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PREMIER - Instrument development of the millimetre-wave limb sounder MWLS

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History and Context

PREMIER (PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation) is the mission proposal for the 7th generation of ESA Earth Explorer satellites aimed at understanding the Upper Troposphere – Lower Stratosphere (UTLS) region of the atmosphere. The core concept of PREMIER is the synergistic deployment of an infra-red limb-sounder (IRLS) and a millimetre-wave limb-sounder (MWLS) from the same satellite platform. The PREMIER/MWLS is the latest iteration of the STEAM-R instrument, a Swedish led initiative based on their successful ODIN satellite.

As part of PREMIER, the MWLS will contribute trace gas measurements in the presence of ubiquitous cirrus clouds which are opaque at infra-red frequencies, thus greatly extending the PREMIER observation range to lower altitudes. Many original STEAM-R specifications are still present in the updated instrument concept, namely

- Use of the **upper tropospheric transparency window** at 300-360GHz
- **Limb-sounding** geometry for high vertical resolution
- Large antenna for a **narrow field of view** in the UTLS region
- Fixed, full-range **antenna array** for rapid observations and reliability
- **Dual polarisation** setup allows tighter stacking of antenna beams
- Along-track sampling enables **tomographic** 2-D retrievals

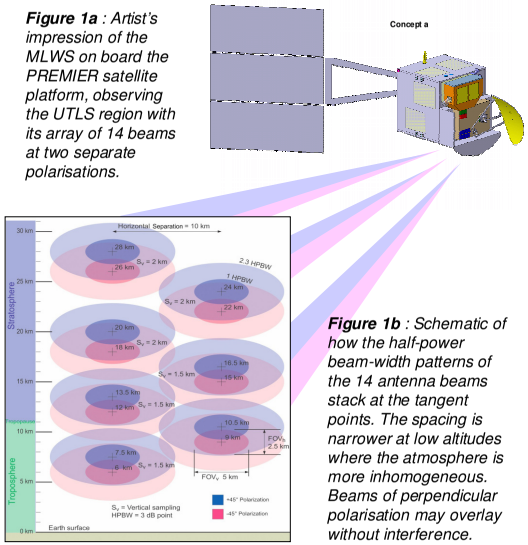

***Figure 1a** : Artist's impression of the MLWS on board the PREMIER satellite platform, observing the UTLS region with its array of 14 beams at two separate polarisations.*

***Figure 1b** : Schematic of how the half-power beam-width patterns of the 14 antenna beams stack at the tangent points. The spacing is narrower at low altitudes where the atmosphere is more inhomogeneous. Beams of perpendicular polarisation may overlay without interference.*

Science Rationale

The PREMIER/MWLS is designed to measure weak trace gases in the UTLS region of the atmosphere in the presence of clouds, providing a higher vertical resolution than previous instruments. Figure 2 shows the two observation bands and a select number of **observable species**.

Science objectives include dynamical stratosphere troposphere exchange processes, tropical tropopause clouds and humidity, radiative forcing, biomass burning events, industrial pollution, ozone chemistry, active nitrogen and halogen gases and general tracer measurements.

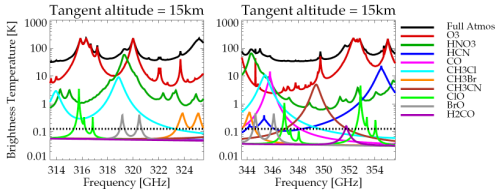

***Figure 2**: Simulation of the atmospheric spectrum to be observed by the MWLS (black line) and contributions from individual species (coloured lines). The dashed line denotes the detection limit due to instrument noise.*

Technical Specifications

Parameter	Unit	Value
Spectral coverage		
Lower sideband	GHz	313.5–325.5
Upper sideband	GHz	343.6–355.6
Sideband separation		
Lower 12 km	–	Separated sidebands
Upper 10 km	–	Double sideband
Vertical Coverage		
Mid-latitude	km	6–28
Arctic	km	2–24
Vertical FOV		
@ 352 GHz	km	2.4
@ 324 GHz	km	2.6
Vertical sampling		
Lower 12 km	km	1.5
Upper 10 km	km	2
Horizontal sampling along track	km	~50
First sidelobe knowledge (ACAP)	dB	<–36
FOV sidelobe knowledge in orbit (ACAP)	dB	<–32
Spectral resolution		
Baseline	MHz	23
In orbit option	MHz	6 to 12
Knowledge of sideband ratio	dB	30
Dynamic range	K	3–300
Radiometric Sensitivity (2.5 s integration)		
10 MHz bandwidth	K	~0.5
23 MHz bandwidth	K	~0.3
Absolute radiometric accuracy	K	~1.0

***Table 1**: Detailed technical specifications of the MWLS instrument.*

Hardware Development

The heterodyne technique traditionally used in millimetre-wave receivers implies that a principal sideband and an image sideband are both mapped onto a single observation band. The resulting spectral confusion is either tolerated, or the image sideband is terminated by a well defined thermal load, which in return increases the noise figure of the receiver. For MWLS a novel sideband separating receiver is being developed. By exploiting the combined signal from two phase-shifted heterodyne receivers, both sidebands are returned individually, without spectral confusion.

