TIFUUN & DESHIMA

Superconducting On-chip Instruments for Mapping the Submillimeter-wave Universe in 3D

Akira Endo

2023-04-20 Cryo Workshop, SRON Leiden

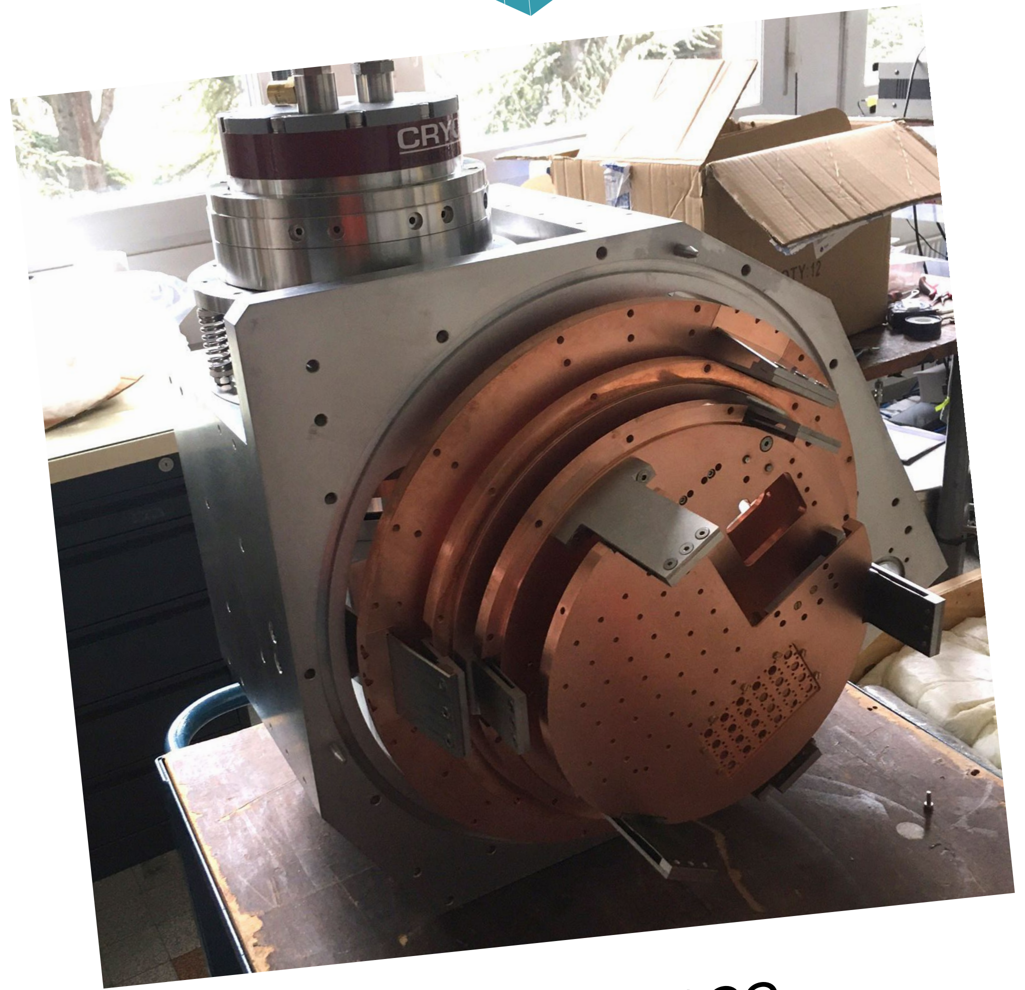
DESHIMA and TIFUUN

- Instruments for the ASTE telescope in Chile
- Observing λ ~ 0.8-3 mm
- ***Unique Strength:***
  Ultra-wideband spectroscopy using
  on-chip filterbank spectrometers

DESHIMA

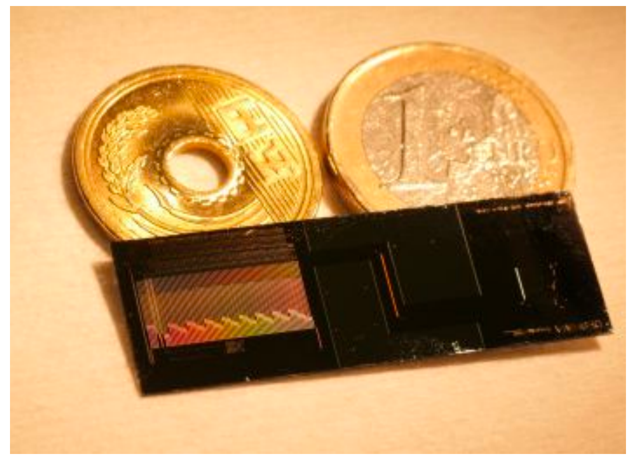
- Development since 2010
- First of its kind
- Tested once on the ASTE telescope
- Science observation from <u>**2023**</u>

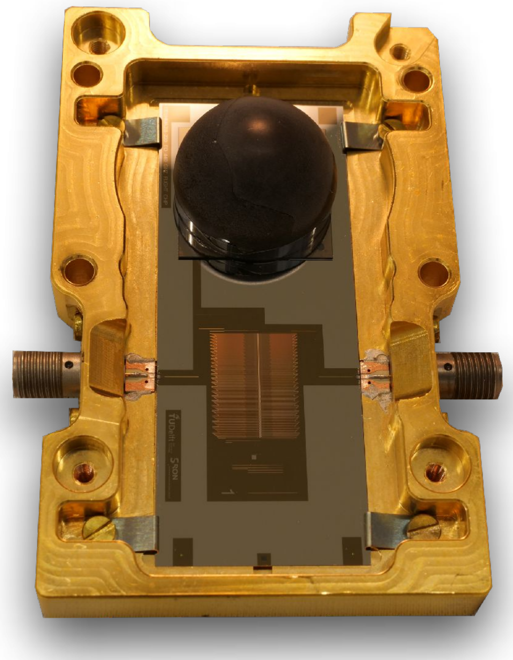
TIFUUN



- New project since 2022
- Performance of
  ~100 DESHIMA's !

Timeline





DESHIMA

DESHIMA 1.0 | DESHIMA 2.0 (MOSAIC)

- DESHIMA gets first funding
- DESHIMA 1.0 First Light
- Jochem's EA group in EWI
- DESHIMA 2.0 Working in Lab

DESHIMA Science on ASTE

2010 2011 2012 2013 2014 2015 2016 2017 2018 2019 2020 2021 2022 2023 2024 2025 2026 2027

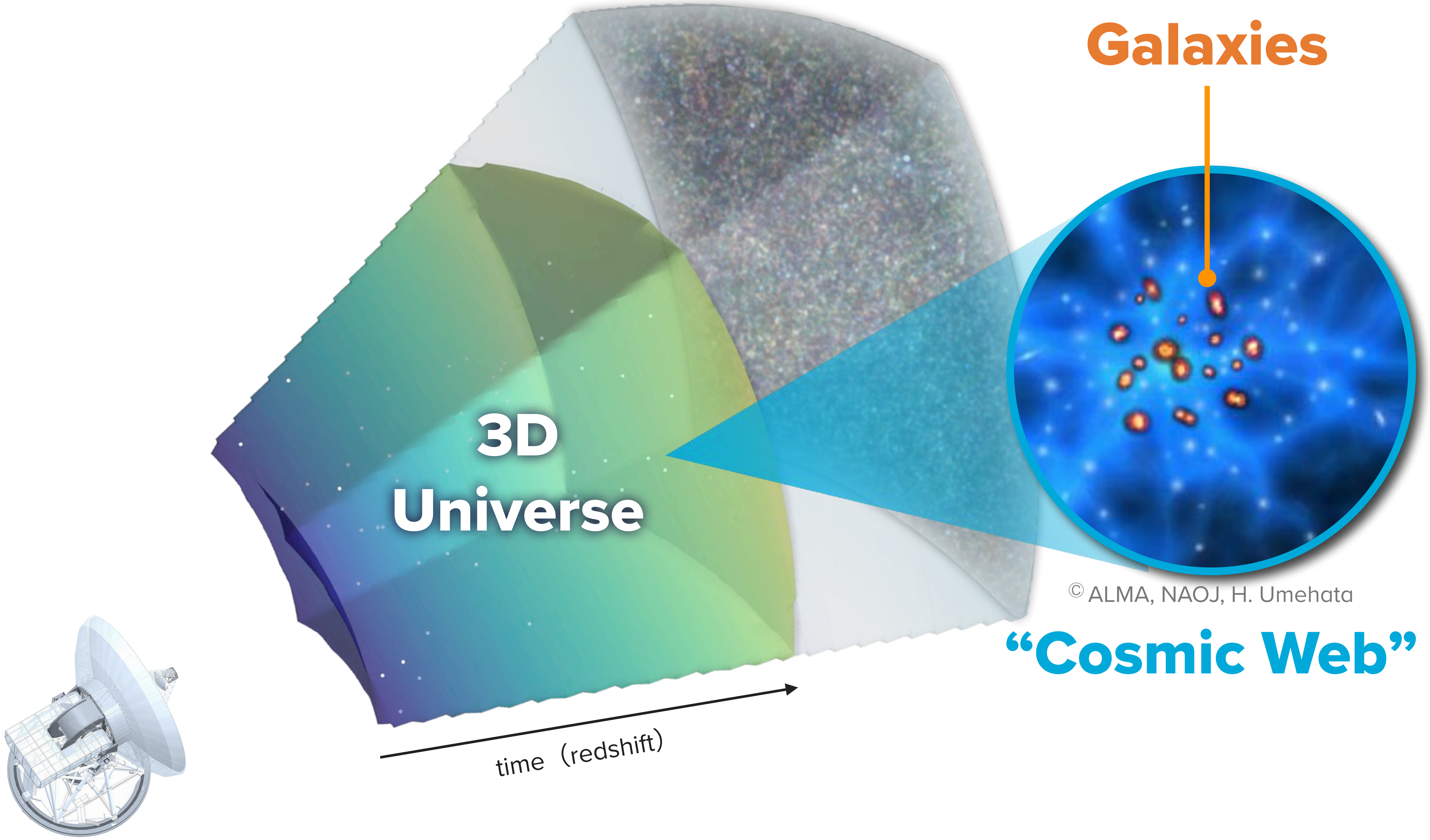
TIFUUN

TIFUUN

TIFUUN Science on ASTE

Kick-Off Symposium (TU Delft, 3 weeks ago)

