



The high-definition future of mm/submm astronomy

ALMA2040 team

Talk given by Martina C. Wiedner (Paris Observatory)

With slides by Jackie Hodge, Stefano Facchini, Eva Schinnerer, Gie Han Tan, Maria Diaz Trigo, Andrey Baryshev, Tom Baxk et al.

The Atacama Large (sub-)Millimeter Array (ALMA)

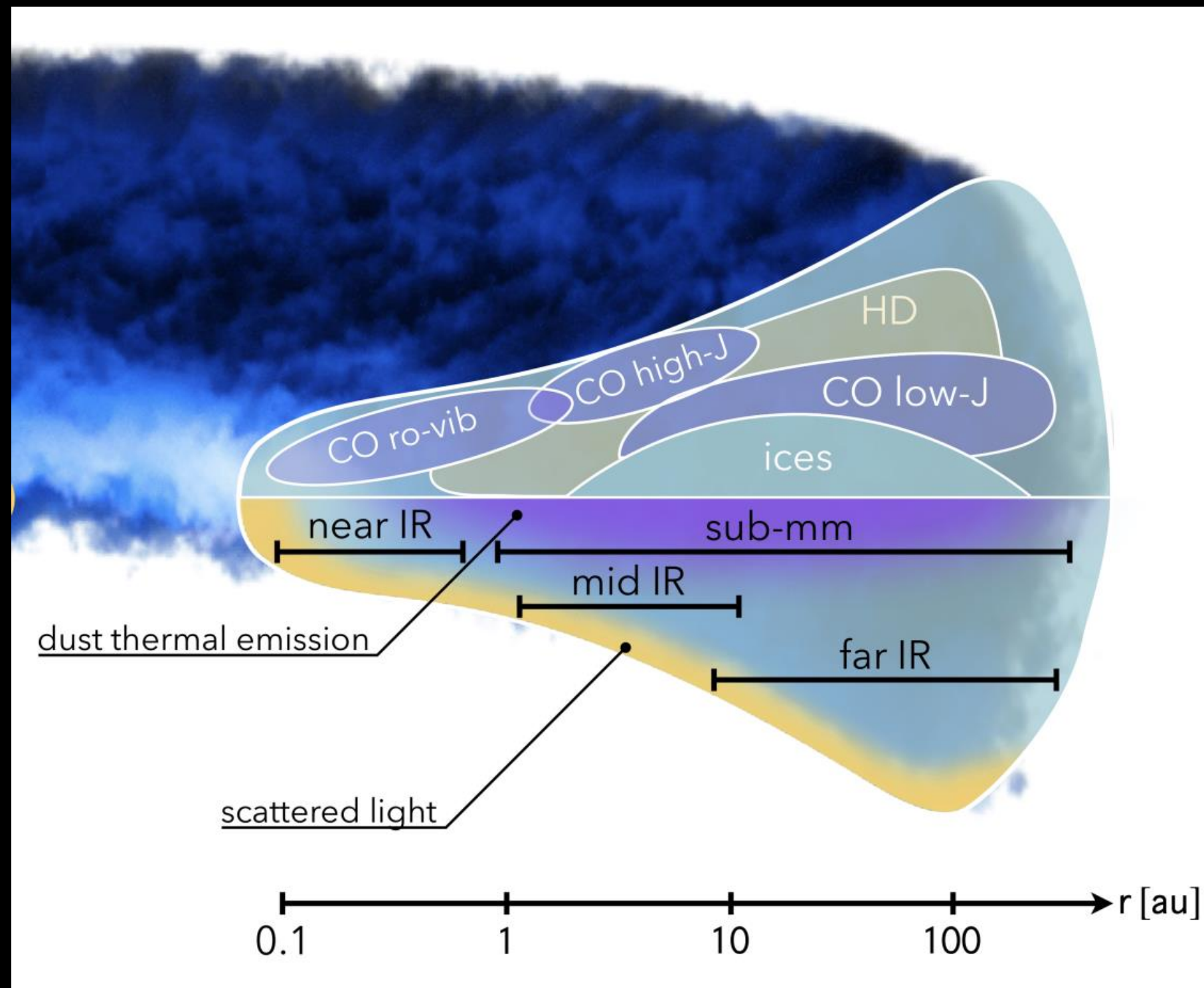


A recent analysis shows that currently, the impact factor for ALMA publications is larger than that of all other major astronomical facilities (Stoehr et al. 2026)*

Sub-mm provides essential access to the cold universe

Protoplanetary disks:

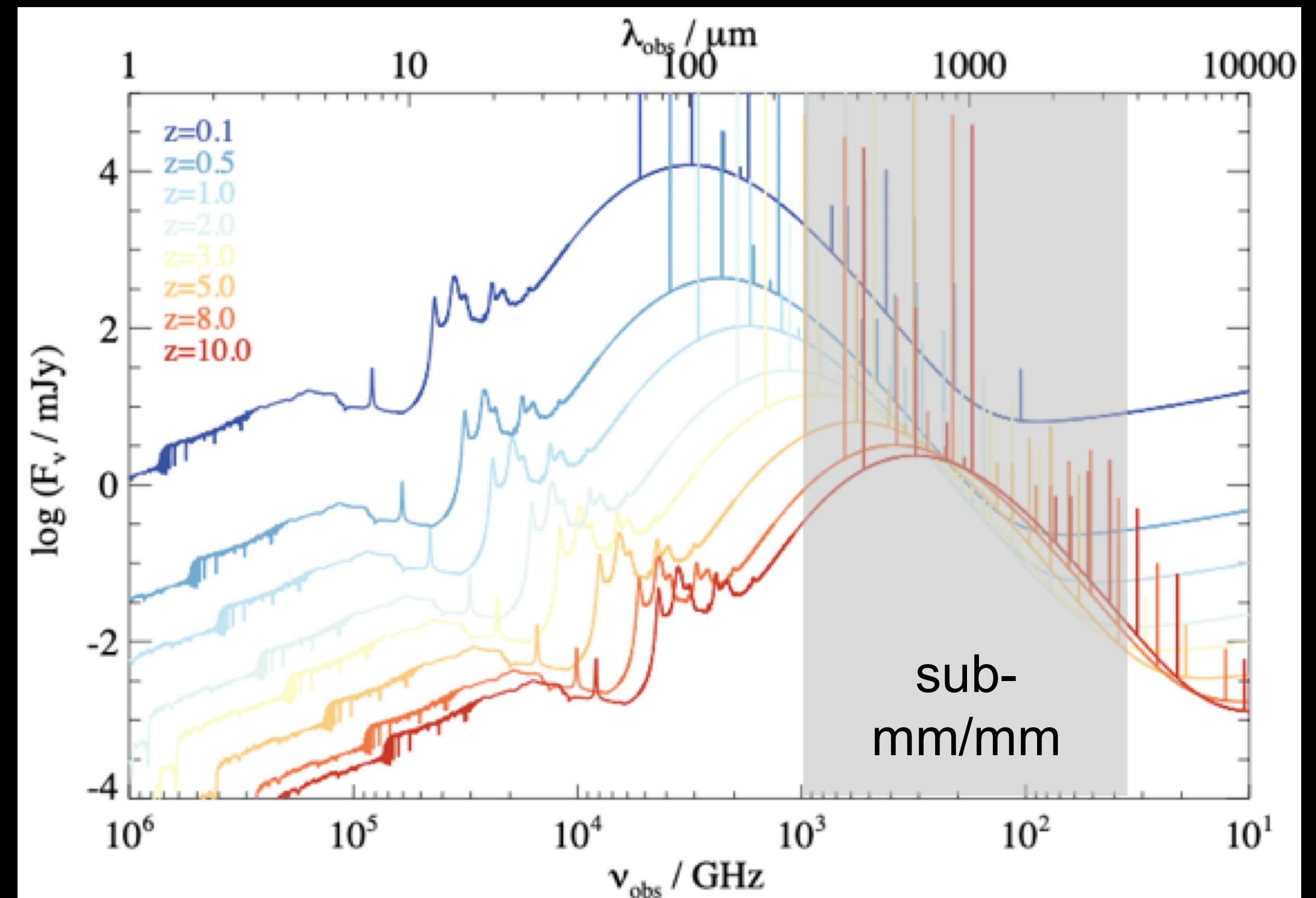
Sub-mm - cm range probes bulk of disk mass (gas and solids)



Credit: Til Birnstiel; Miotello+2023

Galaxies/ISM:

Sub-mm traces dust, molecular & neutral gas, and redshifted FIR fine-structure lines



Hodge & da Cunha 2020

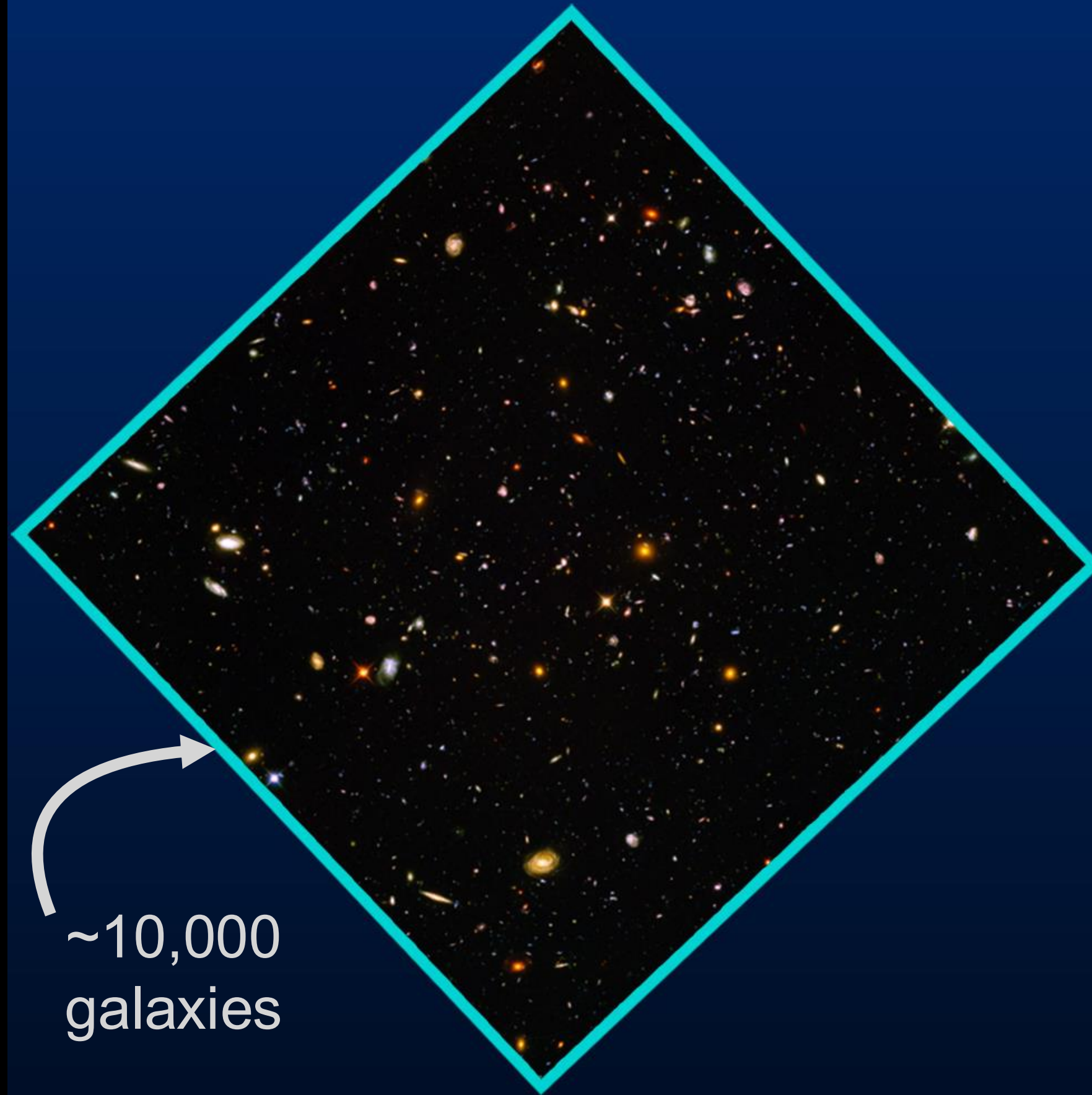
Even *before* JWST, the sub-mm was playing catch-up



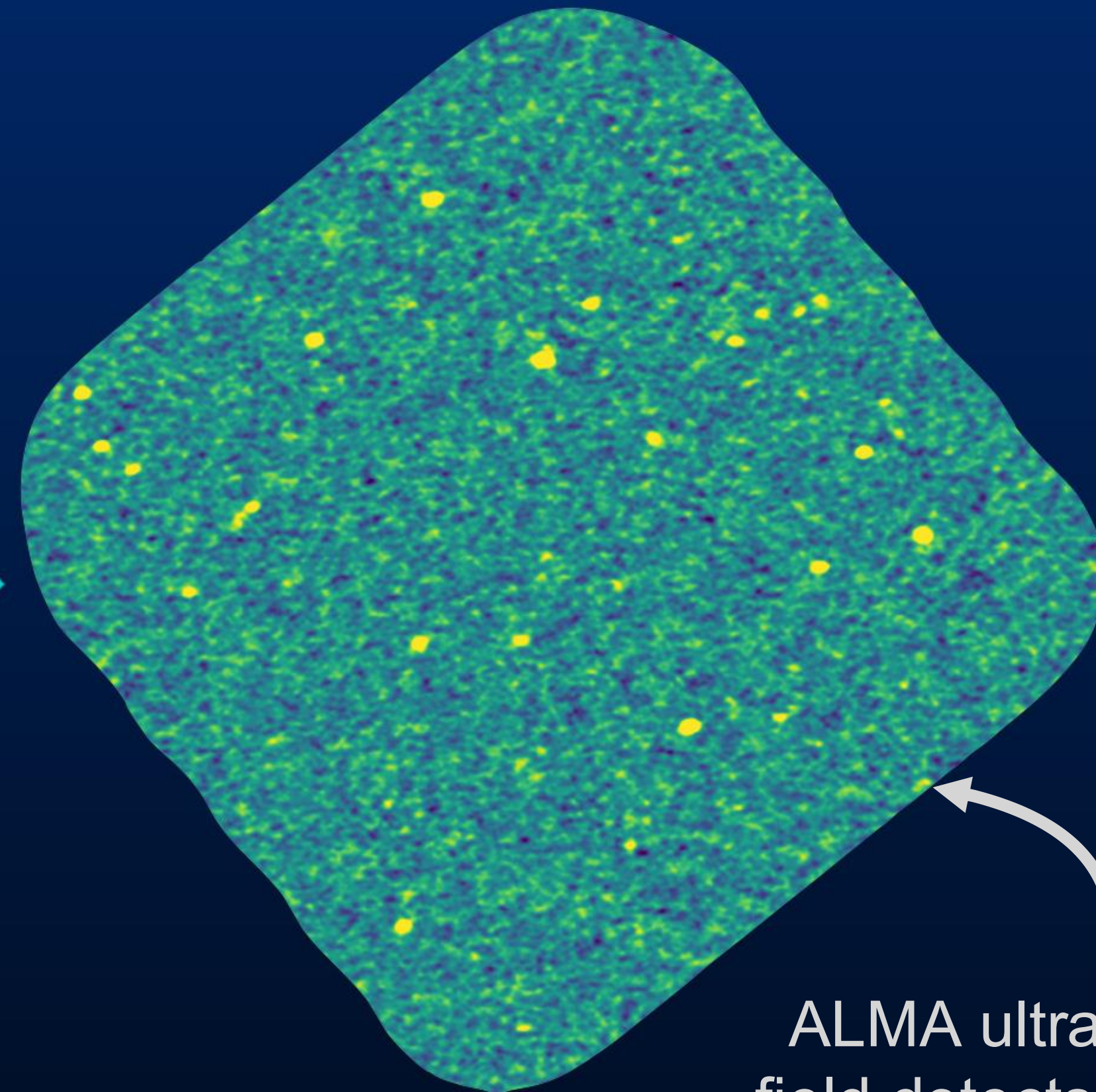
HST stellar emission



ALMA dust emission



~10,000
galaxies



ALMA ultra-deep
field detects *just 35*

Image credits: STScI, Gonzalez-Lopez et al. 2020

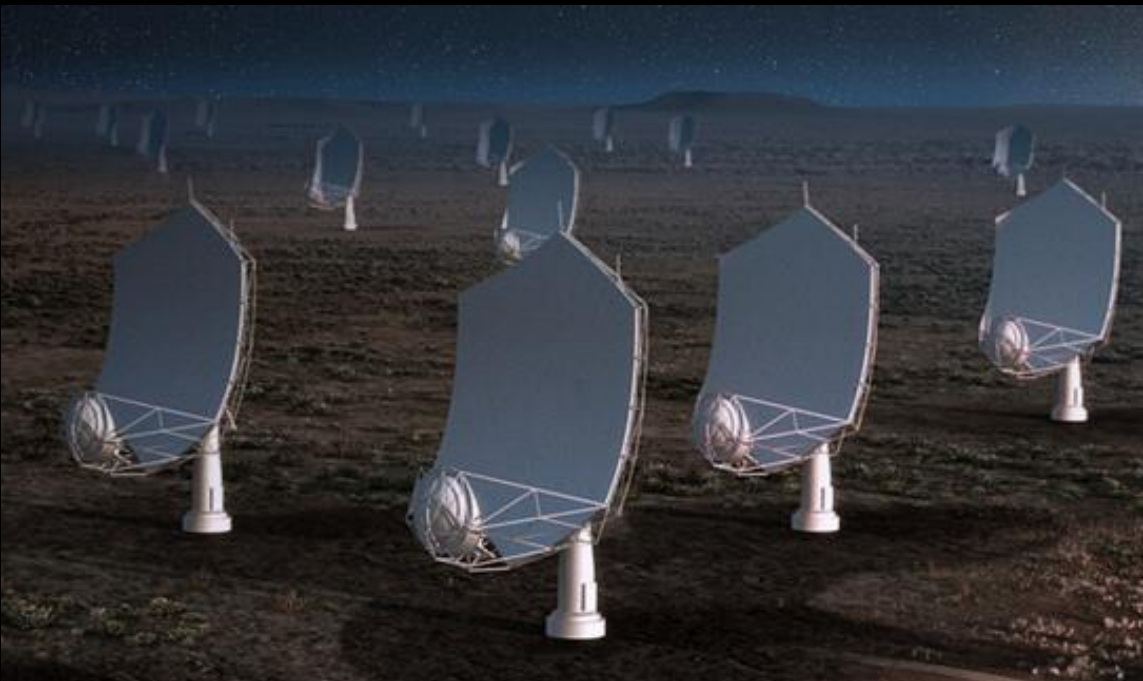
The 2040s will see a giant leap in capabilities

Euclid/Roman/Rubin



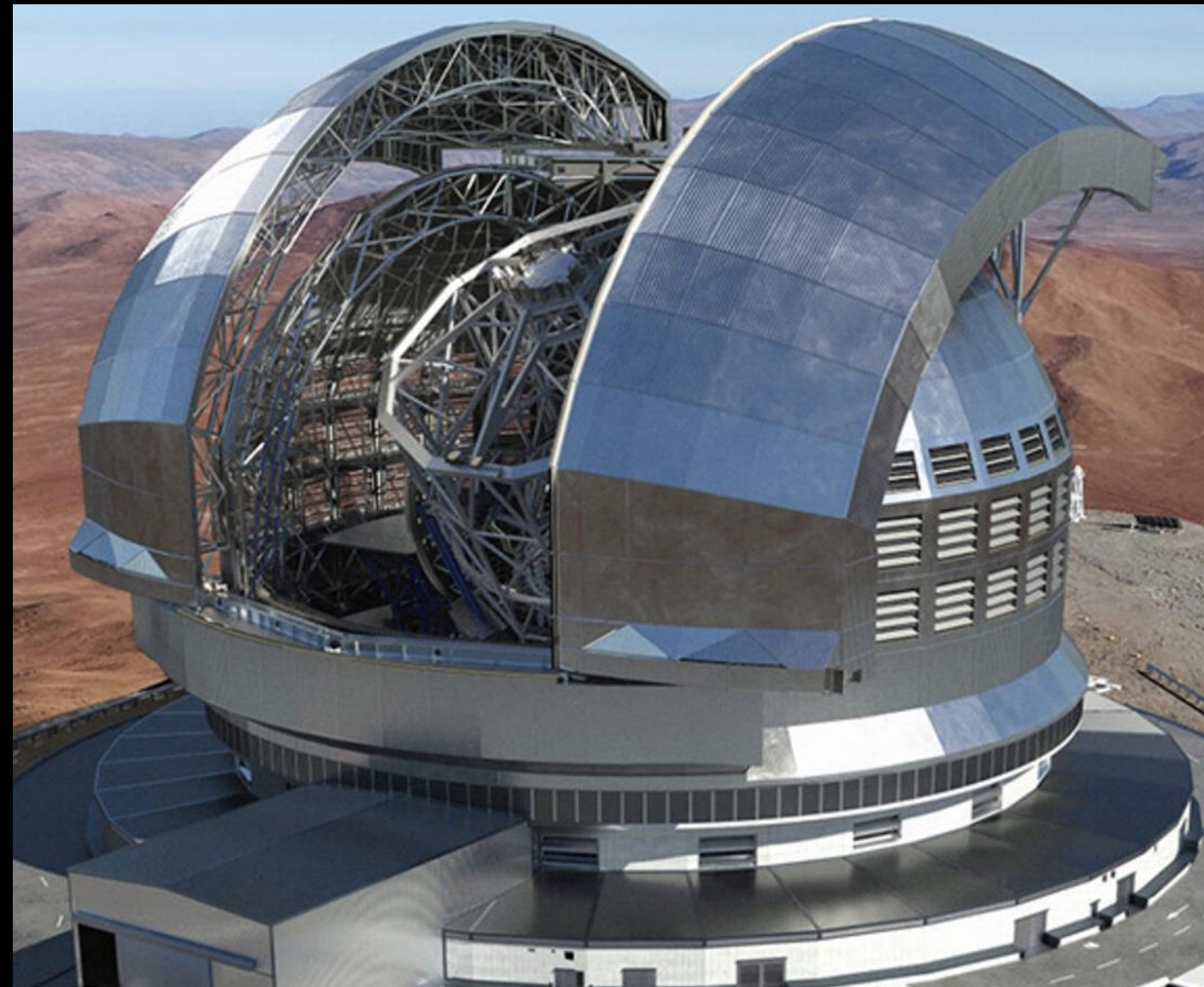
Optical-NIR telescopes

SKA/ngVLA



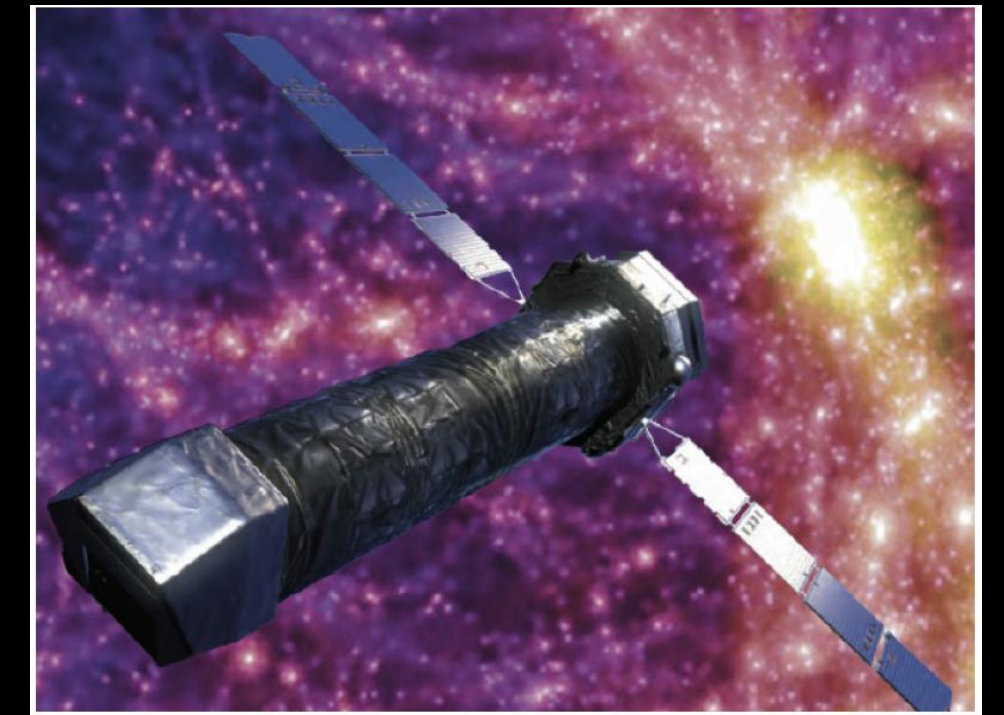
Radio telescopes

ELT/GMT



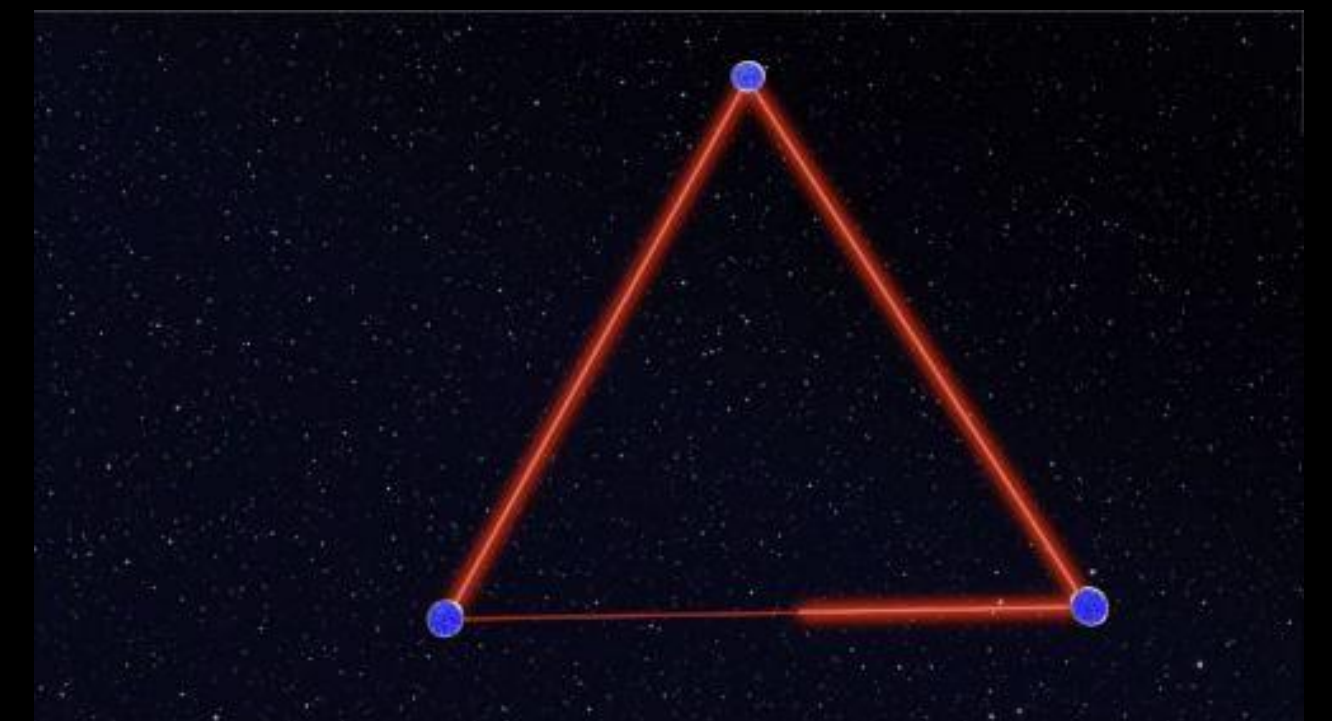
Optical-MIR telescopes

Athena



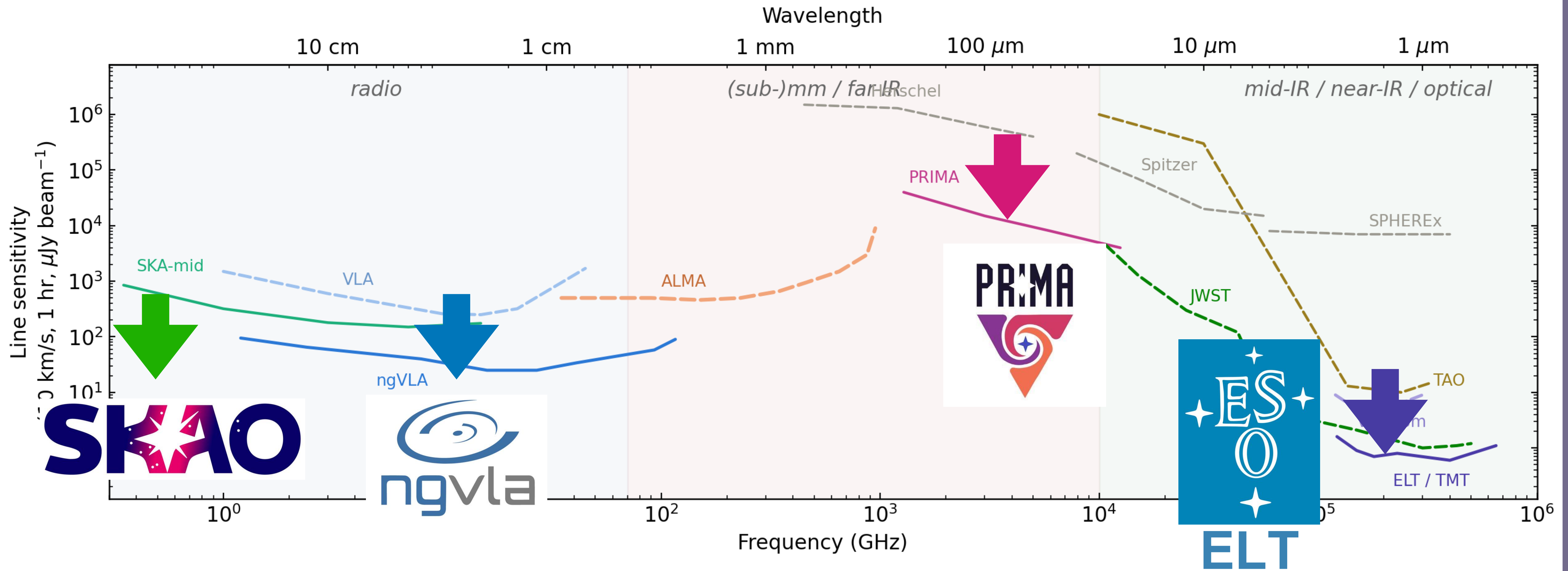
X-ray telescope

LISA



GW telescope

But there is a glaring gap at critical (sub-)mm λ s



* Note that by 2040, the ALMA antennas will have reached the end of their operational lifetime

Graph by Tom Bakx

European-initiated effort towards an ALMA2040 vision



**Transformational science with a (sub-)mm interferometer in
the 2040s**

Towards a next-generation ALMA-like observatory

www.euroalma2040.com

Steering Committee



Stefano Facchini
(U. Milan)



Jacqueline Hodge
(Leiden Observatory)



Eva Schinnerer
(MPIA)



Gie Han Tan
(TU Eindhoven)

ALMA 2040

the next-generation (sub-)millimeter
interferometer



Learn more / join the effort:

euroalma2040.com



ESO Expanding Horizons call

- New facility or substantial upgrade of existing facility

- Selection criteria:

- Science
- Organization
- Sustainability
- Institutional Model
- Risk Assessment

Letter of Intent: 1 December 2026

Proposal: 1 June 2027

→ALMA2040 Initiative

→First white papers Q4 2025

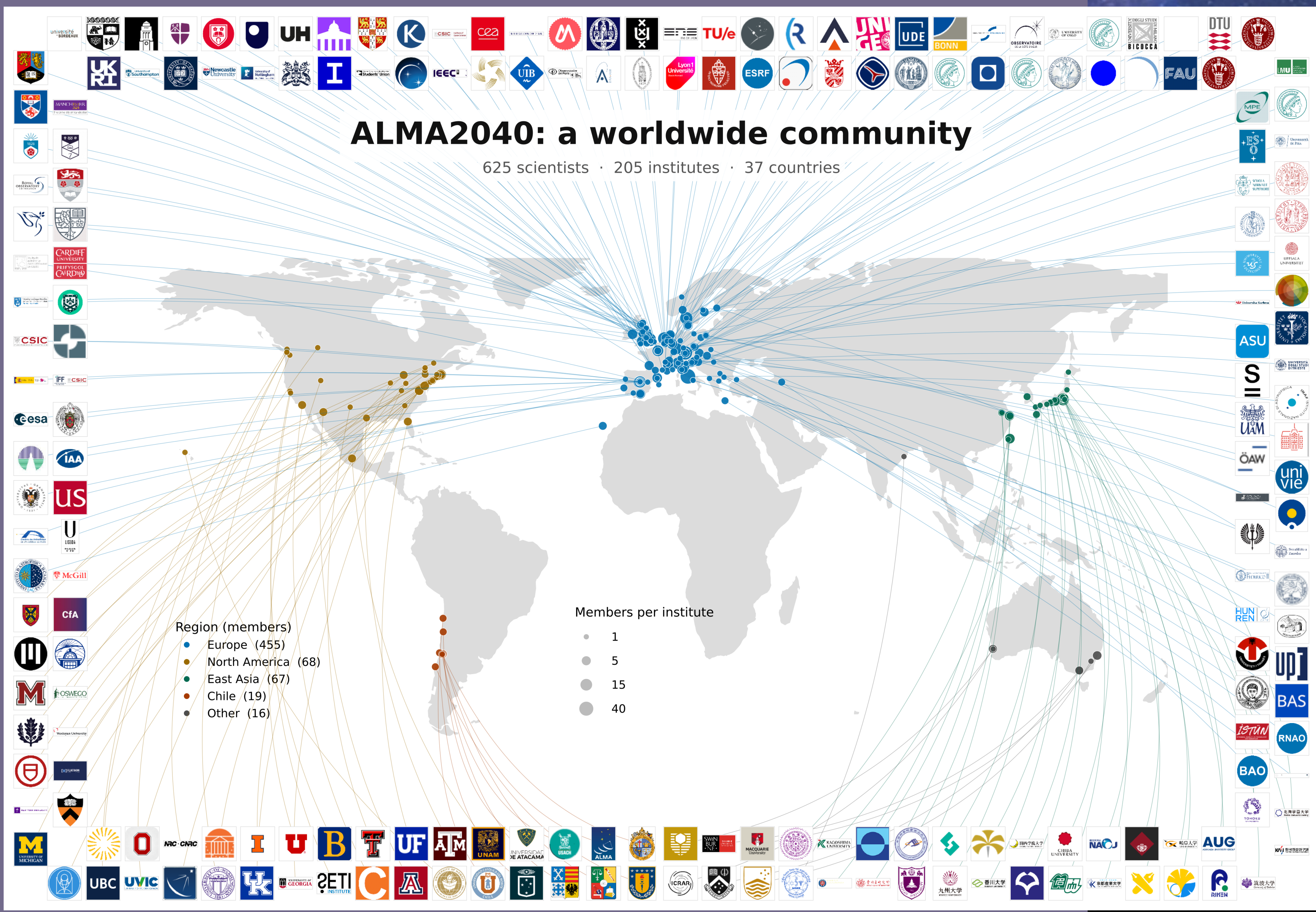
→Lorentz Workshop Dec 2025

→Science requirements

→Exploration of technical solutions

→International opening

→White Paper call: 15 Sept 26



ALMA 2040

the next-generation (sub-)millimeter interferometer



ALMA2040 science working groups

> 600 members from across Europe, East Asia, North America, Chile, etc

► High-redshift Universe

Leads: Tom Bakx (Chalmers) & Francesca Rizzo (U. Groningen)

► Active Galactic Nuclei

Leads: Roberto Decarli (INAF Bologna) & Miguel Pereira Santella (IFF-CSIC)

► Cosmology & Fundamental Physics

Leads: Violette Impellizeri (ASTRON) & Hannah Stacey (ESO)

► Local Universe

Leads: Jan Forbrich (U. Hertfordshire) & Miguel Querejeta (OAN)

