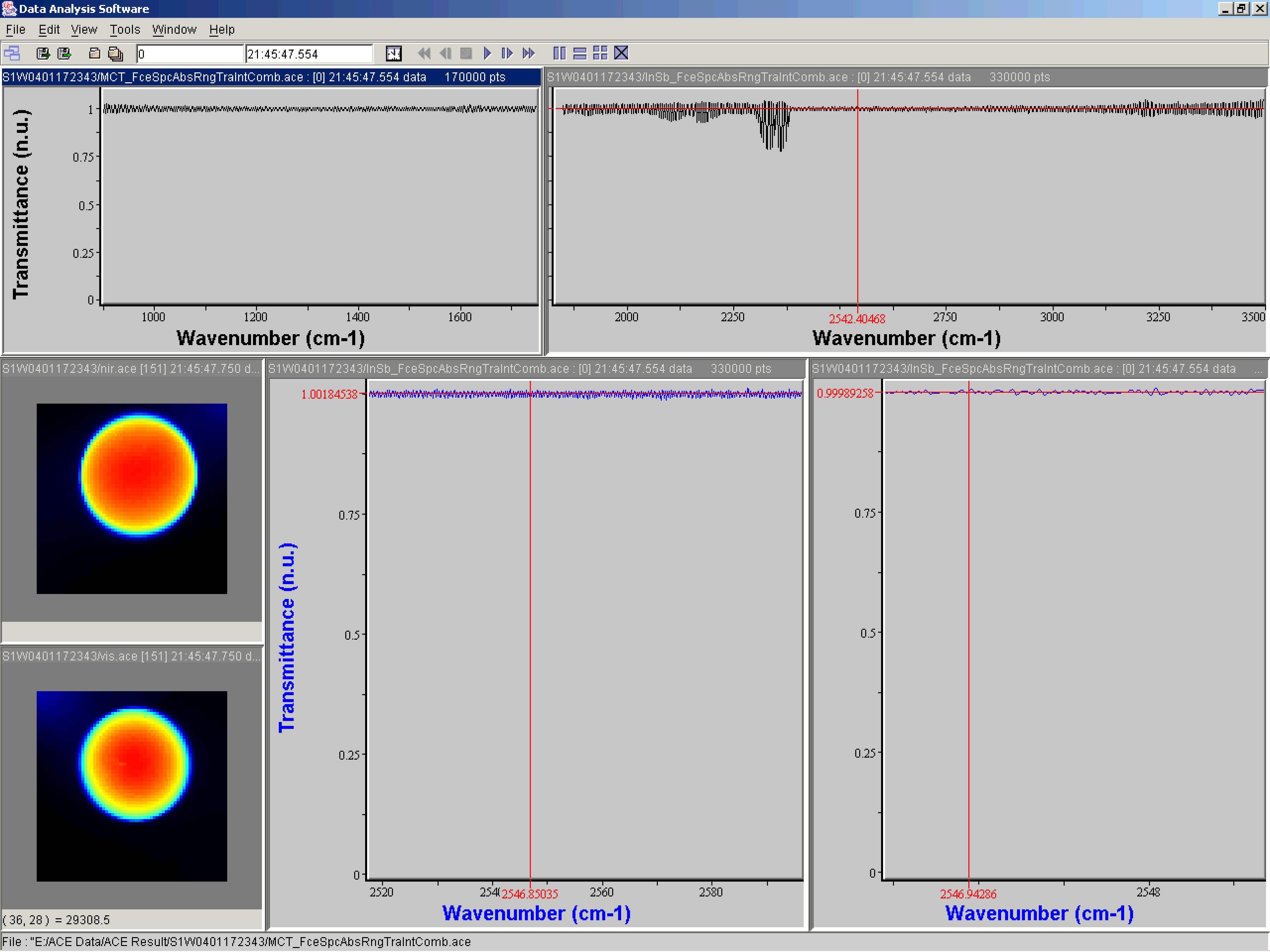
"First Light": InSb Detector Spectrum-Nov. 2003



