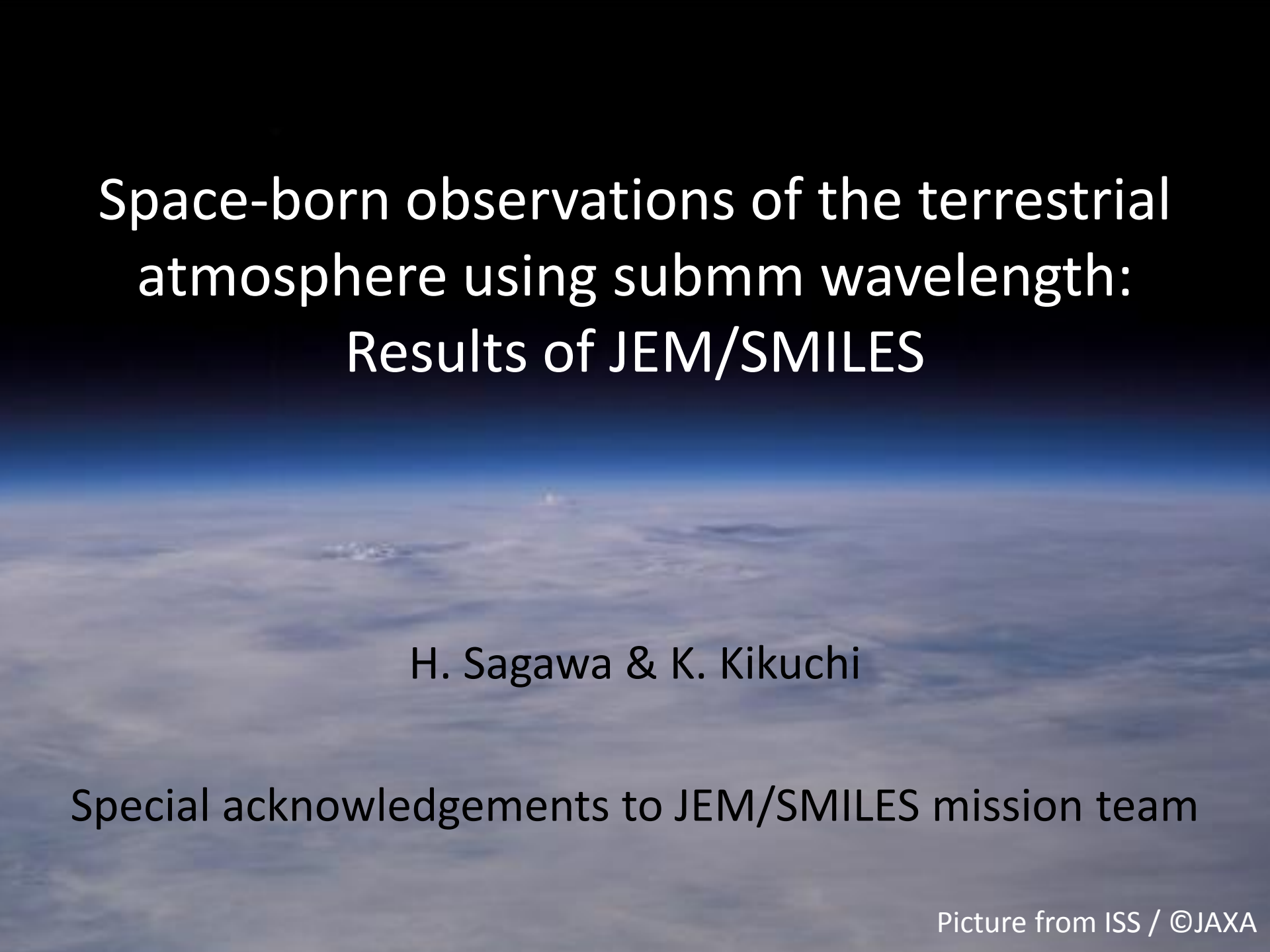
Space-born observations of the terrestrial atmosphere using submm wavelength: Results of JEM/SMILES

H. Sagawa & K. Kikuchi

Special acknowledgements to JEM/SMILES mission team



- Who am I (are we) ?

H. Sagawa (me)

Main research topic: Observational study of planetary atmosphere.

- PhD studies: Ground-based observations Venus atmosphere using near-IR telescopes and millimeter interferometers.
- Postdoc in Max Planck Institute (for Solar System Research), joining the Solar system observation project with Herschel Space Telescope.
- After SMILES' launch, moved to NICT. Mainly working on data analysis (inversion of the measured spectra to derive atmospheric physical parameters) of SMILES.

K. Kikuchi-san

… 20 min later.

- Outline of talk contents

Introduction

- Space-born mm/submm-observations of the Earth atmosphere.
- What is SMILES? What are the differences from other similar instruments?

Scientific findings of SMILES

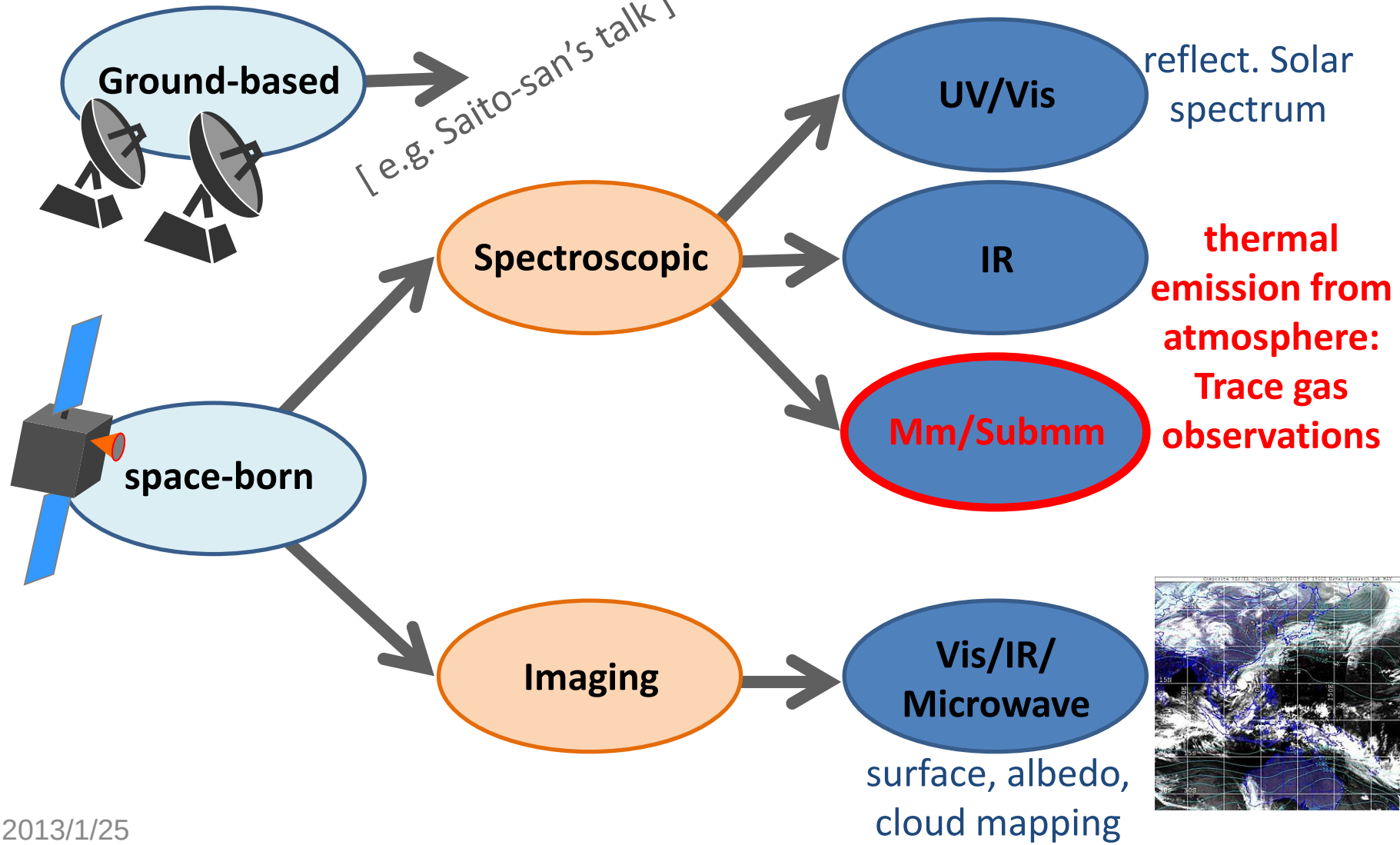
- Still “discoveries” in the Earth atmosphere!
- Atmospheric composition —measuring up to very high altitudes (top of the atmosphere); Diurnal-variation monitoring of the atmospheric chemistry; Direct wind velocity measurements; etc.

