

Toward Ten-Times ALMA: A Large Submillimeter Single-Dish as a Natural Extension of the Array

This talk was originally scheduled to be given by Yoichi Tamura from Nagoya University.
Unfortunately, due to unforeseen circumstances, he is unable to join us today.
I will do my best to present the content on his behalf as faithfully as possible.

Yoichi Tamura (Nagoya) & Kotaro Kohno (UTokyo)

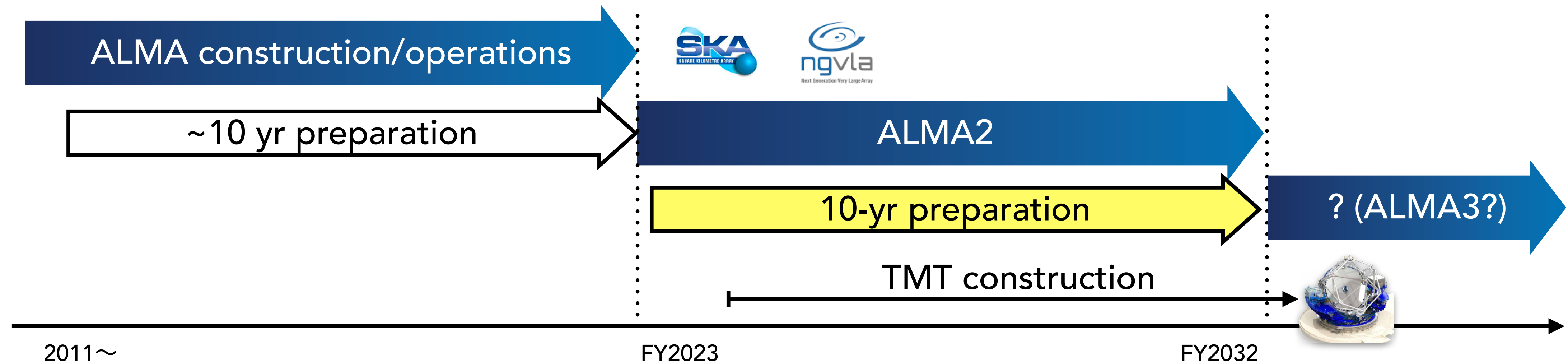
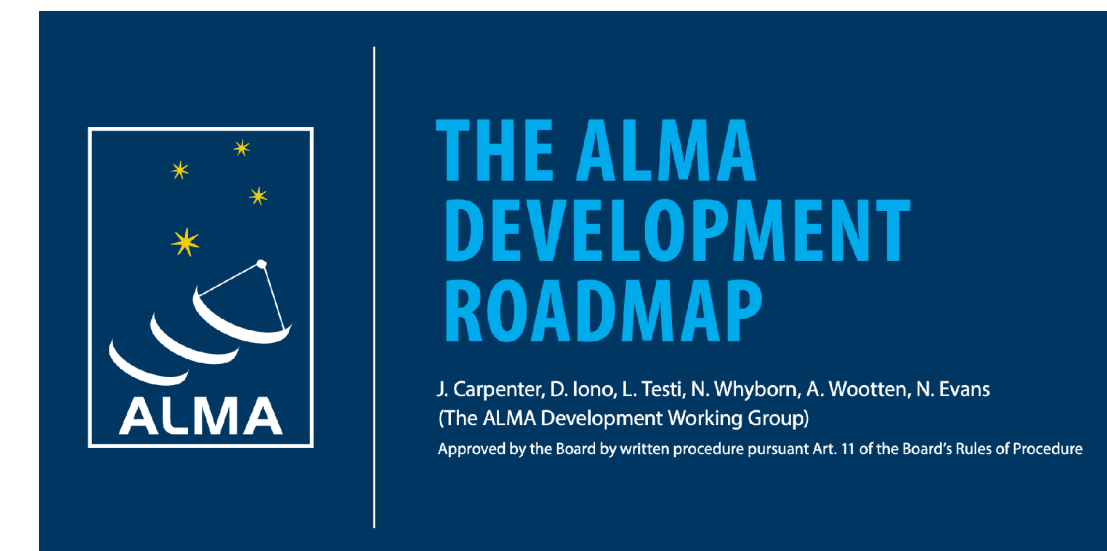
EA ALMA Community Workshop: ALMA2040 Science and Technology Perspectives
15-17 July 2026

Summary

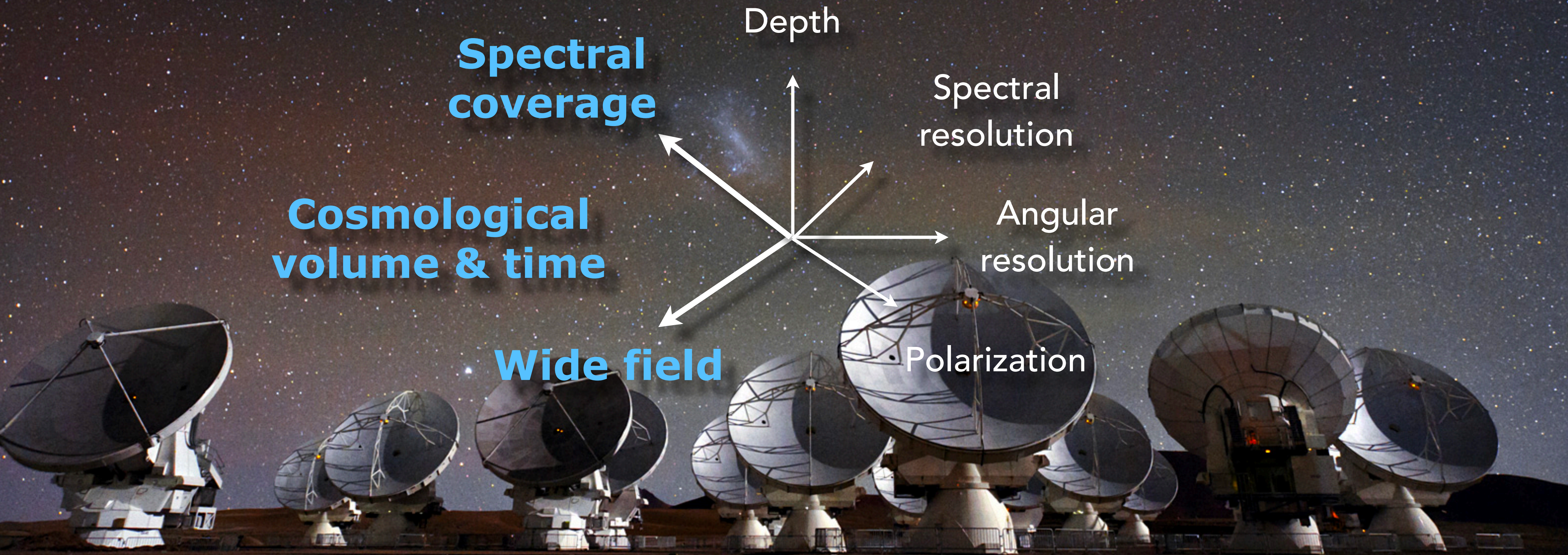
- The ALMA 2040 vision (“ten-times ALMA”) highlights the need for an order-of-magnitude improvement in spectral line sensitivity, motivating consideration of both increased collecting area and expanded array functionality.
- A large-aperture single-dish telescope(s) can play several complementary roles;
 - (1) a **wide-field surveyor** exploiting direct-photon detection technologies, (2) a **zero- and short-spacing sampler** to recover extended emission, and (3) a **high-sensitivity element** contributing to **interferometric and VLBI observations**.
- From a technical standpoint, baselines including a large dish **enhance the fringe sensitivity**, leading to not only improved imaging sensitivity but also **accurate complex gain and bandpass calibration**.
- Cheaper antenna(s) would directly affect the total cost. In addition to **current 12-m ALMA**, AtLAST **50-m (as surveyor and short uv sampler)** plus many cheaper 20-30 m telescopes (**sensitivity enhancer, e.g., 50 x D=25m antennas**) would be a solution?
- Structural optimization and millimeter-wave adaptive optics may enable lighter and more cost-effective large antennas without compromising the surface accuracy required for submillimeter observations.

Toward ALMA2040: A role of large single-dish telescope(s)

- ALMA2030 "long-term" plan: Baseline length, Focal plane array, Number of 12m antennas, **Large single-dish**
- The ALMA Development Roadmap (ALMA2030) has pointed out that **a large-aperture single dish telescope will be complementary to future ALMA** (although ALMA2030 also mentioned that a large SD is beyond the scope).
- Now is the time to think of a long-term plan toward ALMA2040.

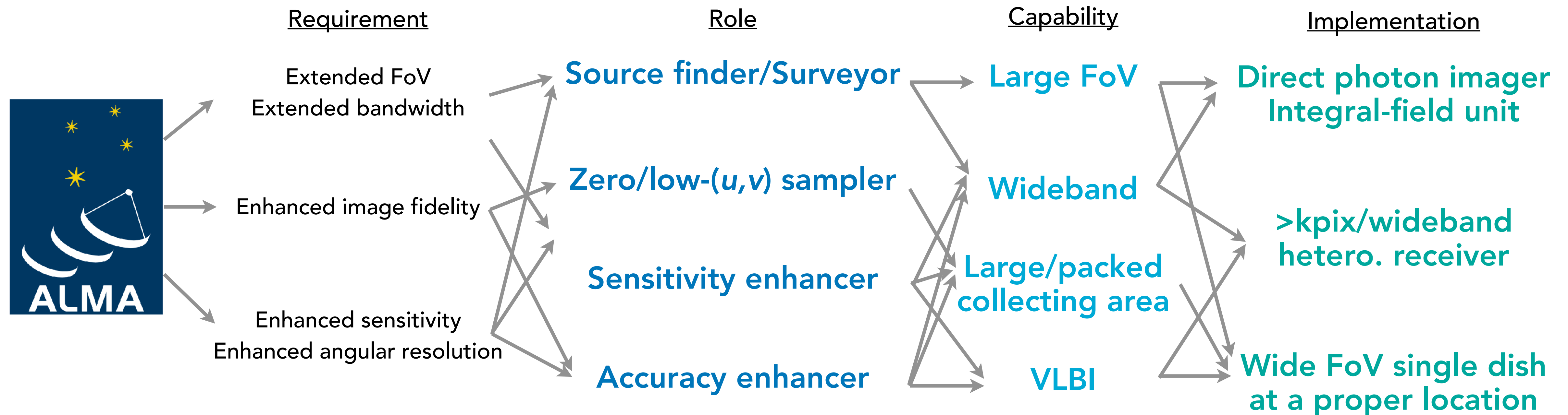


New discovery space?



