Proof-of-concept hyperspectral microwave sounders: calibration challenges and development trade-offs

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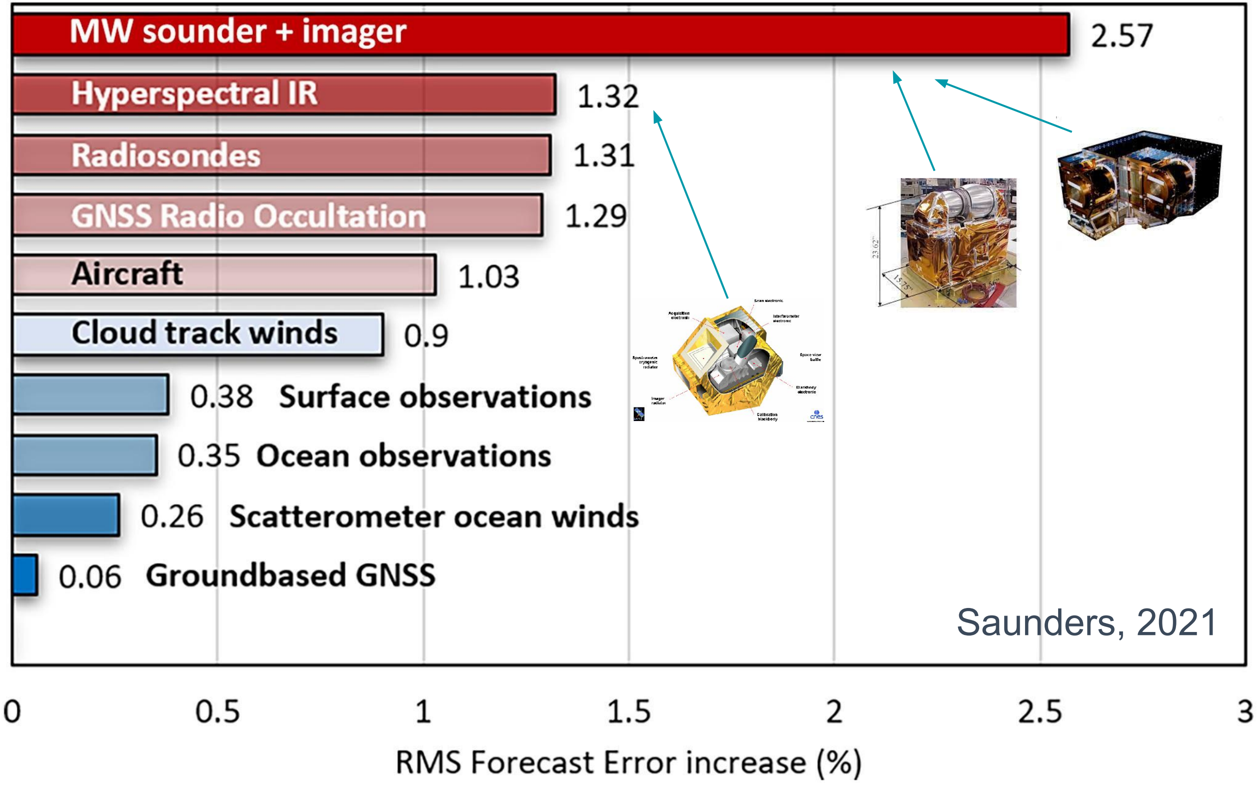
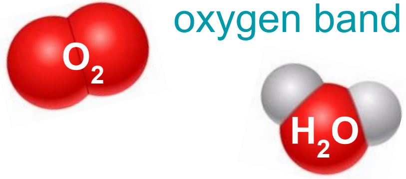
GSICS
GLOBAL SPACE-BASED INTER-CALIBRATION SYSTEM

Current use for NWP and Climate Science



- 45%
- 34% of all satellite information

54 GHz (5.56 mm) oxygen band



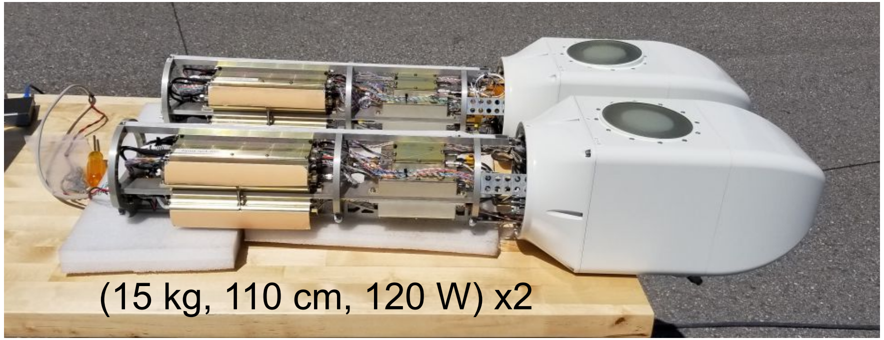
183 GHz (1.64 mm) water vapour band

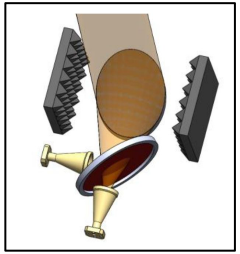
HiSRAMS: High Spectral Resolution Airborne Microwave Sounder onboard NRC Convair-580