SMILES; as a state-of-the-art submm instrument

- … will be presented by by Kikuchi-san.

- Introduction

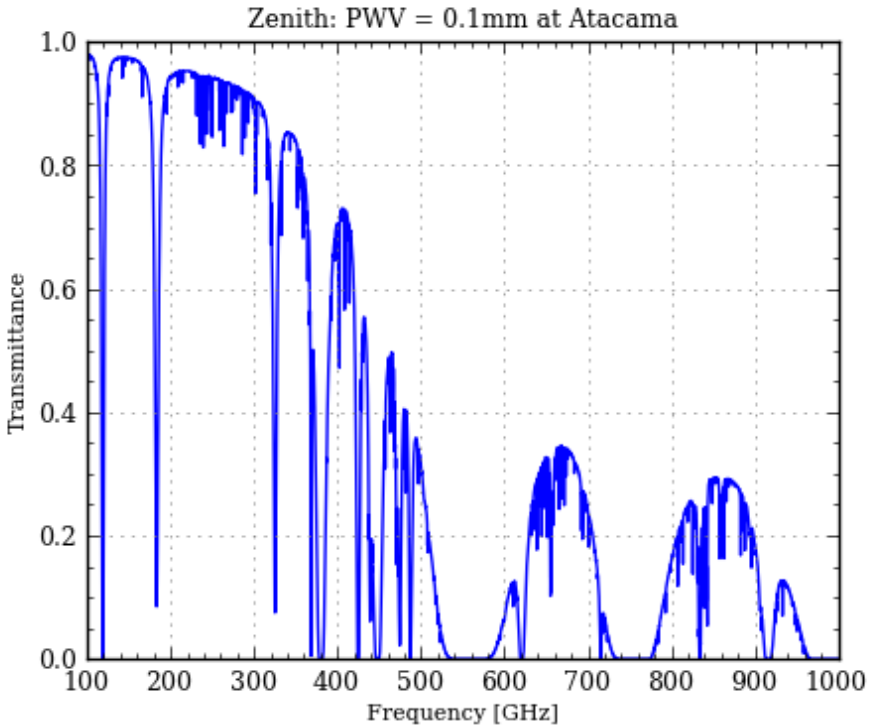
- Rough sketch of “(solar system) planetary observation”



- Introduction: Why mm/submm?

- mm/submm vs IR : Difference in the target species.
- Technical point of view : capability of heterodyne spectroscopy ($\nu/\Delta\nu \sim 10^7$). → Enables to spectrally resolve the line shape of molecular spectra.

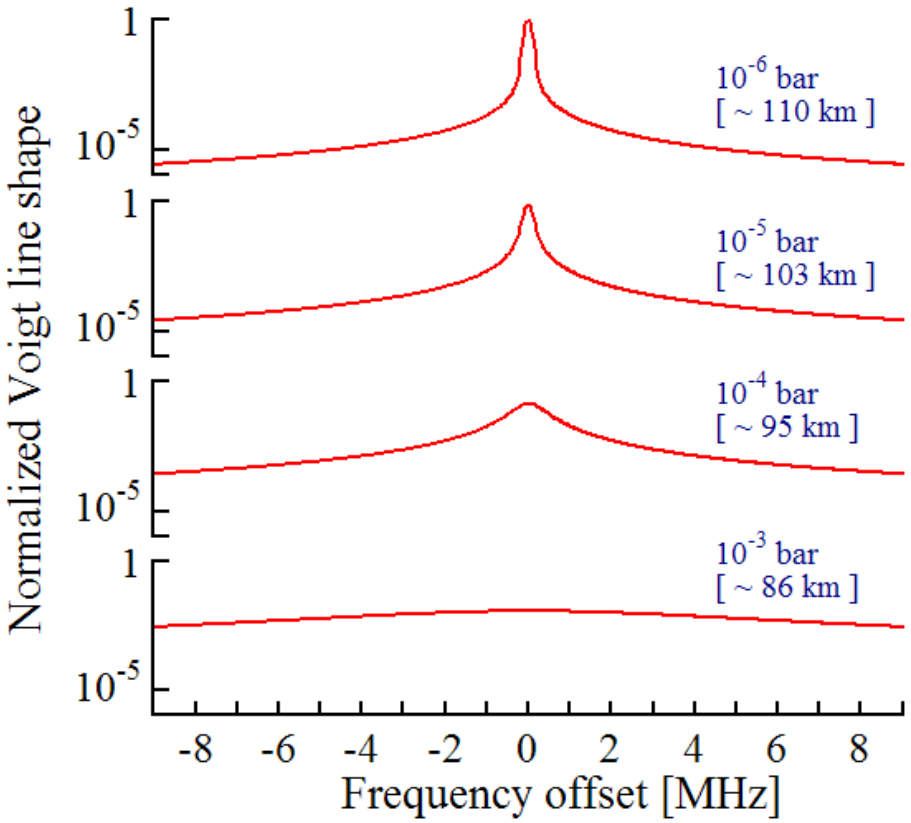
- Well-known problem in the submm-astronomy (or, at any wavelengths) : How to escape from the Earth atmosphere.
- …In other words, we can *use* submm emission to **observe** the Earth atmosphere.

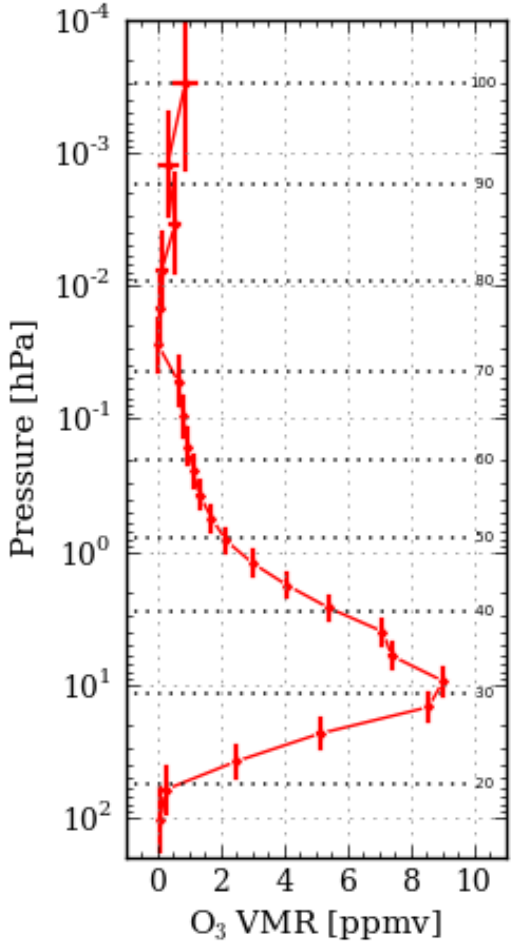


- Introduction: Inversion analysis

- Vertical profile of targeted species can be retrieved by using pressure-dependence of molecular line shapes.