Cosmic 3D Maps @ THz

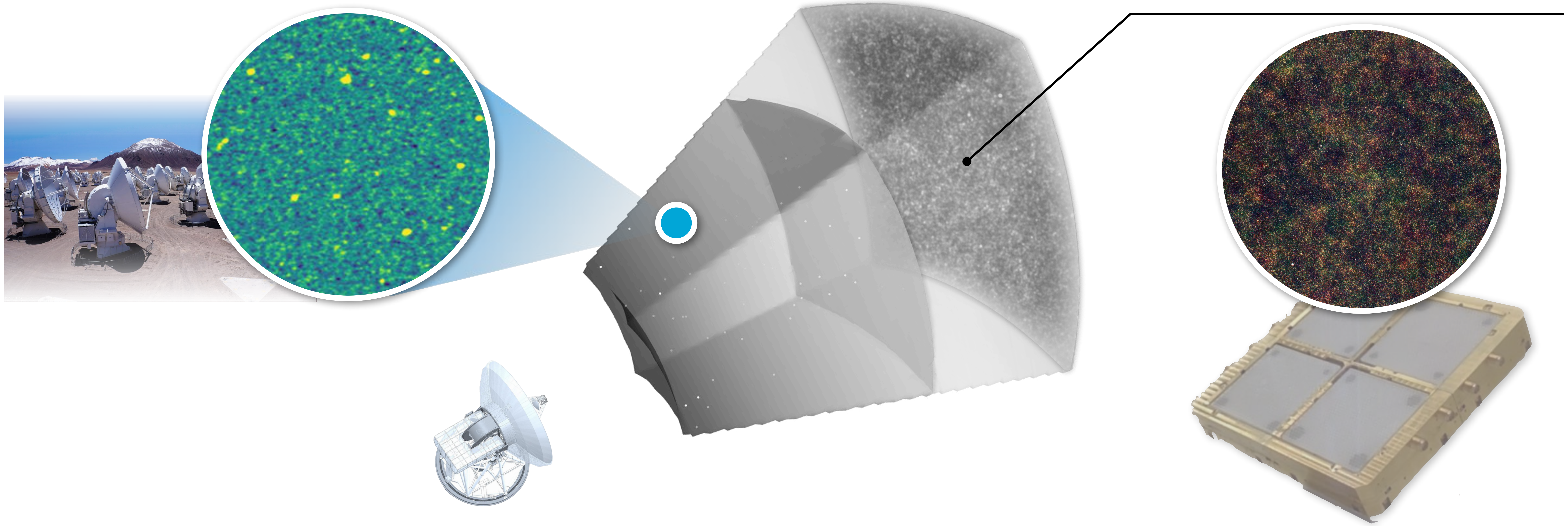


Cosmic 3D Maps @ THz

Dichotomy of THz Technology

Interferometers: Only Minute Volume

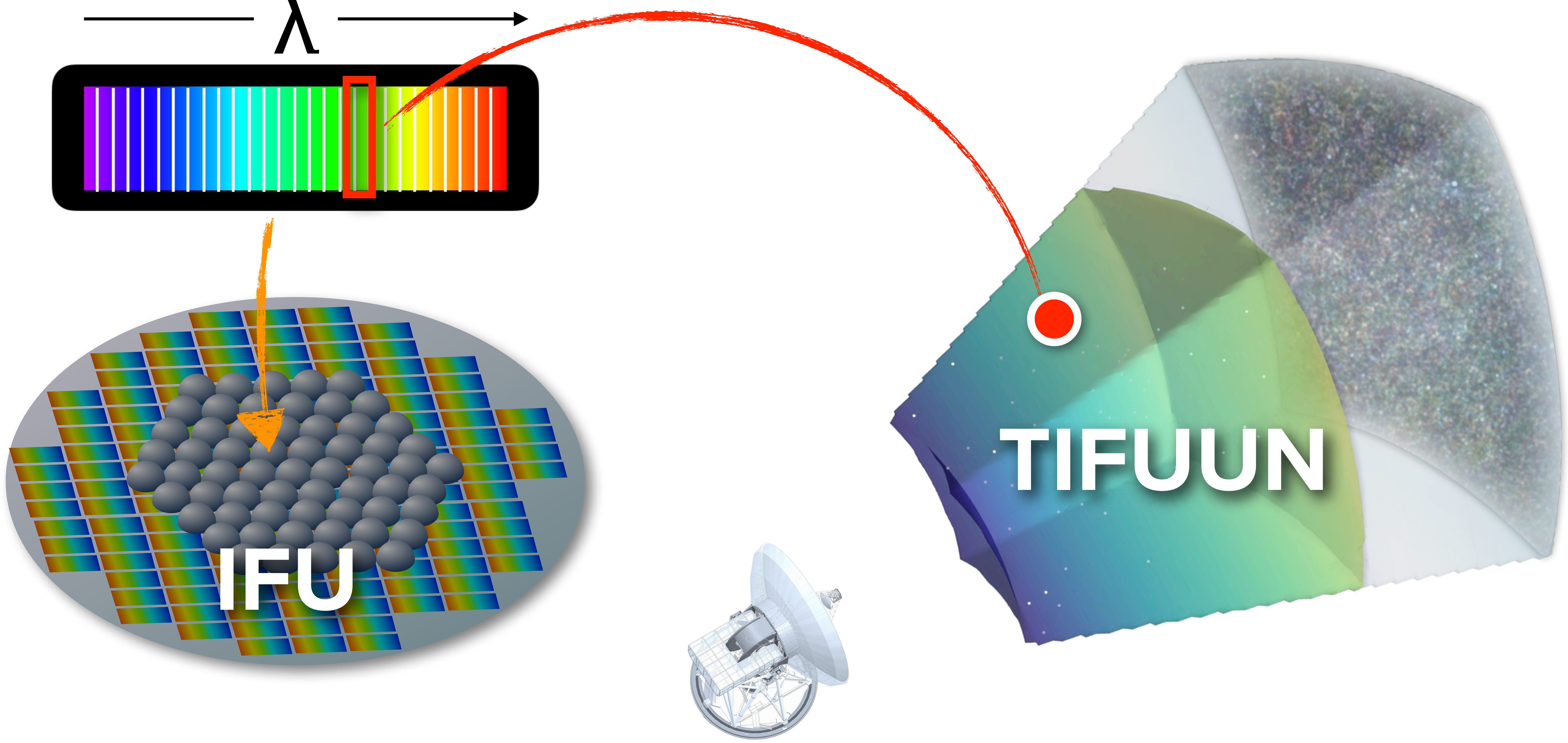
Cameras: Only 2D image



Cosmic 3D Maps @ THz

SPAXELS:
Spectrometer Pixels

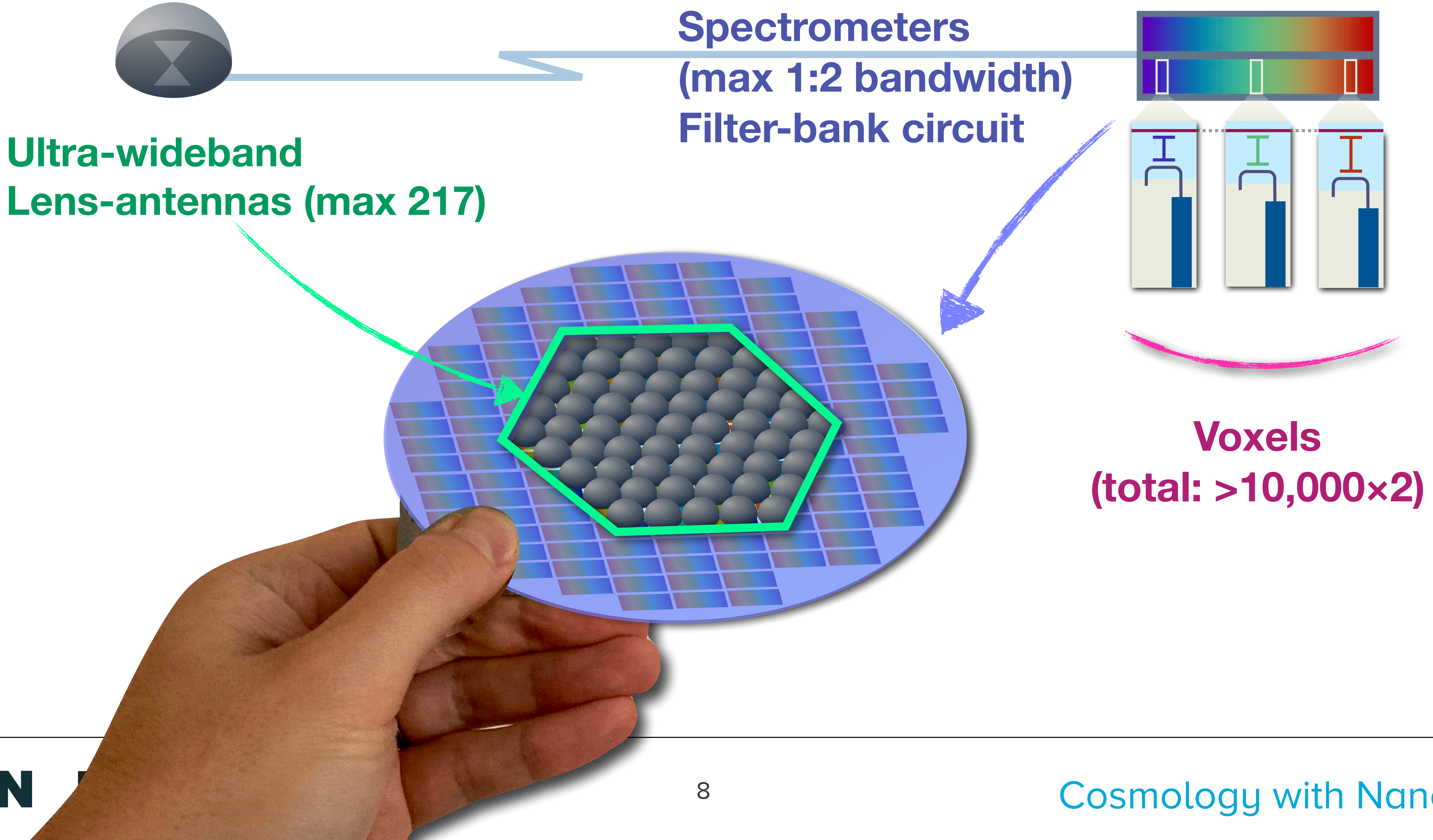
>20,000 VOXELS:
Each VOXEL is a VOLUME of the Universe