HiSRAMS specifications and design

Specification	O_2-band	H_2O-band
RF band (GHz)	49.6–58.3 H or V 52.4–57.2 H and V	175.9–184.6 H or V 178.8–183.5 H and V
Spec. resolution	305 kHz and multiples	
Rec. temperature	160–270 K	590–760 K
Beamwidth	5.2°	1.83°
Scanning range	(optional) $\pm 12^{\circ}$ around zenith and nadir	
Integration time	sky: (2×5×) 0.5 s, calib. load: (2×) 1.0 s	

- Polarized heterodyne receivers
- Polyphase FFT filter bank backend
- Calibration every 7 sec with two (hot and ambient) internal SiC-loaded Stycast absorbers





Engineering vs. scientific development

RF & mechanical design
Prototyping
Lab tests
Integration and airworthiness
Tests & Troubleshooting
Data chain implementation

Observation requirements
Forward model
Retrieval algorithm
Mission planning
Data collection
Conclusion on performance

Cost & Resources

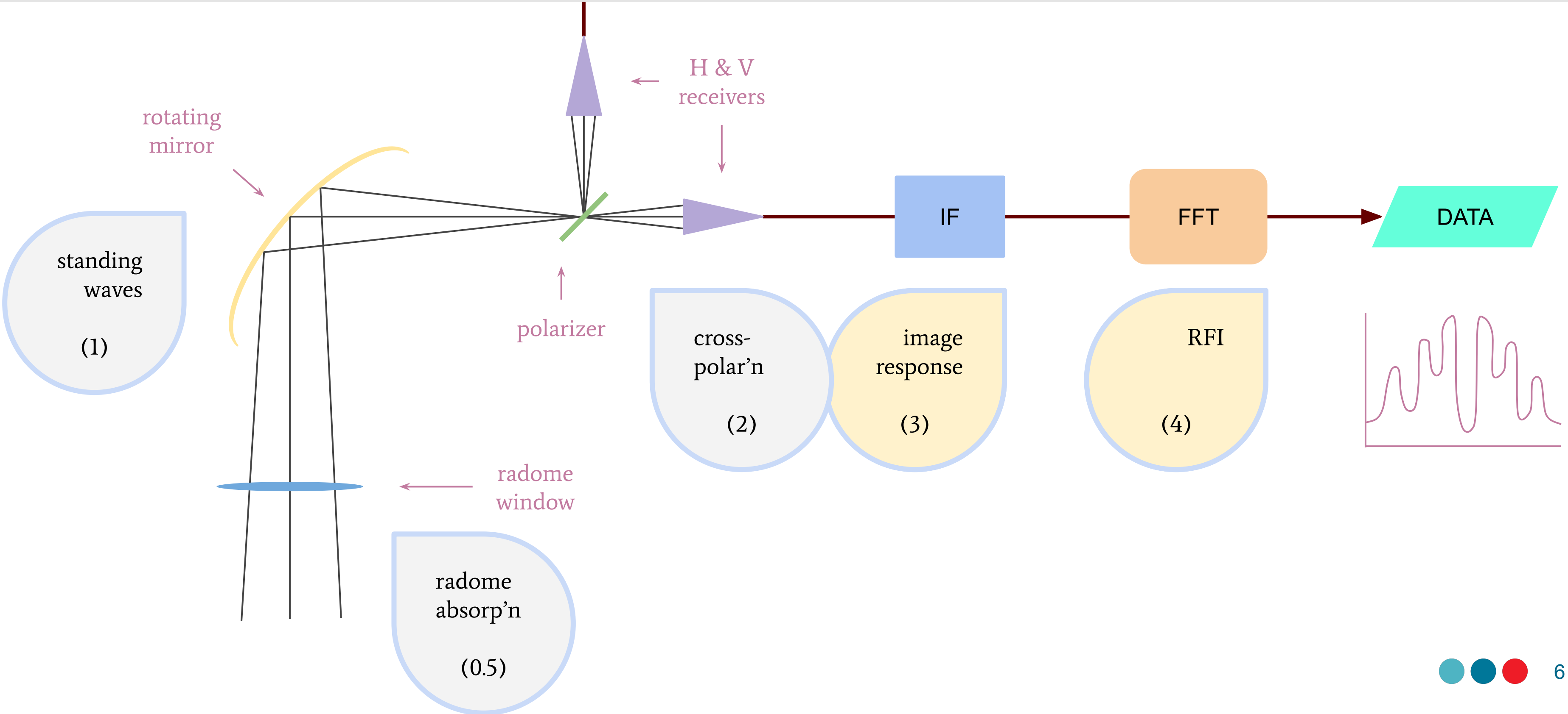
Trade-offs
Decision making
Judgement calls