Line shape of the measured spectrum represents the pressure-broadened line width after line-of-sight integration.





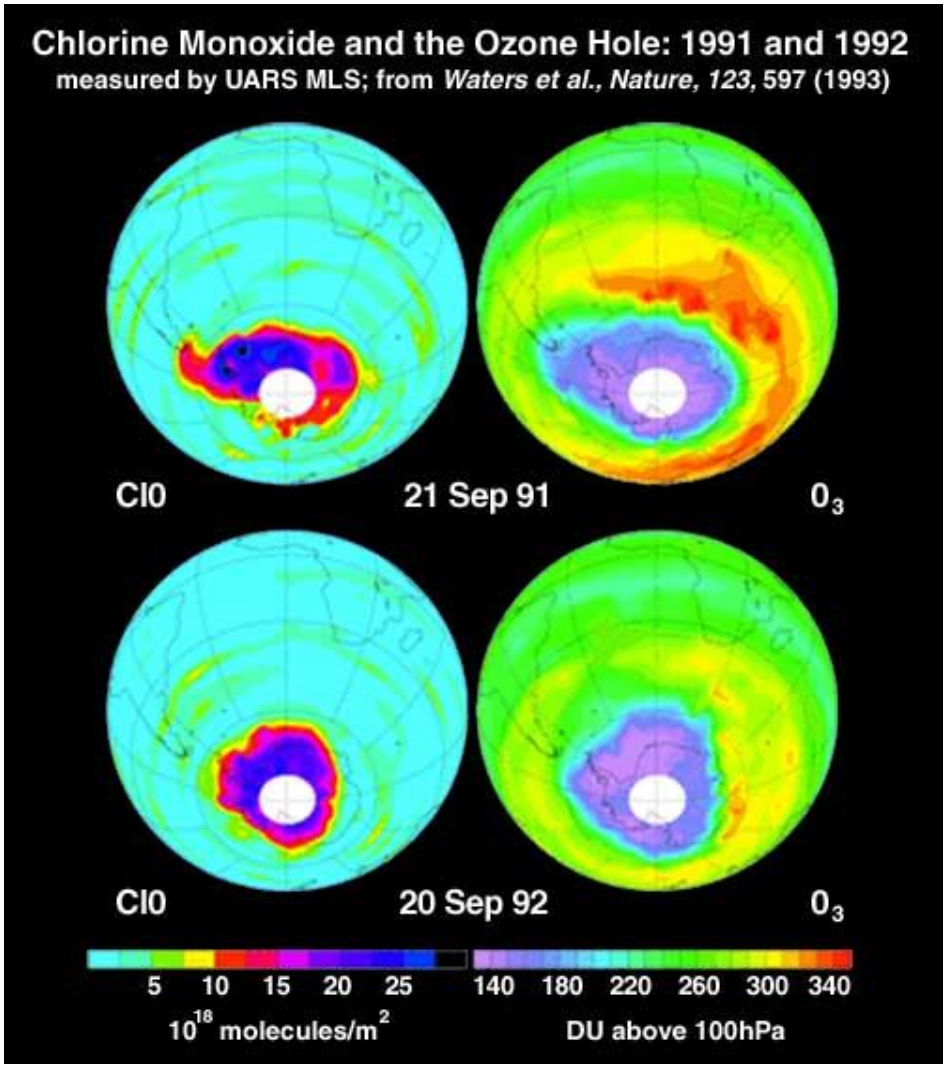
Pressure-Altitude conversion is for the case of Venus.

- Introduction: Earlier mm-sounders

Just for an example:

- UARS / Microwave Limb Sounder (MLS) had clearly observed the strong correlation between ClO enhancement & Ozone hole.

MLS onboard the Upper Atmosphere Research Satellite. Operated 1991 – 2005. Frequency bands at 63, 183, 205 GHz.



- SMILES

Superconducting Submillimeter-wave Limb-Emission Sounder

JAXA-NICT mission using the Japanese Experiment Module (Exposed Facility) of the International Space Station (ISS).