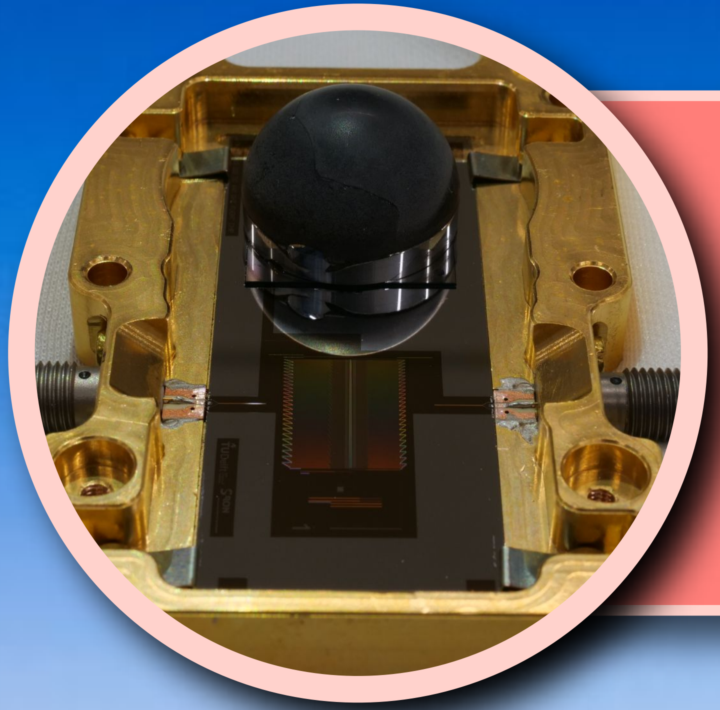
VOLUMIC
Astronomy across the COSMIC WEB

- Star-Forming Galaxies
- Diffuse Matter
- Galaxy Clusters

TIFUUN IFU Concept:
Imaging Spectrometer on a Wafer

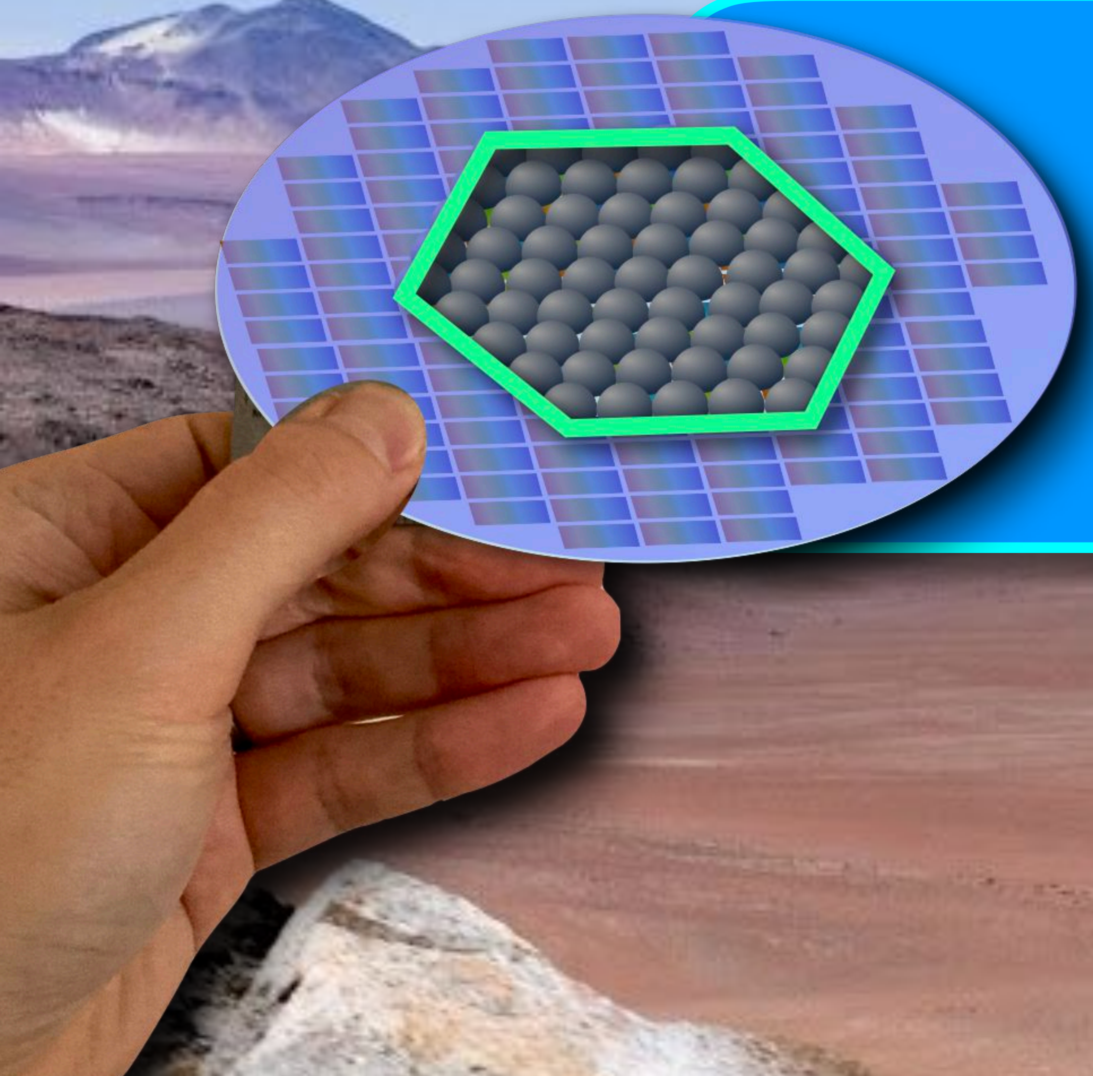


Outline



DESHIMA

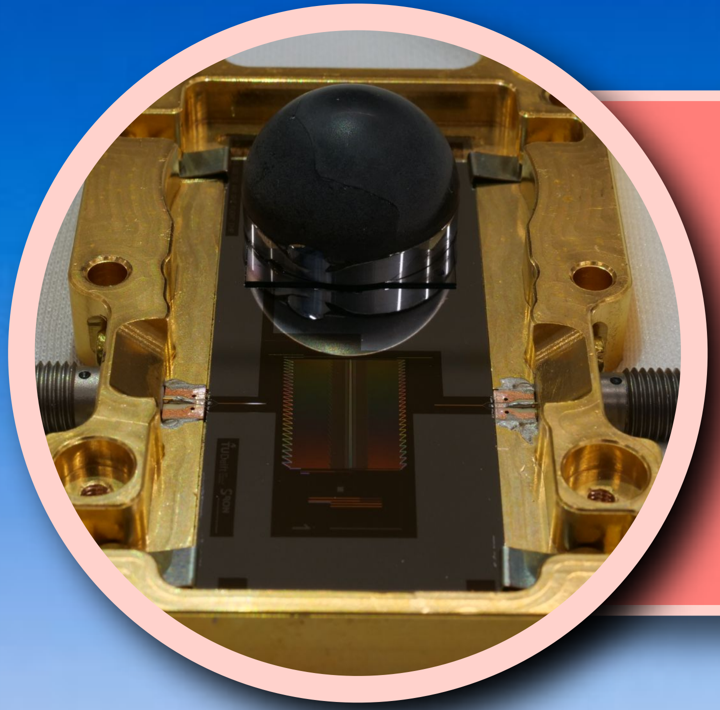
1-spaxel on-chip spectrometer



TIFUUN

>100-spaxel imaging spectrometer

Outline



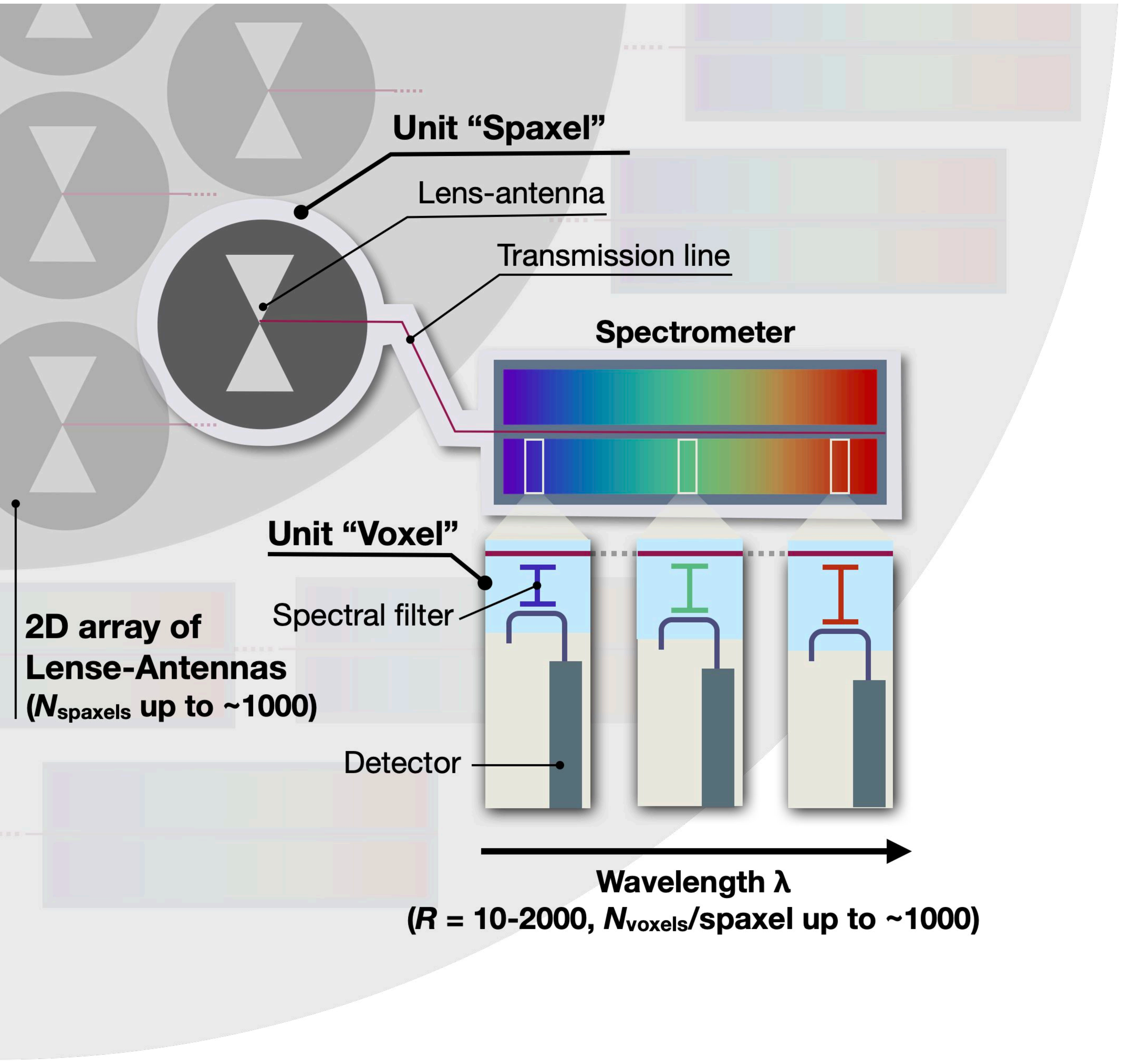
DESHIMA

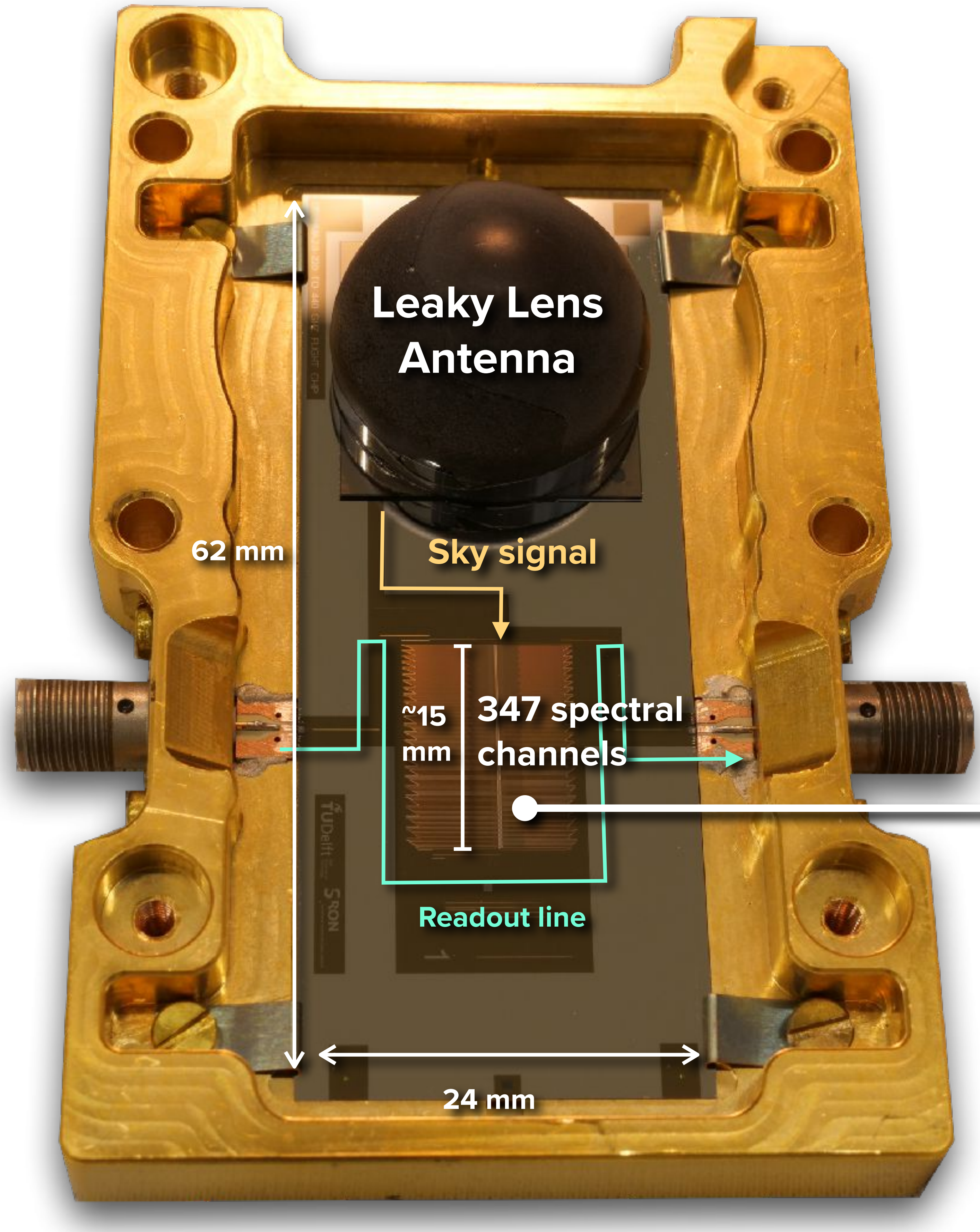
1-spaxel on-chip spectrometer

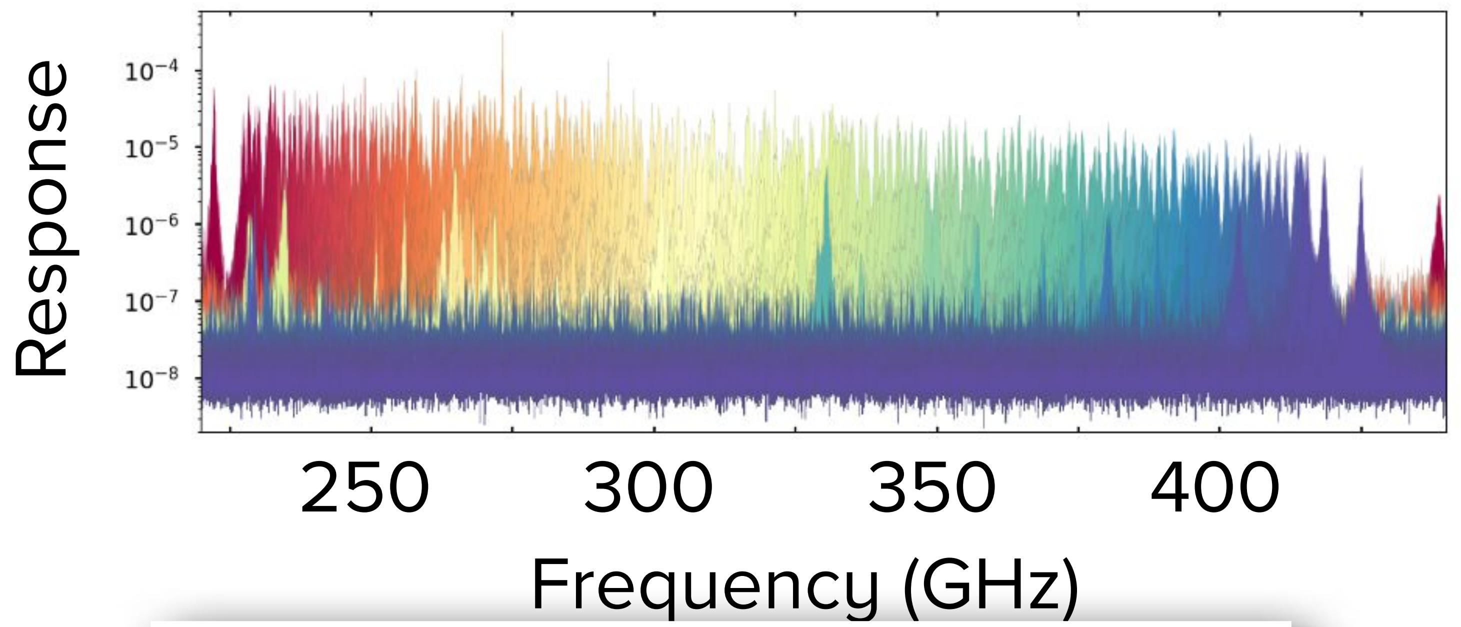
TIFUUN

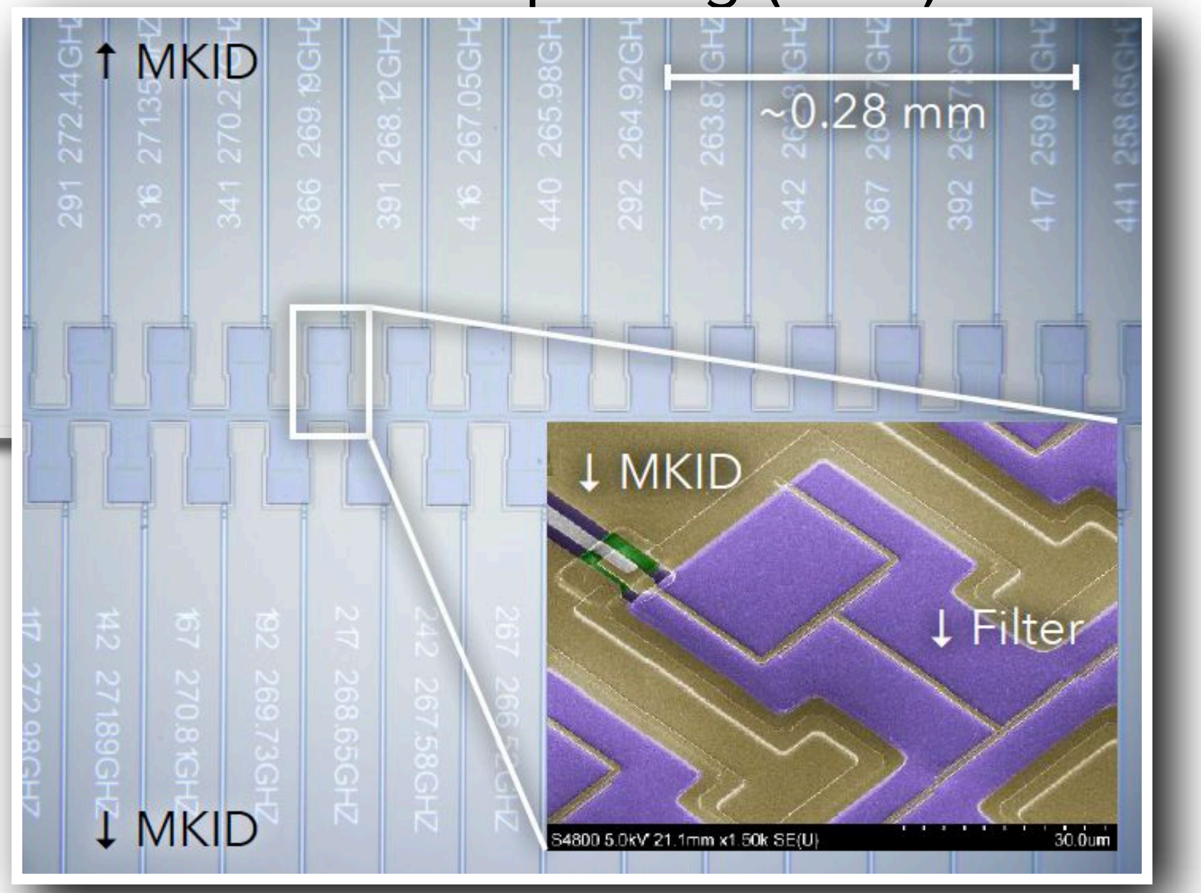
>100-spaxel imaging spectrometer

Unit spaxel of an IFU
= On-chip filterbank spectrometer (DESHIMA)