► Interstellar Medium & Star Formation

Leads: Maite Beltran (INAF-Firenze) & Jes Jørgensen (Copenhagen)

► Planet Formation

Leads: Luca Matrà (Trinity College) & Catherine Walsh (U. Leeds)

► Sun & Stars

Leads: Wouter Vlemmings/Theo Kouri (Chalmers) & Sven Wedemeyer (U. Oslo)

► Transients & Time-Domain Astronomy

Leads: Kuo Liu (MPIfR) & Karri Koljonen (NTNU)

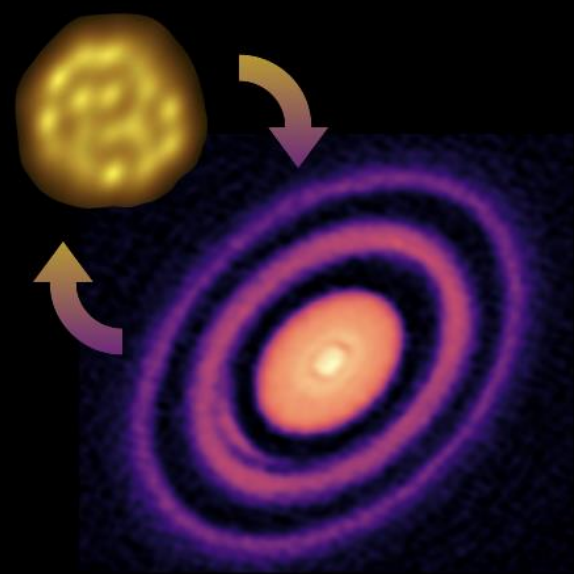
► Solar System Bodies & Exoplanets

Leads: Arianna Piccialli (BIRA-IASB) & Miriam Rengel (MPS)

Coordinators:

Stefano Facchini, Jacqueline Hodge, Eva Schinnerer

ALMA2040 Key Science Drivers



The life cycle of planetary systems & stars

Including the formation of rocky planets down to ~AU scales



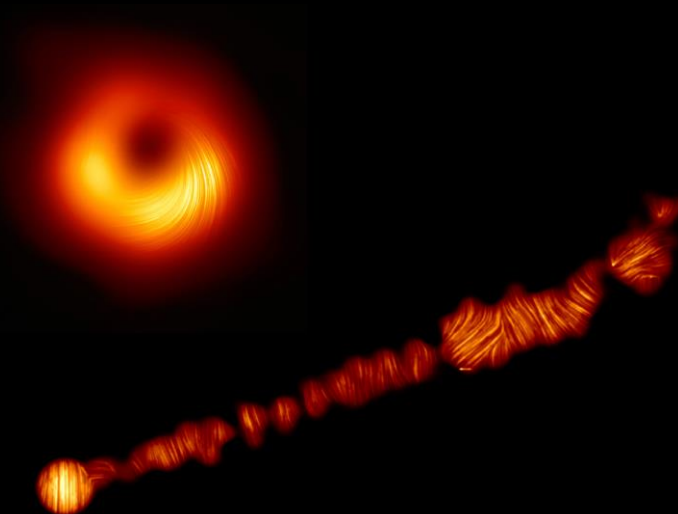
The formation and evolution of structure

Including primordial galaxies and black holes out to $z \sim 20$



Evolution of the cosmic baryon cycle

Including dust & the development of chemical complexity that leads to life



Physics of the extreme universe

Including rapid follow-up of transient and multi-messenger events

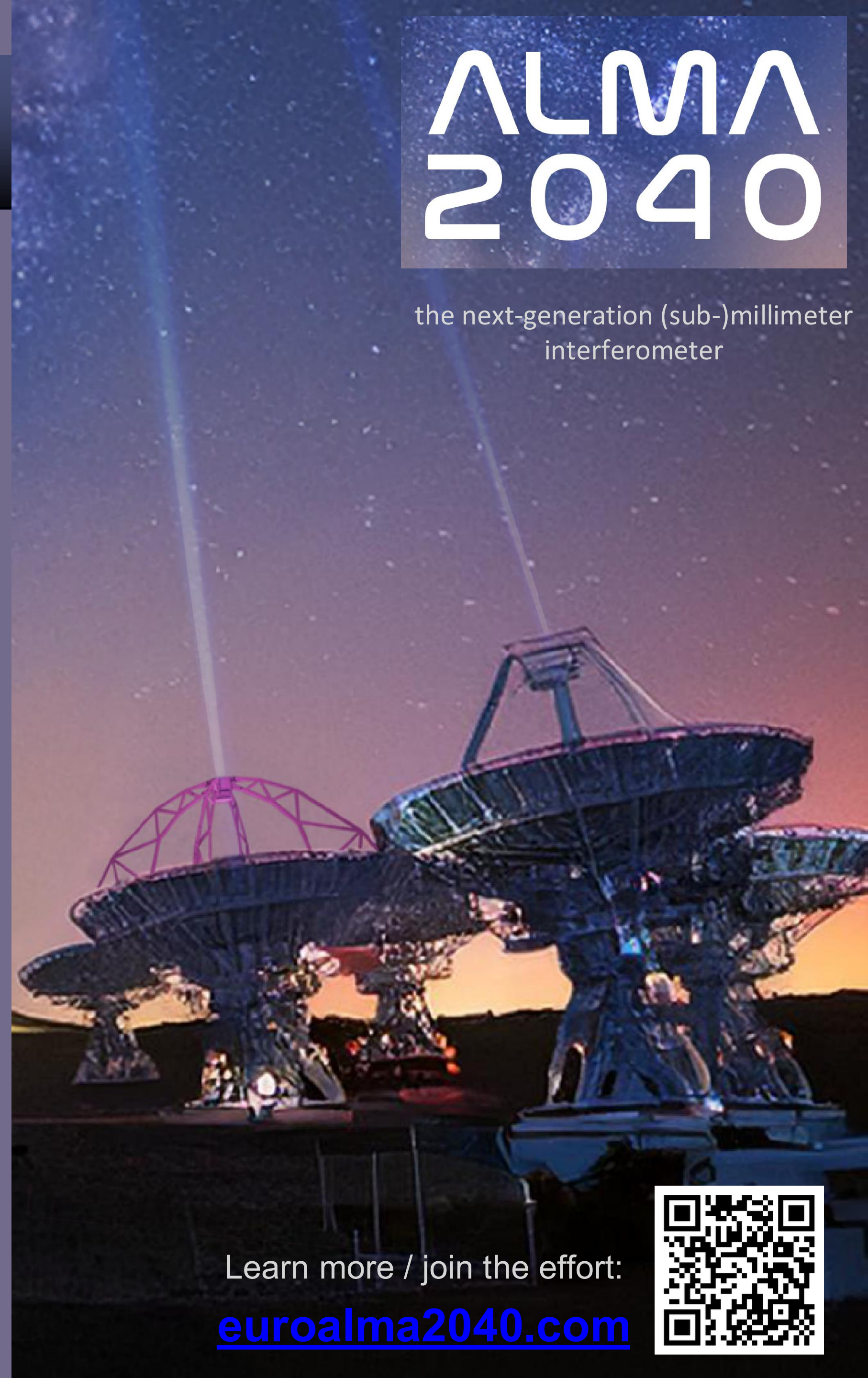
Foreseen capabilities:

5-10× line sensitivity
3× angular resolution

Full instantaneous Bandwidth
On-the-fly calibration

ALMA 2040

the next-generation (sub-)millimeter interferometer



Learn more / join the effort:

euroalma2040.com



How chemical complexity emerges and develops?

- The interstellar medium harbours a rich chemical feedstock (~350 molecules so far) that can provide the ingredients for life to planetary systems.

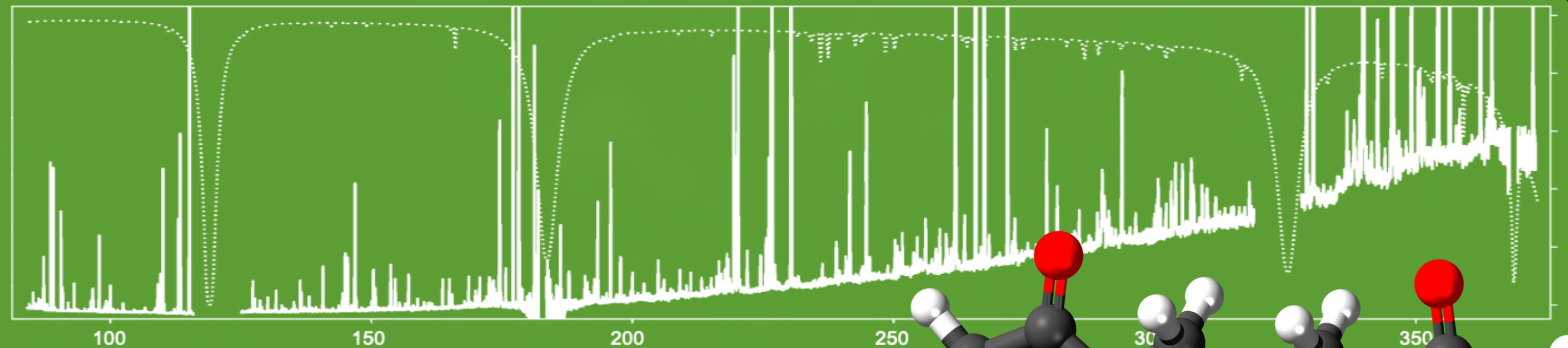
What is the maximum level of chemical complexity

KEY OPEN QUESTIONS

What is the potential for triggering prebiotic chemistry?

Need of deep unbiased broadband spectral surveys

- Multiple transitions to assist robust identifications
- Weak signals from molecules with increasing complexity

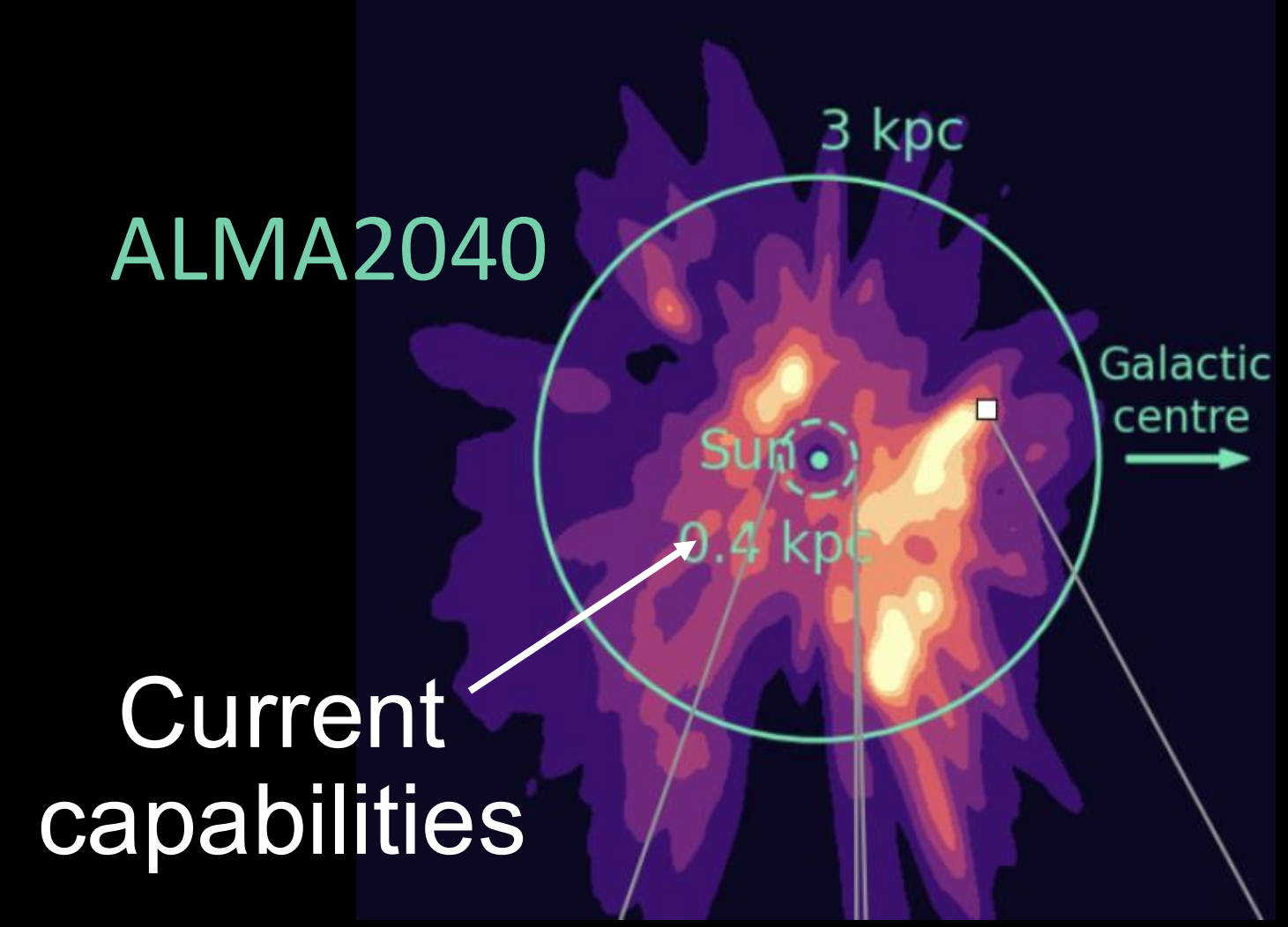


Slide by Victor Rivilla

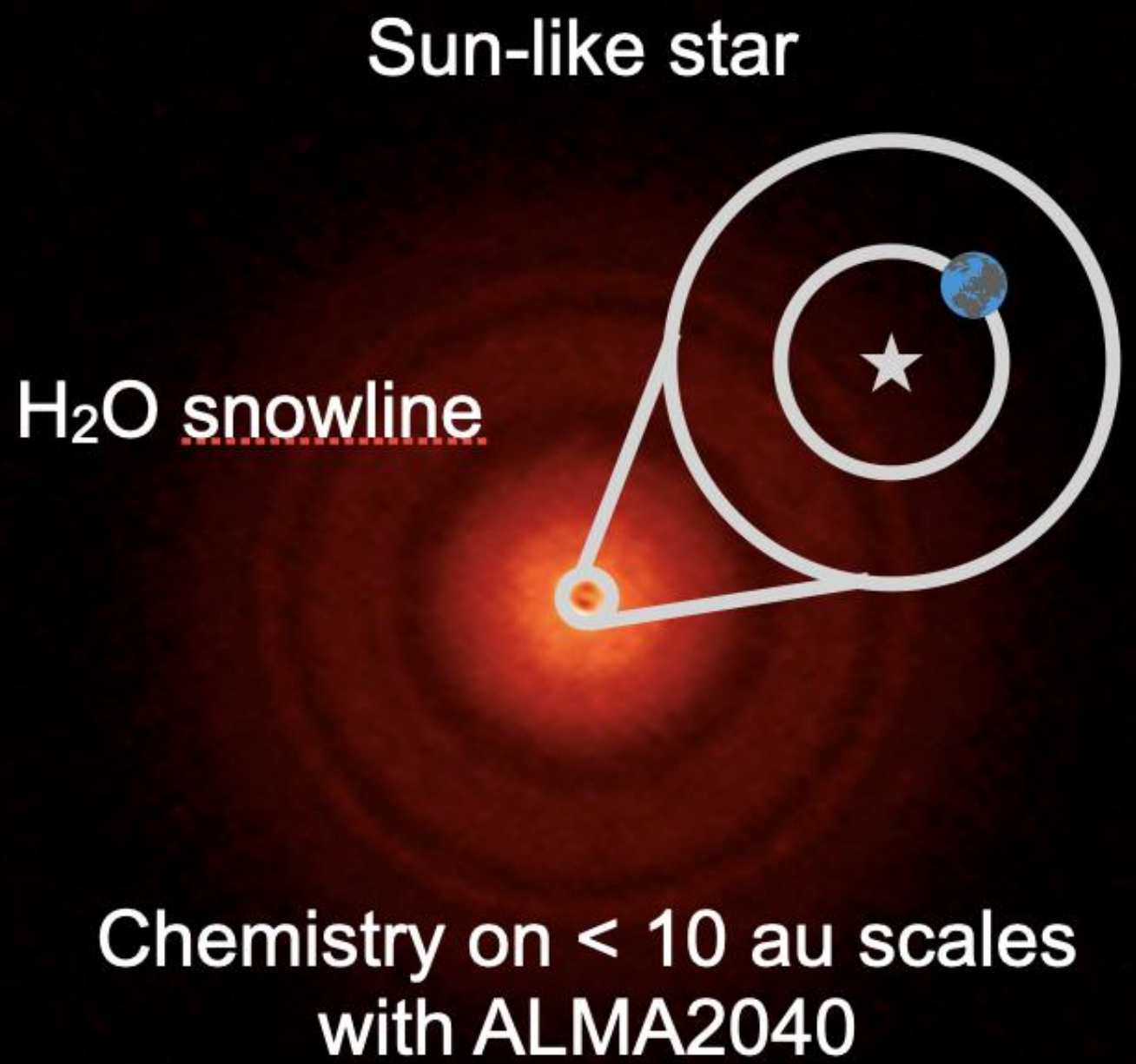
ALMA
2040

Full instantaneous BW > 512 GHz across all ALMA bands will be revolutionary

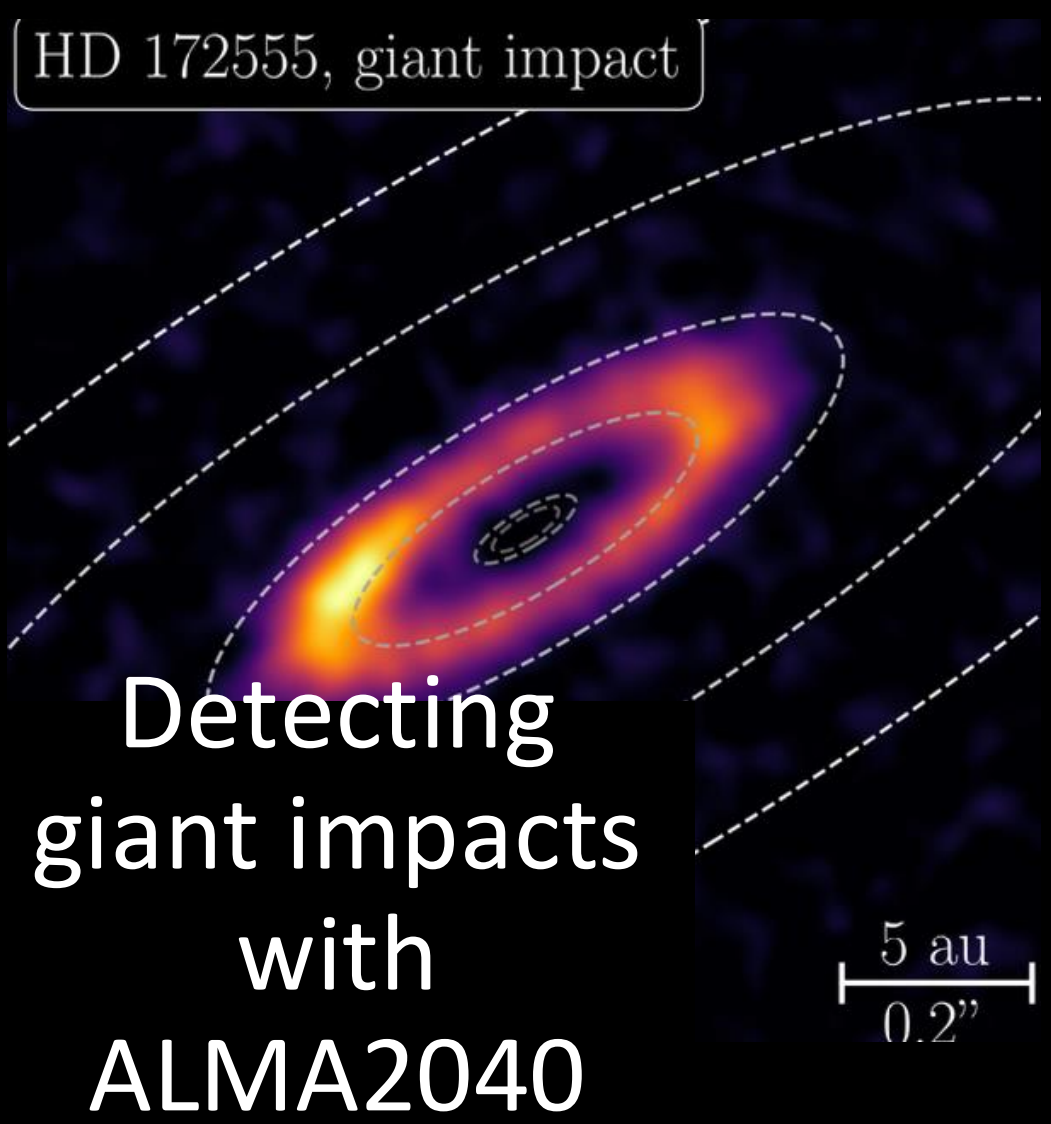
HOW DO PLANETS FORM UNDER THE MOST COMMON
STAR-FORMING CONDITIONS IN THE GALAXY?



WHAT IS THE ELEMENTAL
AND ISOTOPIC
COMPOSITION OF
TERRESTRIAL PLANET
BUILDING MATERIAL?

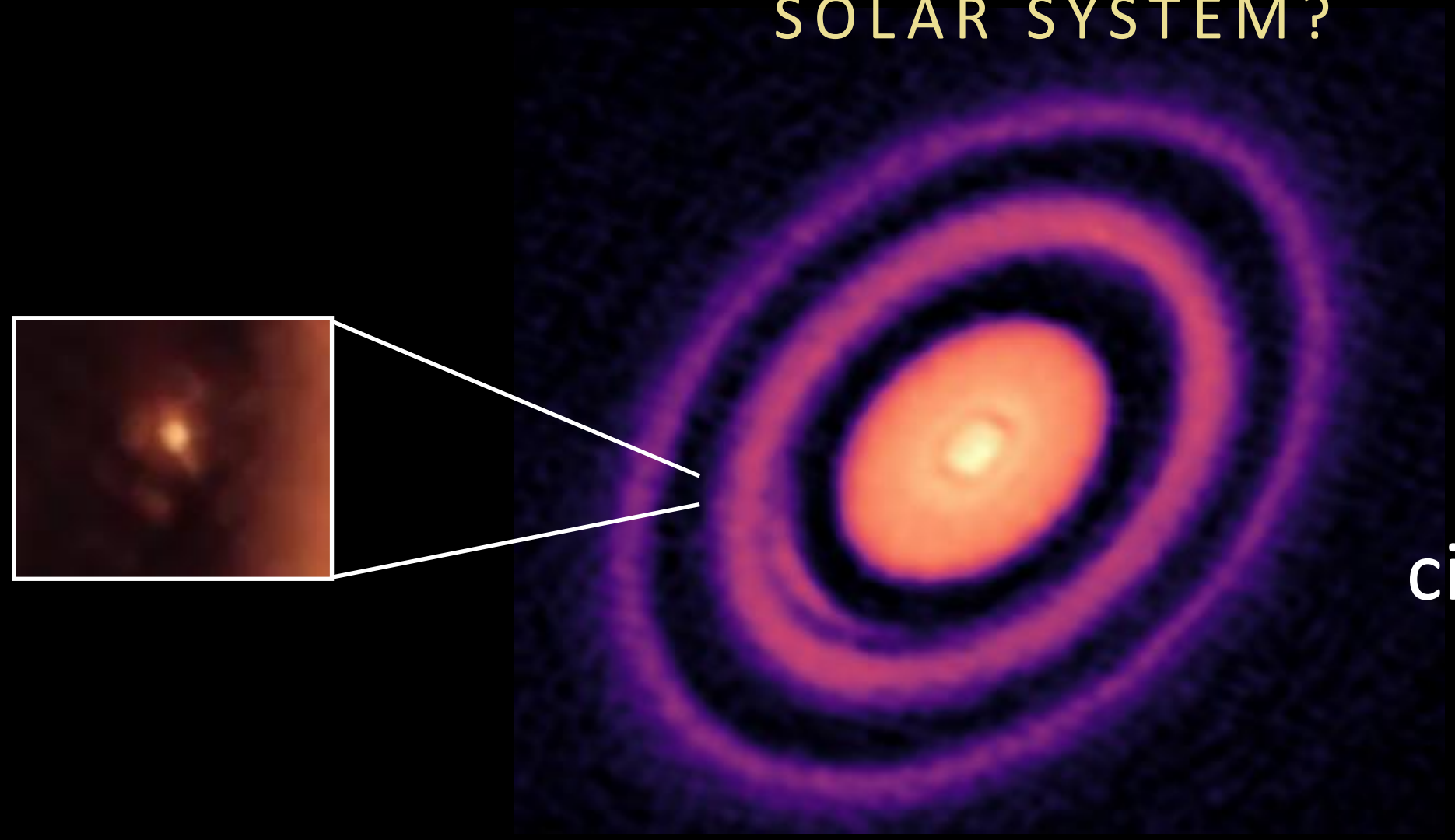


The formation of planetary systems



HOW DO LATE-STAGE
PROCESSES SHAPE
PLANETARY ASSEMBLY
AND VOLATILE
DELIVERY?

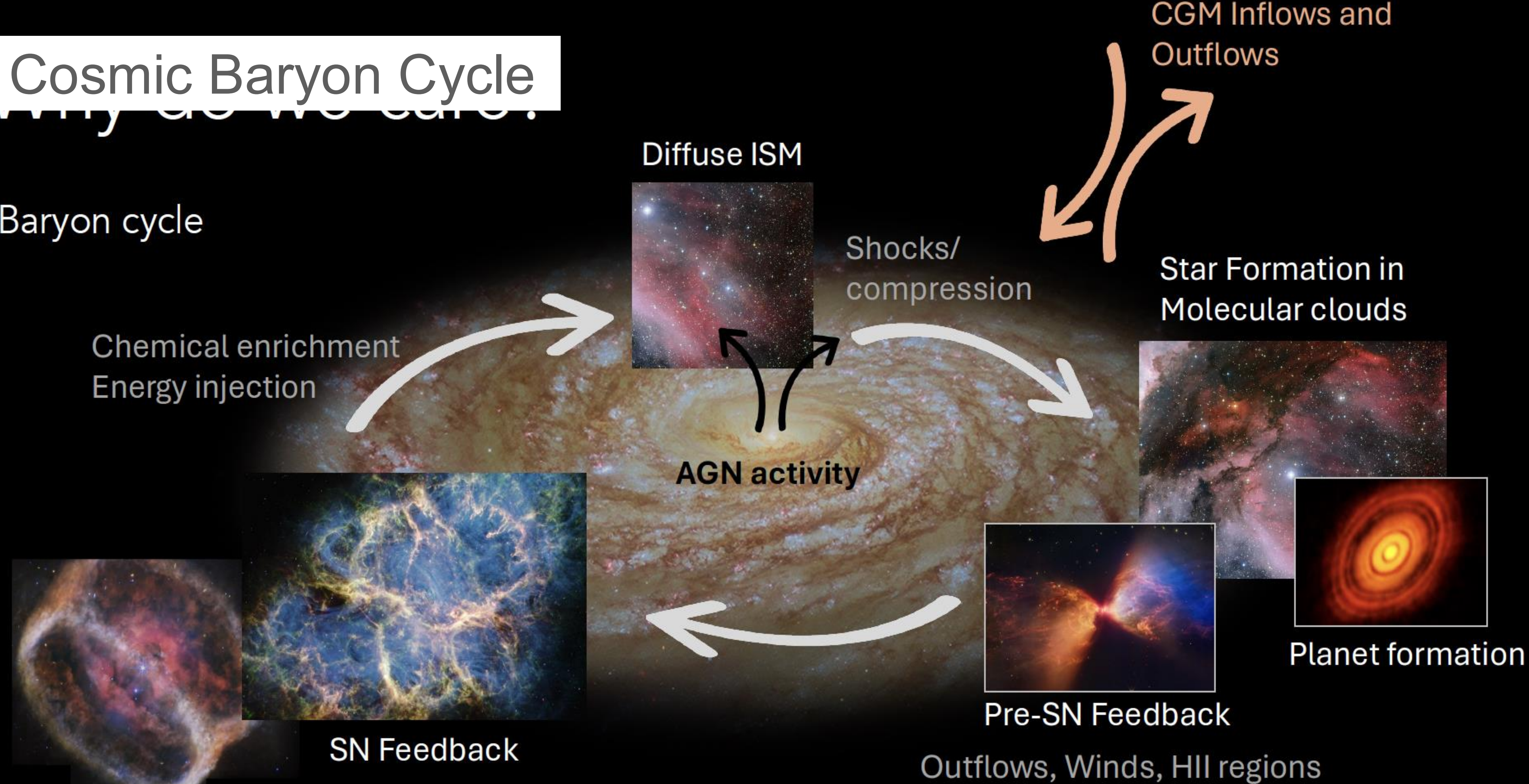
HOW DID JUPITER FORM AND SHAPE THE
SOLAR SYSTEM?



Hunting for
circumplanetary
disks with
ALMA2040

Cosmic Baryon Cycle

Baryon cycle



Regulation of ISM physics via star formation – depends on type of stars formed, and at what rate.
This cycle provides the key elements of galaxy evolution and planet formation.

The Universality of Star Formation

HOWEVER... The past ~15 years of ALMA have challenged this

Universal stellar initial mass function (IMF)
& one-to-one from cores to stars

MW studies



Common filament width (0.1 pc) &
Common column density threshold for SF

Scaling between **surface density of gas**
and SFR (as averaged over entire galaxies)

Extragalactic studies



- Measurements from local few kpc & dependent on methodology.
- Variations of CMF with local gas conditions.
[e.g. Motte+ (ALMA-IMF), Molinari+ (ALMAGAL)]
- CMFs hardly pushing to high-mass (poor statistics in MW)
- Evidence of different thresholds for SF in higher turbulence mediums (CMZ)
[e.g. Longmore+ (ACES)]
- Relation breaks down when resolving individual regions within galaxies.
- Different galaxies show different scalings, different SFE, and no obvious correlation with galaxy type.
[e.g. Saintonge+ (KILQCAS), Leroy, Schinnerer+ (PLANGS-ALMA)]

The Universality of Star Formation

HOWEVER... The past ~15 years of ALMA have challenged this

- Science Questions:
- How does the galactic environment regulate the assembly of molecular gas and its properties?
 - Track the flow of interstellar gas across many scales
 - Track ISM in different environments
- How are the fragmentation and kinematics of molecular clouds regulated?
- What are the physical drivers that determine efficiencies and rates of star formation
- What role do magnetic fields play?

- Measurements from local few kpc & dependent on methodology.
- Variations of CMF with local gas conditions.
[e.g. Motte+ (ALMA-IMF), Molinari+ (ALMAGAL)]
- CMFs hardly pushing to high-mass (poor statistics in MW)
- Evidence of different thresholds for SF in higher turbulence mediums (CMZ)
[e.g. Longmore+ (ACES)]
- Relation breaks down when resolving individual regions within galaxies.
- Different galaxies show different scalings, different SFE, and no obvious correlation with galaxy type.
[e.g. Saintonge+ (KUGCAS), Leroy, Schinnerer+ (PLANGS-ALMA)]

AGN SCIENCE INTO THE FUTURE: ALMA2040

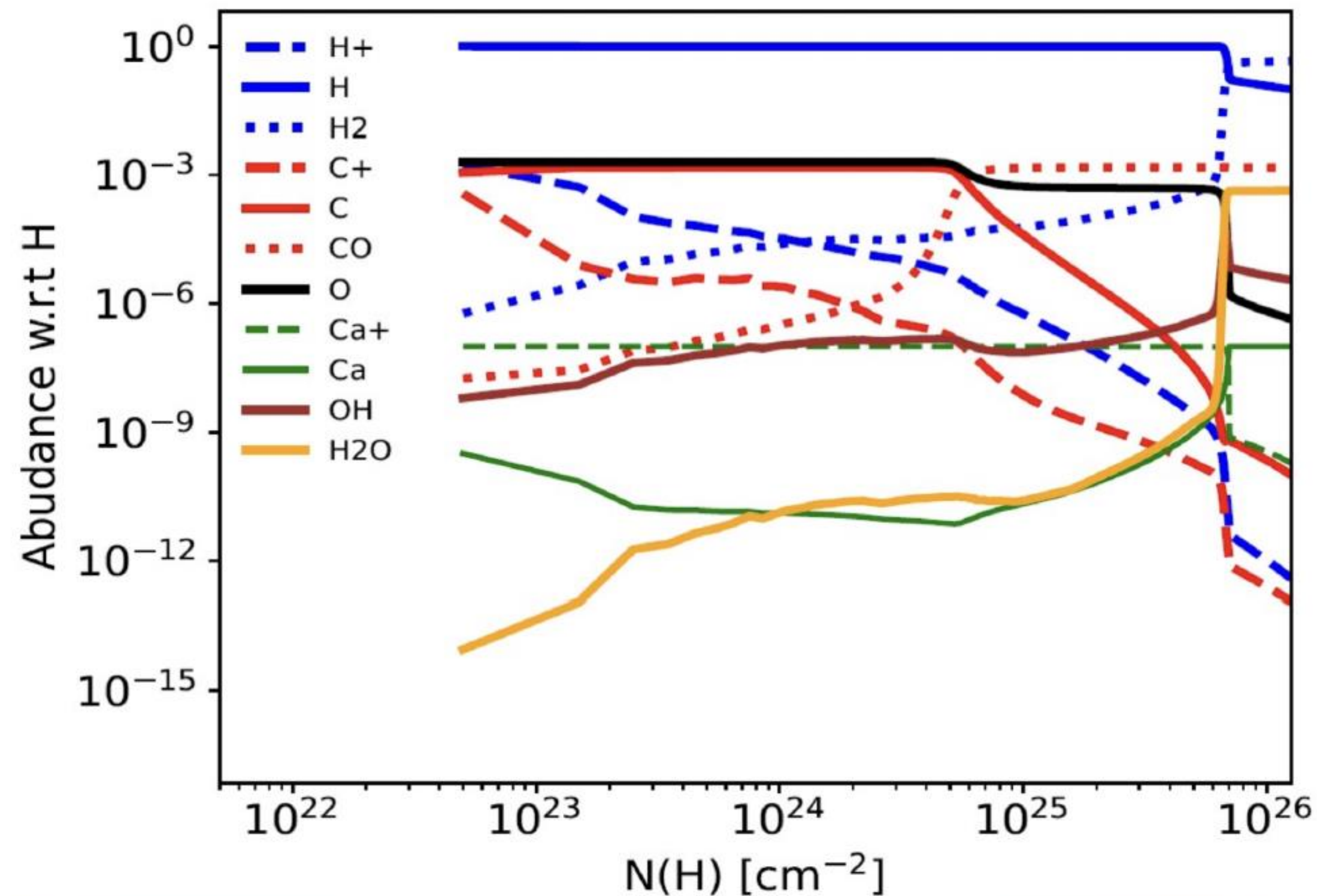
TECH. REQUIREMENTS

- 2-5 x higher spatial resolution compared to current ALMA: 3-8 mas spatial resolution@345GHz
- 8-10 x higher sensitivity compared to current ALMA with >250 antennas

OBSERVATIONS (100-350 GHz)

*Neutral molecular BLR and resolved torus

- CO, HCN, HCO⁺ rotational lines and dust continuum emission



Thi & Papadopoulos +2024

Resolving molecular/dusty tori up to D~30 Mpc with subpc spatial resolution

- AM transport mechanisms
- Clump distribution
- Density stratification

Pushing detection of AGN tori up to D~200 Mpc in QSOs with ~2-3pc spatial resolution