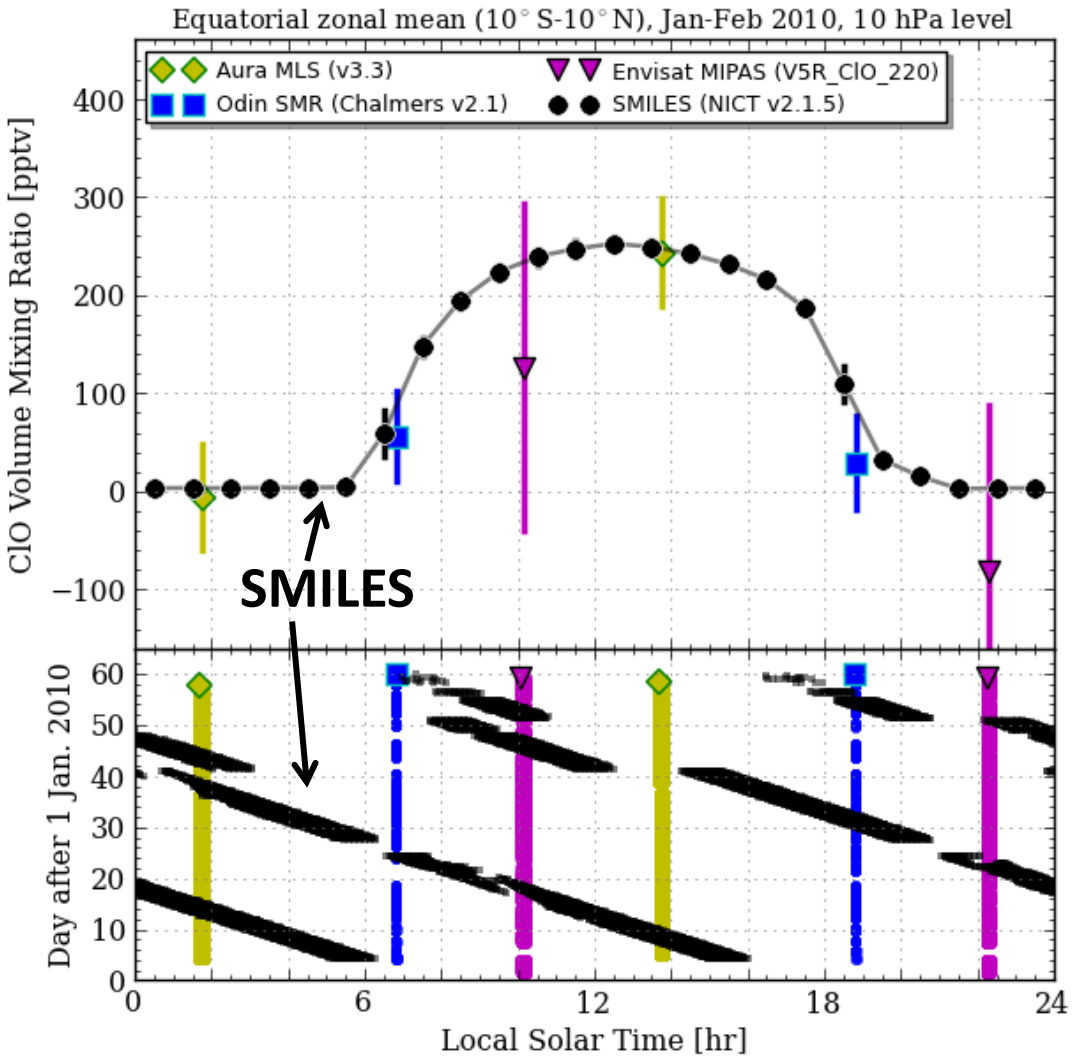
© JAXA/ISS

- Proposal approved in 1997; Launched 11 Sep 2009 by HTV; Attached to JEM on 25 Sep 2009; and Observations started 12 Oct 2009.
- **Telescope (main reflector) : 40 x 20 cm diameter.**
- **Employs a 4 Kelvin mechanical cooler & SIS mixers (625–650 GHz or 0.5 mm).**
- "First" application of SIS mixers in a space-born instruments targeting the Earth atmospheric observations […Herschel/HIFI first light = Jul. 2009].
- **Further details of instrumentation will be presented later.**

- SMILES: uniqueness of ISS-orbit

ISS has **a non sun-synchronized orbit** with an orbit altitude of ~350 km.

- Local time of the sub-ISS point precesses with a full 24 h shift after a 1–2 months period.
- Most of other similar satellite-based instruments have sun-sync orbits = Only fixed local time is sampled.
- Key species in atmospheric chemistry usually show a strong diurnal variation due to photolysis : **SMILES is the only instrument to measure their diurnal behaviors.**

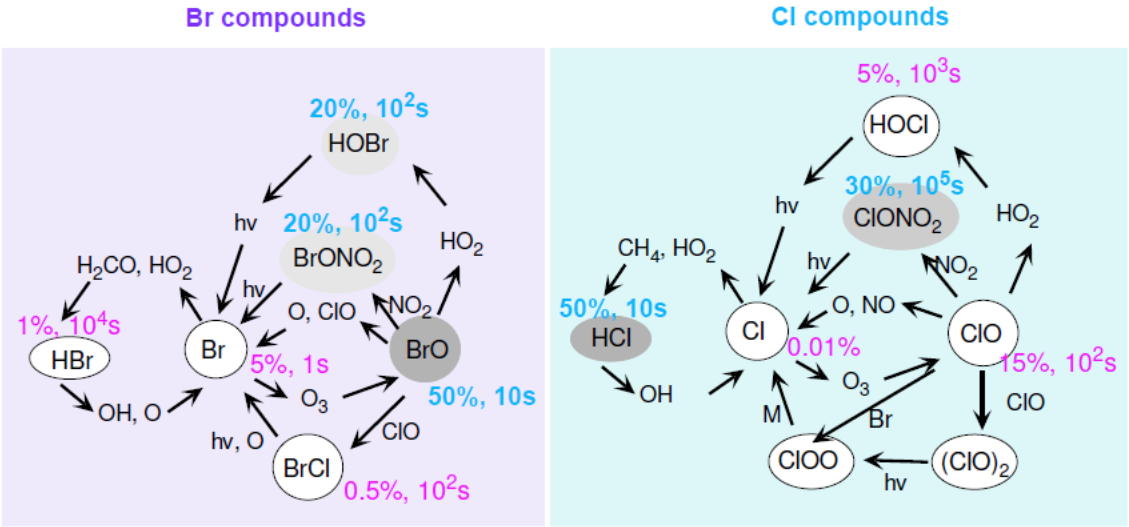


[Sagawa et al., 2012]

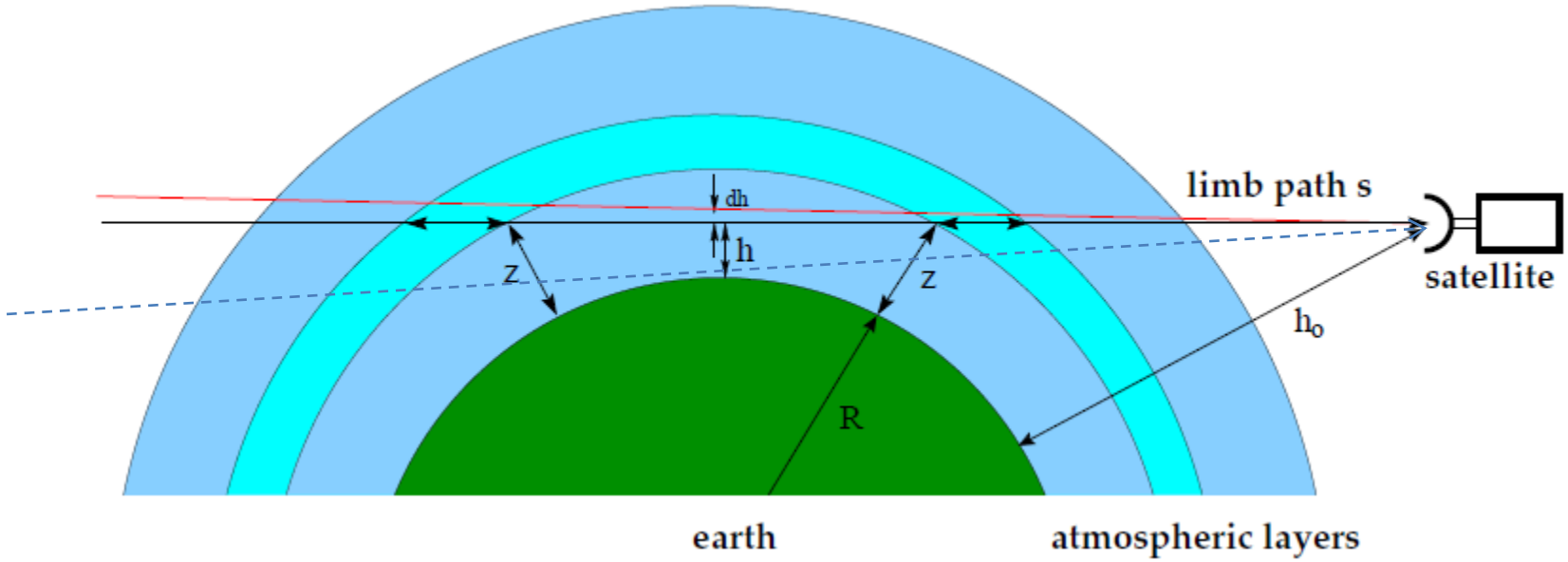
- SMILES: Scientific Objectives

To measure minor species in order to quantitatively understand physical & chemical processes controlling Ozone amount in the stratosphere.

- Background : the mechanisms of Ozone depletion have been nicely understood after these 20 yrs studies.
- Now we know that ClOx, BrOx, HOx chemistries are closely involved the Ozone depletion cycle. However, the amount of these ClOx, BrOx, HOx species in the stratosphere have not been measured sufficiently.
- Uncertainty in the distribution of these radicals introduces a large uncertainty in the prediction of Ozone recovery.