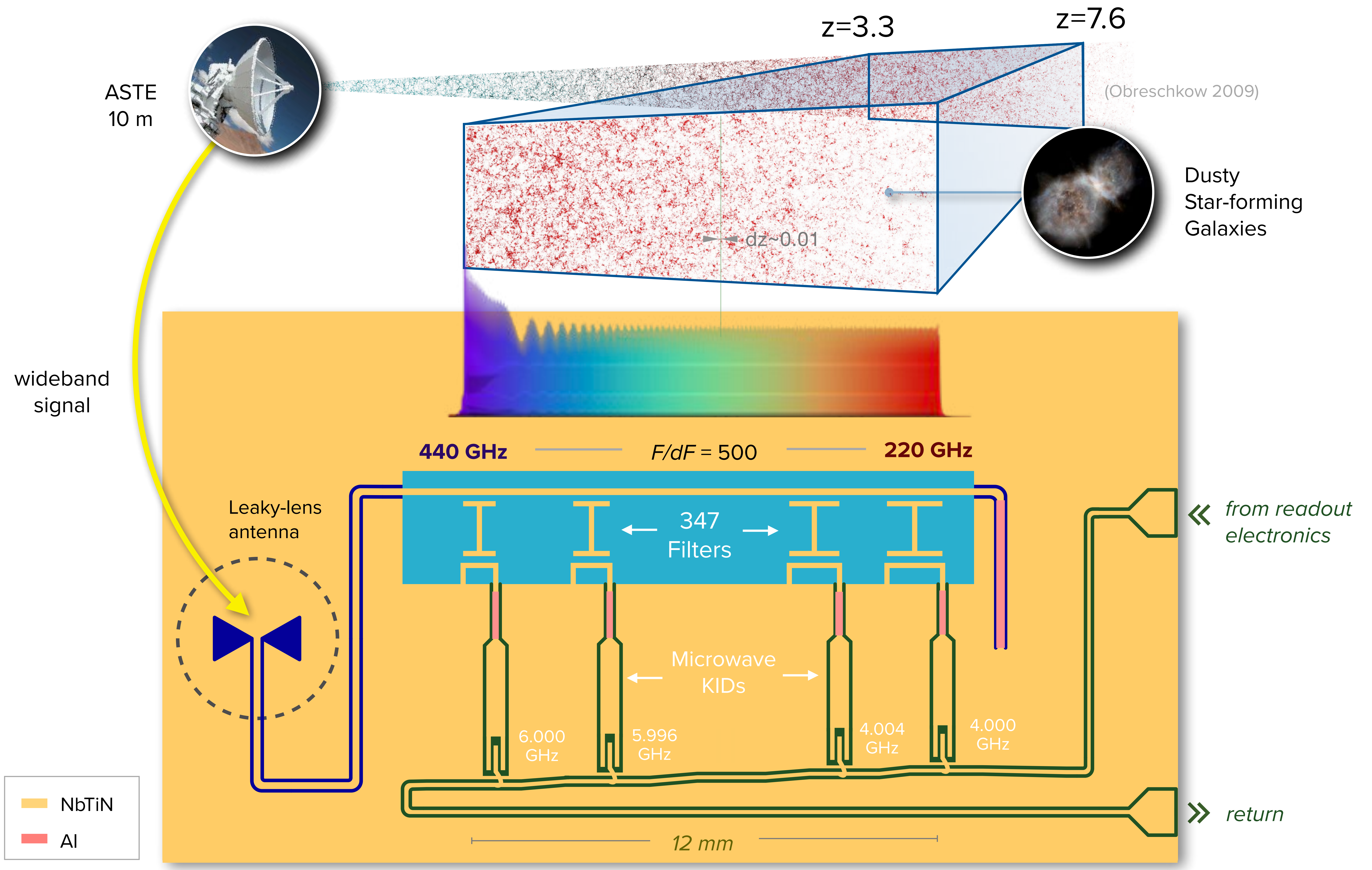


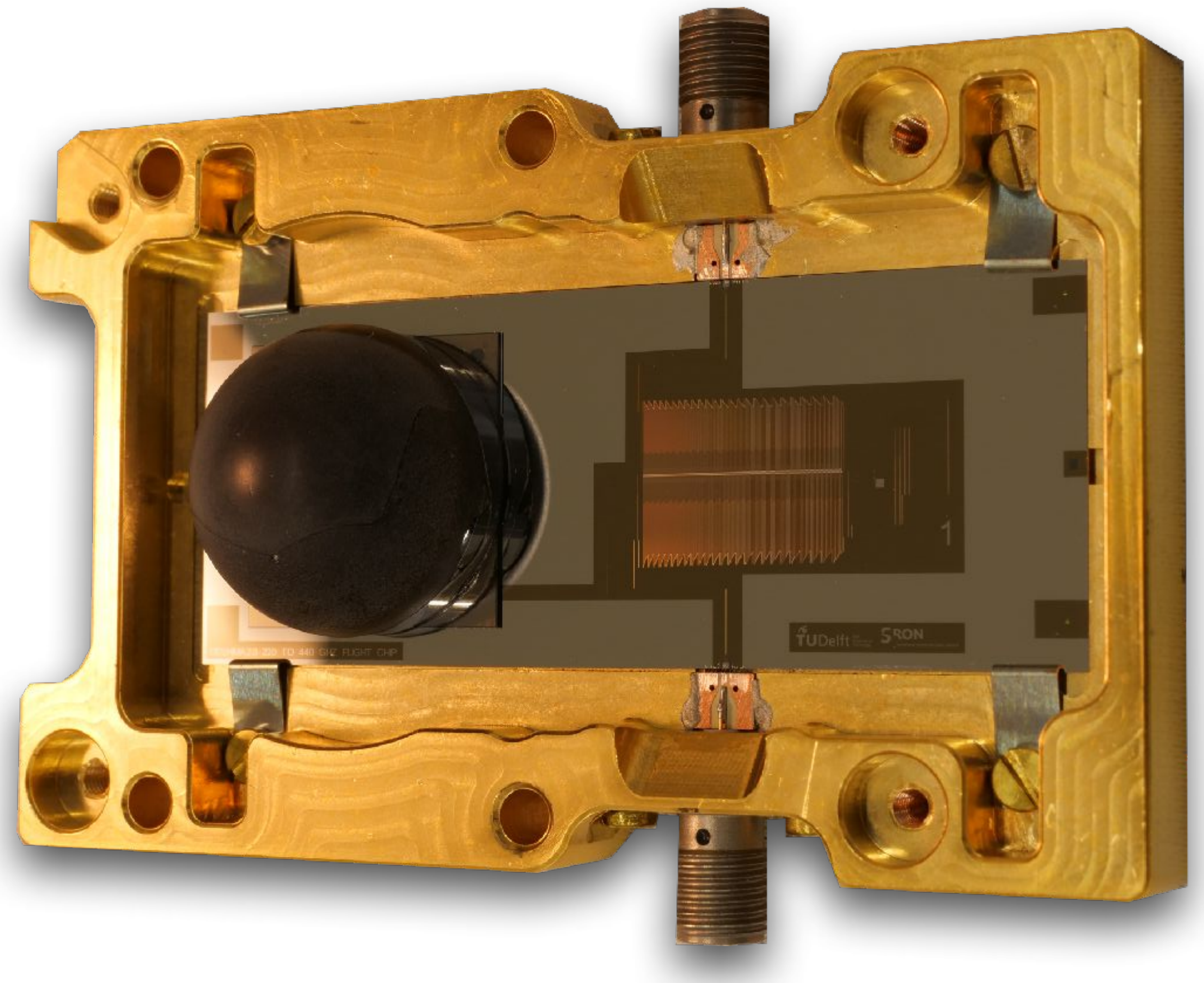


Taniguchi et al., JLTP 209, 278 (2022)

DESHIMA Concept

On-chip Filterbank Spectrometer



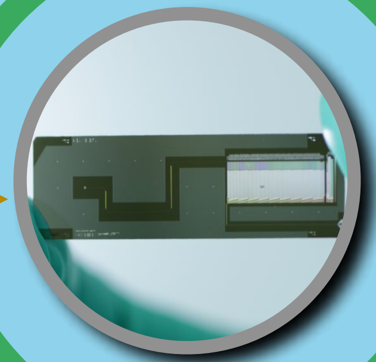


Requirements of the DESHIMA cryostat

ASTE Telescope
+ warm optics

High throughput of
submm signal

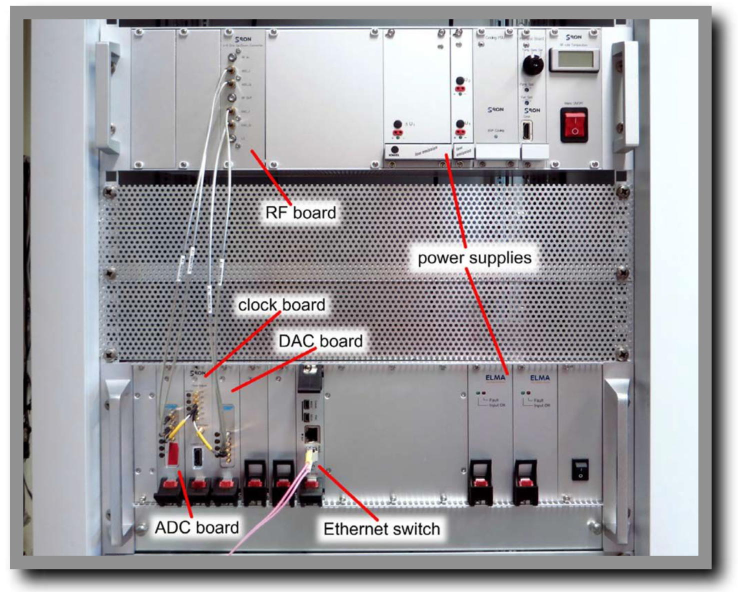
Cryostat:
Chip is cold at 100 mK
for ≳20 hours



Spectrometer Chip

magnetic shielding
& Stray-light shielding

Microwave
access

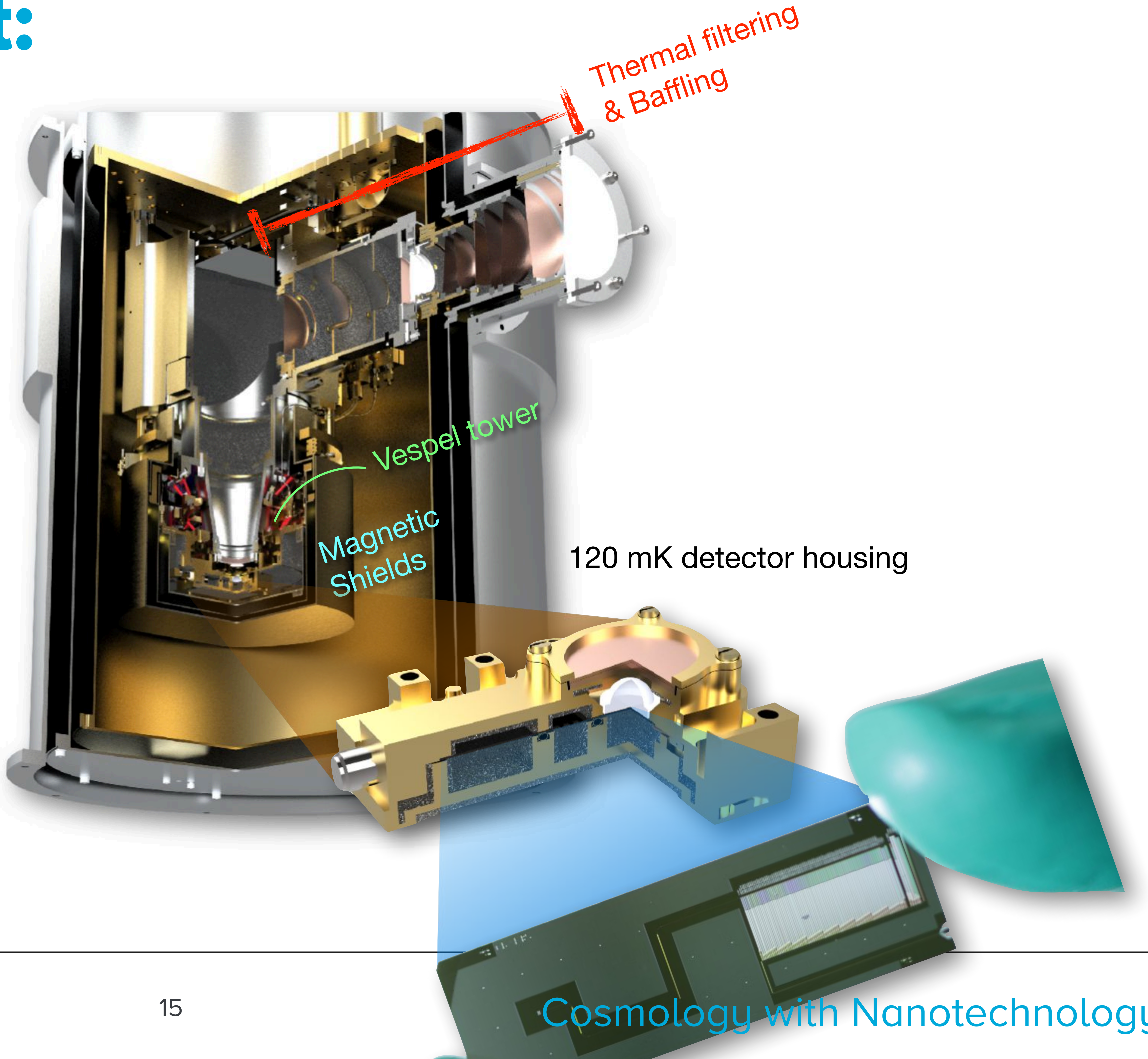


readout
electronics

Tip-tilt

Conflicting requirements:
Signal throughput vs. **Shielding**
Thermal isolation vs. **Mechanical Strength**

