Results of SMILES-2 Feasibility Study

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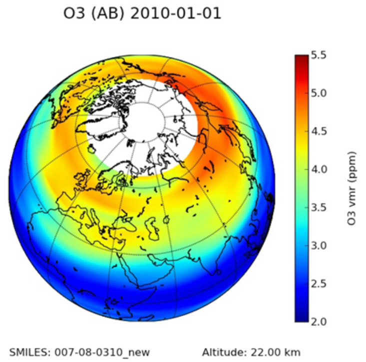
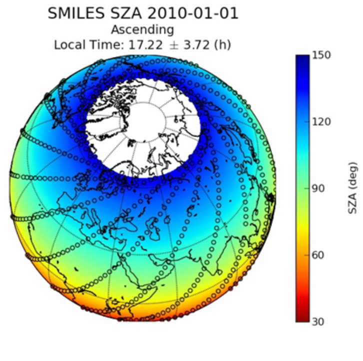
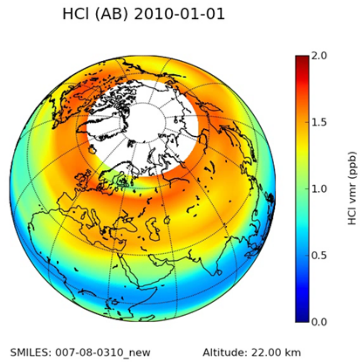
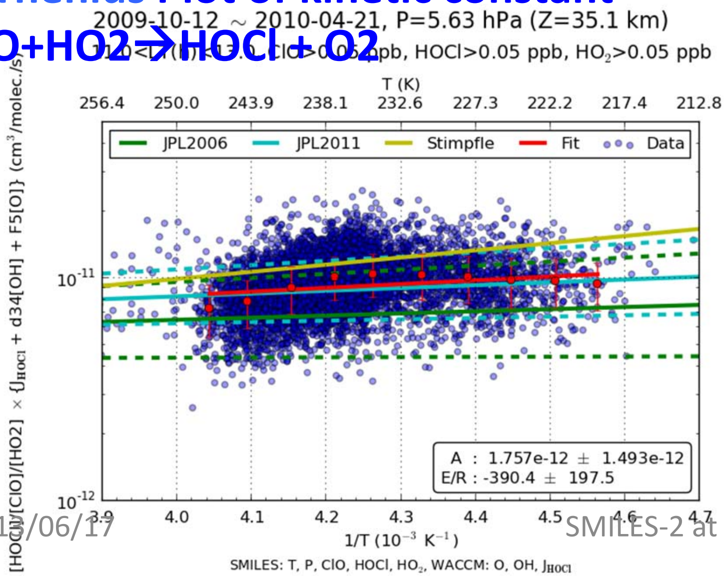


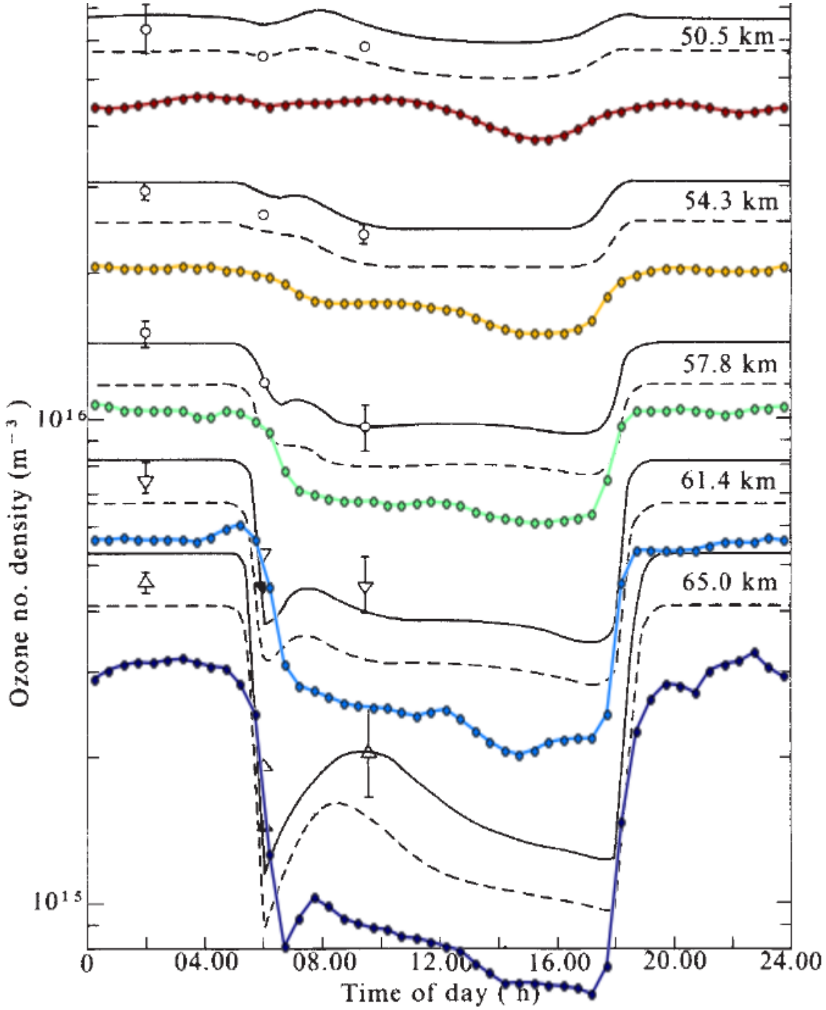


2009/10 Polar Winter Chemistry



Arrhenius Plot of kinetic constant $ClO+HO_2 \rightarrow HOCl + O_2$





Diurnal variation of mesospheric O_3
SMILES and a model calculation
(Vaughan, *Nature*, 1984)

What we missed in SMILES

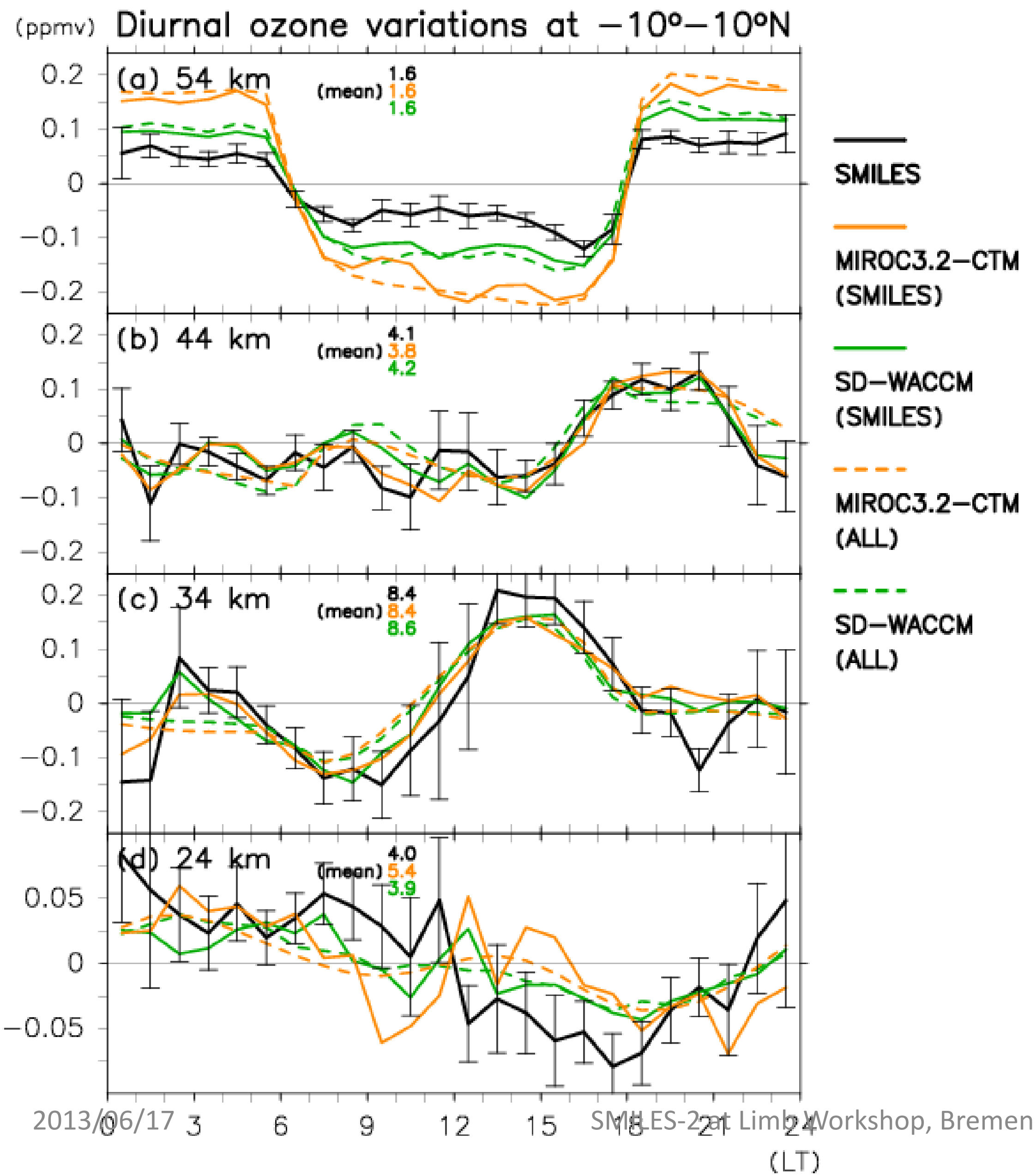
- No temperature channel.
  - very tricky retrieval above 50 km.
  - currently using GEOS-5 extended profile and SD-WACCM temperature nudged to GEOS-5.
- Limited frequency coverage and spectrometer.
  - No tracer and temperature.
- Poor spectral resolution for mesosphere.
- Limitation due to AOS (Acousto Optical Spectrometer)
  - Lifetime of Laser Diode (1 year/1 diode)
  - Frequency scale is not linear, and temperature drift.
  - Non-uniform instrument function and temperature change.

What we should do in SMILES-2

- Longer lifetime (>2 years).
- More species (temp., N2O, etc).
- Reliable mesospheric profile (with temperature observation).
- Line_Of_Sight Wind velocity (2 m/s target).
- Slightly better vertical resolution using larger antenna.

- Multiple IFOV for dense observation
  - 51° orbit, anti-sun and sun side. (200 minutes interval over EQ region) and 80N-80S coverage.
  - 51° orbit, anti-sun and back side (3D retrieval of MIPAS and Aura/MLS)

