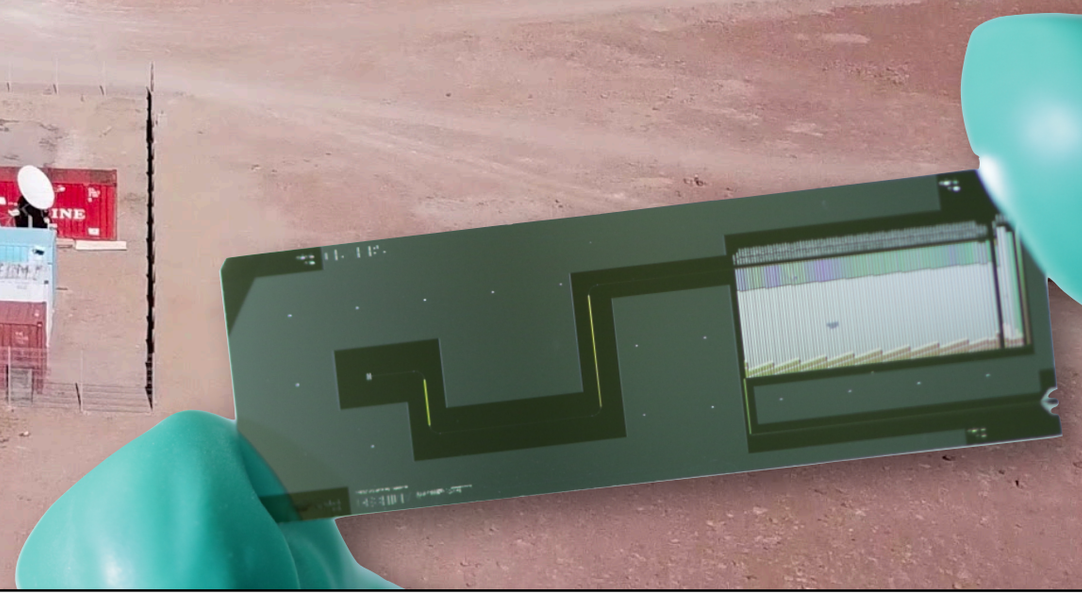
DESHIMA on ASTE

First astronomical light captured with an Integrated Superconducting Spectrometer

Akira Endo (TU Delft)
Kenichi Karatsu, Robert Huiting, Alejandro Pascual Laguna,
Stephen Yates, Vignesh Murugesan, Jochem Baselmans (SRON)
Soh Ikarashi, David Thoen, Sjoerd Bosma, Nuria Llombart, Teun Klapwijk (TU Delft)
Kaui Chin, Akio Taniguchi, Tatsuya Takekoshi, Kotaro Kohno (Univ. Tokyo)
Takashi Tsukagoshi, Shun Ishii, Jun Maekawa, Ryohei Kawabe, Tai Oshima, Toshihiko Kobiki, Shin'ichiro Asayama (NAOJ)
Koyo Suzuki, Tetsutaro Ueda, Yoichi Tamura (Nagoya Univ.)
Masato Naruse (Saitama Univ)
Kazuyuki Fujita, Akira Kouchi (Hokkaido Univ)
Shunichi Nakatsubo (ISAS/JAXA)
Paul van der Werf (Leiden Univ.)



TU Delft Delft University of Technology · SRON Netherlands Institute for Space Research · Universiteit Leiden · 東京大学 The University of Tokyo · 名古屋大学 Nagoya University · NAOJ 国立天文台

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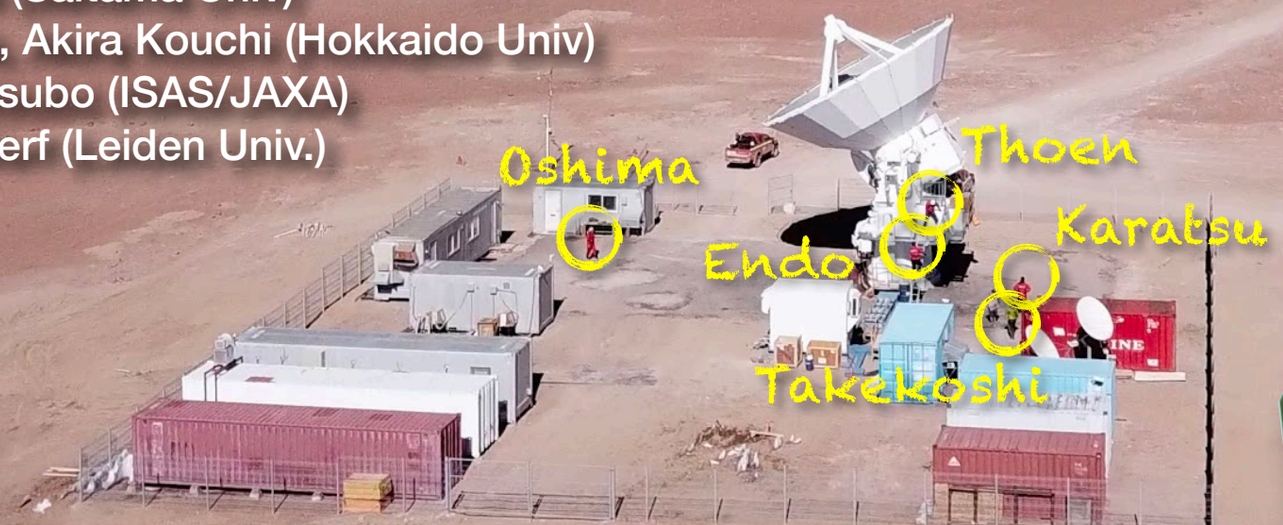

