MgB_2 HEB heterodyne receivers at 20-30 K for S & M-sized FIR space missions

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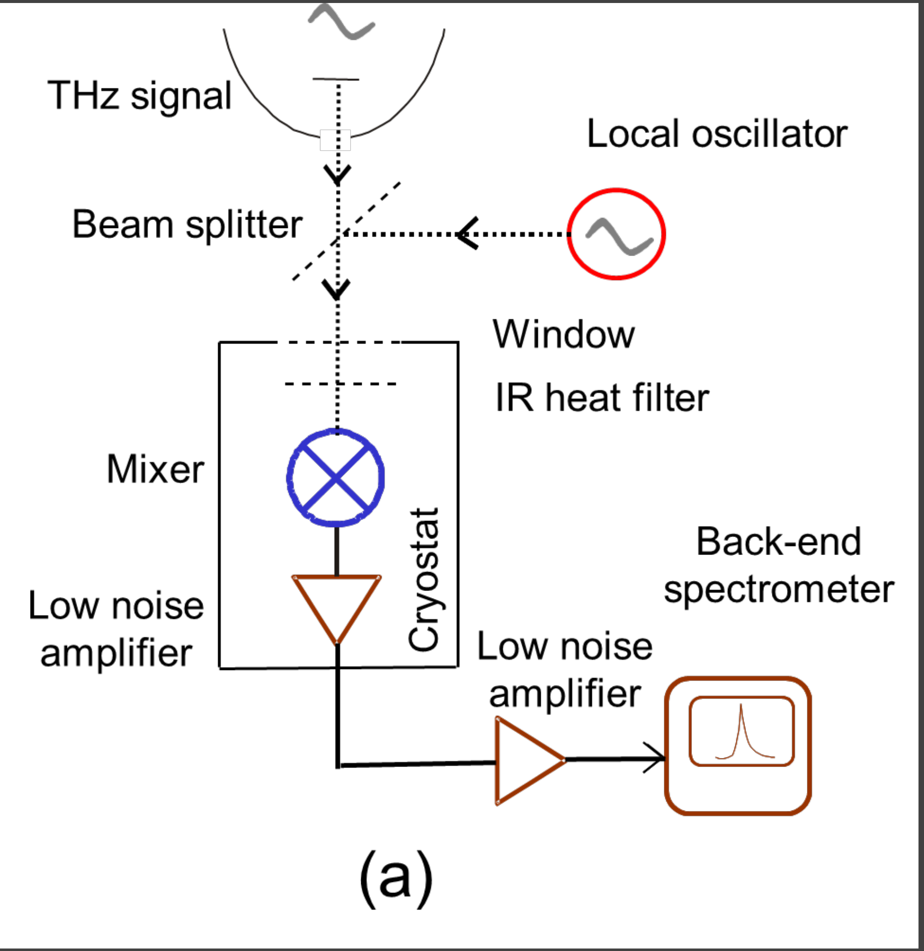
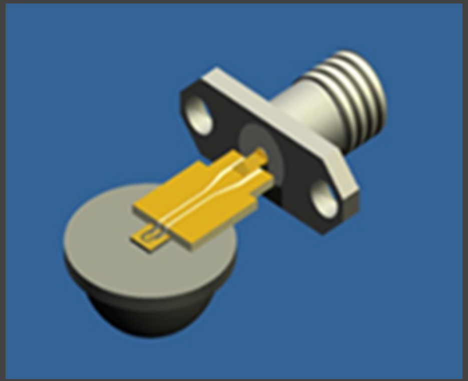
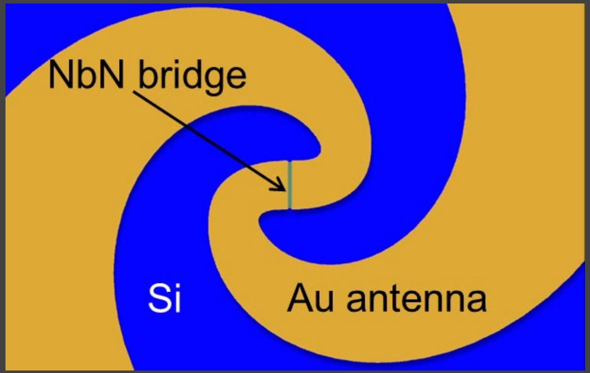
SPACE RESEARCH ORGANISATION NETHERLANDS

HEB heterodyne receiver

High spectral resolution ($\nu/\Delta\nu \geq 10^6$)







- NbN HEB mixer
- 1.4 – 5.3 THz
- Operated at 4 K
- Low T_{mixer}^{DSB} (optics/LNA+ $T_{mixer}^{DSB} \rightarrow T_{rec}^{DSB}$)

J.R. Gao, Chapter 26, book "Observing Photons in Space" by Springer Nature

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THz space observatories with NbN HEB mixers

Herschel

ESA

HIFI: 1.4 – 1.9 THz

Cherednichenko, et al, Rev. Sci. Instrum., (2008)

Stratospheric Observatory for Infrared Astronomy(SOFIA)

