Technological evolutions on the FTS instrument for follow-on missions to SCISAT Atmospheric Chemistry Experiment

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ABSTRACT

The Canadian satellite SCISAT-1 developed for the Canadian Space Agency in the context of the ACE mission (Atmospheric Chemistry Experiment) was launched in August 2003. The mission has been a tremendous technical and scientific success. The main instrument of the ACE mission is a high-resolution Fourier Transform Spectrometer (FTS) designed and built by ABB Bomem. Several new missions are currently considered as follow-on to the ACE mission to ensure continuity of the extensive high-quality data set of the Earth's atmosphere that was started with the ACE mission, but also possibly to bring new improvements and enhance the utilization of these data. A solar-occultation FTS based on the optical design for ACE-FTS, has been selected for a planetary exploration mission to measure the atmospheric composition of Mars that will launch in 2016.

An overview of these different missions will be presented. The need for technological evolutions will be examined for each mission. Some evolutions imply only minor changes, for example, to cope with some parts obsolescence. Others will require increasing instrument capabilities compared to those of the ACE instrument. These different technological evolutions will be presented.

Keywords: ACE, FTS, SCISAT, CASS, TGO, SOAR, Spectrometer, Fourier.

1. INTRODUCTION

The composition of the Earth atmosphere is changing due to the influence of human activity. These changes are affecting, and will continue to affect, the quality of life on Earth. Currently, two of the most important issues in atmospheric science are air pollution and climate change because of their negative effects on human health and ecosystems. Measurements of atmospheric composition, comprising both trace gases and particles, are necessary to better understand these issues and to provide a sound scientific basis for national and international policy decisions.

For this purpose, the Canadian Space Agency (CSA) developed the Atmospheric Chemistry Experiment (ACE). Two instruments were mounted on SCISAT-1 spacecraft: the ACE-FTS solar occultation spectrometer instrument for the infrared spectral range and the MAESTRO spectrometer for the visible and NIR range. The ACE-FTS is composed of a Fourier Transform Spectrometer (FTS) and two imager detectors. The imagers are used to evaluate the atmospheric extinction and validate the Sun pointing. The SCISAT-1 spacecraft was launched by NASA in August 2003. The commissioning activities were conducted by the Canadian Space Agency. Performance evaluations were performed throughout the commissioning activities with most of the data recorded in December 2003 [1]. Science measurements and atmospheric retrievals, conducted by the University of Waterloo [2], started in February 2004. The ACE-FTS instrument has reached seven years of operation in August, 2010: this is more than 3 times the initial original 2-year mission.

The main focus of the ACE-FTS was the monitoring of the ozone concentration near the poles and the measurements of trace gases involved in the photo-chemical processes related to stratospheric ozone creation and depletion. Since its launch, the data acquired by the ACE-FTS has been used to study an ever broadening set of atmospheric molecules at various latitudes. The scientific scope of the mission has moved from an ozone-focused mission to an atmospheric composition monitoring mission.

Several new missions are currently considered as follow-on to the ACE mission to ensure continuity of the extensive high-quality data set of the Earth's atmosphere, and to further improve data and its utilization. The science community is

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now looking at the follow-on missions such as the Chemical and Aerosol Sounding Satellite (CASS) and the Solar Occultation for Atmospheric Research (SOAR).

The first section of this paper presents the ACE mission objectives and ACE-FTS instrument. The second section shows an overview of the next missions following ACE, CASS and SOAR. The Trace Gas Orbiter (TGO) mission is also presented: this is an exploration mission to send a solar occultation spectrometer to orbit Mars. This section also shows the instrument architecture and technology evolution. The last section gives a summary of these evolutions and expected performances.

2. THE SCISAT ATMOSPHERIC CHEMISTRY EXPERIMENT (ACE)

2.1 The ACE Mission

The ACE mission addresses two important and related issues in atmospheric science: air pollution and climate change resulting from increasing greenhouse gas concentrations. Stratospheric ozone loss has been caused by chlorine and bromine released from the breakdown of man-made chlorofluorocarbon (CFC) and halon species. With the Montreal Protocol and its subsequent amendments, the production of ozone depleting substances and the level of chlorine in the stratosphere has started to decrease. From this trend it is expected that the ozone layer will recover. However, changes in climate due to increasing greenhouse gas levels will impact the rate of recovery of stratospheric ozone. To understand changes in ozone concentrations in the stratosphere and identify the causes of these changes, profile measurements, including ozone, chlorine-containing species, greenhouse gases, and temperature, are needed as function of time.