DESHIMA Cryostat:



DESHIMA on ASTE

“DESHIMA 1.0” – Concept Demonstrator

“DESHIMA 1.0”

Minimal chip specs

332-377 GHz (45 GHz BW / 49 voxels)

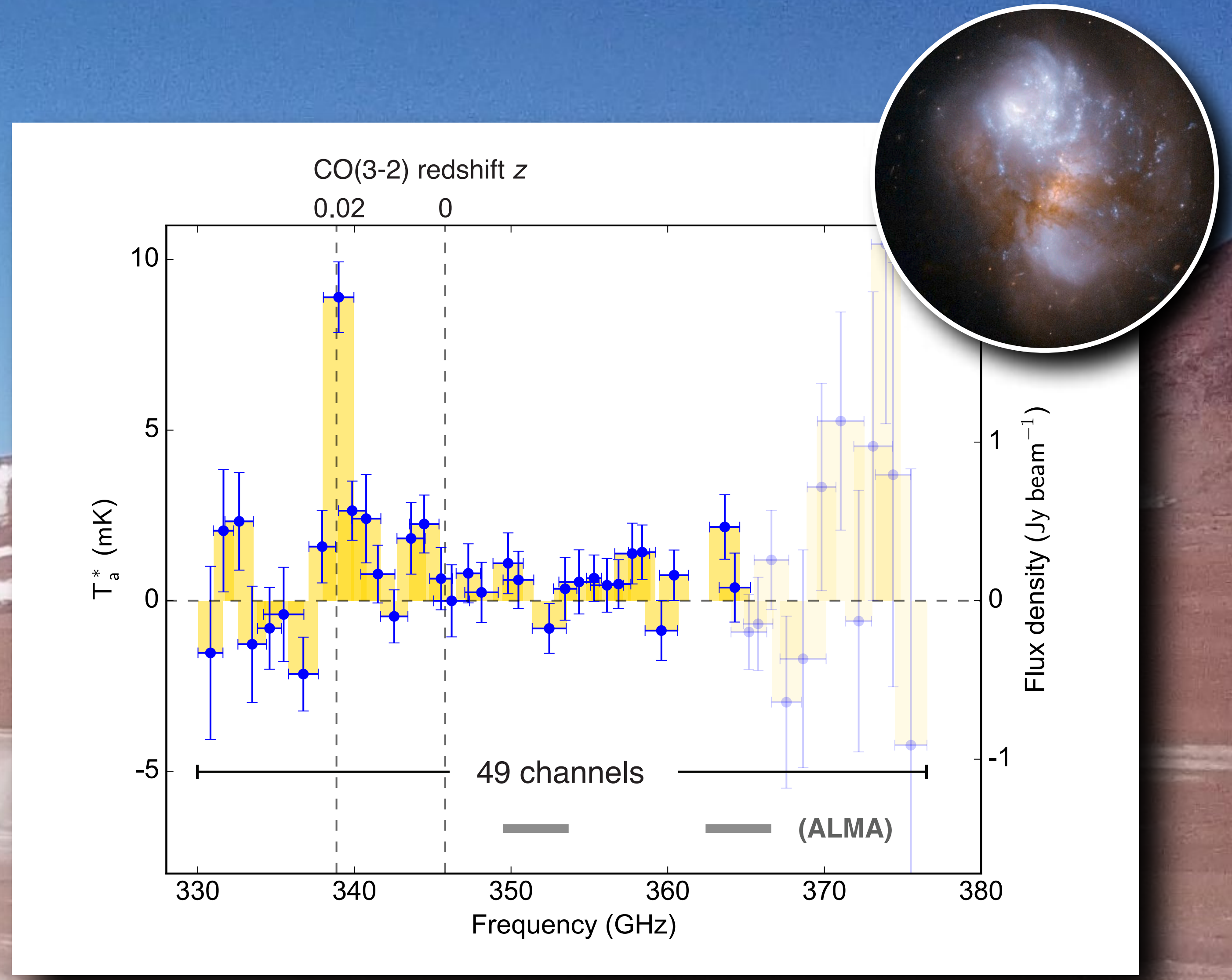
Sufficient sensitivity for system test

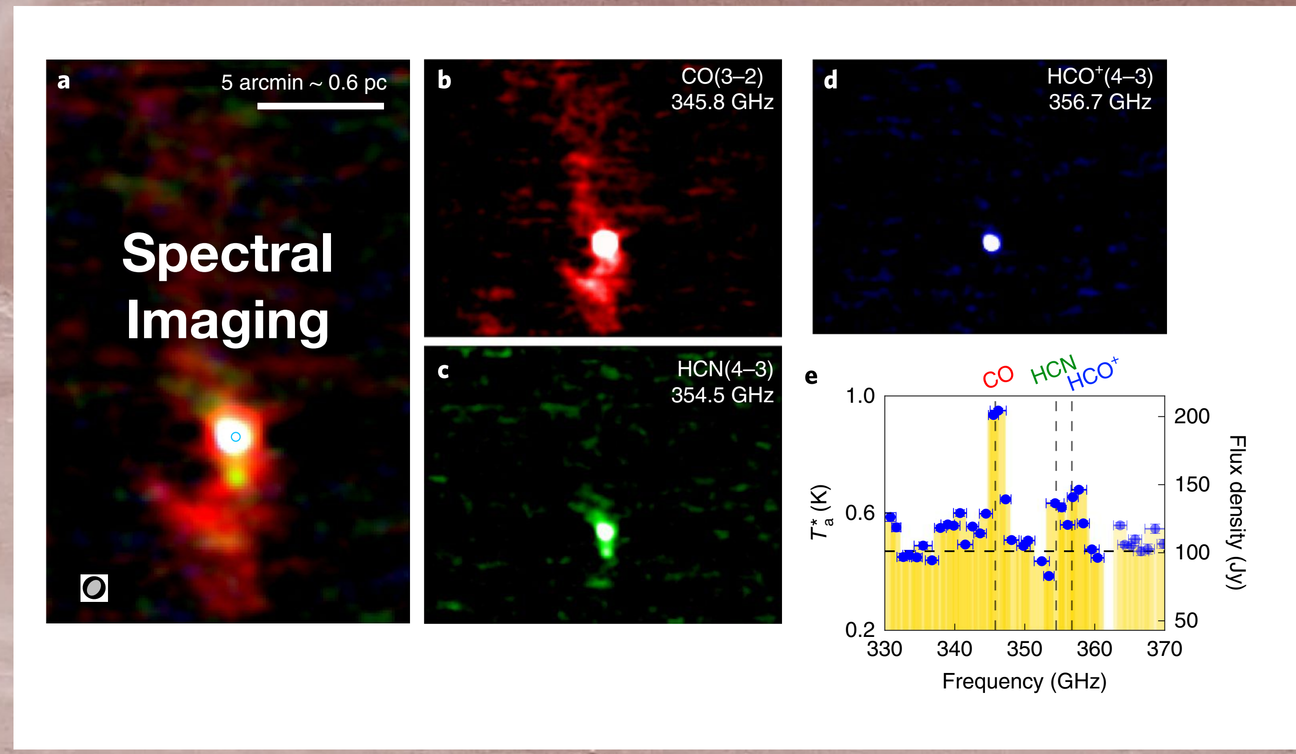
End-to-end system check

- ✓ MKIDs operation on ASTE (Photon-noise limited sensitivity)
- ✓ Readout system
- ✓ Cryostat system
- ✓ Remote control
- ✓ Installation procedure
- ✓ Logistics