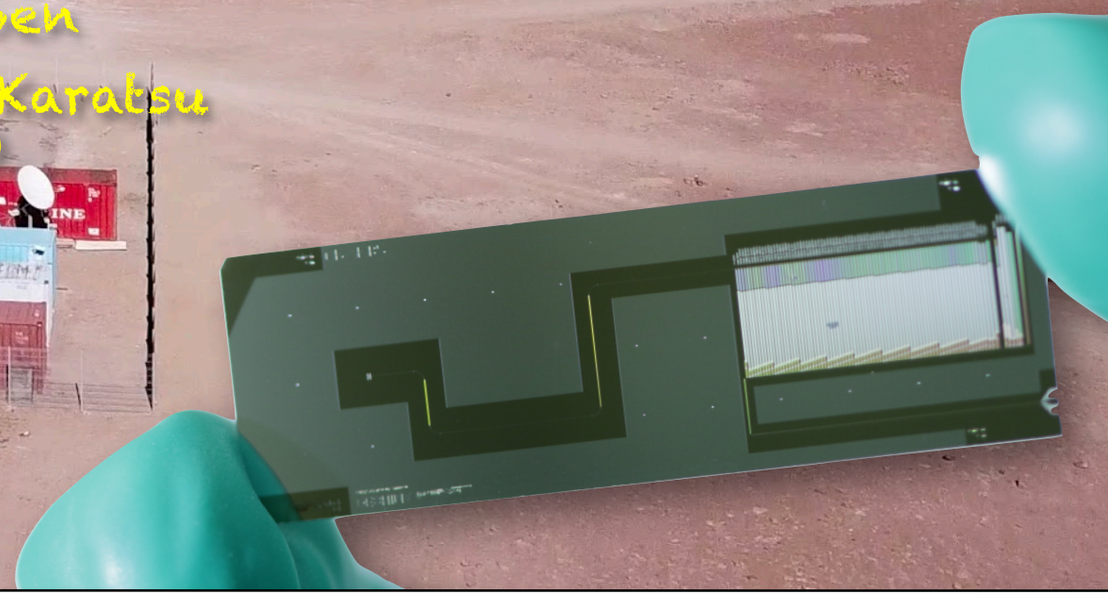

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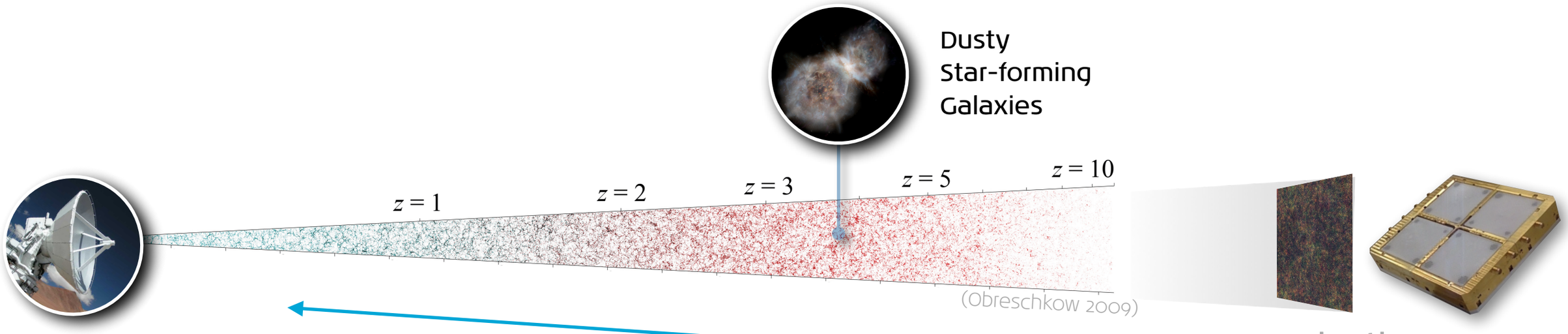
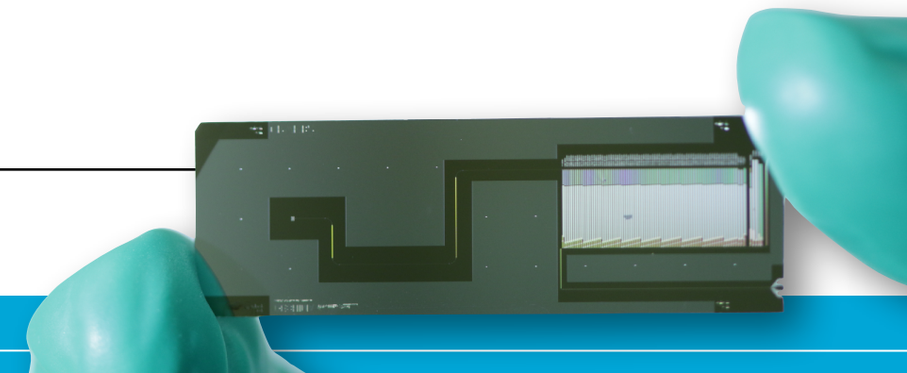
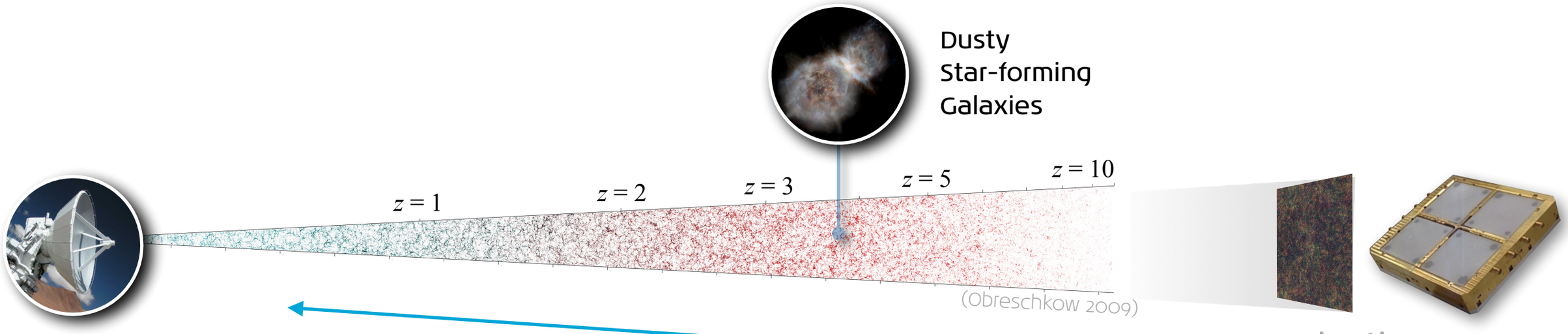
Probing the cosmic history of dust-obscured star/galaxy formation



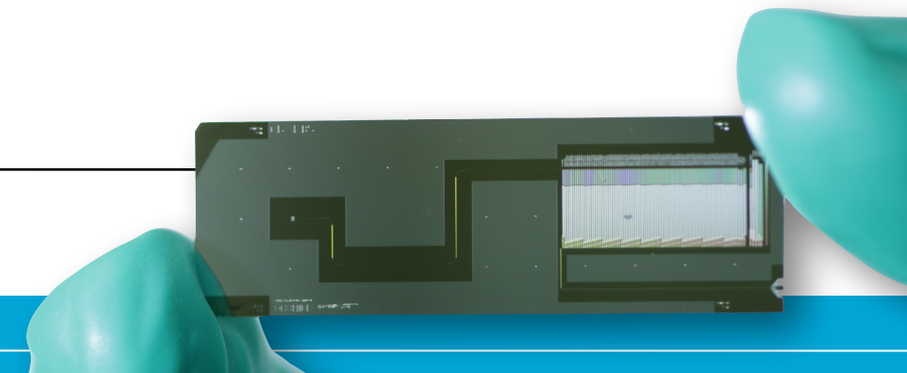


Probing the cosmic history of dust-obscured star/galaxy formation

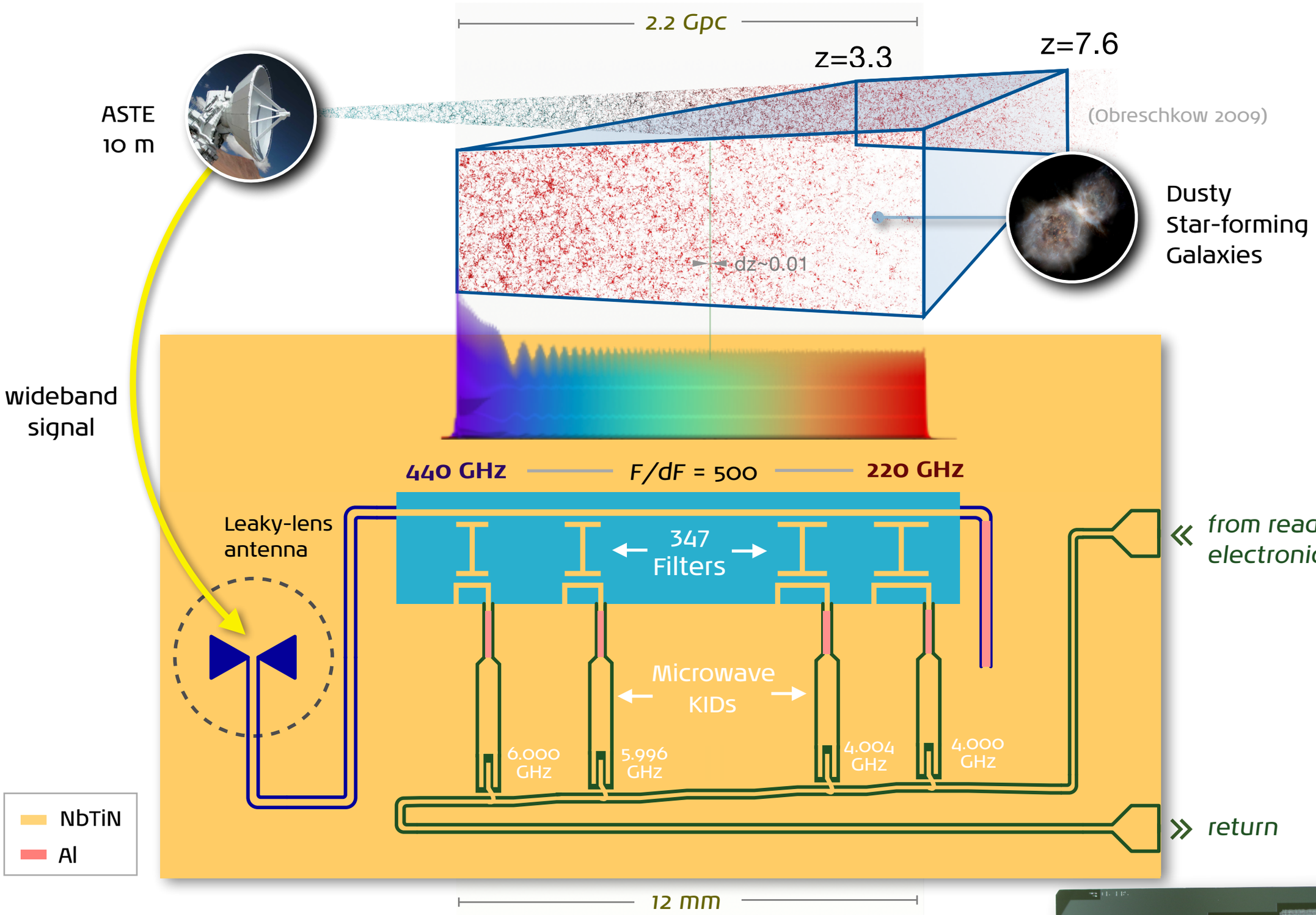


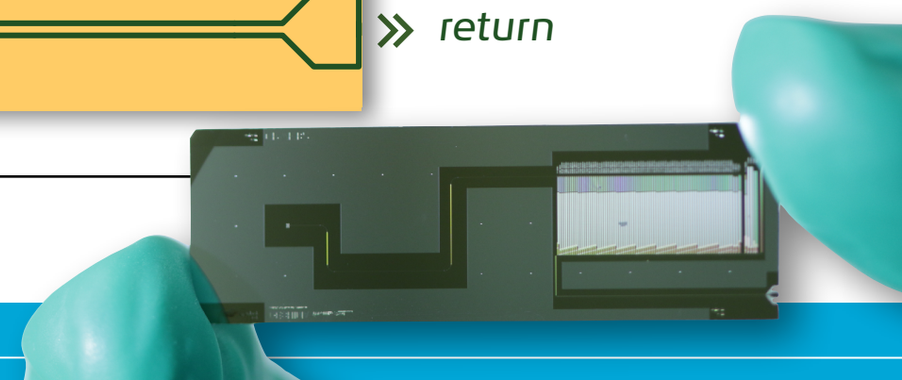
Ultra-wideband mm-submm spectrometer

DESHIMA



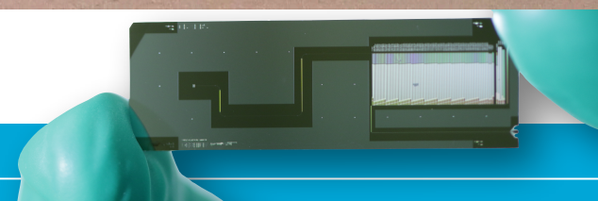
DESHIMA [CII] Redshift Machine on a Chip