What capabilities are anticipated in ALMA 2040?

- Capabilities the ALMA/ALMA2 users potentially want - Expected capabilities from LST White Paper



Synergy with ALMA, extension of ALMA



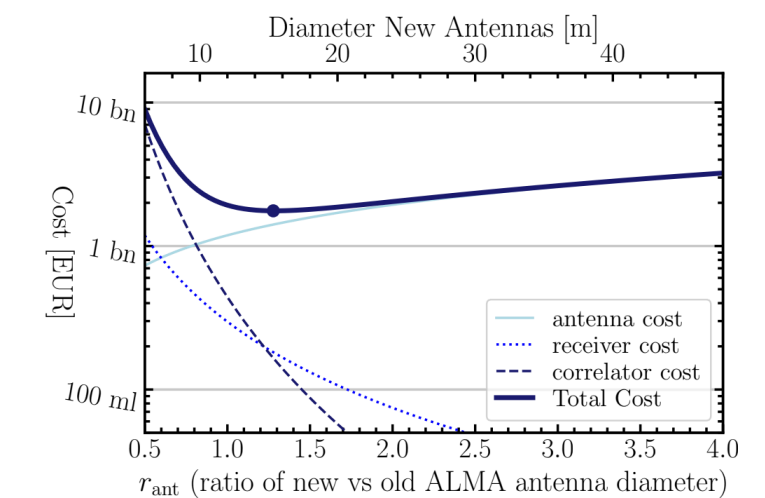
- **Synergy 1: Large SD as an unbiased wide-field surveyor**
 - > sq-deg scale mapping (CMB, clusters of galaxies, galaxy evolution/BH, star-formation/ISM)
 - ~Octave spectral coverage (clusters of galaxies, gal. evo./BH, ISM, planet, astrochem)
 - Transient (gal. evo./BH, SF/stellar evolution, planet)
- **Synergy 2: Large SD as a zero/low-(u,v) sampler**
 - Extended emission recovery (CMB, cluster, SF/ISM, planet, astrochem)
- **Synergy 3: Large SD as a super-sensitive element of ALMA and global VLBI**
 - 40% improvement in point-source sensitivity (all science cases, SMBH)
 - Easy gain/phase cal for long baselines / high-frequencies with 12m-50(?)m gain solutions
 - Free from gain/phase cal limitation of the phasing system (Akiyama et al. (2023), *Galaxies*, ngEHT special issue)

Euro ALMA 2040

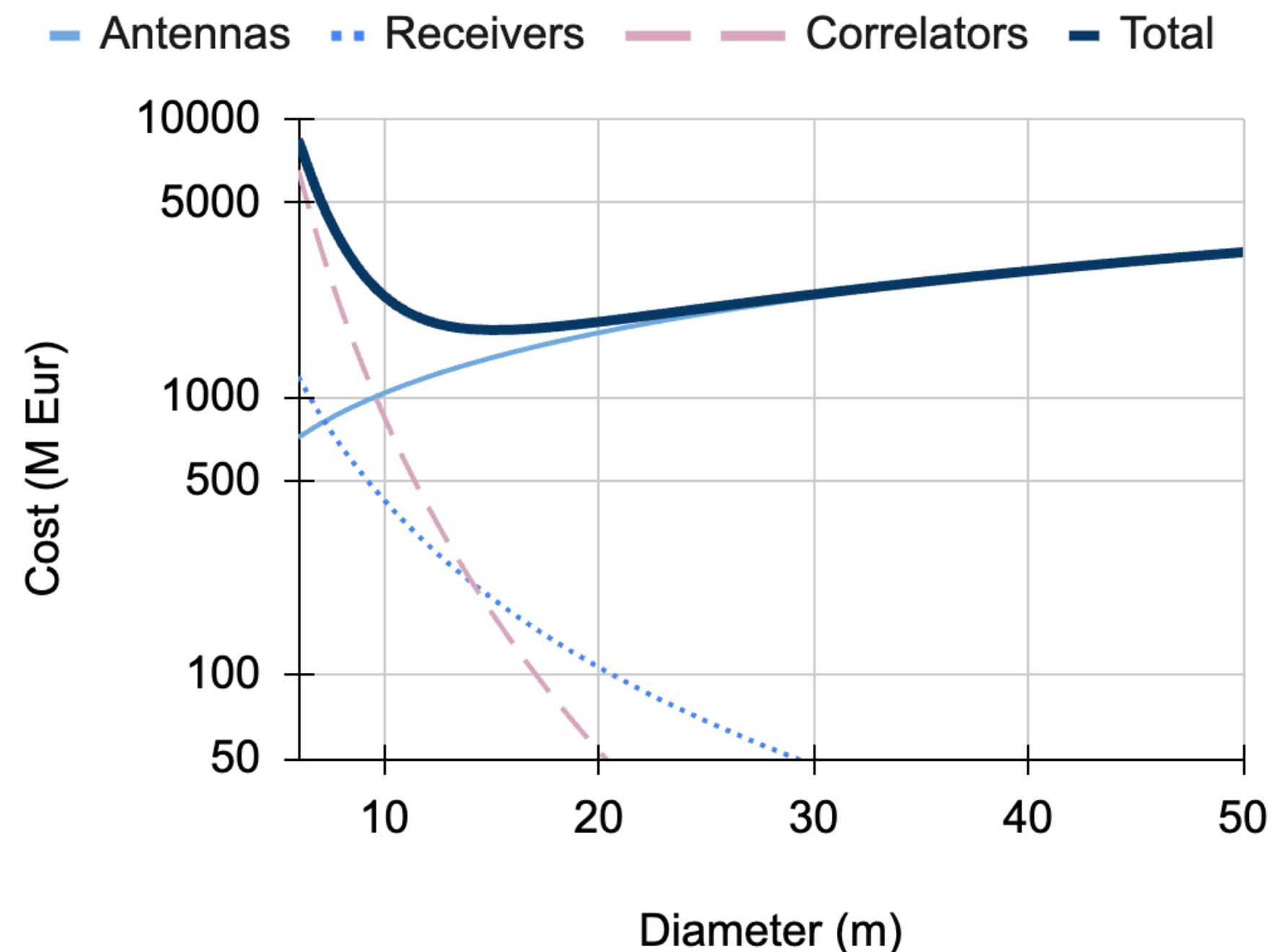
Provided by Tom Bakx
(High-z science WG lead)

Size of telescopes: ~12-15m
Credit to J. den Brok

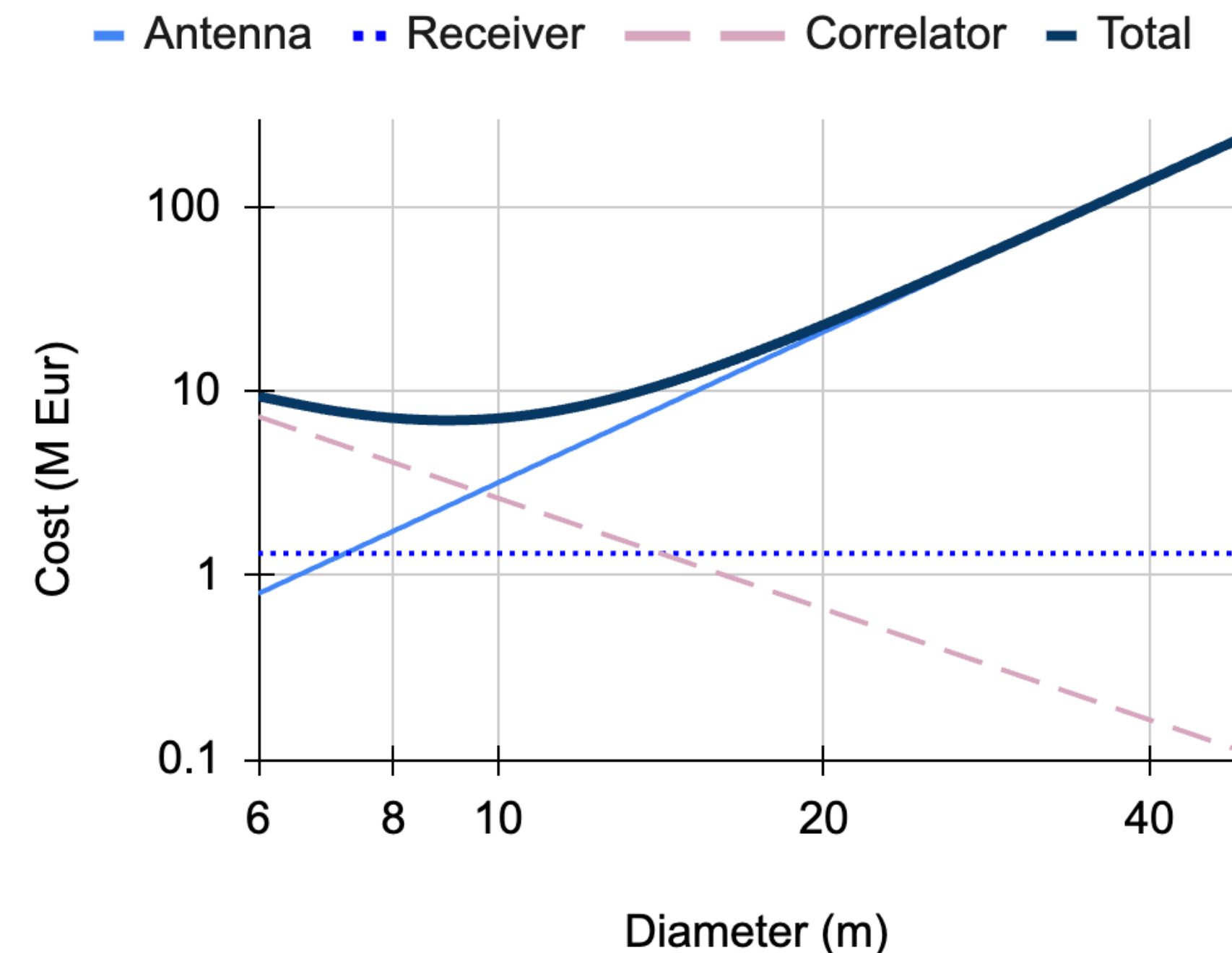
- Antenna cost clearly dominates the total construction cost.
- Re-compute the total cost by assuming:
 - Antenna: €10M/pc * (D/18m)^{2.7} (the famous cost scaling law; Meinel 1978);
 - receiver: €1M/pc; and correlator: €7k/pc