Astronomical + atmospheric data

- ✓ Software & calibration development

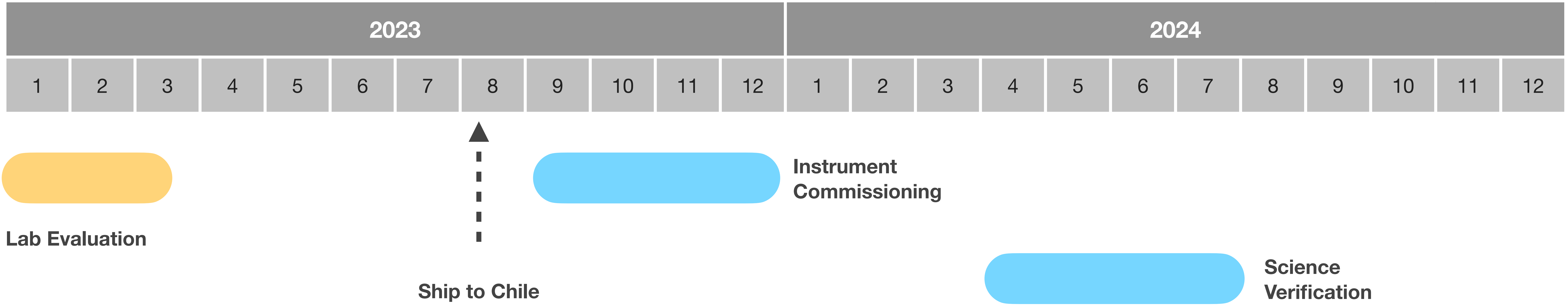




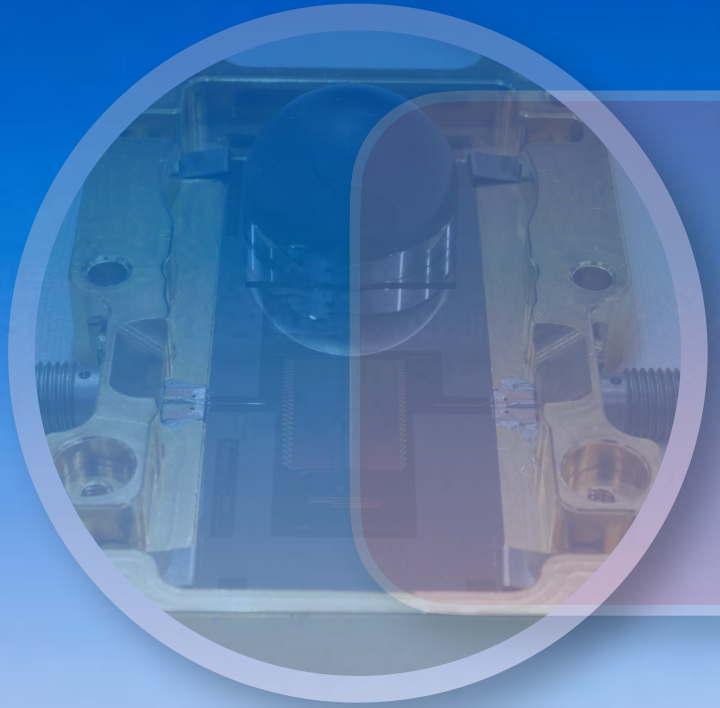
Endo+2019 Nature Astronomy

From DESHIMA 1.0 to DESHIMA 2.0

DESHIMA 2023-2024
Commissioning and Science Verification

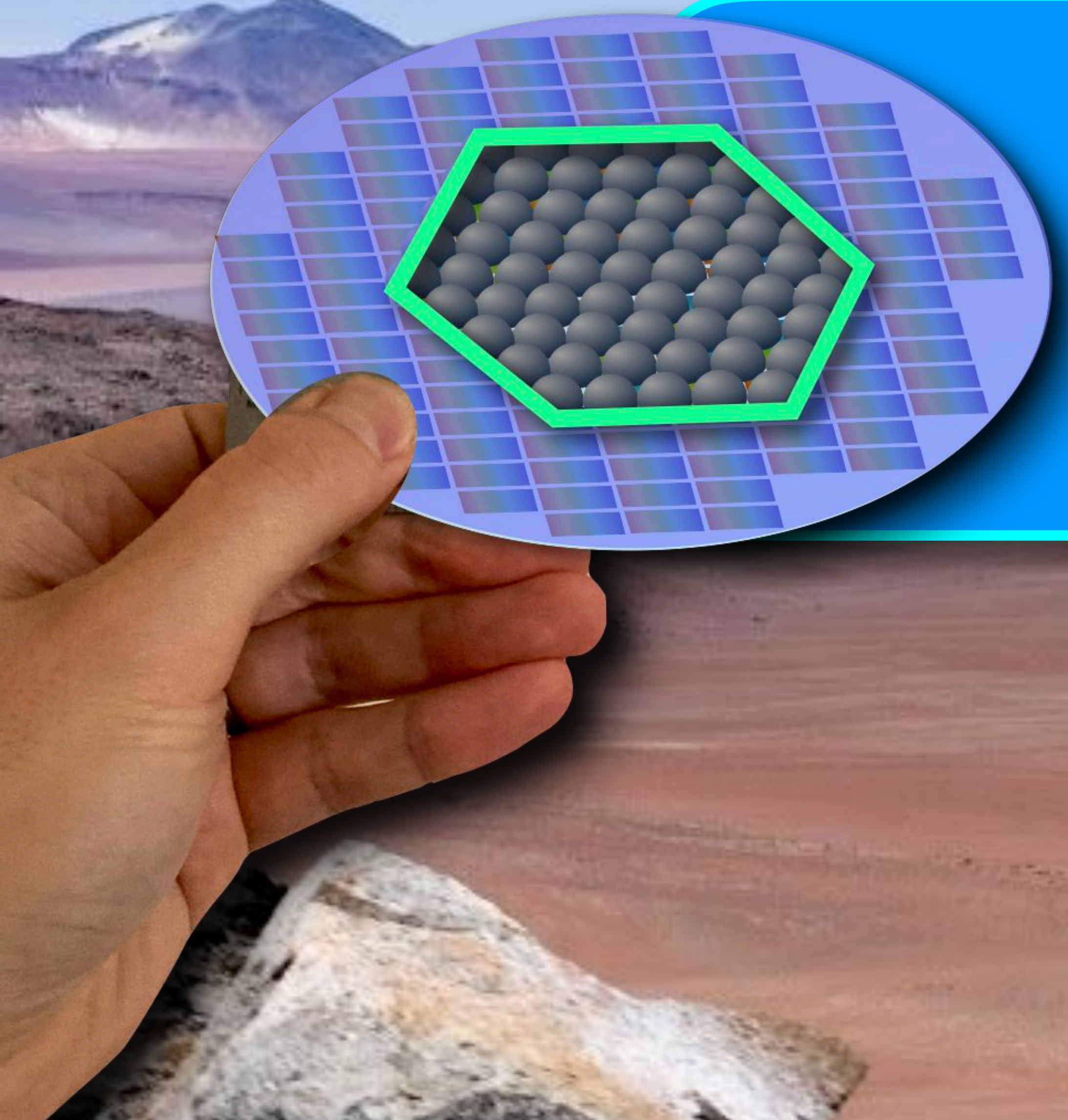


Outline



DESHIMA

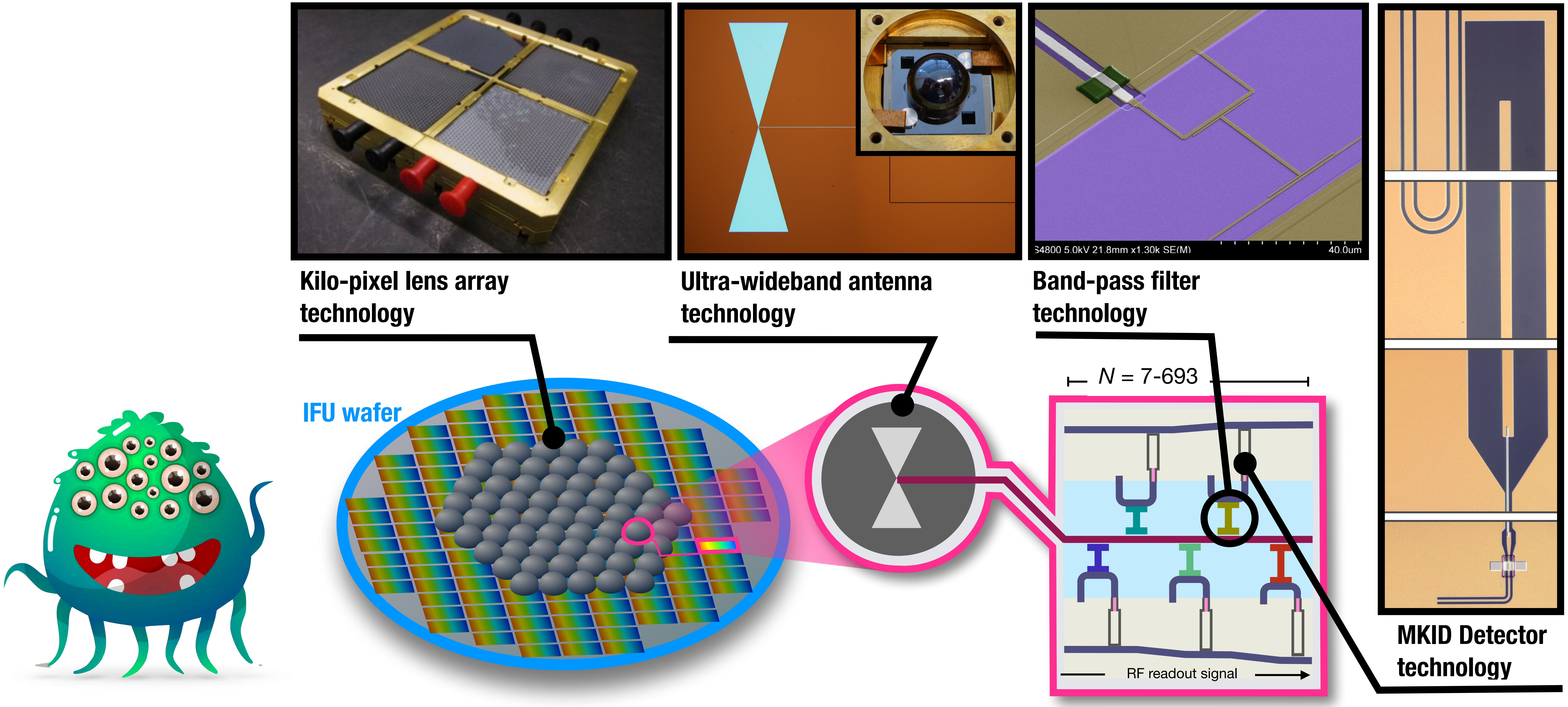
1-spaxel on-chip spectrometer



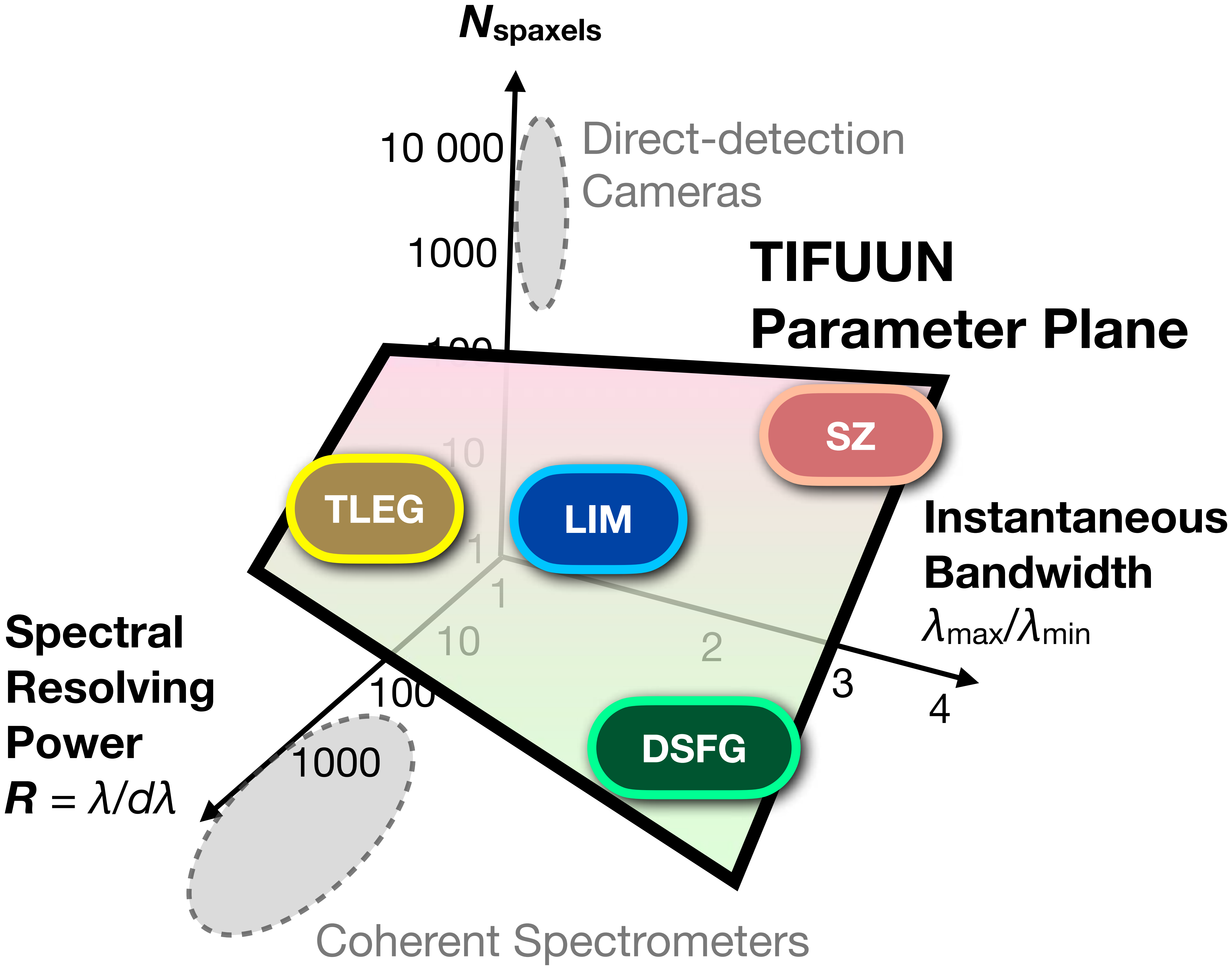
TIFUUN

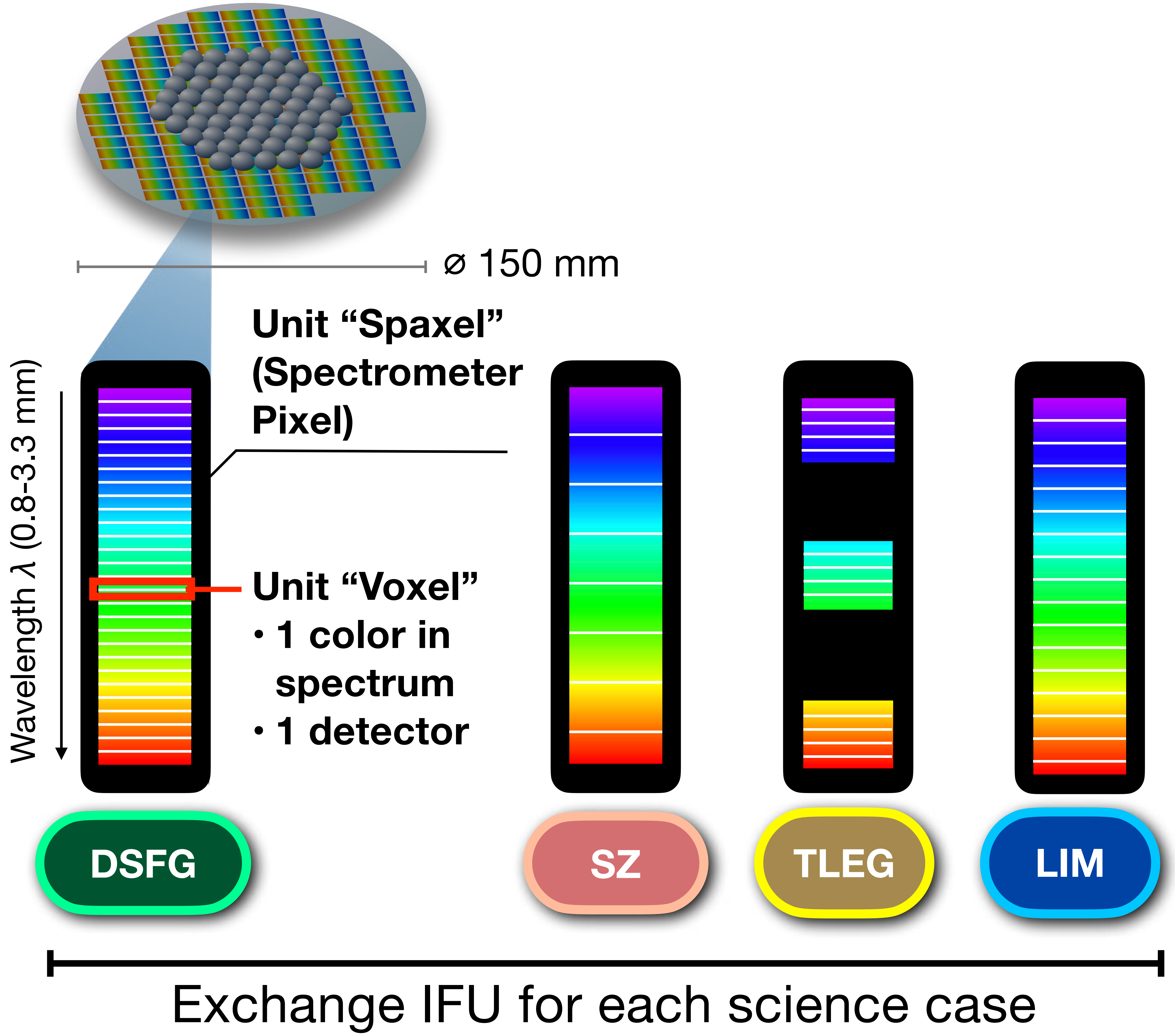
>100-spaxel imaging spectrometer

TIFUUN Concept



One Technology. **Many** Instruments.