…interdisciplinary expertise…

HiSRAMS timeline
2016: first ITT
2017: winning proposal
2018-2021: development
2021: first flight
2022: successful clear-sky validation
2023-2024: warm cloud validation
2025- : ice cloud validation
Bliankinshtein et al. 2023
Liu et al. 2024
Liu et al. 2025

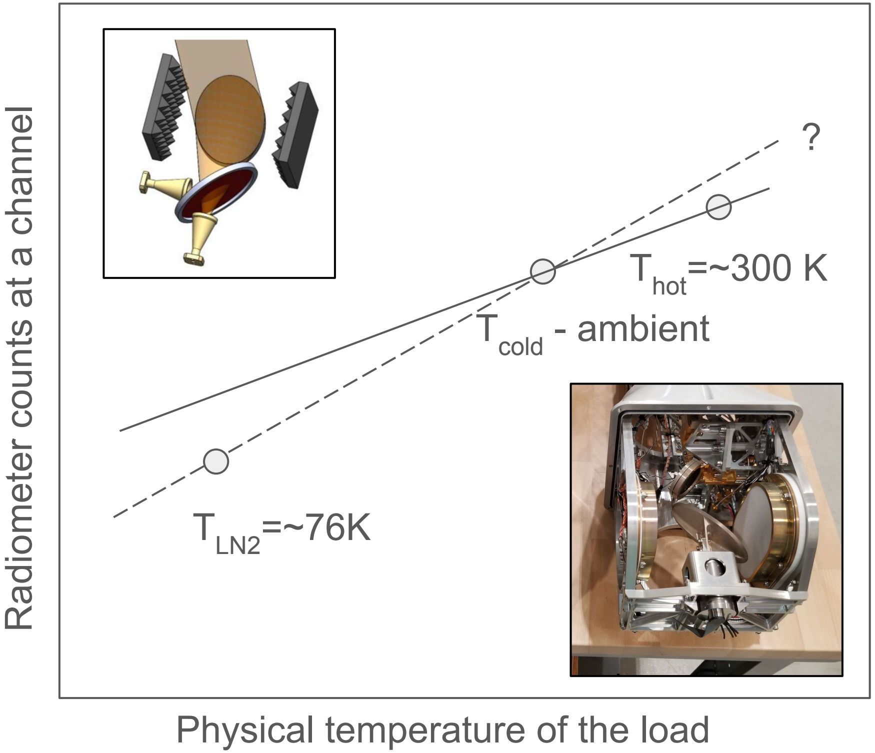
Xu et al. 2023
Bliankinshtein et al. 2023

HiSRAMS L0-L1 processor

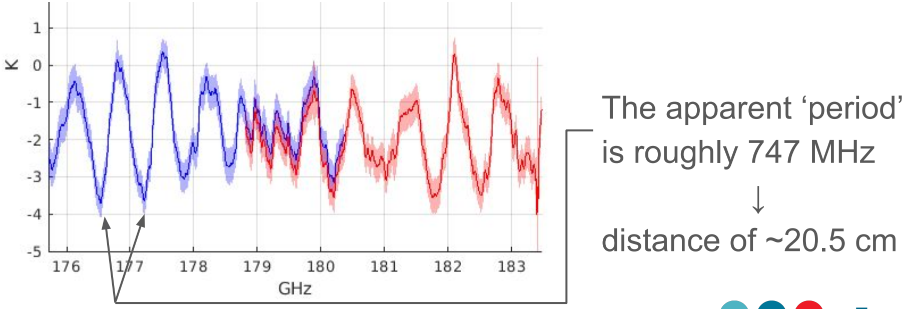


Bliankinshtein et al. 2023

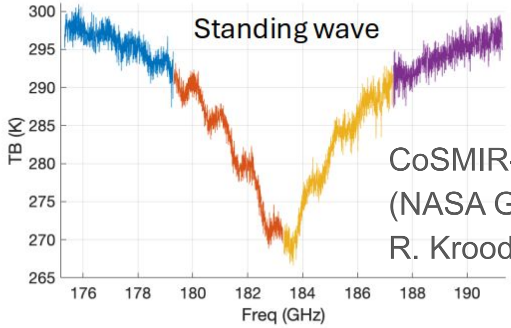
On-ground radiometric calibration with LN_2



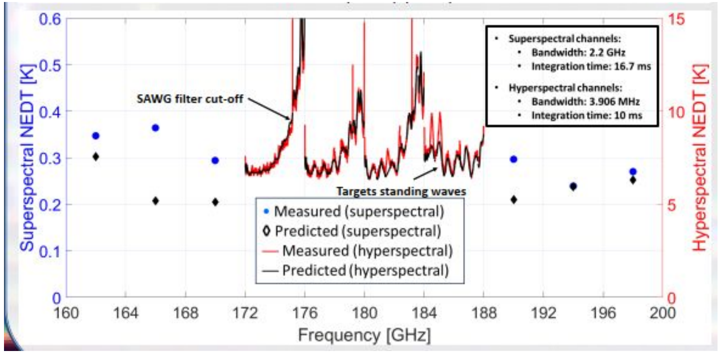
- Typical for lab. instruments is to introduce an offset to T_{hot} (dashed line)
- Three calibration points not forming a line is a concern
- There is an oscillatory pattern in calibrated T_b→
- If performed independently, offsets vary between channels:



Hyperspectral issues…



CoSMIR-H
(NASA Goddard)
R. Kroodsma et al 2025



HyMPI (NASA Goddard)
F. Gambini et al 2024 (PI Antonia Gambacorta)

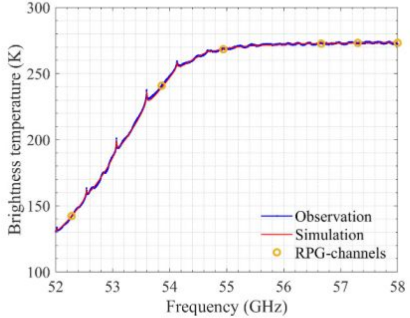


Fig. 11. Observed (from spectrometer) versus simulated (ARTS mod
versus RPG channels (from spectral integration) brightness temperature.

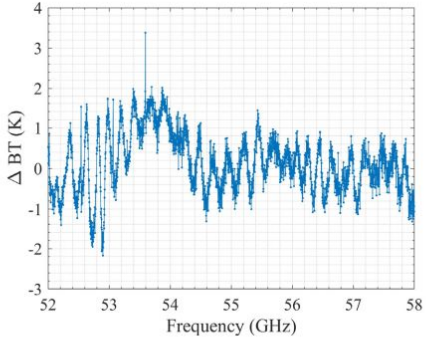
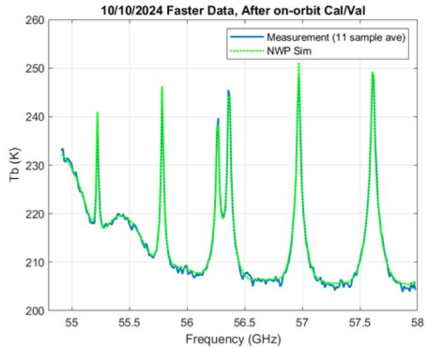
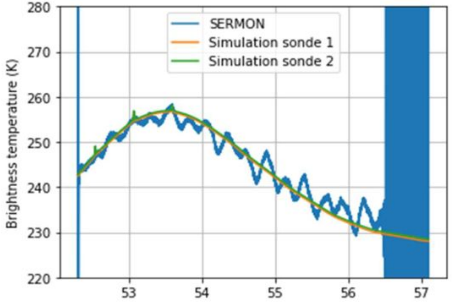


Fig. 12. Differences between observation and simulation.