Diameter (m) and Cost (M Eur)



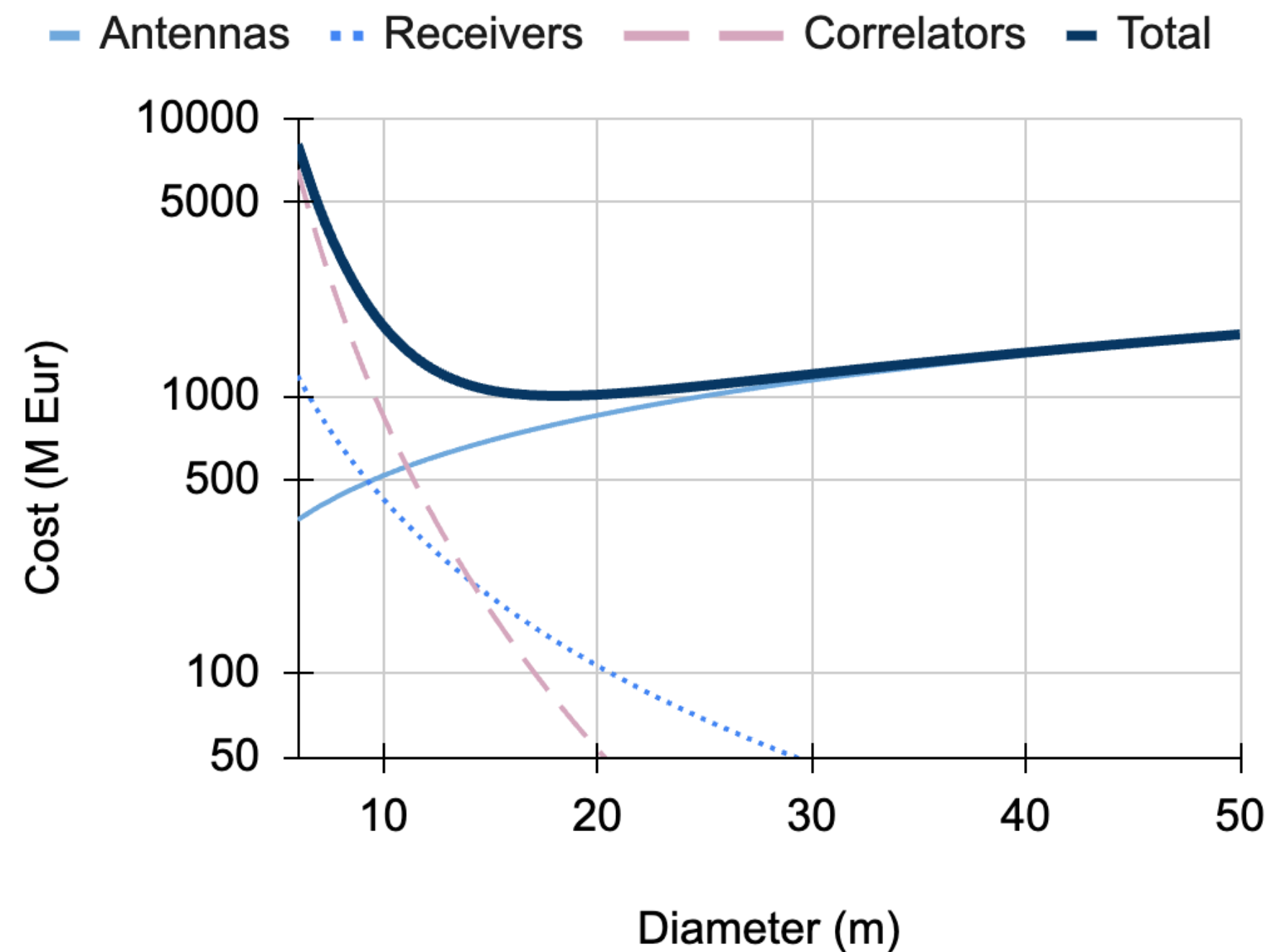
Diameter (m) and Per-Antenna-Cost (M Eur)



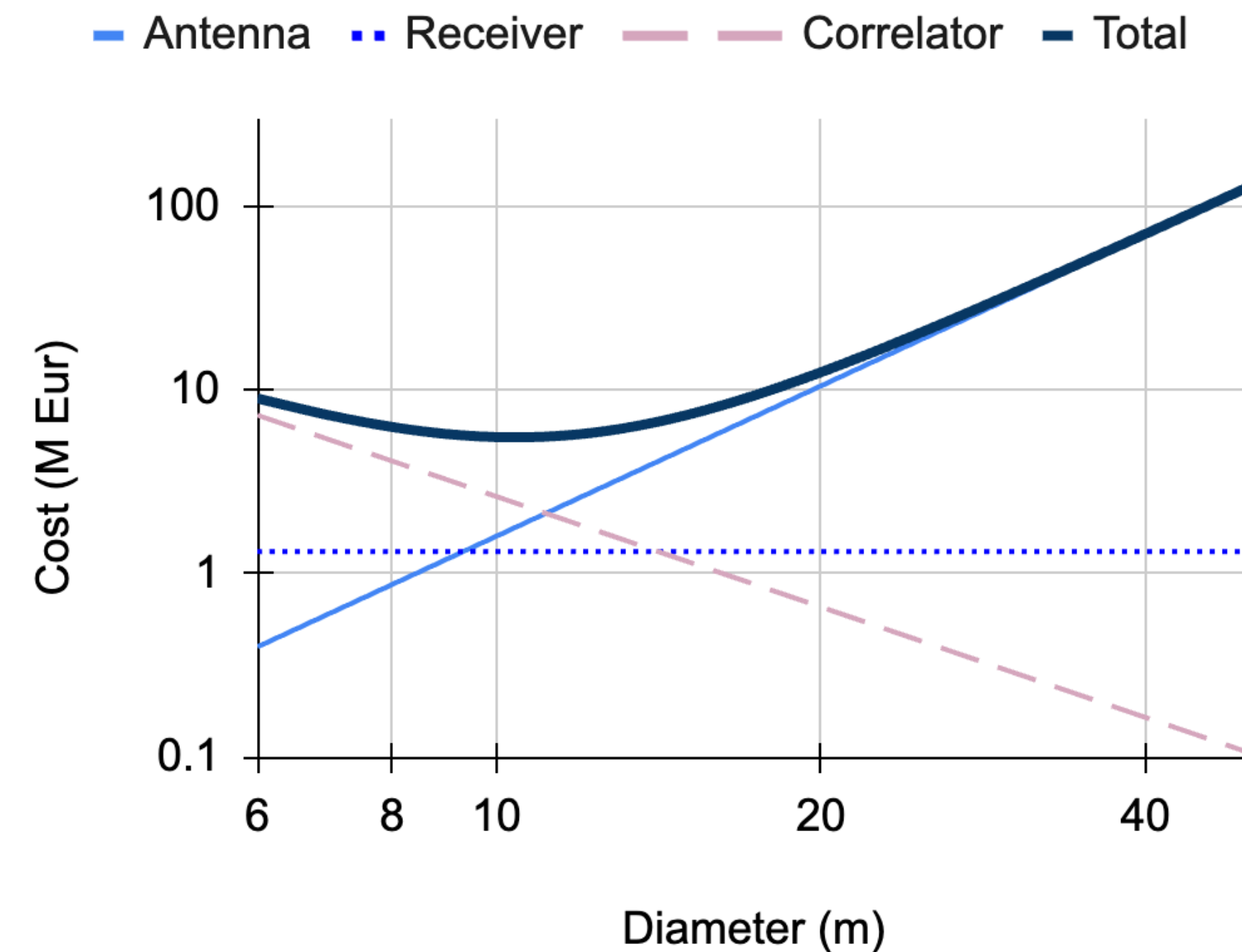
What if Per-Antenna-Cost goes down by 1/2

- If per-antenna cost is reduced by a factor of 1/2, the total cost also goes down.
- Optimal aperture size gets larger.

