Tangent height accuracy of Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES) on International Space Station (ISS)

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Photo courtesy of NASA

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the Superconducting Submillimeter-Wave Limb-Emission Sounder (SMILES)

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Title:
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Introduction of SMILES, including performance results and calibration issues
pp. 4–13

ISS attitude
pp. 14–18

Tangent height accuracy of the SMILES observation
pp. 19–25
**SMILES**  
*Superconducting Submillimeter-Wave Limb-Emission Sounder*

- SIS receivers in 625 and 650 GHz bands; very high sensitivity for submillimeter-wave limb-emission observation
- Atmospheric observation on ISS: from Oct. 2009 to Apr. 2010
- Target species: O₃, HCl, ClO, HOCl, HO₂, HNO₃, CH₃CN, and BrO; Also stratospheric wind, UTLS water vapor and ice clouds.
- Developed jointly by NICT and JAXA

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SMILES is the second payload from this side.
SMILES Instrument

Frequencies:

- **LSB** : **Band A**: 624.26 – 625.59 GHz,
  **Band B**: 625.06 – 626.38 GHz,
  **USB** : **Band C**: 649.05 – 650.38 GHz

Frequency Resolution / Bandwidth: (two AOS units)
- about 1.1 MHz / 1.3 GHz
Antenna and Optics

Elevation steerable antenna
Aperture: 392 mm × 200 mm
Beam widths (@3 dB): 0.089° × 0.173°
Height resolution at tangent point: 3.2 km

Local Oscillator (637.32 GHz)

Submillimeter Optics
includes sideband separator, local diplexer.
The optics is installed in a shielded box.
SubMM Receiver and Cryocooler

**Submm Receiver**  (Superconducting mixer)
Two receivers in 624 – 626 and 649 – 650 GHz
System noise temperature is 315 – 320 K in SSB operation

**Cryocooler**  (Joule-Thomson cycle and Stirling coolers)
Cooling Capacity : 20 mW @ 4.3 K
Power Consumption : 120 W nominal @ BOL
Mass : 82 kg (incl. Cryostat: 24 kg)
Receiver Performance

The SMILES SIS receiver shows very high sensitivity, meeting requirement with a margin.

The noise level is one order of magnitude below the conventional submillimeter sounder in space.

The stability time of the receiver is about 8 s in space.
Antenna Scan Pattern

SMILES repeats limb scannig, cold calib., freq. calib., and hot calib. every 53 s (horizontal sampling period: 360 km)

Considerable long calibration period (53 s) has no impact on spectral $\Delta T (< 0.42 \text{ K})$.

$\Delta T$ for continuum signal is $< 0.27 \text{ K}$.
Example of Observed Spectra

Every 53 s, two of these three sets of limb spectra were observed.

The spectra have low $\Delta T$ and stable spectral baselines.
Calibration of Observed Spectra

- Brightness intensity calibration
  - Intensity-scale calibration
  - Gain-nonlinearity correction

- Frequency calibration
  - Frequency-scale calibration
  - Filter response pattern measurement

- Field-of-view calibration
  - Tangent-height calibration
  - Beam-pattern measurement
Calibration of Observed Spectra

- Brightness intensity calibration
  - Intensity-scale calibration (discussed in profile-validation papers)

- Frequency calibration
  - Frequency-scale calibration See a Wednesday poster WEP.P.363.

- Field-of-view calibration
  - Tangent-height calibration Today’s topics
  - Beam-pattern measurement → *IEEE TAP*, 60(8), 2012.
Calibration of Observed Spectra

• Brightness intensity calibration
  • Intensity-scale calibration
    Brightness resolution: <0.42 K (1.1 MHz resol.)
    → Intensity scale <1 % (~2 K)

• Frequency calibration
  • Frequency-scale calibration
    Frequency resolution: 1.1 MHz
    → Frequency scale <10 kHz (relative)
    → Frequency scale <100 kHz (absolute)

• Field-of-view calibration
  • Tangent-height calibration
    Height resolution: ~3 km
    → Height scale <50 m (relative)
ISS Attitude

We need to know the ISS attitude with enough precision for the limb observation.