- CO vibrational excited (rotational) lines

Imaging the neutral molecular BLR (BLR0) in nearby AGN

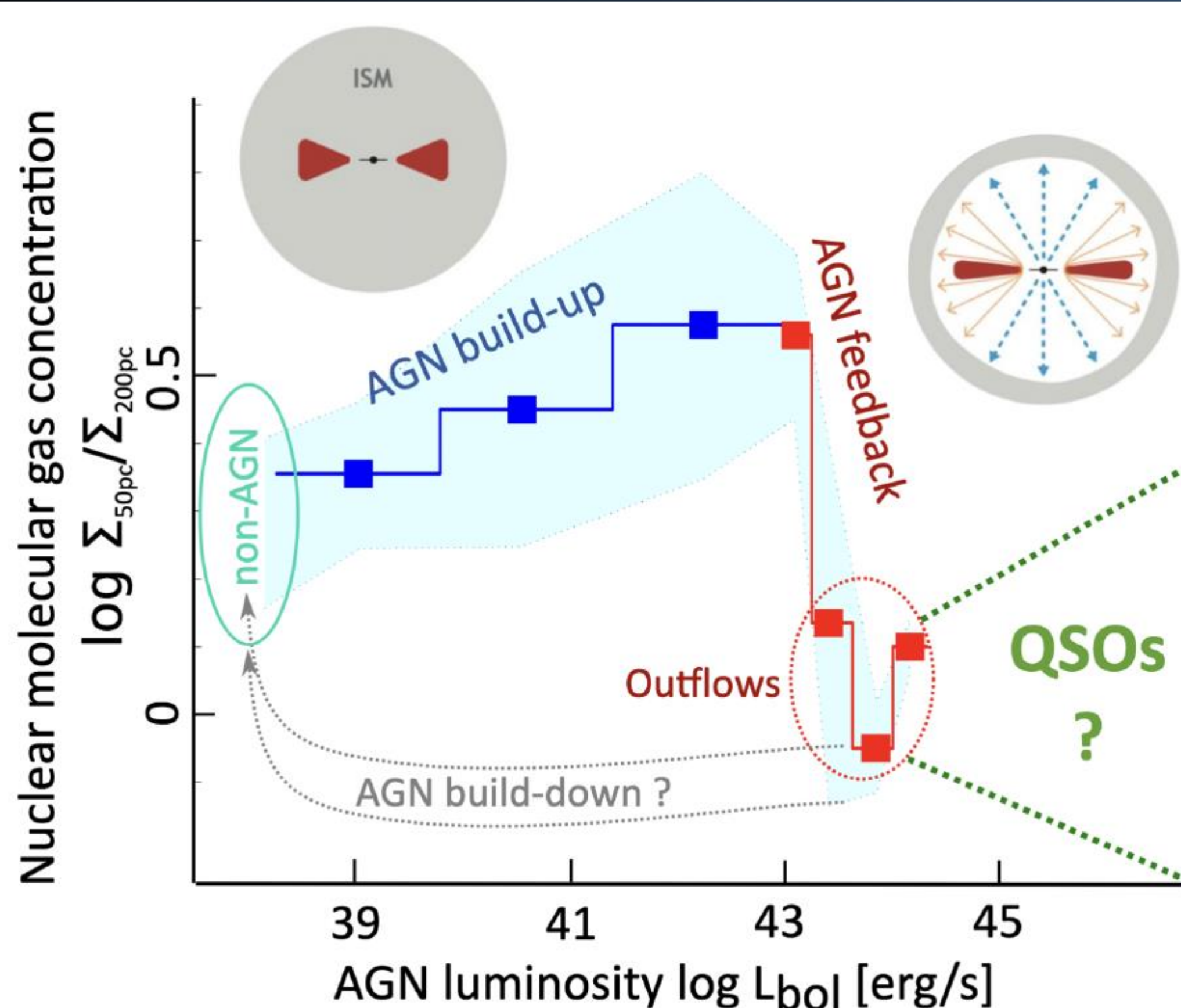
- Probing high column density interface between the torus and the BLR inside dust sublimation radius at $r < 1\text{pc}$ ($< R_{\text{Sol}}^{\text{BH}}$)

AGN SCIENCE INTO THE FUTURE: ALMA2040

TECH. REQUIREMENTS

- 2-5 x higher spatial resolution compared to current ALMA: 3-8 mas spatial resolution@345GHz
- 8-10 x higher sensitivity compared to current ALMA with >250 antennas

*AGN feeding/feedback cycle in QSOs



OBSERVATIONS (100-350GHz)

- CO, HCN, HCO⁺ rotational lines and dust continuum emission

Resolving CND distribution of molecular gas and dust in QSOs up to $D \sim 300$ Mpc with $\sim$ a few pc spatial resolution

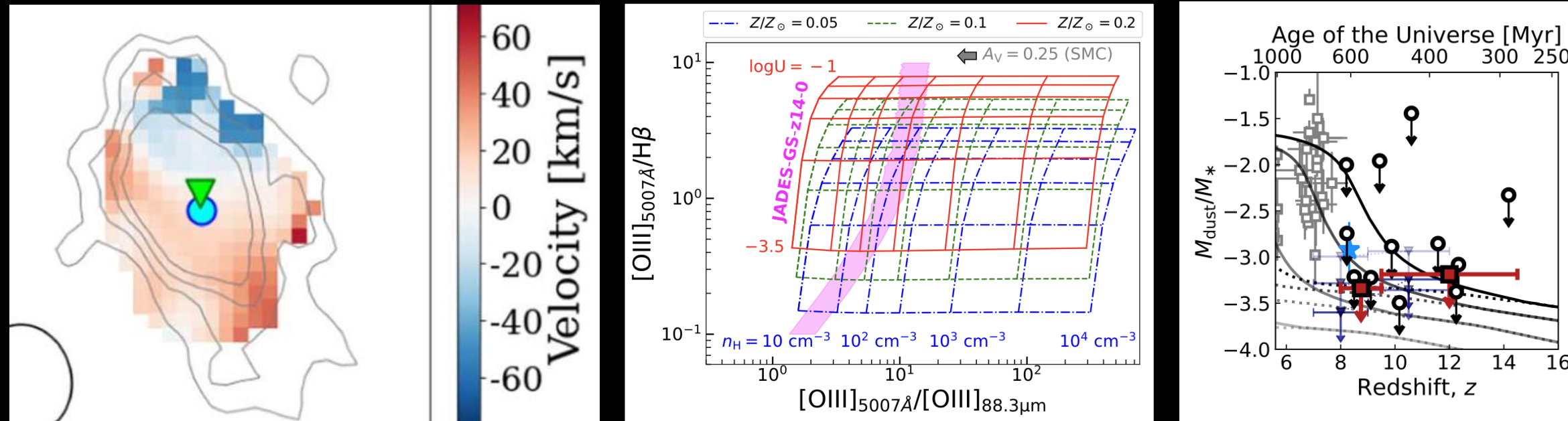
-Quantify AGN fueling efficiency

-Quantify the imprint of AGN feedback (cavities, outflows...)

How did the *first galaxies* form their stars?

Breaking the last cosmic frontier

Need to resolve & characterize the nature of pristine galaxies



Refs: Ciesla+21; Tokuoka+22; Carniani+25; Schouws+25; Bakx+in prep

- *Multi-phase gas content*
- *Densities, temperatures & ionization*
- *Dust-free metallicities*
- *Kinematics & dynamical masses*
- *Emergence of the first dust & metals*

Proof of concept:

Sub-kpc mapping & kinematics of a cold rotating disk galaxy at $z=7.3$



Rowland et al. 2024, ESO Press Release

mm/sub-mm transient sky with alma2040

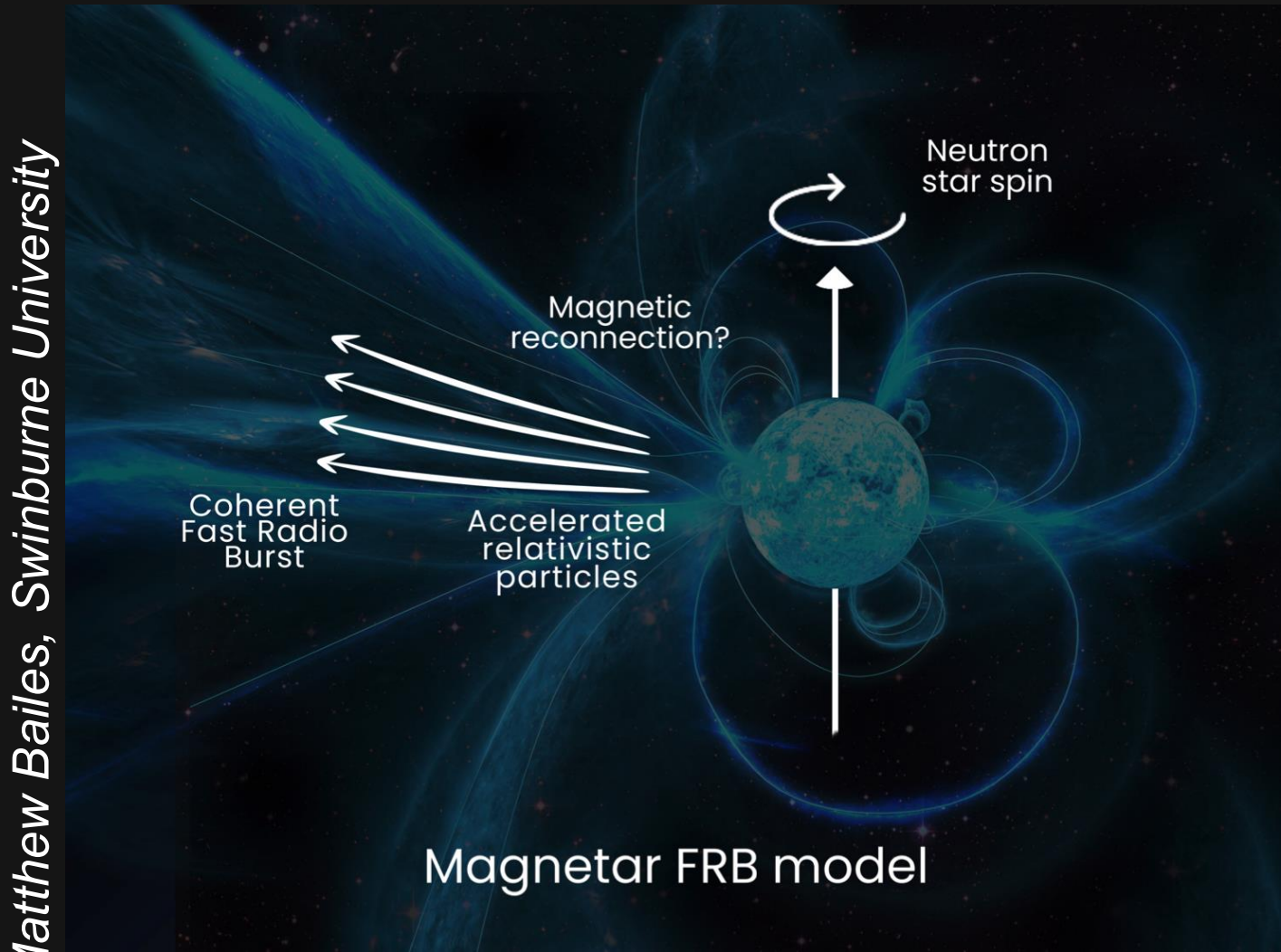
mm observations reduce strong scattering effects, probe optically thin emission and penetrate dust

ALMA2040: 10× sensitivity → from single detections to populations | **terahertz bandwidth** → evolution of spectral breaks/turnovers and emission components | **high spatial resolution** → resolve jet bases, ejecta expansion

WHAT GENERATES BURSTY COHERENT EMISSION IN THE UNIVERSE?

pulsars, magnetars, fast radio bursts

- Population mm spectra + polarization → identify emission mechanism (cutoff vs new component) and local environment
- Cosmology: FRBs up to $z = 3-6$



Matthew Bailes, Swinburne University

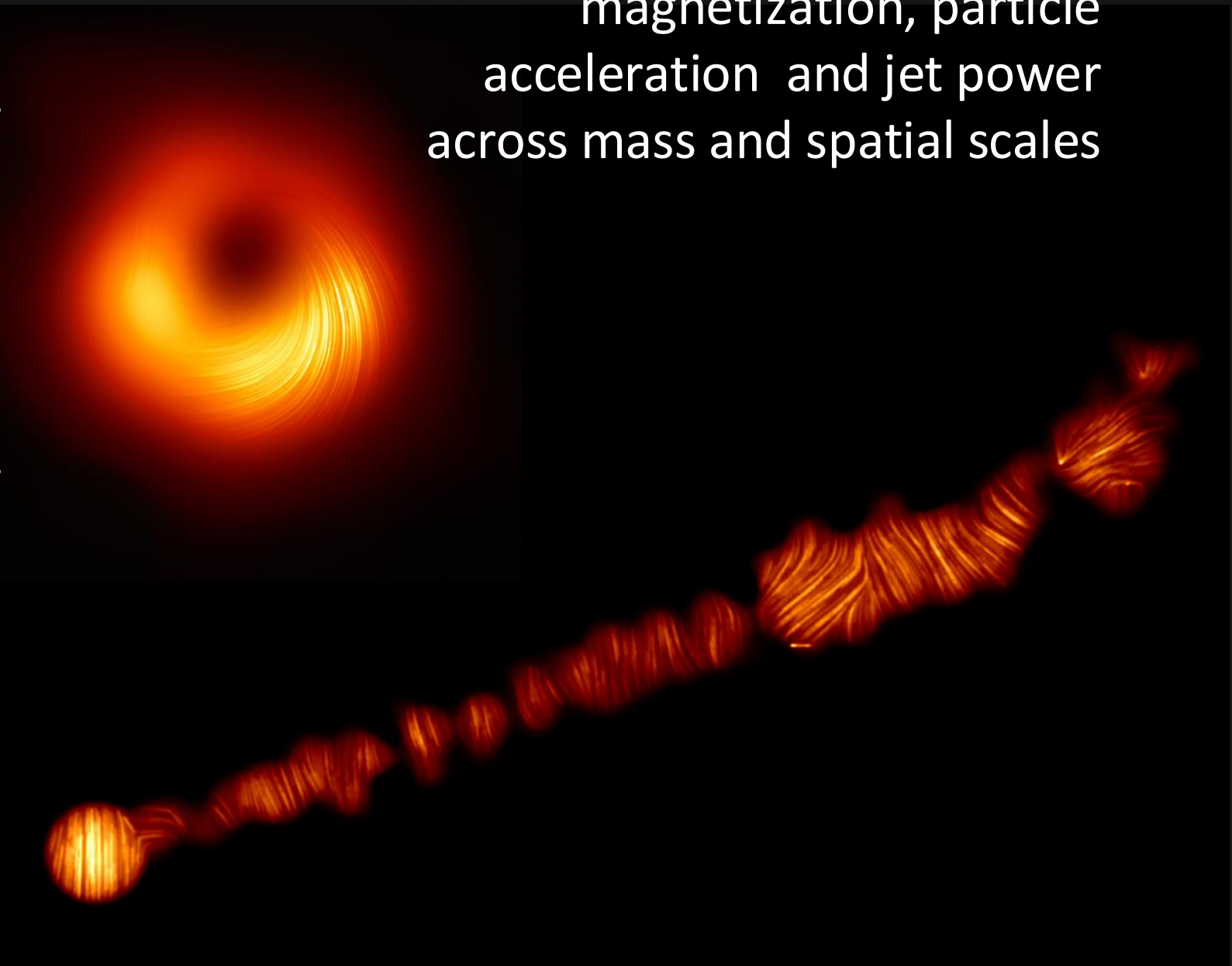
HOW DO JETS LAUNCH, COLLIMATE AND ACCELERATE?

X-ray binaries, active galactic nuclei, gamma-ray bursts, tidal disruption events

- Time-resolved, broadband, polarized jet spectra + VLBI capabilities

→ measure magnetization, particle acceleration and jet power across mass and spatial scales

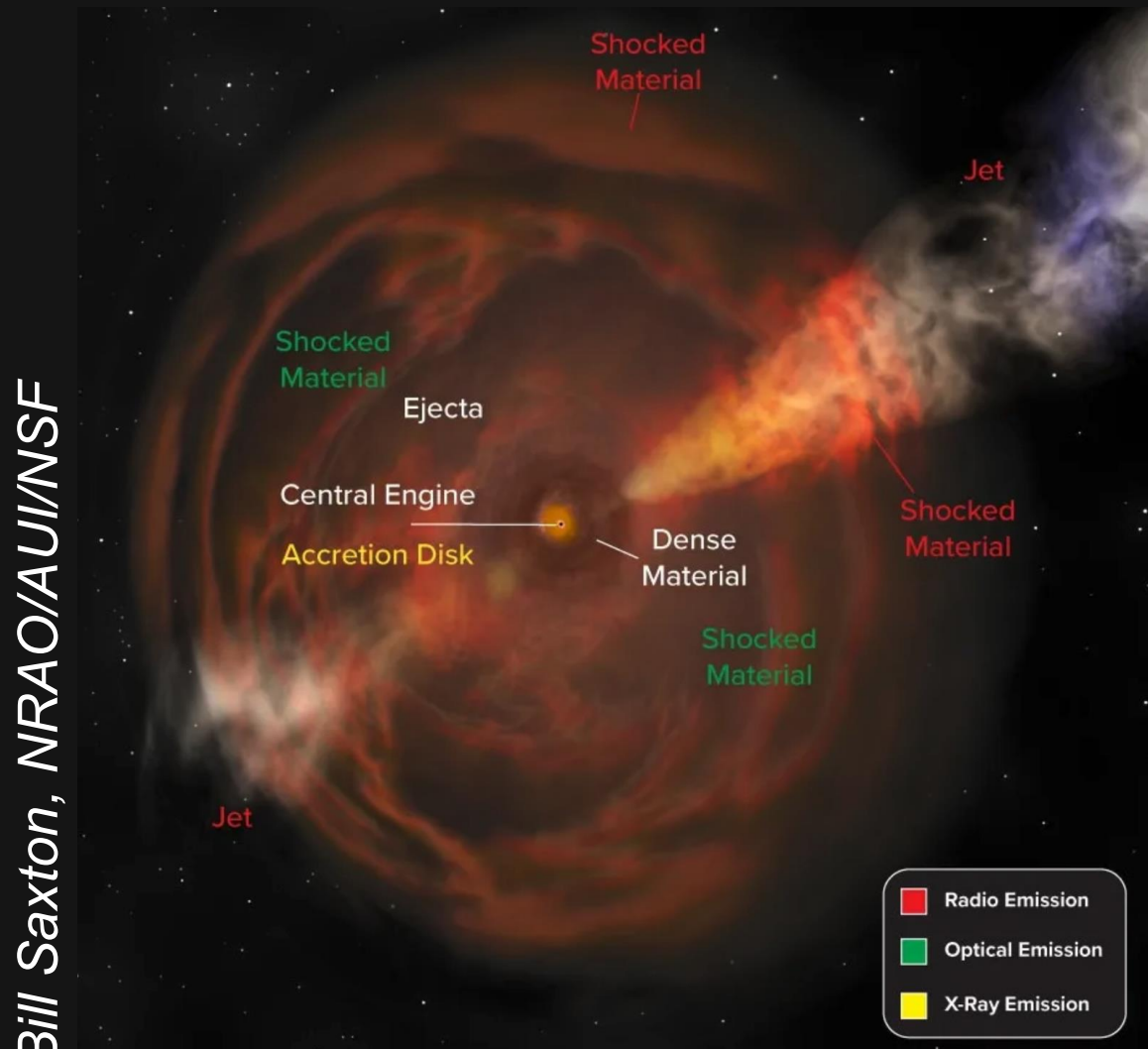
EHT Collaboration, ALMA (ESO/NAOJ/NRAO), Goddi et al.



PRE-EXPLOSION ENVIRONMENTS AND SHOCK PHYSICS

supernovae, fast blue optical transients, novae, stellar mergers, gravitational wave counterparts

- Rapid response, broadband spectra, high-resolution imaging → measure circumstellar medium density profile, dust formation, progenitor physics

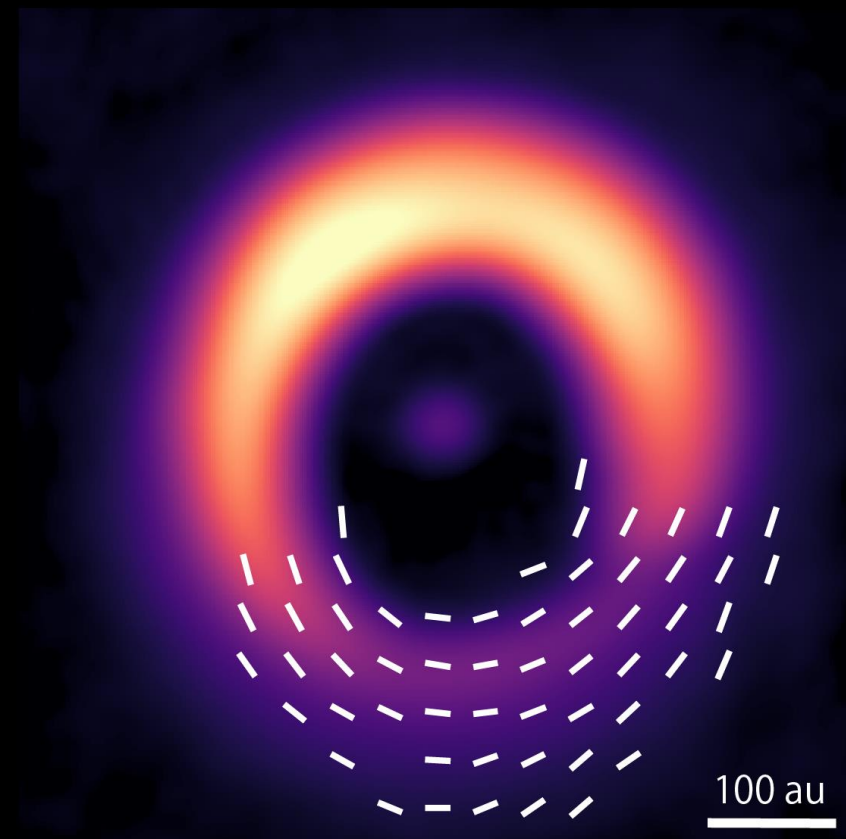


Bill Saxton, NRAO/AUI/NSF

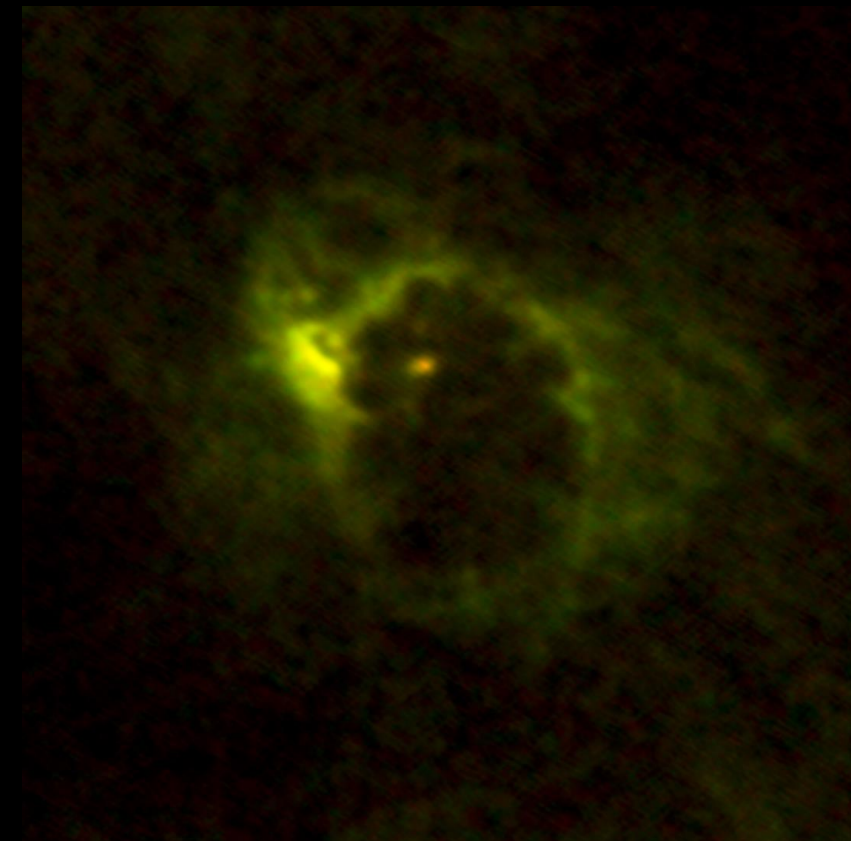
ALMA2040 would also...



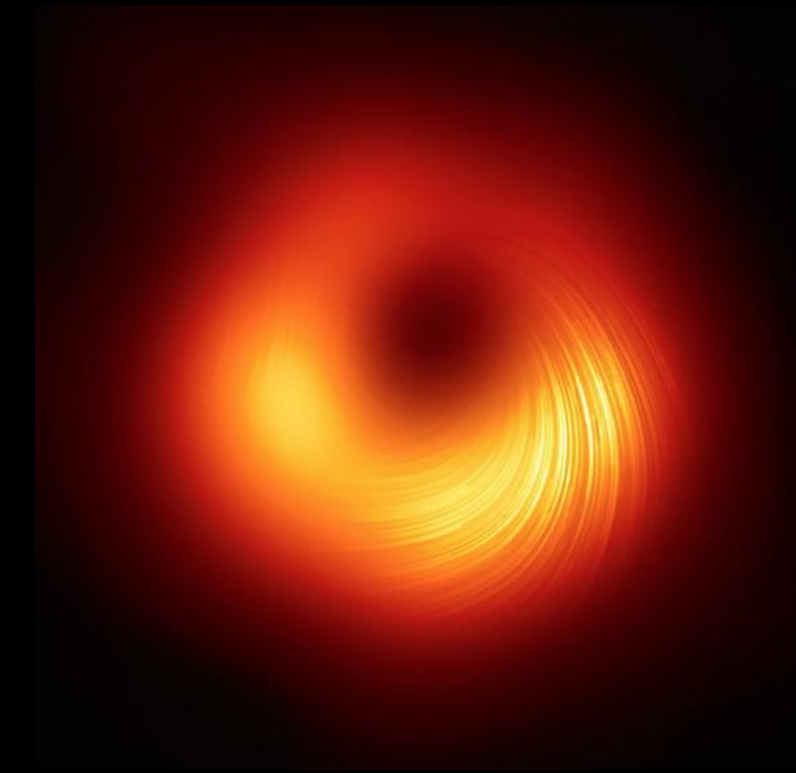
Directly detect **massive (exo-)Jupiters** around nearby evolved stars



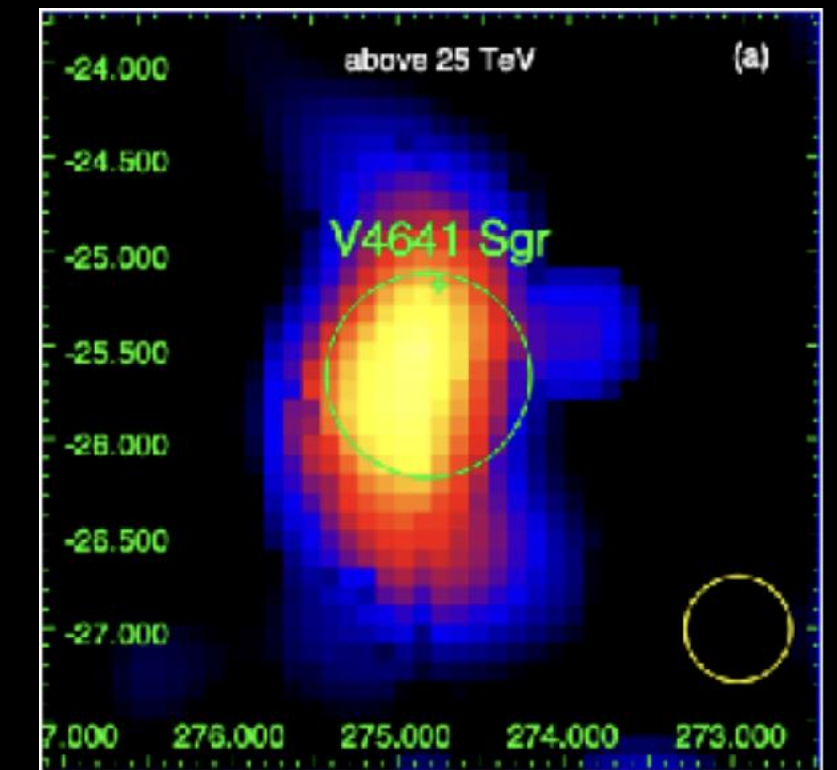
Map the rise of **magnetic fields** across space and time



Resolve the **dusty tori** surrounding Active Galactic Nuclei



Supercharge **tests of General Relativity** through global VLBI



Resolve **multi-messenger sources** in the 2040's

Great complementarity to ELT on similar (or better) scales

Technical working groups

► Science & System Requirements Working Group

Leads: Maria Díaz Trigo (ESO) & Martina Wiedner (Obs De Paris)

► Instrument Working Group

Leads: Andrey Baryshev (Groningen) & Peter Huggard (RAL)

► Operations Working Group

Leads: Elizabeth Humphreys (ESO) & Gergö Popping (ESO)

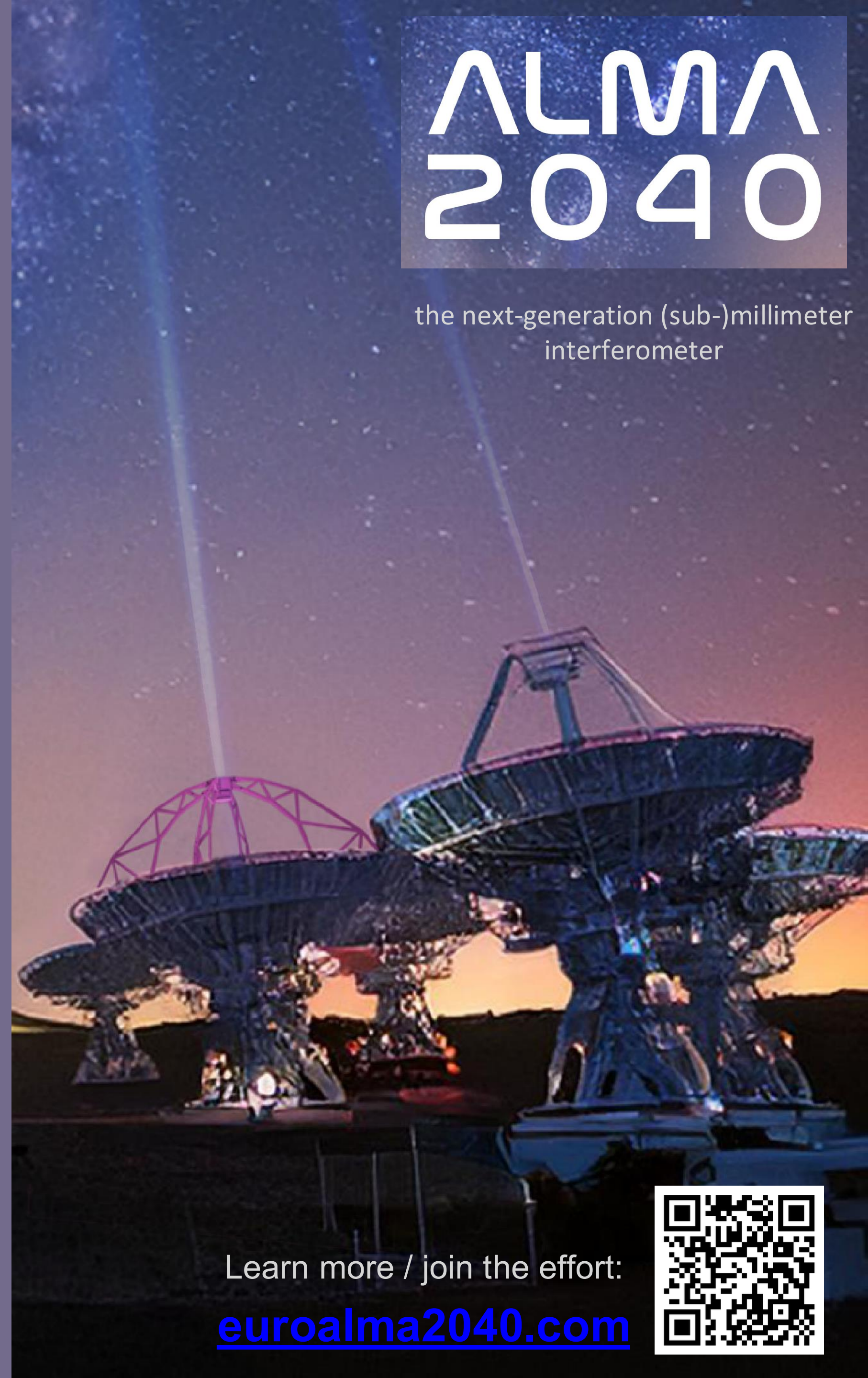
► Data Archive & Processing Working Group

Leads: Marcella Massardi (INAF-IRA, Bologna) & Martin Zwaan (ESO)

Coordinated by: Gie Han Tan

ALMA 2040

the next-generation (sub-)millimeter
interferometer

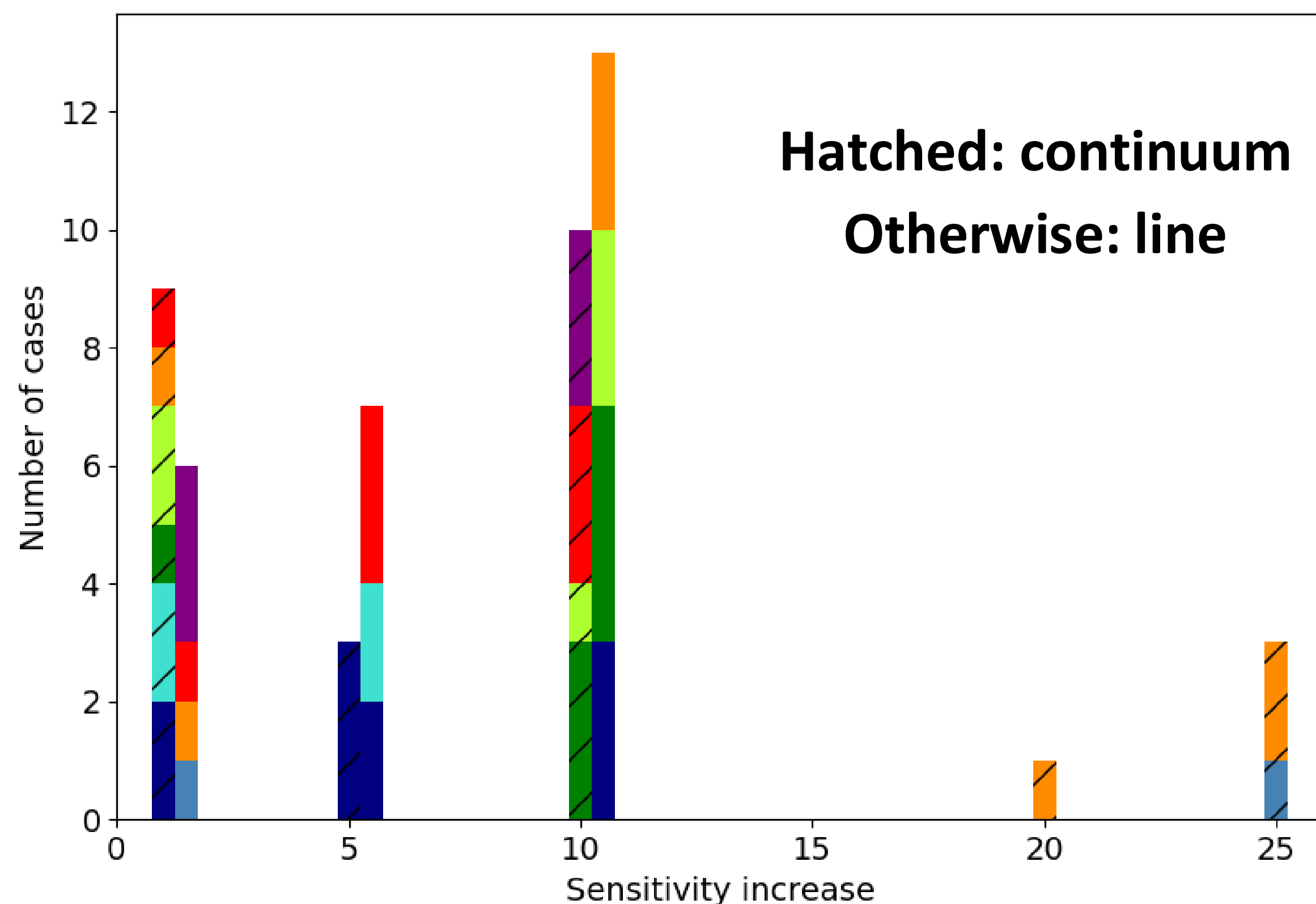


Learn more / join the effort:

euroalma2040.com



Science Requirements: Sensitivity



Line sensitivity boost = 10

Continuum sensitivity
boost = 25

Largest increases requested by:

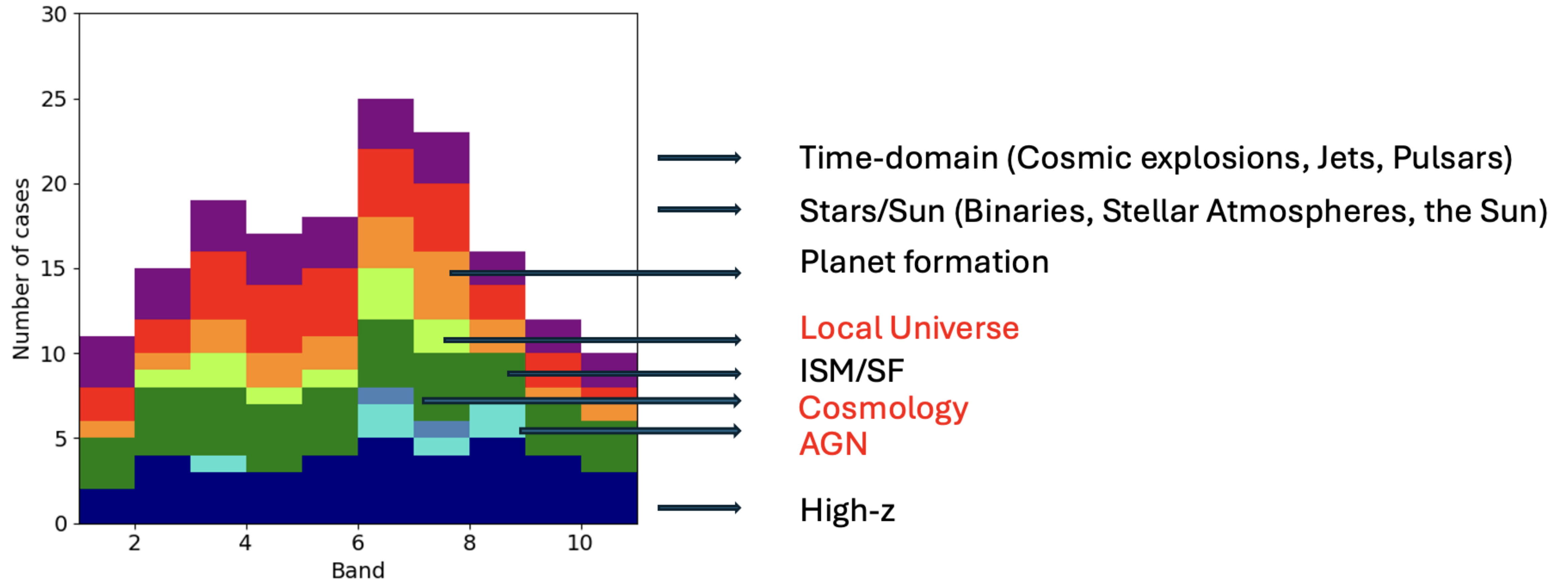
- Line: high-z, local Universe, ISM/SF and planet formation
- Continuum: cosmology and planet formation

Most demanding case: 25x increase in continuum sensitivity, translating to 1 uJy/beam rms per hour at 345 GHz for a 32 GHz bandwidth (finding proto-Jupiters)

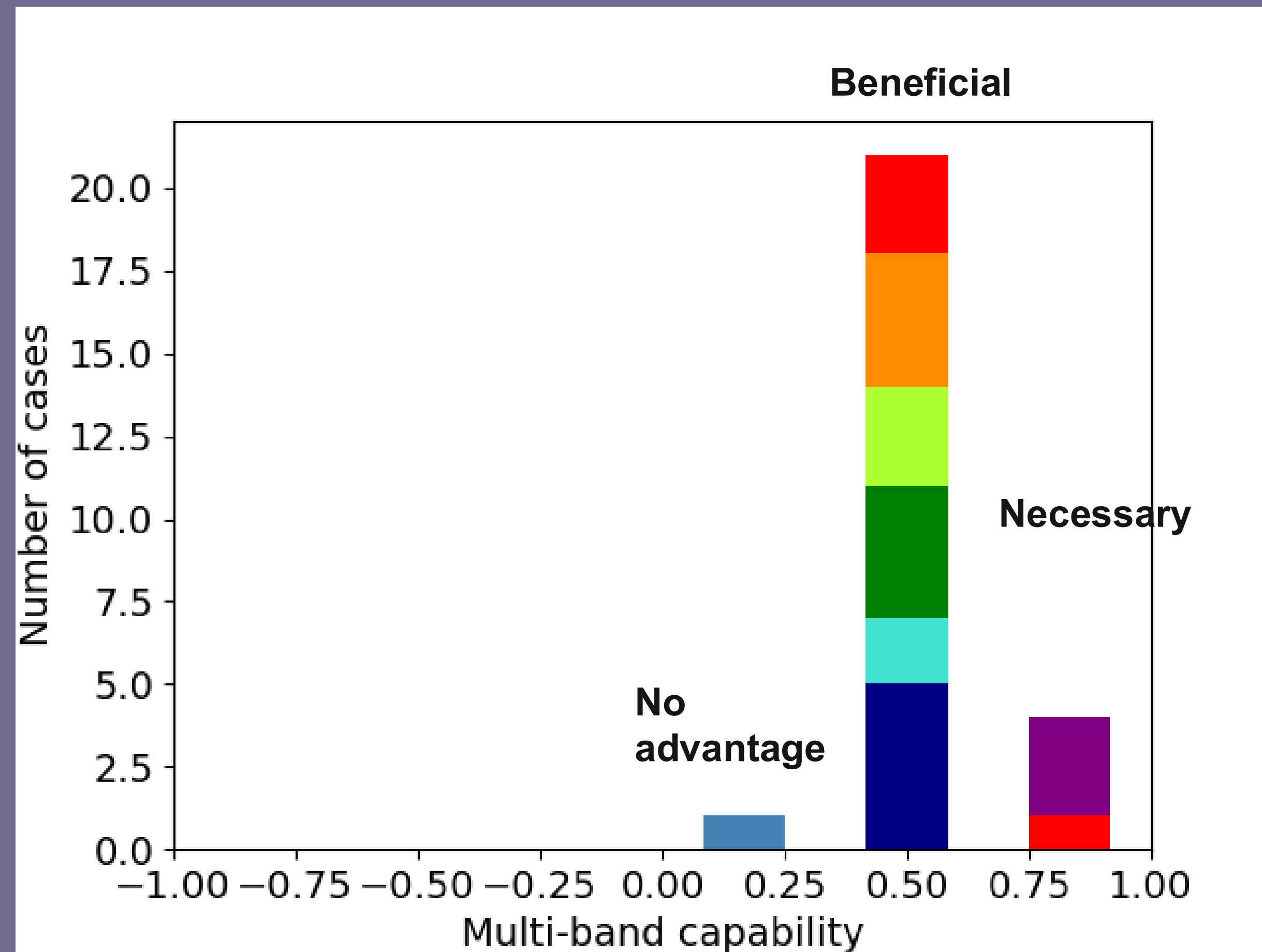
Considerations on sensitivity budget:

- Antenna number
- Receiver noise
- Antenna aperture efficiency (currently 75% at 35 GHz)
- Antenna surface accuracy (currently 25 μm)

Science Requirements: Frequency Bands



Science Requirements: Multi-band

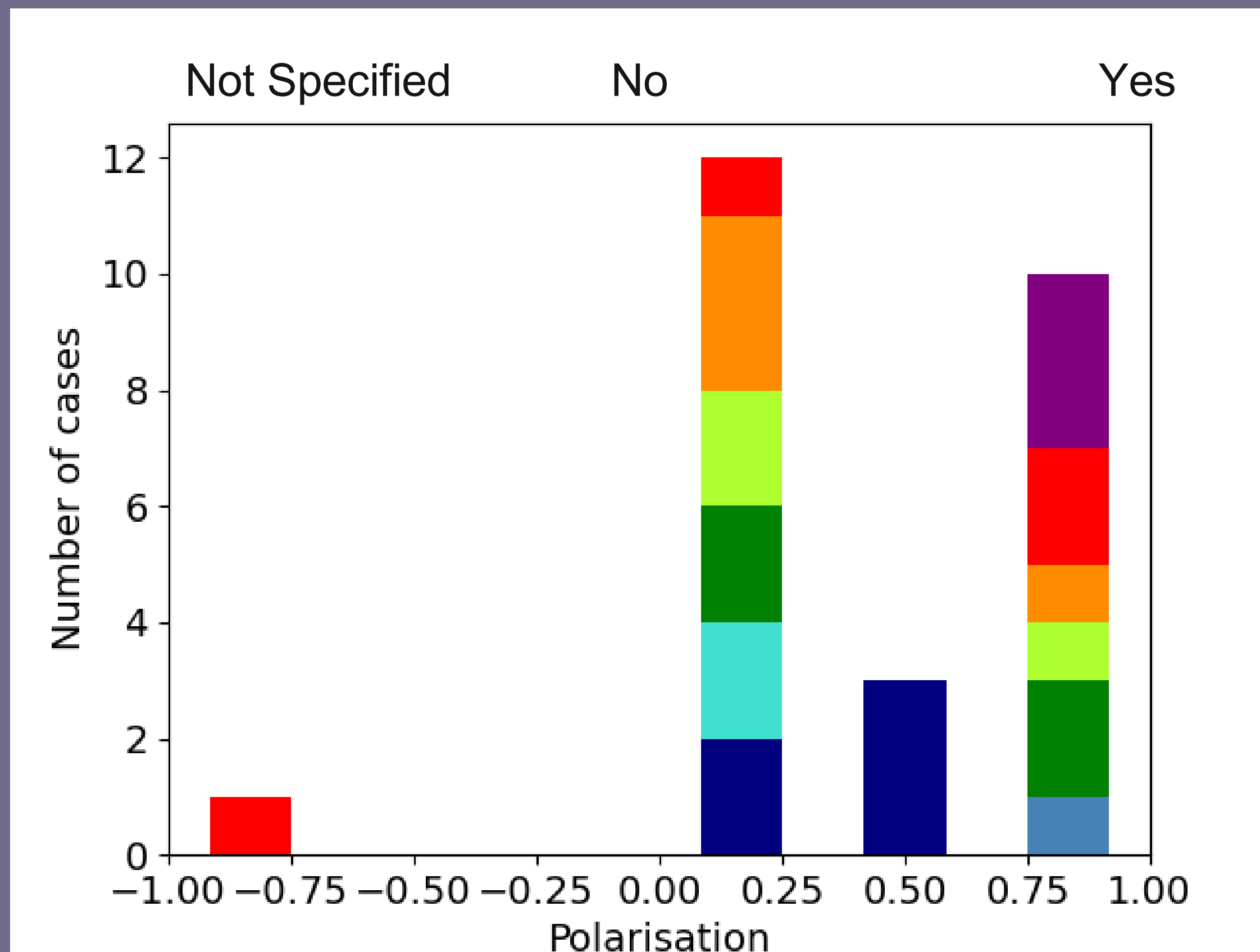


Beneficial: for practically all cases

Necessary: for transients and the sun

No Beneficial
Yes

Science Requirements: Polarization



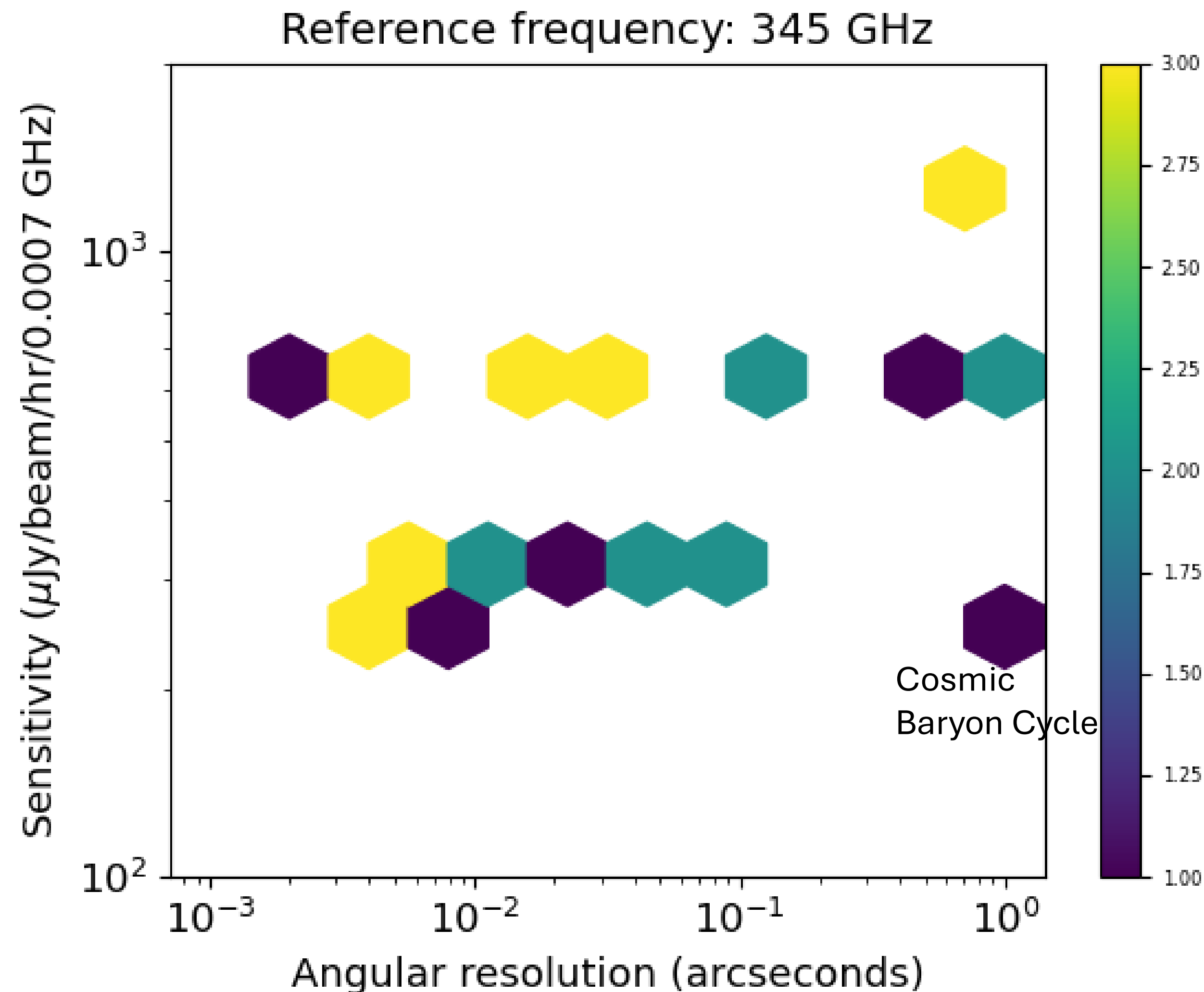
Almost all themes (except high-z Universe and AGN) have at least one case for which polarization capability is critical

Polarization purity of $< 0.1\%$ in line and continuum modes, mosaics, all bands

Science Requirements: Operation

- Target of Opportunity (**ToO**) **response-time of minutes to hours** (CosmExpl, Jets, Pulsars and HighResSun). ToO also needed in combination with VLBI/Phased-Array modes.
- **Monitoring** in scales from high cadence (HighResSun) to daily-weekly-monthly (CosmExpl, Jets, Pulsars) and “multi-cycle” (>~ yearly) (StellarAtm)
- **Coordination** with upcoming high-energy, gravitational-wave, and neutrino observatories (CosmExpl, Jets and Pulsars)
- **Time resolution of 0.1 s** in interferometric mode and **8 microarcseconds** in phased-array mode (CosmExpl, Jets, Pulsars and HighResSun)
- Delivery of products in “**real**” **time for decisions** on follow-up observations
- Investment in **scalable, high-throughput data processing** pipelines to fully exploit these data volumes

Science requirements: Angular Resolution



Angular resolution
requests

Sensitivity boost
over a range of spatial scales

Image fidelity

Additional Science Requirements

- Calibrations
 - Microarcsecond phase stability (for accurate astrometry at the diffraction limit) (Jets)
 - More accurate atmospheric and instrumental phase corrections at the highest frequencies (Bands 9–10) for high-fidelity imaging (CosmExpl)
- VLBI mode (BHs)
- Phased-array mode (Pulsars)
- Solar (HighResSun)

Sustainability incorporated from beginning

- Actively working with experts from Copernicus Institute of Sustainable Development, Utrecht University

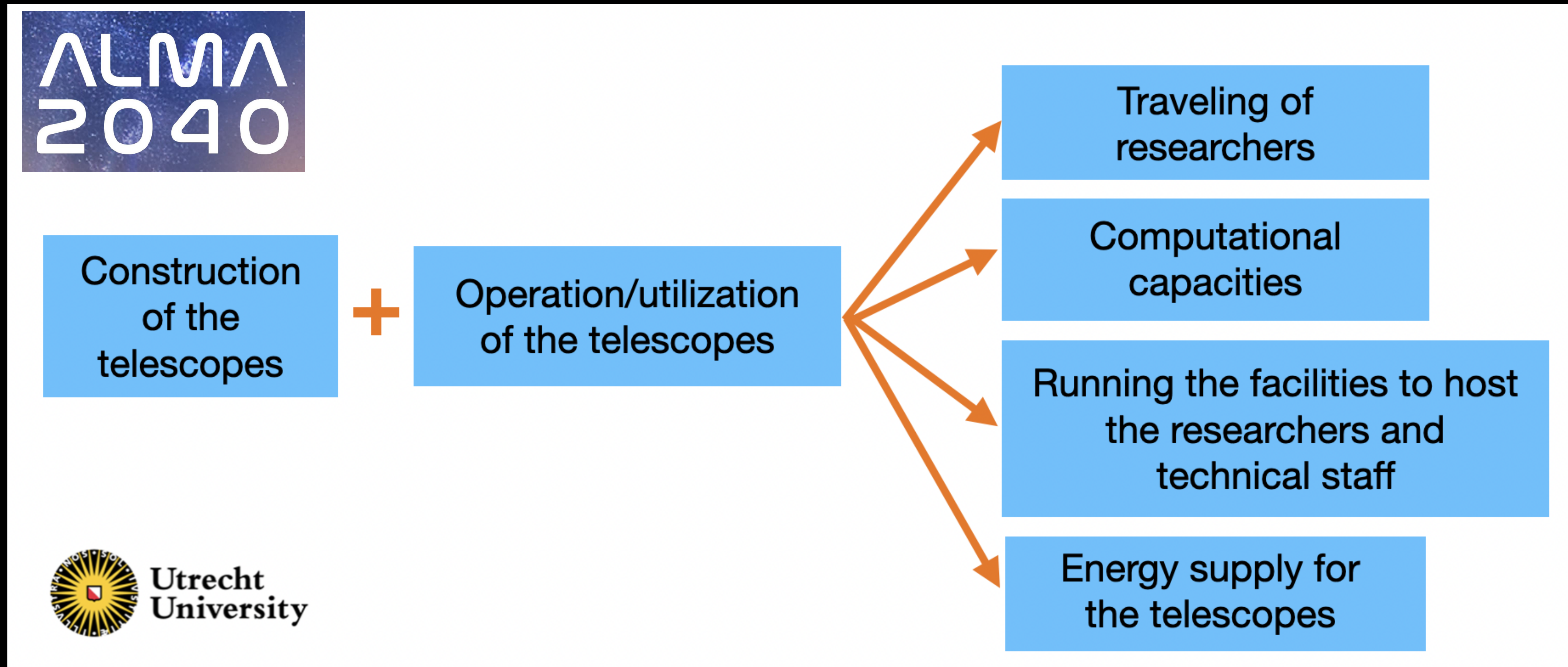
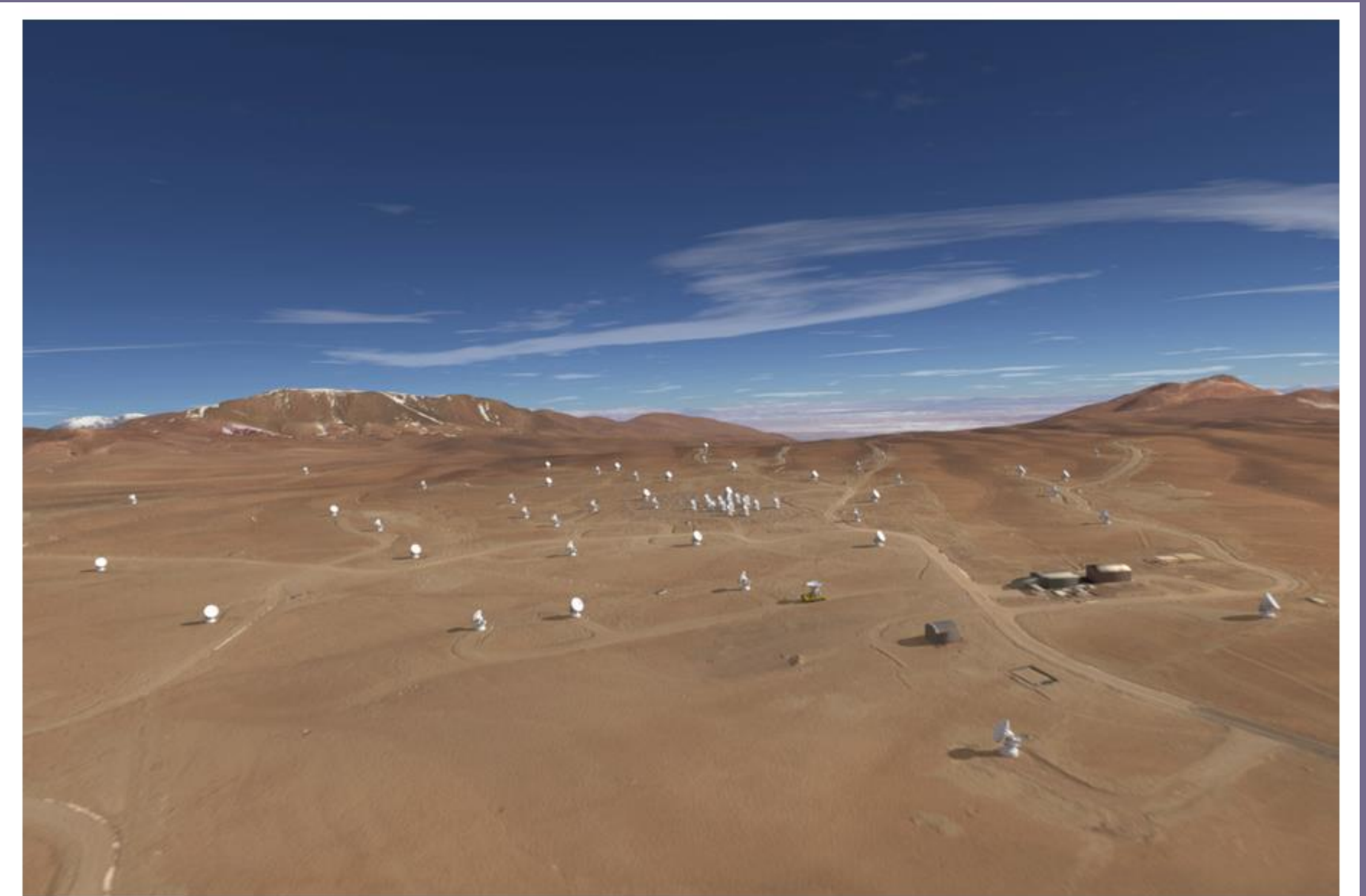


Figure: L. Ramirez Camargo et al., ALMA2040 OWG

Site

- Atacama Astronomical Concession:
 - 360km² @ 4000 to 5600m
 - Good infrastructure
 - max baseline 30 km



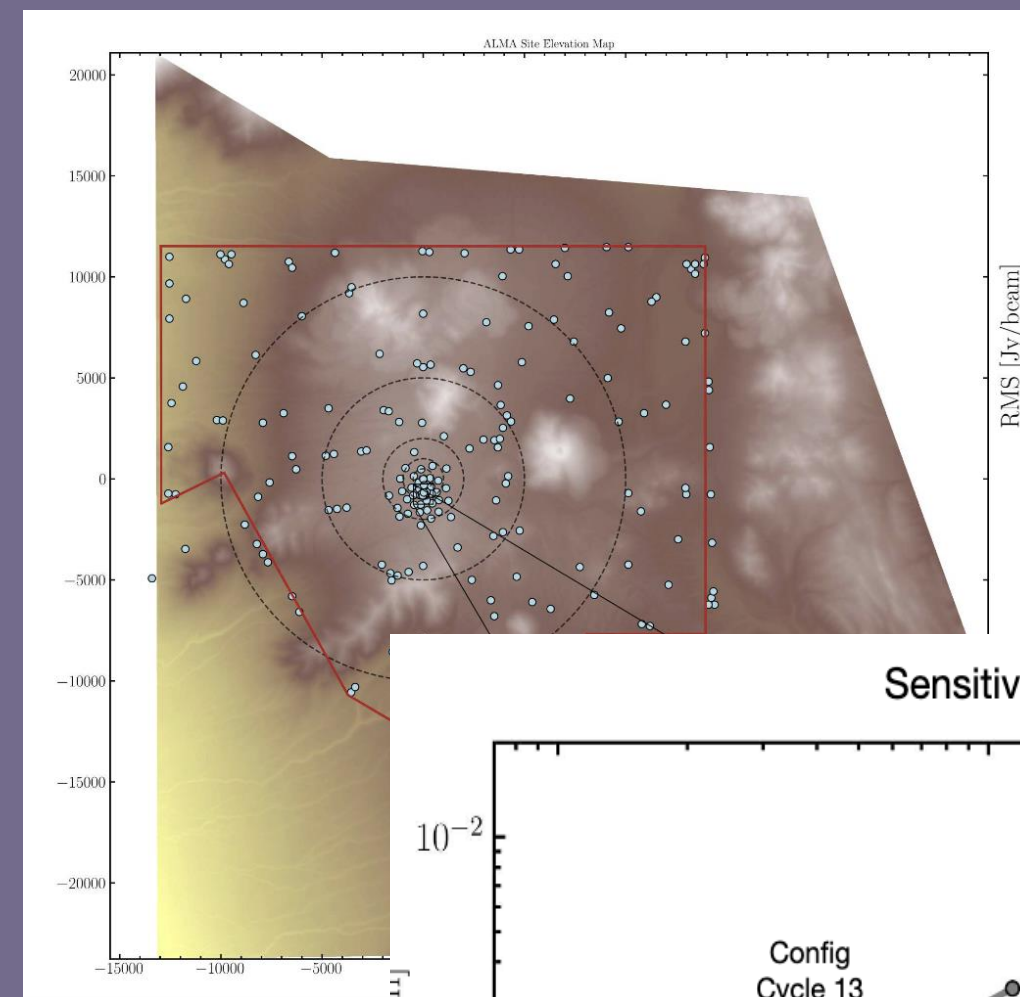
Array Layouts

Fixed vs Movable Arrays

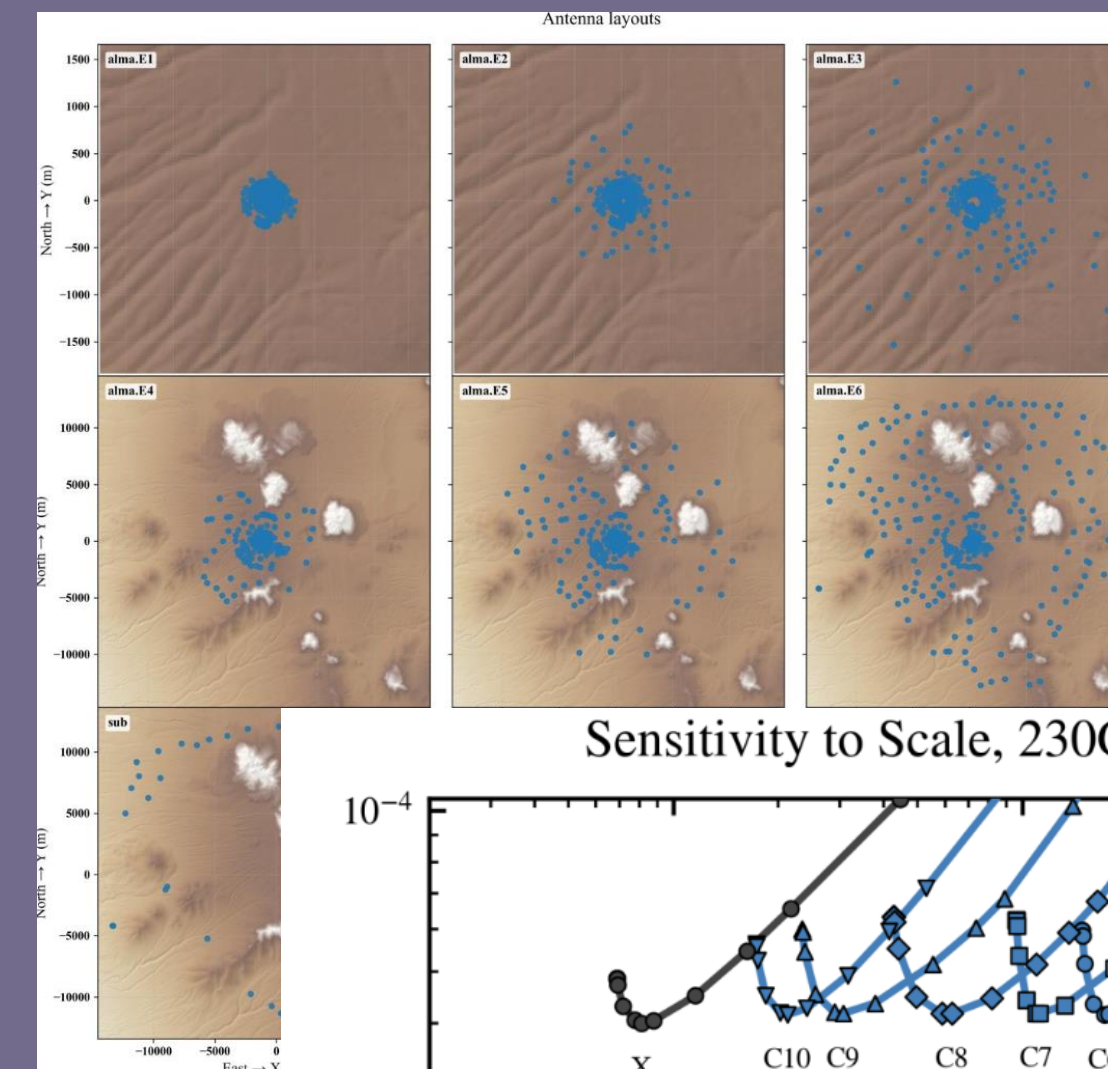
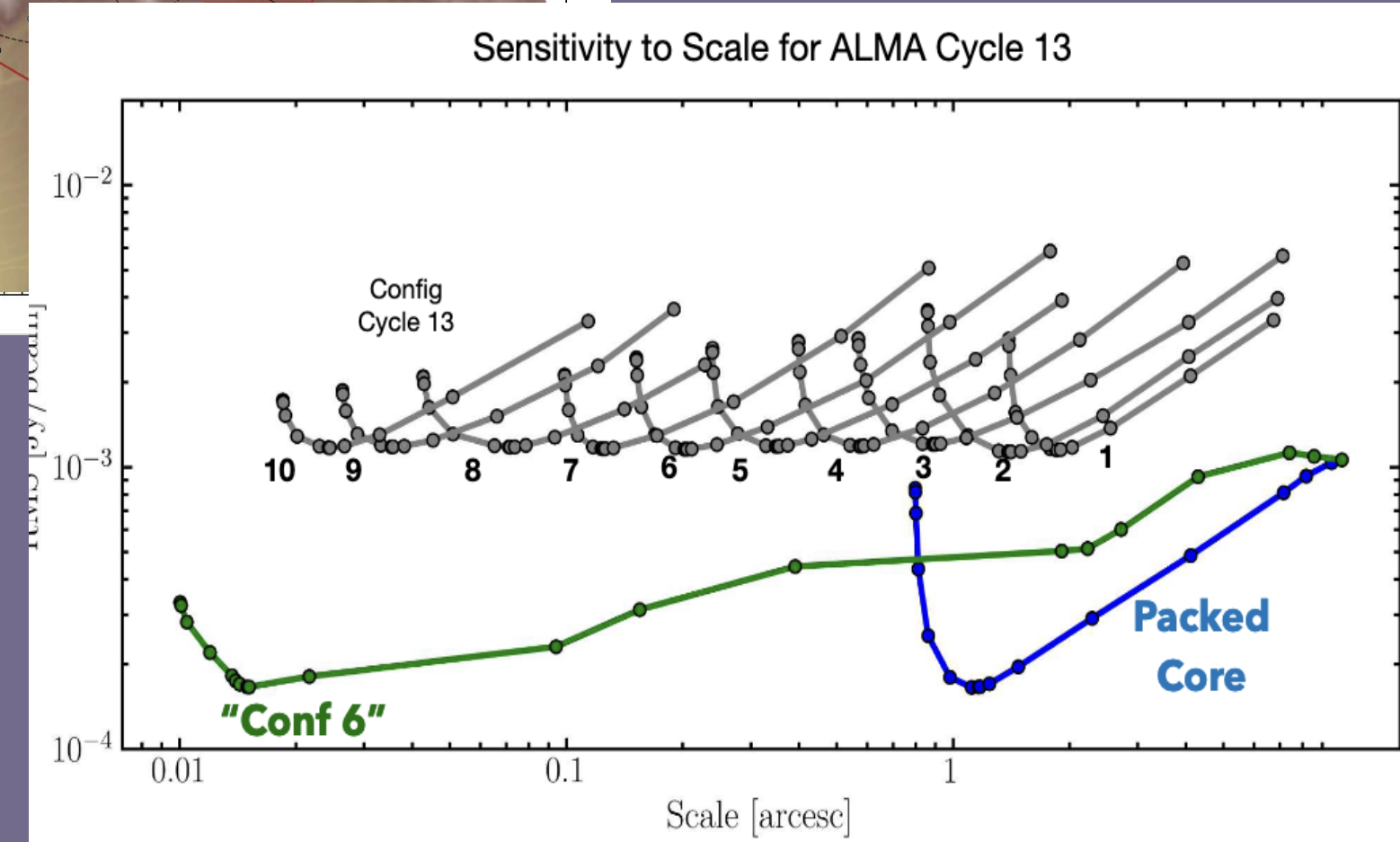
Max baseline within concession: 30 km