- SMILES: Limb scan measurement

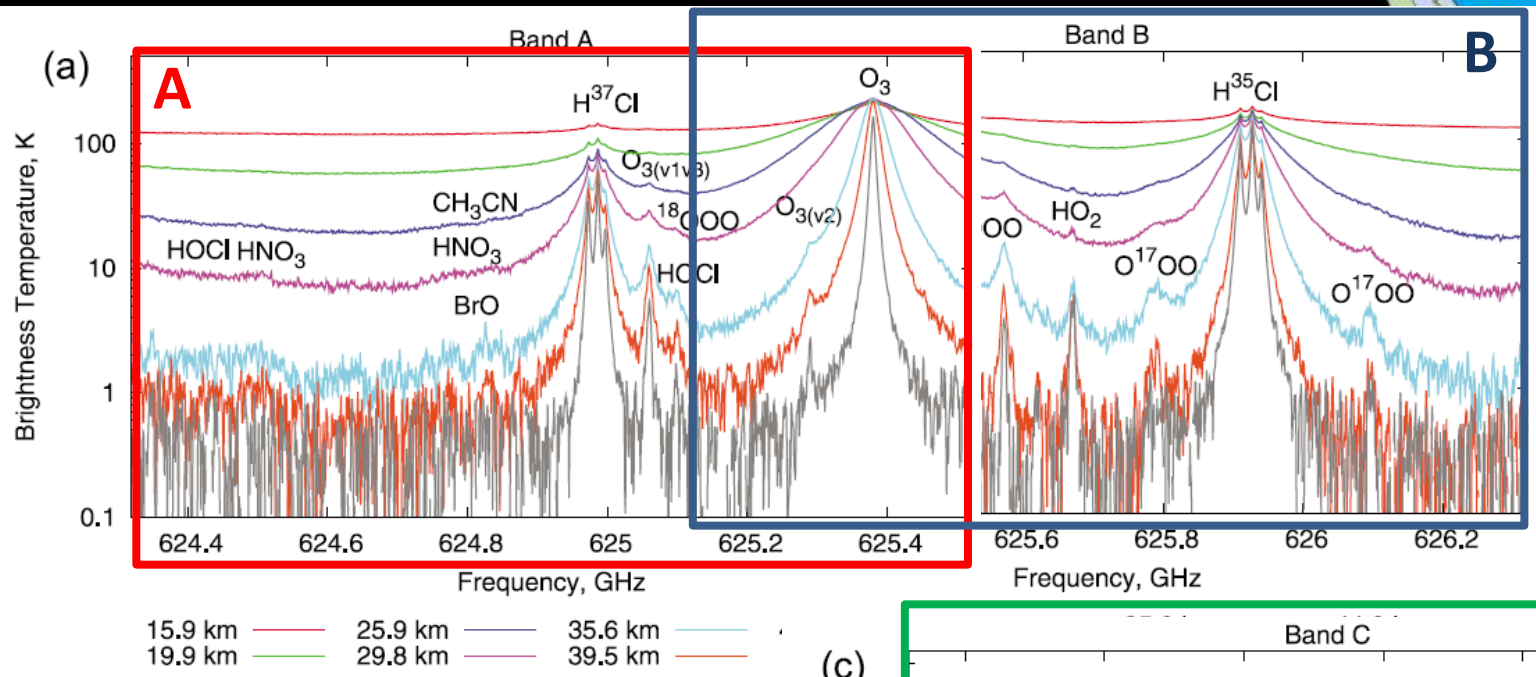


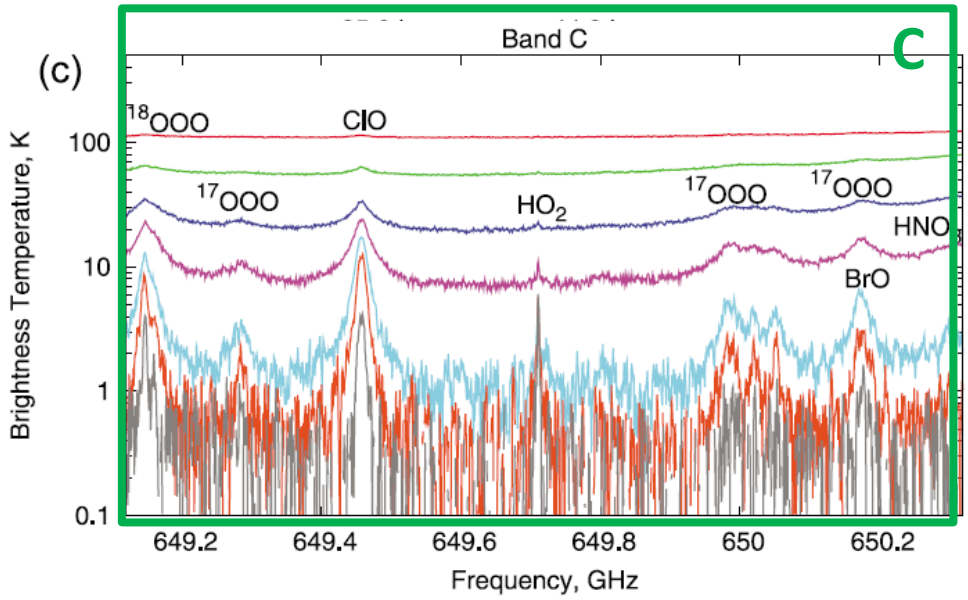
Observe the limb emission of the Earth atmosphere.

→ **Longer line-of-sight in the air, which gains much the sensitivity to very low concentration species.**

SMILES scan(ed) a tangent height range of ~0 – 100 km with a step of ~2 km (68 spectra): 0.47 sec-exposure at individual tangent height, and one scan takes 29.5 s.

- SMILES: Observation Spectra





3 Bands (A, B, C) in 600 GHz domain.

Bands A & B overlap on O_3 625 GHz line.

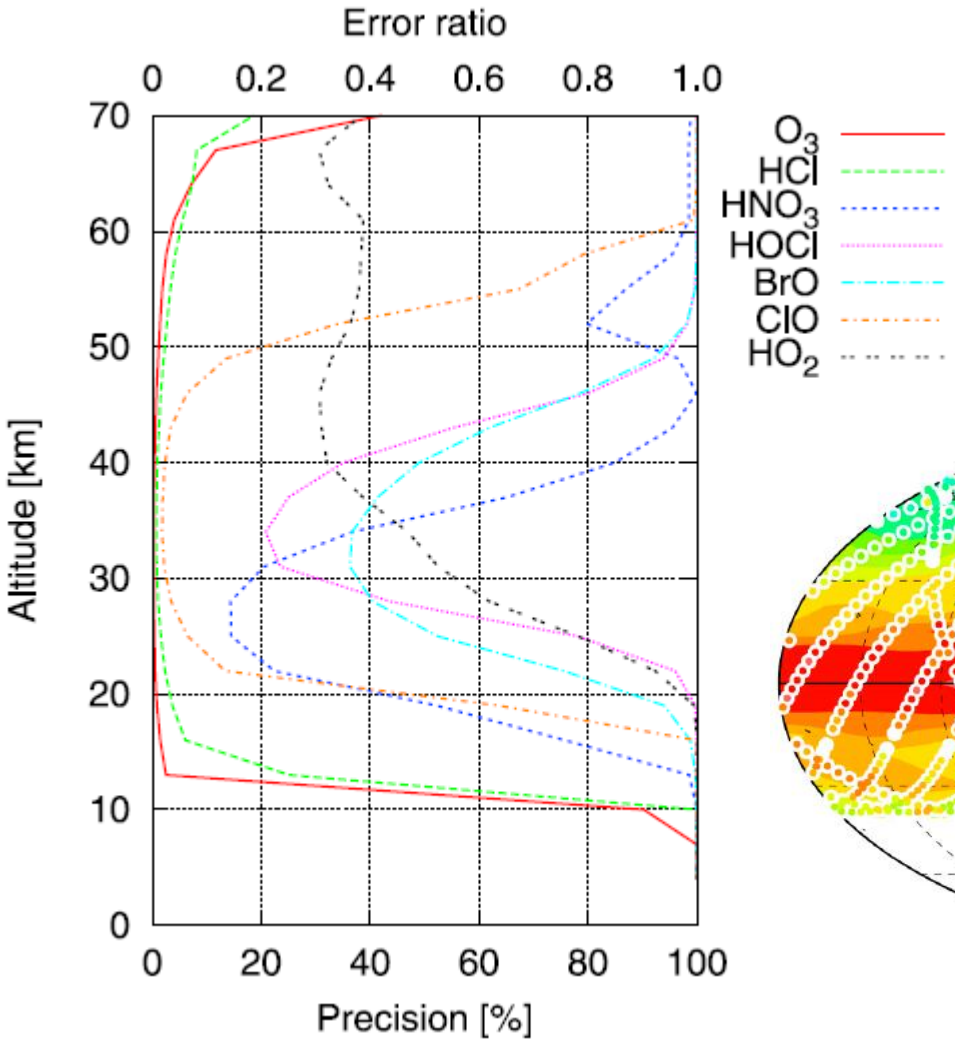
Thanks to having two spectrometers, **two of the three Bands were observed simultaneously, i.e., A+B, B+C, or C+A**.