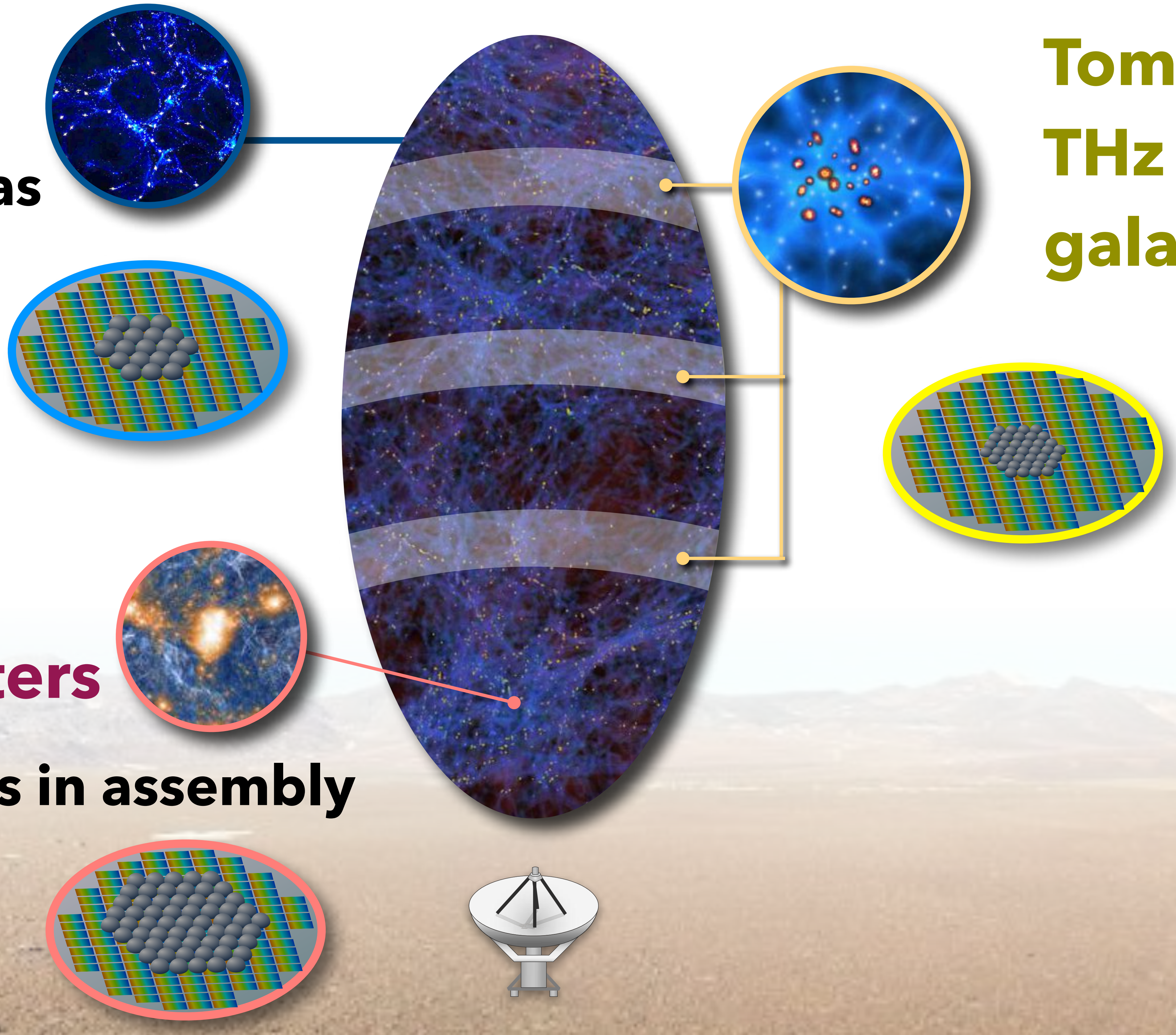
TIFUUN Astronomy:
Volumic 3D Surveys with Plug-and-Play IFUs

[CII] Large Scale Structure

- **Cosmic web of warm gas and star-formation**
  (Line Intensity Mapping)

Tomography of THz line-emitting galaxies (TLEGs)

- **New population of star-forming galaxies hidden by dust**

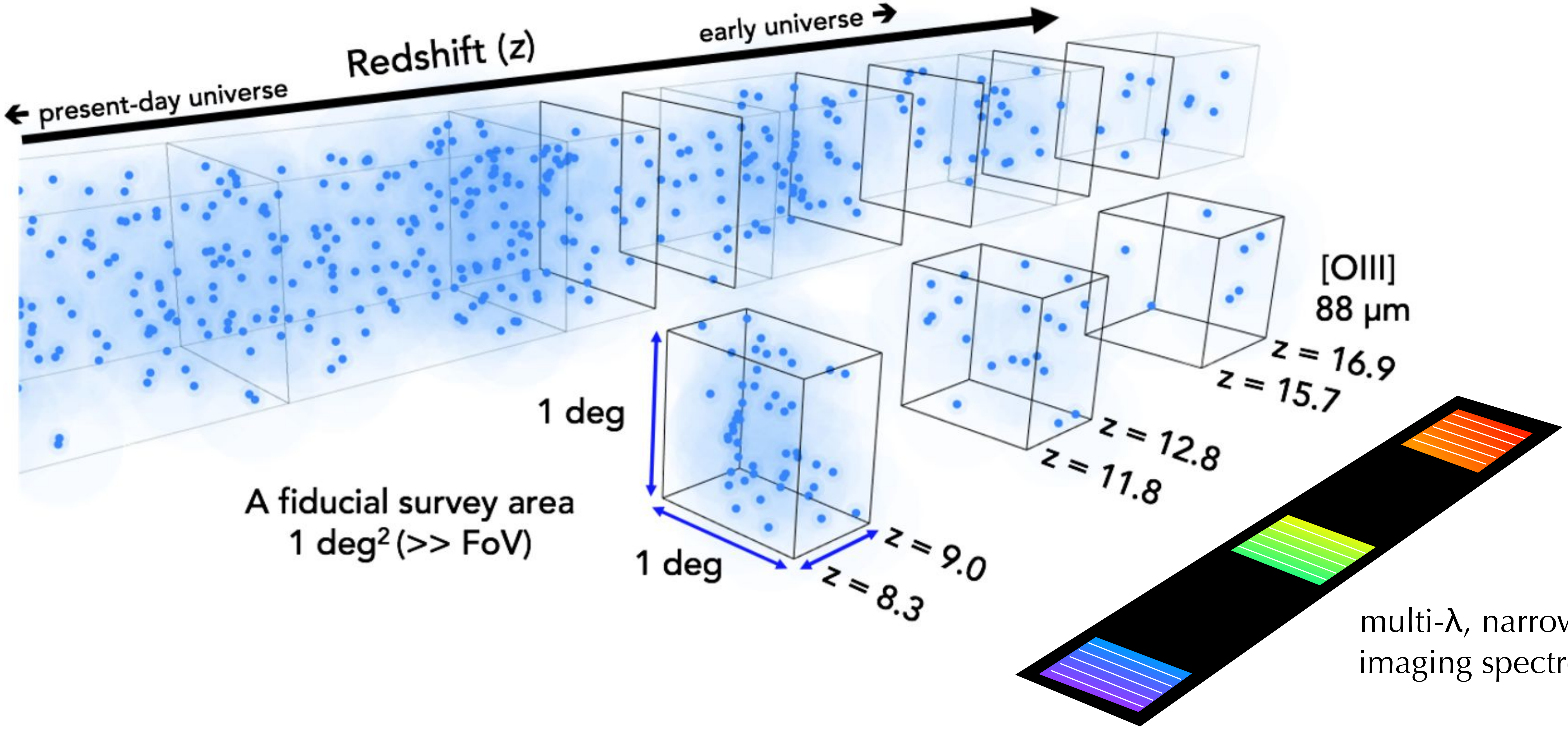


SZ-Clusters

- **Galaxy Clusters in assembly**

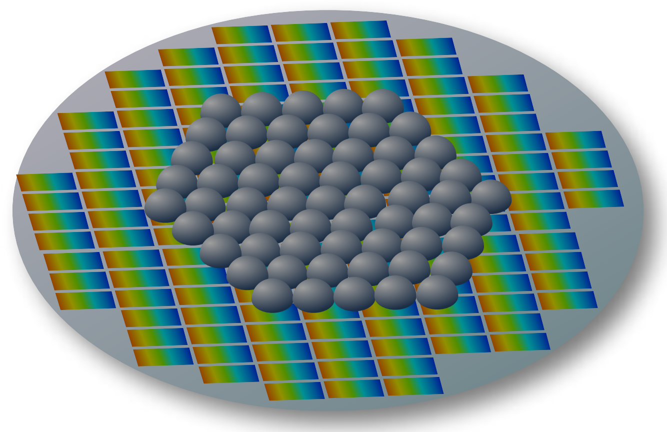
“KATANA” IFU & Survey Concept

Kohno et al., SPIE 2020, https://arxiv.org/abs/2102.08280



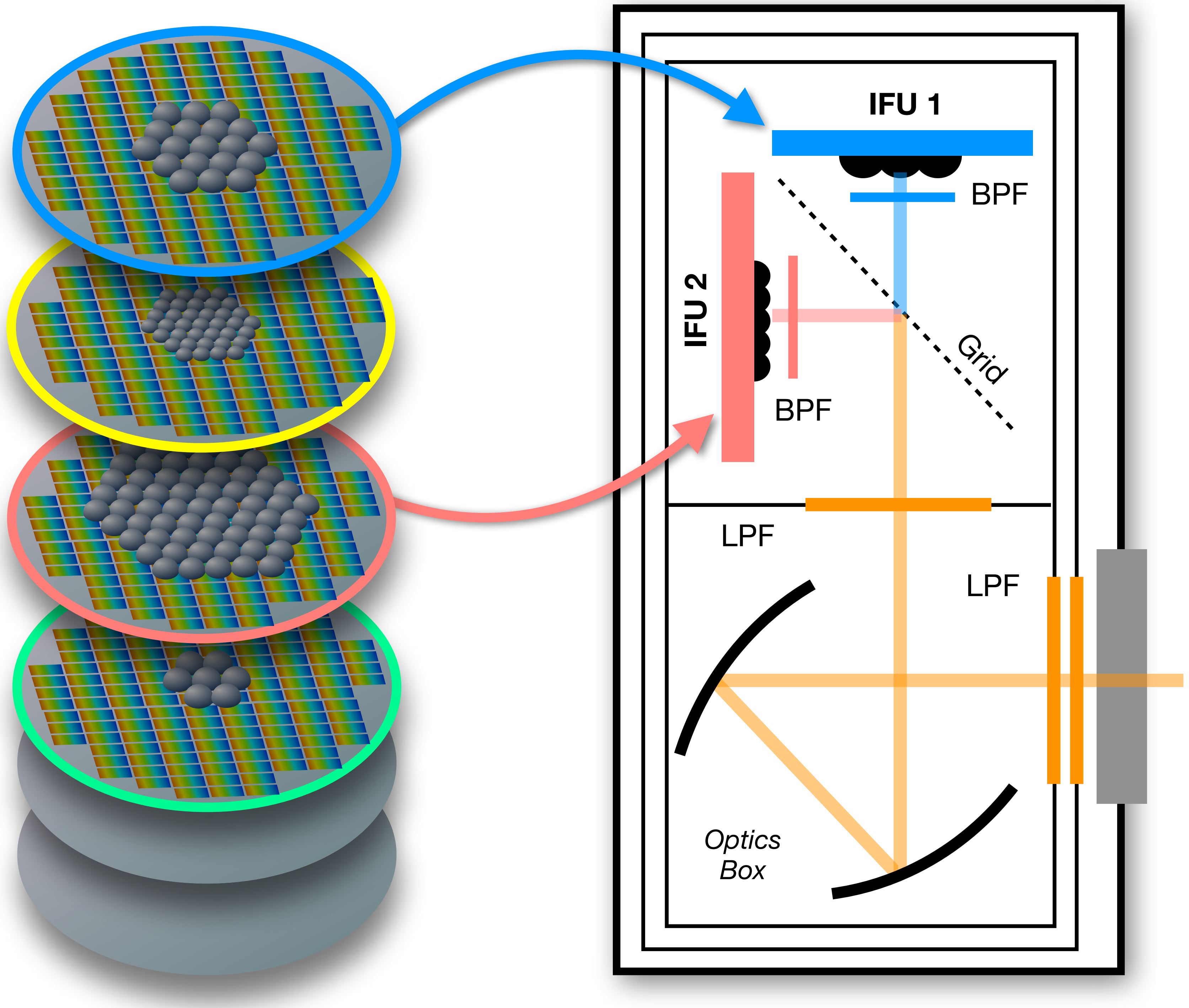
Frequency range	Redshift range	
	[OIII] 88 μm	[CII] 158 μm
190 – 204 GHz	15.7 – 16.9	**8.32 – 9.00**
246 – 265 GHz	11.8 – 12.8	6.17 – 6.73
339 – 365 GHz	**8.31 – 9.00**	4.21 – 4.60