(NSSC CAS) Lu et al 2025

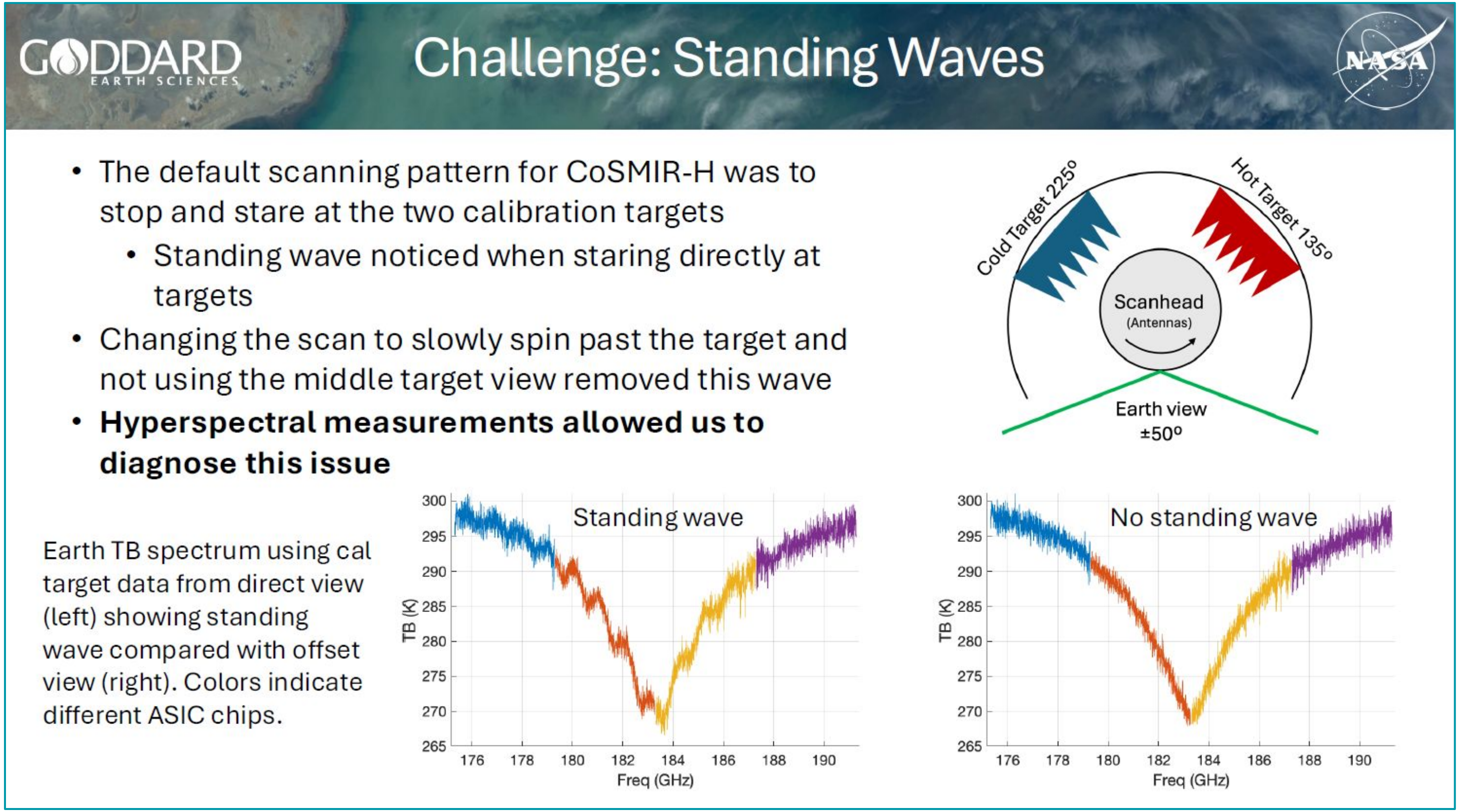


FASTER (BAE Systems) on ISS
D. Newell et al 2025



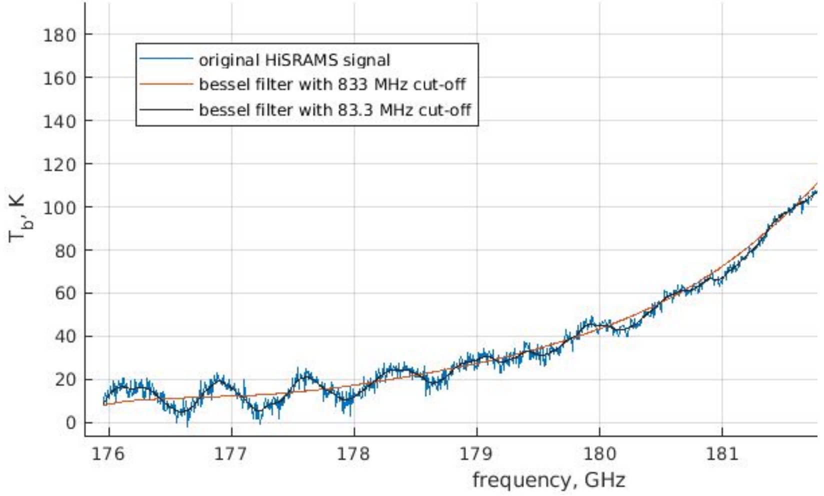
HyMS (Spire) on FAAM
M. Henry et al 2023

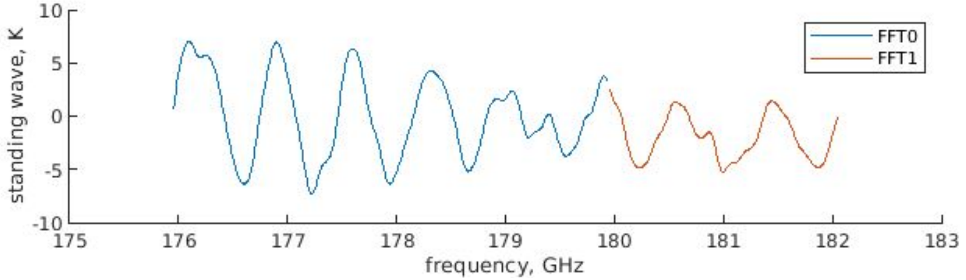
Standing wave removal: CoSMIR-H

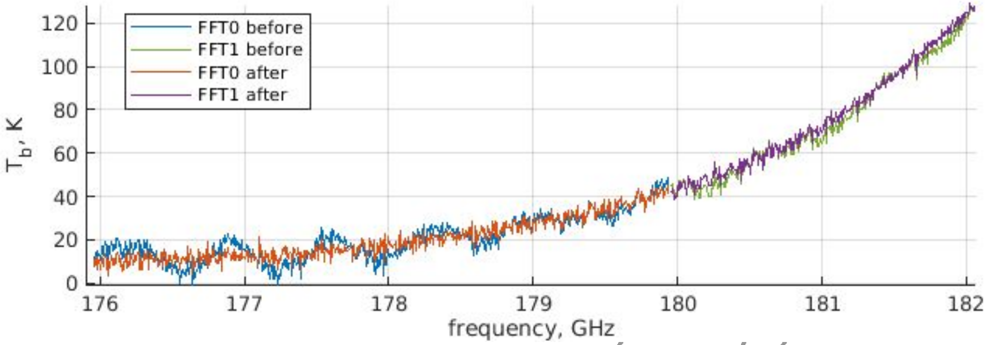


Standing wave removal: HiSRAMS

(In the 183 GHz band only)
Combination of two low-pass Bessel filters of order 16:







Blianktinshtein et al. 2023

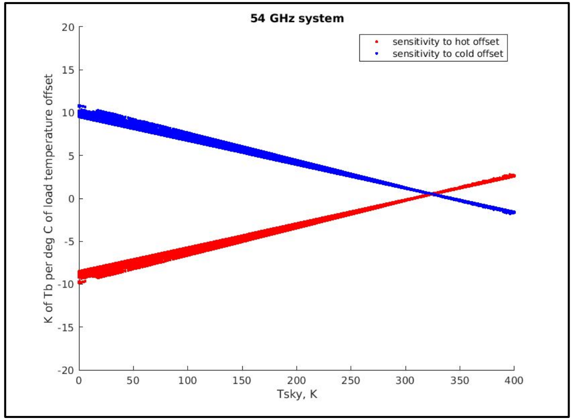
Trade-off: low SWaP-C vs. good cal. loads

$$V_{sky} = kBC_d\left(T_{A,sky} + T_{RAD}\right)$$

$$V_{hot} = kBC_d\left(T_{hot} + T_{RAD}\right)$$

$$V_{cold} = kBC_d\left(T_{cold} + T_{RAD}\right)$$

$$T_{A,sky} = \frac{T_{hot}+T_{cold}}{2} + \left(V_{sky} - \frac{V_{hot}+V_{cold}}{2}\right)\frac{T_{hot}-T_{cold}}{V_{hot}-V_{cold}}$$



For every 1 K of additional offset to the temperatures of hot or cold calibration loads, the calibrated brightness temperatures change as:

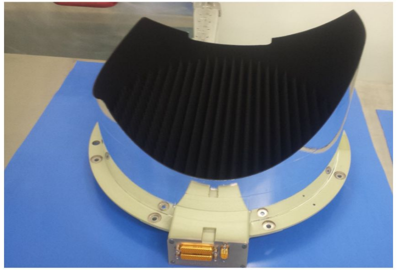
$$\frac{\partial T_{A,sky}}{\partial T_{hot}} = \frac{1}{2} + \frac{1}{V_{hot}-V_{cold}}\left(V_{sky} - \frac{V_{hot}+V_{cold}}{2}\right) = \frac{1}{2} + \frac{1}{T_{hot}-T_{cold}}\left(T_{sky} - \frac{T_{hot}+T_{cold}}{2}\right)$$

$$\frac{\partial T_{A,sky}}{\partial T_{cold}} = \frac{1}{2} - \frac{1}{V_{hot}-V_{cold}}\left(V_{sky} - \frac{V_{hot}+V_{cold}}{2}\right) = \frac{1}{2} - \frac{1}{T_{hot}-T_{cold}}\left(T_{sky} - \frac{T_{hot}+T_{cold}}{2}\right)$$

How to characterize and correct remaining biases?

Space Flight Targets

We are currently making for EuMETSAT's MetOP-SG MWS and ICI's warm calibration targets. Below is the image of the MWS On Board Calibration Target (OBCT) Engineerng Qualification Model (EQM)



.... with remarkable S11 coherent reflectivity .... measured by our colleague Axel Murk in the IAP in Bern.

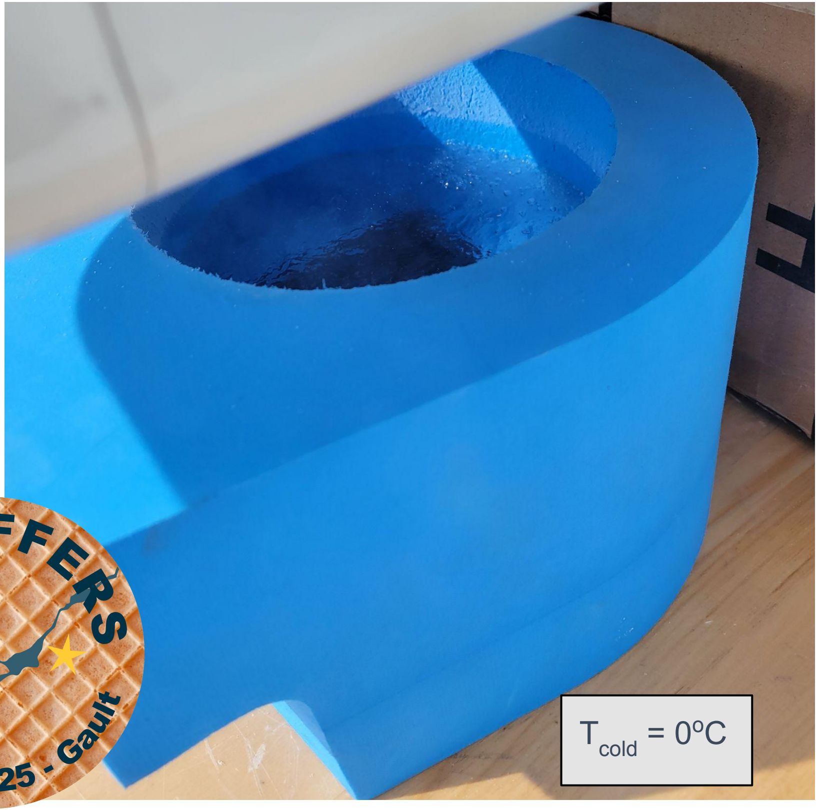
what we would like to have (TK, UBern)