1.83 – 2.06 THz, 4.7 THz

C. Risacher et al.,
IEEE Trans. Terahertz Sci. Technol., (2016)

The Stratospheric Terahertz Observatory (STO2)

1.4 THz, 1.9 THz, 4.7 THz

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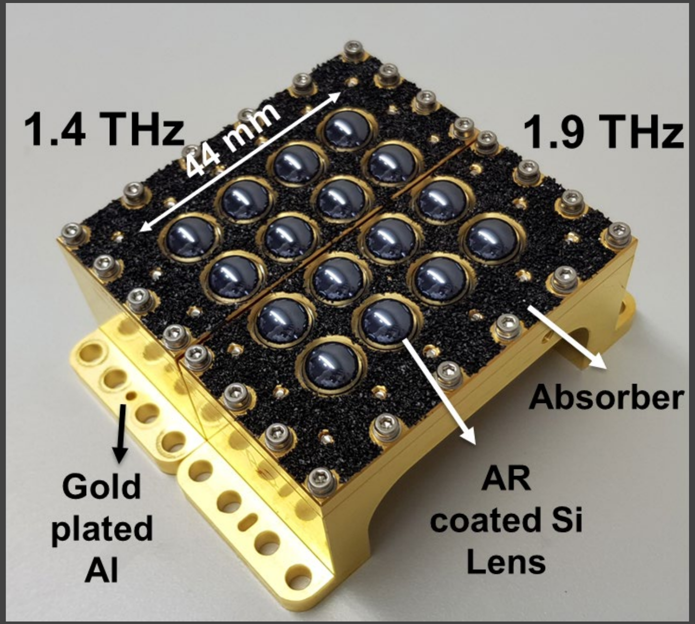
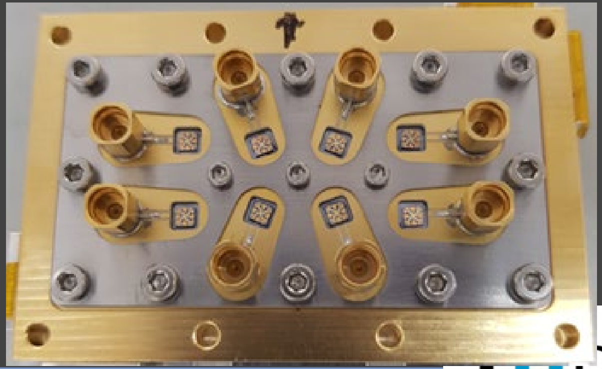
GUSTO with NbN HEB arrays

C. Walker et al, Proc. SPIE 12190 (2022);

- NASA Explore mission with 3 HEB arrays on board
- Flown above Antarctica for 57 days
- Mapping [NII] , [CII] lines for 62 square degrees + LMC (see poster by Russ Shipman)



J. R. G. Silva et al ,
J. Astron. Telesc. Instrum. Syst. (2025)



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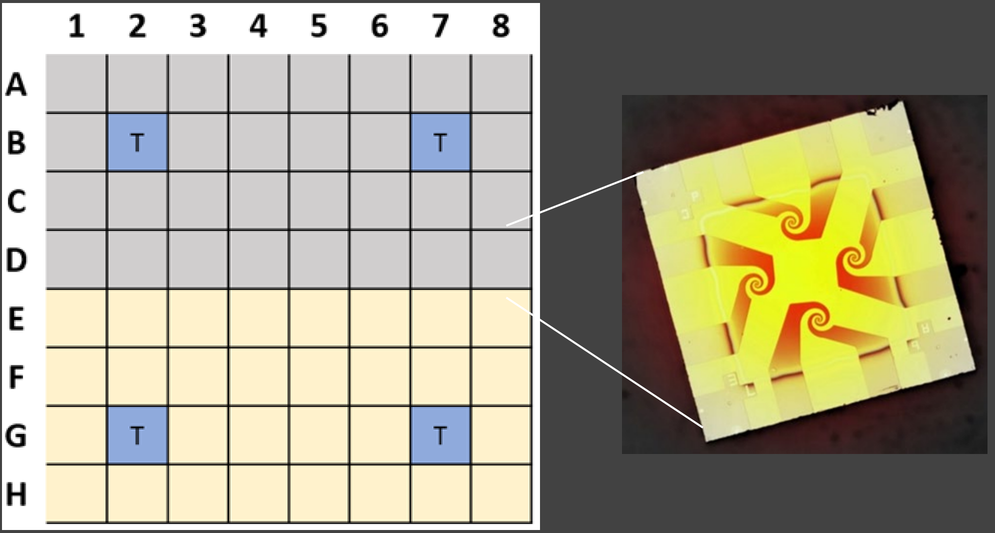
More sensitive NbN HEB mixers available

LO frequency	T_{mixer}^{DSB}	L_{mixer}^{DSB}	T_{mixer}^{DSB} (Quantum noise units)
1.63 THz	240 ± 6 K	4.4 ± 0.09 dB	3.1 × hν/k_B
2.52 THz	290 ± 13K	5.5 ± 0.2 dB	2.4 × hν/k_B
5.25 THz	620 ± 54 K	7.4 ± 0.4 dB	2.5 × hν/k_B

T_{mixer}^{DSB} is in units of hν/k_B (QN). Note that all values are obtained at an IF of 1.7 GHz and an operating temperature of 4.6 K.