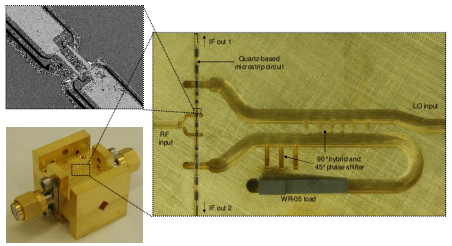

***Figure 3**: First prototype of the sub-harmonic image rejection mixer (SHIRM) developed for the MWLS. Top left: Anti-parallel pair of planar Schottky diodes. Right: Micro-machined cavity. Bottom left: Assembled SHIRM block.*

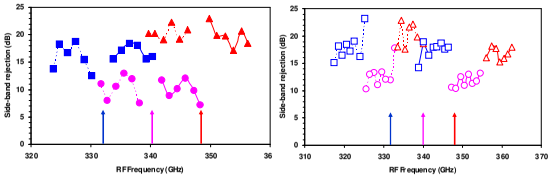

***Figure 4**: Measurements of sideband suppression at different frequencies. Left: 2-8 GHz IF band, Tsys 3800K. Right 6-14 GHz IF band, Tsys 5000K. Consistent suppressions of up to 20dB are achieved by this first prototype.*

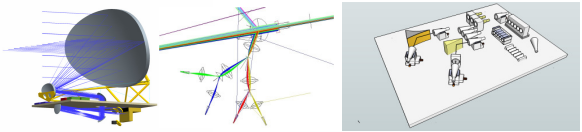

***Figure 5**: Schematics of the antenna main beam (left), the quasi-optical subsystem (centre) and the Straw Cutter concept used to achieve a tight beam stacking despite the dimensional restrictions from the feed-horns (right).* The Straw Cutter concept and application are subject to European Patent Application EP08161213.7.

Radiometric Performance

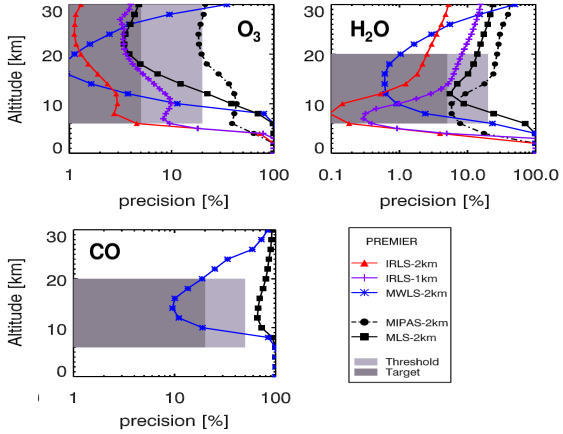

***Figure 6**: 1-D retrieval precision simulations for three major target species of PREMIER. The MWLS results are shown in blue, the IRLS results are shown in red. Both compare favourably with respect to their current benchmark counterparts, i.e. MWLS vs. Aura MLS and IRLS vs. MIPAS, particularly in the targeted UTLS region from ~6km to ~18km.*

Summary

The millimetre-wave limb-sounder PREMIER/MWLS is the latest iteration of the STEAM-R instrument concept.

In the proposed ESA Earth Explorer mission PREMIER, the MWLS will contribute high vertical resolution measurements of UTLS trace gases in the presence of clouds. These measurements are in synergy with 2-D infra-red samplings of the same region by the IRLS, as well as nadir-soundings by MetOp from a shared orbit.

The MWLS will measure, amongst others, water vapour [H_2O], ozone [O_3], carbon monoxide [CO], nitrous oxide [N_2O], nitric acid [HNO_3], hydrogen cyanide [HCN], methyl cyanide [CH_3CN], as well as bromine and chlorine species. These measurements will foster our understanding of tropical tropopause chemistry and dynamics and their key impact on the climate system, ozone chemistry, biomass burning and industrial pollution.

Instrument development to support PREMIER/MWLS is ongoing in Sweden and the UK. Technical highlights are the sideband separating SHIRM receivers, the fixed antenna array with tight beam stacking, the large main reflector, and the large bandwidth digital autocorrelation spectrometers.

Acknowledgements: UK work has been supported by the Natural Environment Research Council (NERC), the Centre for Earth Observation Instrumentation (CEOI) and Astrium UK. Swedish work has been supported by the Swedish National Space Board (SNSB), VINNOVA and the European Space Agency ESA.