Diurnal variations averaged over 10S-10N

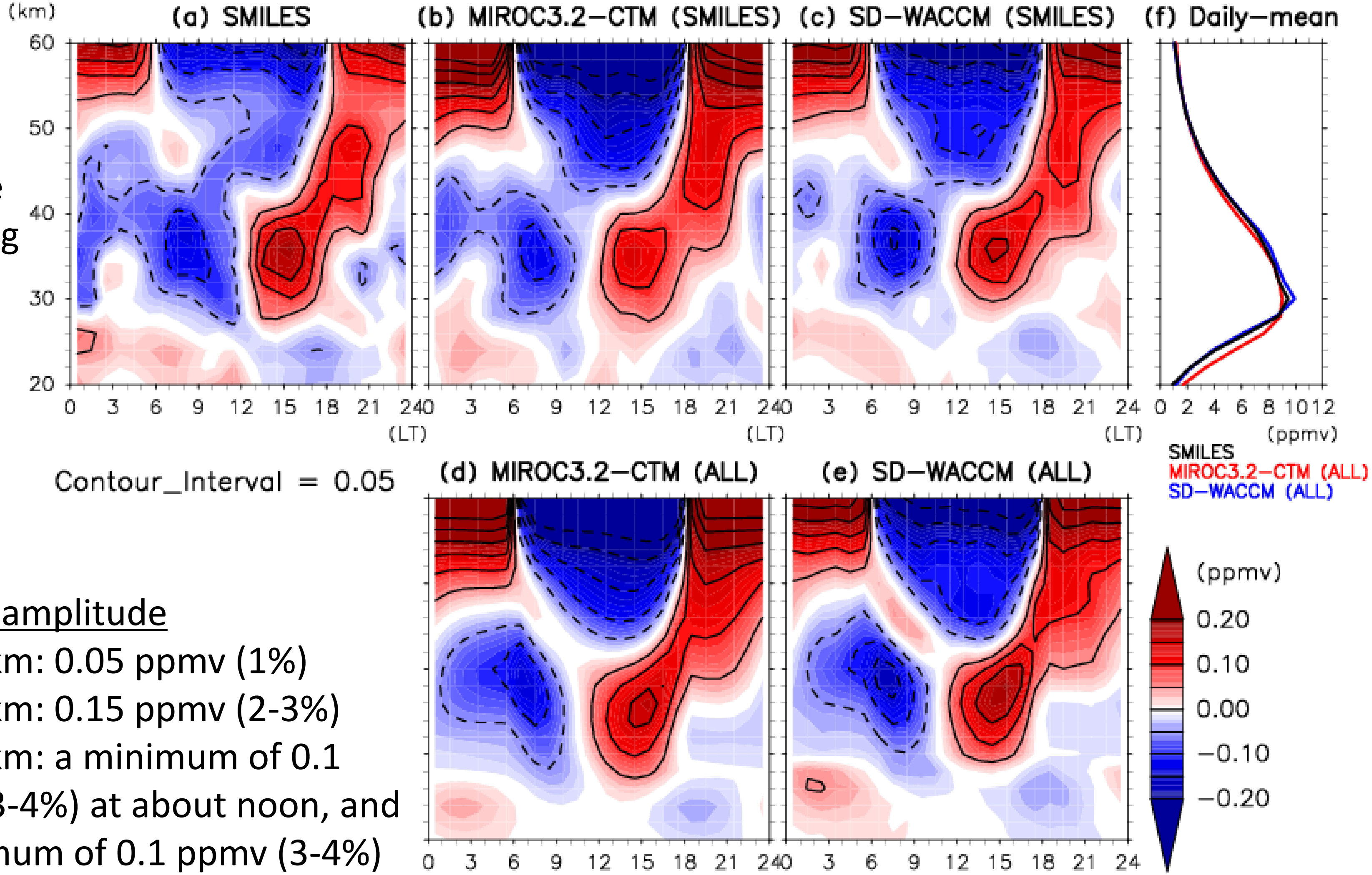


SD-WACCM

- Specified Dynamics (SD) version of WACCM
- Whole Atmosphere Community Climate Model
- Temperature and wind fields from NASA GEOS5.1 are nudged
- horizontal : 1.9°x2.5°, vertical: 88 levels (up to 140km)
- 57 species (Ox, NOx, HOx, ClOx, BrOx etc.)
- 230 chemical reactions

Diurnal variations in ozone

Satellite sampling



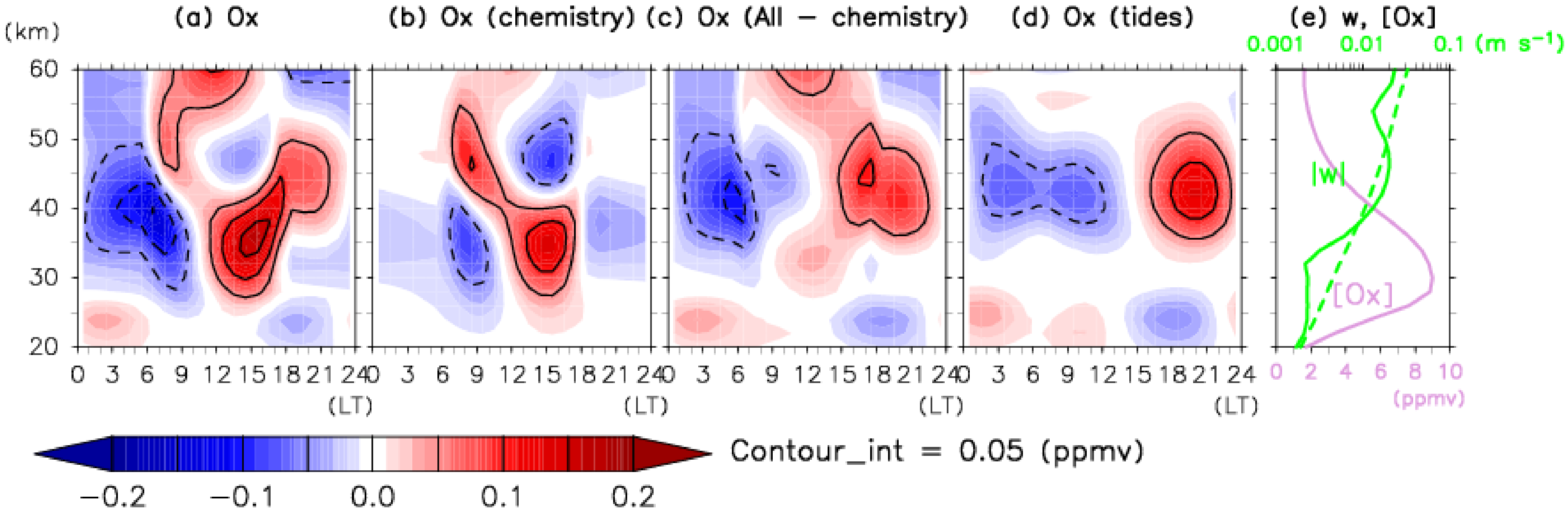
<u>Diurnal amplitude</u>

20–30 km: 0.05 ppmv (1%)

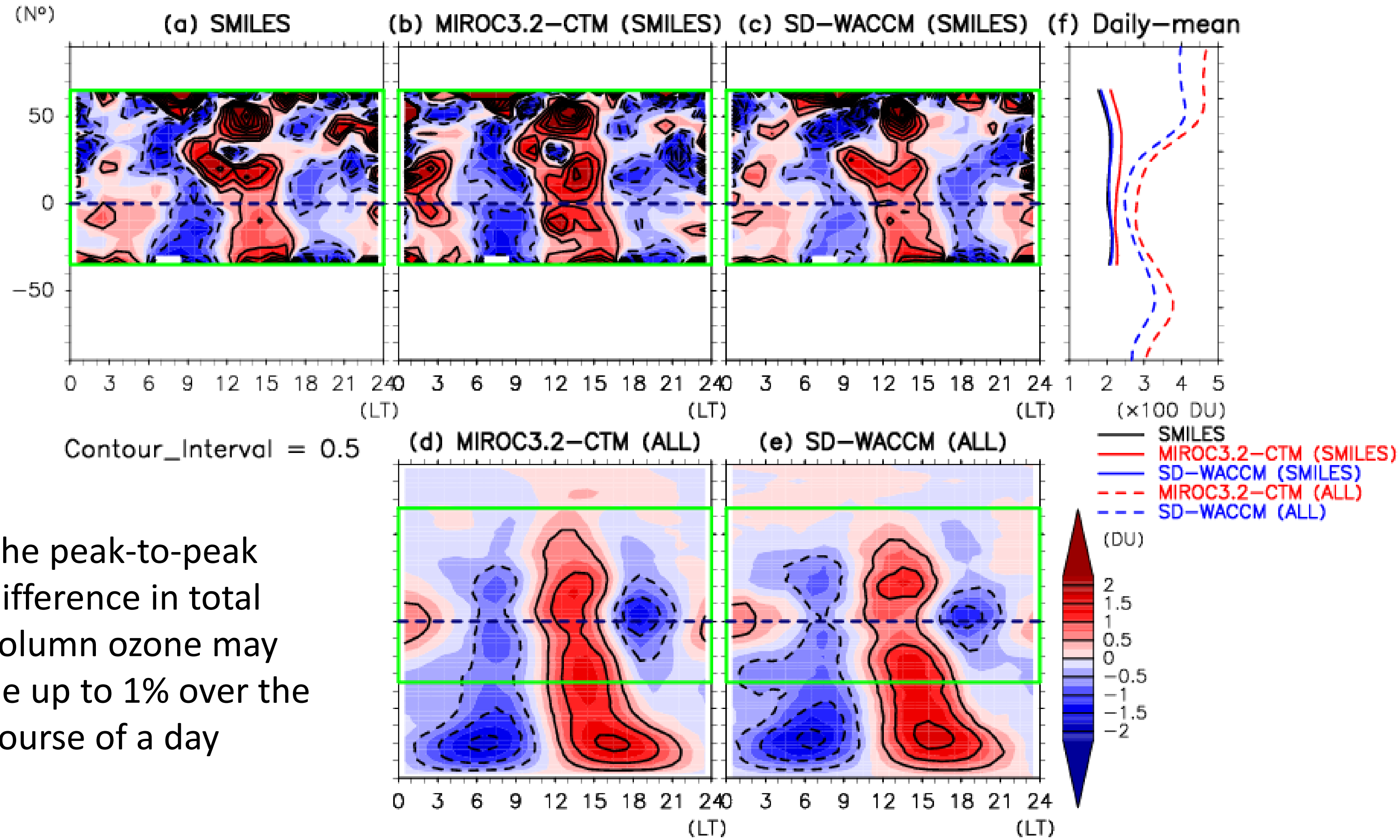
30–40 km: 0.15 ppmv (2-3%)

40–50 km: a minimum of 0.1 ppmv (3-4%) at about noon, and a maximum of 0.1 ppmv (3-4%) in the late afternoon