This talk:
DESHIMA 1st-light experiment

DESHIMA

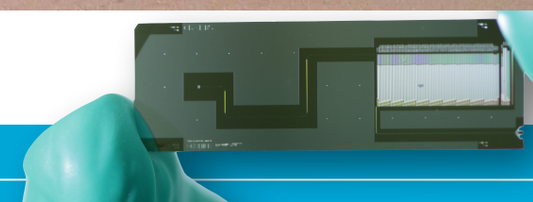


This talk:
DESHIMA 1st-light experiment

Goal: **On-sky verification of the Integrated Superconducting Spectrometer**

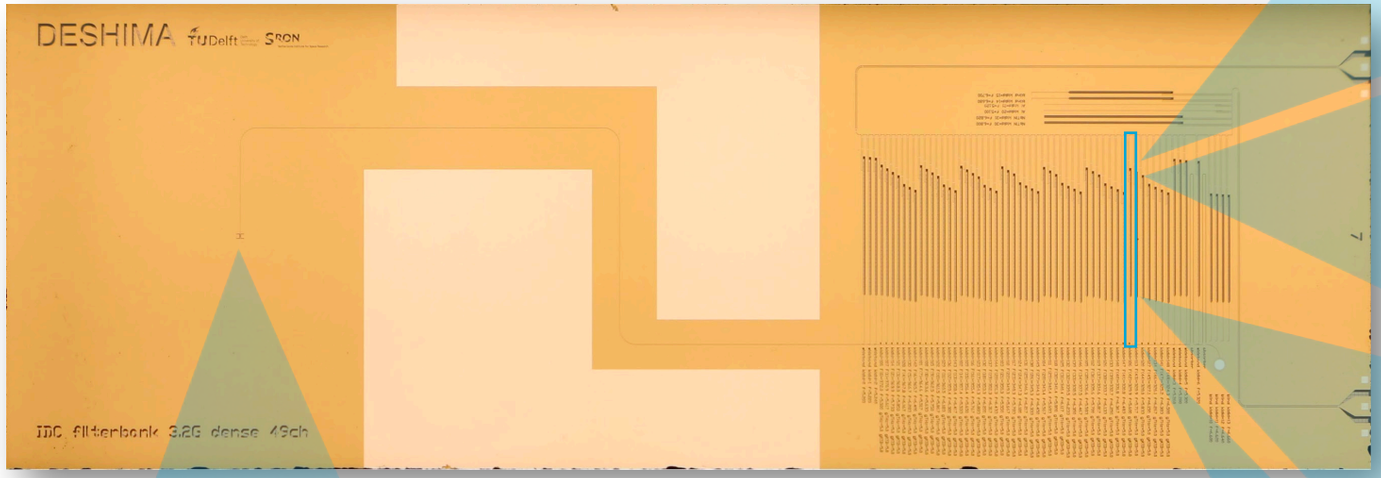
		2017 (this work)	2020 (poster Pascual Laguna)
chip	F	**332-377 GHz**	220-440 GHz
	$N_{channels}$	**49**	347
	filters	**Coplanar**	Microstrip
	antenna	**double-slot**	leaky-lens
readout		**SpaceKIDs**	
cryostat		**Entropy ADR**	

DESHIMA

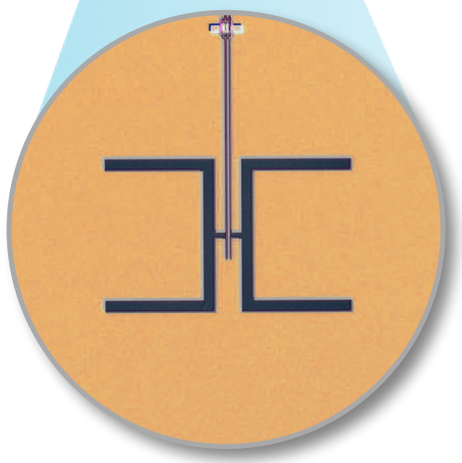


Filterbank-spectrometer
Chip

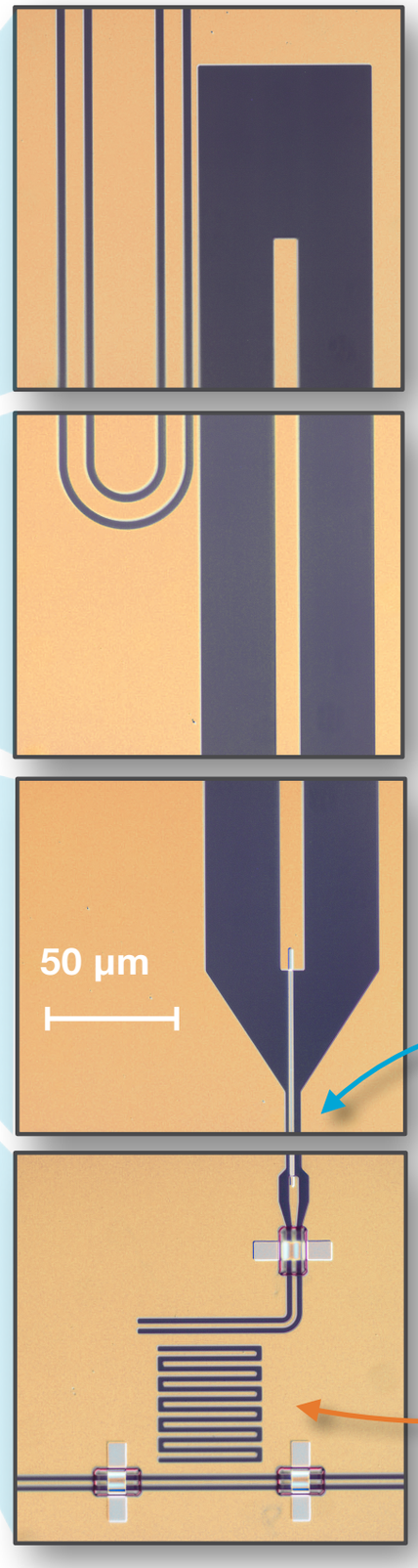
42 mm



Filterbank
49 Channels:
332-377 GHz



double-slot antenna

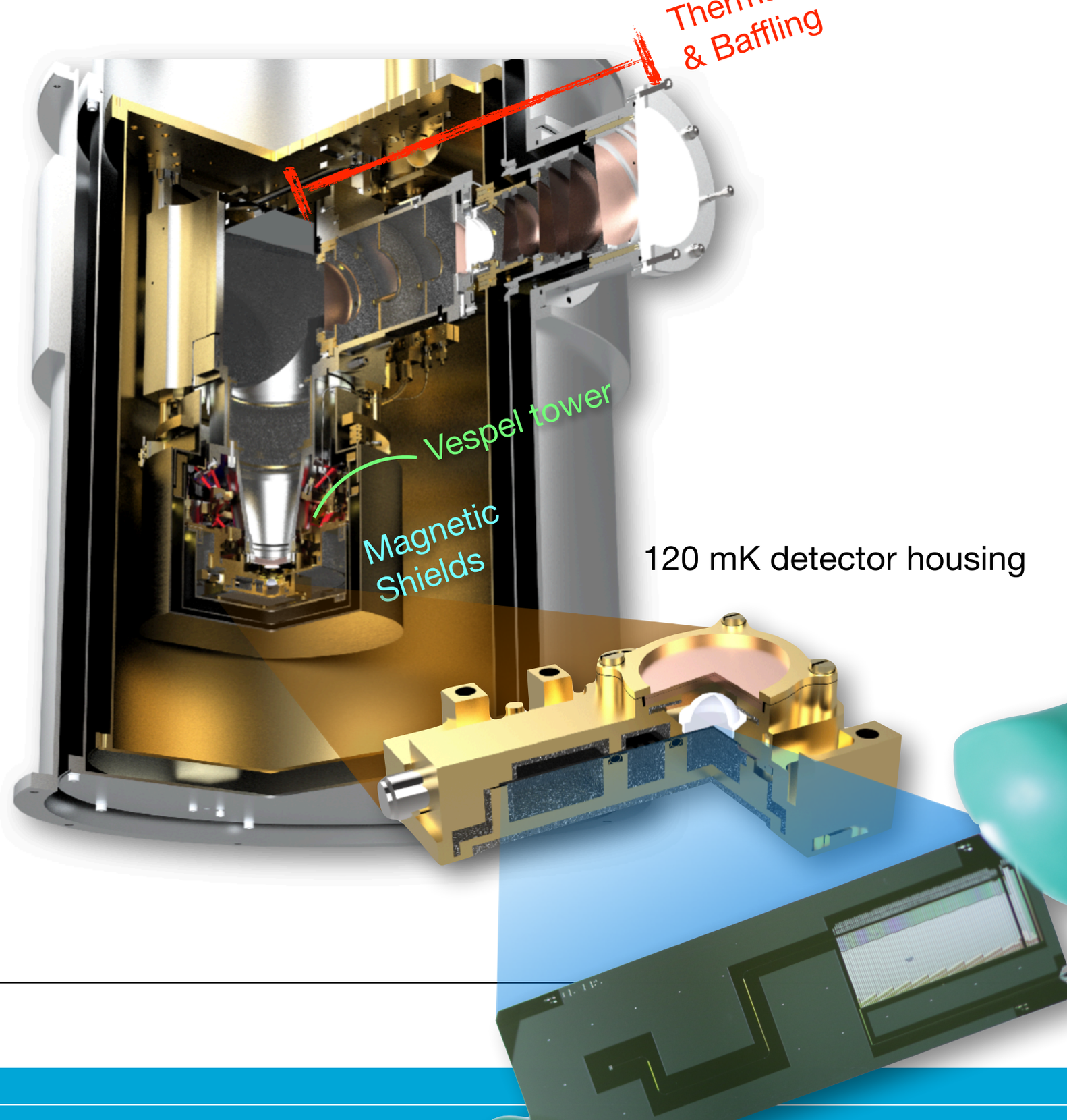


NbTIN/Al Hybrid KID (f_{read}~5GHz)

Al strip

NbTiN Filter (F~350 GHz)

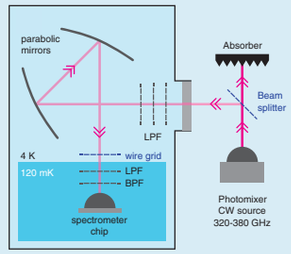
DESHIMA **Cryostat**:

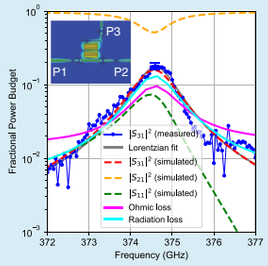


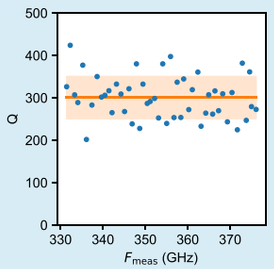
Laboratory characterization

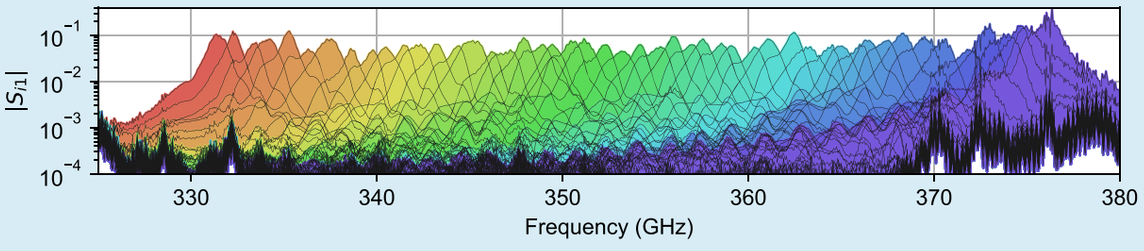
Endo et al., JATIS 5, 035004 (2019) **arXiv 1901.06934**

Frequency response

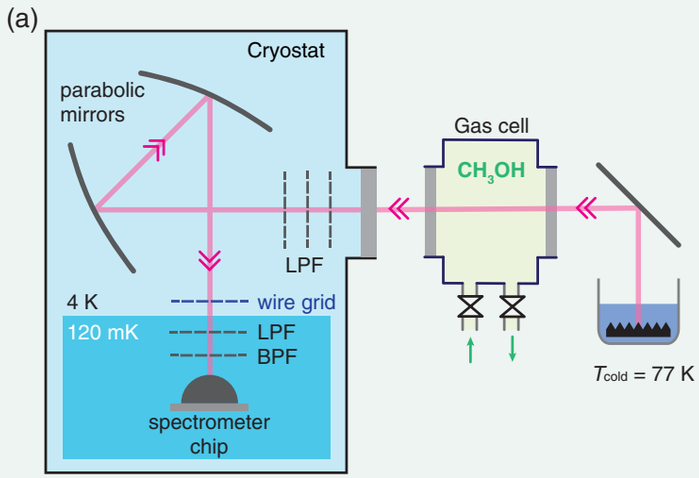


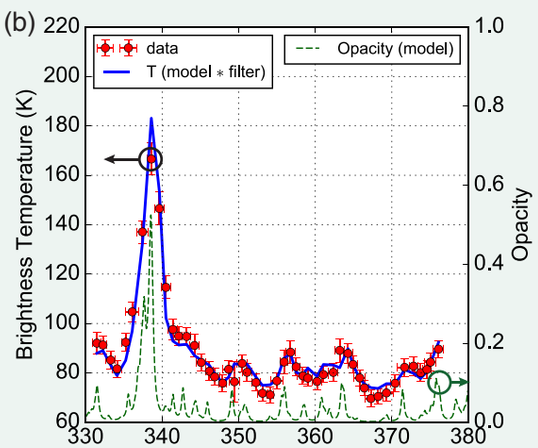






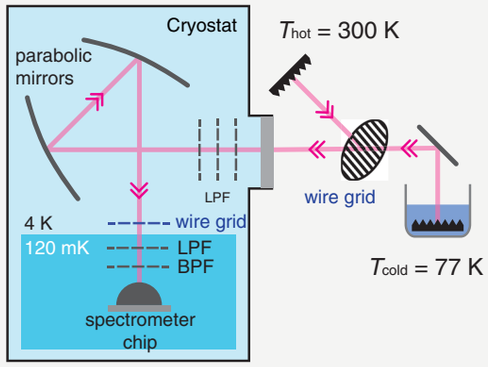
F-calibration using methanol gas emission

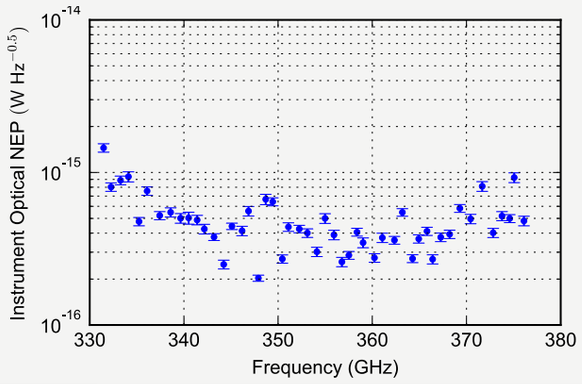




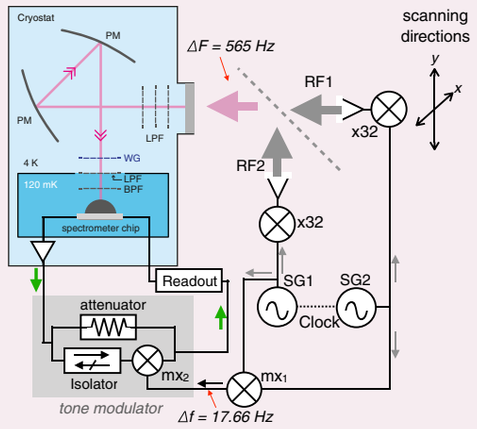
Optical Efficiency & NEP (photon-noise limited)

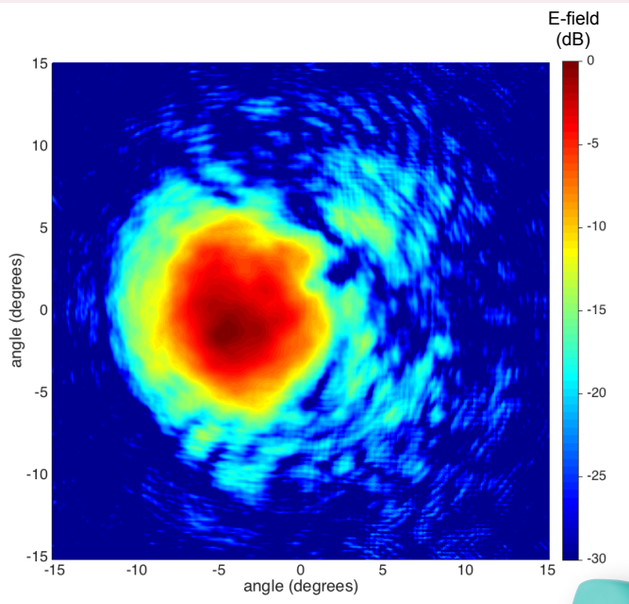
- NEP ~3 × 10^{-16} W $Hz^{-0.5}$
- η_{inst} ~ 0.02



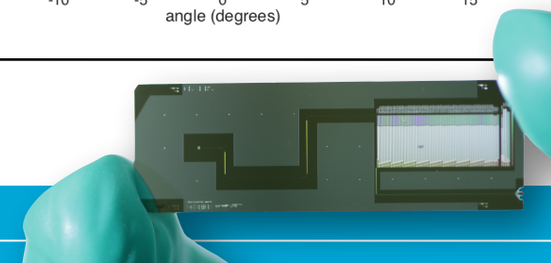


Beam pattern (phase and amplitude)