Can optimize E80

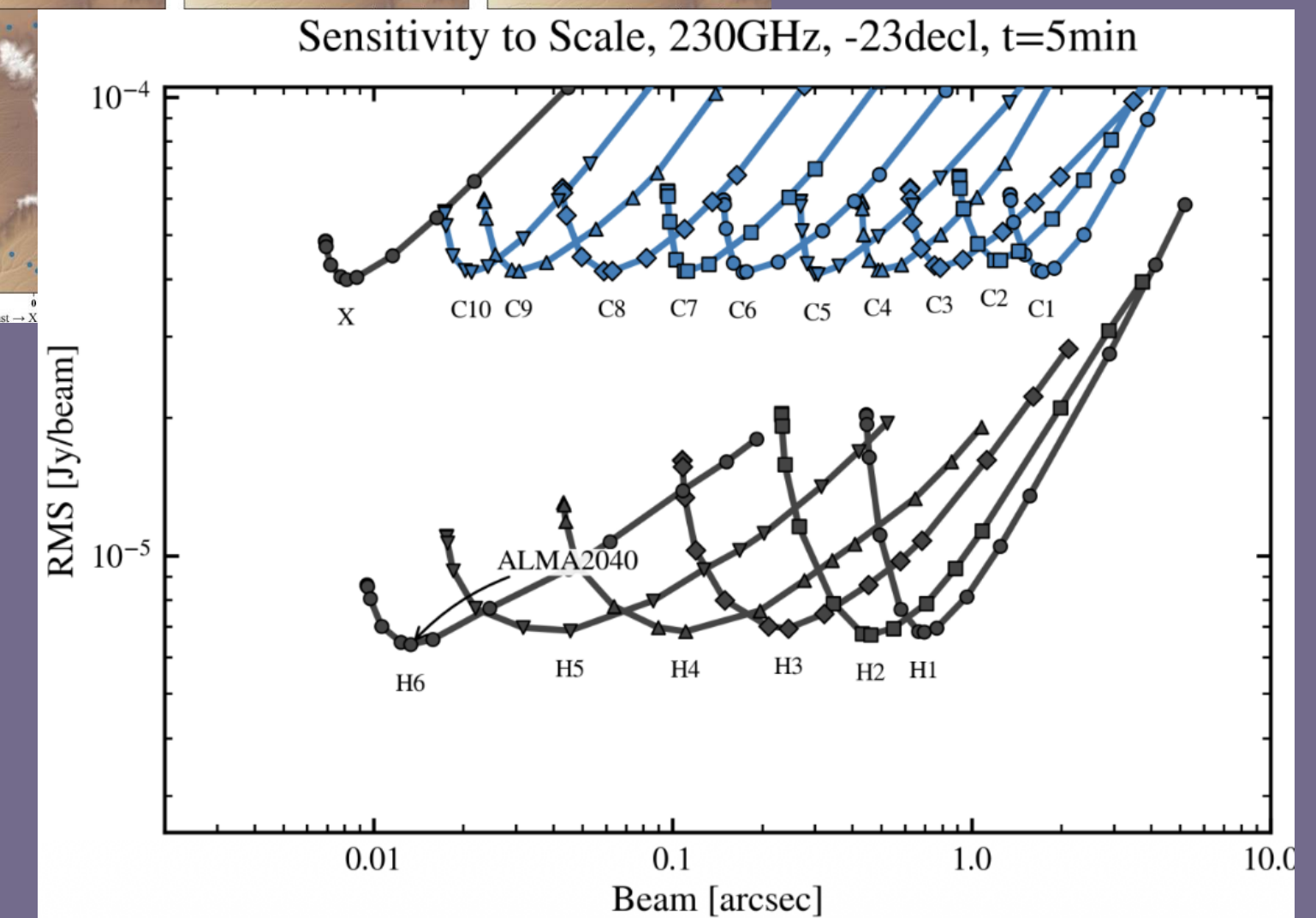
For flux recovery: several large (20 – 30m) antennas
or compact array



Fixed Array



Movable
Array

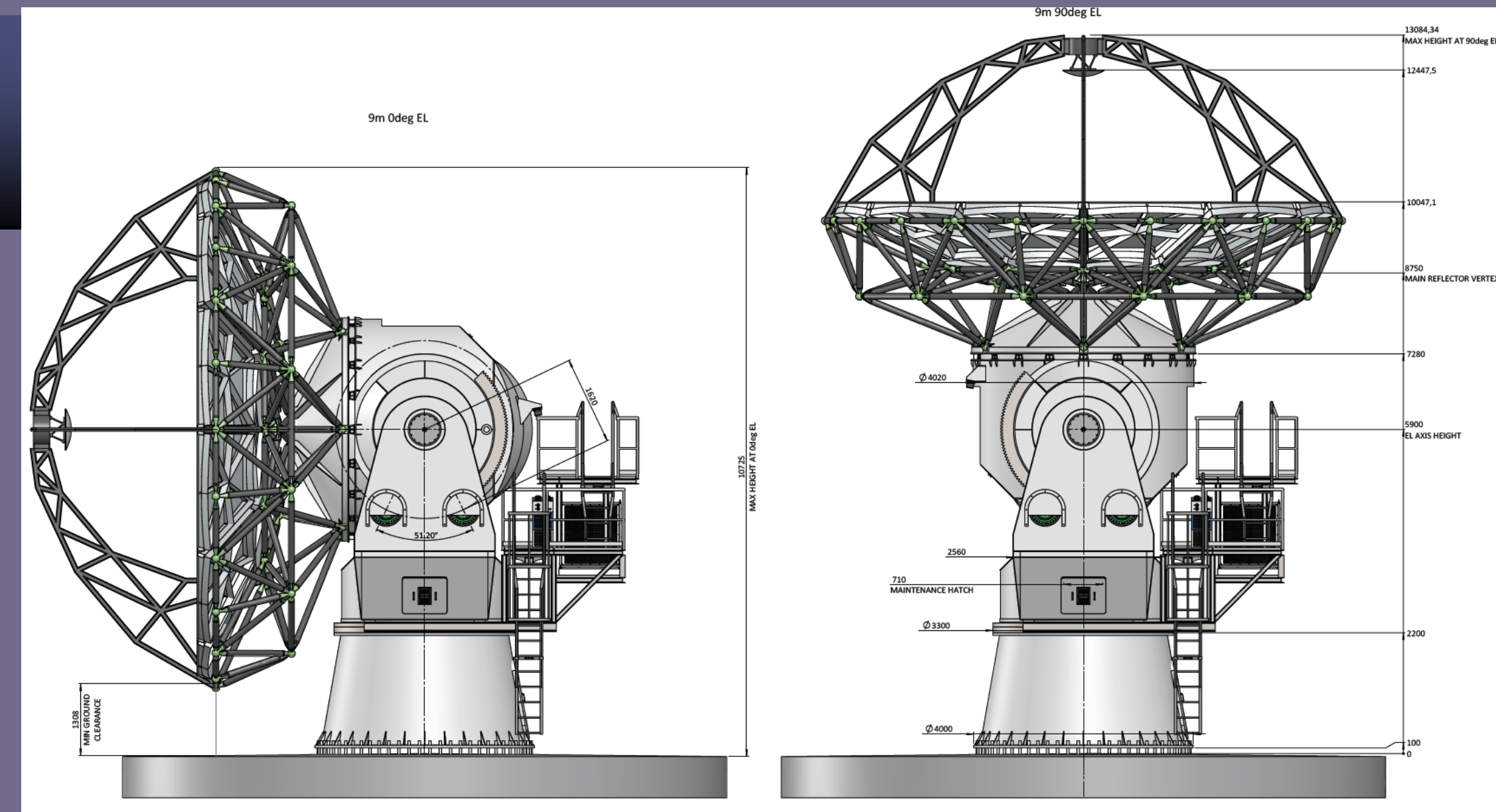
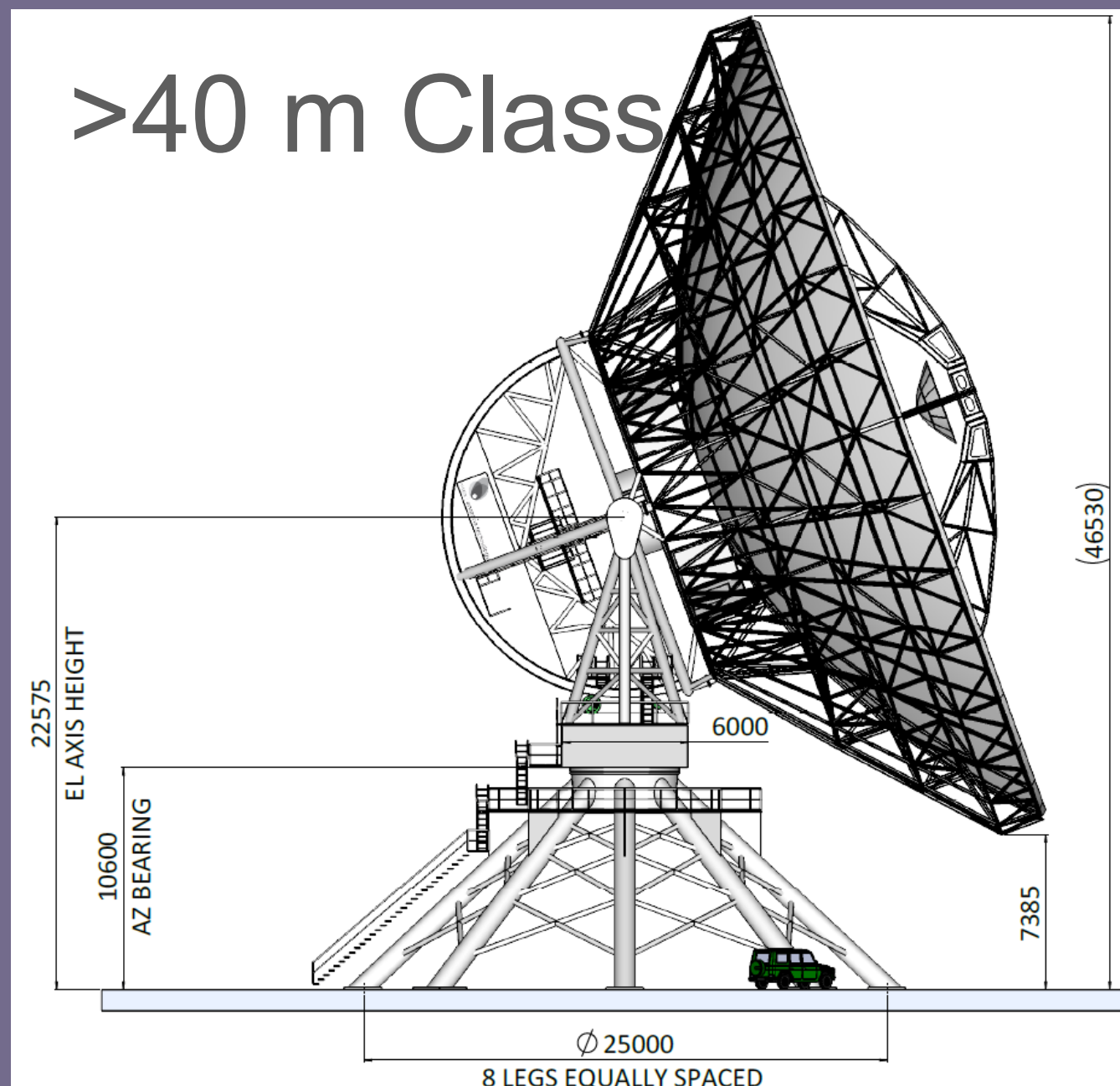


Simulations by Jakob den Brok and Hampus Österbom

ALMA 2040 Antennas

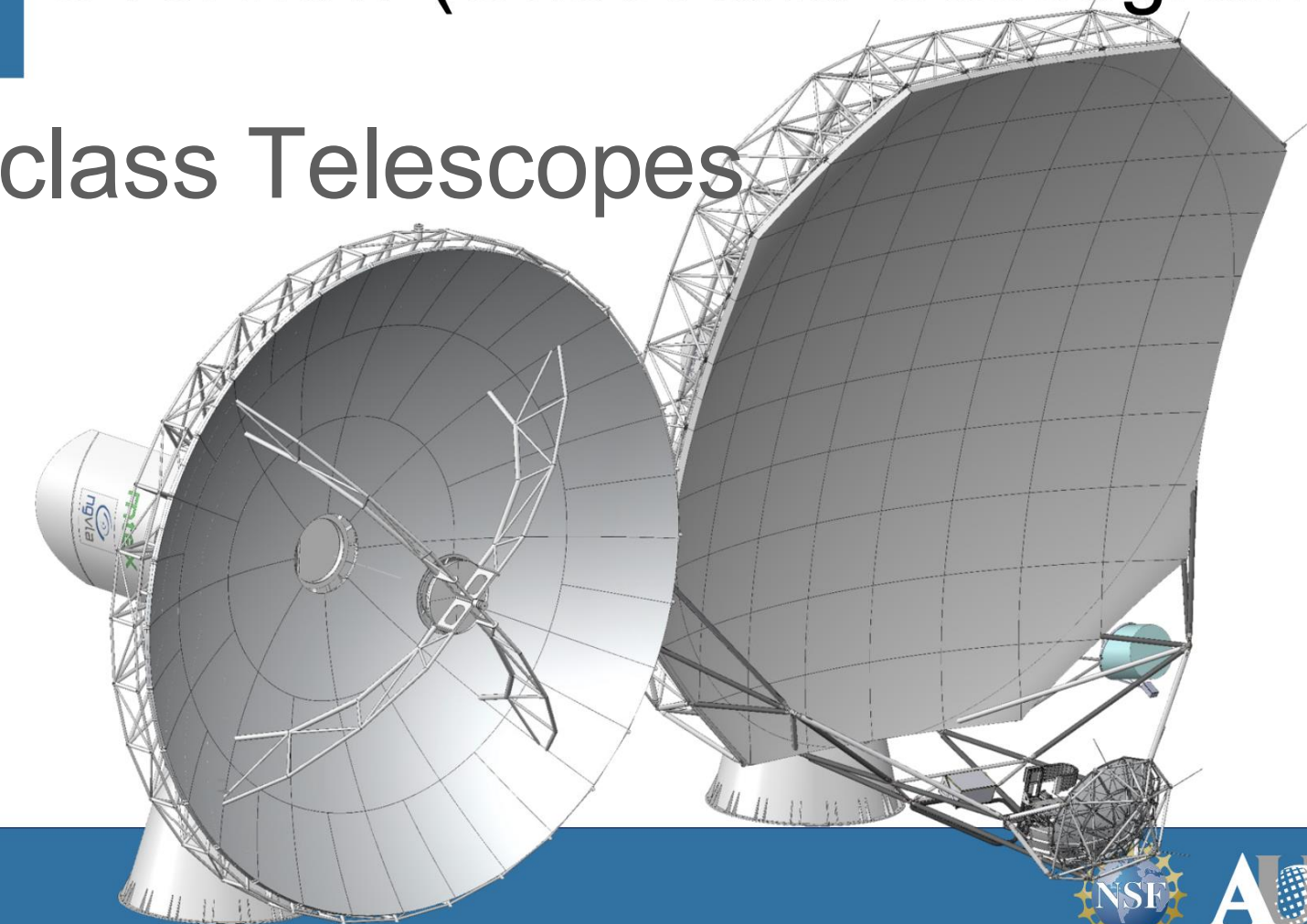
Antennas from 9 – 40 m have been discussed
New Technologies:

- Moveable Antennas based on SPMTs
- Frequencies < 500 Ghz vs. up to 950 Ghz
- Active closed Loop Surface Adjustment with Satellite beacon
- Latest Technology in Mass Production from planned big Arrays like ngVLA and DSA
- **Cost per square meter**
- **Sustainability**



Overview (Offset and Cassegrain I FRONT)

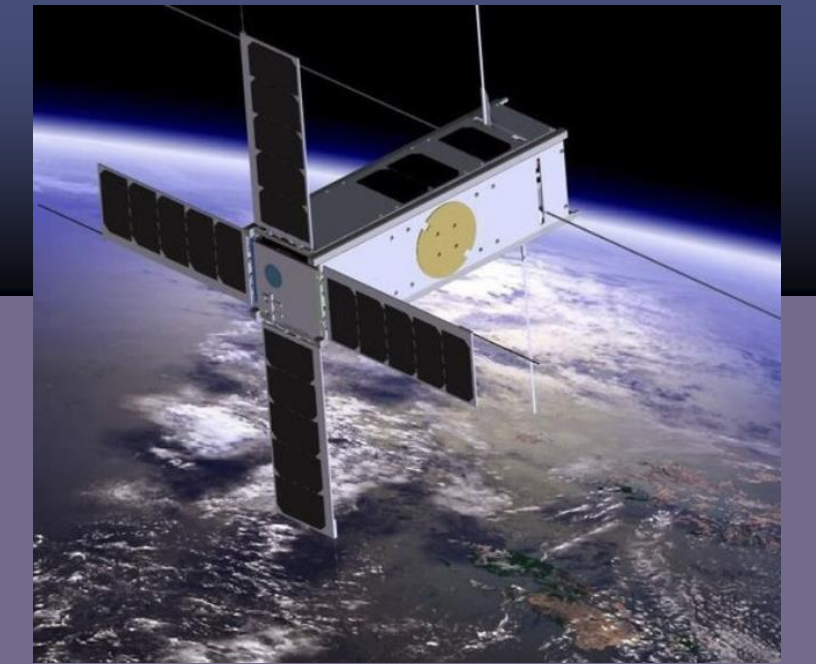
20 m class Telescopes



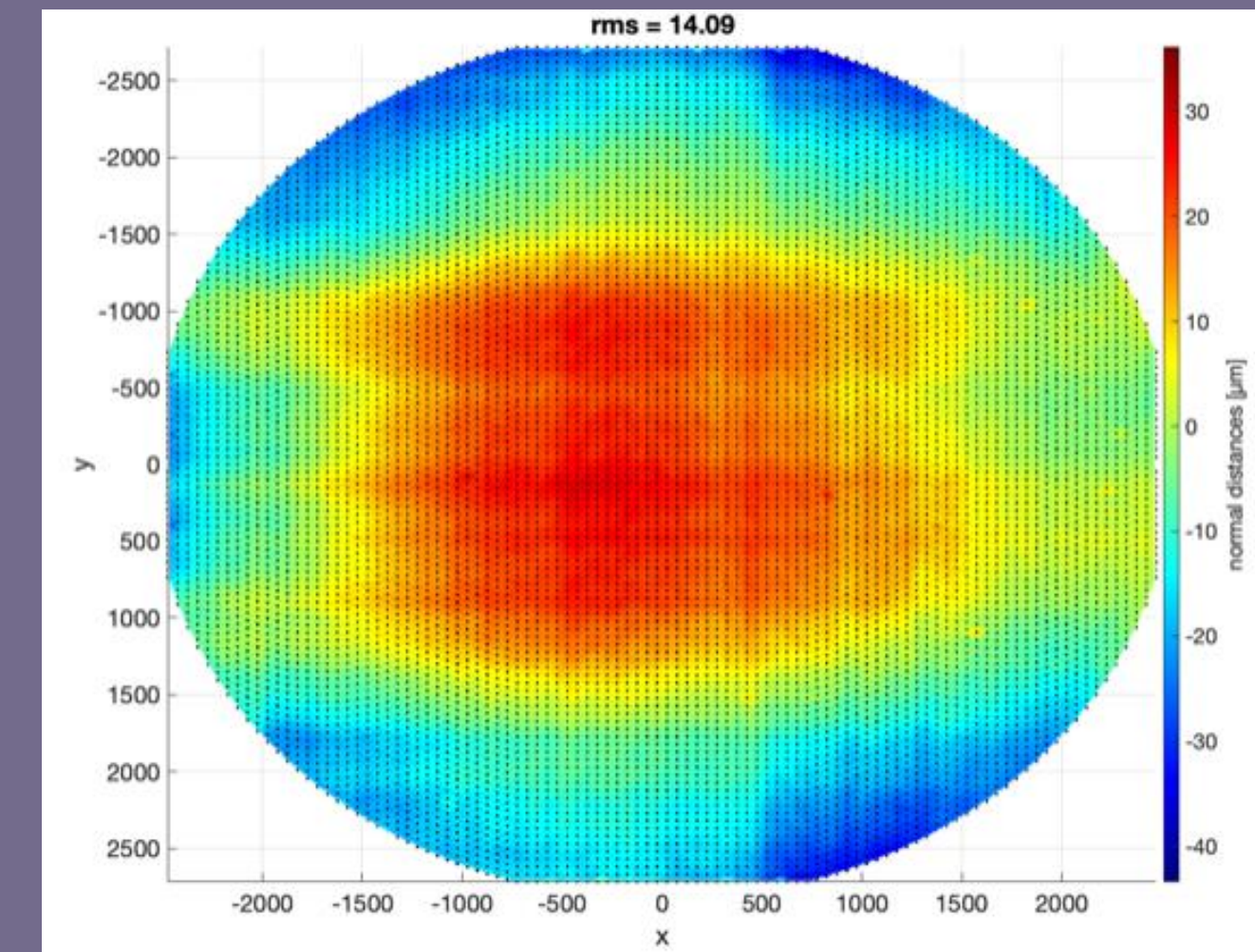
New Technologies: Movable Antennas, beacons

Fully independent moveable antenna systems
New Surface and Adjustment Technologies

Active Telescope Surface with Feedback from Holography
Satellite Beacon



Satcom Groundstation fully independent with Battery system



Large Telescopes could be transported with Self-Propelled Modular Transporter (SPMT)



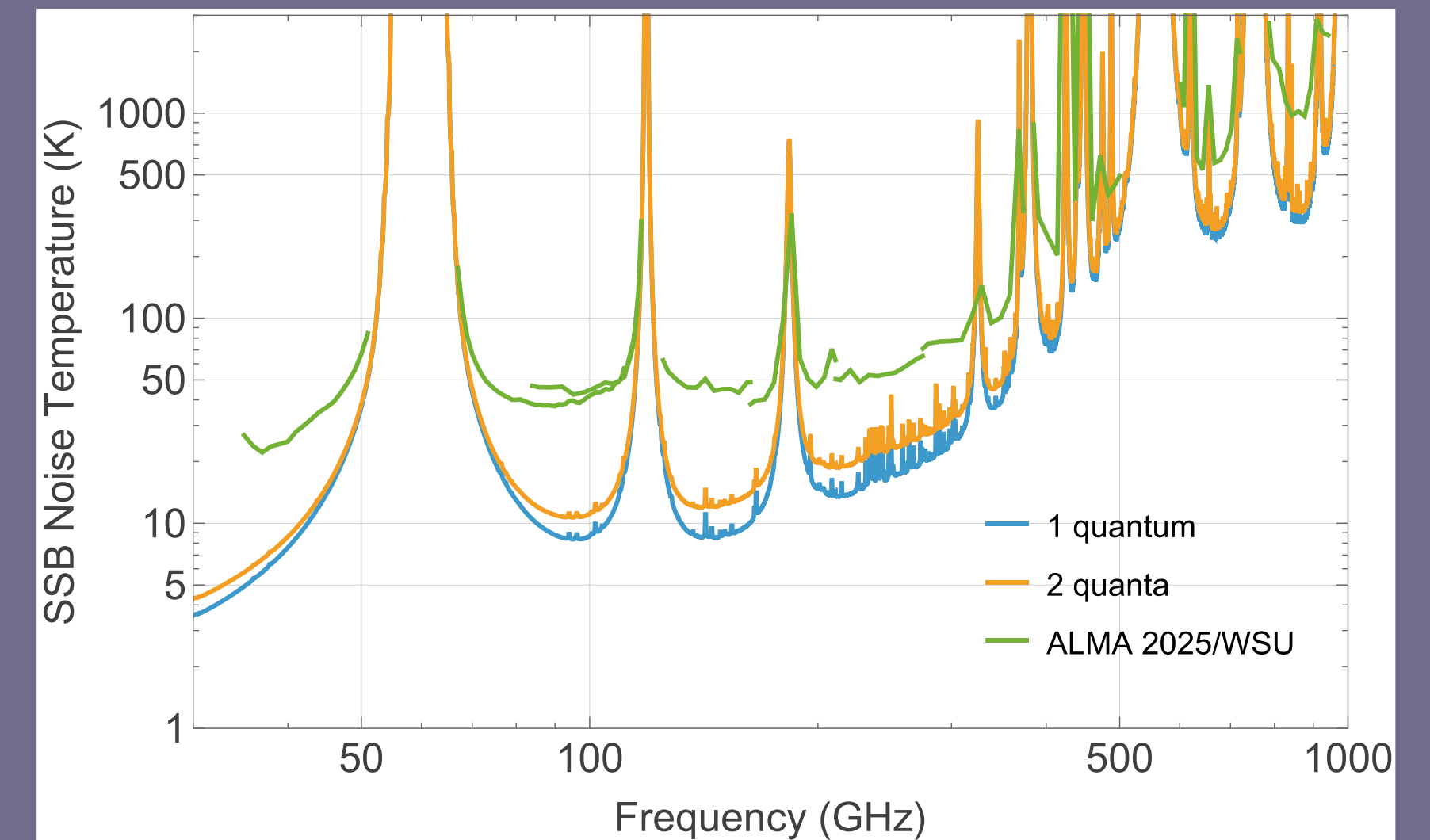
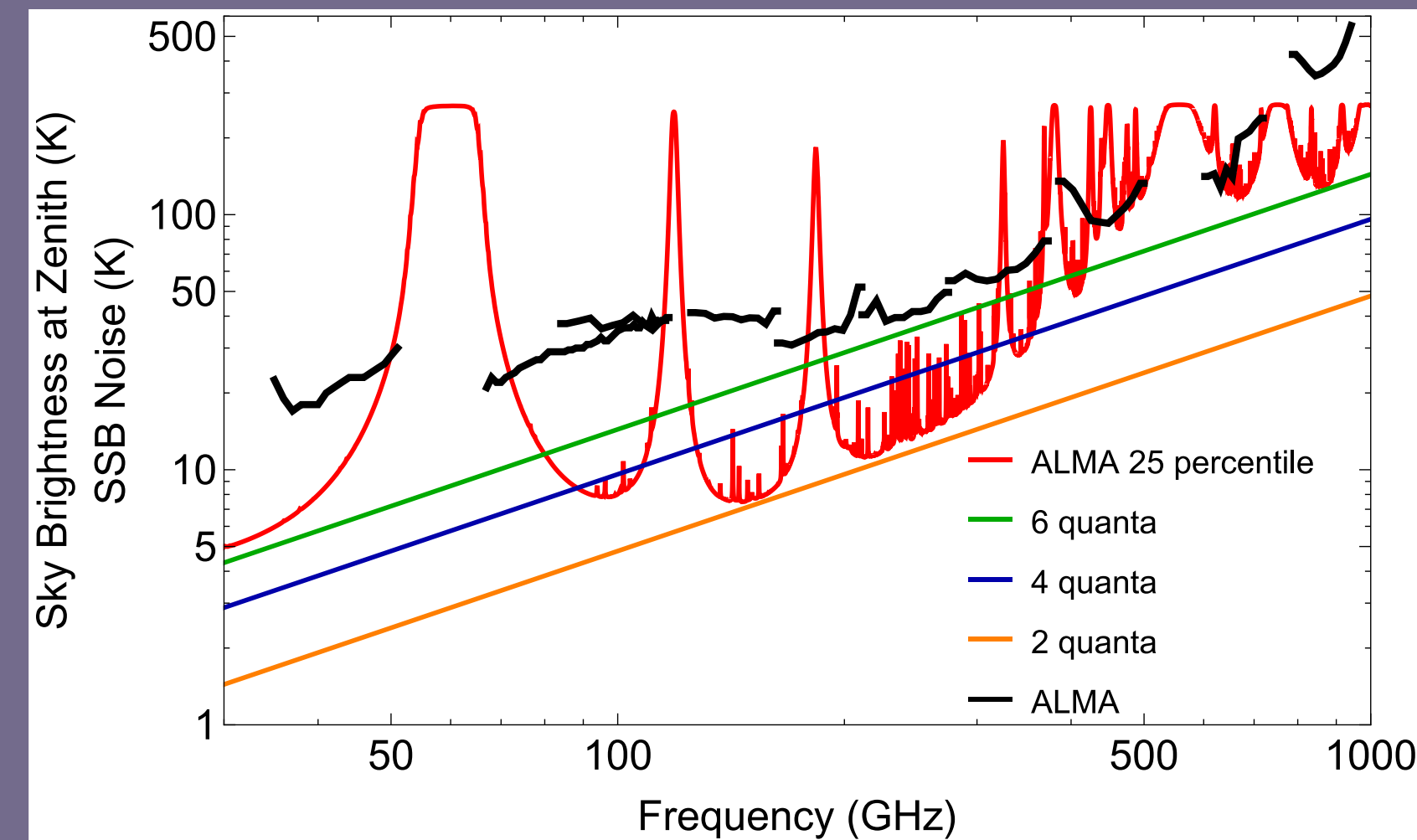
THE NEXT-
GENERATION
(SUB)MILLIMETER

Slide by Andrey Baryshev

Receivers

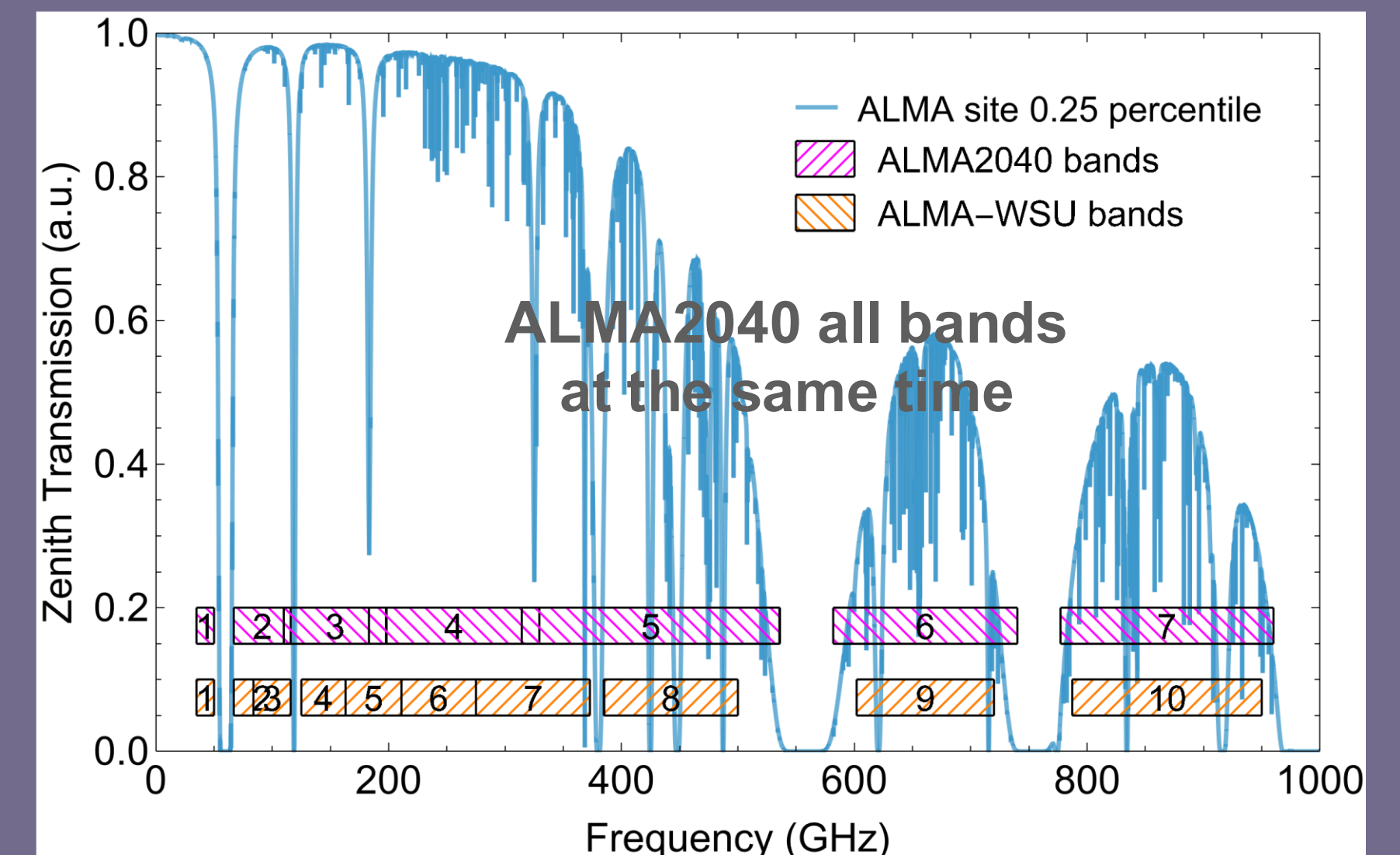
Comparison of sky brightness with quantum limit

Possible Improvement of Tsys



Parameter	ALMA-WSU	ALMA2040
# antennas	54 (12m), 16 (7m)	~200..300 (12m+)
Relative Tsys	1	1/2 ... 1/5
Sky bandwidth	16*2*2 = 64 GHz	~1800 GHz
On sky	1 band	All bands
Relative Line sensitivity	1	1/10...1/20
Relative total power sensitivity	1	1/50...1/100

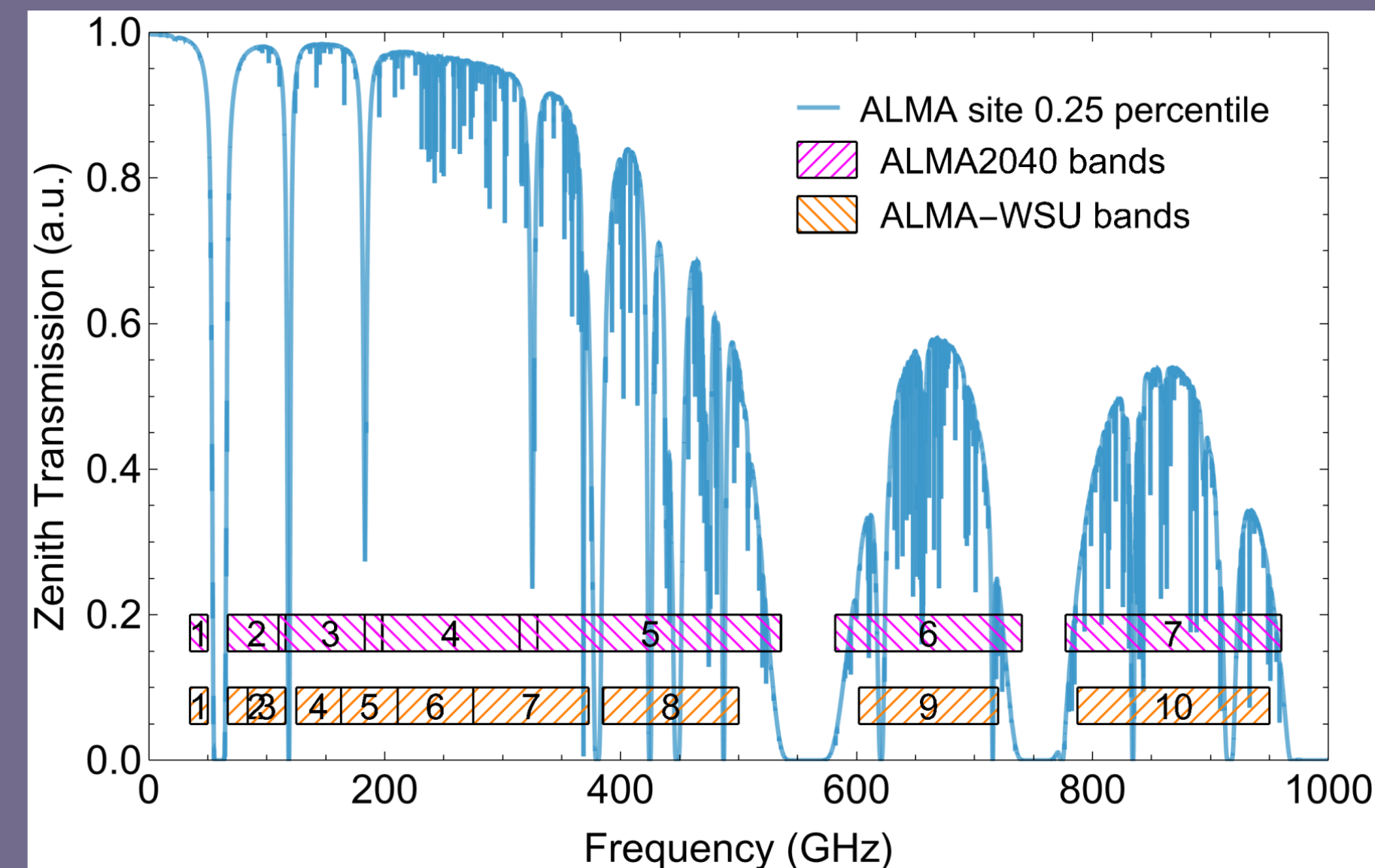
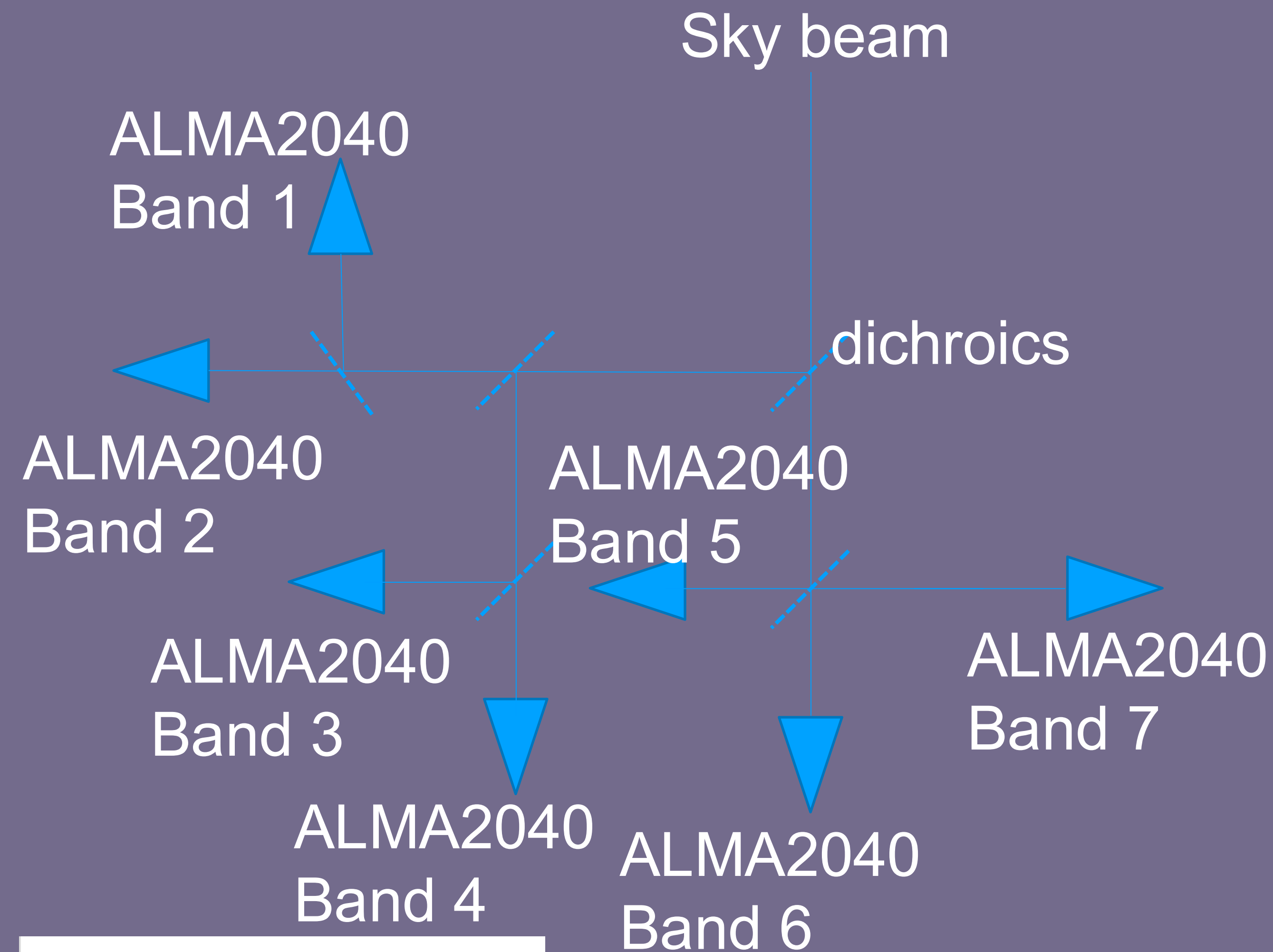
ALMA2040, All bands point same direction and operate at the same time