Mechanism of the diurnal variations



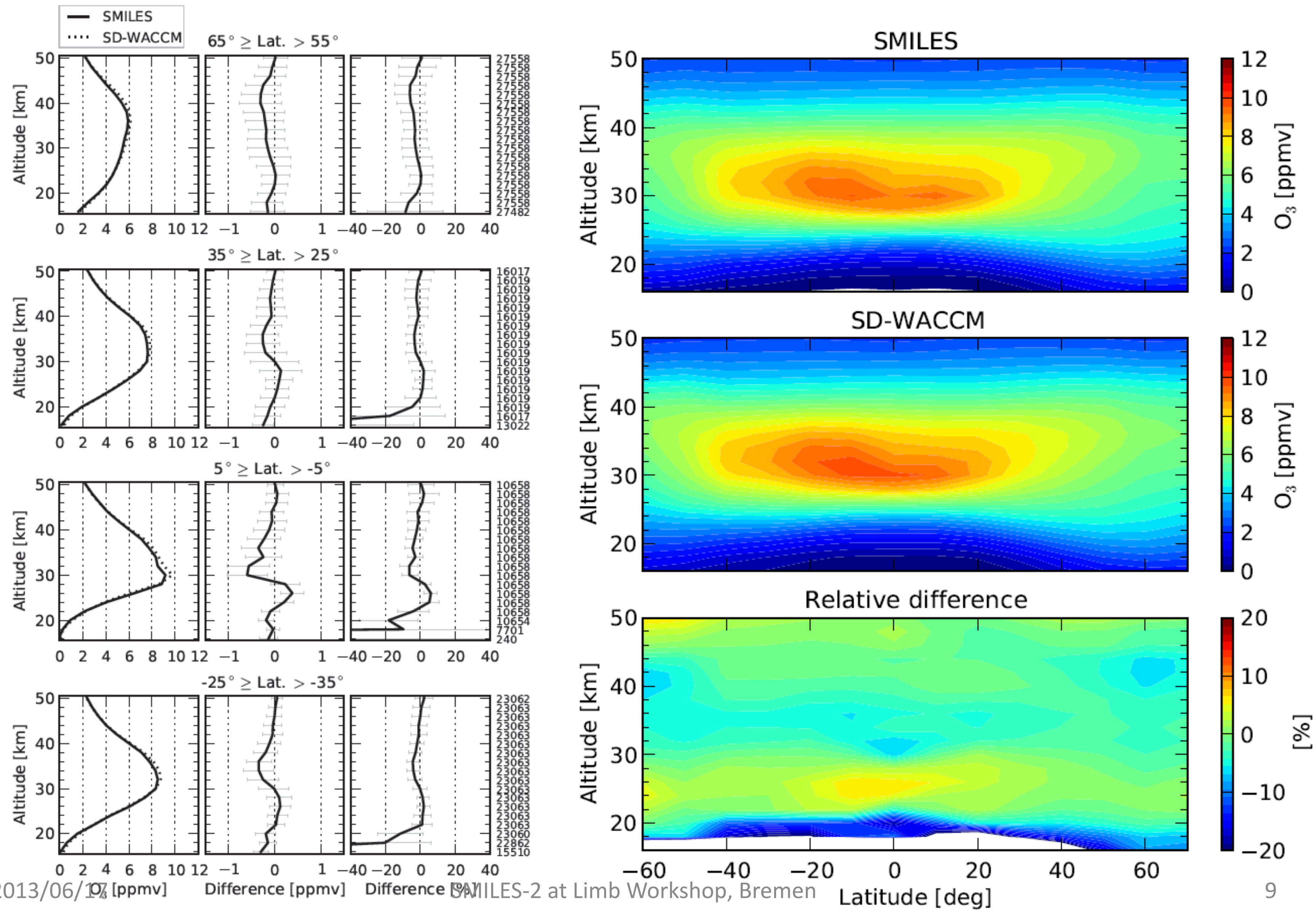
Diurnal variations in total ozone



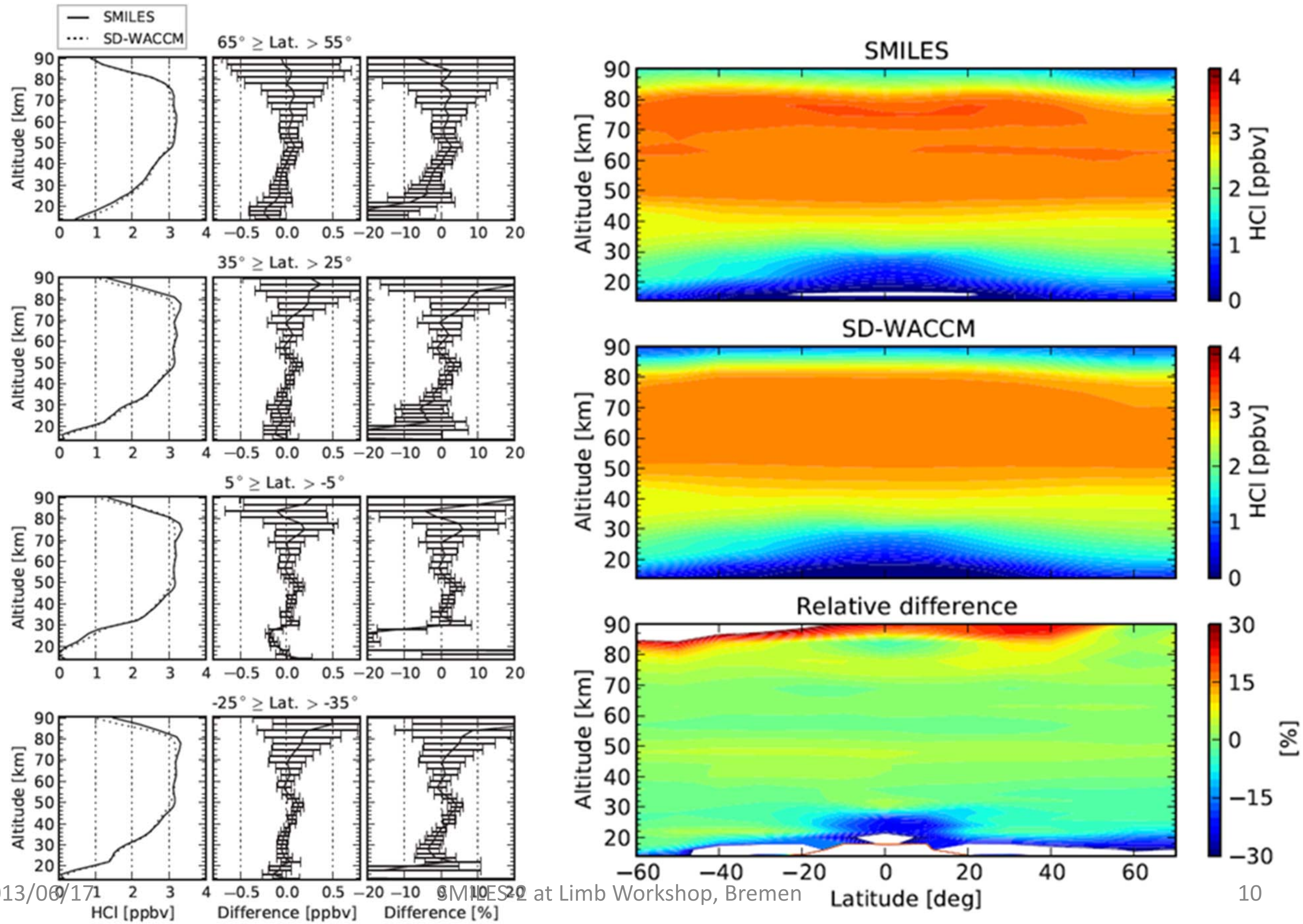
The peak-to-peak difference in total column ozone may be up to 1% over the course of a day

- A bias in the SAGE sunrise and sunset profiles [McLinden et al., 2009]
- Orbital drift of SBUV onboard NOAA satellites [Wang et al., 2012]
- TOMS and OMI measurement local times are 1130 LT and 1330 LT

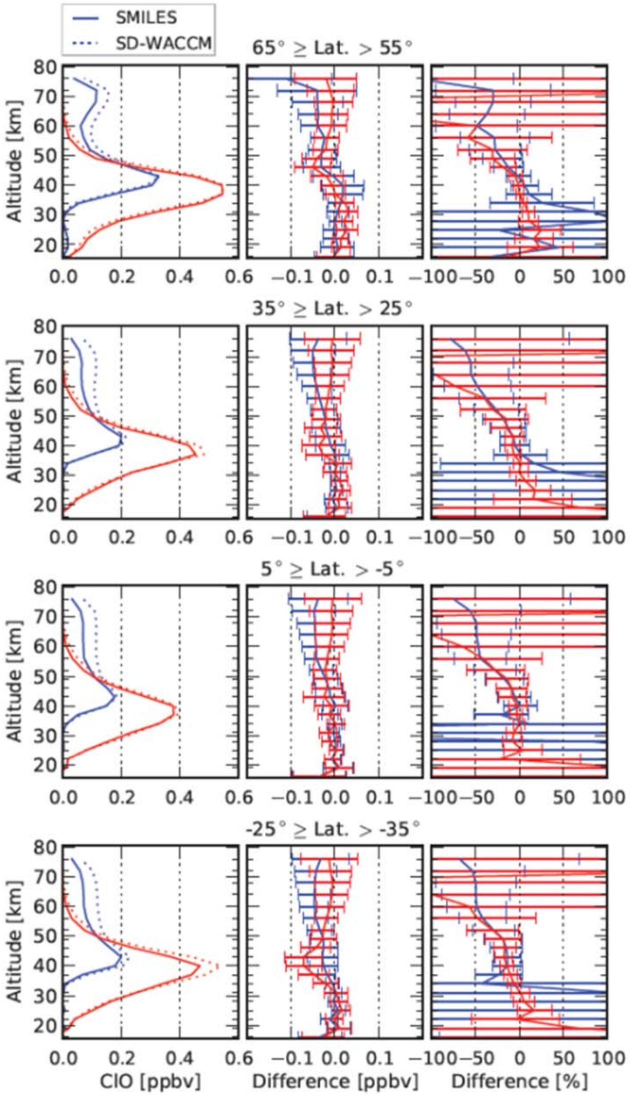
SMILES and SD-WACCM O3 comparisons

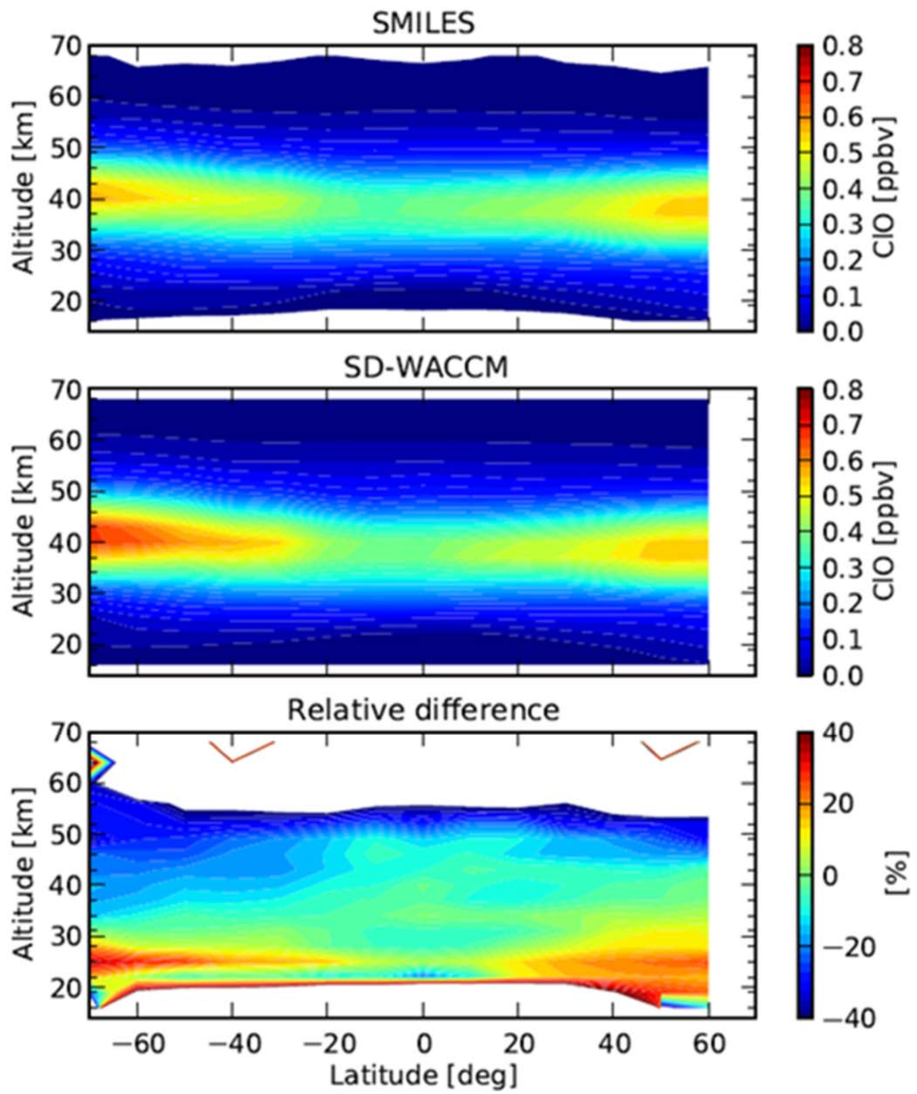


SMILES and SD-WACCM HCl comparisons



SMILES and SD-WACCM ClO comparisons





Our current feeling are as follows.

- If we have a very good temperature (and wind) field, we only need one good satellite measurement over two tears, to conclude the agreement of model and observation.
- Nudged model are likely outperform observations (at least for the homogeneous chemistry).
- We need more temperature measurement above 30 km (up to 100 km or even more) from space.

- SMILES-2 and temperature measurent
  - SMILES-2 should have temperature channel

SMILES-2

- SMILES-2 is in per-Phase-A, with no budget.
- Study of 4K-cooled sub-mm limb sounder.
- ISAS small science satellite (SPRINT series)
  - Possible Japanese Science Mission
    - ISAS : 500 (small) ~ 1.5 t (medium) science satellite
    - JAXA/EORC : remote sensing programs such as GOSAT
    - METI : ASNARO series (700kg-1t), and sensors to JAXA or NASA
  - Sprint-A (2013, EXCEED, Planetary EUV Telescope)
  - Sprint-B (2014-15, ERG, Magnetosphere)
  - Sprint-C and later (2017~, budget ceiling from $10M to $40M)
- We have been investigating the Sprint-C/D for candidate target of SMILES-2 proposal, but last week we were asked to submit the proposal to Sprint-C selection from ISAS.

400 kg class science satellite (SPRINT) and its relative ASNARO satellites

- JAXA/ISAS has 400 kg science satellite series for Upper Atmosphere, Planetary Science (orbiting telescope), Astronomy, and Engineering Subjects.
  - 5 Spacecraft are scheduled within 8-10 years starting from SPRINT-A launch (2013), or every two years.
    - H. Saito et al, A series of smallscientificsatellite with flexiblestandardbus, Acta Astronautica, 65(9-10), 1345-1359 (2009).
    - K. Yoshikawa et al, EUV observation from the Earth-orbiting satellite, EXCEED, ASR, 45 (2), 314-321 (2010).
- Proposals to the SPRINT satellite program are still open to competition for the SPRINT-C/D/E.