- Realized even more sensitive NbN HEBs for OASIS and SALTUS
- More than 30 % improvement in T_{mixer}^{DSB} than GUSTO HEBs (1.6 and 2.5 THz)
- 60 chips ready for future missions, e.g. LETO for M8

B. Mirzaei, J. R. G. Silva, W. -J. Vreeling, W. M. Laauwen, D. Ren and J. -R. Gao,
IEEE Trans. Terahertz Sci. Technol., (2025)

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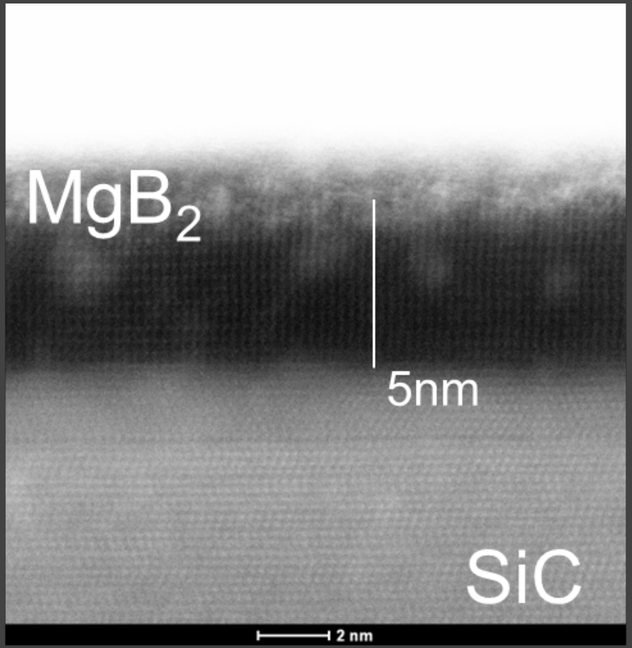
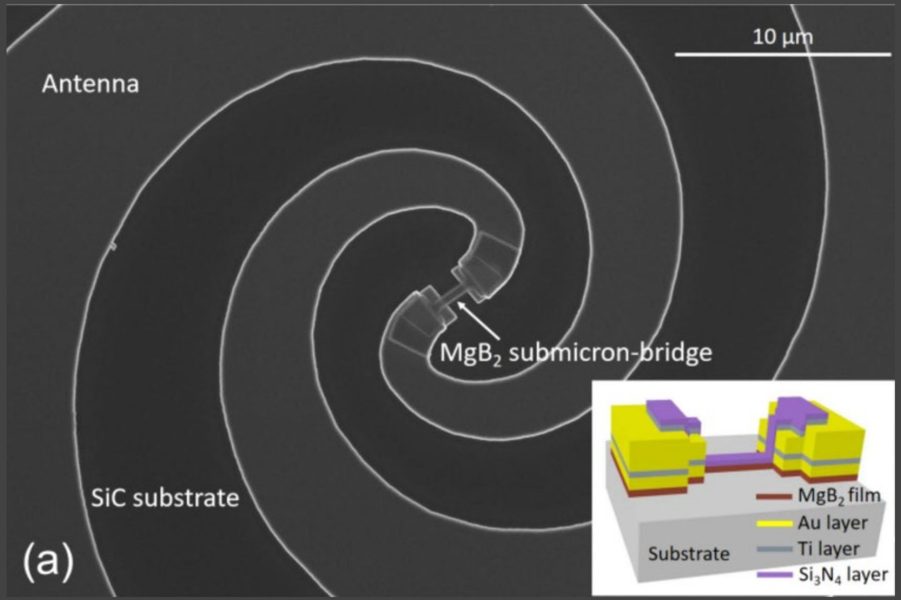
Alternative technology: MgB_2 HEBs