DESHIMA



DESHIMA /ASTE system

DESHIMA Local Controller

submm galaxy

ASTE telescope

ASTE RX cabin

Cabin Optics

Cryostat

SpaceKIDs
Readout Electronics

RF board
power supplies
clock board
DAC board
ADC board
Ethernet switch

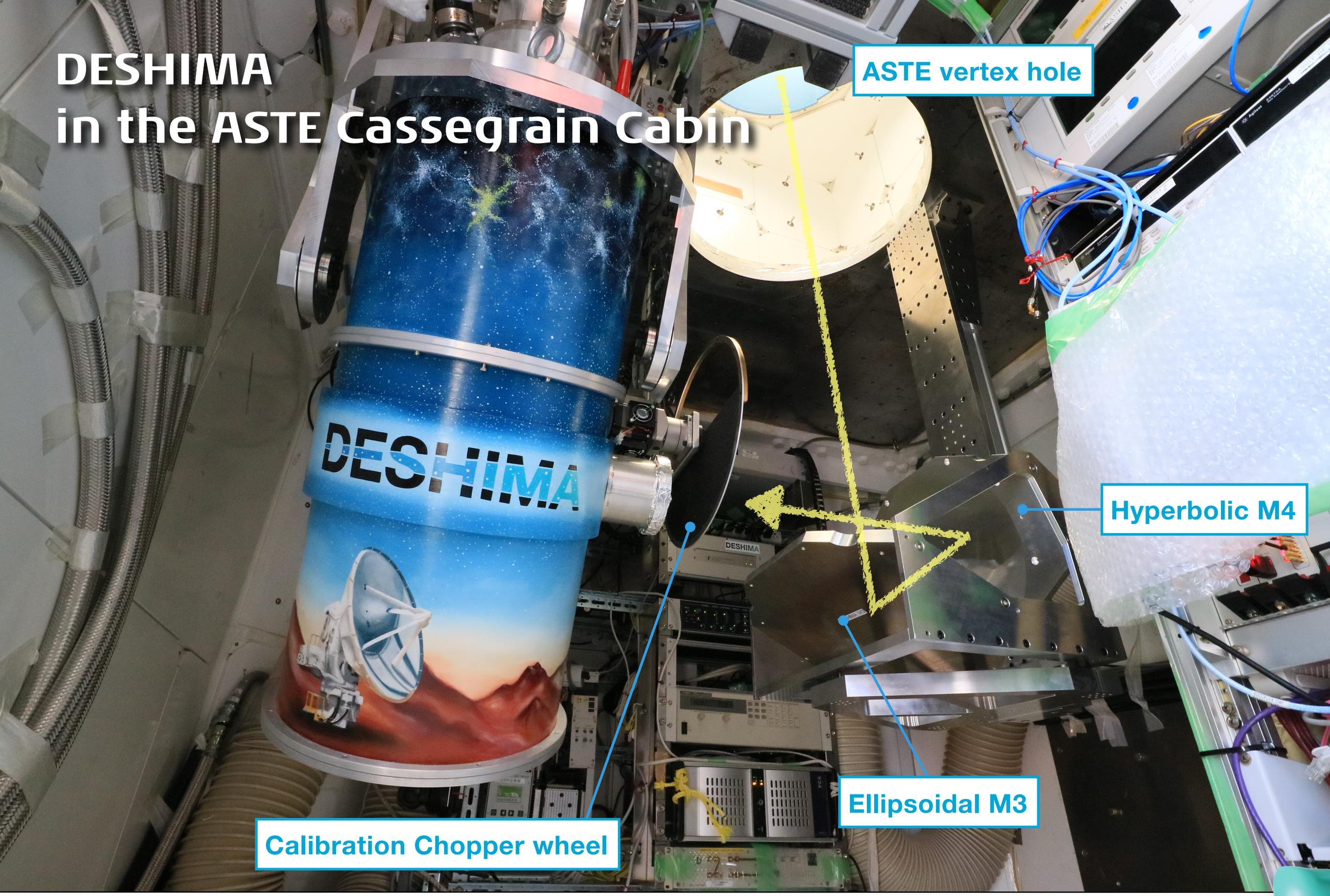
4-6 GHz readout signal

Remote control
from Base Camp
or Japan

Cryostat & Optics

DESHIMA

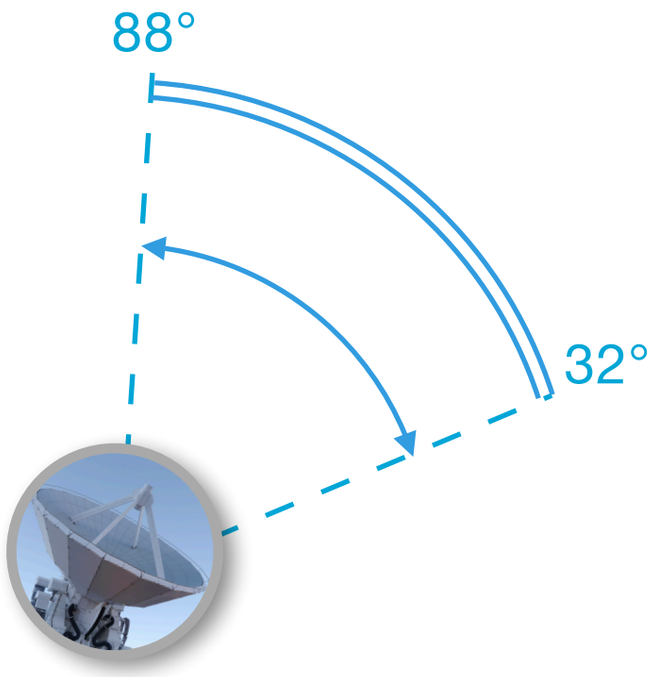
DESHIMA
in the ASTE Cassegrain Cabin



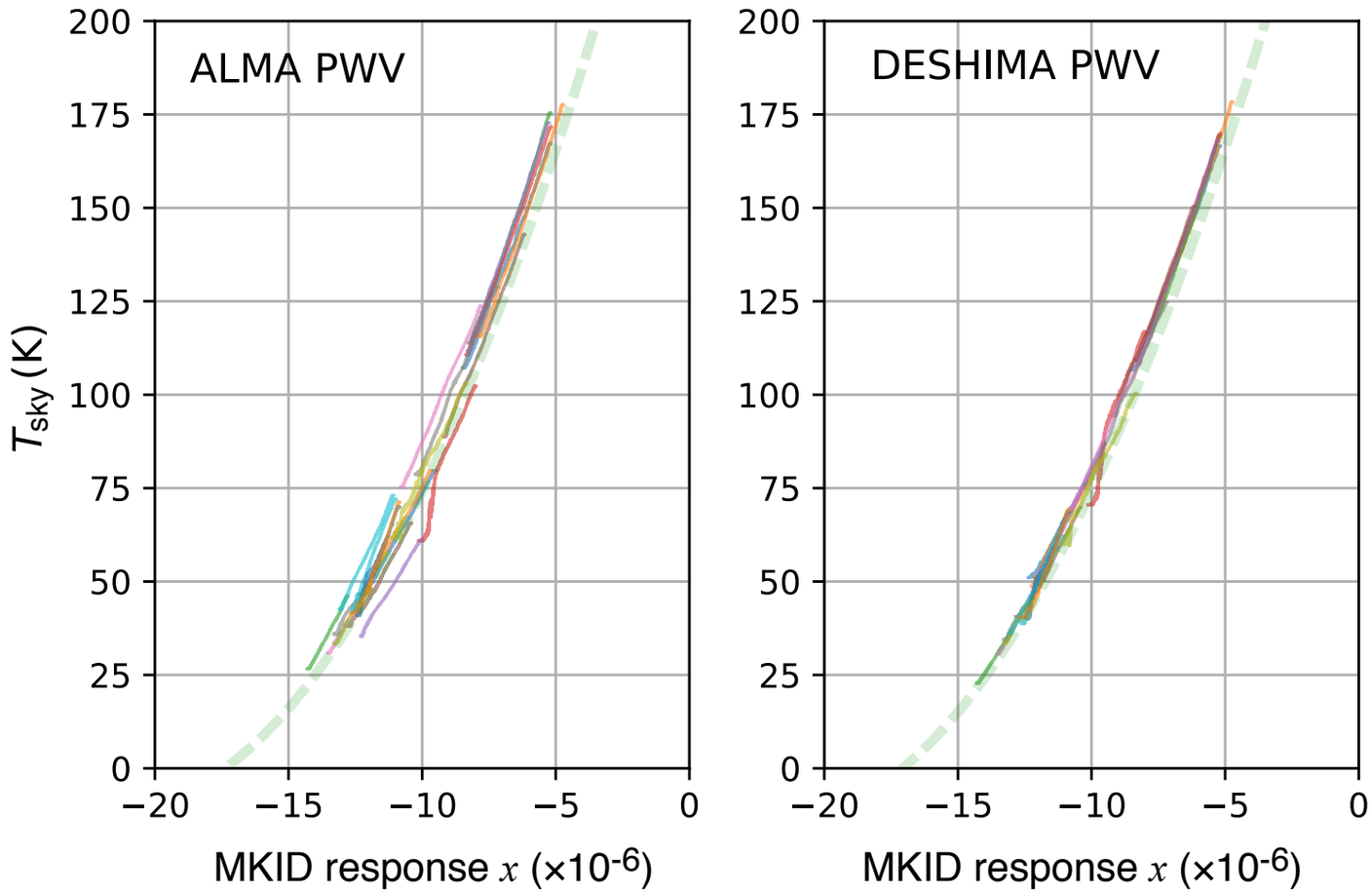
Calibration of sky response

T. Takekoshi et al., Poster #229

$$T_{\rm sky} = \eta_{\rm fwd}(1-\eta_{\rm atm})T_{\rm atm} + (1-\eta_{\rm fwd})T_{\rm amb}$$

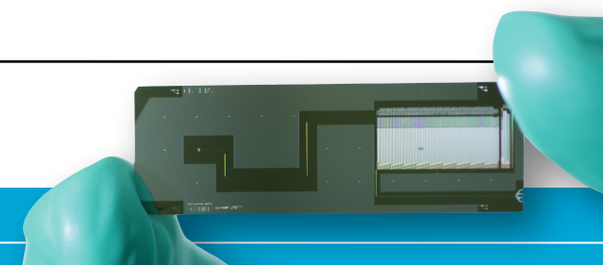


(One channel, 22 scans)



$$x \equiv \{f(T_{\rm sky}) - f(T_{\rm amb})\}/f(T_{\rm amb})$$

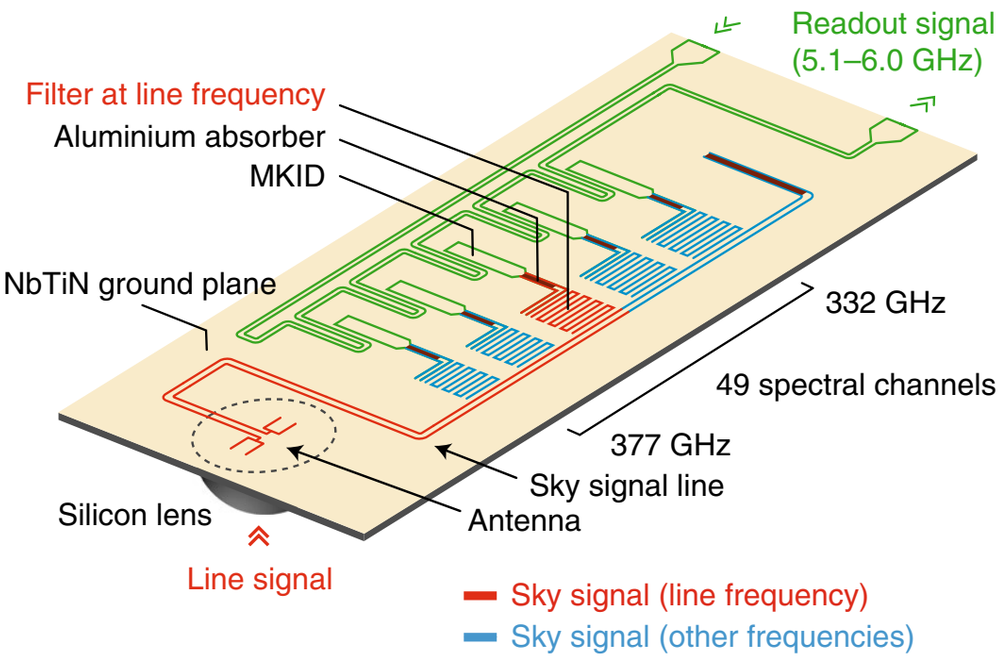
Iterative re-estimation of PWV (precipitable water vapor) using DESHIMA data