This means, some species were continuously observed over the full SMILES period (O_3, HCl, HO_2, BrO, etc).

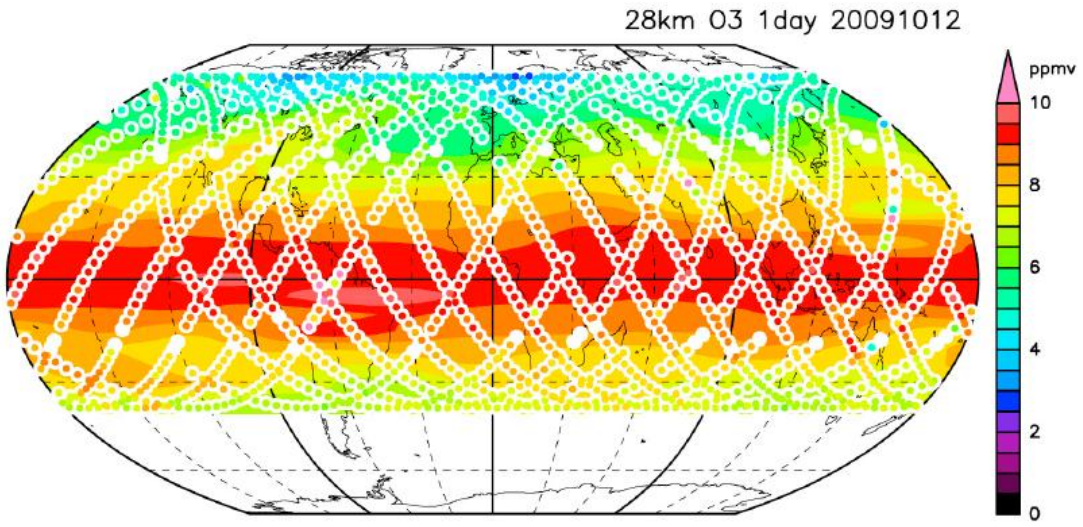
Kikuchi et al. (2010)

- SMILES: Sensitivity & Coverage

High performance of SIS receiver provided an unprecedented sensitivity.



- 1 global map from 1 day observations (~1630 points).
- Due to ISS-orbit inclination, 38S – 65N latitudinal coverage.



[Kikuchi et al., 2010]

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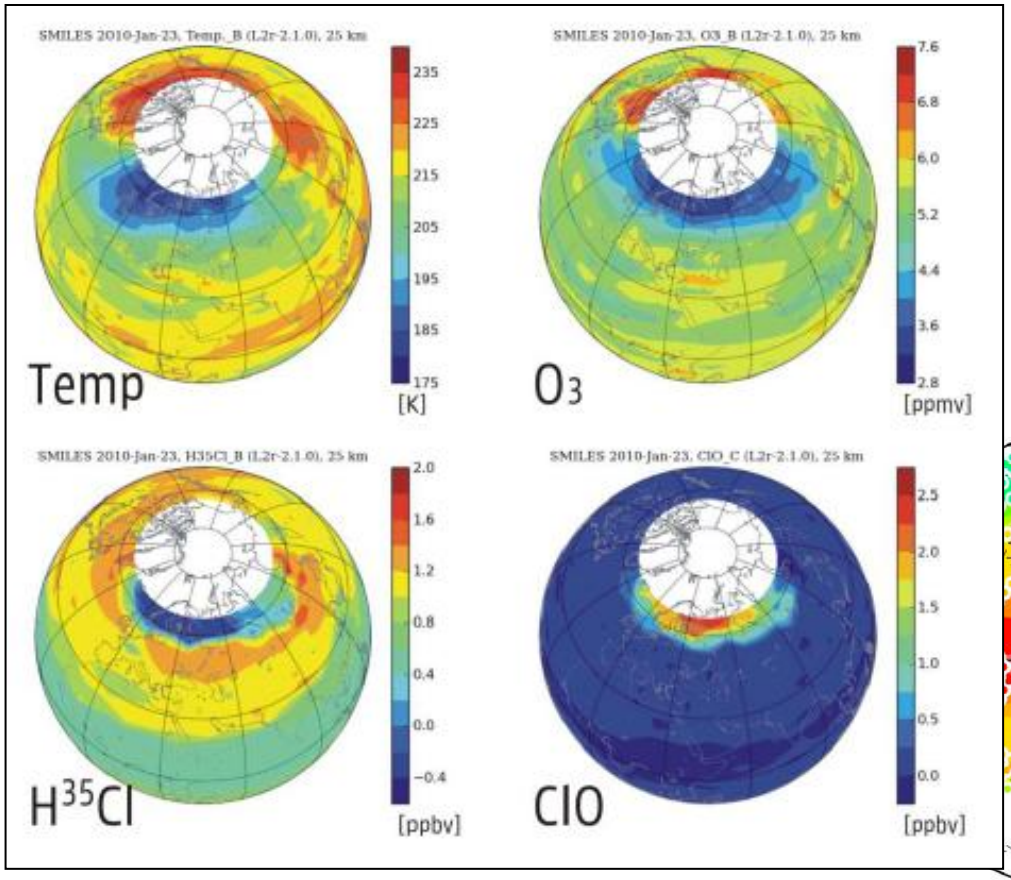