TEM



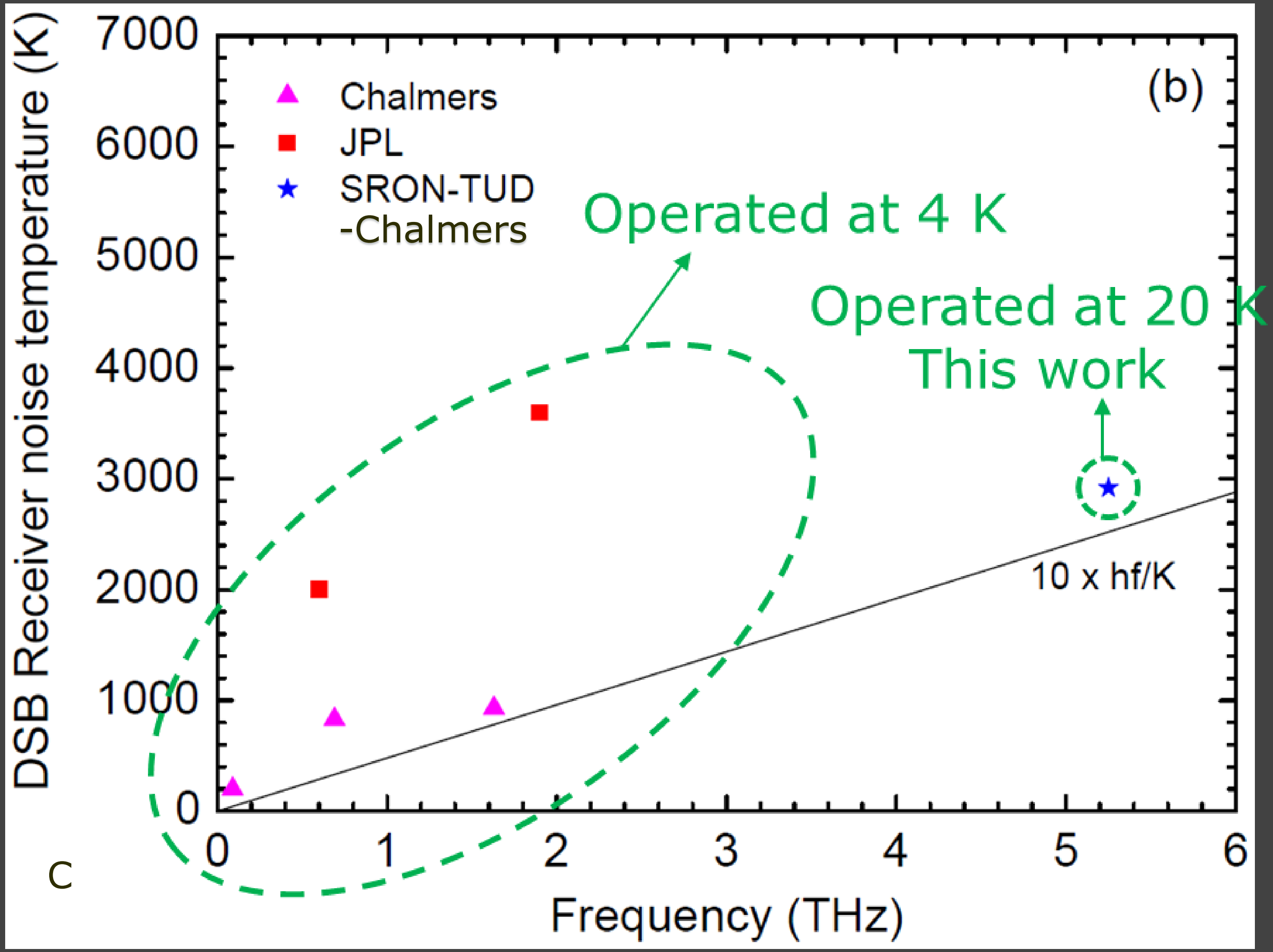


Magnesium diboride (MgB_2) films grown
by Hybrid Physical CVD at Chalmers

- MgB_2 films (6-8 nm) with a T_c of 34–40 K →High operating temperature of ≥20 K