2.2 Measurement Concept

The ACE mission is based on solar occultation. The ACE-FTS operates in low orbit by using the direct Sun, the highest source of natural sustained radiance in the solar system, as a source of background illumination. In the course of a sunrise or sunset, the instrument tracks the Sun in order to probe the atmosphere. The spectra acquired while the instrument line of sight goes through the atmosphere are divided by the measurement made when the Sun is above the atmosphere (Figure 1). The resulting data is a series of self-calibrated transmittance spectra of the atmosphere at different altitudes. By inversion, it is possible to retrieve the vertical distribution of the concentration of various chemicals in the atmosphere. Because a solar occultation spectrometer uses the Sun, a high sensitivity can be achieved even at relatively high spectral resolution. Concentrations of the order of parts per billion or better in some cases can be retrieved.

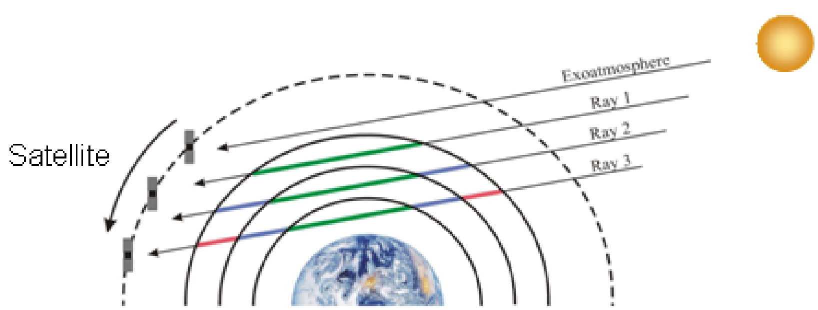

Figure 1: Solar Occultation Principle around the Earth

2.3 ACE-FTS Instrument Overview

The ACE-FTS, operating from 2.4 to 13.3 µm, measures at high spectral resolution (0.02 cm^{-1}) the infrared absorption for different tangent heights. The atmospheric absorption provides information on vertical profiles of atmospheric constituents, temperature, and pressure. The imager monitors aerosols based on the extinction of solar radiation using two filtered detectors at 1.02 and 0.525 µm.

The spectrometer is a modified version of the classical Michelson interferometer using an optimized optical layout and moving cubes corner on rotating “V”-shaped scan arm. The optical path within the interferometer is doubled with the insertion of a flat mirror as it was done for the ATMOS instrument that flew on the Space Shuttle. This double-pass configuration increases the achieved spectral resolution and also completely compensates the initial tilt and the shear in the interferometer as well as any subsequent variation of the tilt and shear due to thermo-elastic deformation or other sources of misalignment. The scan arm rotates about the beamsplitter to vary the optical path difference as function of time. The mechanism is based on flexure blades designed for infinite life time. The optical path difference that is achieved by the combination of the motion of the scan arm and the optical doubling is ±25 cm plus margin for turn-around. The instrument has a field-of-view (FOV) of 1.25 mrad and an aperture diameter of 100 mm. A suntracker is included in the instrument, which provides fine pointing toward the center of the Sun. The Suntracker maintains the FOV centered on the radiometric centre of the Sun during the data acquisition.

The instrument optical layout is based on a folded design which results in a very compact instrument. The instrument optical layout is presented in Figure 2. Starting from the input, the first optical component is the suntracker module (1) that tracks the radiometric centre of the Sun. The infrared and visible signals are then directed to the primary mirror (3) of a 5× magnification telescope. A small bandpass filter (19), mounted on the primary telescope mirror, transmits the 1.52 μm to 1.59 μm wavelength range to a quad cell (21) that is used as the feedback source for the suntracker module, and reflects the remaining spectrum to the VIS and NIR imagers (22 to 28).