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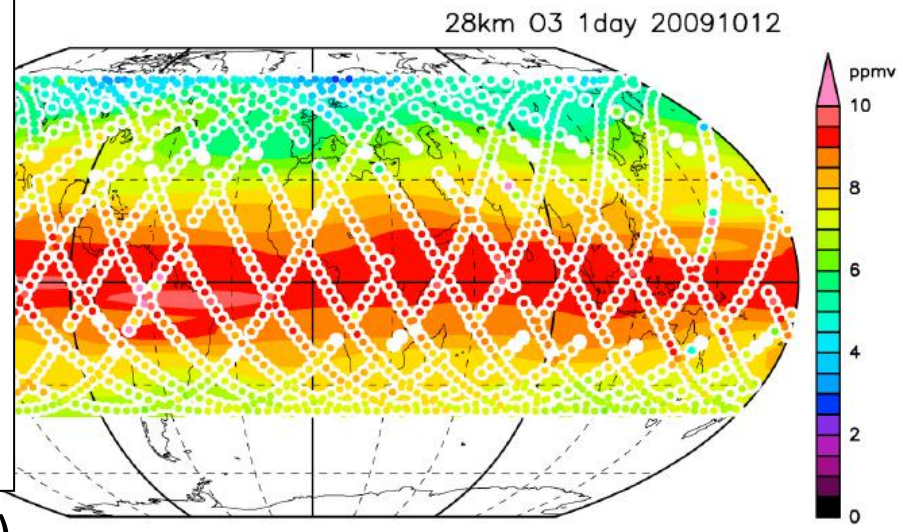
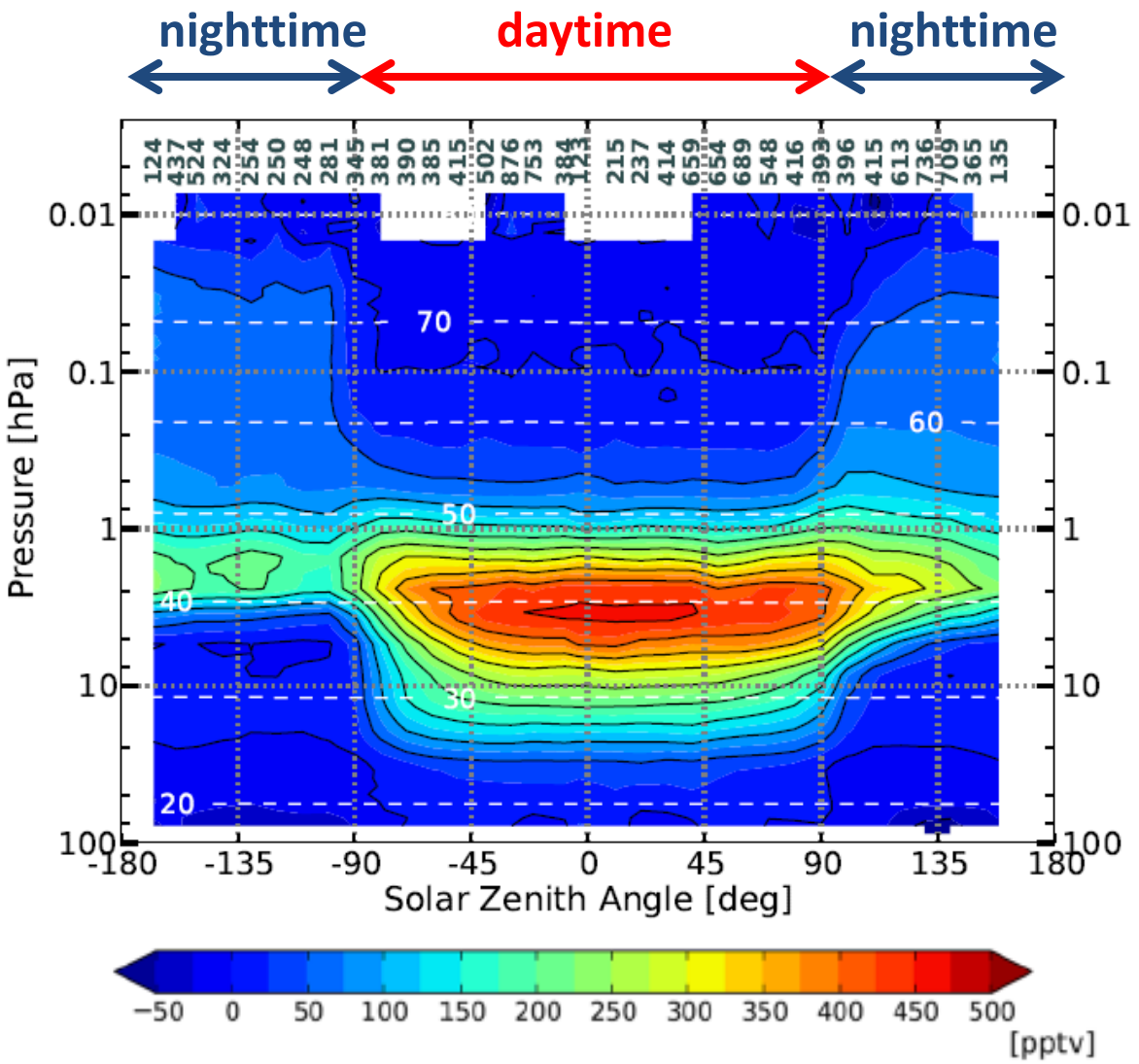


Features inside polar vortex are (partially) observed as wells.

- Results: ClO diurnal variations



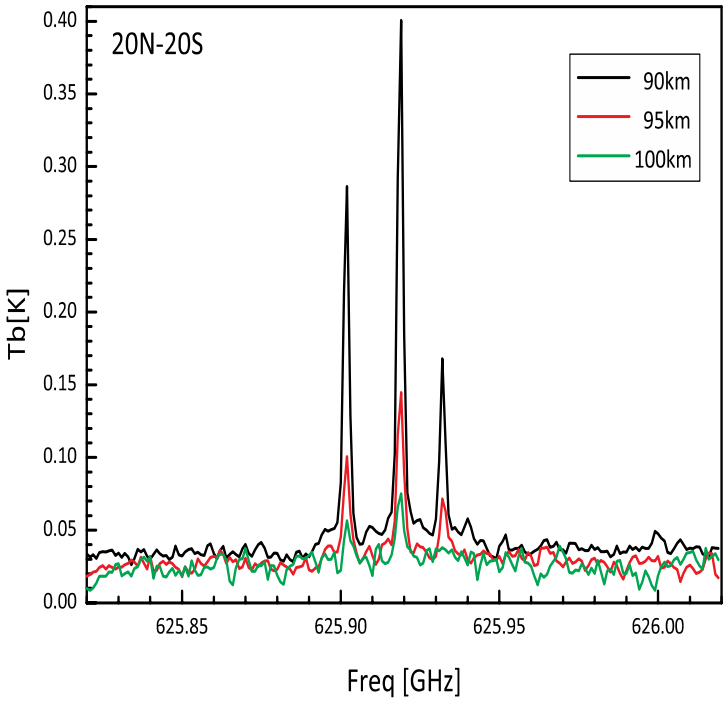
[Sato et al., 2011]

Diurnal variation (as a function of the solar zenith angle) **of ClO** obtained from SMILES observations of Oct. + Nov. 2009 (20S – 20N).

Daytime enhancement of stratospheric ClO and **the opposite behavior in the mesosphere**: Drastic diurnal behavior of ClO is nicely observed ☺ !