Slide by Andrey Baryshev

Multi-band

Dichroic solution

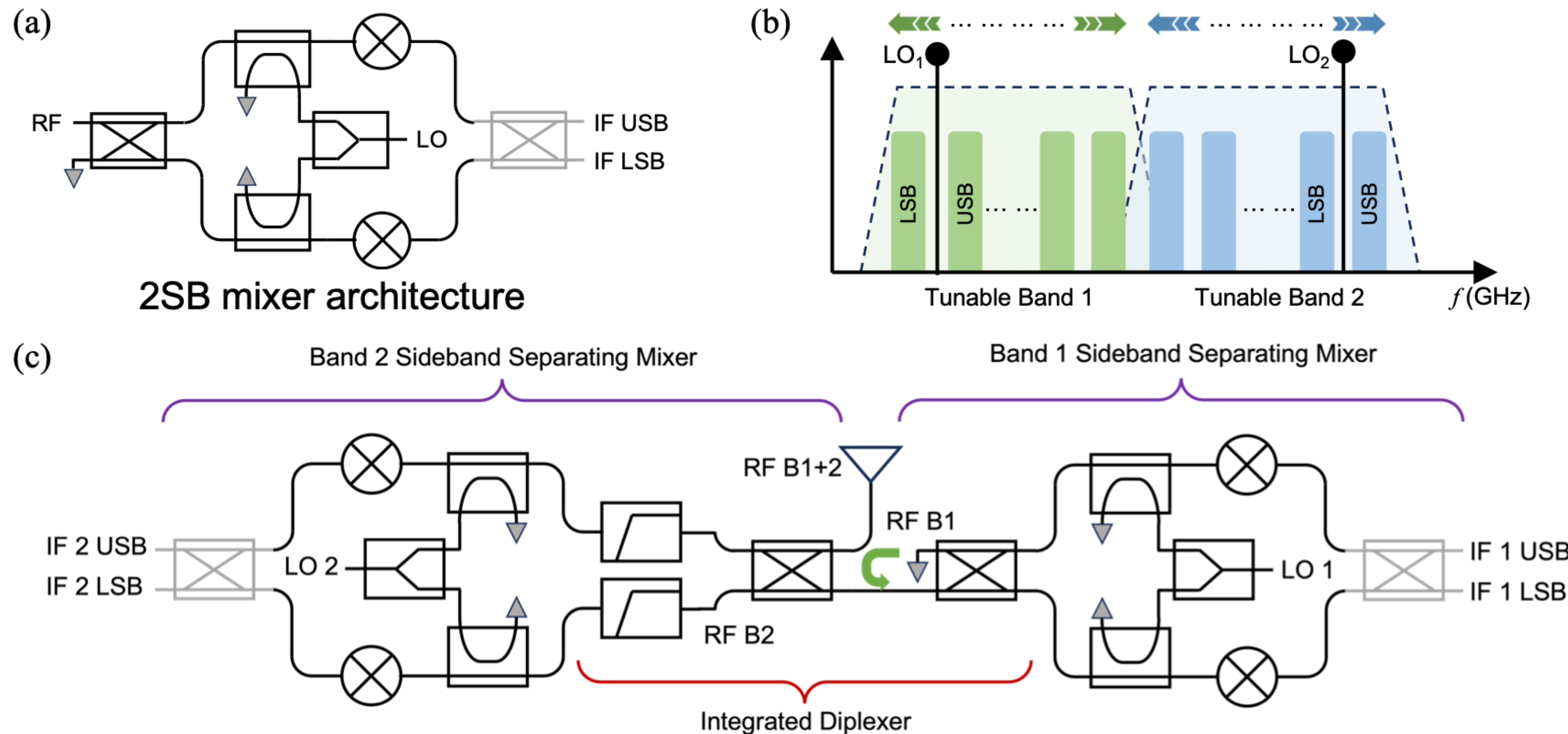


Classical dichroic solution

- Cold dichroic (4K)
- Low loss
- Large bandwidth
- Guard bands (band overlap)
- No cartridge

But there are better ways

Band Combination on Rx level

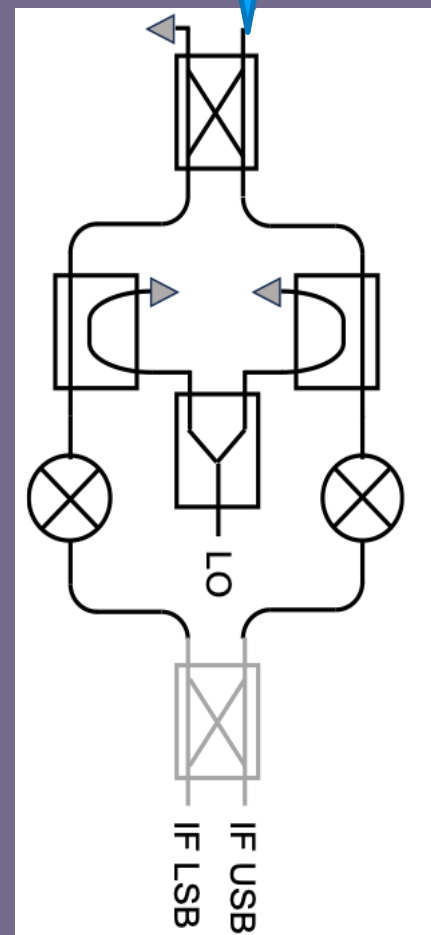


Using waveguide hybrid technology

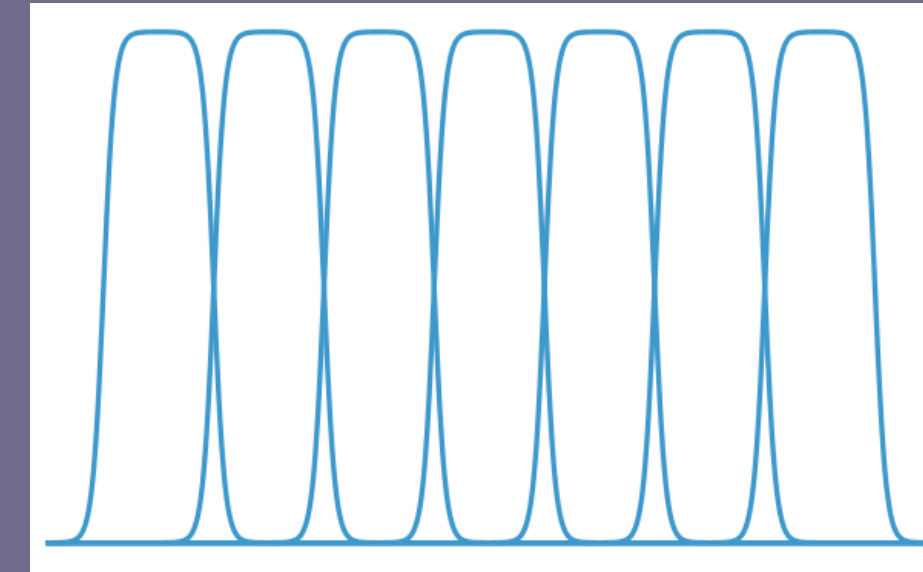
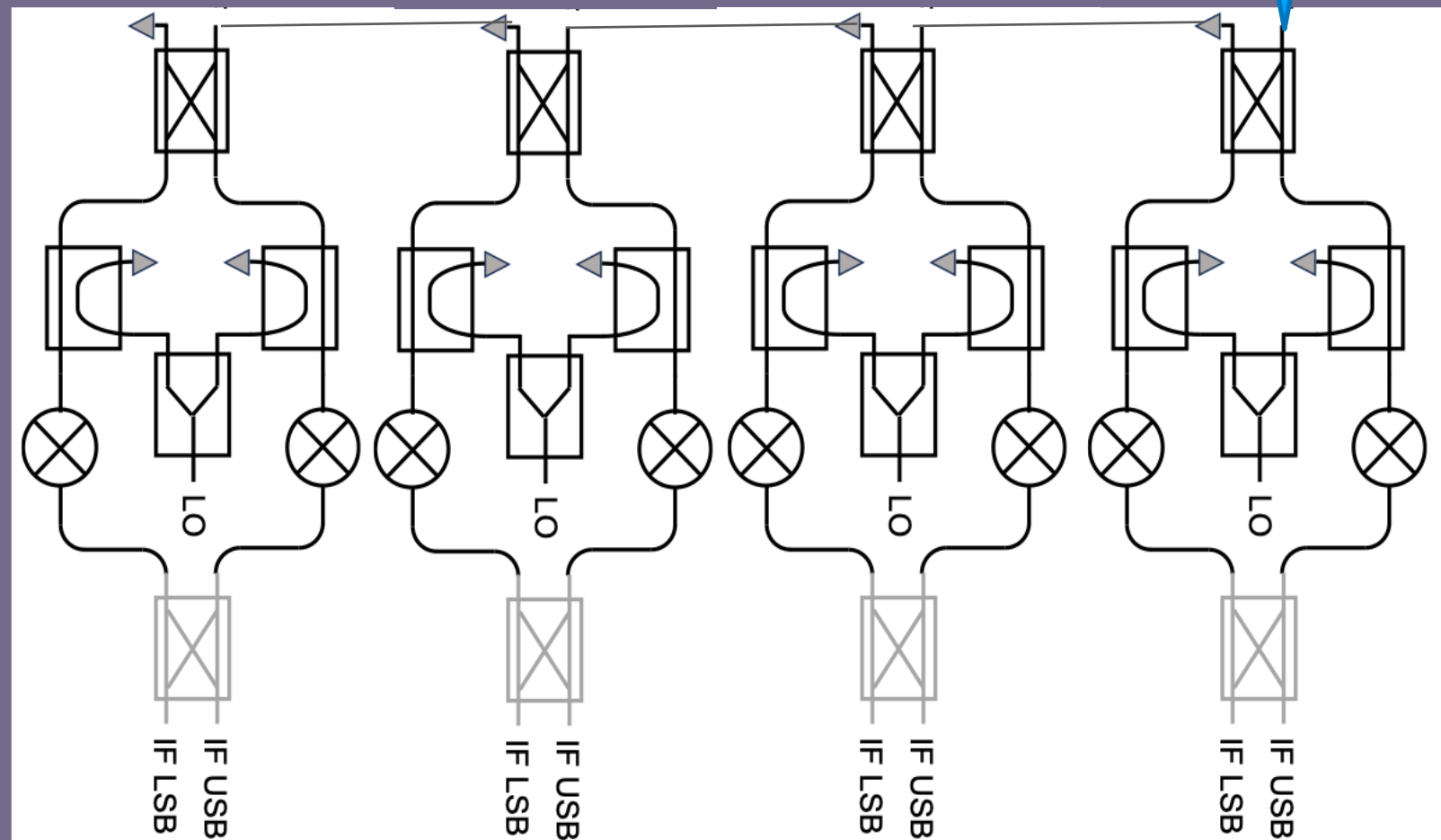
**Combine two bands
In one receiver,
Low loss**

Receiver Architecture

Single
band



Channelizer
(32/64 GHz)



Amplifier band

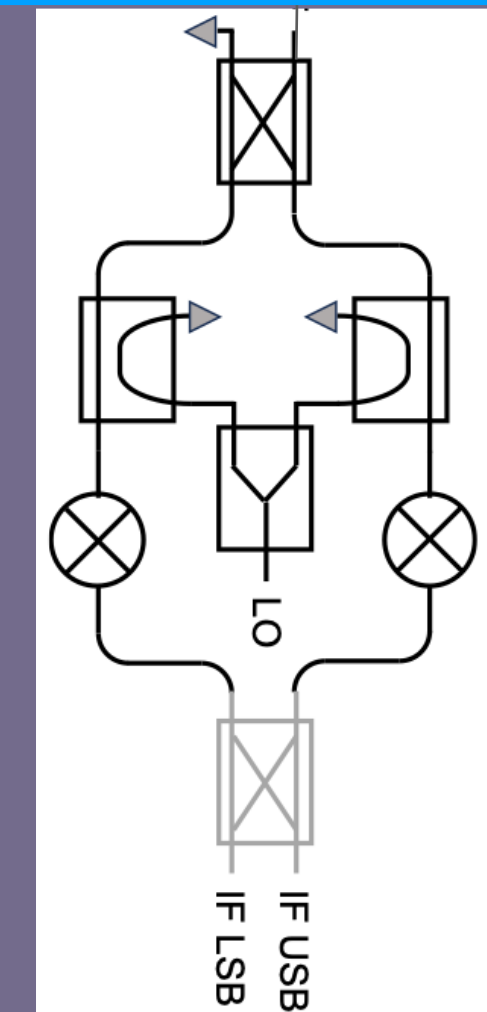


HEMT or
Parametric amplifier

Cold Space

Warm space

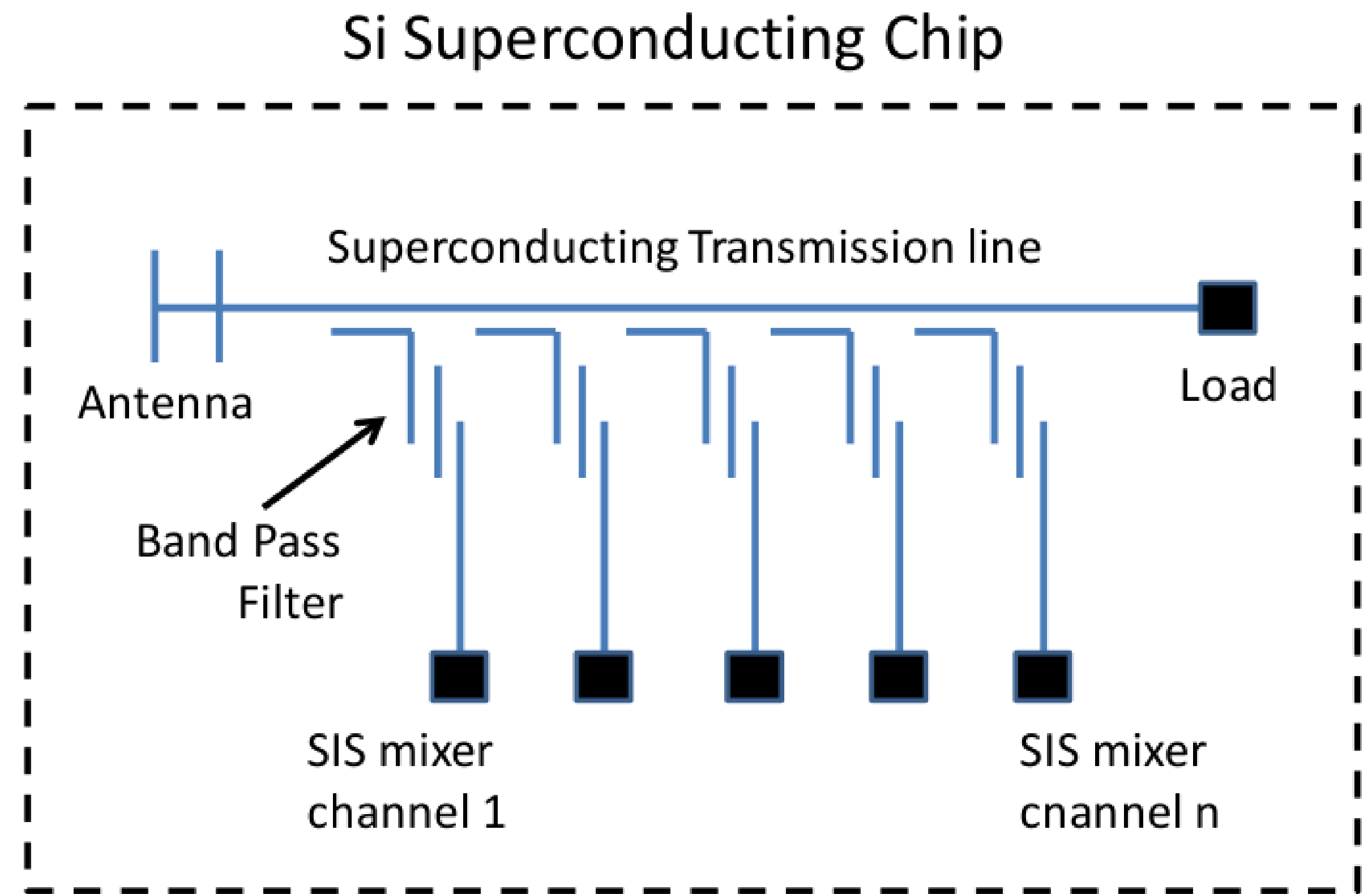
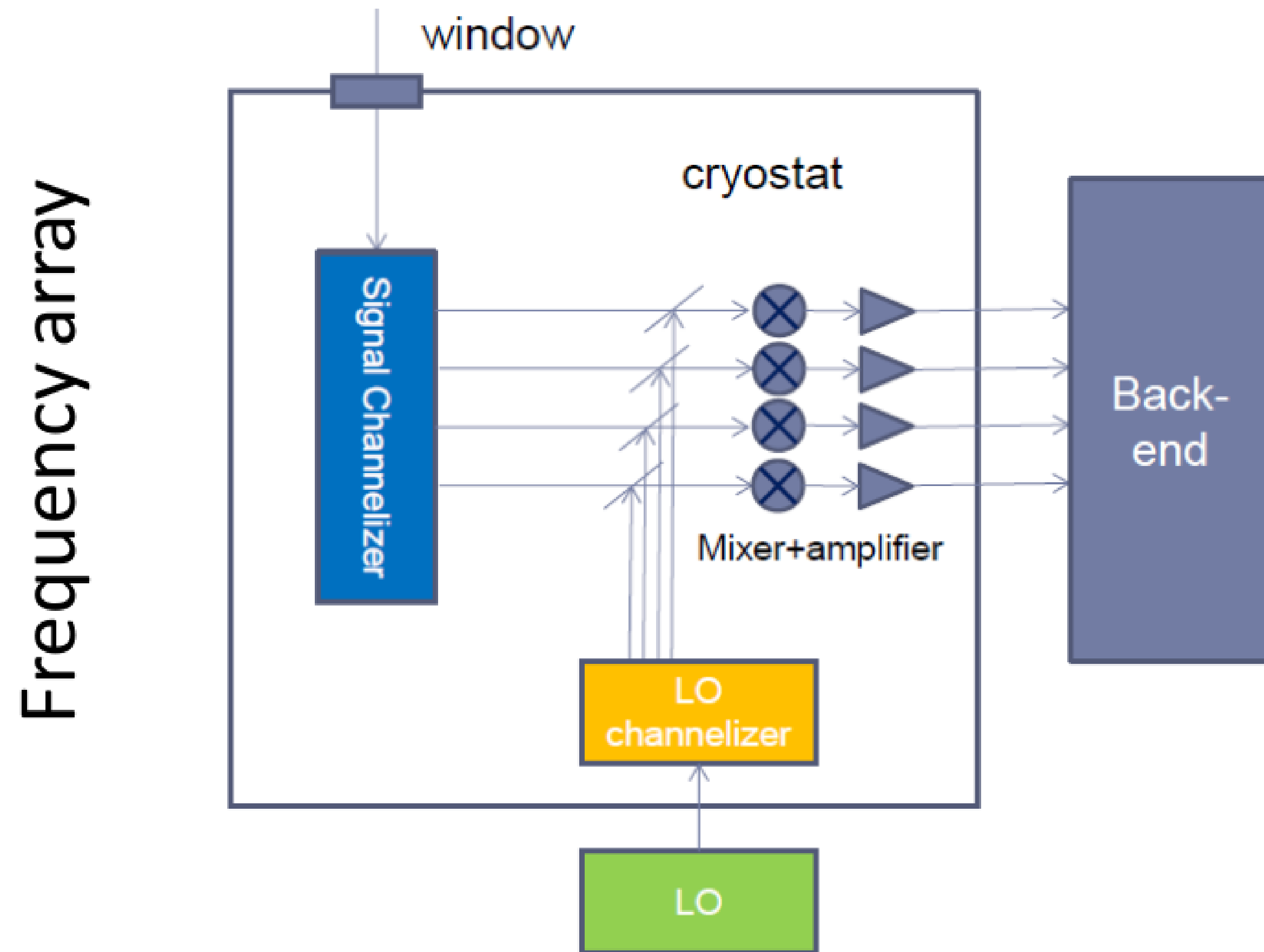
digitizer



Each mixer is:

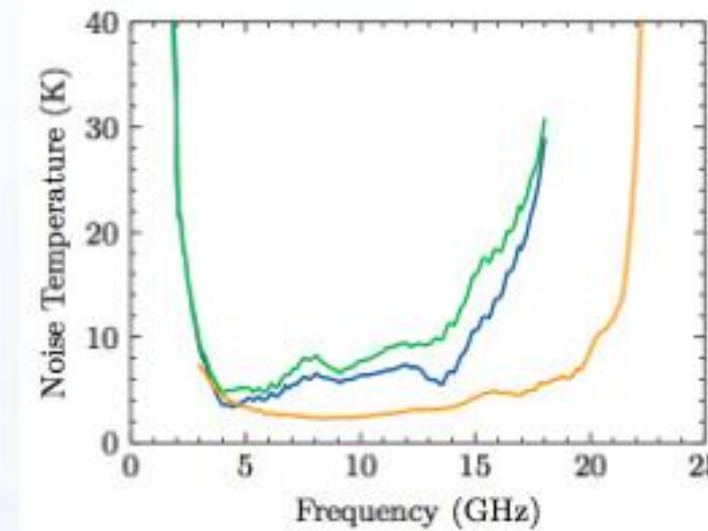
- Quantum limited **balanced** SIS mixer
- 2SB scheme made out of unit balanced mixers
- Several mixers per band to cover **FULL** band

Channelizer Technology

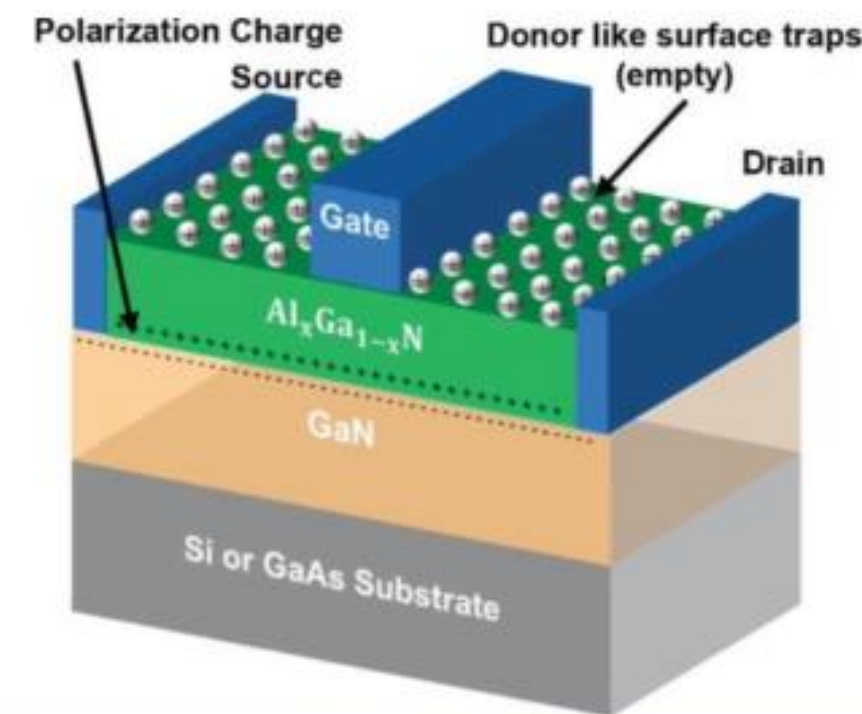


Commonly-Used Microwave Amplifiers

High Electron Mobility Transistor (HEMT) Amplifier

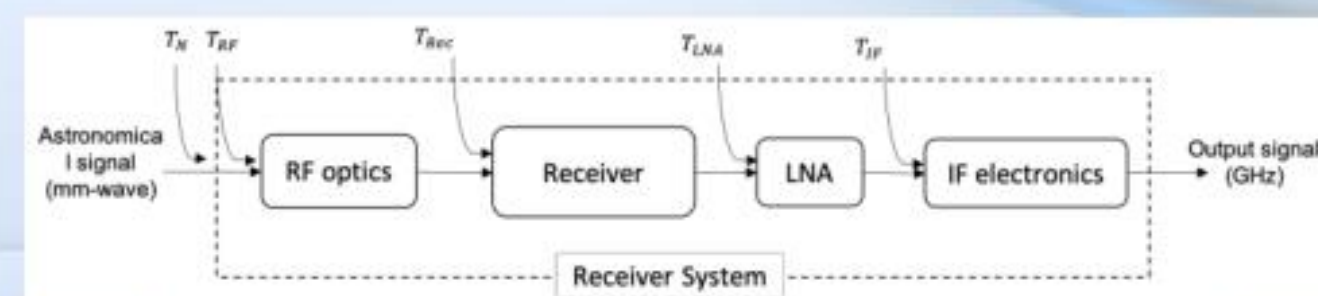


$$T_N = T_{RF} + \frac{T_{Rec}}{G_{RF}} + \frac{T_{LNA}}{G_{RF} \cdot G_{Rec}} + \frac{T_{IF}}{G_{RF} \cdot G_{Rec} \cdot G_{LNA}} \rightarrow \sim 0$$



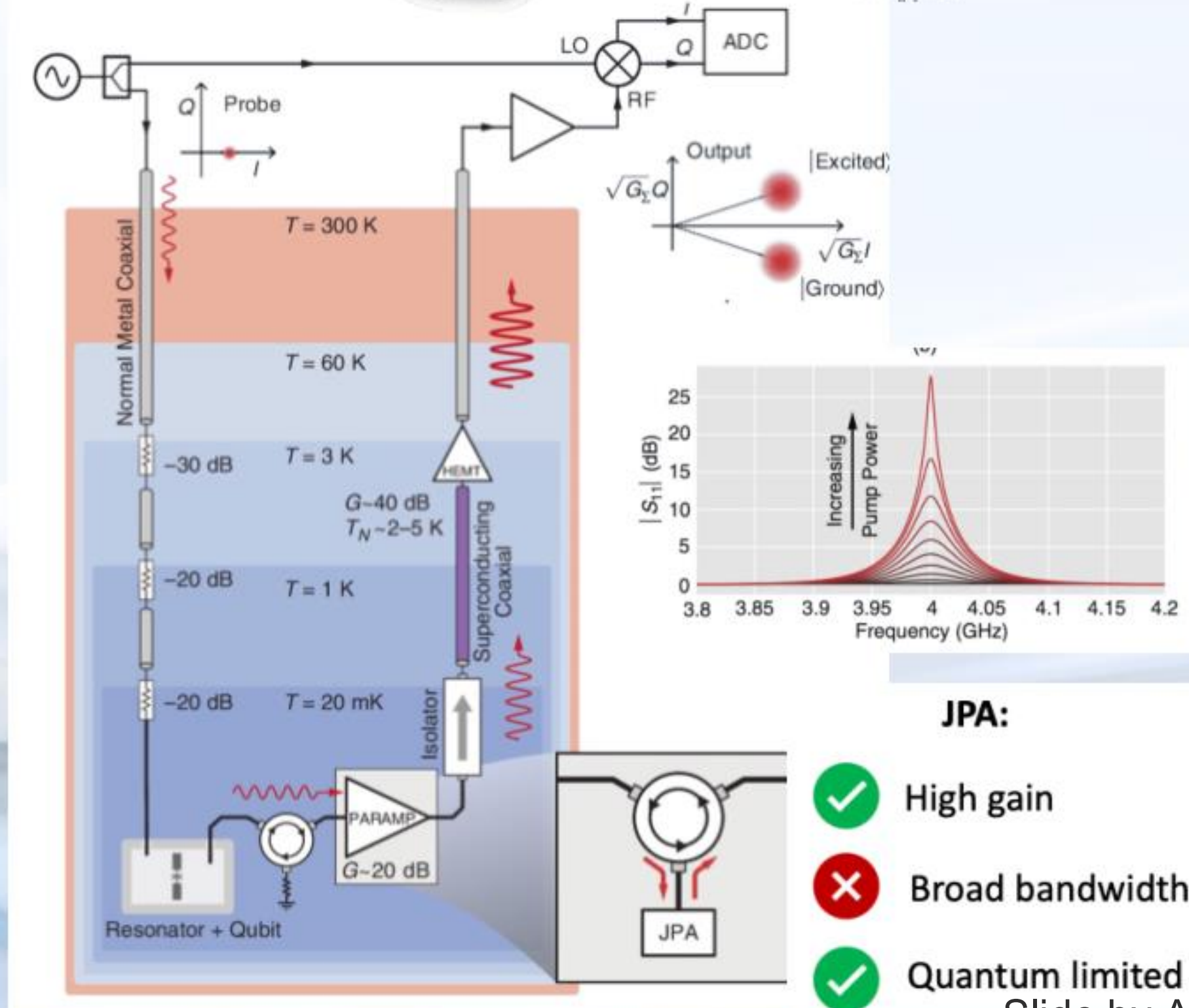
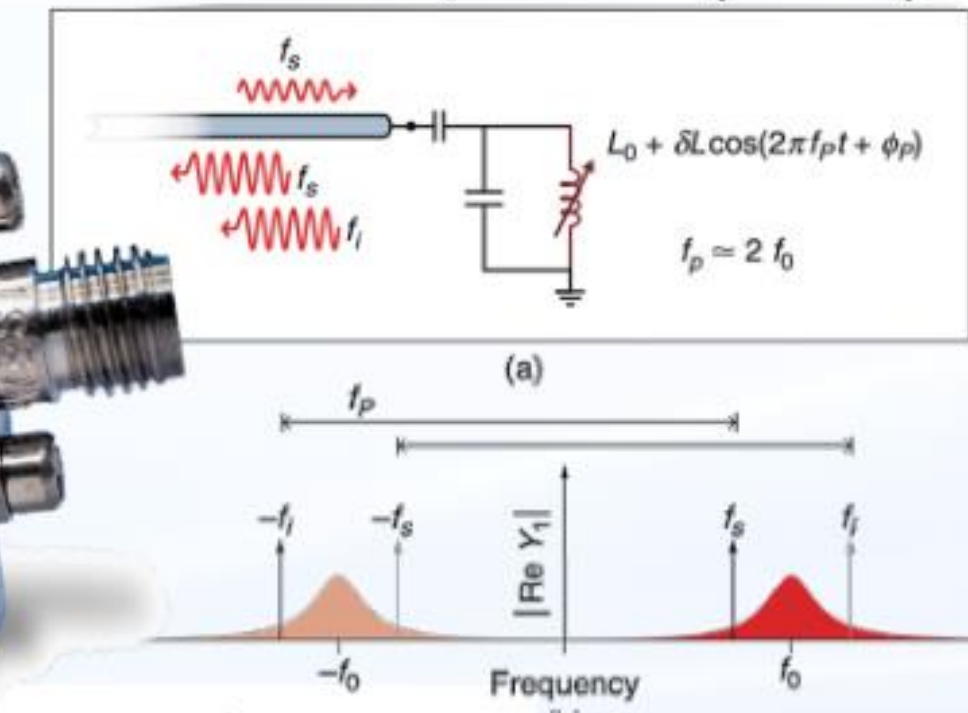
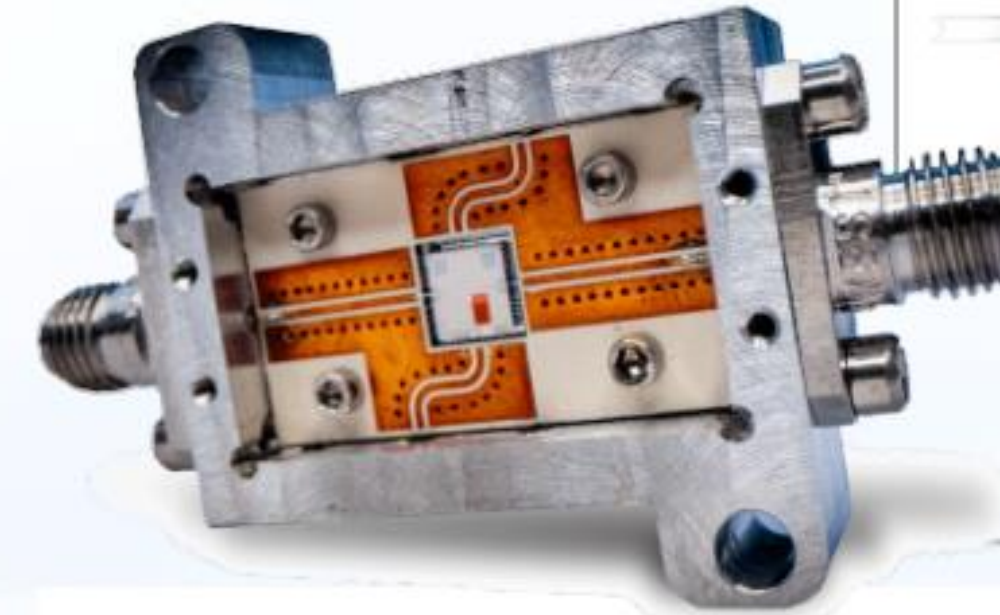
HEMTs:

- ✓ High gain
- ✓ Broad bandwidth
- ✗ Quantum limited



$$T_N = T_{RF} + \frac{T_{Rec}}{G_{RF}} + \frac{T_{LNA}}{G_{RF} \cdot G_{Rec}} + \frac{T_{IF}}{G_{RF} \cdot G_{Rec} \cdot G_{LNA}} \rightarrow \sim 0$$

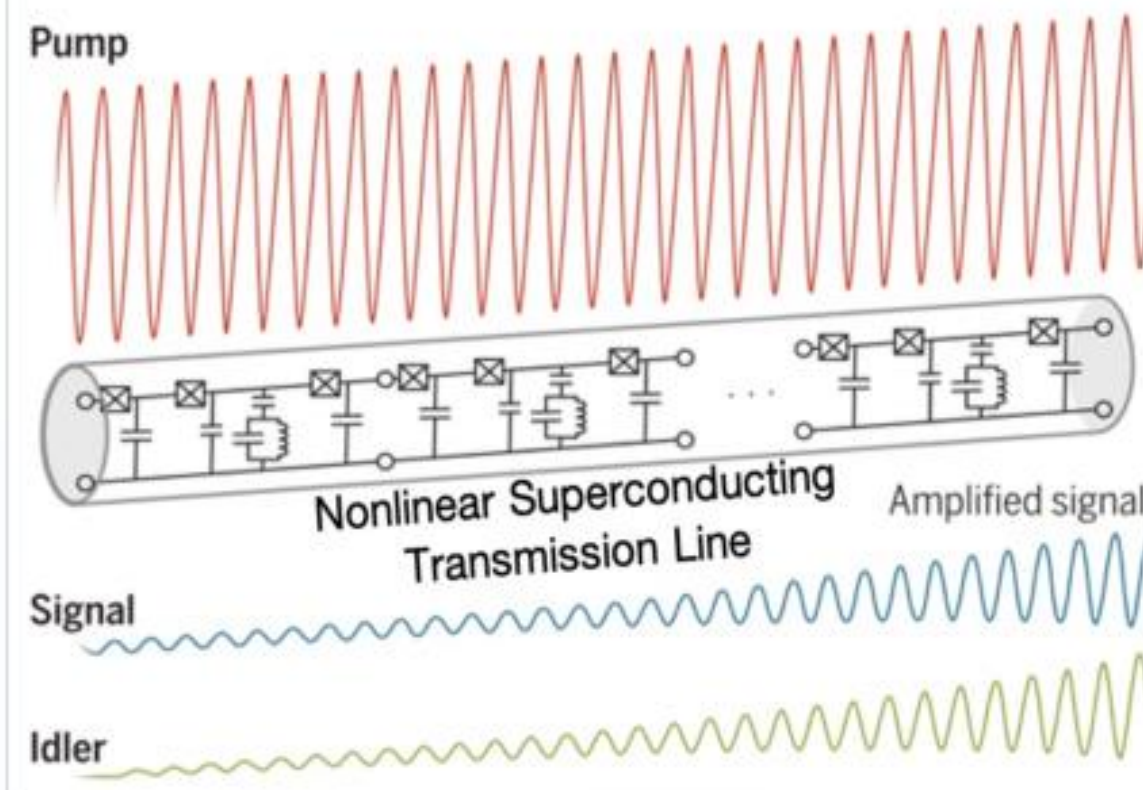
Josephson Parametric Amplifier (JPA)



JPA:

- ✓ High gain
- ✗ Broad bandwidth
- ✓ Quantum limited

Travelling Wave Parametric Amplifiers

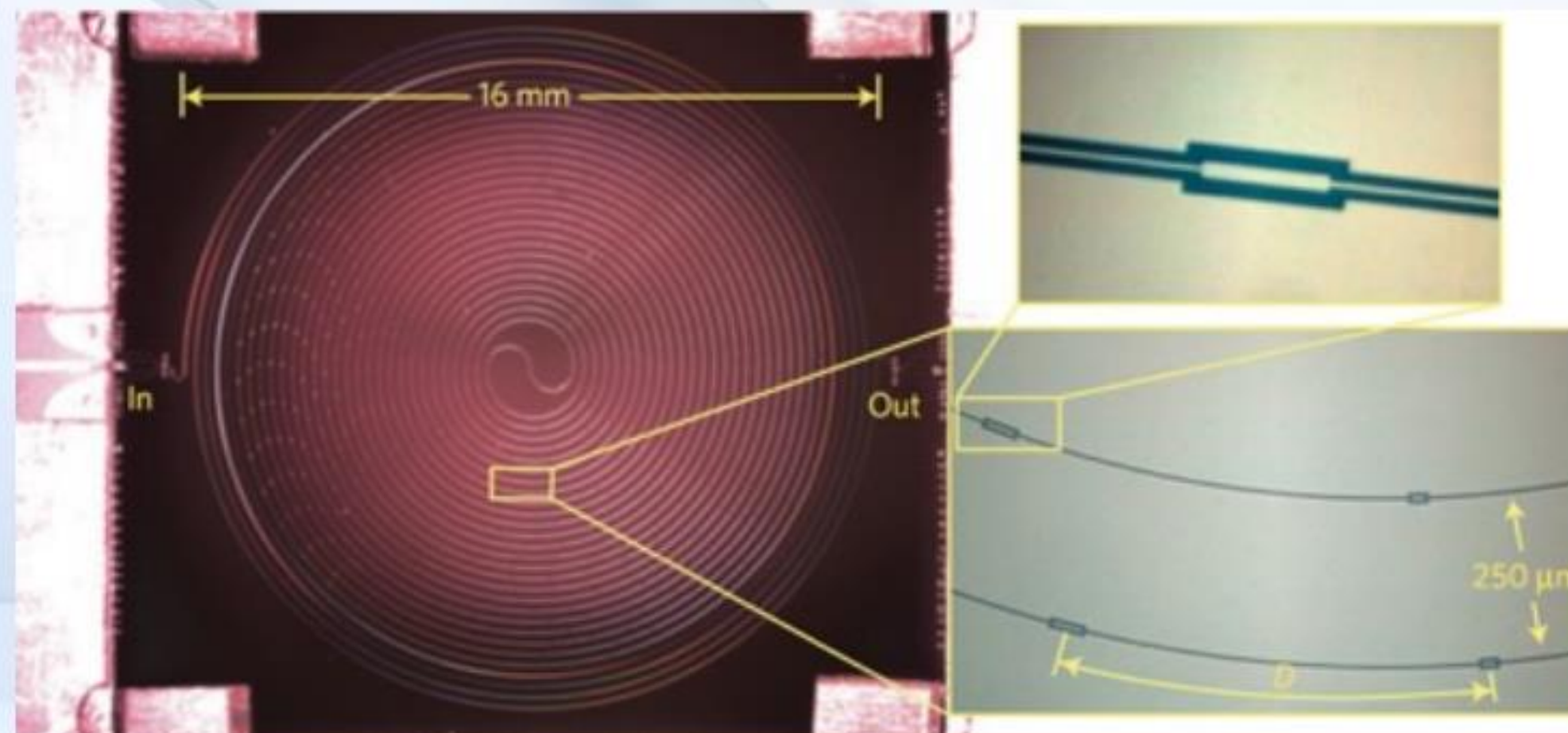


- ✓ High gain
- ✓ Broad bandwidth
- ✓ Quantum limited

Superconducting instead of semiconductor device

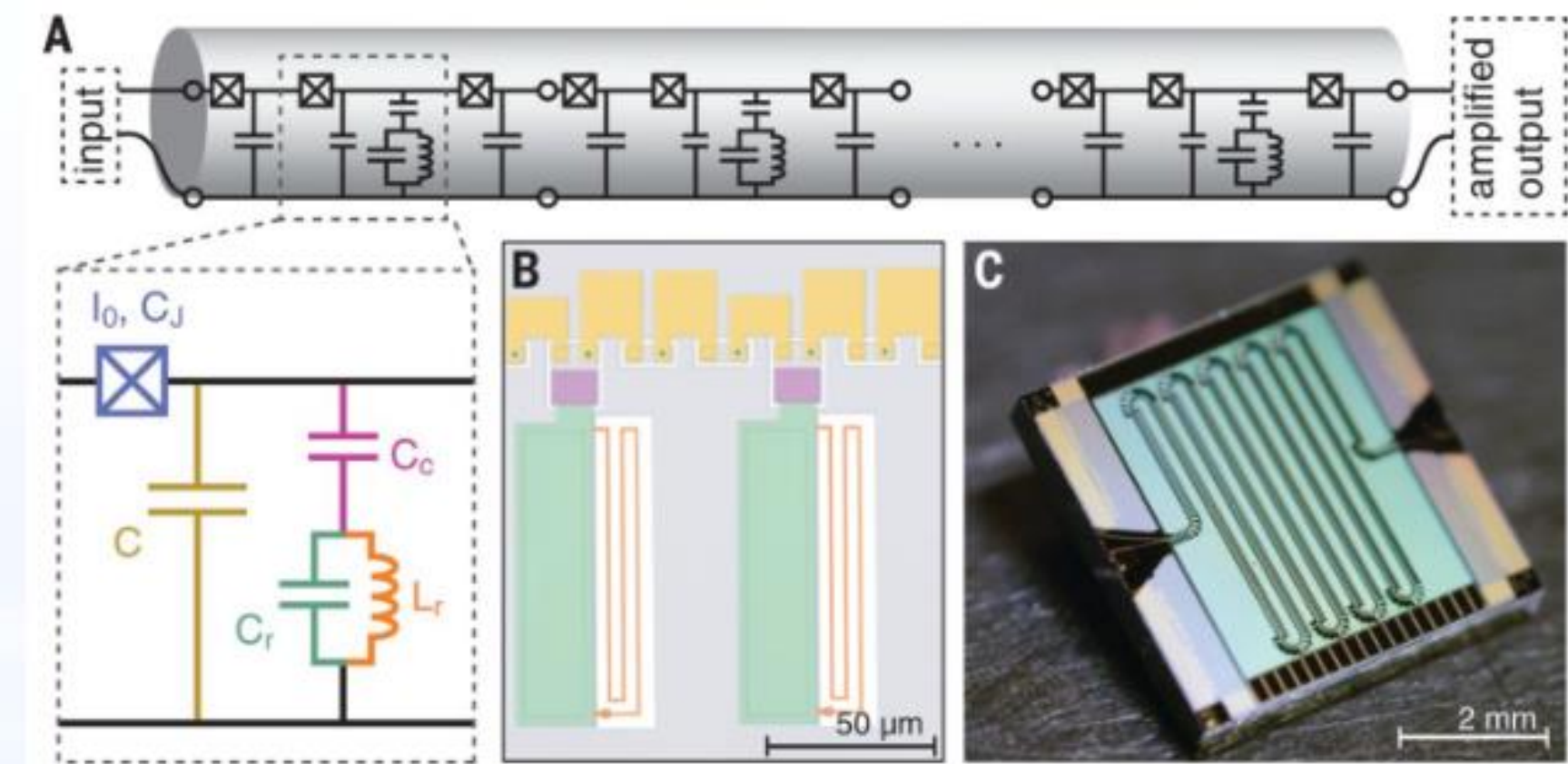
- negligible heat dissipation – important for array application
- Planar circuit, easy to mass fabrication
- Compact and compatible with detector circuits
- Potential operation up to THz frequencies
- Beyond quantum limitation with noise squeezing technique

Thin-Film Kinetic-Inductance TWPA



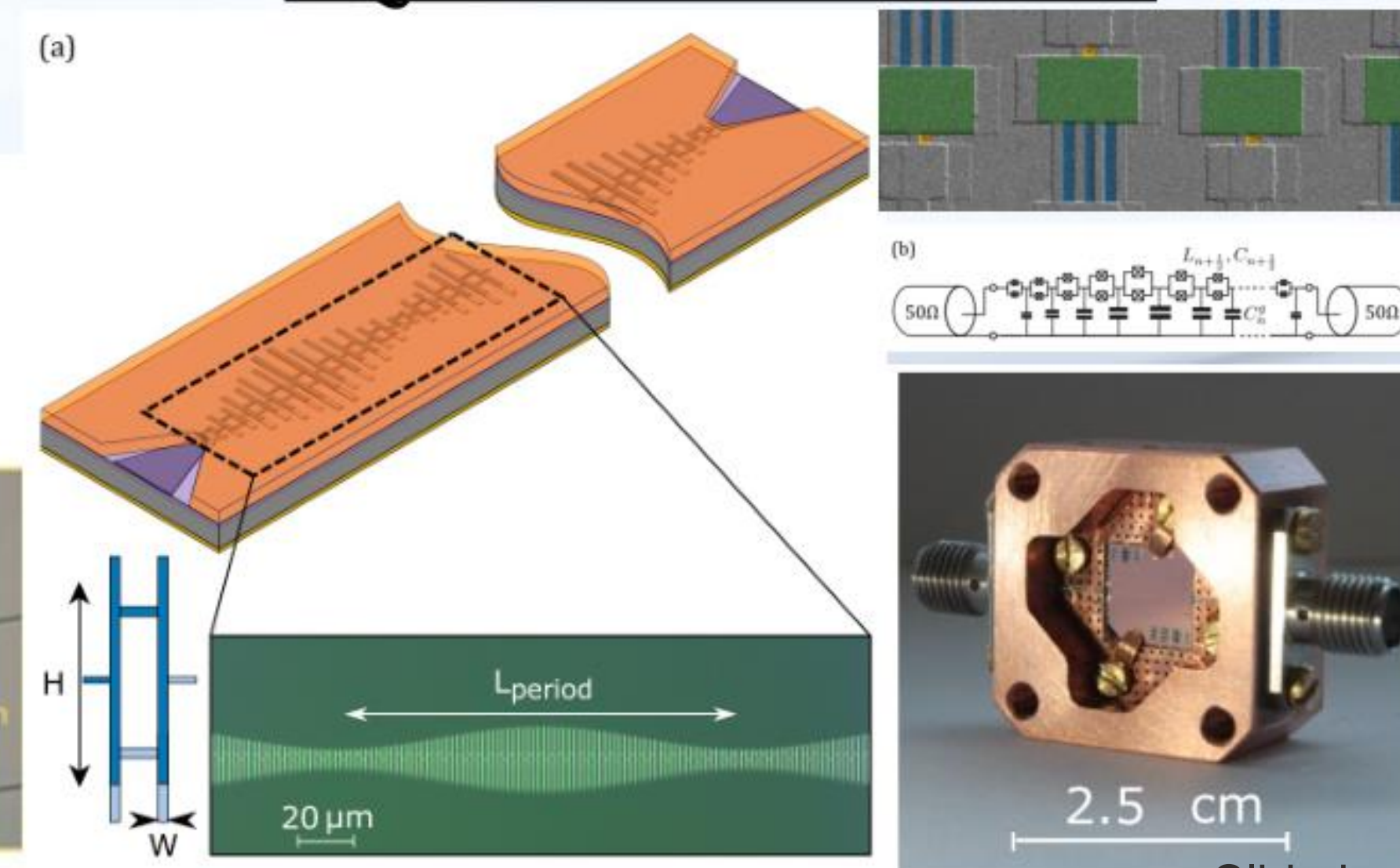
B. Eom Nature Physics 8, 623-627 (2012)

Josephson Junctions TWPA



C. Macklin, Science, 350 (6258), p. 307, 2015

SQUID_s/SNAIL_s TWPA



Digitizer Technology

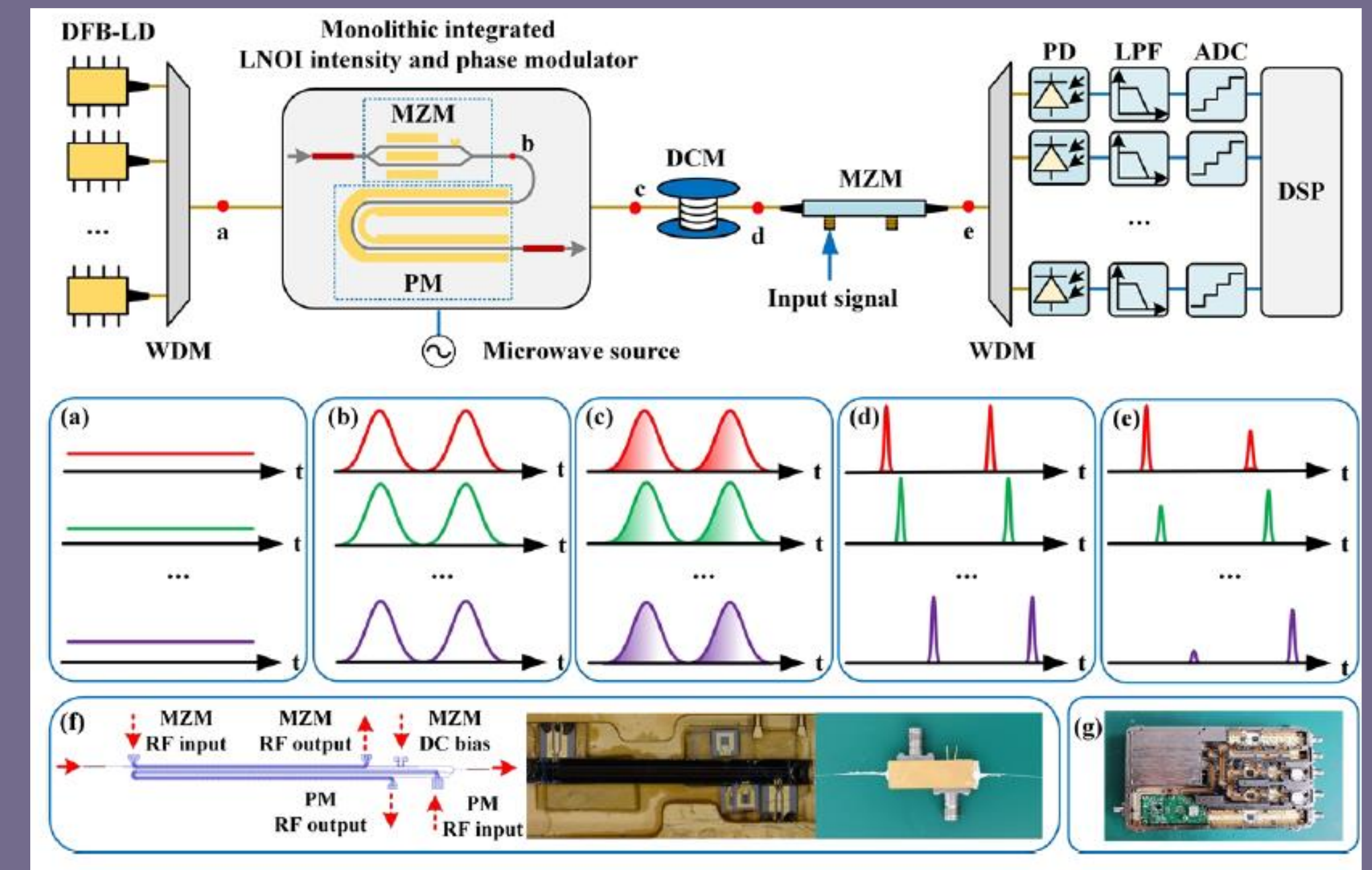
“Traditional” AD-converters

- Driven by 6G mobile telecom (RFSoc) and GbE applications (IP cores)

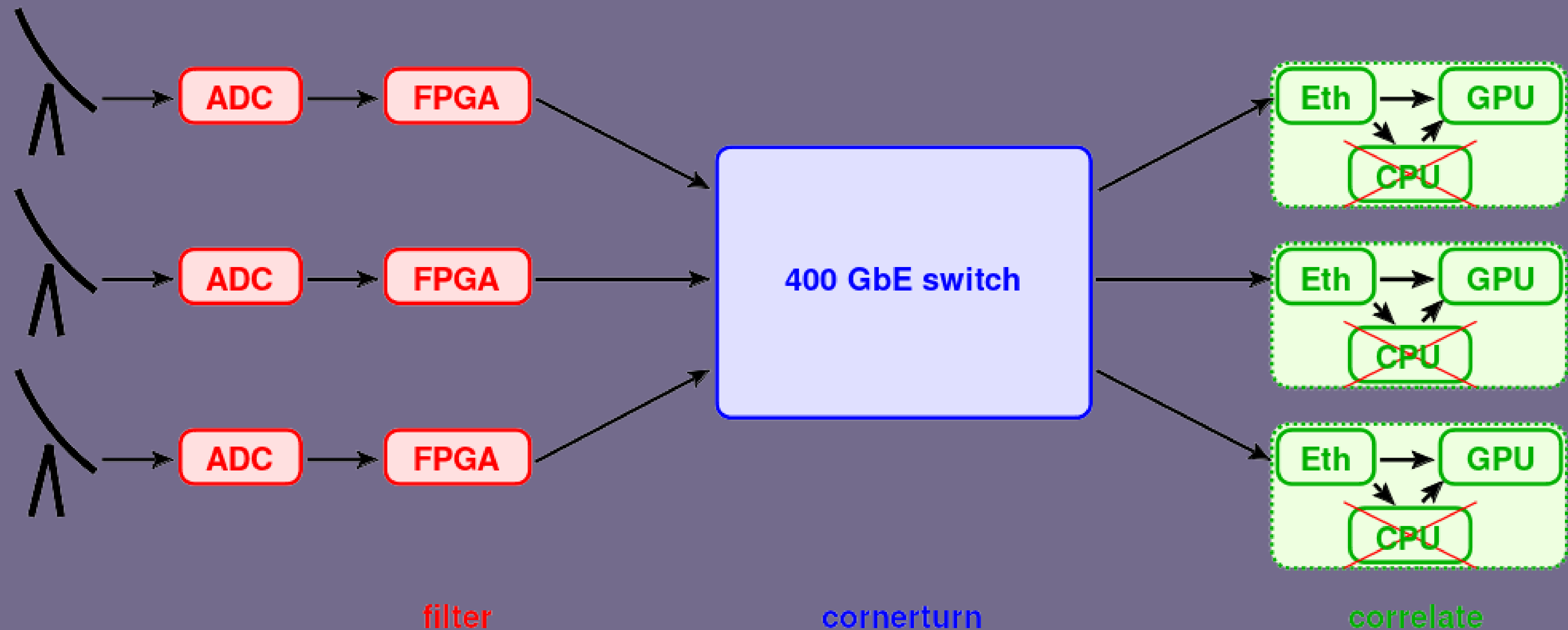
Photonic AD-converters

- Would allow in principle very high sampling speeds enabling direct digitization of sub-mm signal

Zhengkai Li, et.al., "Photonic sampling analog-to-digital conversion based on time and wavelength interleaved ultra-short optical pulse train generated by using monolithic integrated LNOI intensity and phase modulator," Opt. Express 30, 29611-29620 (2022)



Backend GPU correlation



Backend

- Current NVIDIA GPU technology: ALMA WSU correlator fits in one 19" rack
- ALMA 2040 correlator needs
 - 300 Antennas
 - 1 THz bandwidth
 - 42 19" Racks (NV4)
 - Data speed 1.4 Pb/s
 - GPU's are energy efficient
- Much more efficiency expected in 2040s
- One could consider getting available resources from AI datacenter

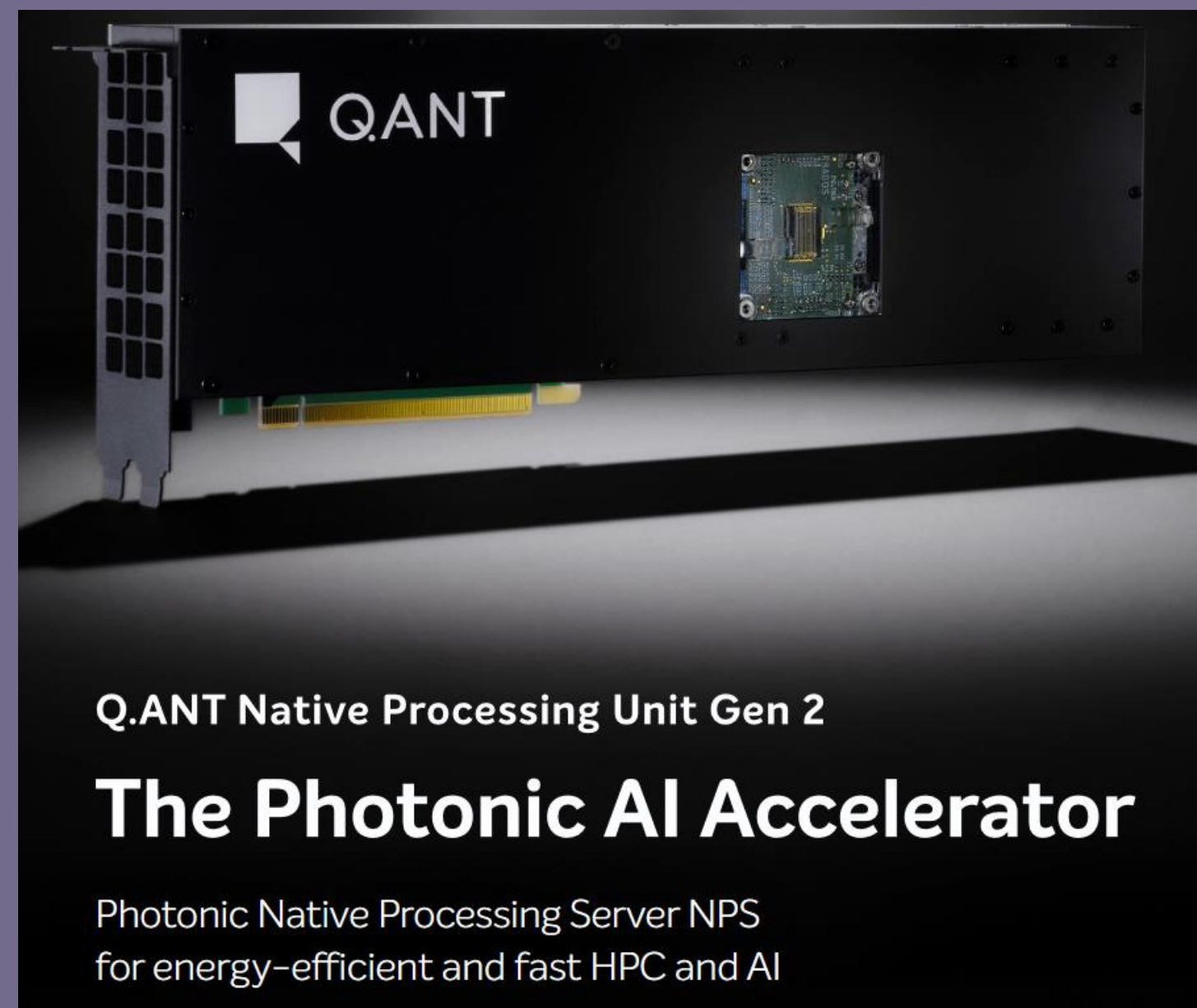


J. Romein

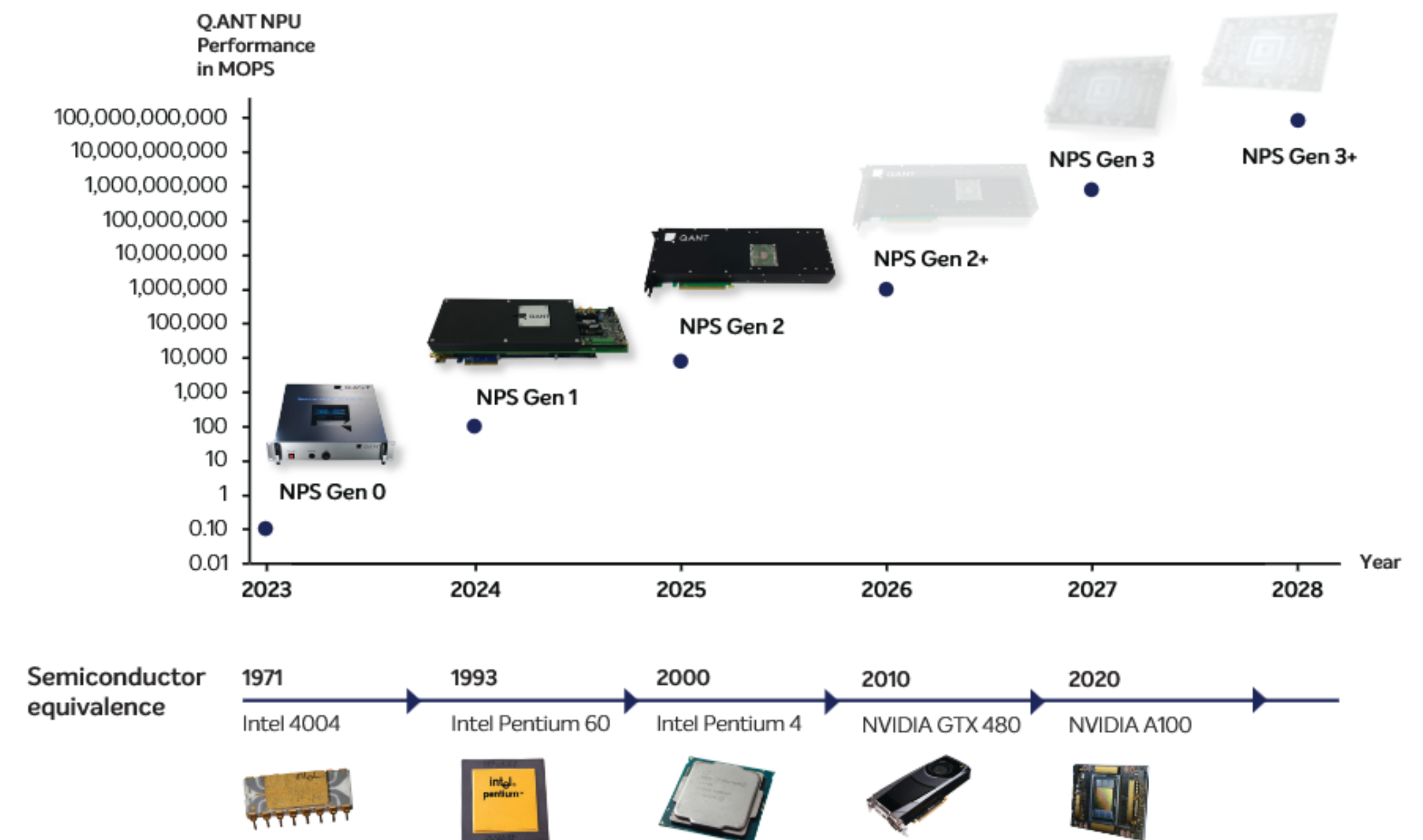
(Optical) Signal Processing

Photonic Computing

- Example Q.ANT GmbH
<https://www.quant.com/>



In just two years, Q.ANT's photonic processor development has matched the performance progress of thirty years of digital processors.