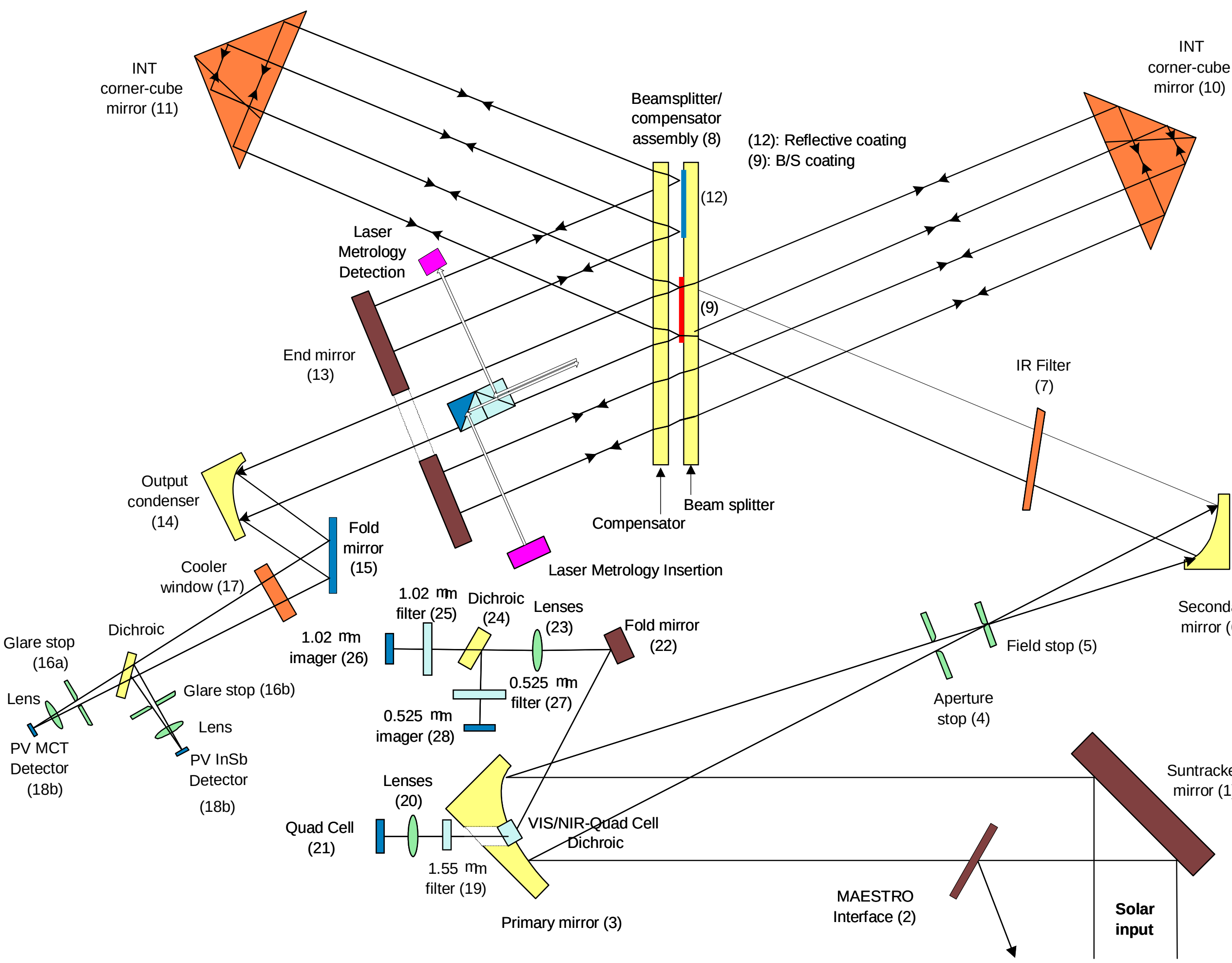

Figure 2: ACE-FTS instrument optical layout

The Telescope primary mirror (3) then reflects the signals through the aperture (4) and field stops (5) to the Telescope secondary mirror (6). Then, the collimated beam is directed towards the interferometer (8 to 13). A filter (7) is installed between the input optics and the interferometer to minimize the thermal load on the interferometer. The output of the interferometer is then condensed to the InSb/MCT detector assembly (16-18) using another off-axis parabola (14).

The optical path difference of the interferometer is measured in real time by injecting the beam from a laser diode in the interferometer. The laser diode is a 1550 nm distributed feedback laser diode with controlled current and regulated temperature. The temperature is regulated with a thermo-electrical cooler. At the output, the laser beam is captured by a pair of photodiode. The metrology signals are used to accurately measure the optical path difference and to determine the scanning direction in order to trigger the acquisition of the infrared science signals at known optical path positions and also to servo-control the motion of the interferometer scan arm. The metrology subsystem (source and detection) is cold redundant. More information regarding the instrument design can be found in [3] and [4].

The ACE-FTS has been designed for a 2-year mission. The choice of parts, the redundancy scheme, the shielding, the qualification and testing of some elements have all been done with a 2-year mission in mind. After more than seven years in orbit, no significant degradation or impact on the reliability has been observed yet. Information on the instrument performance after launch can be found in reference [5].