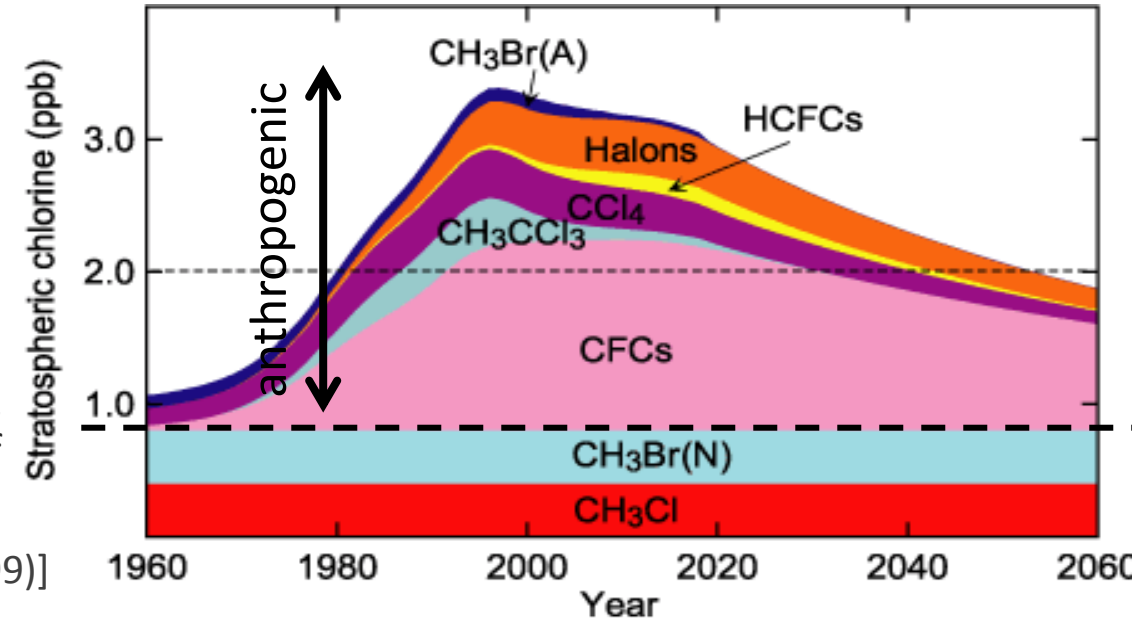
$$\begin{aligned} \mathrm{Cl} + \mathrm{O_3} &\rightarrow \mathrm{ClO} + \mathrm{O_2} \\ \mathrm{ClO} + \mathrm{O} &\rightarrow \mathrm{Cl} + \mathrm{O_2} \\ \textit{net}\quad \mathrm{O} + \mathrm{O_3} &\rightarrow \mathrm{O_2} + \mathrm{O_2} \end{aligned}$$

- Results: HCl distributions in high alt.



HCl spectrum taken by SMILES limb measurements with pointing at tangent heights of **90**, **95**, & **100 km** (approx. 500 spectra averaged).

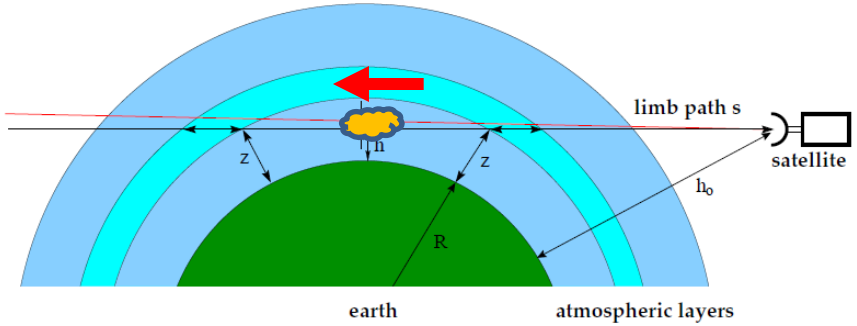
HCl is the major reservoir of chlorine, thus it's a good proxy to consider how *anthropogenic* chlorine is distributed in the Earth atmosphere.

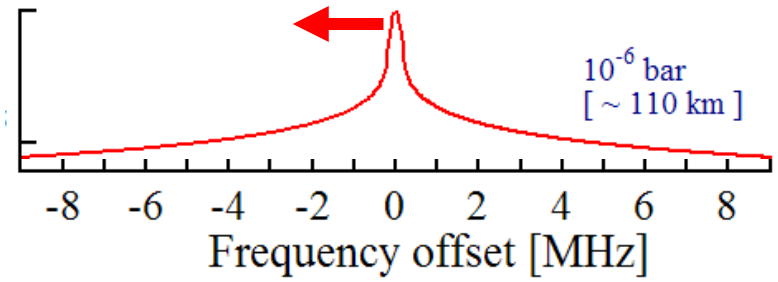


Stratospheric chlorine levels based on global atmospheric observations (1980-2000), historic (1960-1980) & projected emission data (2000-2050) of the major ozone-depleting substances.

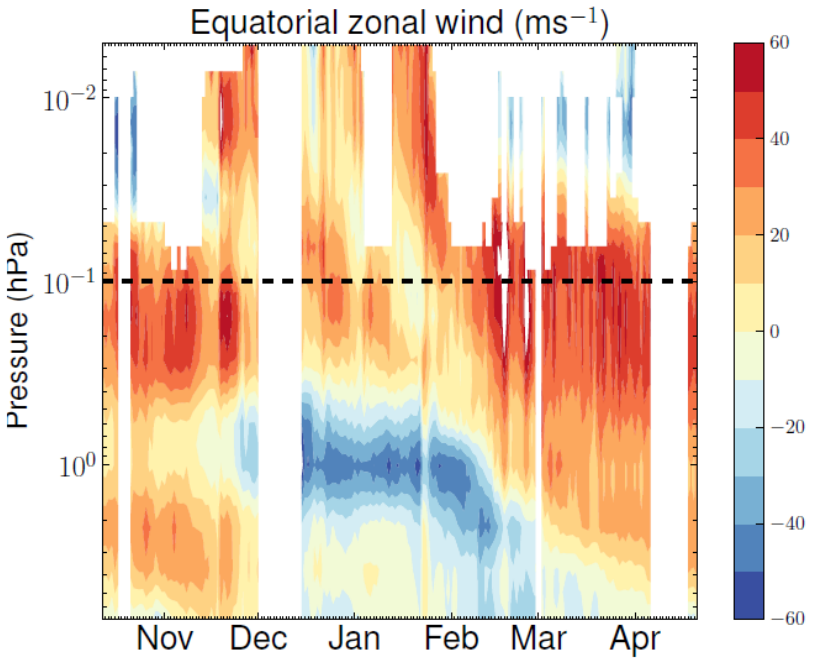
[Madronich & Velders (1999)]

- Results: Stratospheric Winds



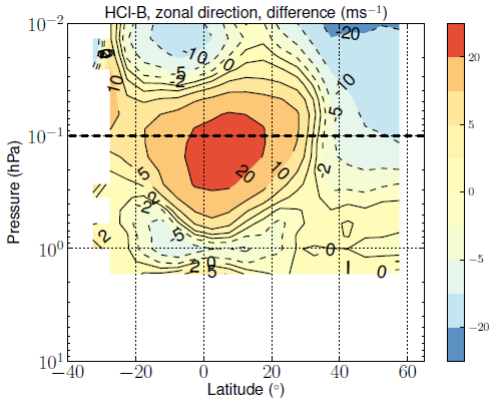


Doppler shift of the molecular line according to the movement of the airmass (projected to line-of-sight) = **Wind velocity measurements!!**



[Baron et al. (2012)]

Semi-annual oscillation of the zonal winds over the equator. Red regions correspond to eastward (westerly) winds.



← comparison with ECMWF numerical model (geostrosphic wind).

- To summarize

Scientific findings of SMILES

- Achieved a high sensitivity due to SIS mixers.
- Diurnal variation monitoring using ISS' non sun-synchronous orbit.

→ These characteristics makes SMILES output as a remarkable data. Despite of its short life time, many interesting scientific researches are now on going.

- Although the instrument is not optimized for this, direct measurement of wind is successfully achieved.

  This result brought a new possible application of a submm instrument to Earth atmospheric science.

→ **Next: SMILES as a state-of-the-art submm instrument, and its future.**