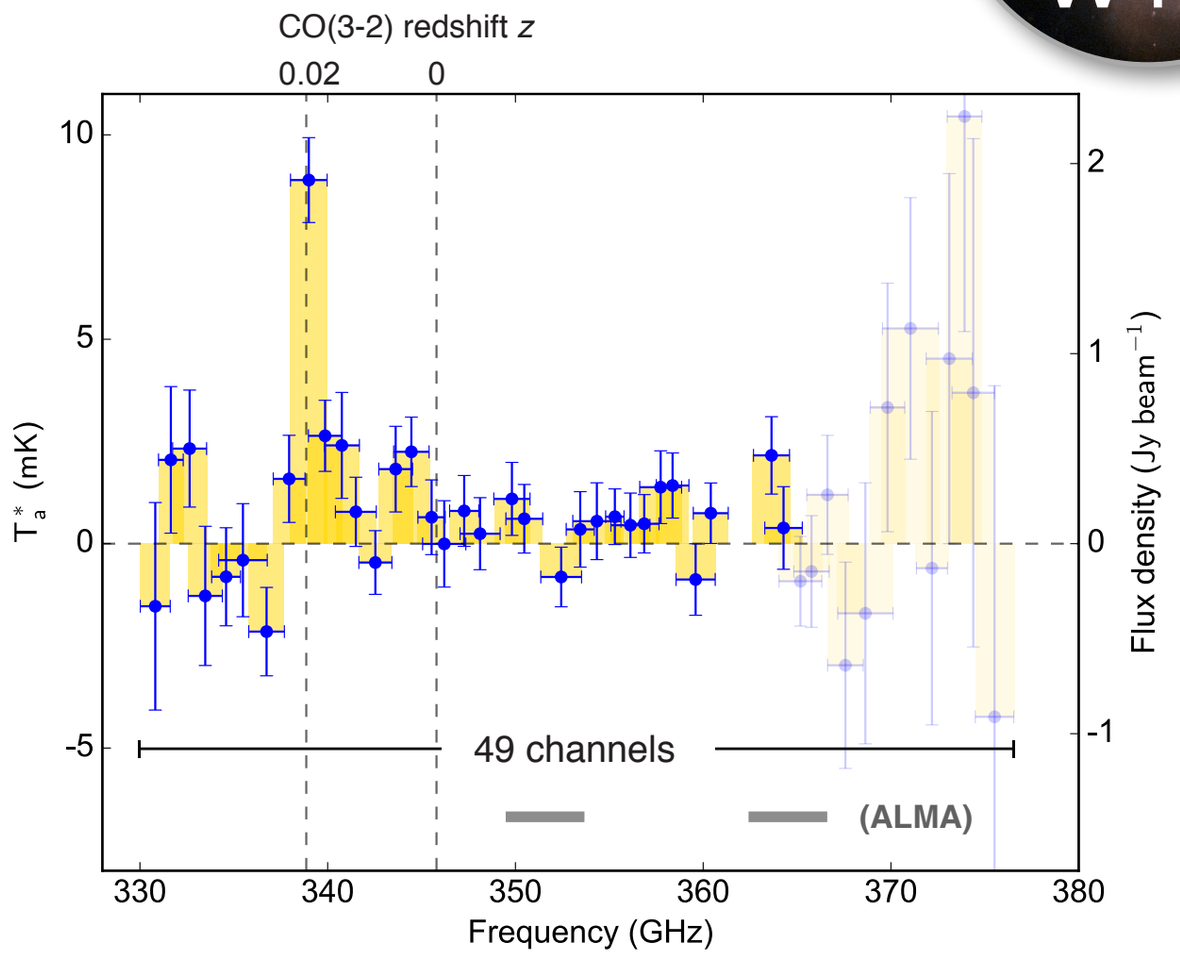


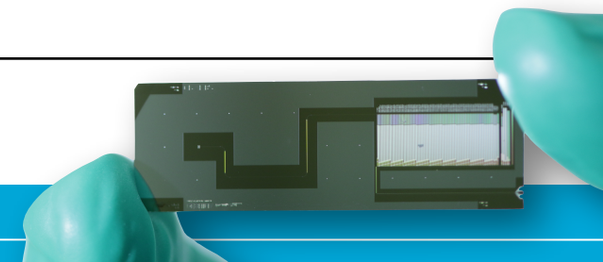
Proof of ISS key applications 1:

Efficient Redshift Machine

- ISS detection of a CO line from a luminous IR galaxy



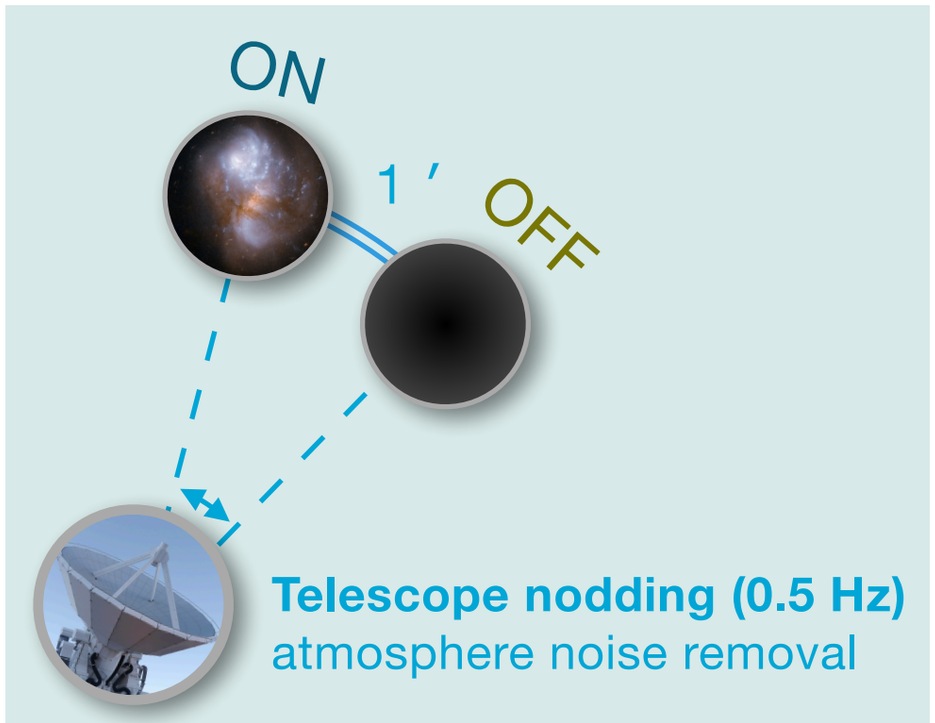




DESHIMA

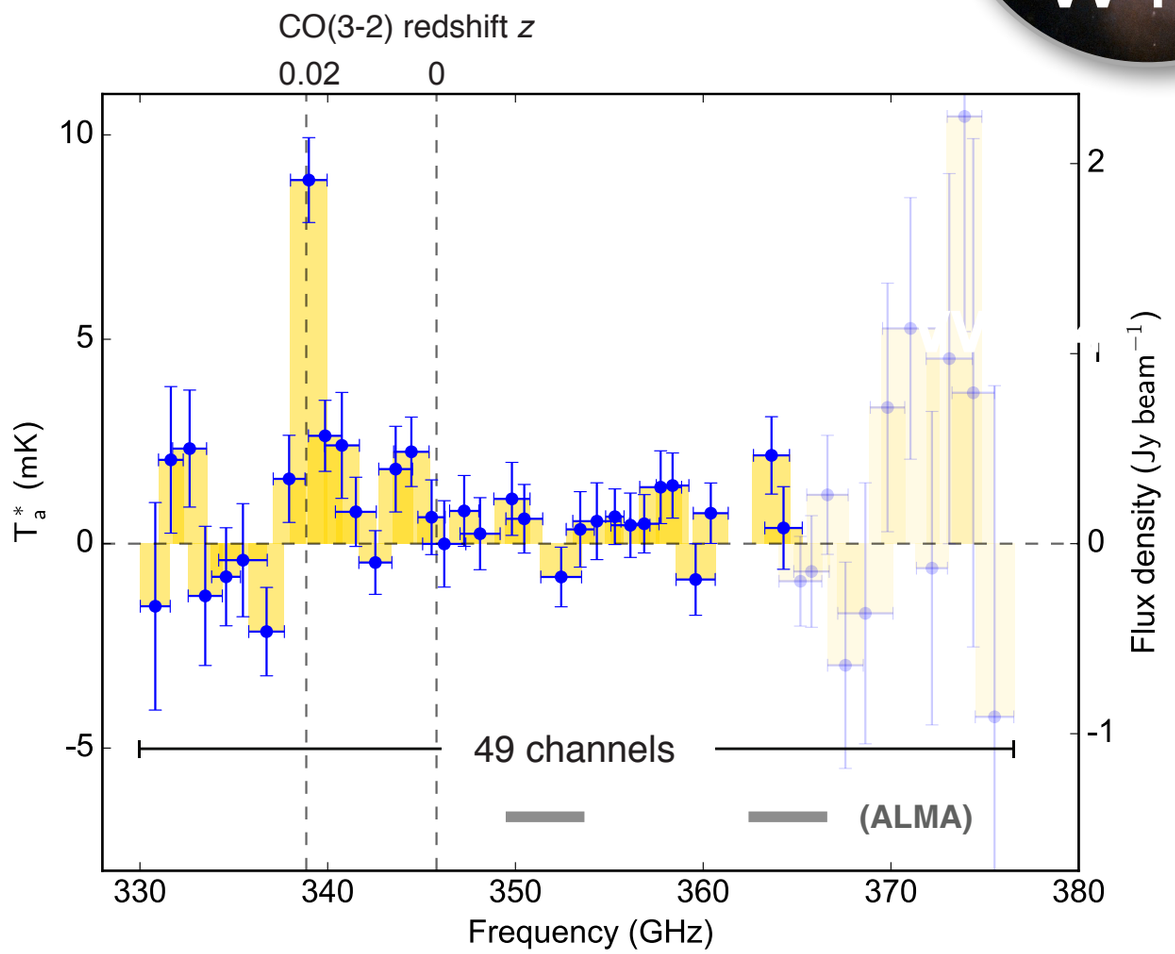
Proof of ISS key applications 1:
Efficient Redshift Machine