multi-λ, narrow-band imaging spectroscopy

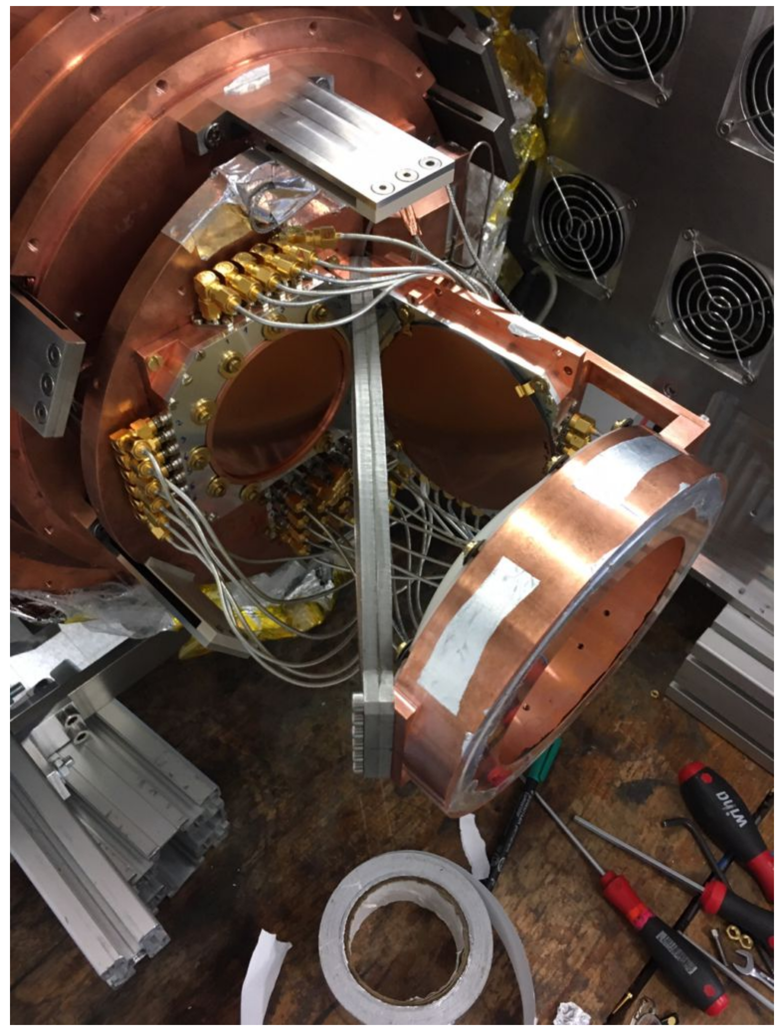


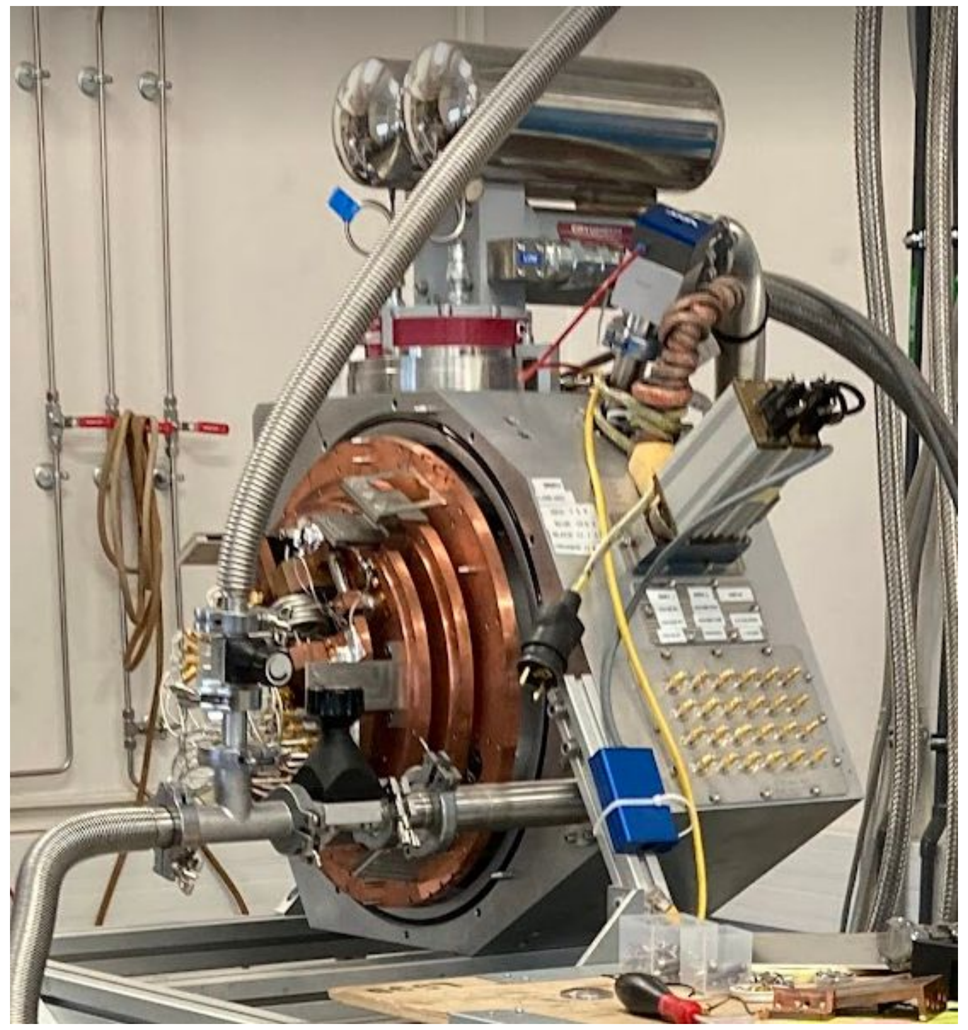
“Plug-and-Play” IFU System

Integral Field Units



Optics and Cryogenics





CONCERTO Dilution Cryostat (Monfardini et al.)
+ New optics for TIFUUN/ASTE

https://neel.cnrs.fr/en/news/concerto-takes-height

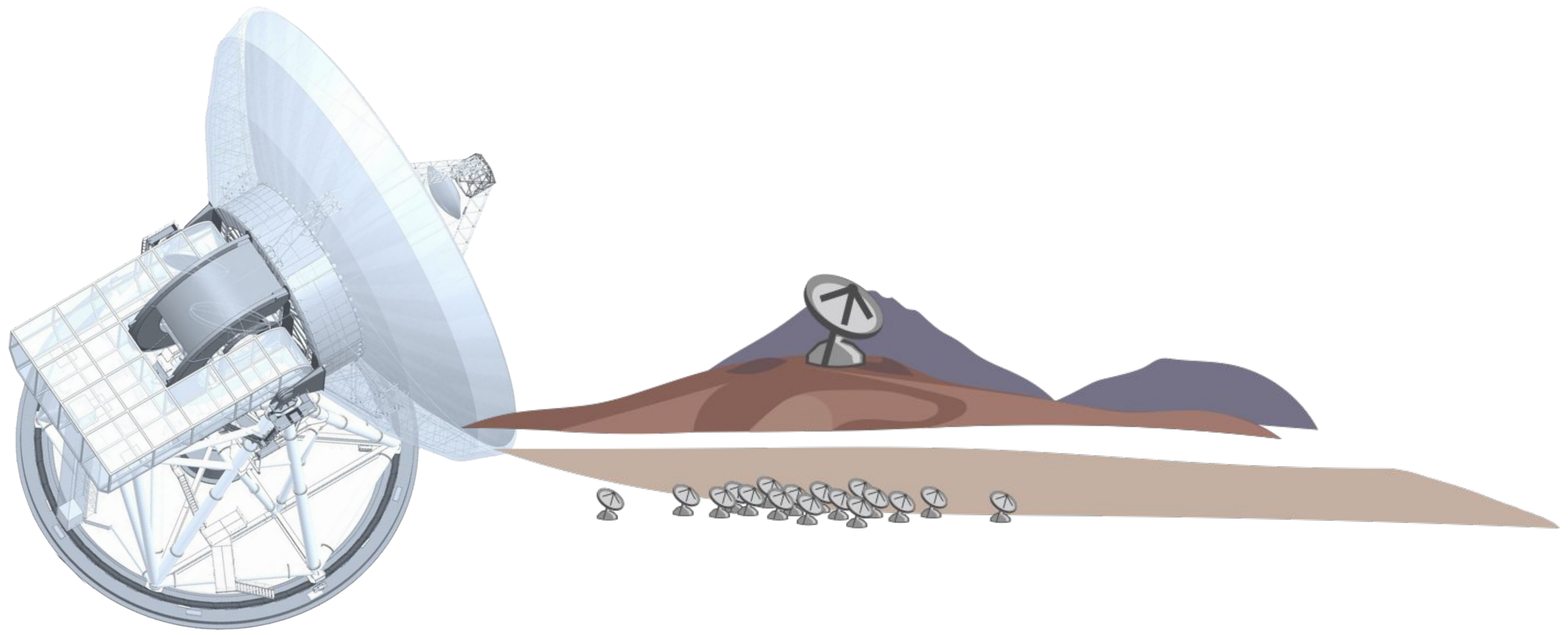
Readout Electronics

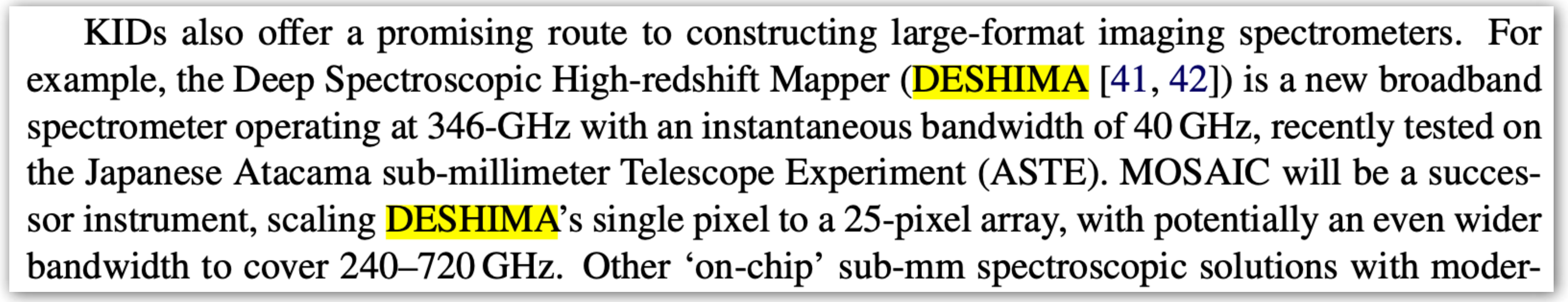
Outlook: THz-IFUs for future observatories

Advantages of superconducting IFUs:

scalable | flexible design | compact | light-weight | no moving parts

Ground (LST, AtLAST)




KIDs also offer a promising route to constructing large-format imaging spectrometers. For example, the Deep Spectroscopic High-redshift Mapper (DESHIMA [41, 42]) is a new broadband spectrometer operating at 346-GHz with an instantaneous bandwidth of 40 GHz, recently tested on the Japanese Atacama sub-millimeter Telescope Experiment (ASTE). MOSAIC will be a successor instrument, scaling DESHIMA's single pixel to a 25-pixel array, with potentially an even wider bandwidth to cover 240–720 GHz. Other 'on-chip' sub-mm spectroscopic solutions with moder-

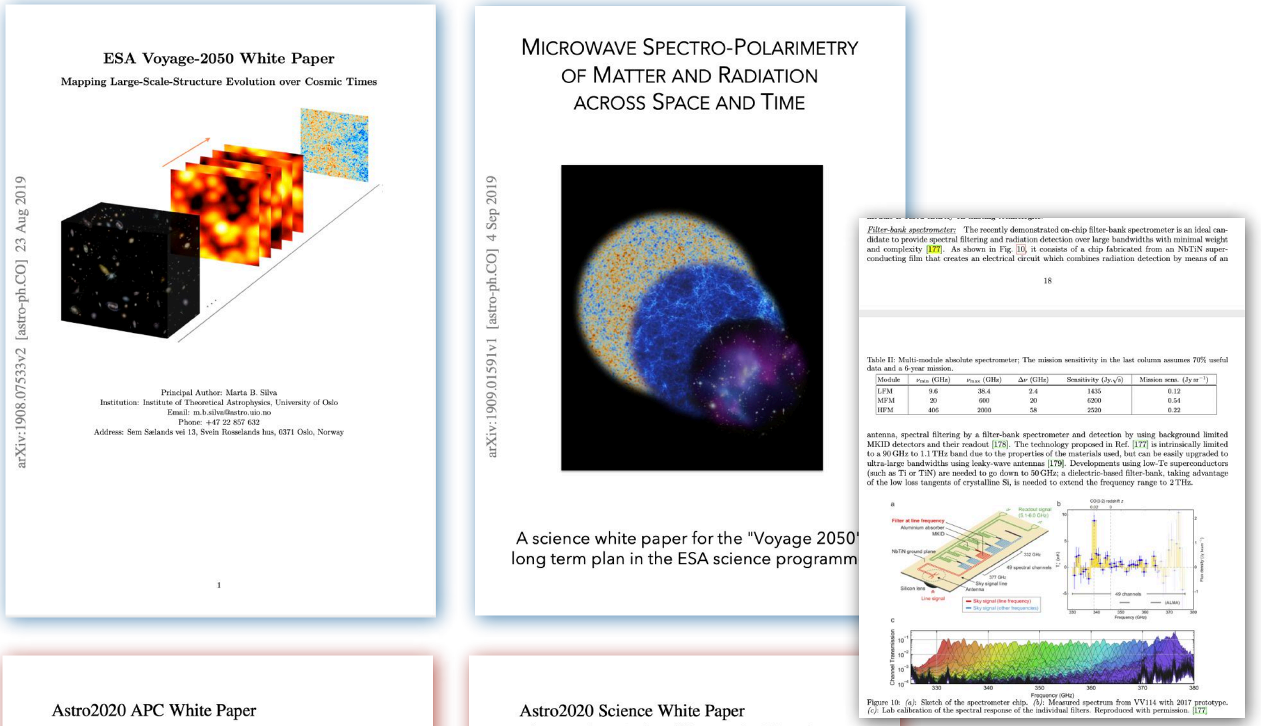
ASTE

DESHIMA (2023)

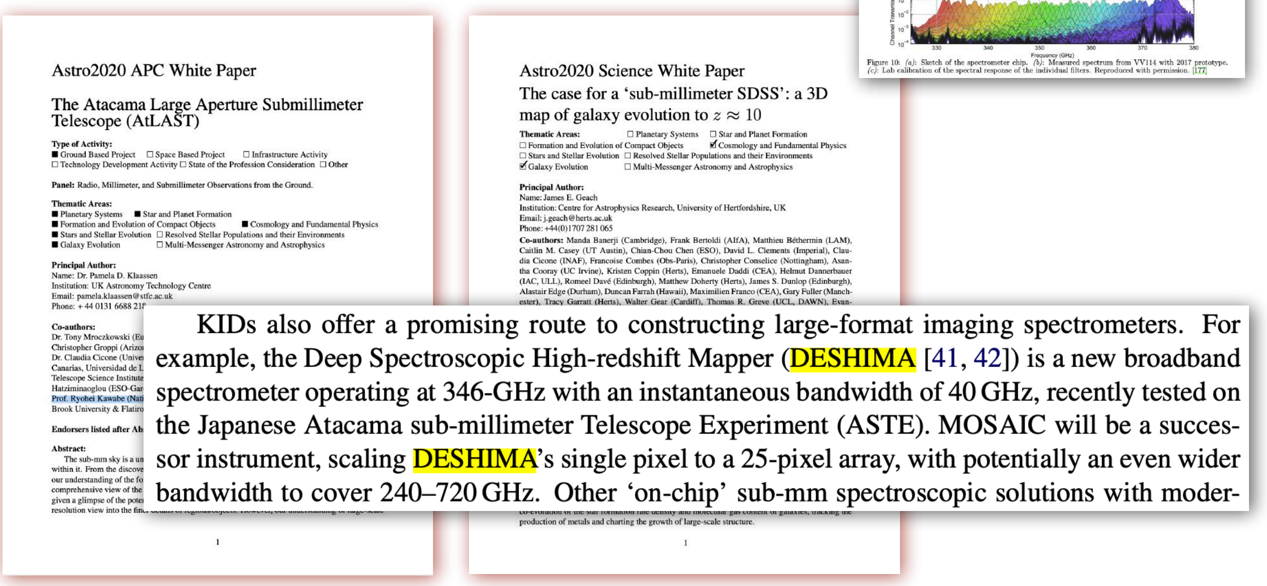
TIFUUN (~2026)

Space (Astro, CMB)

ESA Voyage-2050 White Papers



NASA/NSF Astro2020 White Papers



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