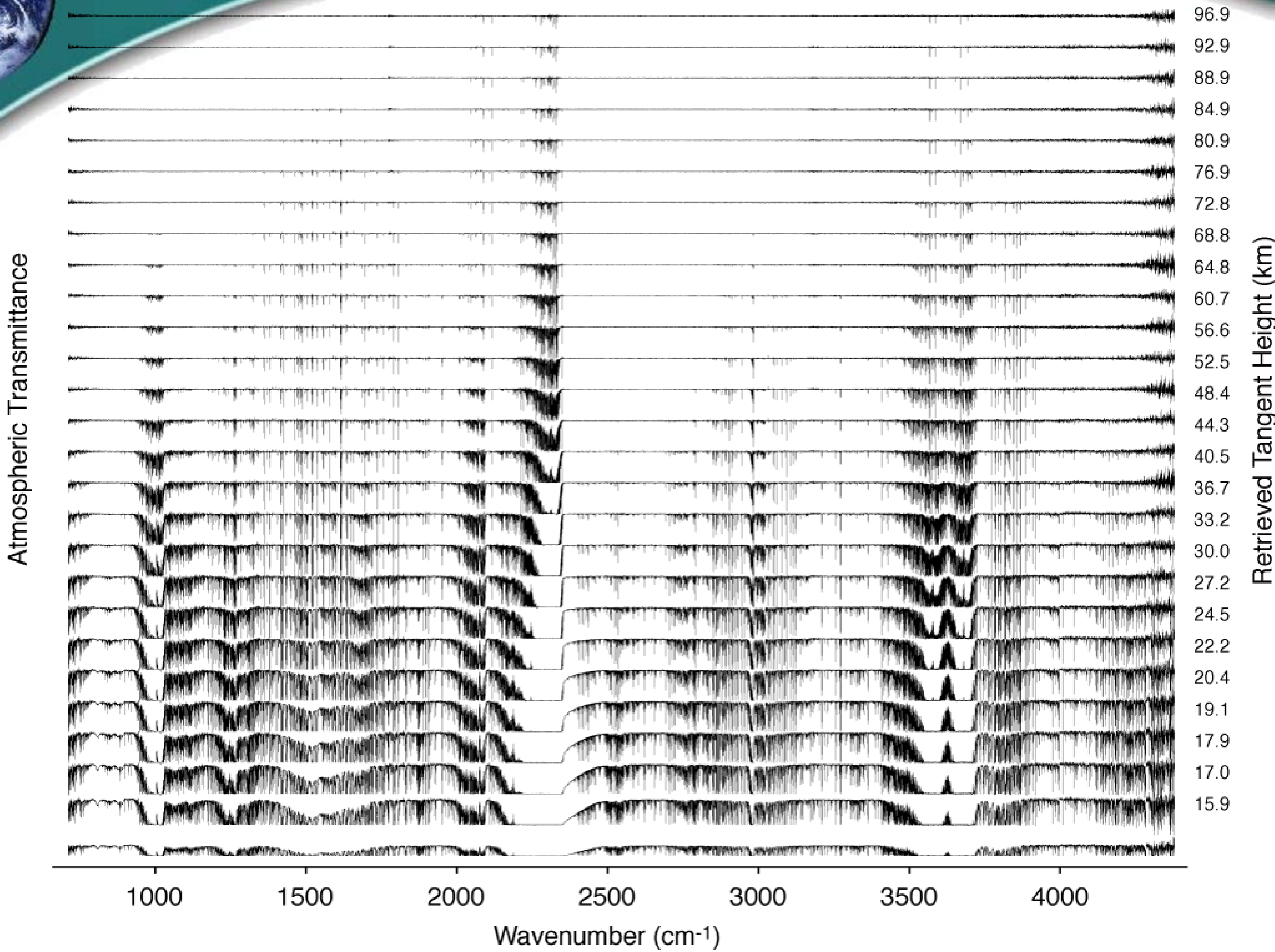
Note: exo-atmospheric data (pure Sun) with absorption due to many atomic lines and CO (IR Fraunhofer spectrum)

Jan. 12, 2004 9:50:23 (UTC)