	SPRINT	ASNARO
Organization	JAXA/ISAS	METI/USEF
Application	Science	Commercial Remote Sensing
Manufacture	NEC	
Launcher	EPSILON (IHI) solid rocket.	
1st launch	2013	2013 ?
Mass (mission)	400 (200) kg	500 (250) kg
Power	1.0 (0.4) kW	1.4 (0.4) kW
Attitude Control	3-axis Spin, or any	3-axis
Plan	5 (3 open for competition)	4-5 including ODA satellites for Vietnam

ASNARO-1 Spacecraft

500 kg (250kg bus, 200kg instrument), 1m commercial imager

T. Oawa (NEC Tech Report, 2011)

Table 1 ASNARO system specifications.

Item	Detail
Mission - Optical sensor - Data storage - Data transmission	 Panchromatic/multi-spectrum sensor. Resolution: ≤0.5 meter (Pan, altitude 504 km) Swath: 10 km ≥120 GB X-band, 16-phase QAM, approx. 800 Mbps
Image capturing range	Inside the cone in ±45° from nadir.
Agility	45°/45 sec. (Ave. 1°/sec.)
Launch	FY2012 (scheduled). Compatible with major launch vehicles including the Epsilon rocket and H-IIA of Japan as well as foreign commercial rocket, such as Dnepr and Rockot.
Orbit	Sun-synchronous sub-recurrent orbit (Altitude 504 km). Orbit inclination angle: 97.4° Local sun time at descending node: 11:00
Ground stations	Commercial ground stations and mobile stations in Japan, plus overseas stations
Operating period	≥3 years (Target 5 years)
Weight	■ Bus: 250 kg (excl. propellant) ■ Mission: 200 kg (max. weight) ■ Propellant: 45 kg (max. weight) <TOTAL>: 495 kg
Power	Generated power: 1,300 W (3 years after) Mission supply power: 400 W

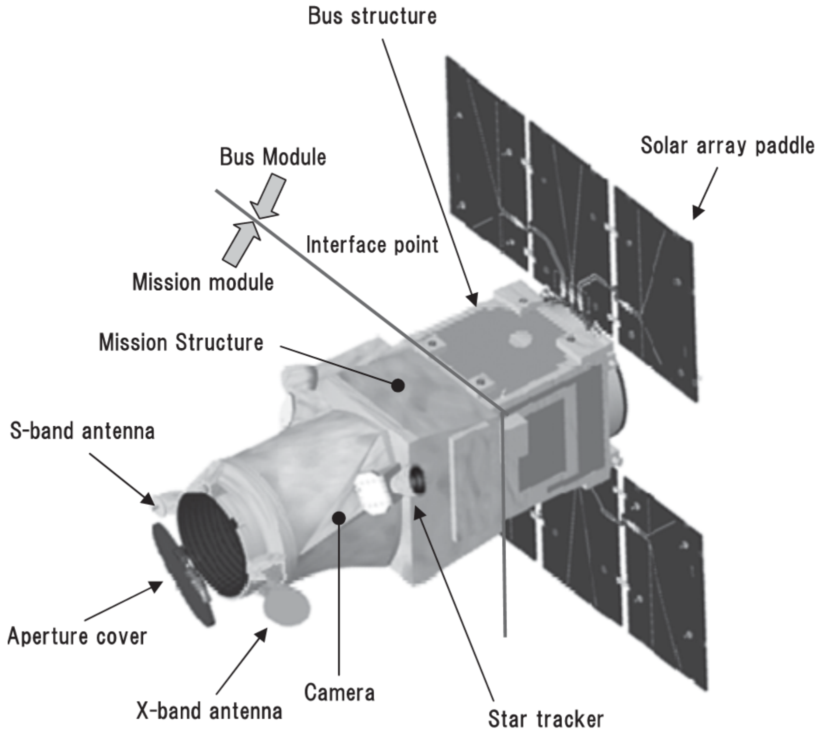
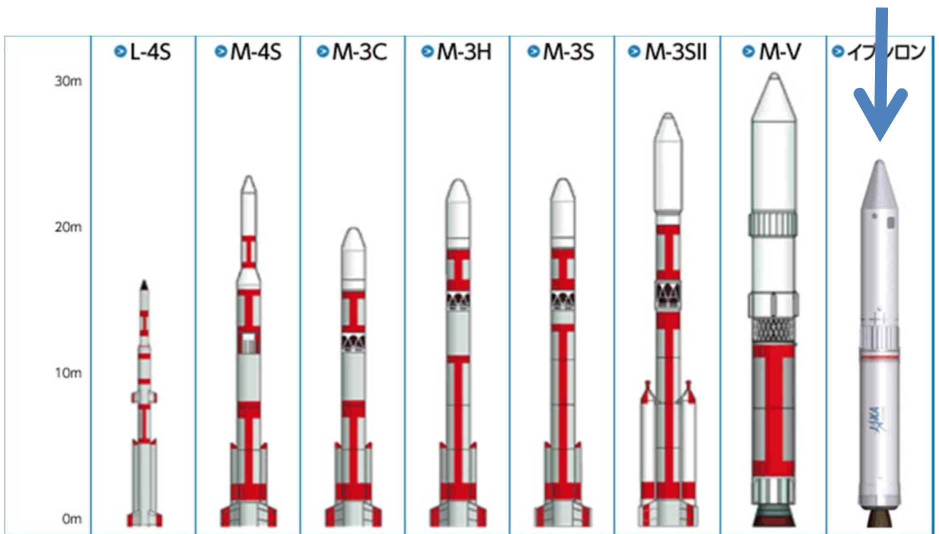


Fig. 1 External view of ASNARO.

Epsilon, Japanese new solid rocket launcher starting from Aug. 2013., upgraded version will have capability of 1.2 t to LEO



	L-4S	M-4S	M-3C	M-3H	M-3S	M-3SII	M-V	イプシロン
全長(m)	16.5m	23.6m	20.2m	23.8m	23.8m	27.8m	30.7m	24.4m
直径	0.735m	1.41m	1.41m	1.41m	1.41m	1.41m	2.5m	2.5m
全重量	9.4t	43.6t	41.6t	48.7t	48.7t	61t	139t	91t
打ち上げ能力	26kg	180kg	195kg	300kg	300kg	770kg	1800kg	1200kg(※)

If we could win the competition ...

- 500-700 kg LEO satellite with 150-250 kg payloads.
  - above 500 kg, we have to wait for the upgraded launcher.
- Dedicated launcher (single launch), to any orbit inclination and altitude.
  - some proposals are for lunar landing, asteroid exploration, Jupiter exploration using solar sail etc.

- 3 years lifetime.
- 1.3 kW total, 400 W for payloads (max available).
- Up to 800 Mbps downlink (if we pay for spacecraft and ground segment.)
- Good attitude control and knowledge suitable for limb observation.

If we design SMILES today, SMILES should have ...

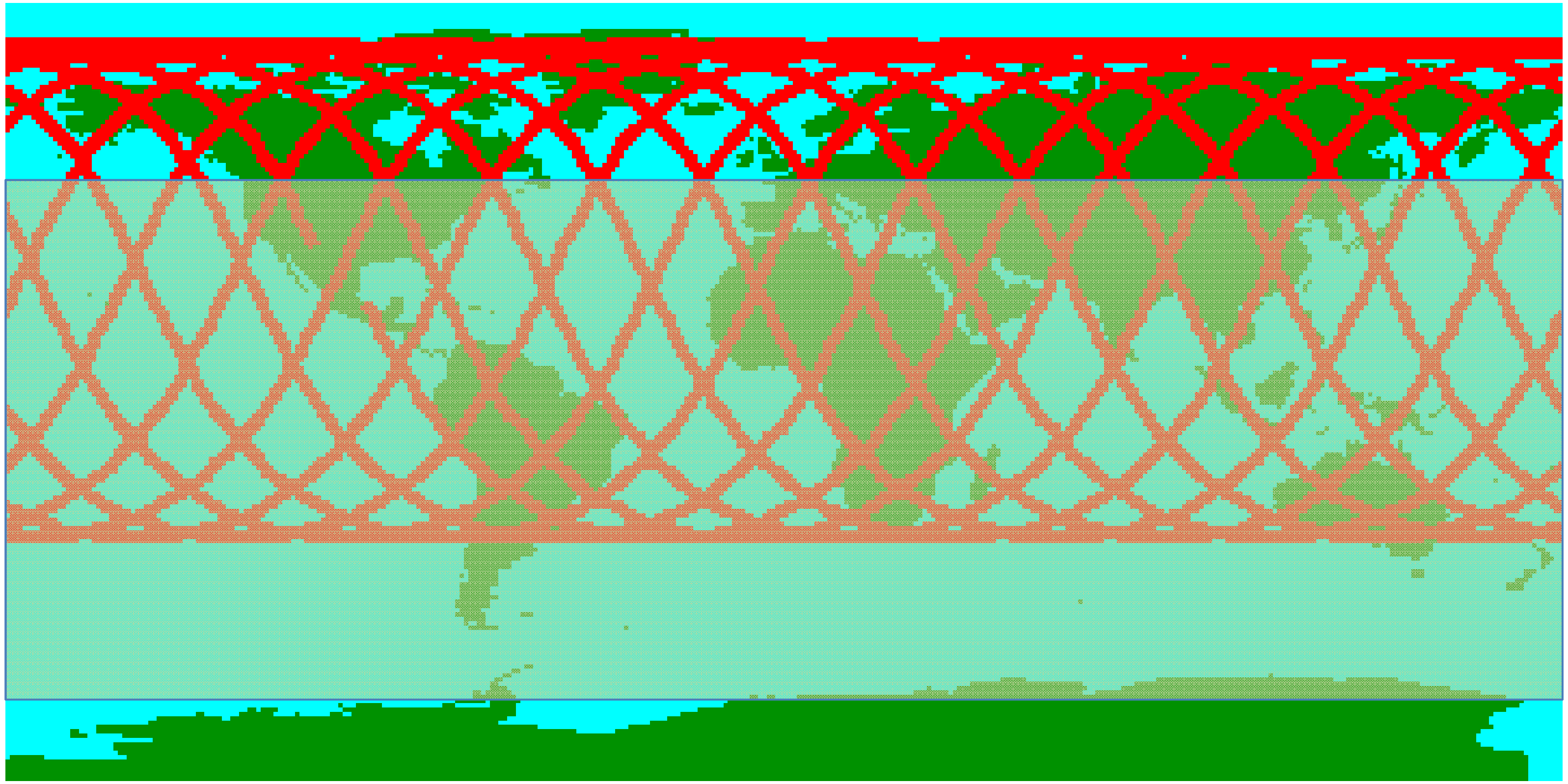
- SMILES Bands A+B, and C observation.
  - O3, HCl, ClO, HO2, BrO, O3 isotope (667, 668, 676), HNO3, CH3CN

- 1 K Temperature Sensitivity with 118 GHz O_2 lines.
- Larger Antenna (1-1.6 m) for better vertical IFOV.
  - 1 m = 1.6 km, 1.6 km = 1 km IFOV.
- Wind velocity (2 m/s, line of sight, stratosphere).
  - 100 kHz resolution spectrometer, ~2 kHz frequency stability/calibration
- Addition of a Tracer (N2O) and source gas (CH3Cl).
- Up to lower thermosphere (100-120 km).

- Multiple horizontal IFOV (similar to OMPS-limb) to improve horizontal resolution.
- 2.5 THz OH observation (with cooled detector ?)

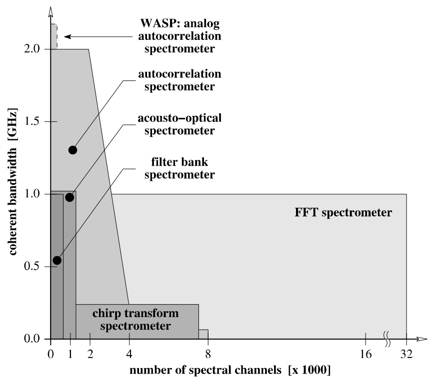
Anti-Sun side + Sun side, if possible.

In EQ region, 4 observations/day for some small region, something like, 0am, 3am, 0pm, and 3pm. And wide latitudinal coverage.