S. Cherednichenko et al, Supercond et al, Sci. Technol. 34 044001 (2021).

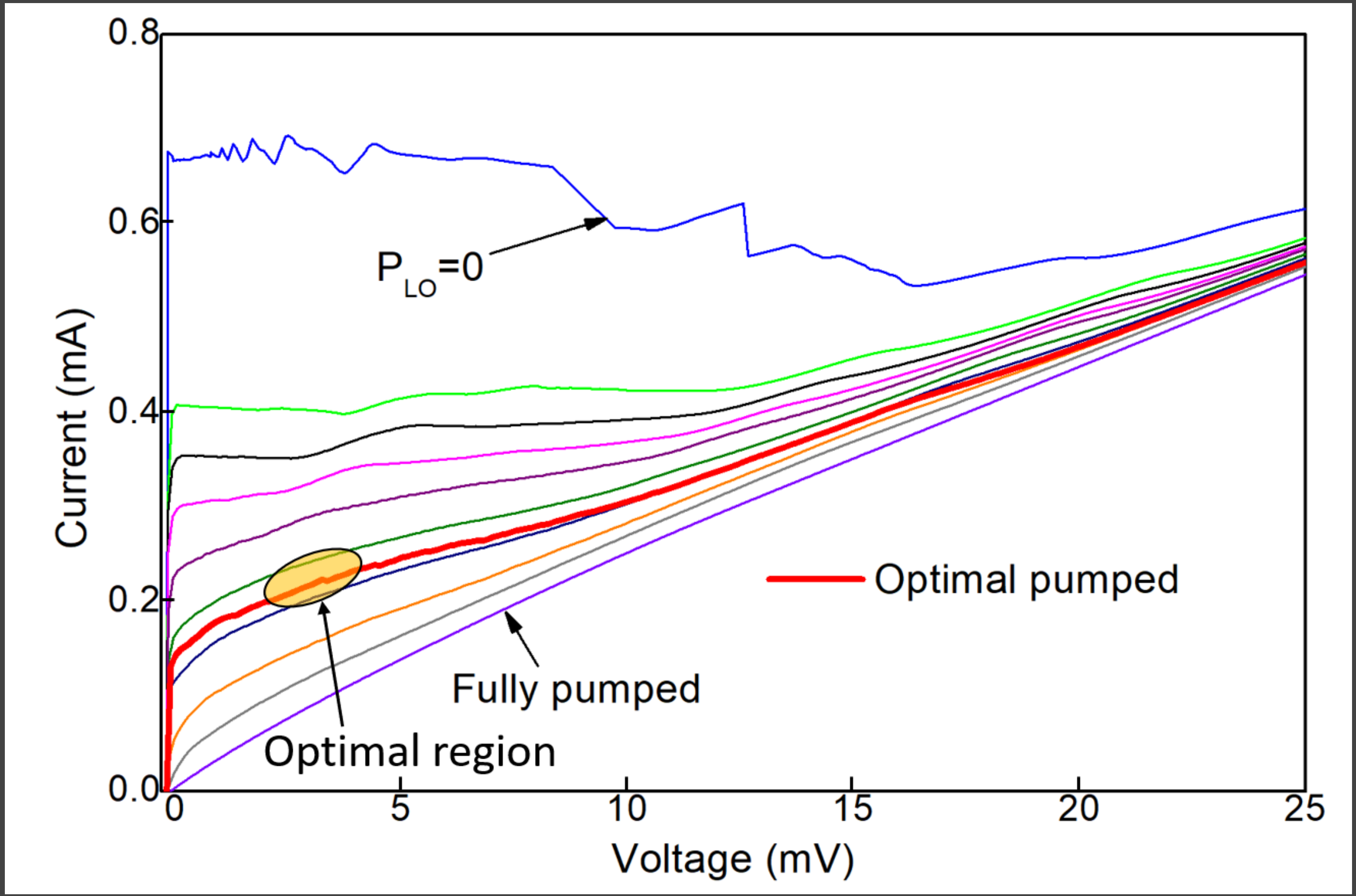
MgB_2 HEB mixers: results so far

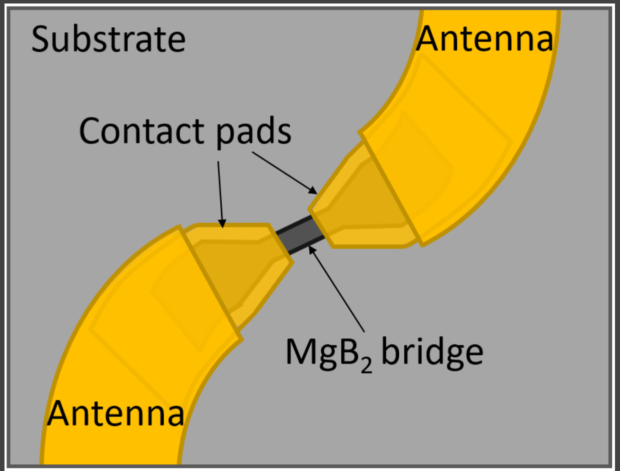


IF bandwidth of ≥10 GHz

- Novoselov, E. and Cherednichenko, S., Appl. Phys. Lett. (2017). Also reports at 15K and 20K.
- Cunnane, D., Kawamura, J. H., Wolak, M. A., Acharya, N., Tan, T., Xi, X. X. Karasik, B. S., Appl. Supercond.(2017).
- Gan, Y., Mirzaei, B., Silva, J. R. G. D., Chang, J., Cherednichenko, S., van der Tak, F., and Gao, J. R. Appl. Phys. Lett. (2021).
- Y. Gan, B. Mirzaei, J. R. G. D. Silva, S. Cherednichenko, F. van der Tak, and J. R. Gao, J. of Appl. Phys. (2023)