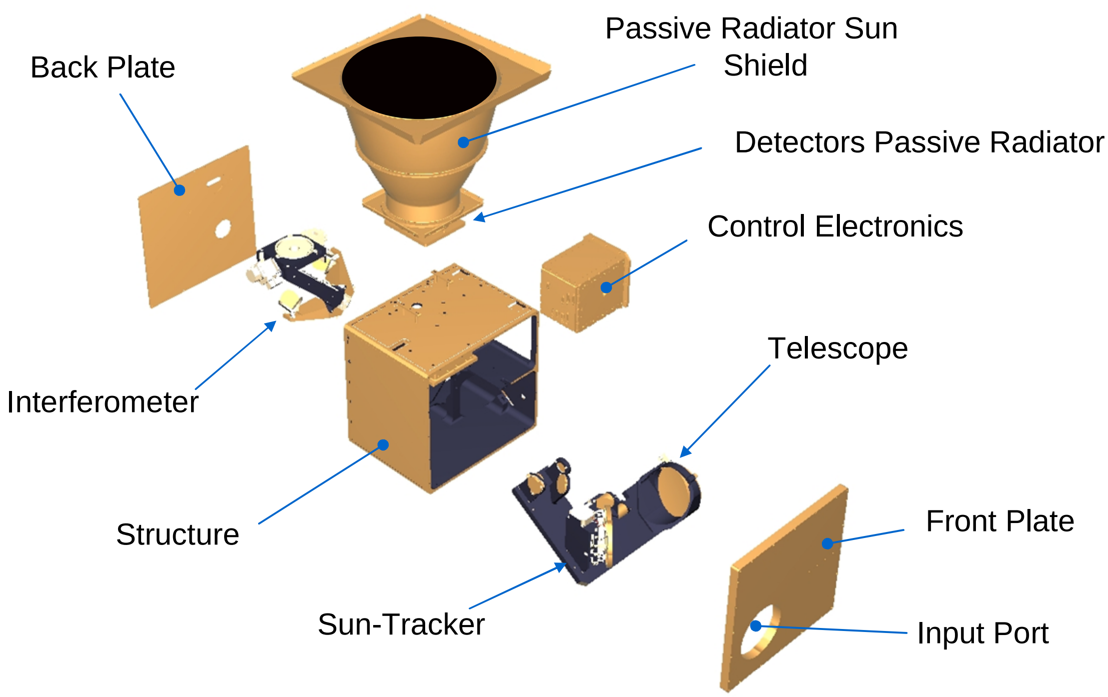

Figure 3: Exploded 3-D view of the ACE-FTS

3. FOLLOW-ON MISSIONS

3.1 CASS

The space instruments currently in operation for atmospheric composition measurements are not likely to continue operating past 2014 and there are only few profiling instruments planned for future short term missions. Therefore, the scientific community is at risk of losing continuity in the time series of profiles of ozone, chlorine-containing and related species. The nadir-viewing measurements that are planned will not provide the altitude information or numbers of species required to understand the recovery of stratospheric ozone.

CASS (Chemical and Aerosol Sounding Satellite) is a proposed collaborative mission by CSA and NASA. CASS is meant to be a low-cost, fast-track mission to ensure a continuity of stratospheric composition measurements between the measurements being made by the current SCISAT-1 and EOS-Aura missions and future atmospheric composition missions such as GACM.

The main objectives of CASS will be to measure the concentration of trace gases in the stratosphere and upper troposphere and to measure the characteristics of stratospheric aerosols. CASS will have two payloads; both will make measurements through solar occultation across the atmospheric limb. One payload will be based on the ACE-FTS that flies on the Canadian SCISAT-1 satellite, the payload described in the previous section. The other payload will be a spare model of SAGE III, a UV/Visible grating spectrometer developed by NASA Langley Research Center and built by Ball Aerospace. A first feasibility concept have completed in Q2 2010. In that first study, it was considered that both payloads would fly on a spacecraft based on the Bristol Aerospace MAC-200 Multi-Mission Smallsat bus. Another feasibility study is ongoing. In that second study, the possibility of installing both payloads on one of the external payload pallets of the International Space Station is being considered. CASS will allow measuring high vertical resolution profiles of ozone, chlorine-containing species, tracers of atmospheric dynamics, and other key atmospheric constituents. It will monitor stratospheric volcanic aerosols whose impact on climate change: this parameter has one of the larger uncertainties for future climate predictions. CASS will also measure the main greenhouse gases (CO_2, H_2O, CH_4, N_2O, CFCs and tropospheric O_3). These results will contribute to improving scientific community understanding of climate change.

By using existing designs with minimal changes, the development cost and time can be kept low to ensure a timely launch in order to maintain the continuity of the invaluable data acquired by the previous versions of these instruments. The target launch date is 2014.

To ensure a fast development and manufacturing, the CASS FTS will be as close as possible to the original ACE-FTS instrument. Note that SCISAT-1 has been launched 10 years ago and some modifications are necessary to address the obsolescence of some parts, in particular electronics components. Some valuable improvements are also considered to incorporate new knowledge obtained from the ACE mission. For example, more scientific interests have been given to higher wavenumber with higher sensitivity in order to proceed to a broad survey of trace gases. Consequently, the spectral range coverage is extended to the range of 4500 cm^{-1} by changing coatings specifications and improving modulation efficiency. Also, the original ACE-FTS design is adapted to fit the mechanical interface of the CASS platform (or of a mounting pod for the International Space Station). The control electronics is based on the more recent electronics built for the GOSAT-FTS. An option is to include the improvement of tangent height knowledge and tracking at lower altitude. More information can be found on the other payloads and spacecraft in [6].