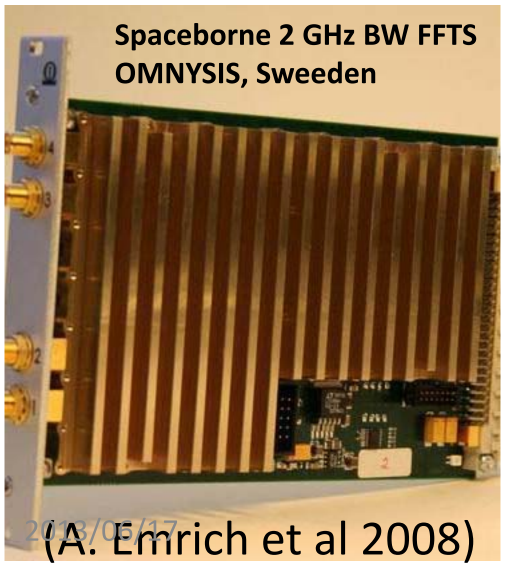
FFT spectrometer

OMNISYS Spaceborne FFTS: 2 GHz BW, 20 W (2007); 2 GHz BW x4, 3-5 W (201X).



Figu... term... appl... vide both wide bandwidths and an impressive number of spectral channels, thus high frequency resolution.

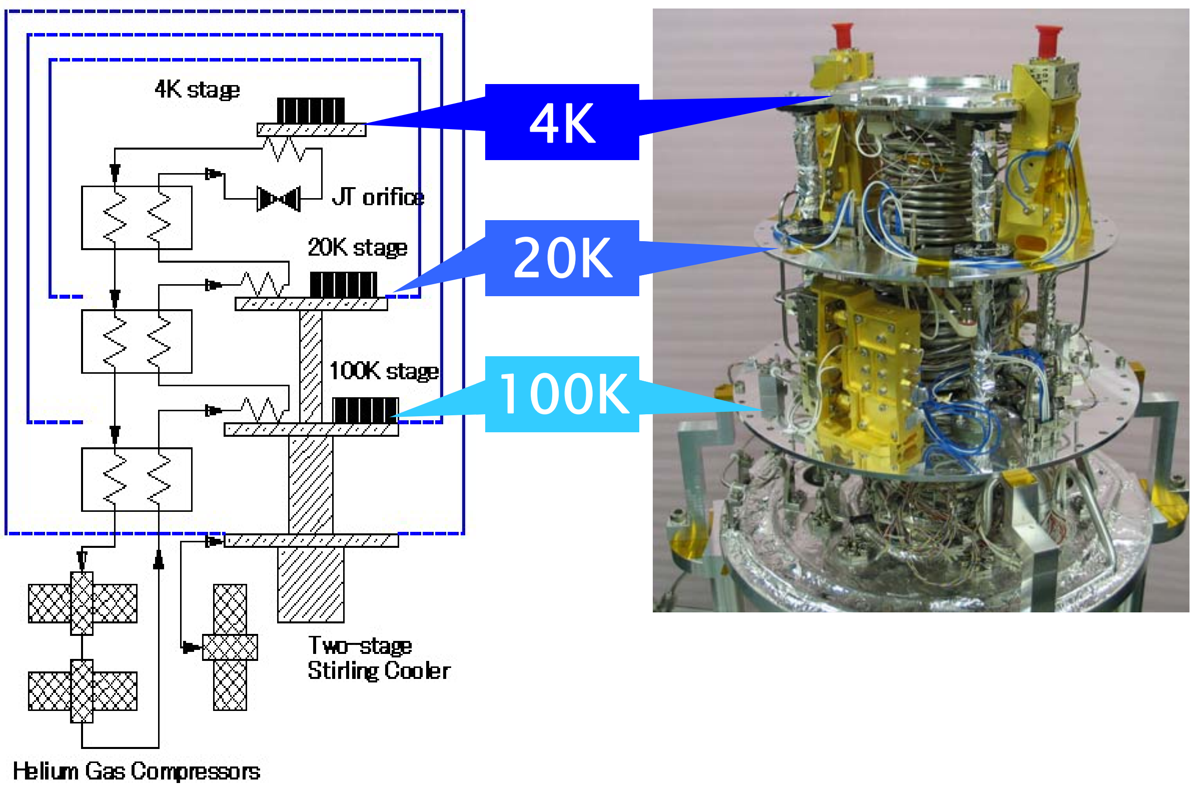
(Bernd Klein et al 2006)



(A. Emrich et al 2008)

	AOS	FFTS	
Life time	1 year/diode	no issue	5 year lifetime
Frequency Scale	Opt. Aberration Temp. Drift	Linear and No drift	Retrieval.
Frequency Drift	Significant	Negligible	Retrieval, Wind Ob.
Spectral Response	Not uniform over 1500 pixels	Uniform	Retrieval
Resolution	800 kHz	$\leq$ 50 kHz	Mesosphere Obs. Wind Obs.
Band Width	1.5 GHz	2-8 GHz	Tropospheric Obs. More Species
Power, Mass	only 2 AOS for SMILES	1 kg, 5 W 2GHz x 4	

4K, 3 stage cooler



Mass: 81.6 kg (total)
Cooler 33.2 kg
Cryostat 23.9 kg
Electronics 24.5 kg

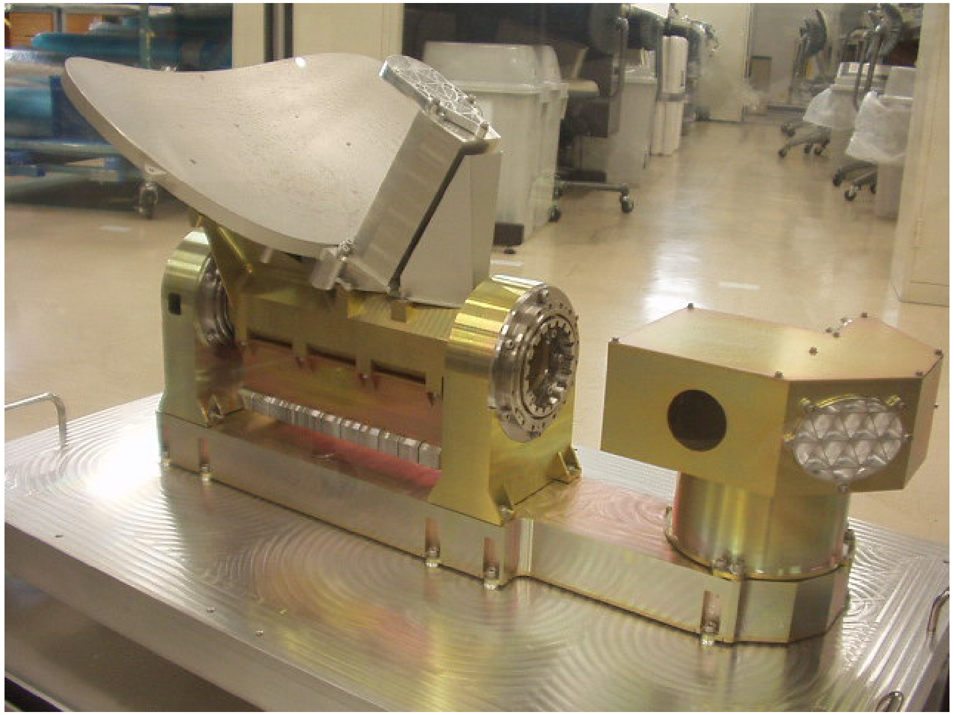
Cooling Capacity:
~20 mW @ 4.5 K
~200 mW @ 20 K
~1000 mW @ 100 K

Power Consumption:
Total <304 W @ 125 VDC (ST: <100 W, JT: <60 W)

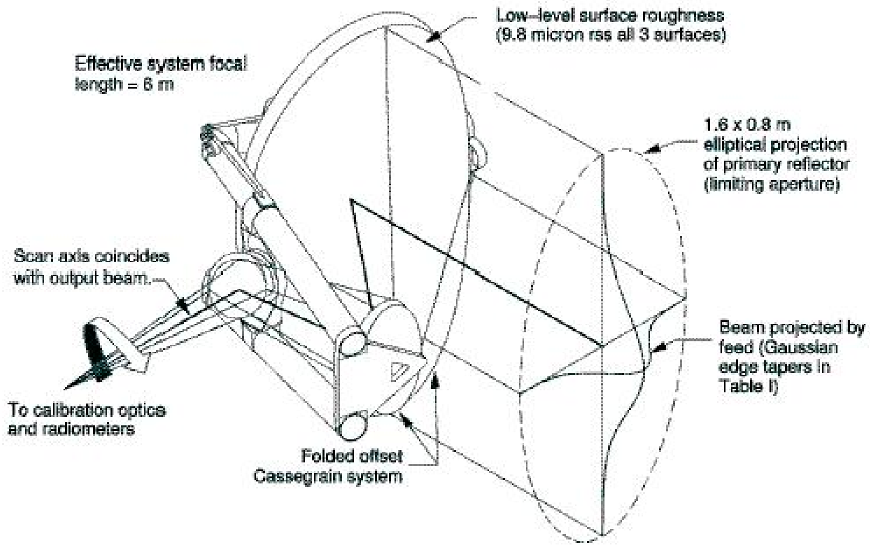
Lifetime:
1 year (Lifetime test is still running, exceeds 15,000 hrs.)

SMILES: 80+ kg
SMILES-2: Design target 55 kg
Design limit 50- kg is feasible by the study of SHI (cooler manufacture) and JAXA-SMILES team.

Antenna, 0.4 m to 1.0-1.6 m



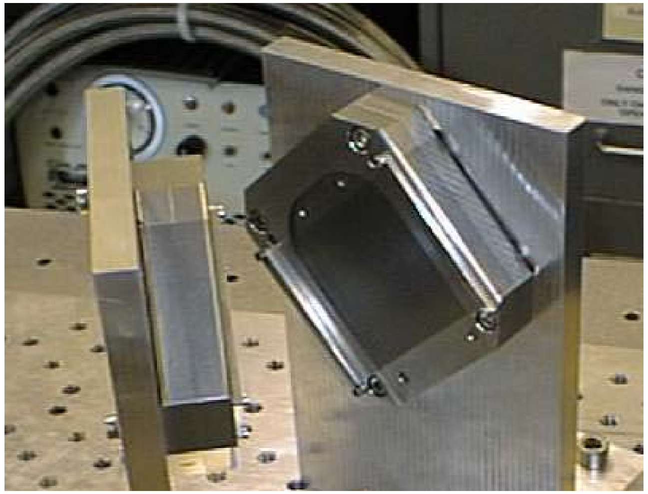
40 cm (major axis) x 20 cm antenna of SMILES, 3 km IFOV from 350 km