IV curves at 5.3 THz

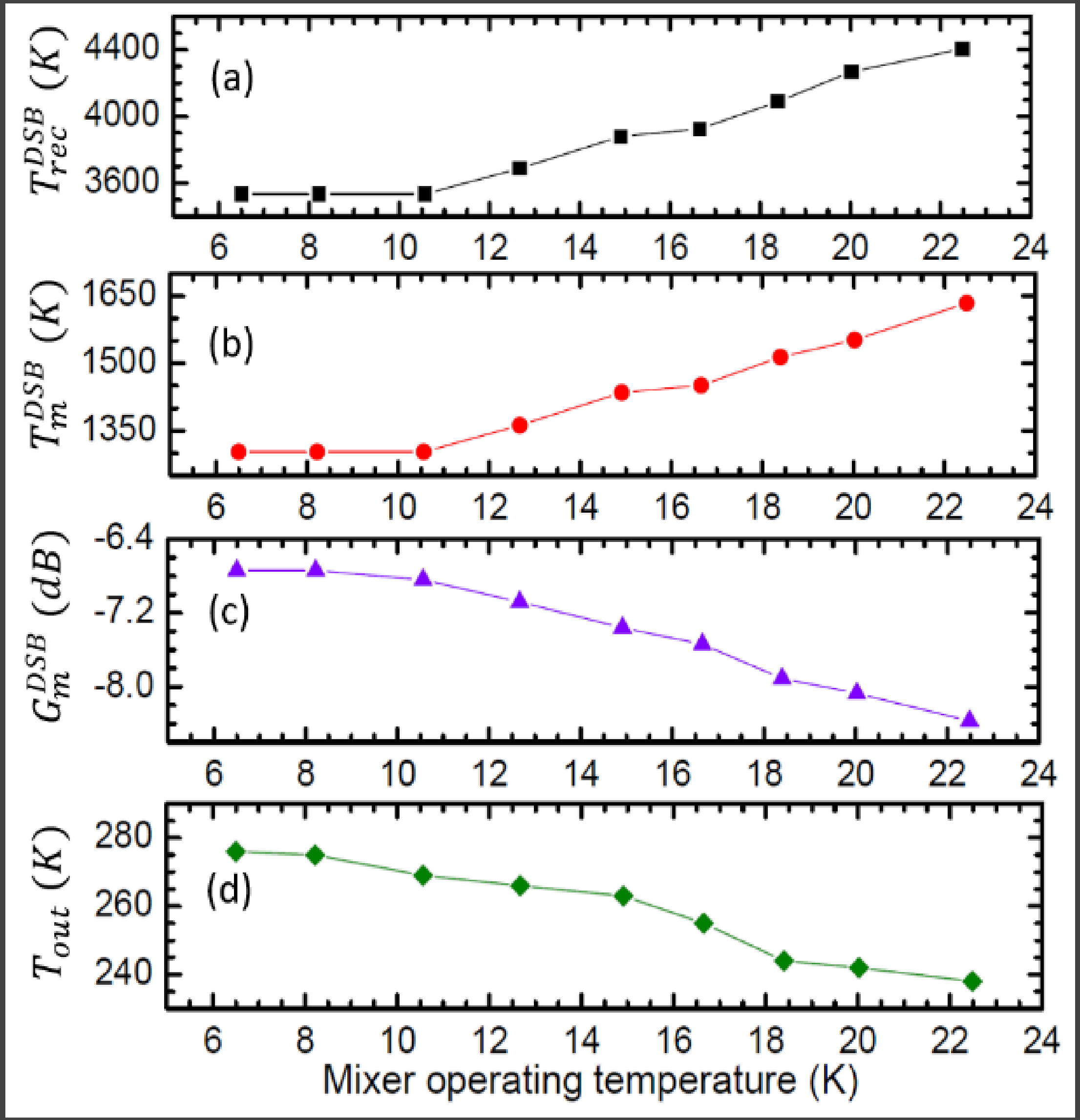




- T_c=38.4 K, W=280 nm, L=850 nm, R_N=51 Ω,
- Optimal pumped IV gives LO power of 10 μW

Gan et al, Appl. Phys. Lett. (2021).

Measured temperature dependence at 5.3 THz



$$T_{rec}^{DSB} = T_{opt} + \frac{T_{mixer}^{DSB}}{G_{opt}} + \frac{T_{IF}}{G_{opt} G_{mixer}^{DSB}}$$

- T_{mixer}^{DSB} increased by 17 % from 6 to 20 K
- T_{mixer}^{DSB} (1540 k) at 5.3 THz is 2.5 times the best NbN HEB mixer
- T_{mixer}^{DSB} (950 k) at 1.63 THz is 4 times the best NbN HEB mixer
- can be improved by cleaning the interface between MgB_2 and Au

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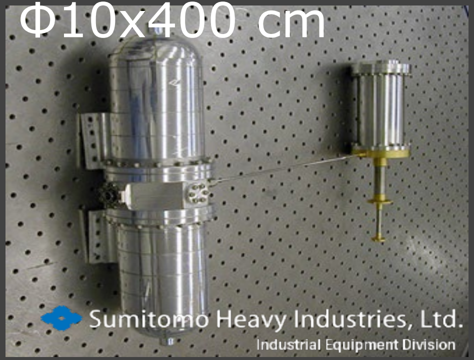
Y. Gan et al, Appl. Phys. Lett. (2021).