If CASS is deployed onto the International Space Station (ISS), the design will diverge more from the original ACE design. The operational constraints on the ISS impose more modifications than if the payload is to fly on a dedicated satellite. For instance, it is likely that passively cooling the infrared detectors will be impractical on the ISS because it will be difficult to maintain the passive cooler toward deep space at all time. A mechanical cooler will have to be added to the design. In the case of the ACE mission, the SCISAT satellite is manoeuvring in order to bring the centre of the Sun within 1° of the nominal optical axis of the spectrometers. Such mode of operation is impractical on the ISS. A coarse azimuth and elevation pointing system will have to be added either to the instrument itself or to the pallet interface. The specific environment of the ISS and regulations for the operation of external equipment on the ISS will also impose some minor modifications such as the addition of a door to protect the optics from contamination when the instrument is not in use and during higher contamination events (such as docking and undocking of transit vehicles), reduction of the payload electro-magnetic signature, etc.

The science objectives of CASS ask for similar instrument performances as for SCISAT. The philosophy of the mission is also to re-use as much as possible the SCISAT design in order to speed up the development and achieve a launch as early as possible. That leaves little possibility of improvement or innovation with respect to SCISAT. The instrument design will be very similar to the ACE-FTS. Beside addressing electronic components obsolescence and potentially adding features to adapt the payload to the ISS as mentioned above, the improvements that will be implemented into the CASS FTS are:

- Extending the spectral measurements in the short-wave from 4100 cm^{-1} initially to 4500 cm^{-1}.
    - This can be achieved by changing the coatings on the optical components and by refining the alignment of the interferometer.
- Improving the pointing knowledge to ±500 m (1-sigma) at the tangent plane.
    - This can be achieved by combining a series of modifications such as increasing the numerical resolution of the time tag of the data, increasing the resolution of the Sun-tracker encoder, having a

more precise pre-launch characterisation of the relative alignment of the instrument LOS with respect to the spacecraft references, etc.

- Increase the capability of the instrument to acquire at low altitude. SCISAT is able to track the Sun below 5 km of altitude at the tangent plane about 30% of the time (mostly because of clouds and refraction).
    - This can be achieved by reducing the relative gaps between the photo-sensitive cells of the quad cell that feeds the servo-control of the Sun-tracker.

All of the above are relatively minor improvements that have no impact on the instrument concept. The overall design remains mainly unchanged. ABB can build a new copy of the ACE-FTS sufficiently rapidly, with no negative impact on the risks, to satisfy the fast-track schedule of CASS and ensure that the data gap between SCISAT and CASS is small or non-existent.

3.2 SOAR

While CASS will re-use mostly the same instrument design as the ACE-FTS, the Solar Occultation for Atmospheric Research (SOAR) mission presents an innovative “next-generation” solar occultation remote sounding mission to provide critical data for studies of atmospheric changes related to air quality and climate change [19].

SOAR will focus on making improved profile measurements of atmospheric composition with higher vertical resolution and wider altitude coverage. These results will be used, in concert with other contemporaneous satellite experiments and in combination with chemical transport and inversion models, to investigate the chemical processes and transport of pollutants in the troposphere, to monitor changes in the major greenhouse gases (water vapour, carbon dioxide, methane, nitrous oxide, chlorofluorocarbons) and the expected recovery of stratospheric ozone, and to study interactions between chemistry and climate in the upper troposphere and lower stratosphere.

The mission objectives of SOAR are to:

- Investigate chemical processes and transport of pollutants in the troposphere, with a particular focus on organic molecules.
- Study interactions between chemistry and climate especially in the upper troposphere and lower stratosphere (UTLS).
- Monitor changes in atmospheric composition to improve our knowledge of climate change and stratospheric ozone recovery.

To meet these objectives, the SOAR mission will need to provide measurements of a broad range of atmospheric constituents with high vertical resolution and over a wide altitude range. Also, observations of atmospheric parameters such as temperature and pressure and the presence of clouds are needed. While the ACE mission focused mostly on the upper latitudes, SOAR will use a different orbit that will result in measurements being more evenly spread across all latitudes.

To further the study of the UTLS and troposphere where phenomena occur on small scales, SOAR will provide profiles with vertical resolution better than 2 km (target 1.5 km) for all species and better than 1 km (target 0.5 km) for O3, NO2 and aerosols. Extending these high vertical resolution measurements to lower altitudes is also needed to better understand the free troposphere. SOAR will provide profiles that reach from as low as 5 km and up to 100 km, depending on the specific species. To understand and predict changes in atmospheric chemical processes, it is necessary to have simultaneous measurements of a wide range of constituents. These results give important context and constraints for chemical modeling and provide higher confidence when attributing the sources of atmospheric change. SOAR will develop an extensive dataset of atmospheric constituent measurements by providing measurements of over 40 different species and parameters.

The main instrument of the SOAR mission is a solar occultation FTS similar to the ACE-FTS but with some improved features. SOAR will also fly a two-band imager and UV-VIS-NIR spectrometer, both with improved capabilities compared to their predecessors currently flying on SCISAT. The measurements contributed by the three SOAR instruments are listed in Table 1 with their corresponding science goal.