Diameter (m) and Cost (M Eur)



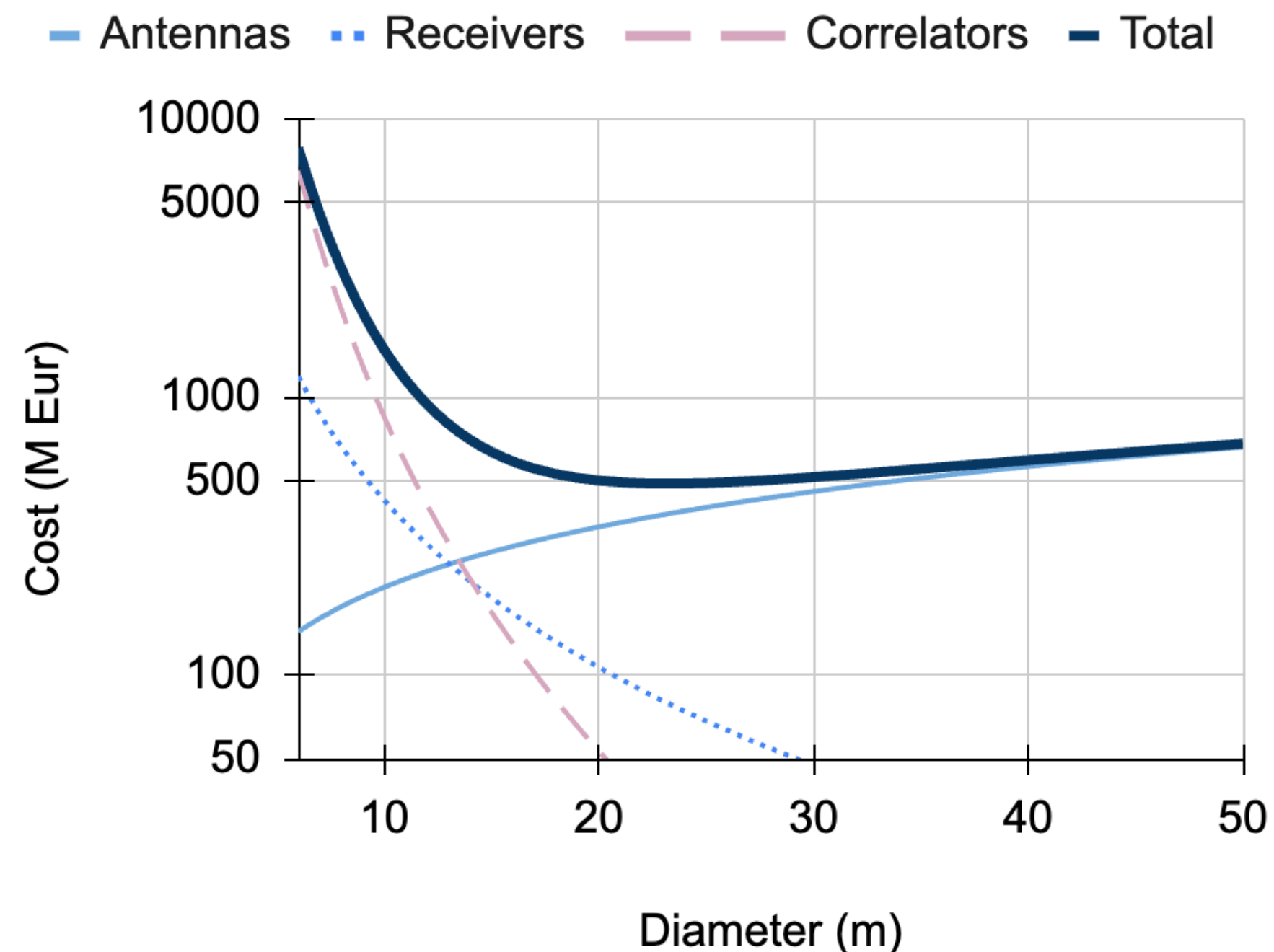
Diameter (m) and Per-Antenna-Cost (M Eur)



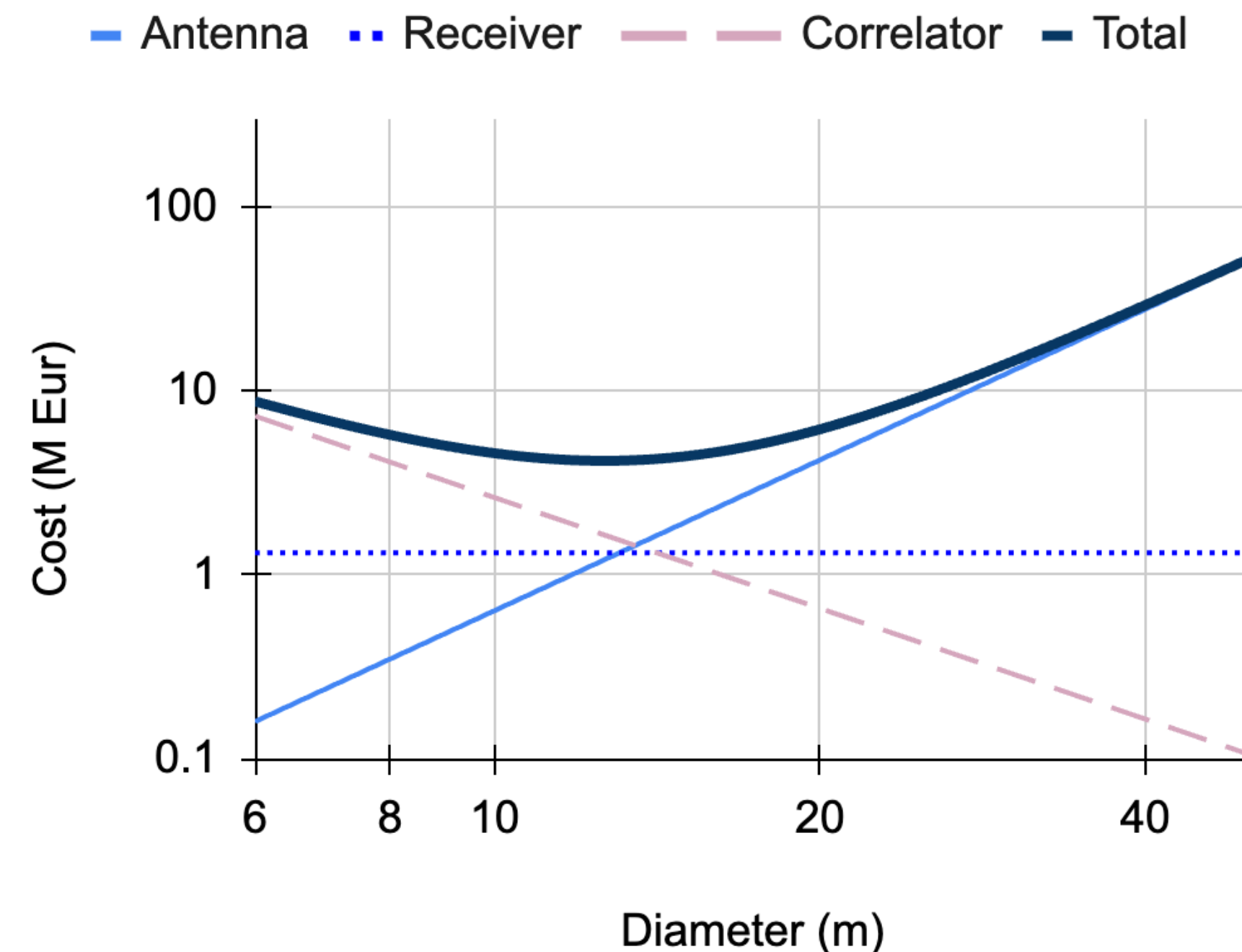
What if Per-Antenna-Cost goes down by 1/5

- If per-antenna cost is reduced by a factor of 1/5, the total cost also goes down.
- Optimal aperture size gets larger.
- The total cost gets almost flat over $D \sim 20\text{-}50$ m and amounts $< 1\text{B}$ Eur.

Diameter (m) and Cost (M Eur)

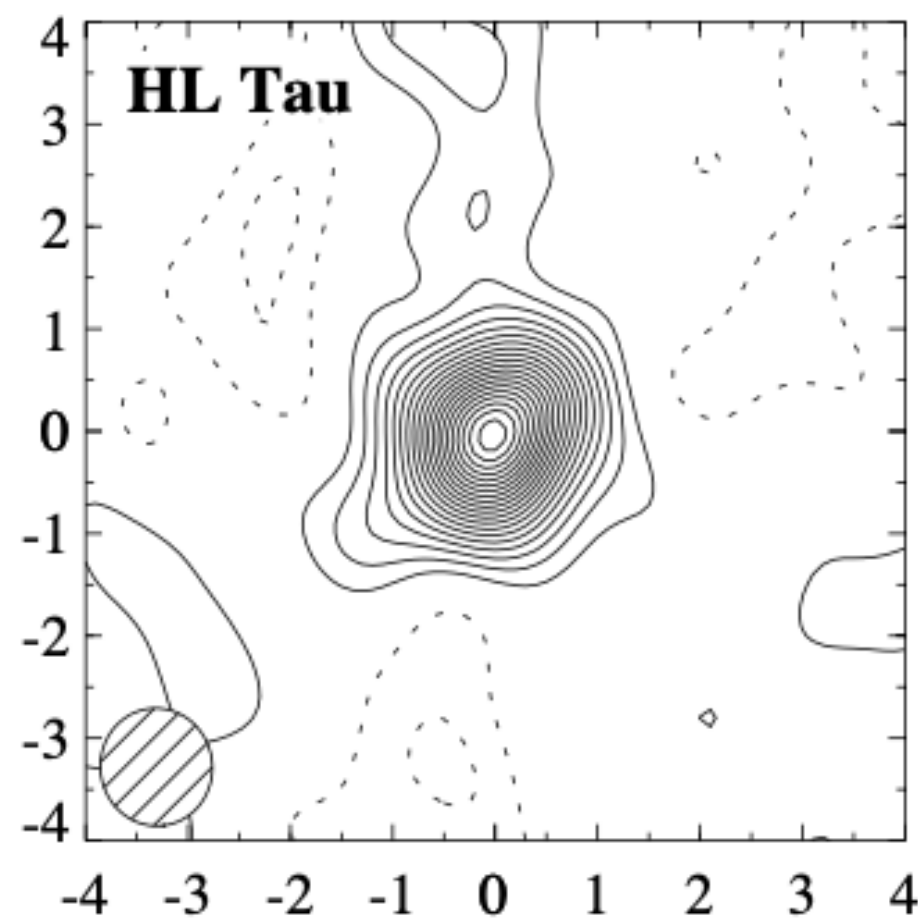


Diameter (m) and Per-Antenna-Cost (M Eur)