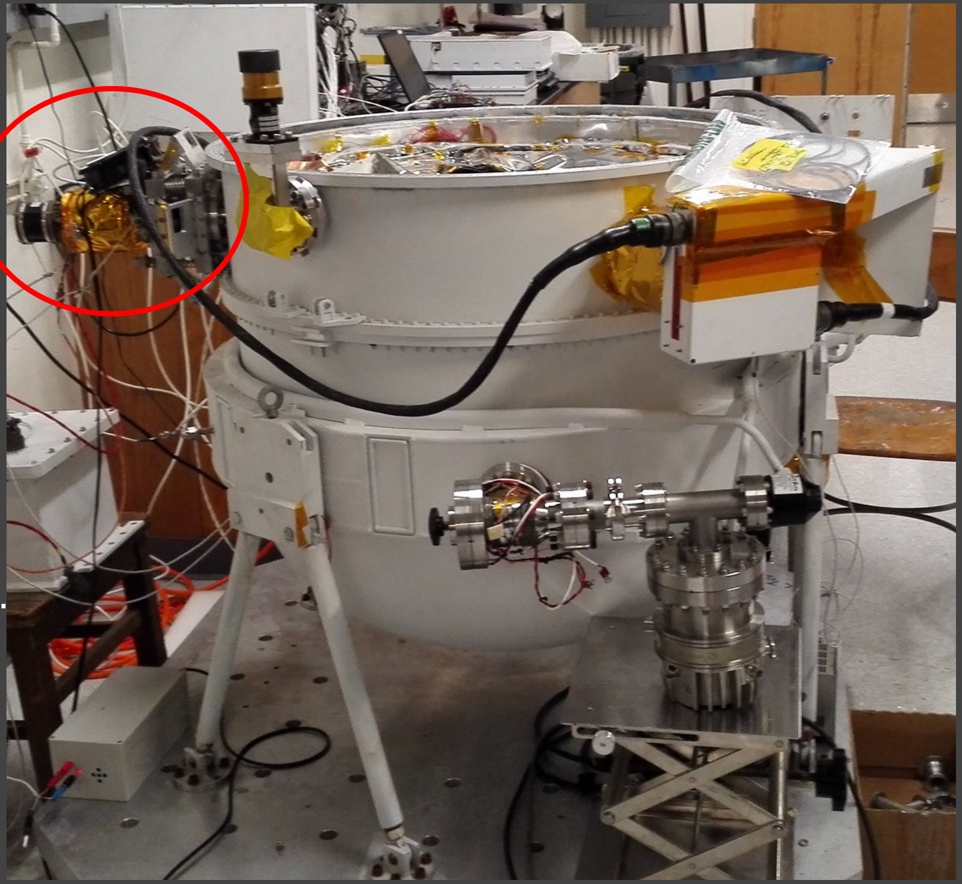
MgB_2 HEBs can be operated at a 20 K cooler

- Apply a 20 K Stirling cooler (XRISM)