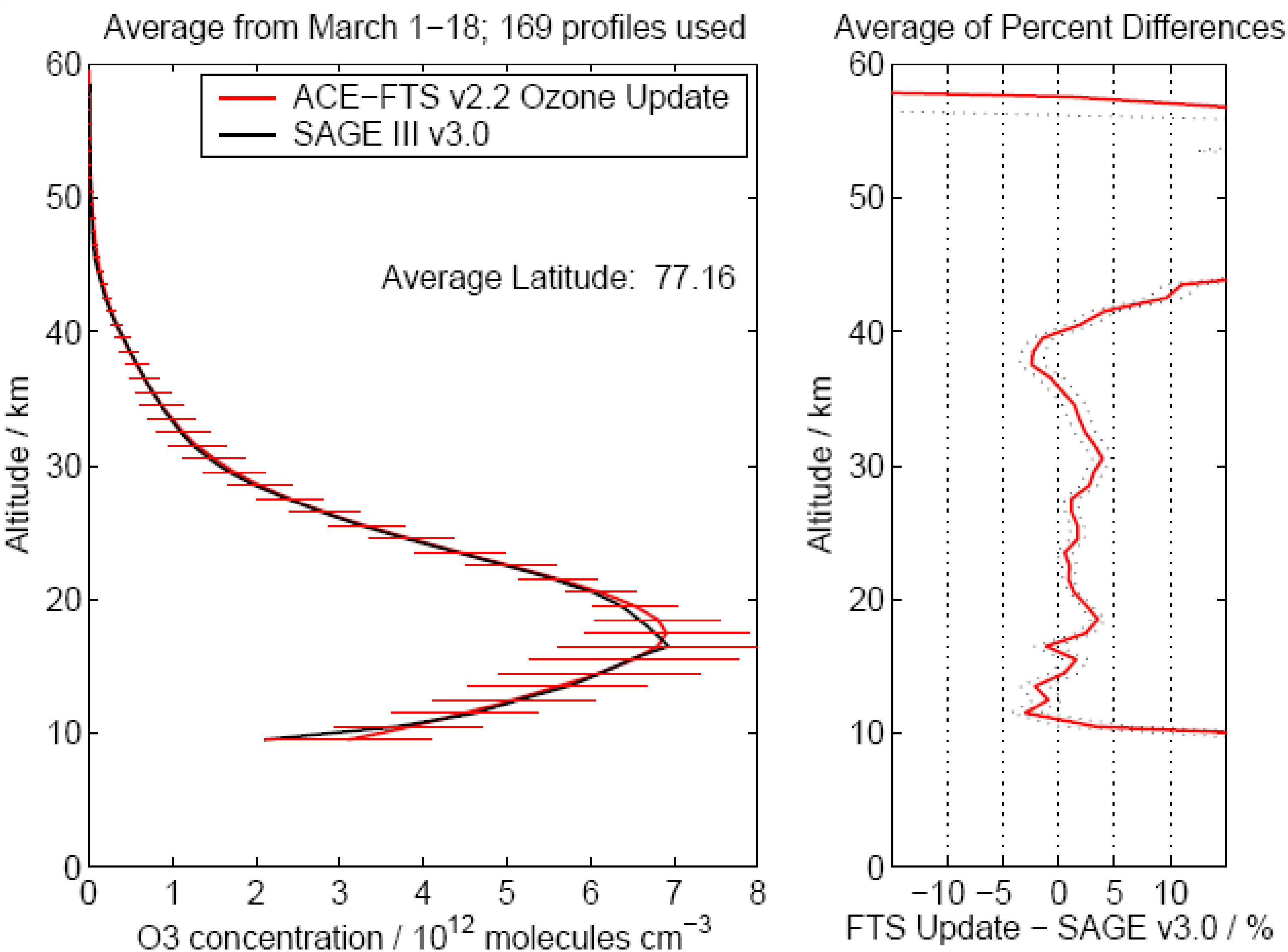



Data Analysis Software
File Edit View Tools Window Help
0
21:45:47.554
S1W0401172343/MCT_FceSpcAbsRngTraIntComb.ace : [0] 21:45:47.554 data 170000 pts
Transmittance (n.u.)
1
0.75
0.5
0.25
0
1000
1200
1400
1600
Wavenumber (cm-1)
S1W0401172343/InSb_FceSpcAbsRngTraIntComb.ace : [0] 21:45:47.554 data 330000 pts
2000
2250
2542.40468
2750
3000
3250
3500
Wavenumber (cm-1)
S1W0401172343/nir.ace [151] 21:45:47.750 d...
S1W0401172343/vis.ace [151] 21:45:47.750 d...
(36, 28) = 29308.5
S1W0401172343/InSb_FceSpcAbsRngTraIntComb.ace : [0] 21:45:47.554 data 330000 pts
1.00184538
0.75
0.5
0.25
0
Transmittance (n.u.)
2520
254(
2546.85035
2560
2580
Wavenumber (cm-1)
S1W0401172343/InSb_FceSpcAbsRngTraIntComb.ace : [0] 21:45:47.554 data
0.99989258
0.75
0.5
0.25
0
2546.94286
2548
Wavenumber (cm-1)
File : "E:/ACE Data/ACE Result/S1W0401172343/MCT_FceSpcAbsRngTraIntComb.ace

Occultation sequence



Ozone ACE Cal/Val



K. Walker

Science Goals (Verbatim from Phase A Report)

PRIORITY 1

•Measurement of regional polar O_3 budget to determine the extent of O_3 loss. This will require measurements of O_3, tracers (CH_4 and N_2O), and meteorological variables (pressure and temperature).