✳ ISS detection of a CO line from a luminous IR galaxy

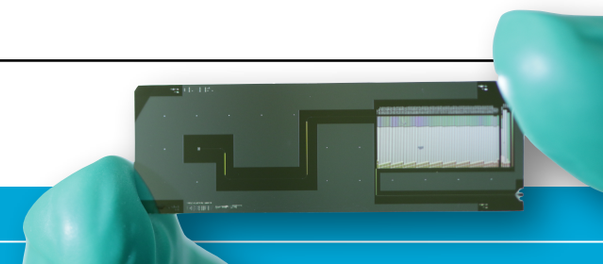


Telescope nodding (0.5 Hz)
atmosphere noise removal

Room-temperature Calibrator (10 Hz)
KID 1/f noise removal




```
# data reduced with decode:
# github.com/deshima-dev/decode
# Akio Taniguchi et al.
```

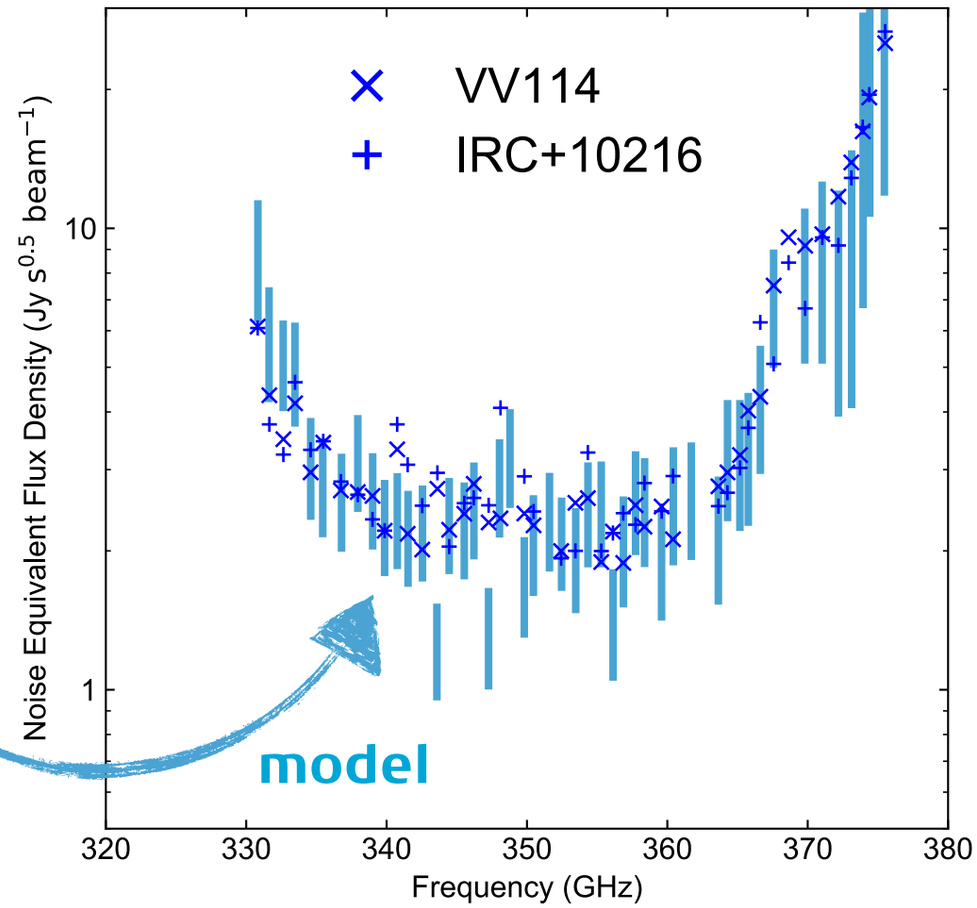
Point-source sensitivity:
Foreground Photon-noise Limited

✳ **Photon-noise NEP of an MKID**

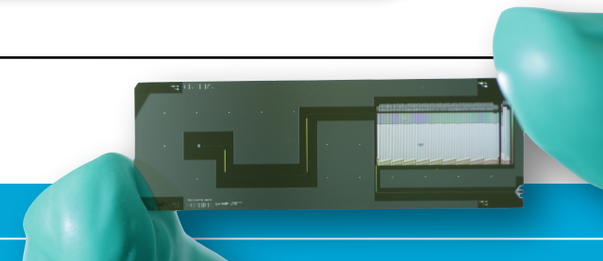
$$\mathrm{NEP_{ph}} = \sqrt{2P_{\mathrm{MKID}}(hF + P_{\mathrm{MKID}}/\Delta F) + 4\Delta_{\mathrm{Al}}P_{\mathrm{MKID}}/\eta_{\mathrm{pb}}}$$

Photon (Poisson) | **Photon** (Bunching) | **quasiparticle recombination**

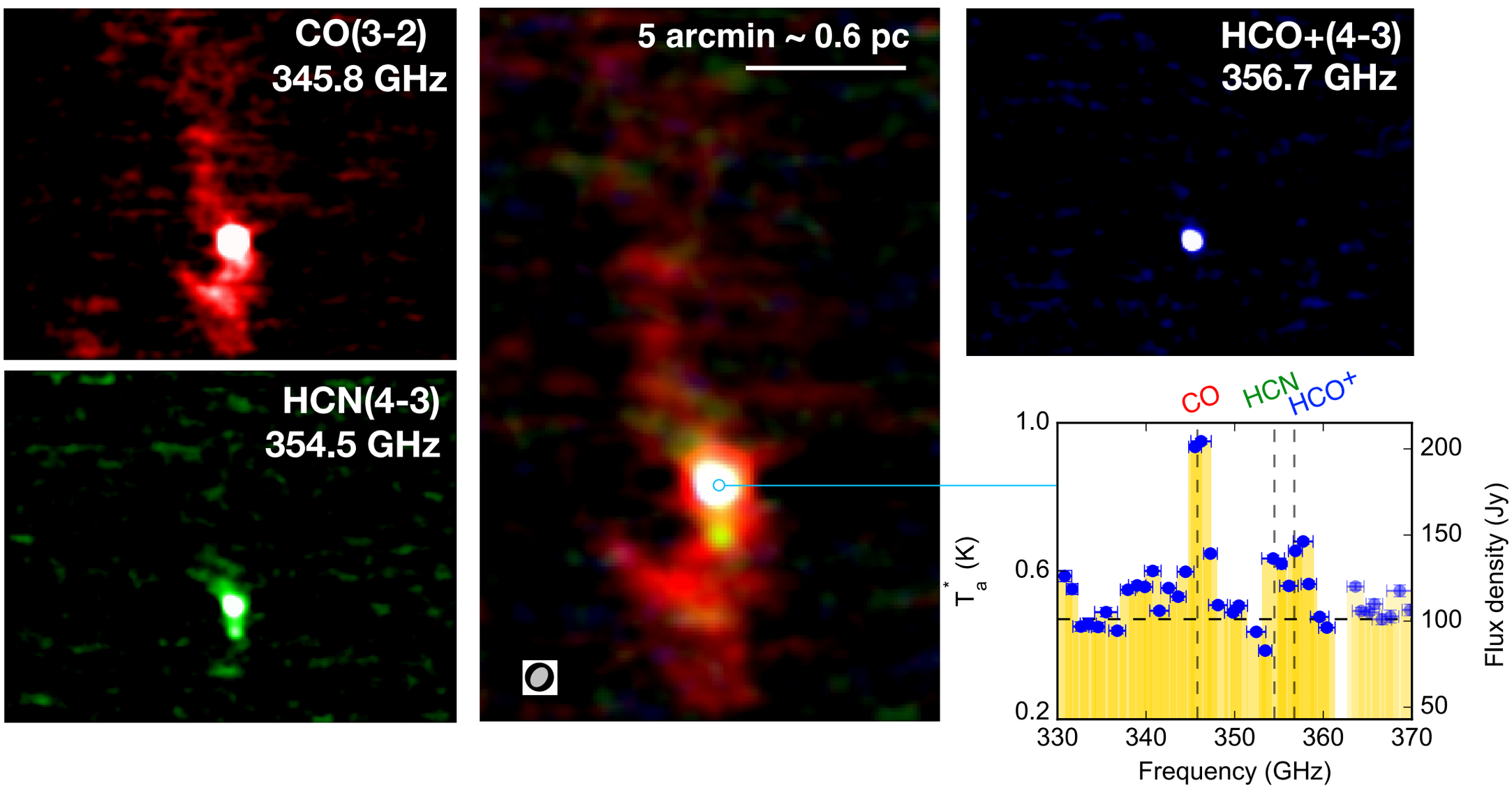
$$\mathrm{NEFD_{ph}} = \frac{\mathrm{NEP_{ph}}}{\sqrt{2}\eta_{\mathrm{pol}}\eta_{\mathrm{inst}}\eta_{\mathrm{fwd}}\eta_{\mathrm{atm}}\eta_{\mathrm{A}}A_{\mathrm{p}}\Delta F}.$$