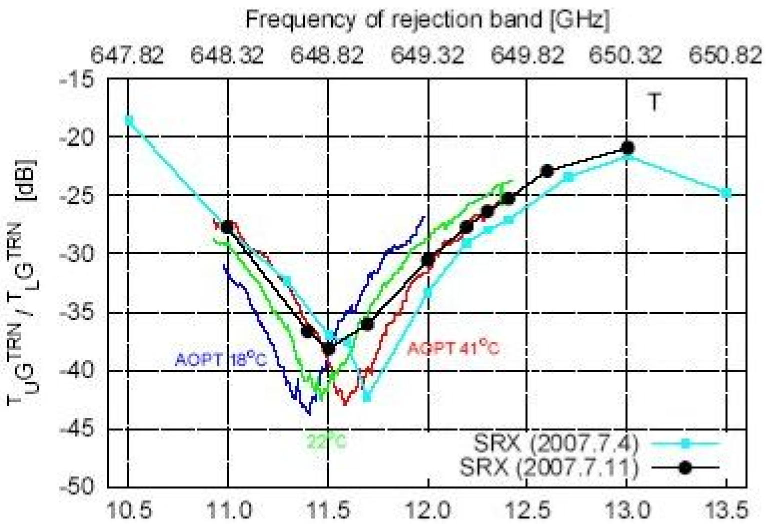


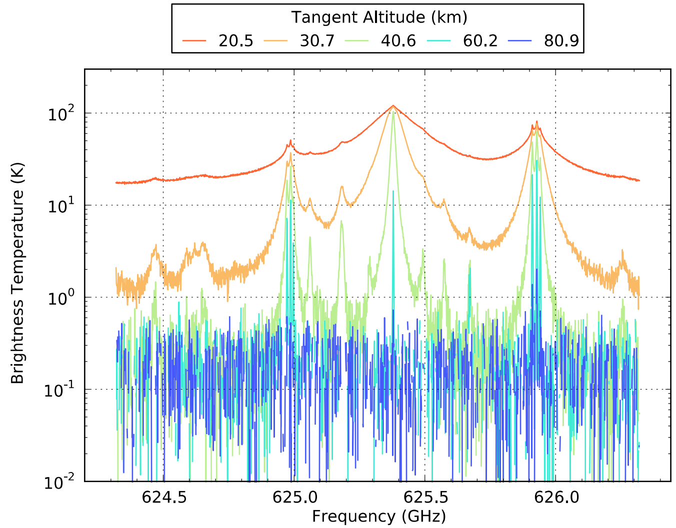
Aura/MLS antenna, Waters et al 2006

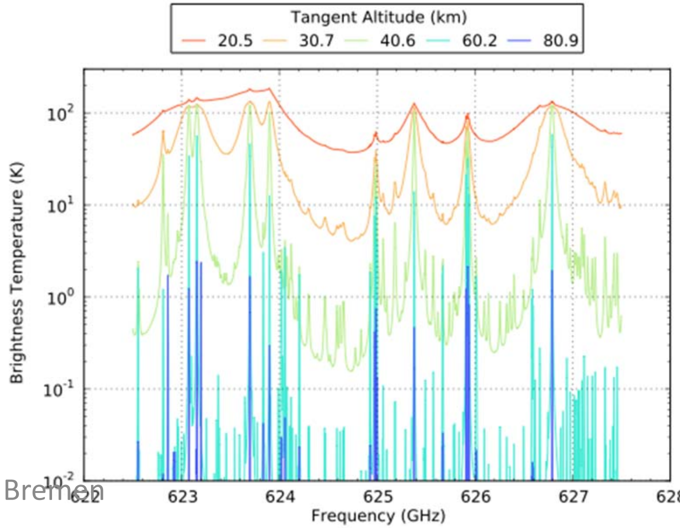
1.6 m antenna from 550 km orbit gives 1 km IFOV, 1.0 m = 1.6 km

SMILES A+B_C to Double Side Band

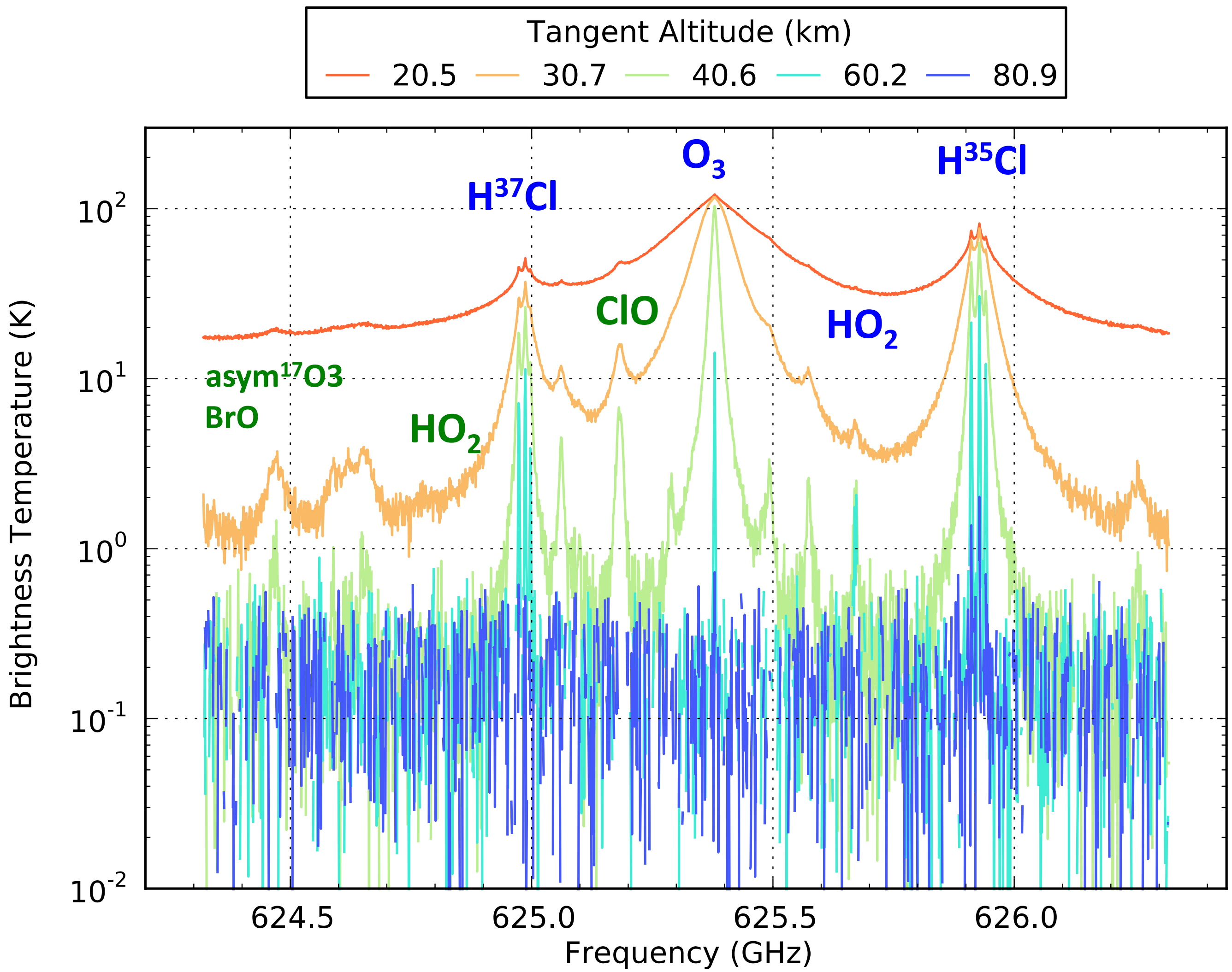




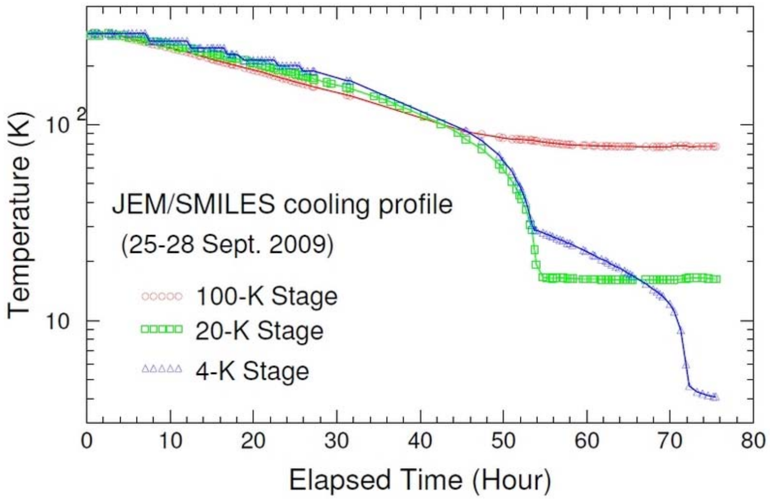


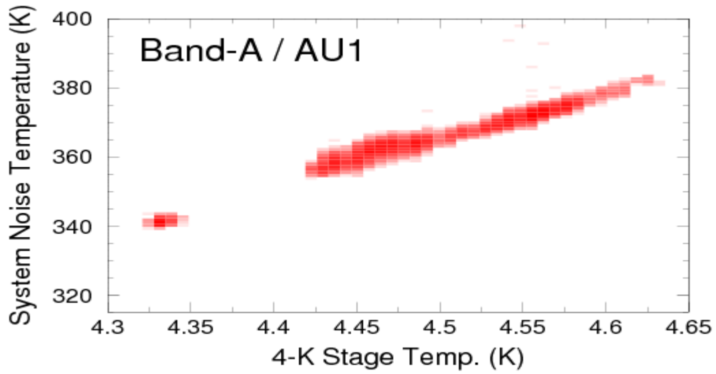


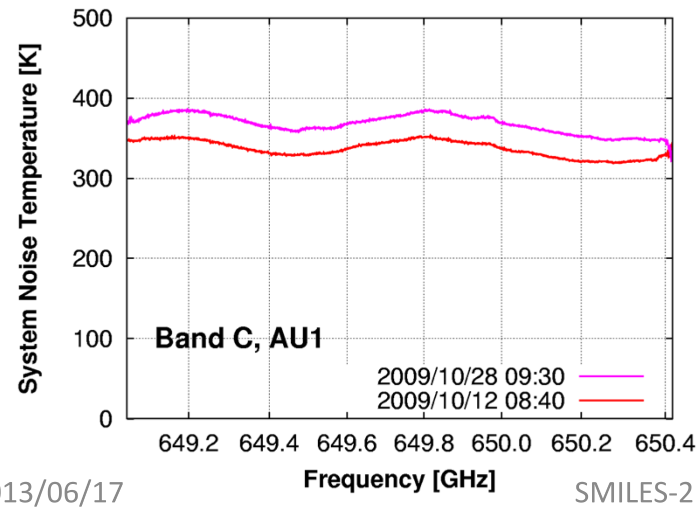
Double Side Band Spectrum, LSB and USB

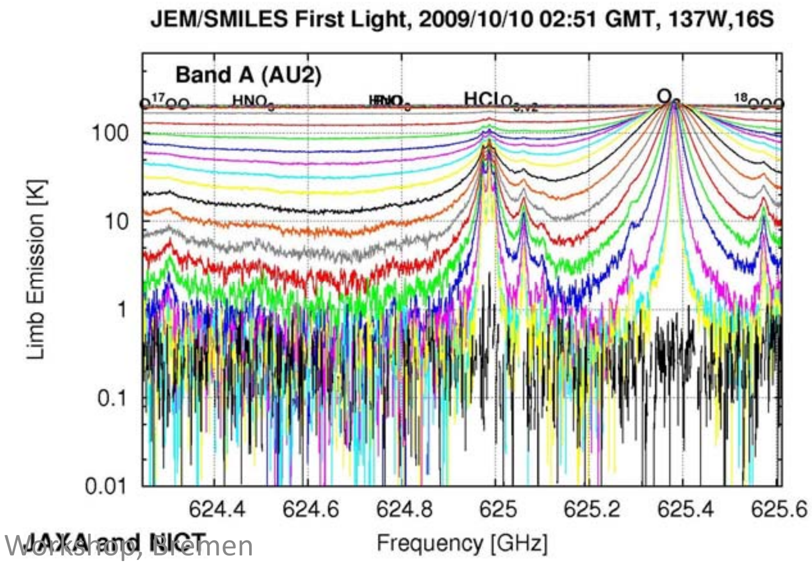


Tsys ~ 340 K was achieved in SMILES SSB.
If we use DSB, it becomes 250 K.