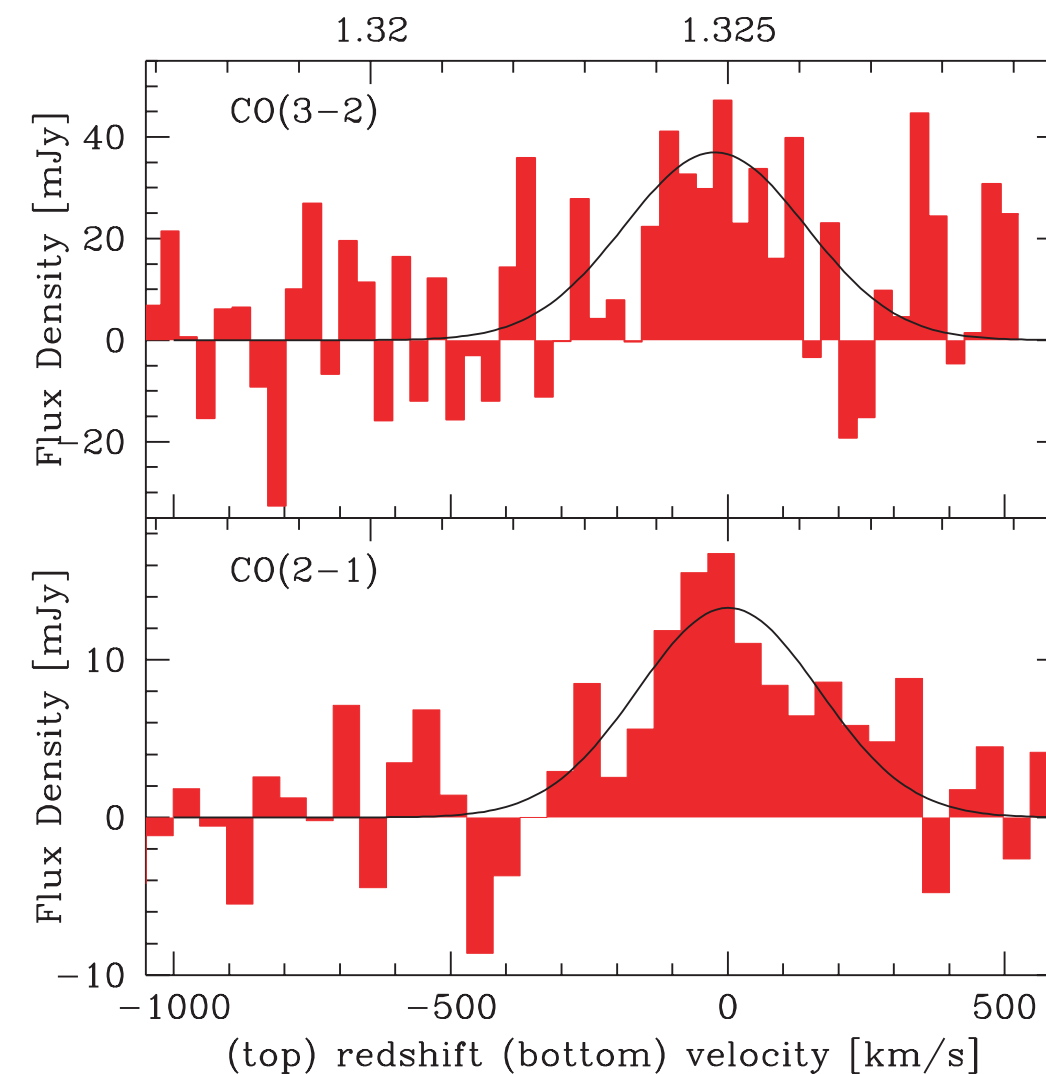


Nobeyama Rainbow Interferometer

- The concept builds on our experience of the Nobeyama Rainbow interferometer; a heterogeneous array combining the 45 m and the Nobeyama Millimeter Array (NMA), used for studies on proto-planetary disks and high-redshift galaxies.
- Extending such an approach to ALMA may provide a useful pathway toward improving sensitivity and expanding its scientific capabilities.



Kitamura, Momose, et al. (2002)