what we have

Figure 27 Calibration load based SiC in stycast. The load to the right is heated, and ambient design will be < 10 mm thick.

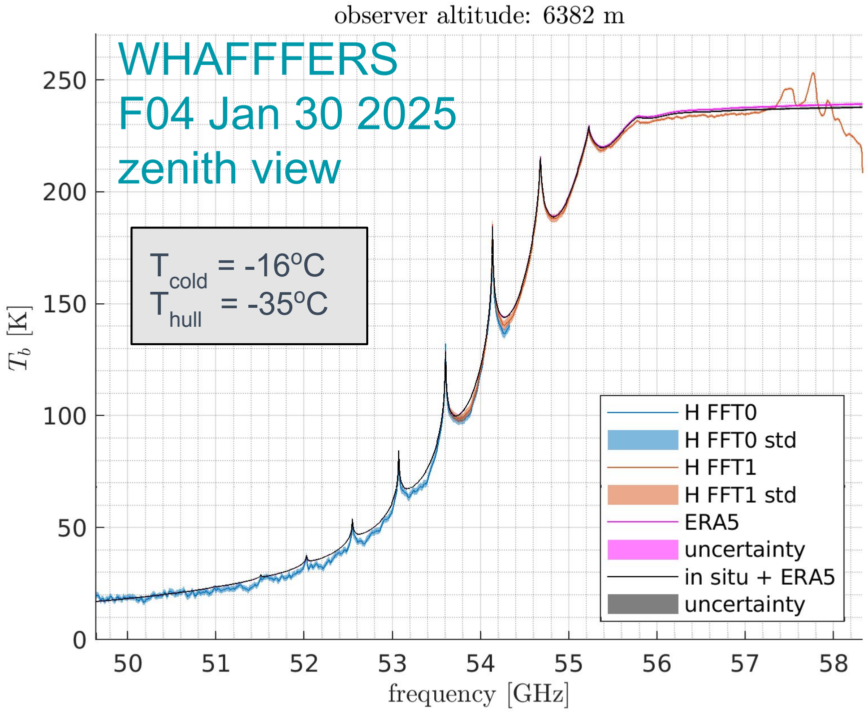
Cold Weather Calibration

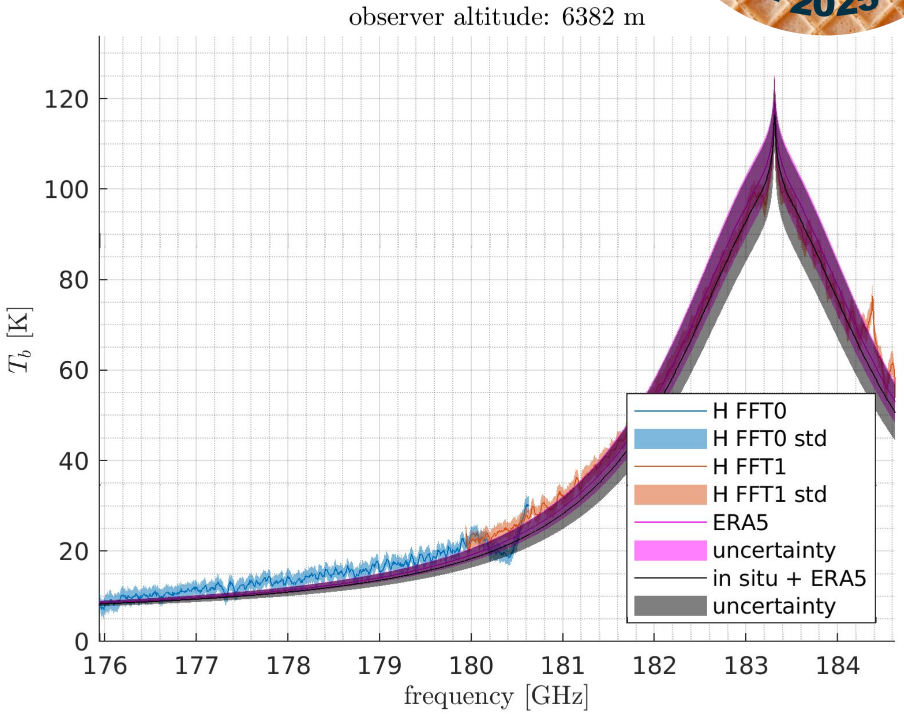
February 2025



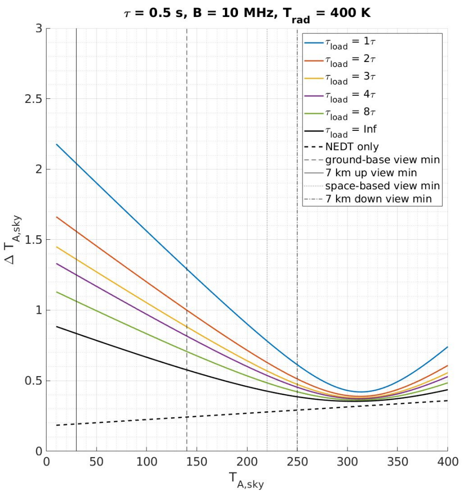
WHAFFFERS
Ottawa - 2025 - Gault

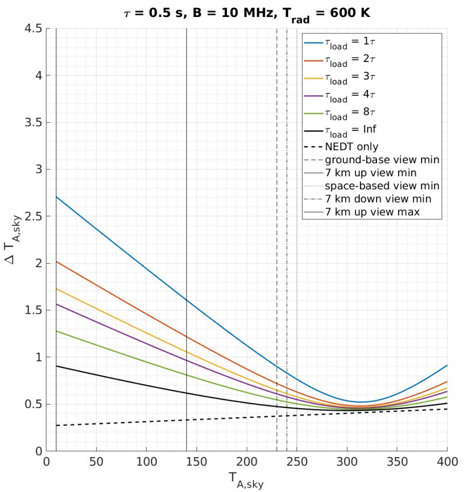
HiSRAMS radiation closure

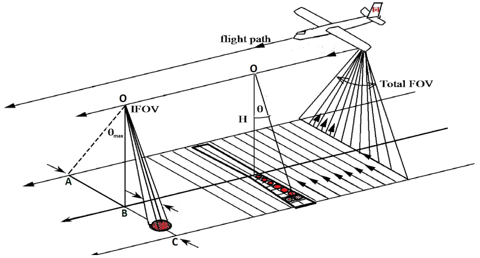


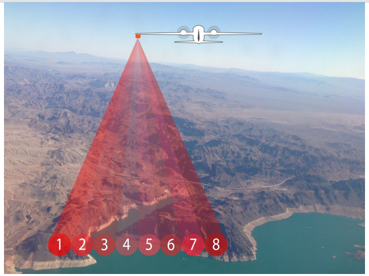


Trade-off: noise vs. resolution vs. dwell time









$$\Delta V_{sky} = kBC_d\, NEDT_{sky} = kBC_d \frac{T_{A,sky}+T_{RAD}}{\sqrt{B\tau}}$$

$$\Delta V_{hot} = kBC_d\, NEDT_{hot} = kBC_d \frac{T_{hot}+T_{RAD}}{\sqrt{B\tau_{hot}}}$$

$$\Delta V_{cold} = kBC_d\, NEDT_{cold} = kBC_d \frac{T_{cold}+T_{RAD}}{\sqrt{B\tau_{cold}}}$$

$$\Delta T_{hot} = \varepsilon_{hot}$$

$$\Delta T_{cold} = \varepsilon_{cold}$$

$$\Rightarrow$$