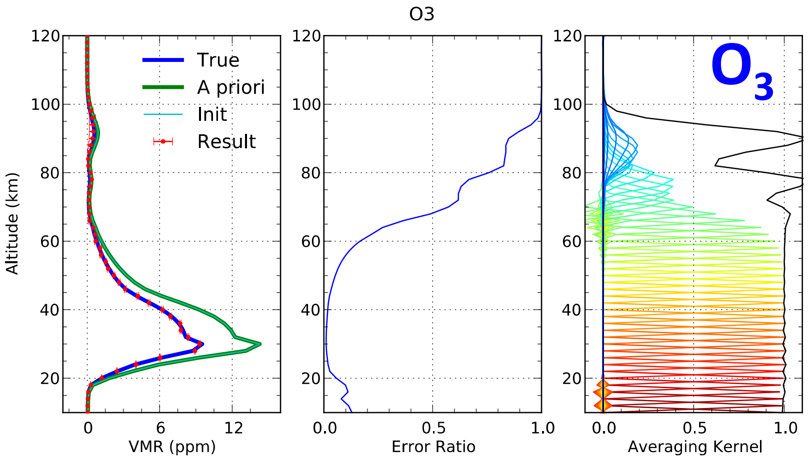


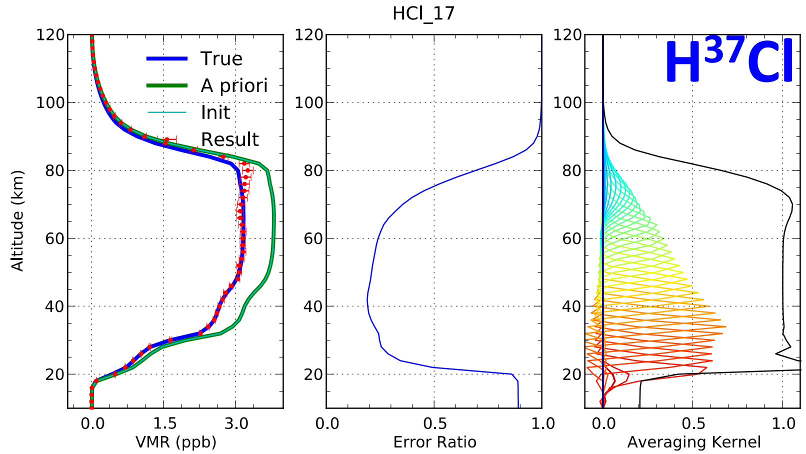


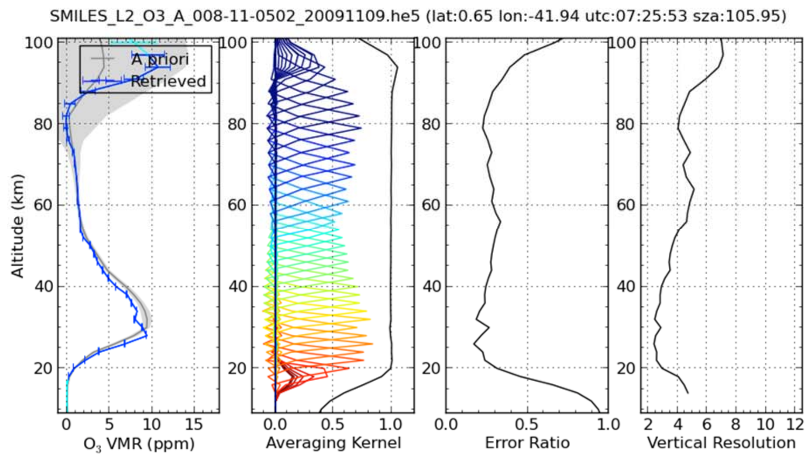


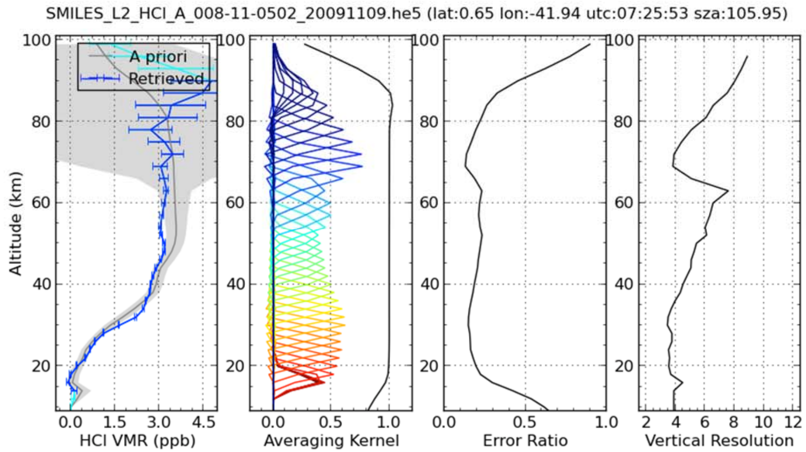
SMILES-2 Sensitivity Study: O3, $H^{37}Cl$

Upper Panel A+B and C+ Dual Side Band, Lower Panel SMILES



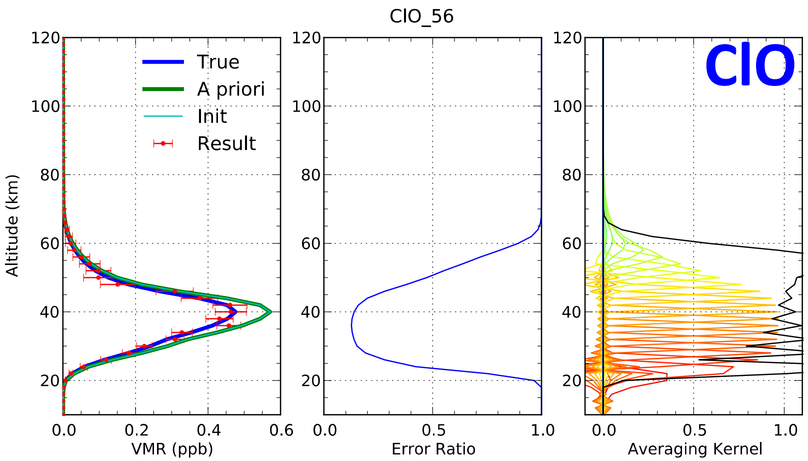


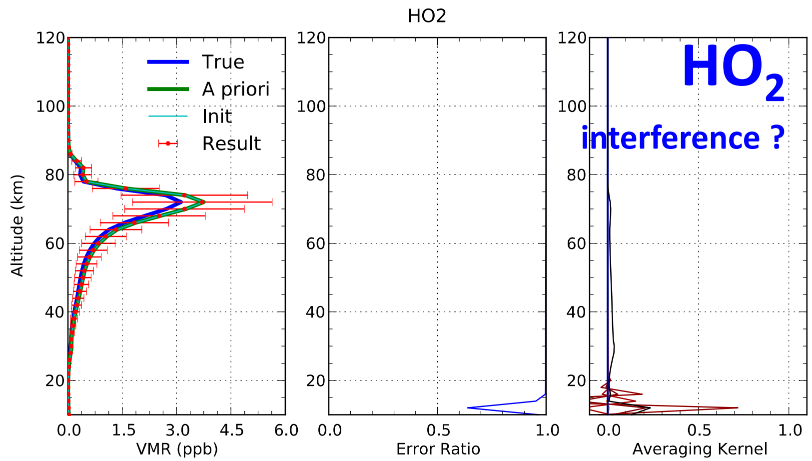


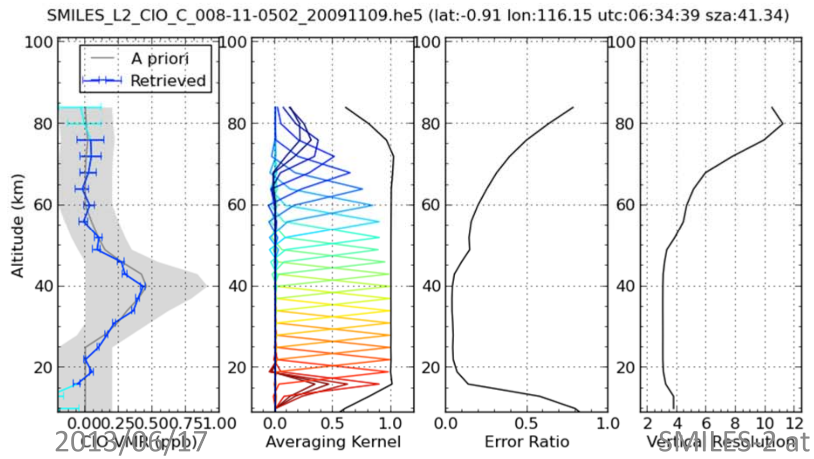


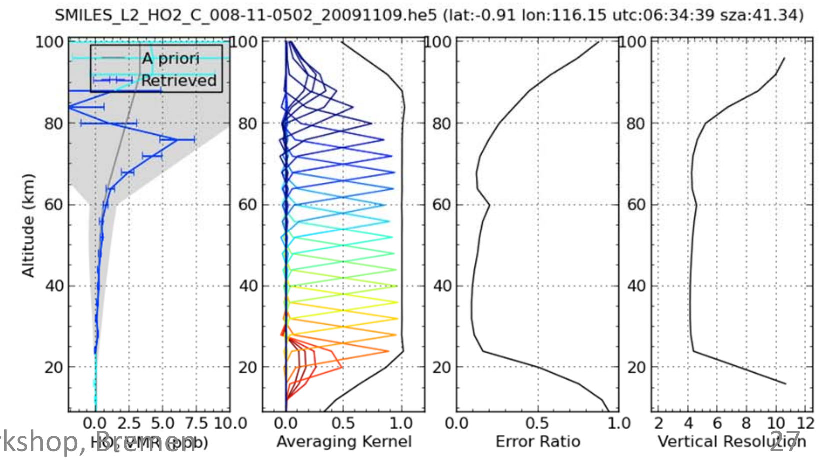
SMILES-2 Sensitivity Study: ClO, HO_2

Upper Panel A+B and C+ Dual Side Band, Lower Panel SMILES



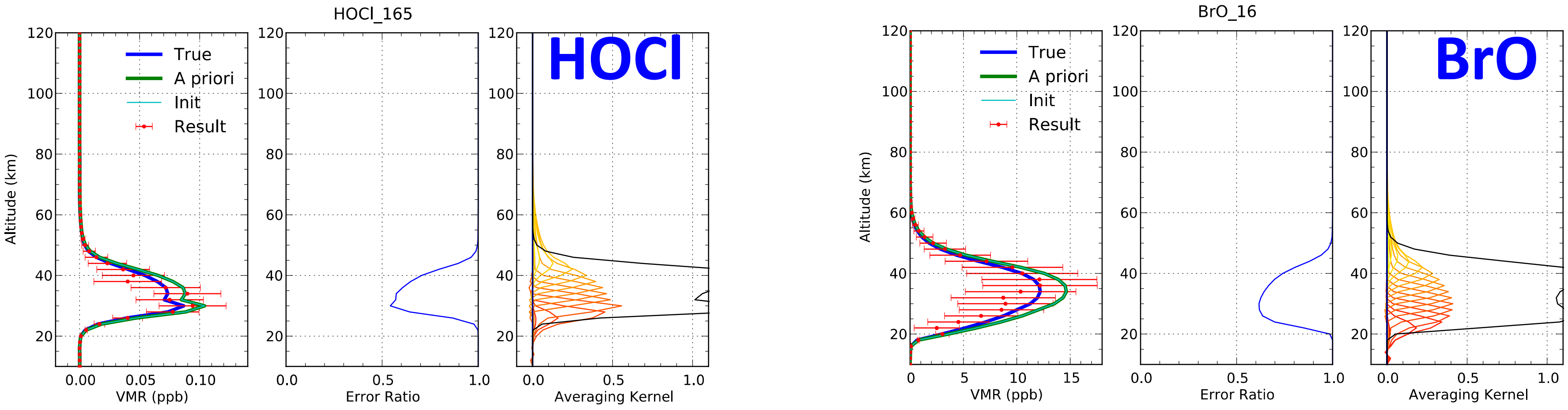


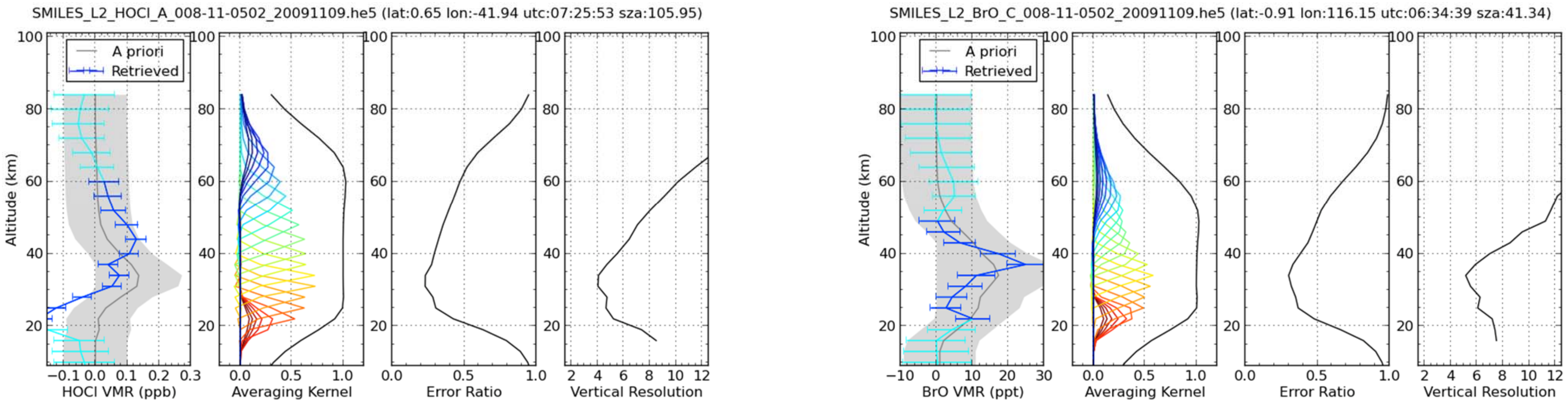




SMILES-2 Sensitivity Study: HOCl, BrO

Upper Panel A+B and C+ Dual Side Band, Lower Panel SMILES





Aura/MLS alike as a test bed for the SMILES-2 concept design.
Not necessary SSB, use DSB if it is acceptable.