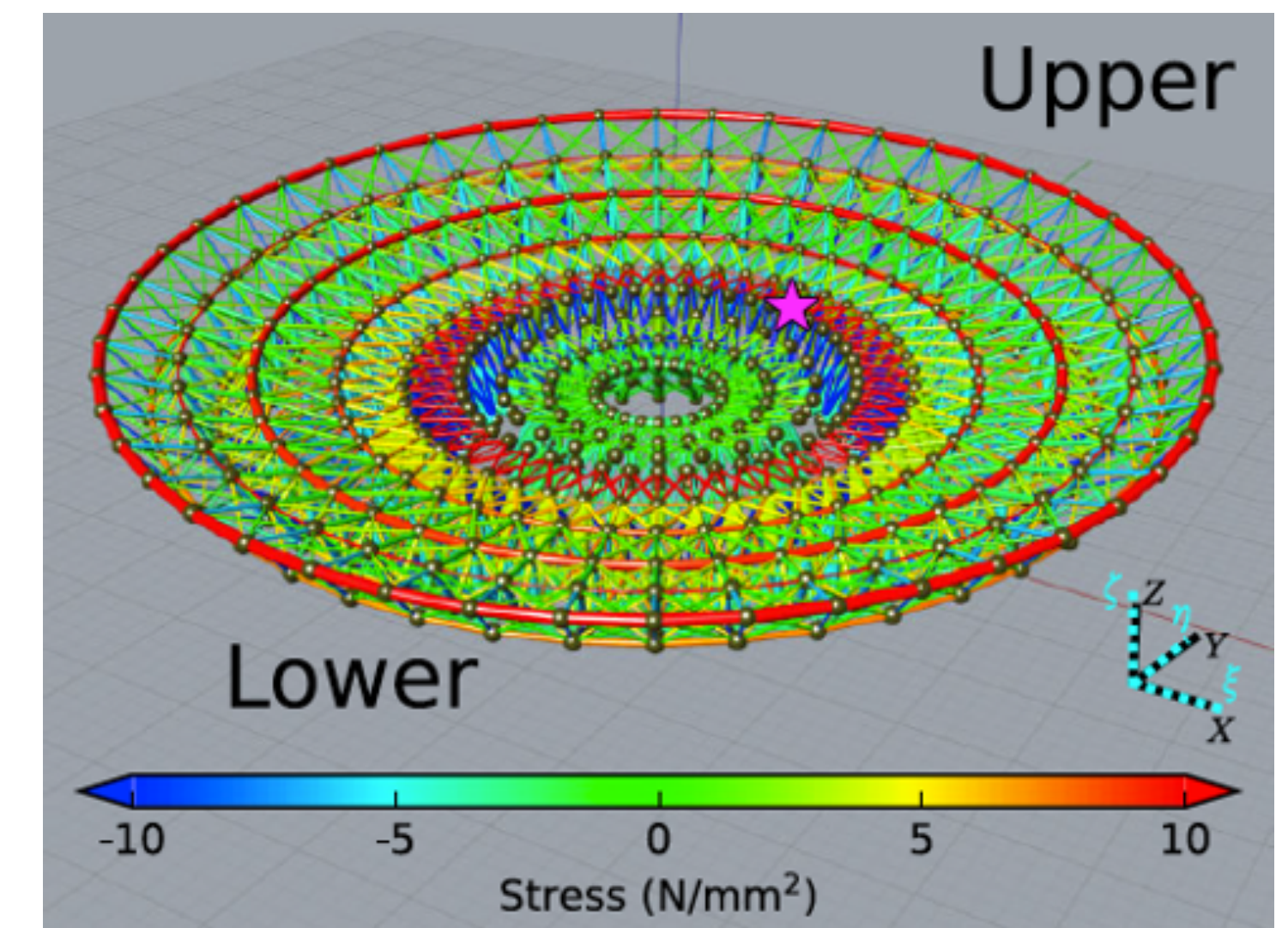
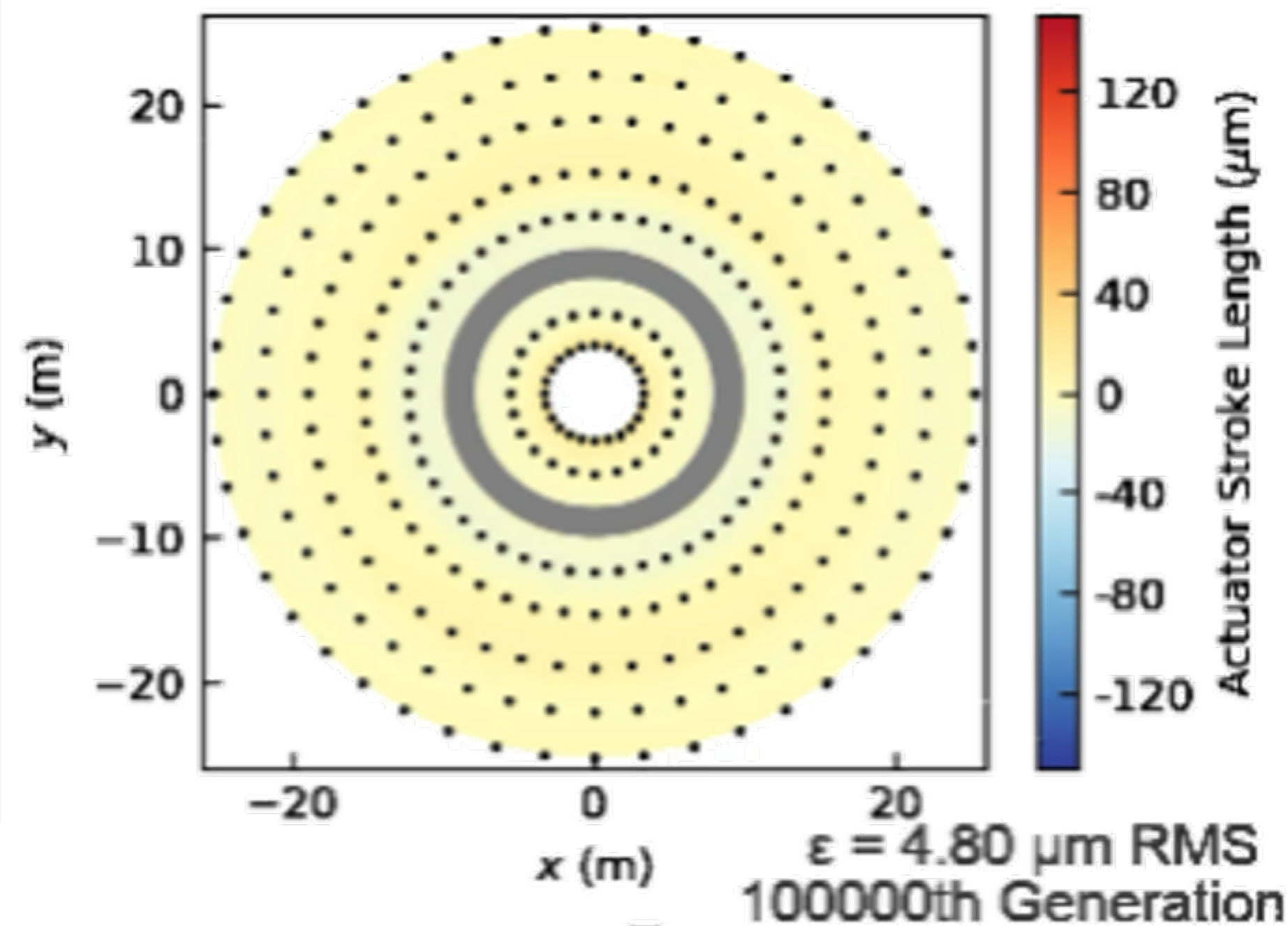
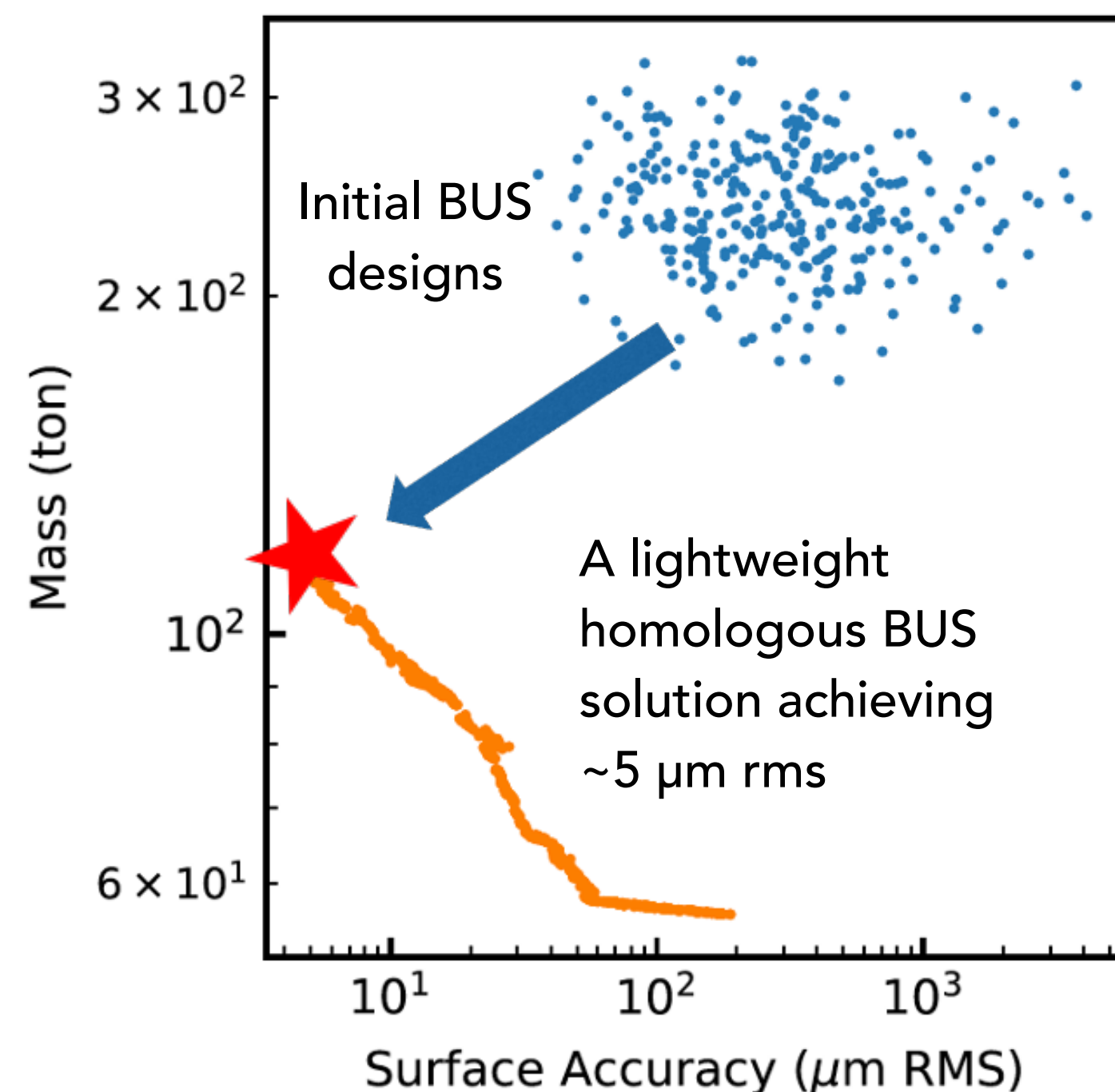
Iono, Tamura, Nakanishi, Kawabe, Kohno et al. (2006)



Reducing Antenna Cost through Structural Optimization

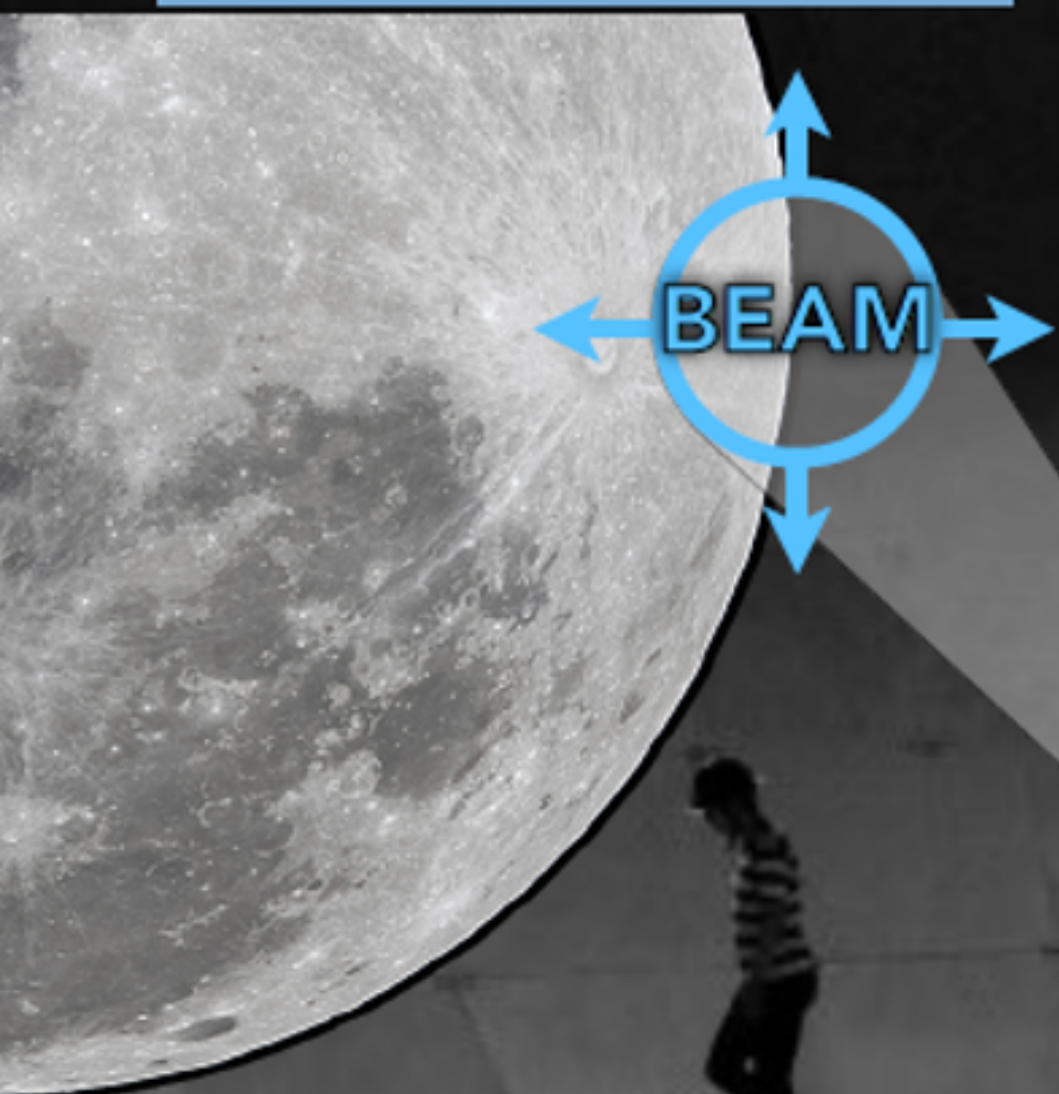
- Developed backup structure (BUS) design methodology for a 50-m class submillimeter telescope with a genetic algorithm, an optimization technique inspired by natural selection
- The algorithm searches for lightweight, high-stiffness structural solutions
- Achieved 5 μm RMS surface accuracy in numerical simulations