Table 1: SOAR sciences goals and instruments contributions

Science Goal	Measurement	Instrument Role
Tropospheric Chemistry and Transport of Pollutants	***IR FTS:*** O_3, CO, NO, NO_2, N_2O_5, HNO_3, HCN, HNO_4, PAN, CH_3OCCH_3, C_2H_2, C_2H_4, C_2H_6, CH_3OH, H_2CO, HCOOH	Simultaneous measurements of reactive species
	UV-VIS-NIR Spectrometer: O_3, NO_2, H_2O, aerosol	Higher vertical resolution profiles with higher precision
Chemistry and Climate Studies in UTLS	***IR FTS:*** H_2O, HDO, $H_2{}^{18}O$, O_3, CO, HNO_3, HCl, CH_4, N_2O, HCN, NO, NO_2	High vertical resolution profiles of large suite of molecules
Climate Change Studies	***IR FTS:*** CO_2, N_2O, CH_4, H_2O, O_3, CFC-11, CFC-12, CH_3Cl, SF_6, CF_4, CCl_4, CFC-113, HCFC-142b, HCFC-22, HFC-134a	Profiles of major greenhouse gases including halocarbon species
	UV-VIS-NIR Spectrometer and Imagers: Aerosol in UV-VIS-NIR (composition/distribution)	Optical enhances wavelength coverage, higher vertical resolution
Stratospheric Ozone Chemistry and Ozone Recovery	***IR FTS:*** O_3, HCl, $ClONO_2$, CFC-11, CFC-12, CH_3Cl, CCl_4, CFC-113, HCFC-142b, H_2O, HCFC-22, HFC-134a, COClF, $COCl_2$, NO, NO_2, N_2O_5, HNO_3, HNO_4, HF, CH_4, N_2O	Measurements of ozone and species involved in depletion processes as well as tracers of atmospheric dynamics
	UV-VIS-NIR Spectrometer: O_3, NO_2, H_2O, other species	Higher vertical resolution profiles BrO and OClO
Atmospheric Parameters	Temperature profiles from ***IR FTS, UV-VIS-NIR Spectrometer and Imagers***	Simultaneous retrieval from different spectral bands

The FTS of SOAR will have the same basic characteristics as the ACE-FTS of SCISAT with the following modifications and improvements:

- The spectral range will be extended in the short-wave to about 4500 cm^{-1}.
  - This can be achieved by changing the coatings on the optical components and by refining the alignment of the interferometer.
- The signal to noise ratio in the short-wave will be improved
  - This can be achieved by using two detectors to cover the short wave IR, for a total of three detectors for the total spectral range of the instrument. The ACE-FTS had two detectors to cover the full range. In the short-wave IR, the total noise of the instrument is dominated by the photon shot noise of the scene. If the spectral bands are narrower, the total amount of photons per bands will be reduced and the shot noise will be smaller, resulting in an improved signal to noise ratio.
- The vertical resolution will be improved by a factor 3.
  - An image slicer will be used to reduce the vertical FOV by factor 3 while increasing the horizontal FOV by the same factor. In the image domain, the field of view will remain symmetric (see Figure 4). The total view solid angle will remain the same as ACE. The observation time per spectrum will be reduced from 2 s to 1.3 s. The aperture area will be increased by a factor 1.44 to compensate the reduction of observation time and avoid negative impact on the signal to noise ratio.
- A camera will be used to collect the feedback signal of the Sun-tracker instead of the 4-quadrant cell of SCISAT. This will improve the accuracy of the tracking, especially at lower altitudes.