•Measurement / inference of details of O_3 budget by detailed species measurements (for O_3, H_2O, NO, NO_2, N_2O_5, HNO_3, HCl, $ClNO_3$, ClO) and modelling.

•Measurement of composition, size and density of aerosols and PSCs in the visible, near IR and mid IR.

•Comparison of measurements in the Arctic and Antarctic with models to provide insight into the differences, with emphasis on the chlorine budget and denitrification.

PRIORITY 2

•Mid-latitude O_3 budget.

•Measurement of Arctic vortex descent.

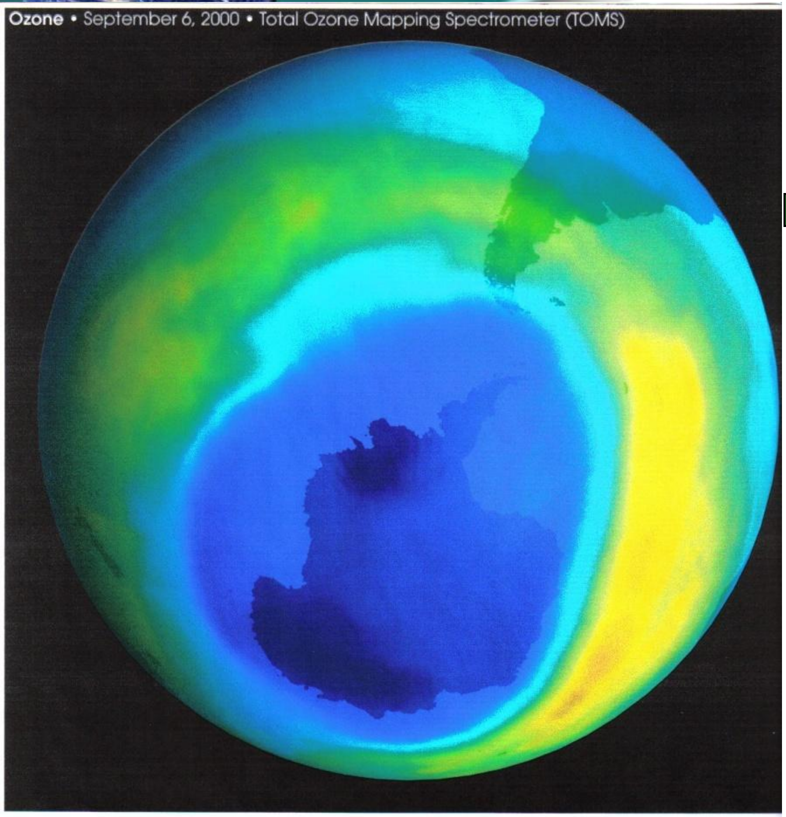
PRIORITY 3

•Measurement of winds.

•Study of upper tropospheric chemistry.

•Monitoring of CFCs, CFC substitutes and greenhouse gases.

Space Agency View of Mission Design



Science problem (e.g., understand and measure ozone hole)

Science Requirements Document
(e.g., ozone VMR with 5% accuracy from 10-50 km altitude)

Instrument Requirements Document (e.g., FTS with transmittance accuracy of 1%)

Subsystem hardware requirements

Average CO_2 Profile 60-100 km

CO_2 Mystery:

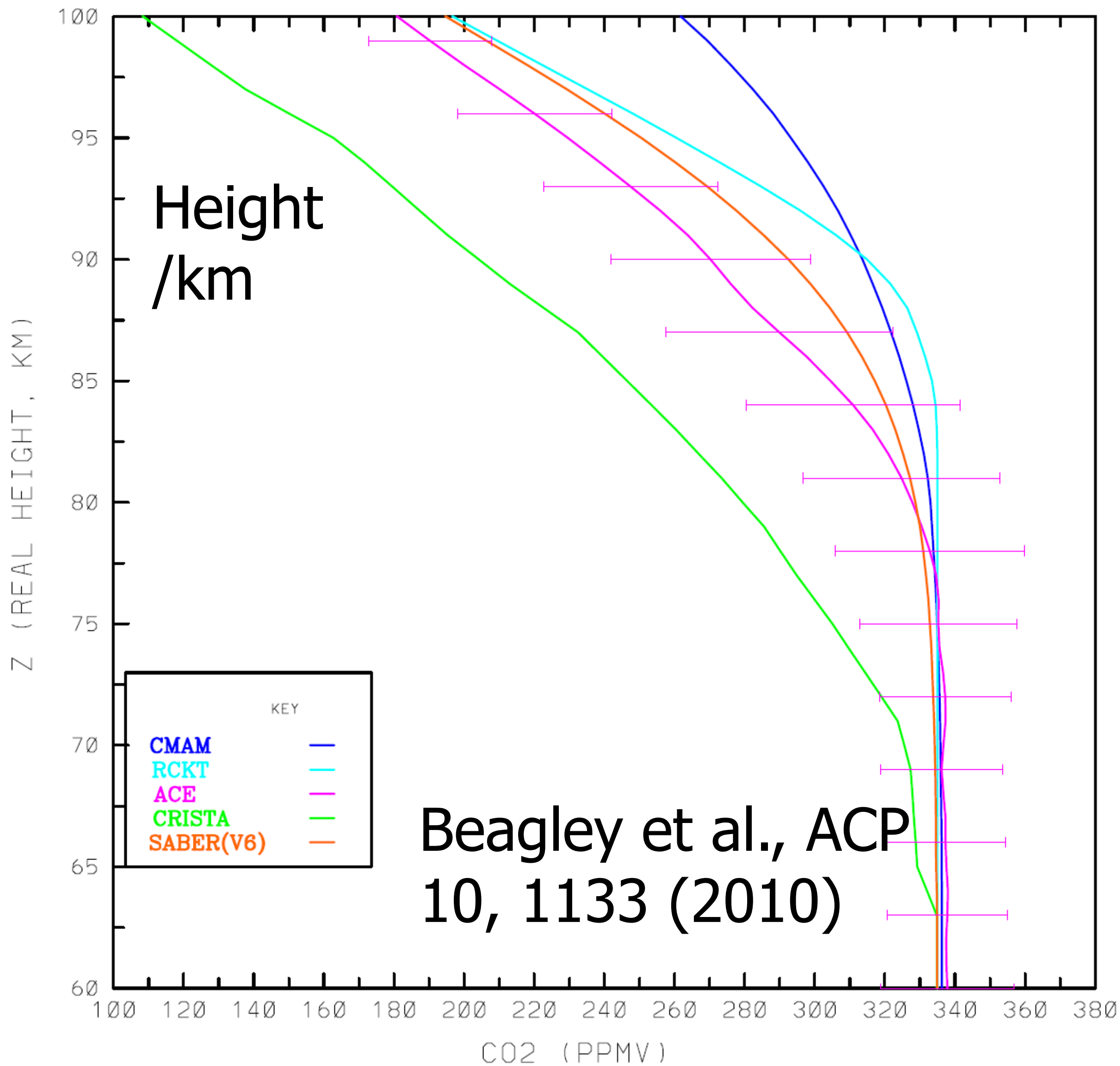
$CO_2 + h\nu \rightarrow CO + O$

ACE profile (purple) does not agree with CMAM model (blue)

Good agreement for CO, however.

Where has CO_2 gone?

Perhaps there are reactions with meteoritic dust?