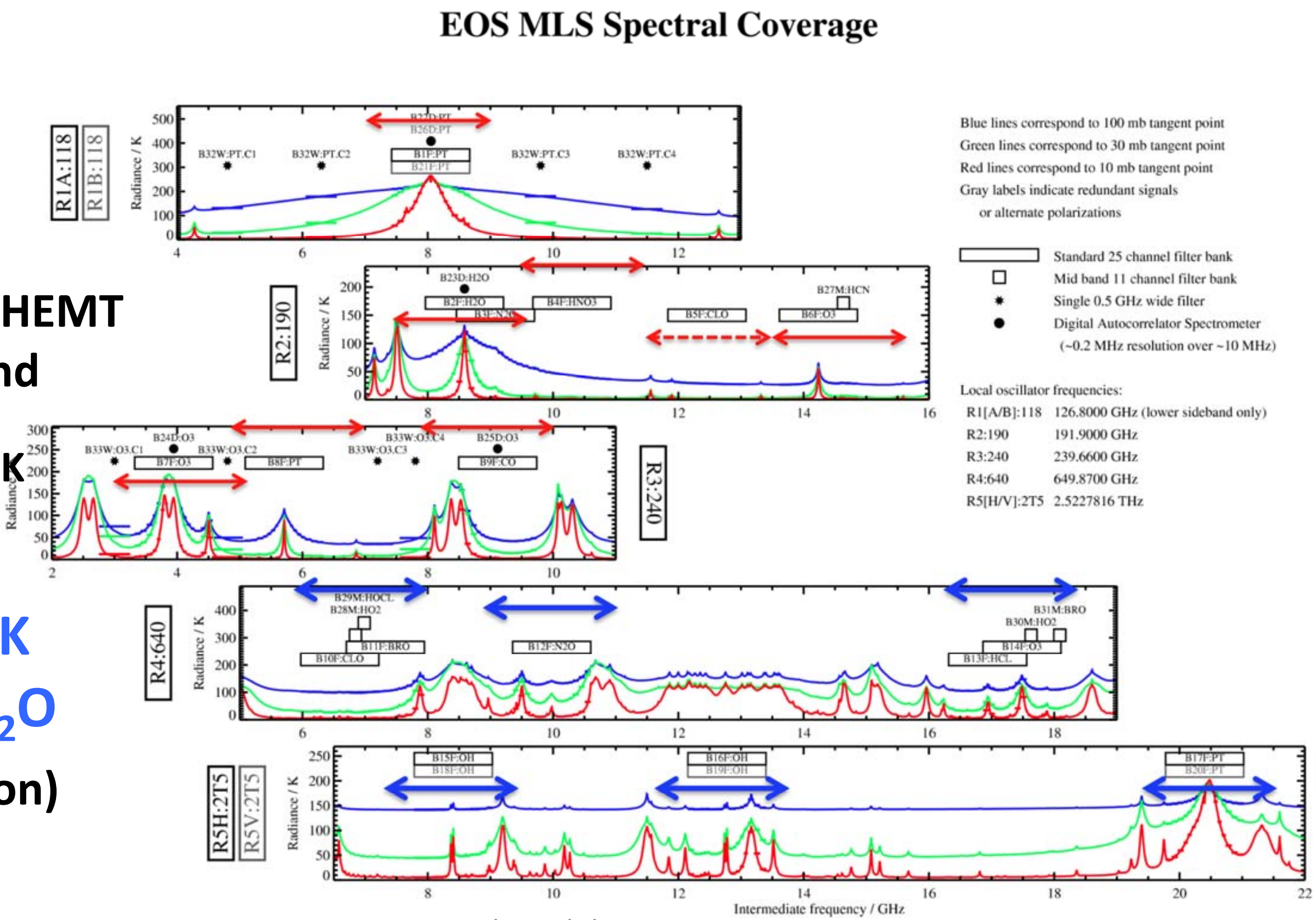
118 GHz
O_2, R.T.

190 GHz, 20 K HEMT
H_2O, UARS Band

240 GHz, 80 K SK
Trop. CO, O_3

640 GHz, 4 K
SMILES + N_2O

2.5 THz (option)
OH

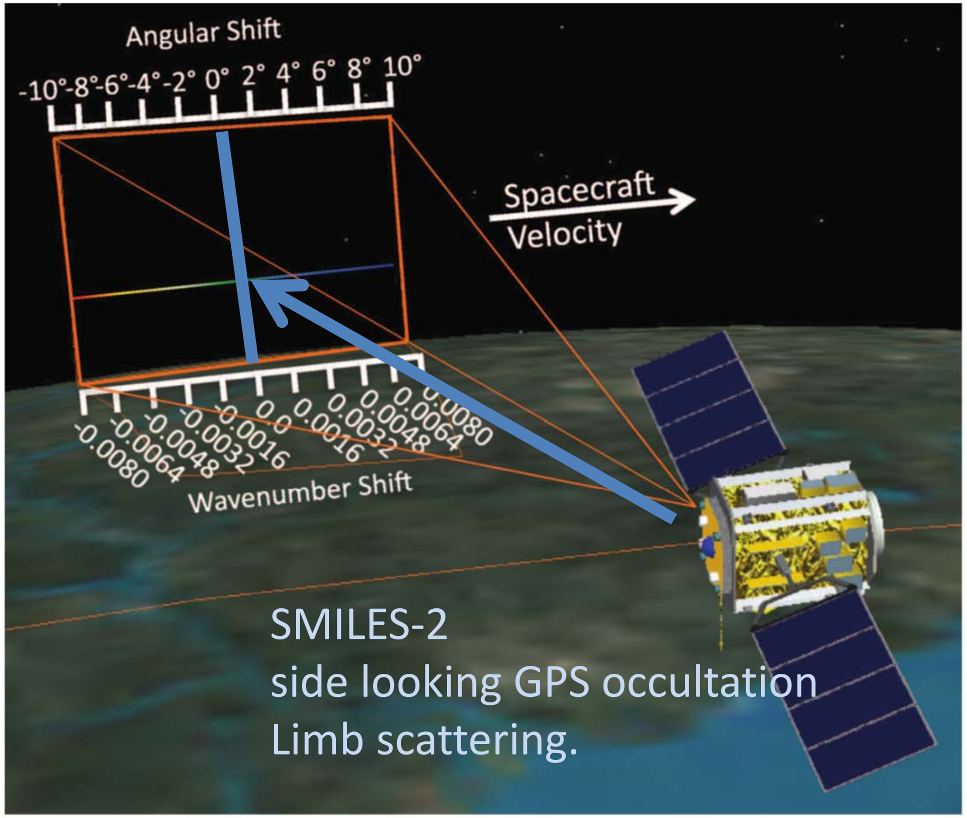


Status of research

	mass	Scientific Target	organization	Status
SMILES-2	**150 kg ?**	**Minor species : O_3, $H^{35}Cl$, $H^{37}Cl$, ^{35}ClO, HO_2, ^{81}BrO, O_3 isotopes, HNO3, CH3CN + Temp., N_2O and other species.**	JAXA/ISAS + National Astronomical Observatory of Japan + Universities	**Cooler weight reduction study completed.** only preliminary concept study. It may enter Phase-A this year.
DWTS	**20 kg**	**CT wind 2 m/s (20-200 km) Temp. < 1% (25-250 km)**	**GATS Inc. by US government funding**	it will be presented by Dr. M. McHugh in this afternoon.
OSIRIS-2 SCIA-limb	**20 kg**	**limb O3, NO_2, BrO, OClO, aerosol etc. Airglow**	**CSA or DLR**	**1) CSA: ? 2) DLR: ?**
GPS occultation	8 kg	**Temp. and Total Electron Concentration**	**JAXA/TKSC (ISAS budget)**	JAXA-NGPSR (2014) GPS occultation, Phase-A done, **Drawing/EEE parts list ready.** 24 months, $2M to Flight Model.

Observation geometry

SMILES-2 + side/back looking GPS occultation, DWTS and limb scattering.

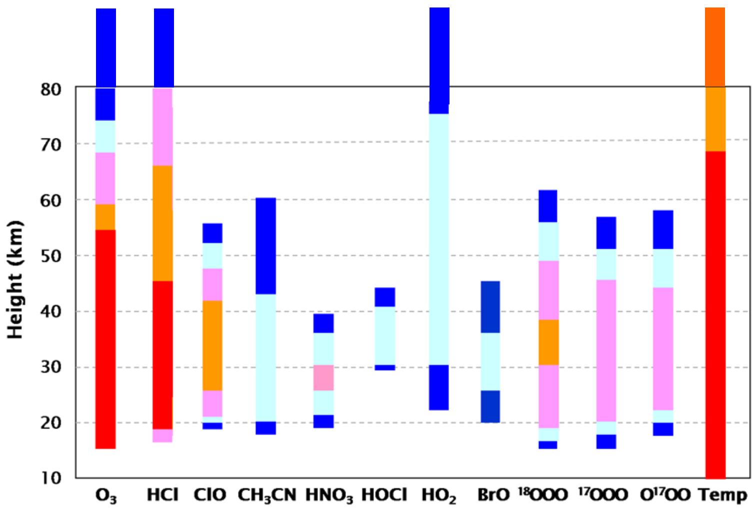


L. L. Gordley et al. 2011

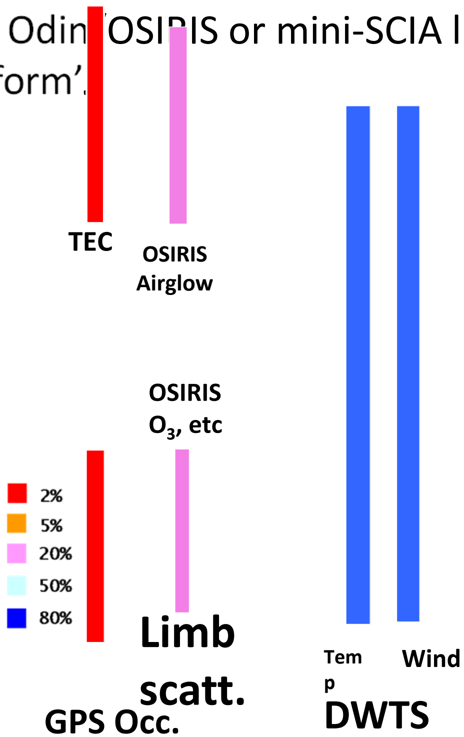
Fig. 2 Example DWTS viewing geometry. A FPA collects a (20×20)-deg square image of the limb, centered near the zero relative velocity direction. Pixels in forward columns see blueshifted emission; trailing columns see redshifted. Each row collects a full DIP signal (only the 100-km row is illustrated/colored) for an observed limb air volume as it passes through the FOV.

Summary

- After getting strong support to SMILES-2, and the discontinuity issue of the stratosphere-mesosphere limb observation, we started to try to propose SMILES-2 satellite together with international collaborators.
- Retrieval carried out for Double Side Band configuration and it looks feasible, and it should reduce size of 4K cryogenic part and power consumption
- It could/should be SMILES-2, DWTS, Odin OSIRIS or mini-SCIA limb., and GPS occultation for the ISAS small science satellite 'platform'.



SMILES O_3,HCl, HO_2 observation is extended to 95km. Aura/MLS compatible observation will be studied in near future.



OSIRIS
- 10-40 km O_3, NO_2, OClO, BrO, aerosol
- 80-100 km Airglow

GPS occultation
- 0-40 km Temp.
- 80-600 km TEC