$$\left(\Delta T_{A,sky}\right)^2 = \left(NEDT_{sky}\right)^2 + \left(\frac{T_{A,sky}-T_{cold}}{T_{hot}-T_{cold}}\right)^2 \left(NEDT_{hot}^2 + \varepsilon_{hot}^2\right) + \left(\frac{T_{A,sky}-T_{hot}}{T_{hot}-T_{cold}}\right)^2 \left(NEDT_{cold}^2 + \varepsilon_{cold}^2\right)$$

$$= \frac{(T_{A,sky}+T_{RAD})^2}{B\tau} + \left(\frac{T_{A,sky}-T_{cold}}{T_{hot}-T_{cold}}\right)^2 \left(\frac{(T_{hot}+T_{RAD})^2}{B\tau_{load}} + \varepsilon_{hot}^2\right) + \left(\frac{T_{A,sky}-T_{hot}}{T_{hot}-T_{cold}}\right)^2 \left(\frac{(T_{cold}+T_{RAD})^2}{B\tau_{load}} + \varepsilon_{cold}^2\right)$$

Summary

Hyperspectral radiometer challenges and trade-offs:

- Filter bank spurs/RFI (not shown)
- Standing waves
- SWaP-C vs. good quality calibration loads (vs. noise diodes?)
- Noise vs. resolution vs. integration time

HiSRAMS status in 2026:

- Collected 100+ hours of flight data
- Investigating environmental biases
- Testing radiation closure in presence of ice clouds

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