Imamura, C., Tamura, Y., et al.
2025, PASJ, 77, 945

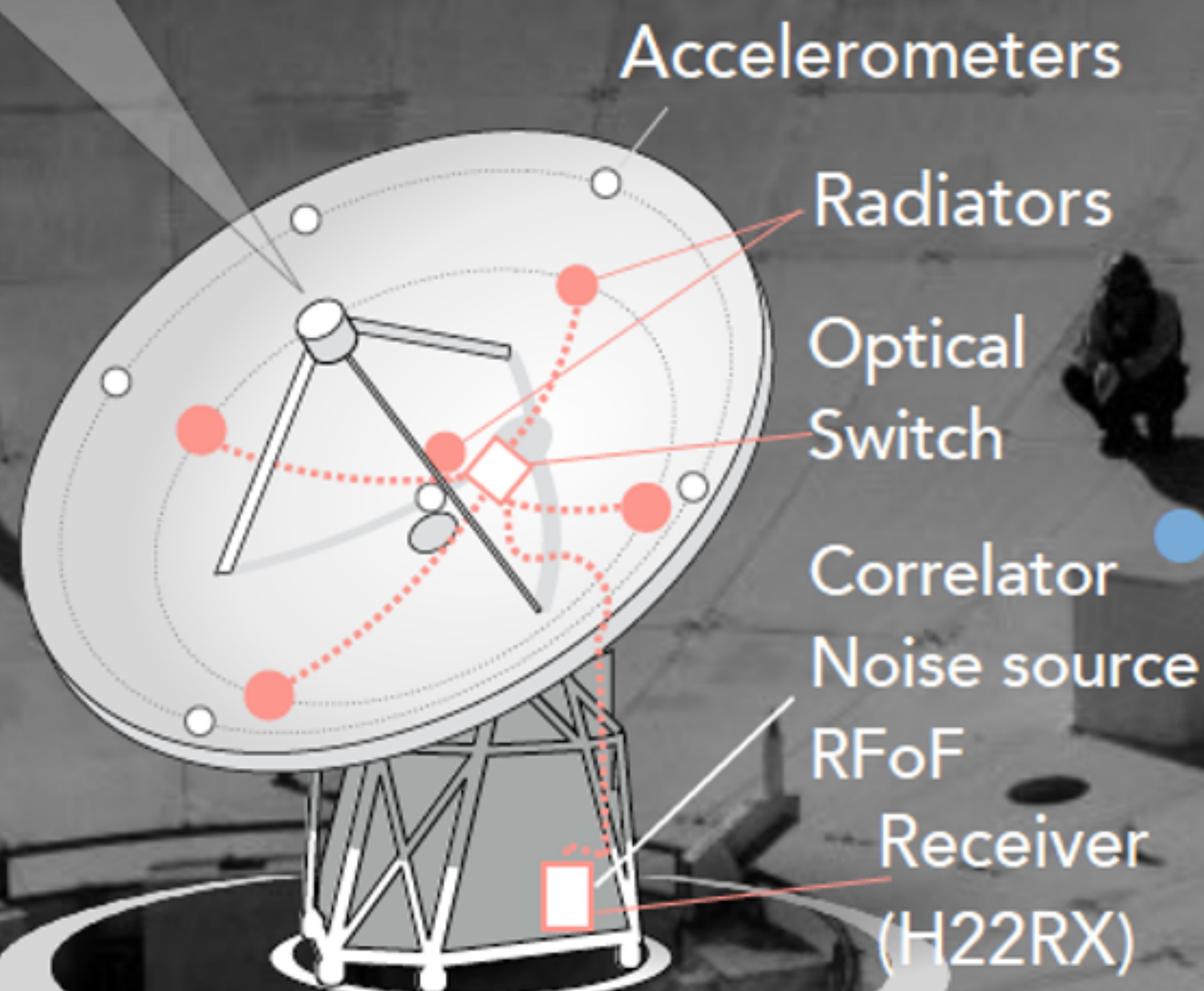
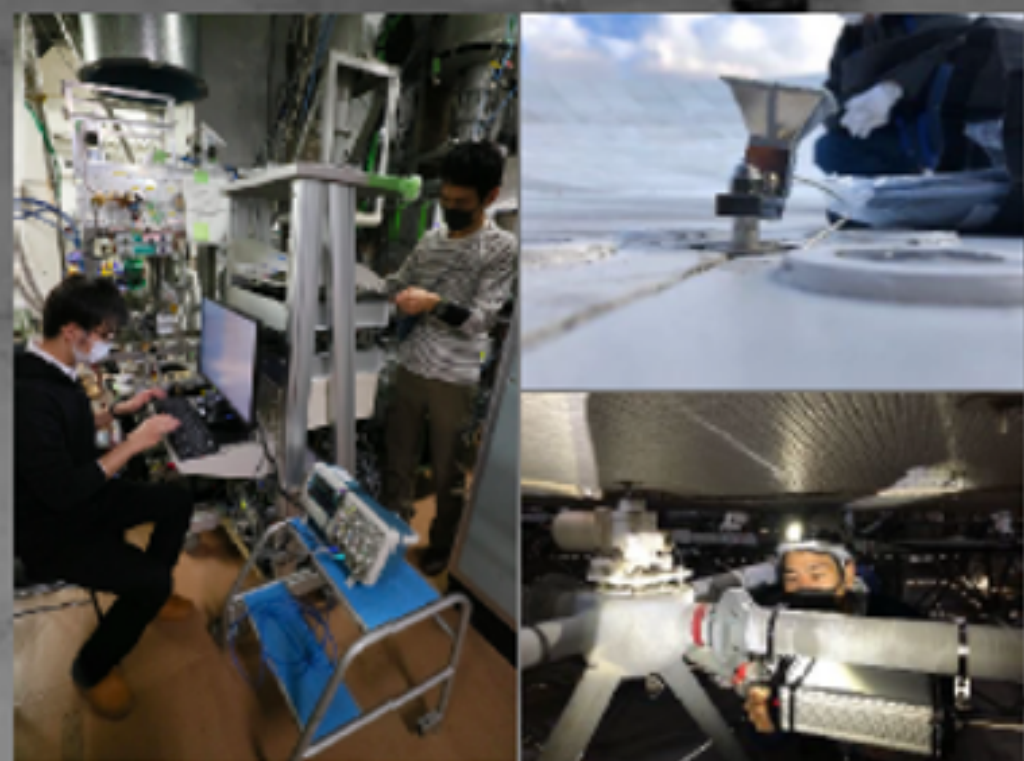


Microwave Wavefront Sensor at Nobeyama 45 m

See Taniguchi, A., Tamura, Y., et al., presented at SPIE Copenhagen 2026, for the latest results.



Beam filling factor
= Pointing error in radial
direction



- **Demonstration with 5-element 20-GHz wavefront sensor (2020, 2022, 2024)**

- Broadband noise source at 16–24 GHz was used as a phase reference and was radiated from 5 feed horns on the M1 surface.
- A statistical error of $8\text{ }\mu\text{m}$ RMS is achieved (for 100 ms integration). S/N is limited by the power of reference signal. (Nakano+2022, Proc. SPIE)
- ~30–100 s stability is assured.

- **"Moon edge" experiment**

- Pointing as the lowest order of deformation
- The beam filling factor for the Moon edge is monitored by RX's total power while the wavefront sensor is being operated.