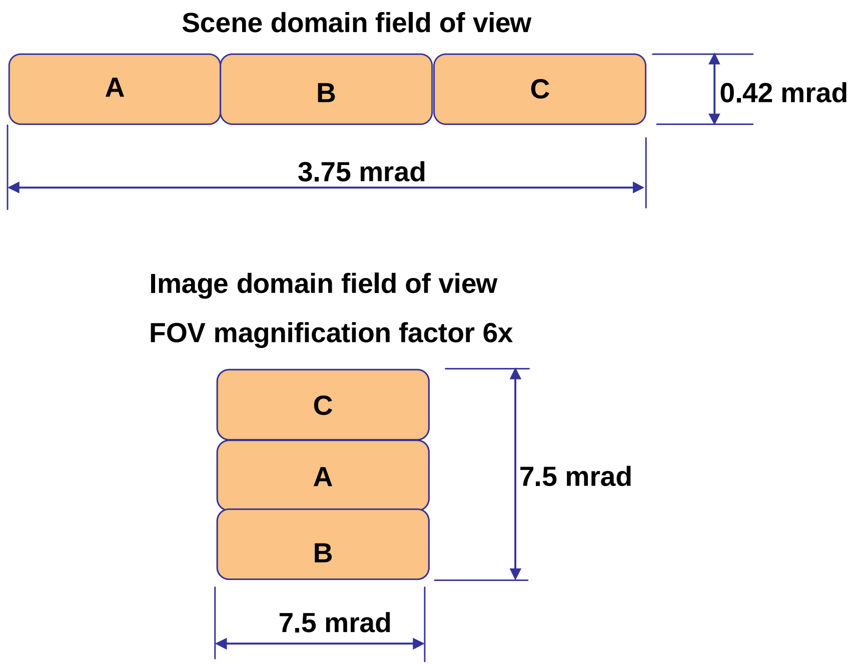

Figure 4: SOAR field of view reorganisation

The Canadian SOAR mission will provide this essential data set to continue the time series of height-resolved composition measurements and thereby contribute to improving our understanding of the changes occurring in the Earth's atmosphere and to providing the policy-relevant results that are needed nationally and internationally. SOAR provides an opportunity for the ACE team to contribute internationally in the efforts to better understand climate change and air quality using a measurement technique for which it established an international leadership.

SOAR is a mission concept provided to the Canadian Space Agency as part of the Atmospheric Processes of Climate and its Change Mission Concept Studies Program. The target launch date for SOAR is after CASS, around 2016.

3.3 ExoMars TGO / MATMOS

The ExoMars Trace Gas Orbiter (TGO) is a NASA-ESA mission that plan to send an orbiter to Mars in January 2016 [7], [8] [9]. An Announcement of Opportunity (AO) was released in January 2010. Proposals include scientific instruments to measure trace gases in the Mars atmosphere and monitor surface changes from the orbit [10], [11]. In recent years, several NASA reports proposed an FTS operating in solar occultation mode as a primary and high priority instrument for the Martian atmospheric mission [12], [13], [14], [15]. The goal of this instrument is to detect and characterise low concentrations of chemicals in the Martian atmosphere (trace gases). An instrument based on ACE-FTS has been explicitly mentioned as a desired instrument for TGO and its performance values, mass, power, resolution, have been used as baseline for preliminary payload allocations.

The data from an FTS will allow the science community to perform a precise and global survey of the Martian atmosphere, to determine the underlying processes controlling atmospheric composition, to quantity the sources of the trace chemical species to the Martian atmosphere, to localize their sources and variability and to determine the lifetime of these species within the atmosphere [16].

To achieve theses objectives, the temperature, pressure and concentration profiles of the Martian atmosphere species including clouds and dust are retrieved from the TGO-FTS instrument spectra. Because an FTS is not tuned to specific molecules, this instrument is able to detect the presence of atmospheric species that scientists are presently unaware, providing a valuable "discovery" capability. This instrument will supply the first global set of profiles for water vapour and relative humidity with an understanding of the transportation processes. In the short term, therefore, the instrument will provide information on the Martian weather. Combining the weather information with atmospheric modeling over the course of a Martian year, it will contribute strongly to the scientific community understanding of the Martian climate [16].

Over the last decade, the Canadian Space Agency has financed several feasibility studies involving a solar occultation instrument in orbit around Mars. The last of these studies evaluated the possibility of adapting the ACE-FTS concept to meet the requirements of the TGO mission.

The study concluded that a rebuilt of the ACE-FTS for TGO will achieve the atmospheric composition requirements of the mission. Because the field of view of the ACE-FTS is still smaller than the Sun at the Mars-Sun distance, the performance of the instrument in orbit around Mars will be similar to the performances of the instrument in orbit around the Earth.

The California Institute of Technology (Caltech), NASA Jet Propulsion Laboratory and the Canadian Space Agency have recently been awarded a project to develop the solar occultation spectrometer for the ExoMars TGO, the Mars Atmospheric Trace Molecule Occultation Spectrometer or MATMOS. The Canadian contribution to the instrument will include the interferometer and its control electronics, the input optics and a four-band imager and ABB is the selected supplier for these elements. The interferometer is based on the ACE-FTS interferometer. The baseline design for the input optics and four-band imager is adapted from the dual-band imager of ACE. These three modules are described below.

The aft optics and signal processing electronics will be developed and built at JPL. Several advances on the ACE-FTS design are planned to provide high signal-to-noise spectra in the presence of large and variable dust loading. These include use of 24-bit delta-sigma ADCs for digitization and extensive on-board processing to account for scene variability while converting the interferograms to spectra as the downlink from Mars is insufficient to return the raw interferograms.

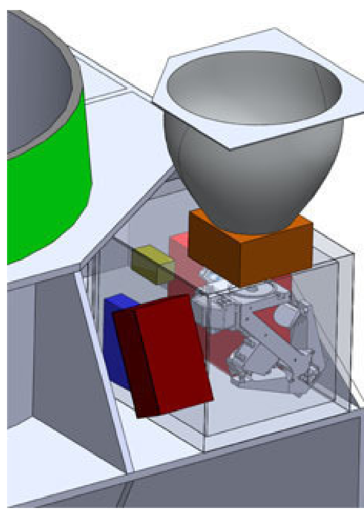

Figure 5: Schematic view of the MATMOS instrument (image from JPL)

The input telescope is based on the telescope designed for ACE-FTS. The design uses the same etendue but with a slightly larger field of view (1.56 mrad for MATMOS instead of 1.25 mrad for ACE) and a smaller aperture (8 cm instead of 10 cm). This is required because the distance to the limb is smaller in the case of MATMOS because the TGO satellite altitude is lower (between 300 km and 400 km) compared to the altitude of SCISAT (650 km). To preserve the same spatial resolution, the FOV has been increased. The input optics is an all-reflective off-axis telescope with an effective magnification factor of 4.