- Tangent-height precision ~ 50 m
- → Pointing precision needs to be less than 0.0014° (5 arcsec)

ISS Altitude: 333 - 370 km

SMILES observes limb emission in a tangent height range between ~0 and 100 km with a step of about 2 km.
Typical ISS Attitude

ISS circulates around the Earth with a period of about 91 min.

The attitude varies almost periodically, but the orbit-by-orbit variation is unpredictable.
Bending of ISS Structure

Mutual movement between SMILES and the ISS main body depends on the direction toward the sun.

SMILES moves slowly relative to the ISS main body with an amplitude of about 0.05° or less.
Vibration of ISS Structure

In short time scale, the attitude around SMILES moves by about $0.003^\circ$ (peak-to-peak) occasionally.
Vibration of ISS Structure

A remarkable vibration around 0.25 – 0.3 Hz is observed from 7:00 to 23:00 (GMT). This vibration is known as a resonant frequency of ISS excited by activity of astronauts.

Color spectrogram of angular attitude difference between ISS GN&C and MAXI. The colored value is an integration of vibration amplitude density over a third octave.
Tangent Height Calibration

- The tangent height can be retrieved from the spectra.

- The tangent height can be derived from geometrical data.

We discuss here the geometrical derivation.
Geometrical Tangent Height Derivation

Error sources of geometrically derived tangent height:

(1) Offset of the submillimeter beam direction from a mechanical axis (stable systematic error)

(2) Error in an encoder of the antenna elevation angle (∼0.0008°)

(3) Error of the position of ISS (basically negligible, except the JEM’s error)

(4) Error of the attitude in inertial space
SMILES Star Sensor

SMILES detects the attitude with a star camera.

The error in the star sensor of an axis around the camera bore (r.m.s. 0.017°) propagates to the tangent height error (r.m.s. 0.01° in elevation angle).
MAXI Ring Laser Gyroscope

The ring laser gyroscope (RLG) installed on the Monitor of All-sky X-ray Image (MAXI) is used to determine the SMILES attitude.

The tangent height is derived from an attitude that is based on the RLG data and averagely aligned with the SMILES star-sensor attitude.

RLG has an attitude precision of about 0.001° (rms).
Attitude based on the RLG Data

From the ring laser gyroscope (RLG) data, an attitude data is estimated so as to agree with the star-sensor attitude averaged for SMILES scan period (53 s) in $X$ and $Y$ axes, and for longer time scale ($\pm 3$ min.) in $Z$ axis. This alignment estimation gives an error of about $0.003 \degree$.
**Tangent Height Profile of a Scan**

Tangent height is estimated from SMILES star sensor, ISS GN&C, and MAXI RLG.

Offset (~0.1°) in ISS/GN&C tangent height is removed in the figures.
Tangent Height Profile of a Scan

The standard deviation of the tangent-height mean offset, which is calculated by retrieval process from spectra of a scan, is 0.14 km (0.0038° in elevation angle). That is consistent with a root sum-square of:

- RLG-attitude standard deviation: 0.001°
- Error in estimation of the initial orientation for RLG: 0.003°
- Encoder error of the antenna elevation angle: 0.0008°
- Error in calculation of the tangent-height mean offset from spectra: 0.002°

The initial-orientation error (0.003°) is the error in aligning the RLG data with the SMILES star-sensor attitude. It will be reduced in future improvement of the algorithm.

The relative error of the tangent heights in a scan is about 46 m (0.0013°)
Summary

- **SMILES performance and calibration**
  - Atmospheric limb was successfully observed for 6 month with very low noise and almost perfect baseline feature.
  - The spectra are well-calibrated in intensity and frequency scales.

- **ISS attitude**
  - SMILES moves slowly relative to the ISS main body with 0.1° p-p.
  - JEM occasionally has a vibration of 0.003° p-p with a frequency of about 0.25 Hz.

- **SMILES tangent-height accuracy**
  - The data from the ring laser gyro. of MAXI is used to calculate tangent heights.
  - The error of the tangent height is about 46 m (0.0013°) in a scan.
  - The standard deviation of the tangent-height offset error of each scan is less than 140 m (0.0038°).
IGARSS 2012  Tangent height accuracy of SMILES on ISS, Ochiai Satoshi, 2012/7/24