From Nobeyama Demonstration toward AtLAST Implementation

AtLAST

<https://www.atlast.uio.no/>

Towards an Atacama Large Aperture Submillimeter Telescope

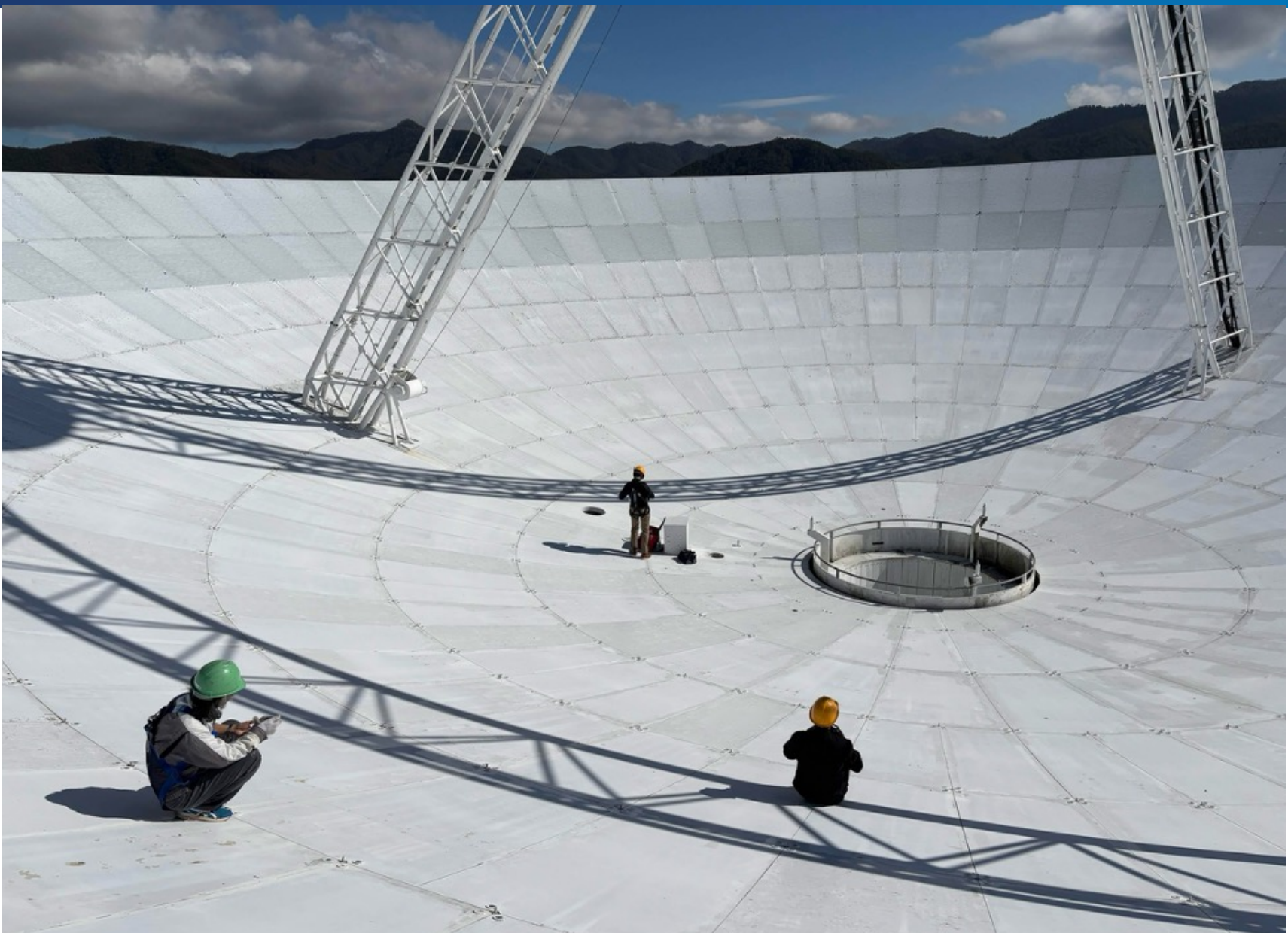


Intranet Search



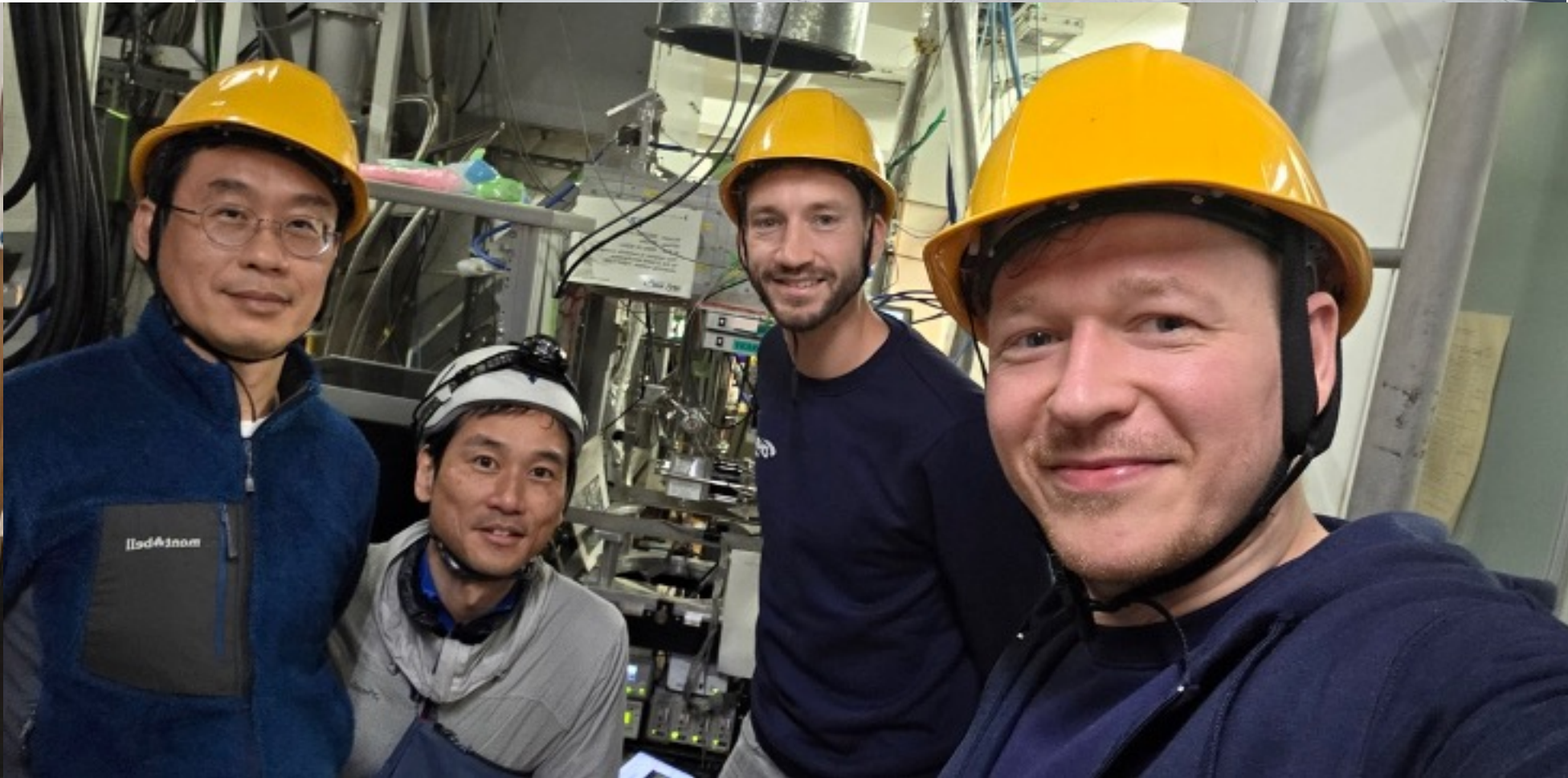
Home AtLAST2 Science Publications Memo series Sensitivity Calculator News and Events About

In October 2025, experts from OHB Digital Connect joined the millimeter-wave adaptive optics experiment at Nobeyama as part of the AtLAST2 program.



Learning Millimeter-Wave Adaptive Optics for AtLAST: Insights from Nobeyama

Experts from OHB Digital Connect are collaborating with the Nobeyama team to investigate Millimeter-Wave Adaptive Optics (MAO), a promising technology that could facilitate unprecedented levels of optical control for AtLAST.



Summary

- The ALMA 2040 vision (“ten-times ALMA”) highlights the need for an order-of-magnitude improvement in spectral line sensitivity, motivating consideration of both increased collecting area and expanded array functionality.
- A large-aperture single-dish telescope(s) can play several complementary roles;
 - (1) a **wide-field surveyor** exploiting direct-photon detection technologies, (2) a **zero- and short-spacing sampler** to recover extended emission, and (3) a **high-sensitivity element** contributing to **interferometric and VLBI observations**.
- From a technical standpoint, baselines including a large dish **enhance the fringe sensitivity**, leading to not only improved imaging sensitivity but also **accurate complex gain and bandpass calibration**.
- Cheaper antenna(s) would directly affect the total cost. In addition to **current 12-m ALMA**, AtLAST **50-m (as surveyor and short uv sampler)** plus many cheaper 20-30 m telescopes (**sensitivity enhancer, e.g., 50 x D=25m antennas**) would be a solution?
- Structural optimization and millimeter-wave adaptive optics may enable lighter and more cost-effective large antennas without compromising the surface accuracy required for submillimeter observations.

Note

- Cheaper antenna(s) would directly affect the total cost. In addition to current 12-m ALMA, AtLAST 50-m (as surveyor and short uv sampler) plus many cheaper 20-30 m telescopes (sensitivity enhancer, e.g., 50 x D=25m antennas) would be a solution?
- Current ALMA: 50 × 12-m antennas The comparison uses the nominal 50 × 12-m main array as the reference and does not include the ACA.
- Adding one 50-m antenna, equivalent to approximately 17 × 12-m antennas, increases the total collecting area by a factor of approximately 1.35.
- Adding 50 × 25-m antennas increases the total collecting area by a factor of approximately 5.3, equivalent to approximately 267 × 12-m antennas in total.
- Adding both 50 × 25-m antennas and one 50-m antenna increases the total collecting area by a factor of approximately 5.7, equivalent to approximately 284 × 12-m antennas in total.