On-sky performance — Lab Performance — Design



Proof of ISS key application 2:
Multi-line spectral mapper



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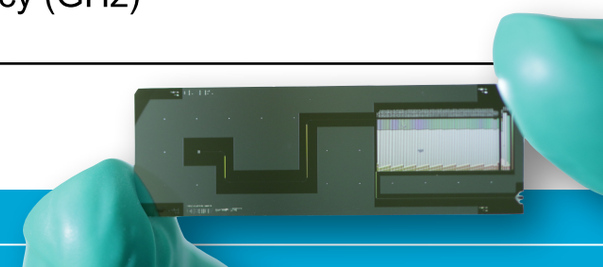
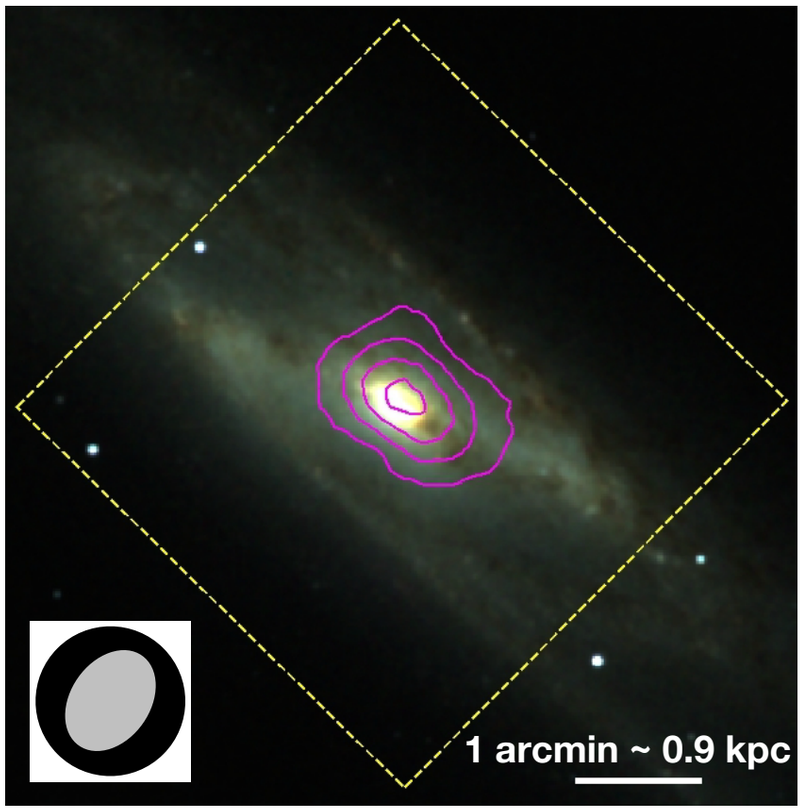
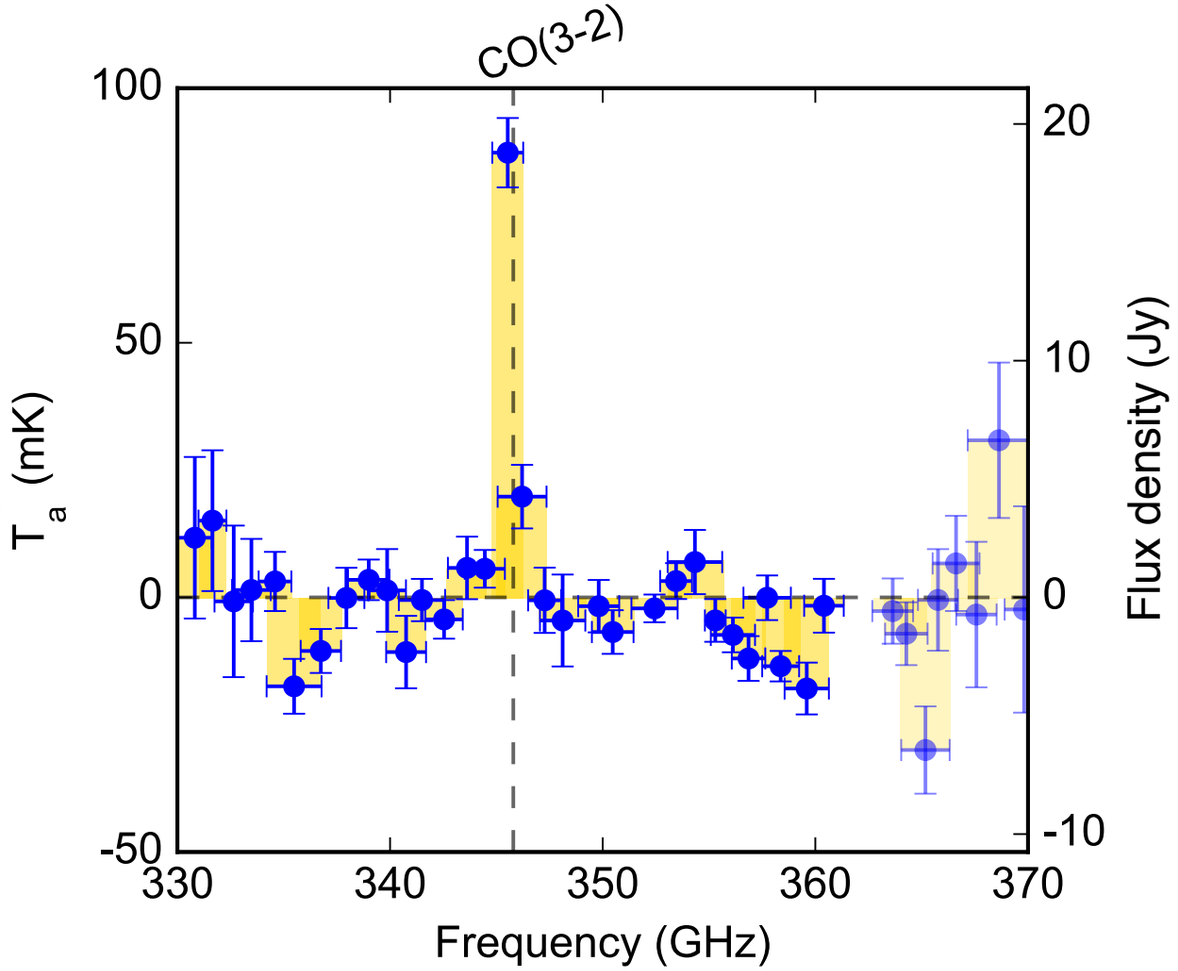
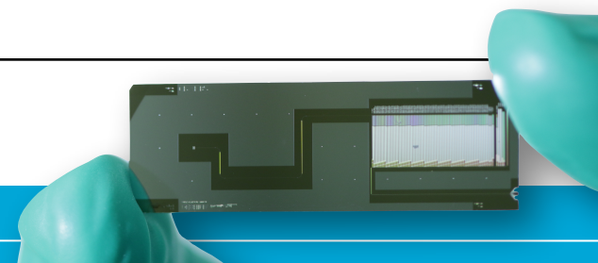


Proof of ISS key application 2:
Multi-line spectral mapper

Spectral Map of NGC 253







Conclusion

Conclusion

arXiv preprints:
- 1906.10216: **First-light on ASTE**
- 1901.06934: **Lab performance**

DESHIMA 1.0 Success:
On-sky demonstration of the Integrated Superconducting Spectrometer

1. As an efficient redshift machine
2. As a multi-line spectral imager

Together, these features enable spectral surveys of large cosmological volumes

		2017 (this work)	2020 (poster Pascual Laguna)
chip	F	332-377 GHz	220-440 GHz
	$N_{channels}$	49	347
	filters	Coplanar	Microstrip
	antenna	double-slot	leaky-lens
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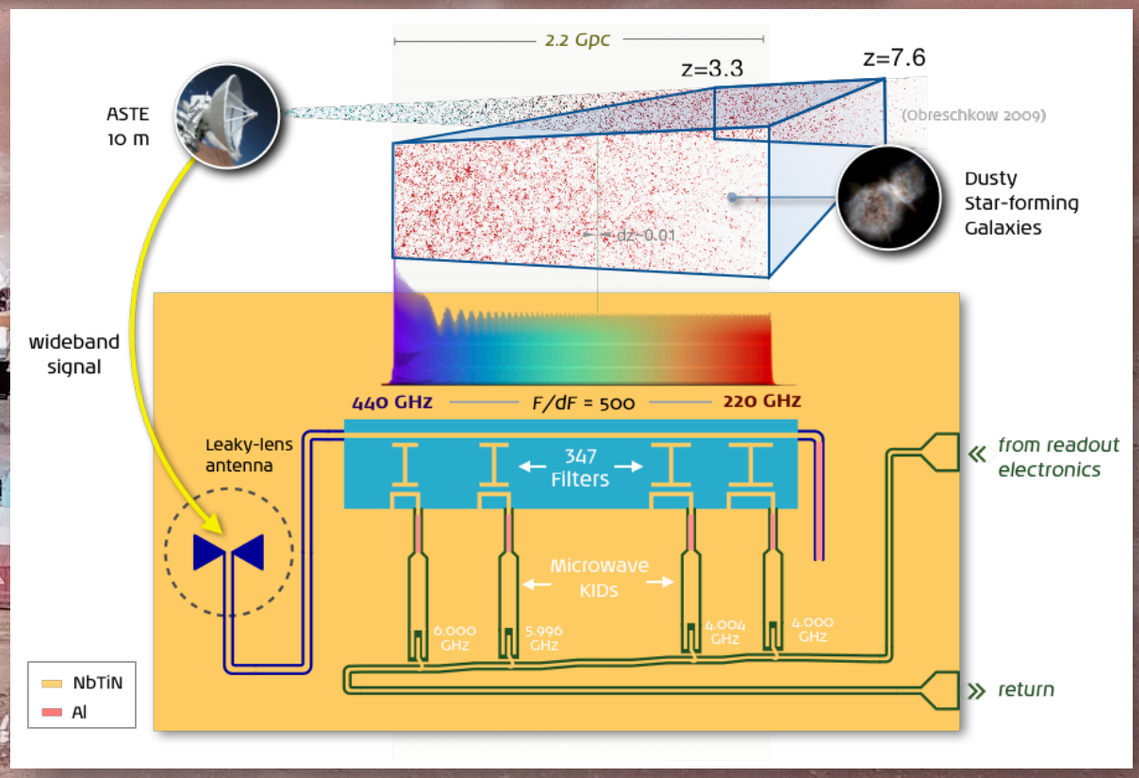

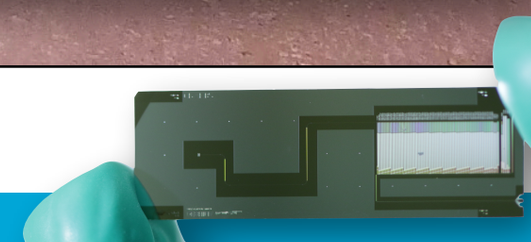

DESHIMA