Atmospheric Dynamics: Asian Summer Monsoon Anticyclone

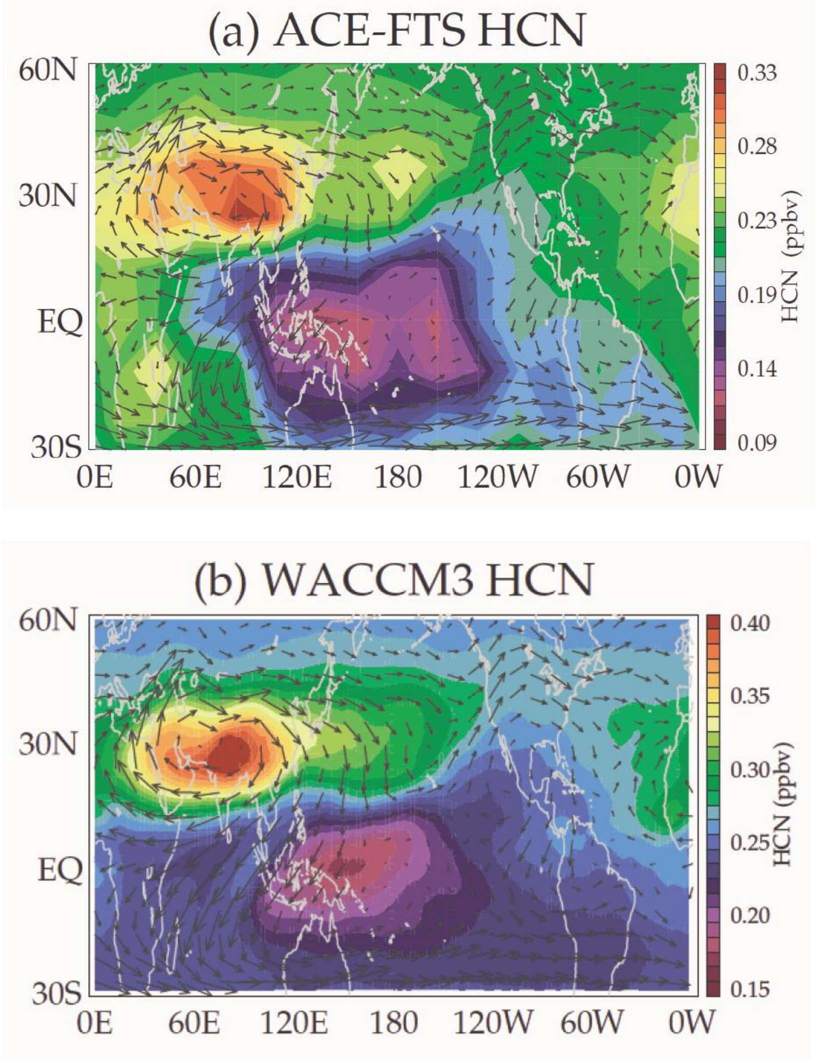


Figure 1. Time average mixing ratio (ppbv) of hydrogen cyanide (HCN) near 13.5 km during boreal summer (June-August) derived from (a) ACE-FTS observations during 2004-2008, and (b) WACCM chemical transport model calculations. Arrows in both panels denote winds at this level derived from meteorological analysis, showing that the HCN maximum is linked with the upper tropospheric Asian monsoon anticyclone.

At 13.5 km in altitude, HCN is high over Tibet because of rapid lofting of polluted air from India and China during summer; it is lower over the Pacific Ocean because of deposition and destruction in the ocean. Randel et al., *Asian monsoon transport of pollution to the stratosphere*, Science (in press)

Some Lessons Learned

1. Don’t micromanage- a professional manager is needed (lots of paper work!)
2. Sign up partners from all sectors as early as possible – industry, government labs (e.g. weather service, etc.), other universities, especially international partners with money (e.g., Belgians and NASA)
3. Be open and inclusive (and avoid internal competition) - personal factors are important
4. Be very suspicious of claims of suppliers
5. Engineers work to requirements (not the same as scientists!)
6. Good acronym, well written proposal, timely science, favourable politics, etc.

ACE Partners (Selected)

- Canada- K. Walker, J. Drummond, K. Strong, J. McConnell, W. Evans, T. McElroy, I. Folkins, R. Martin, J. Sloan, T. Shepherd, T. Llewellyn, etc.
- USA- NASA launched ACE: C. Rinsland, L. Thomason (NASA-Langley), C. Randall (U. Colorado), M. Santee, L. Froidevaux, G. Toon, G. Manney (JPL), etc.
- Belgium- supplied CMOS imager chips: R. Colin, P.-F. Coheur, M. Carleer (ULB), D. Fussen, M. DeMaziere (IASB), M. Mahieu, R. Zander (Liege), etc.
- UK- J. Remedios (Leicester), P. Palmer (Edinburgh), M. Chipperfield (Leeds), etc.
- France- C. Camy-Peyret, C. Clerbaux, C. Brogniez, G. Dufour, D. Hauglustaine (Paris)
- Japan- M. Suzuki (JAXA), Y. Kasai
- Sweden- G. Witt (Stockholm)

Funding: CSA, NSERC, NERC

National Centre for Earth Observation

NATURAL ENVIRONMENT RESEARCH COUNCIL