Y. Sato et al, J. of Space Technology and Science, (2013).

STO2 4K L-He cryostat

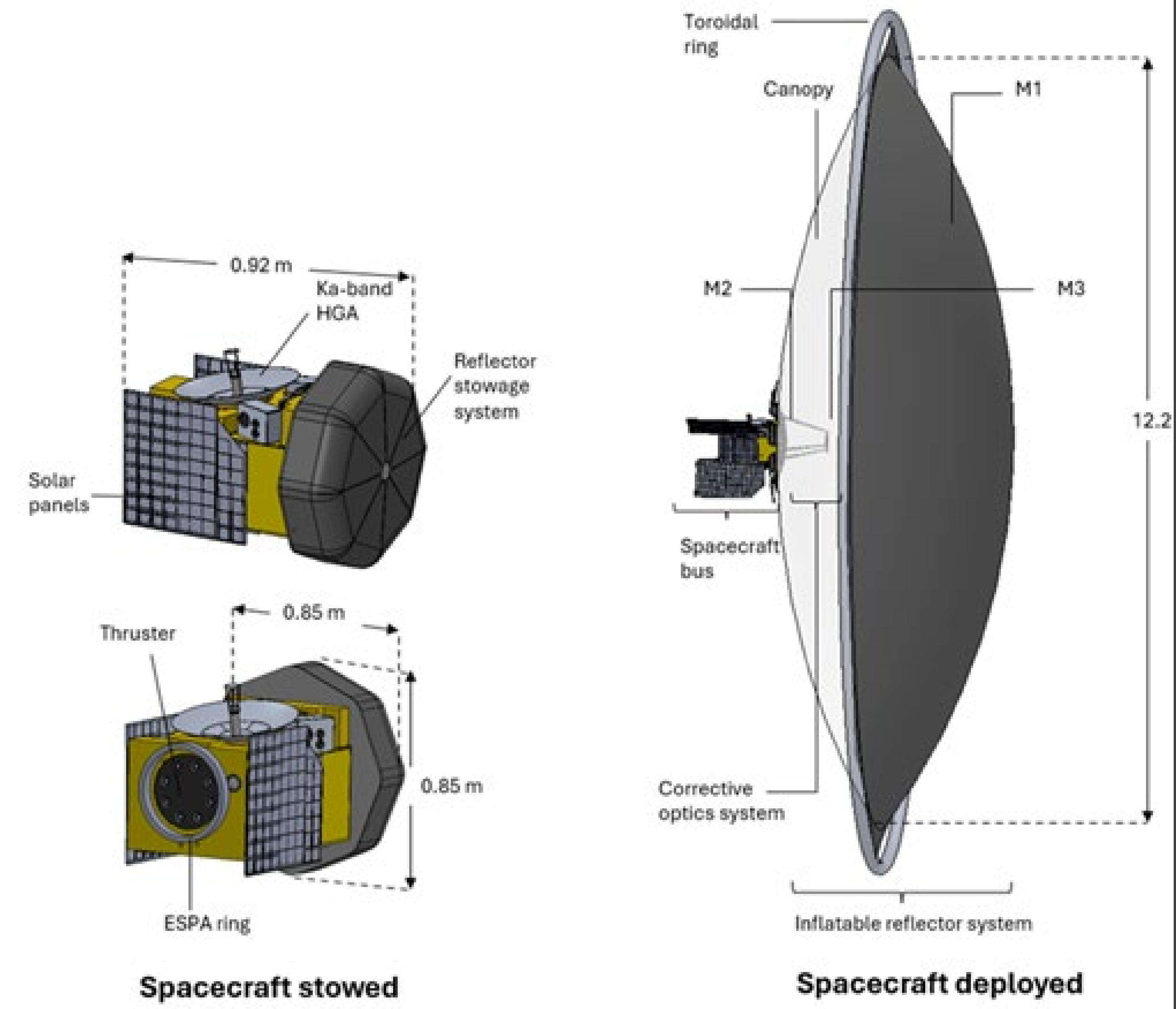


- MgB_2 HEBs enable S & M FIR missions

- MgB_2 HEBs facilitate Space FIR Interferometers

MgB_2 HEBs for TOP, proposed to NASA "Pioneers"

- Terahertz Orbiting Pioneer (TOP)

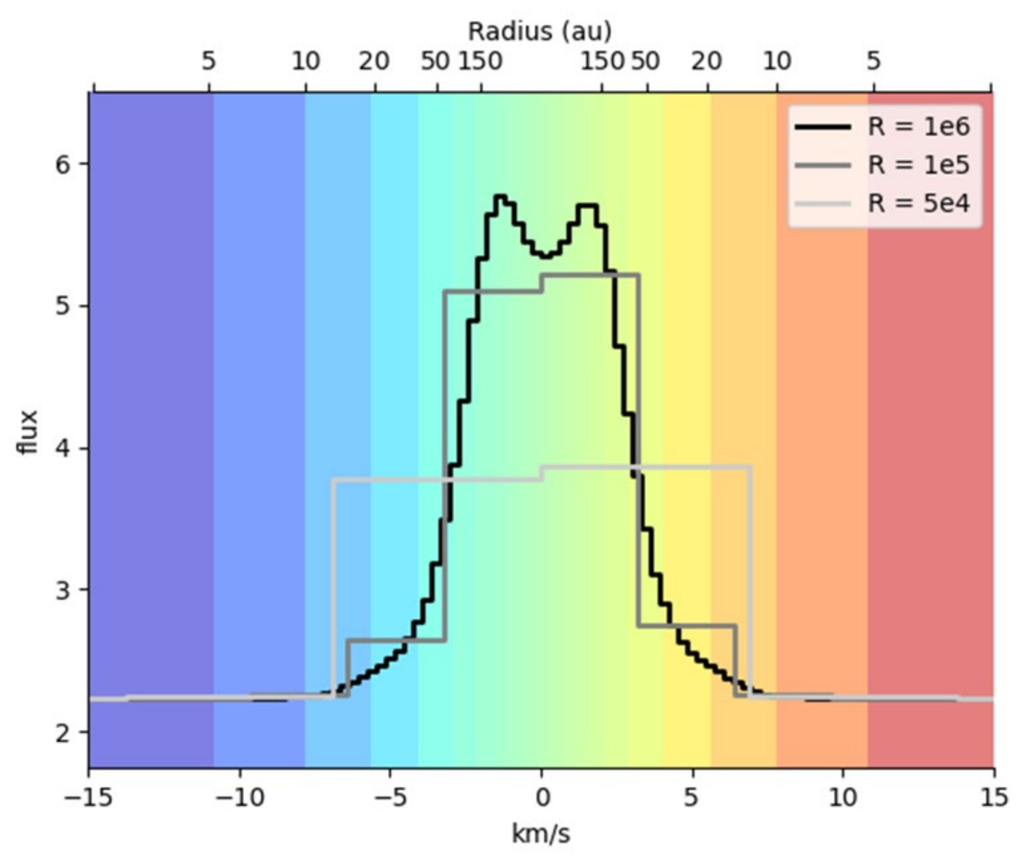


- Inflatable telescope, effective diameter of 8 meter
- Introduce a 20 K cooler
- With 4 MgB_2 HEB mixers
- HD (1-0)@2.7 THz and (2-1)@5.3 THz
- PI: Chris Walker at UA
- SRON/Chalmers : deliver MgB_2 HEBs

Credit: Chris Walker

TOP has unique science capability

- TOP: Spectral resolution $R=10^6$



Credit: Chris Walker and Peter Roelfsema

- the mass distribution and dynamics within protoplanetary disks
- Simulated disk-integrated flux emission spectra of GM Aurigae for the HD 1-0 line
- High spectral & spatial resolution

Key takeaways

- MgB_2 HEBs, with limited efforts, have shown promising results between 0.5 to 5.3 THz
- MgB_2 HEBs, requiring a 20 K cooler, enable small & medium FIR missions
- If TOP can fly, TRL of MgB_2 HEBs will increase