The interferometer maintains the heritage of the ACE-FTS interferometer. A higher transmittance, an extension of the spectral range up to 4500 cm^{-1}, and improvement of the modulation efficiency will enhance the overall instrument performance through planned modifications to the beamsplitter. The metrology and the electronics are based on the design used for the Japanese Satellite Ibuki. The strong heritage of these subsystems from previous successful space programs will ensures a high maturity and low development risks and cost for these elements.

The imager system looks at the Sun in order to measure the extinction as a function of altitude. That information is used to infer the nature and the amount of aerosols in the atmospheric path. The imagers have a more prominent role in the Mars atmospheric chemistry investigation due to the high dust loading seen seasonally at Mars. MATMOS will include an investigation of heterogenous chemistry. Characterising thin cloud layers observed by the Mars Phoenix mission in 2008 are also a scientific objective of the mission. The images can also be used to verify the accuracy of the pointing. Four spectral bands will be available to image the Sun during FTS measurements, supplying data on dust layering to complement FTS measurements for data quality control and providing atmospheric optical depth (AOD) at four wavelengths for dust studies. The imager technology evolution needs are to extend the imagers capability from two to four spectral bands and accommodate it in a more compact volume. A single detector design is also being explored to optimise mass, power and volume.

4. INSTRUMENTS COMPARISON

The solar occultation FTS for the missions described in the previous sections are all based or inspired by the ACE-FTS that flies on the Canadian SCISAT satellite. These instruments will either be copies of the SCISAT / ACE-FTS or will use some of its modules.

Table 2: Comparison of the characteristics of the solar –occultation FTS for the presented missions

Mission	SCISAT / ACE	CASS (on the ISS)	SOAR	ExoMars TGO / MATMOS
Location	Earth orbit (650 km)	Earth orbit on the ISS (460 to 280 km)	Earth orbit (650 km)	Mars orbit (300 to 400 km)
Target Launch date	2003	2014	2016+	2016
Spectral range	750 – 4100 cm^{-1}	750 –4100 cm^{-1}	750 –4500 cm^{-1}	750 – 4500 cm^{-1}
Spectral sampling interval	0.02 cm^{-1}	0.02 cm^{-1}	0.02 cm^{-1}	0.02 cm^{-1}
FOV	1.25 mrad	1.25 mrad	0.42 × 3.75 mrad	1.5 mrad
Aperture diameter	10 cm	10 cm	12 cm	8 cm
Telescope magnification	5 ×	5 ×	6 ×	4 ×
Observation time per spectrum	2 s	2 s	1.3 s	2 s
Pointing method	Coarse pointing with the satellite Fine active Sun tracking with the instrument	Coarse pointing with the platform or the instrument Fine active Sun tracking with the instrument	Coarse pointing with the satellite Fine active Sun tracking with the instrument	Fine pointing with the satellite
Number of IR detectors	2	2	3	2 (TBR)
IR detector cooling	Passive to ~95 K	Active to ≤ 85 K	Passive to ~95 K	Passive to ~95 K

5. CONCLUSION

This paper presented an overview of the follow-on ACE missions, CASS and SOAR. ACE has been already a tremendously technical and scientific success. The ACE instruments and its satellite have been designed for a mission time of two years. The mission is now in its eighth year in space, demonstrating the very high reliability of its design and manufacturing.

SOAR is an innovative "next-generation" solar occultation remote sounding mission to provide improved critical data for studies of atmospheric changes related to air quality and climate change. In the mean time, the CASS mission will ensure that the data collection currently accomplished by ACE will be pursued in the coming years. Hopefully, there will be data overlap between ACE and CASS and between CASS and SOAR.

The MATMOS instrument for the ExoMars mission can be seen as an "Advanced ACE for Mars" instrument. MATMOS will re-use some of the key sub-systems of ACE with flight-proven modifications to enhance performance at high frequencies. Improved signal processing and data compression will allow MATMOS to see through the dusty Martian atmosphere to provide invaluable information about the atmospheric composition and chemical dynamics of Mars. It will provide much clearer evidence on the presence of methane in the atmosphere of Mars and measure its spatial and temporal distribution. The measurements will also help to determine if the methane is from biological or geological origin.

Each FTS in these missions is based on the solar occultation FTS that ABB built for the ACE mission, launched in 2003. This very successful technology will be further deployed and enhanced through several new space missions.

6. ACKNOWLEDGMENTS

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