Operations

- **Science Operations**
 - Automated proposal verification and AI assisted evaluation
 - Automated scheduling
 - Online calibration
 - Target of Opportunity short response time
- **Engineering**
 - AI and robotic supported maintenance and repair
 - Fixed versus Movabale antennas with or without pads
- **Computing:** reliable, simple, cybersecurity
- **Sustainability:**
 - natural and social
 - Renuable energies



Automation inspired by progress in mining in Chile

Current ALMA2040 base concept and Next steps

Requirements from consolidated key science goals:

- Collecting area of 30,000 m² (200-300 antennas)
- 3× angular resolution
- 10x line sensitivity, 40x continuum sensitivity
- Short-spacing capabilities
- FULL instantaneous bandwidth
- Complete (current) frequency range
- Solar observing capabilities
- Sub-arraying capabilities
- Strict polarization purity
- Coordination with multi-messenger facilities
- ToO trigger response (including for VLBI)

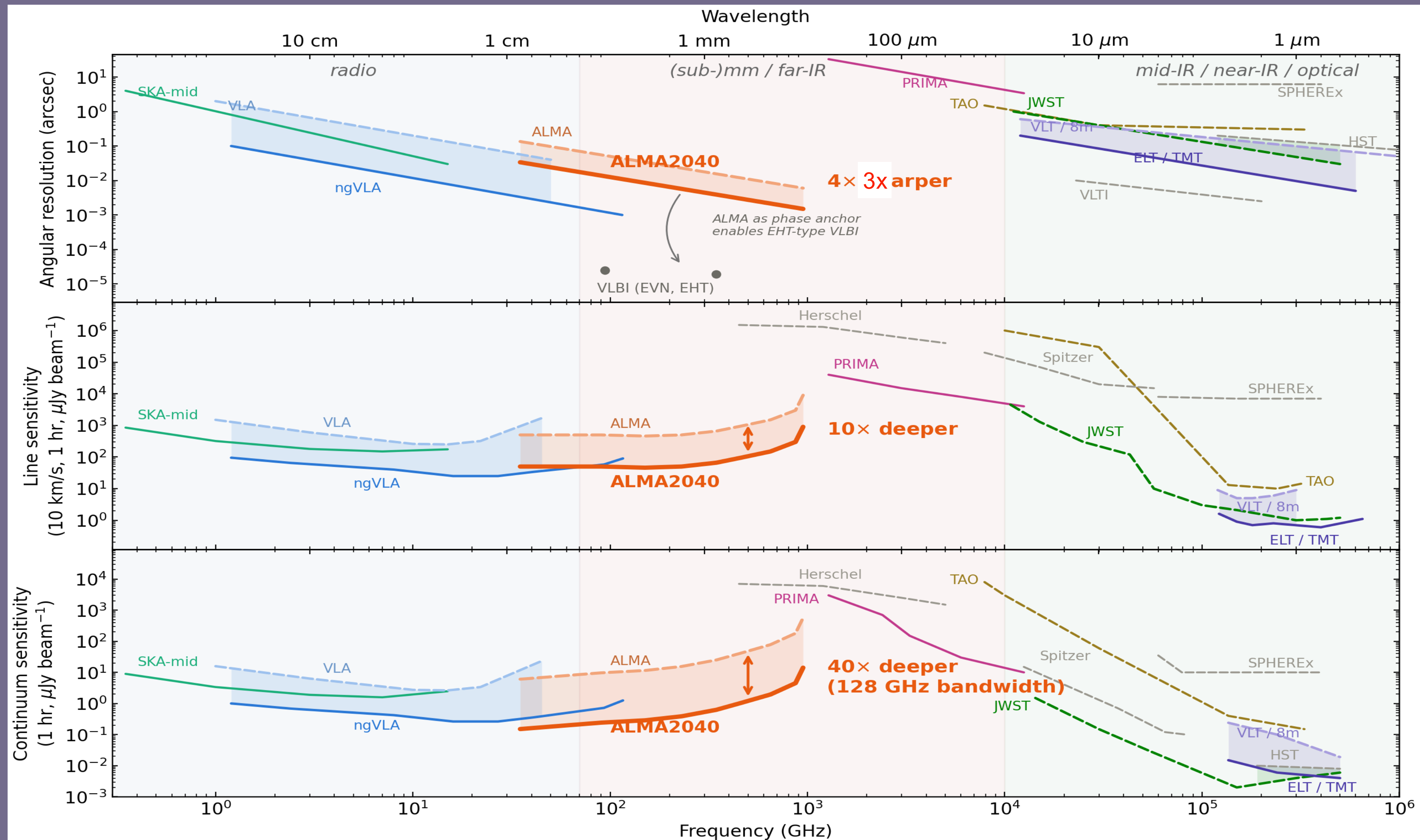


<https://www.euroalma2040.com/>

Next step:

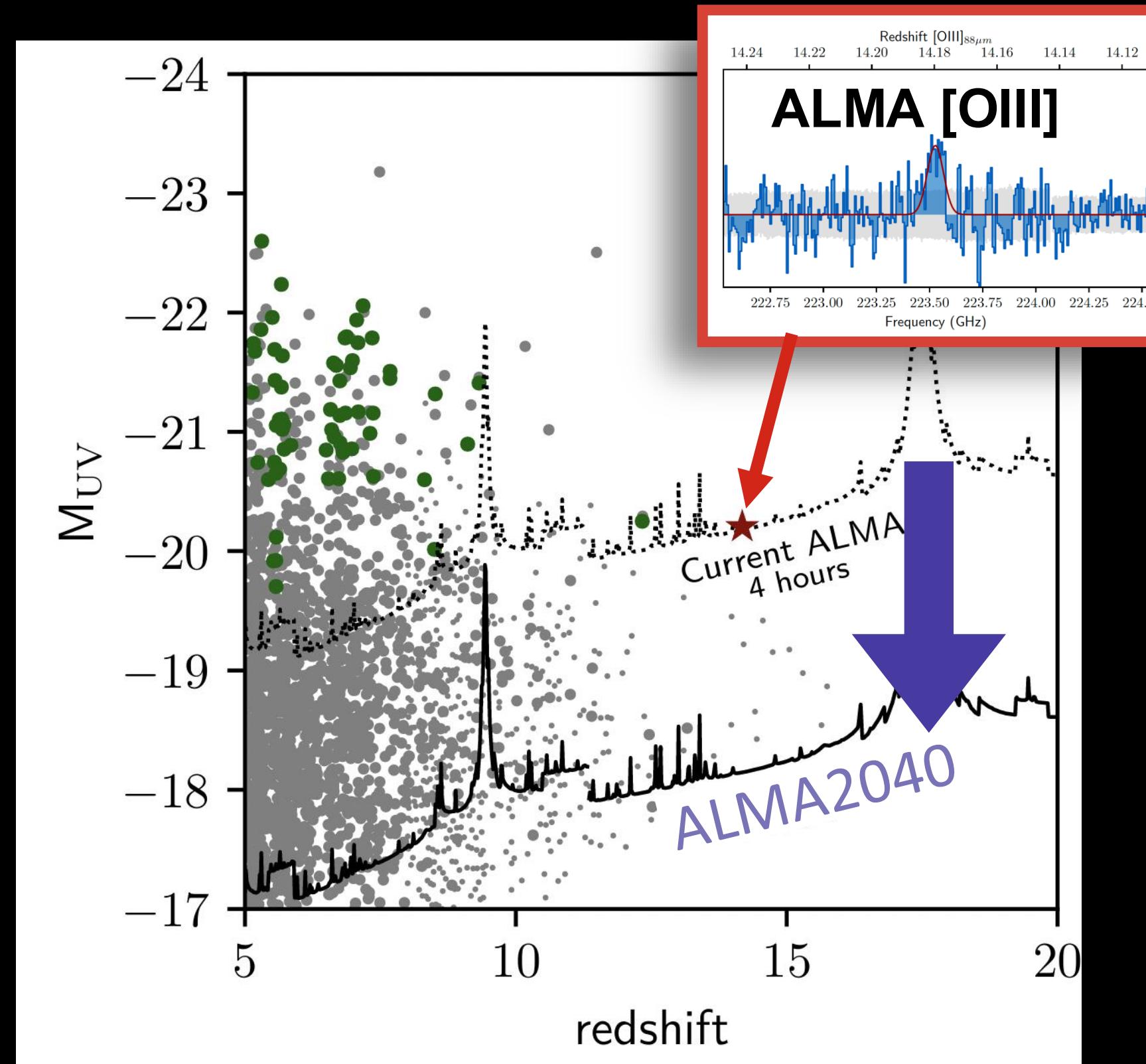
Input from East Asia, North America and Chile

Expected ALMA2040



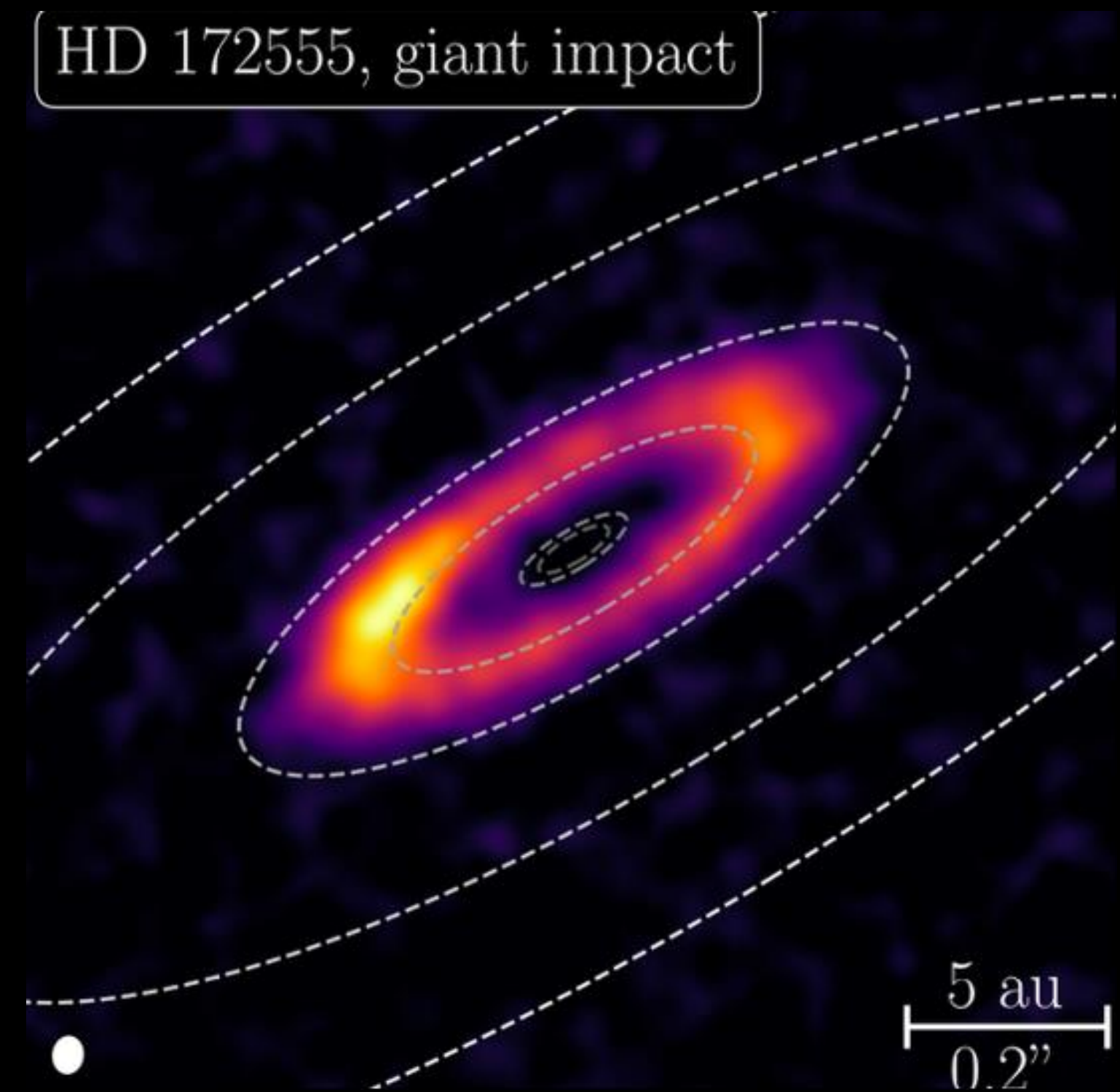
ALMA2040: a leap in line sensitivity...

...will uncover the origin of the *very first* galaxies



by detecting *and resolving* galaxies out to $z \sim 20$

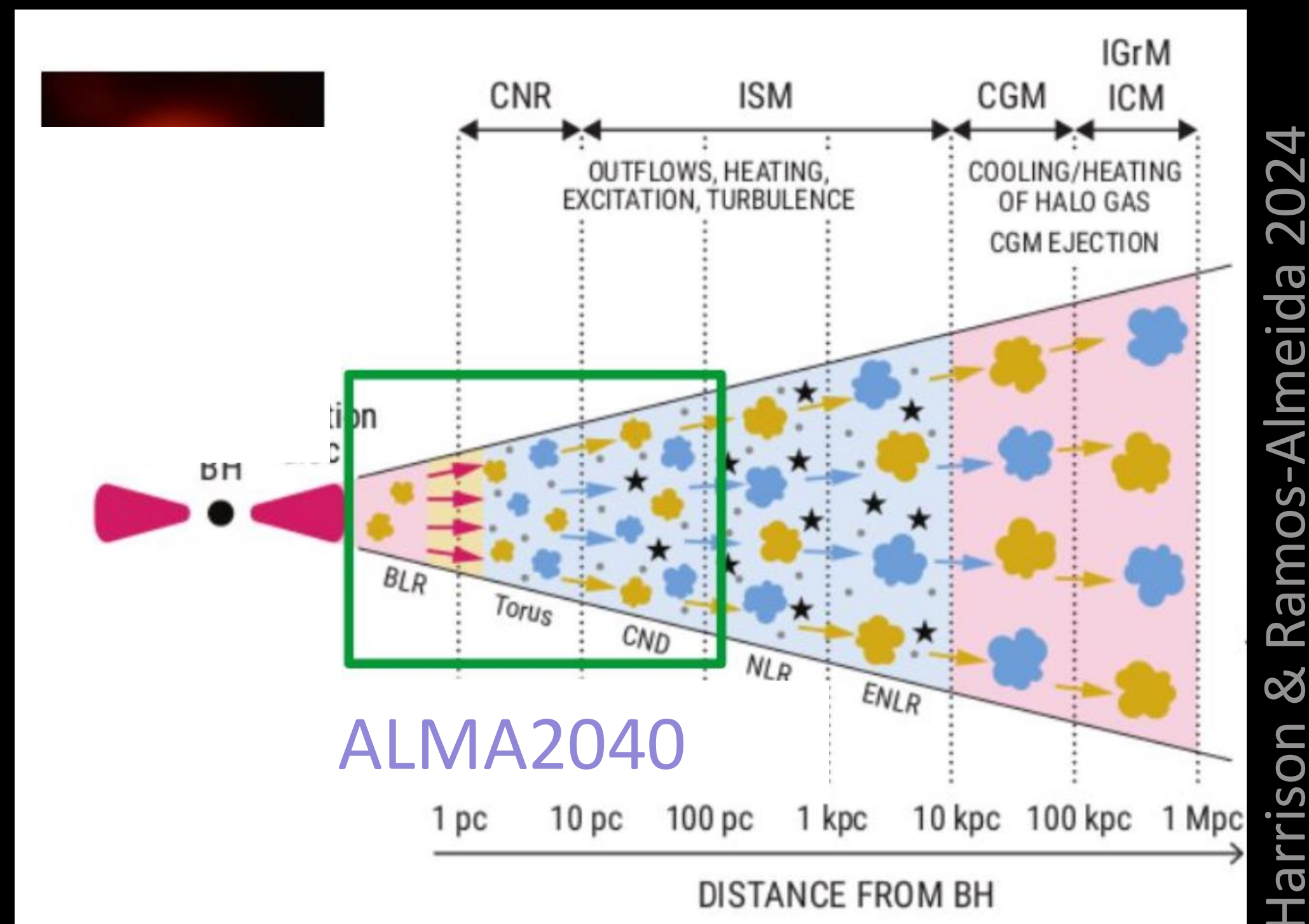
...will reveal how *Earth-like planets* form



by detecting the giant impacts that shape them

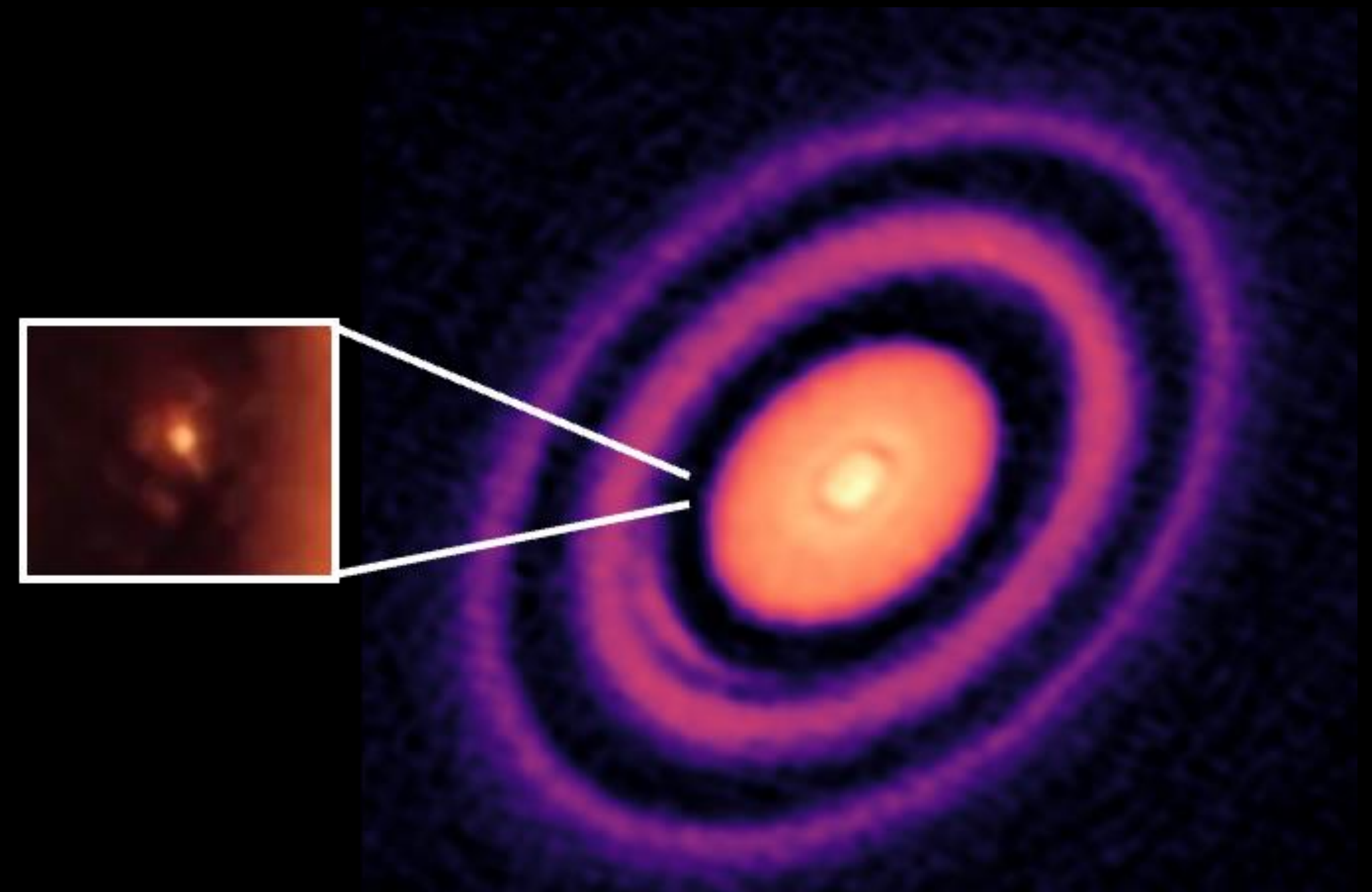
ALMA2040: ELT-matched spatial resolution...

...will determine the mechanisms regulating AGN feeding and feedback



by directly resolving dusty AGN tori

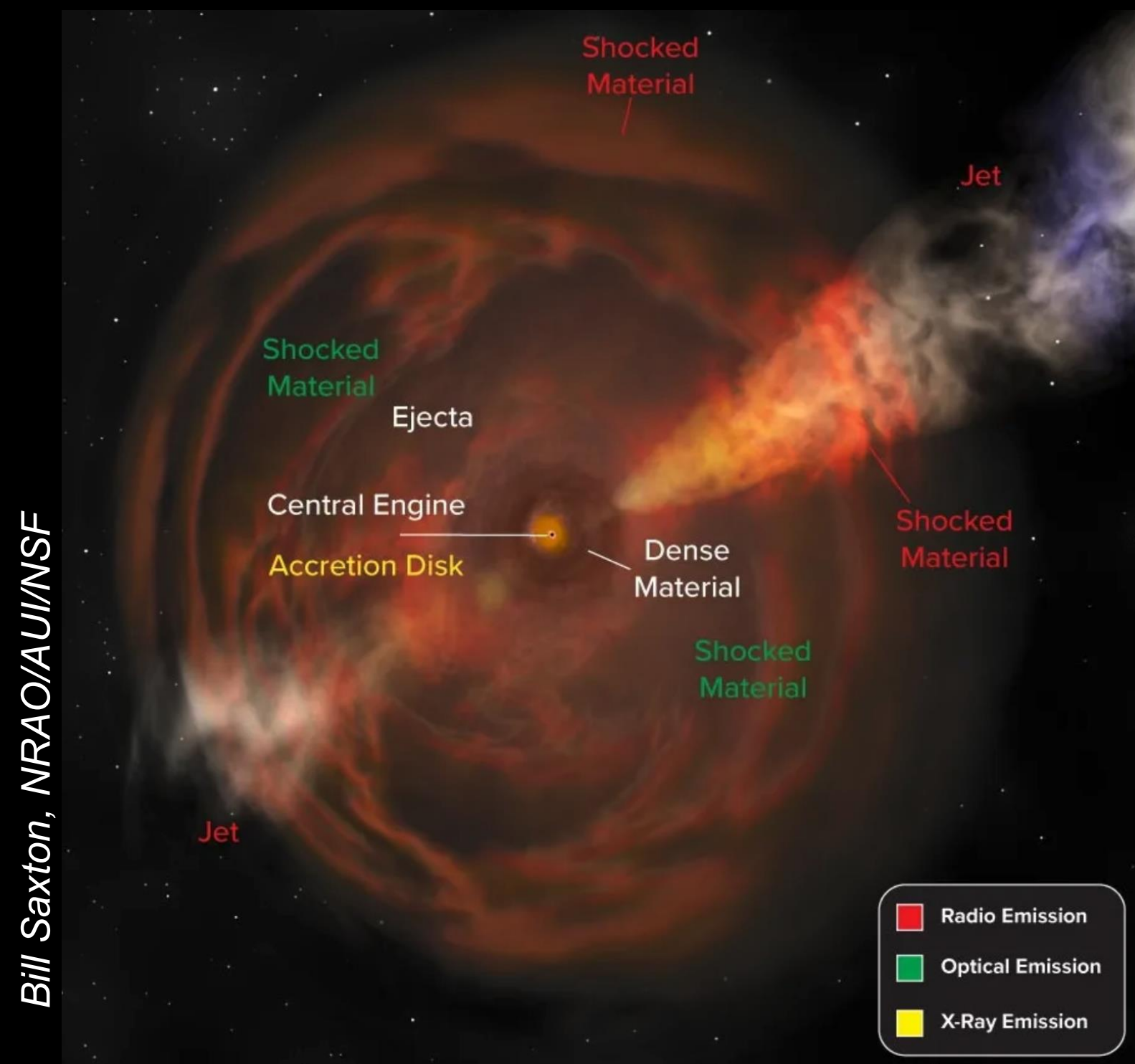
...will reveal how gas giants form and shape their solar systems



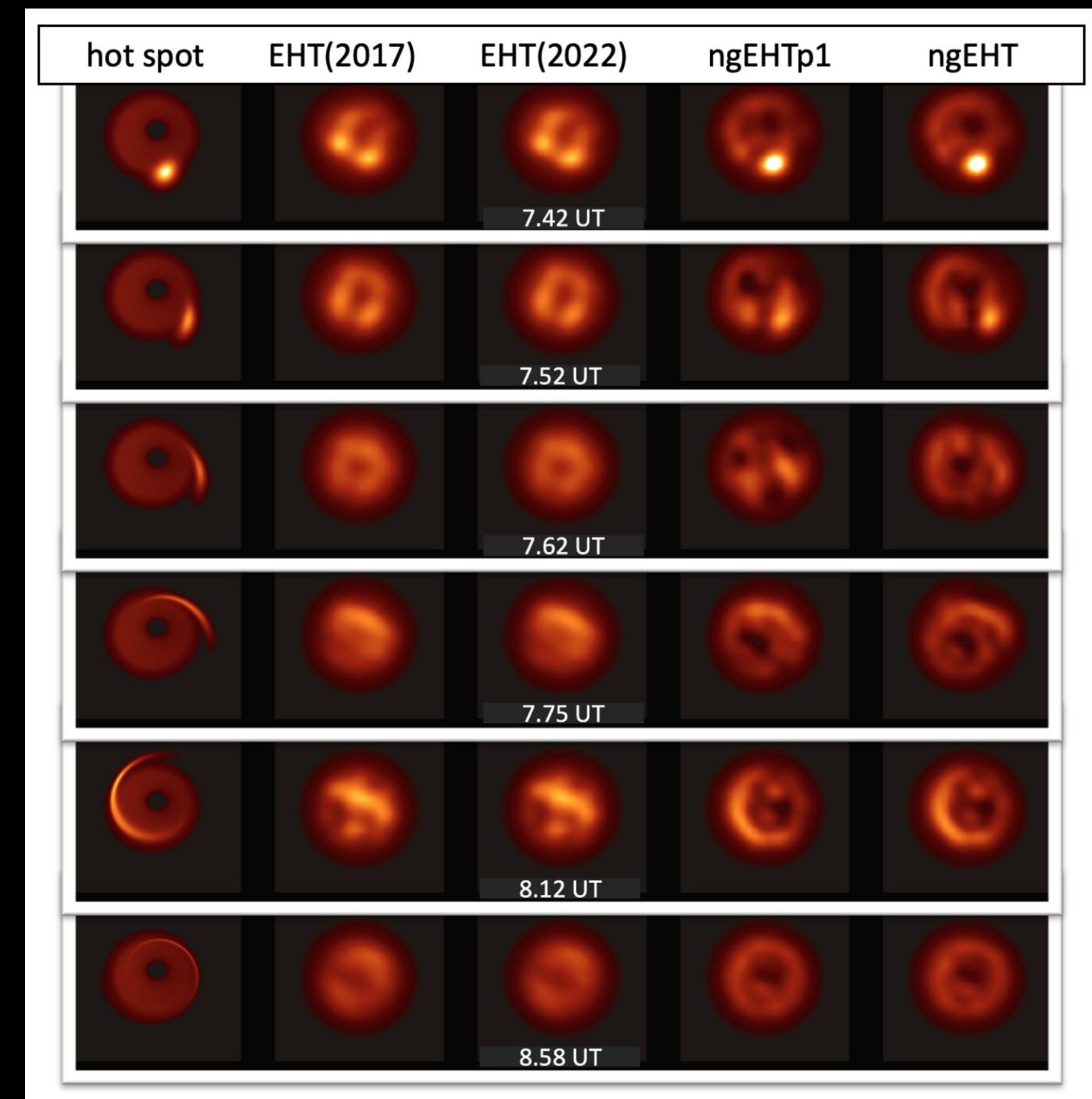
by resolving massive Jupiter-like planets in circumplanetary disks

ALMA2040: Rapid ToO triggers & next-gen VLBI...

...will reveal the progenitors and environments of transient and GW/multi-messenger events



...will transform the EHT into a time-domain observatory



allowing precision tests of strong-field gravity and potentially even measuring BH spin

International collaboration



We would very much appreciate your participation:

- sign up for the ALMA2040 mailing list
- https://www.euroalma2040.com/contact_1 →
"express interest", fill in form
- join working group(s)
- Contact relevant person, or anybody from steering committee
- Write or get actively involved in white papers
- https://www.euroalma2040.com/contact_1

<https://www.euroalma2040.com/>

<https://alma-ghost.jb.man.ac.uk/>

Release of dedicated GHOST simulation tool

ALMA GHOST

BETA

HomeNew JobMy JobsHelp

ALMA GHOST

Generalised Hybrid Observation Support Tool

Create synthetic observations using expanded and heterogeneous ALMA array configurations

Start New Simulation

View Job History





[ALMA Helpdesk](#) · [UK ARC Node](#) · [Acknowledge](#) · [Help](#) · [Contact](#)

ALMA GHOST — Generalised Hybrid Observation Support Tool © 2026 UK ALMA Regional Centre Node

<https://alma-ghost.jb.man.ac.uk/>

Submit Simulation Job

Array Configuration

- ☐ Use standard ALMA configuration
- ☒ Use experimental configuration
- ☐ Upload custom configuration

200×12m



Homogeneous array with 200×12m antennas

Observation Parameters

Declination * 

-23d00m00.00

Format: ±DDdMMmSS.SS (e.g., -23d00m00.00). Range: -70° to +40°.

Time on Source



1h

Range: 10s to 12h (e.g., 30s, 5m, 2h)

PWV (mm) 



1.0

Range: 0.2 - 10 mm

Frequency Setup

Central Frequency *

230GHz

e.g., 230GHz, 100GHz

Bandwidth *

7.5GHz

e.g., 7.5GHz, 1.875GHz

ALMA2040 global coordination

Global White Paper Call

WPs on ArXiv Autumn 2026

Advisory Board

Stuartt Corder (NOIRLab)

Paul Ho (ASIAA)

Daisuke Iono (NAOJ)

Kelsey Johnson (U. Virginia)

Noami McClure-Griffiths (SKAO)

Monica Rubio (U. Chile)

Leonardi Testi (U. Bologna)

Upcoming IAU Focus Meeting at the 2027 IAU GA

Scientific Organizing Committee

Kate Alexander (USA)

Sean Andrews (Co-Chair; USA)

Sara Ellison (Canada)

Stefano Facchini (Italy)

Misato Fukagawa (Japan)

Bunyo Hatsukade (Co-Chair; Japan)

Paul Ho (Taiwan)

Jacqueline Hodge (Chair; Netherlands)

Jongsoo Kim (S. Korea)

Daizhong Liu (China)

Liton Majumdar (India)

**Chiara Mazzucchelli (Co-Chair;
Chile)**

James Miller-Jones (Australia)

Laura Perez (Chile)

Eva Schinnerer (Germany)

Patrick Woudt (S. Africa)



Learn more at FM website:

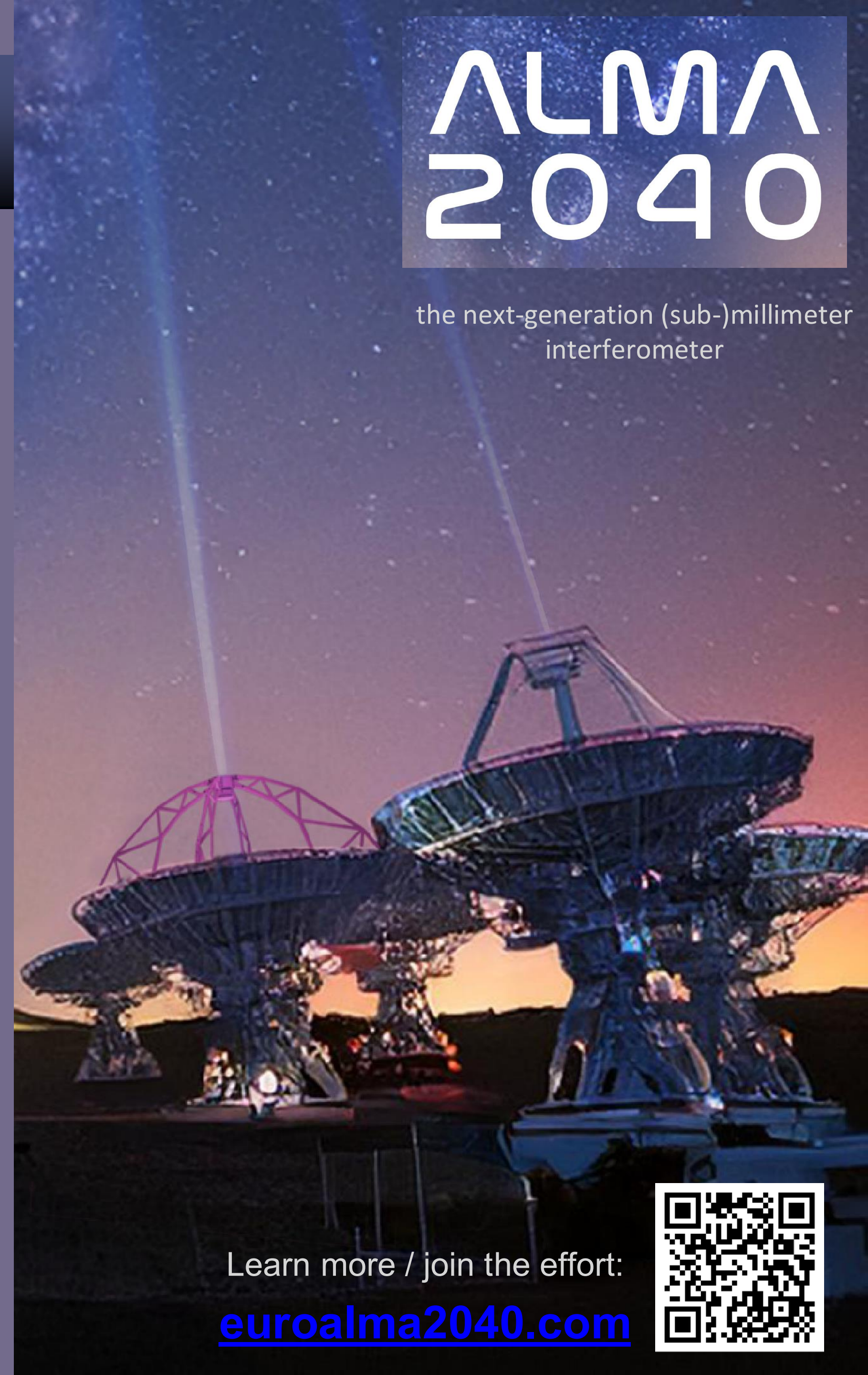


Summary

- ALMA2040 is a community-driven effort defining the next-generation, **flagship** mm/submm interferometer
- It will be **transformative** for a **huge range** of fundamental questions in the 2040s spanning from the very first galaxies to the formation of Earth analogs
- Recent advances in emerging and disruptive technologies make this vision **technically achievable**
- **Sustainability** analysis is already underway
- Building such a facility requires a global community please, join in!

ALMA
2040

the next-generation (sub-)millimeter
interferometer



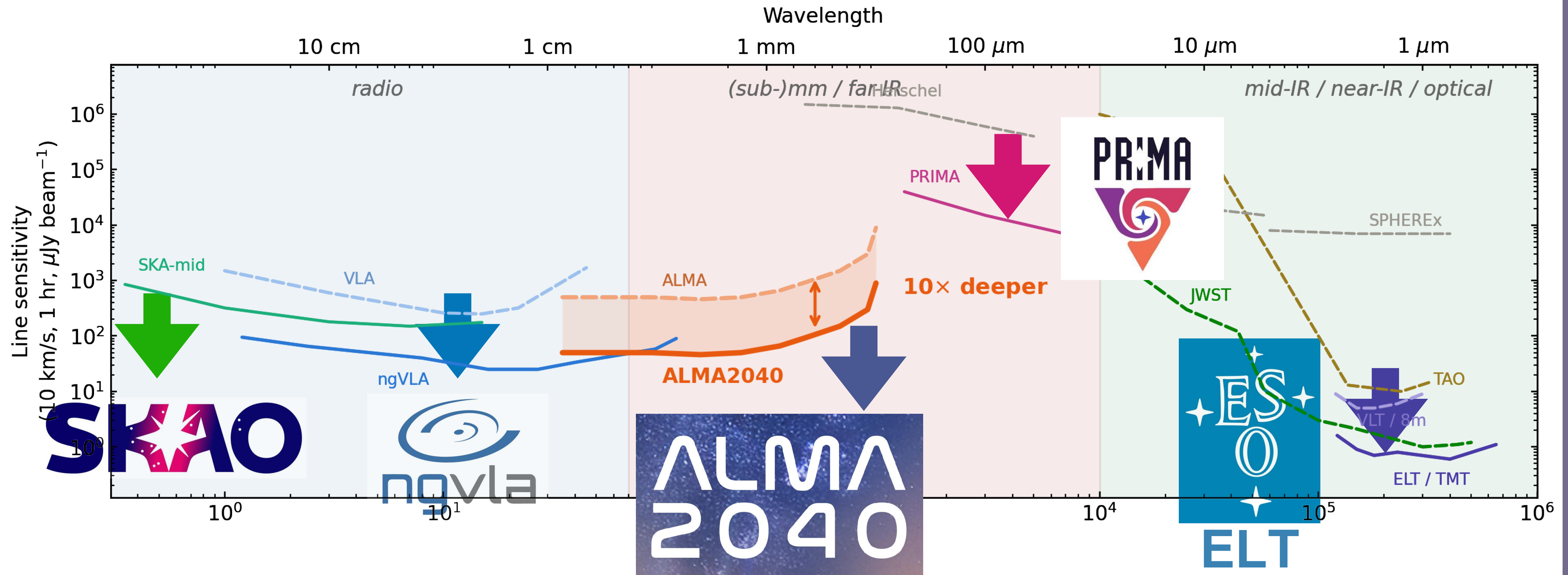
Learn more / join the effort:

euroalma2040.com



Backup Slides

ALMA2040: a leap in line sensitivity...



* Note that by 2040, the ALMA antennas will have reached the end of their operational lifetime

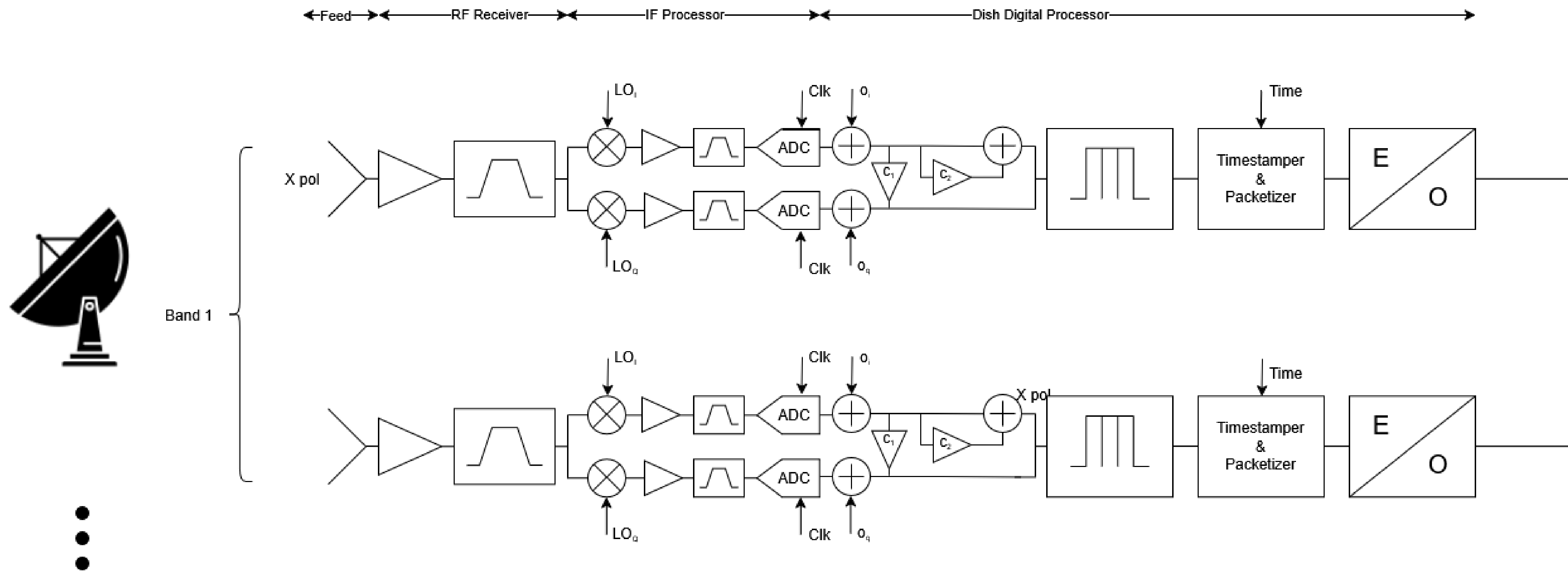
Graph by Tom Bakx

Geostationary satellite beacon

- We would like to realize a GEO satellite (co flight with big platform) source
- **10 cm antenna**, CW, pulse, tone forest ... (10..100mW)
- 200 km spot size (ALMA)
- Instantaneous very fast holography surface measurements
- Instantaneous phase calibration
- Instantaneous phase closure – Antenna positions determination
- ... much more
- Other projects also proposing similar calibrators – let us combine the effort



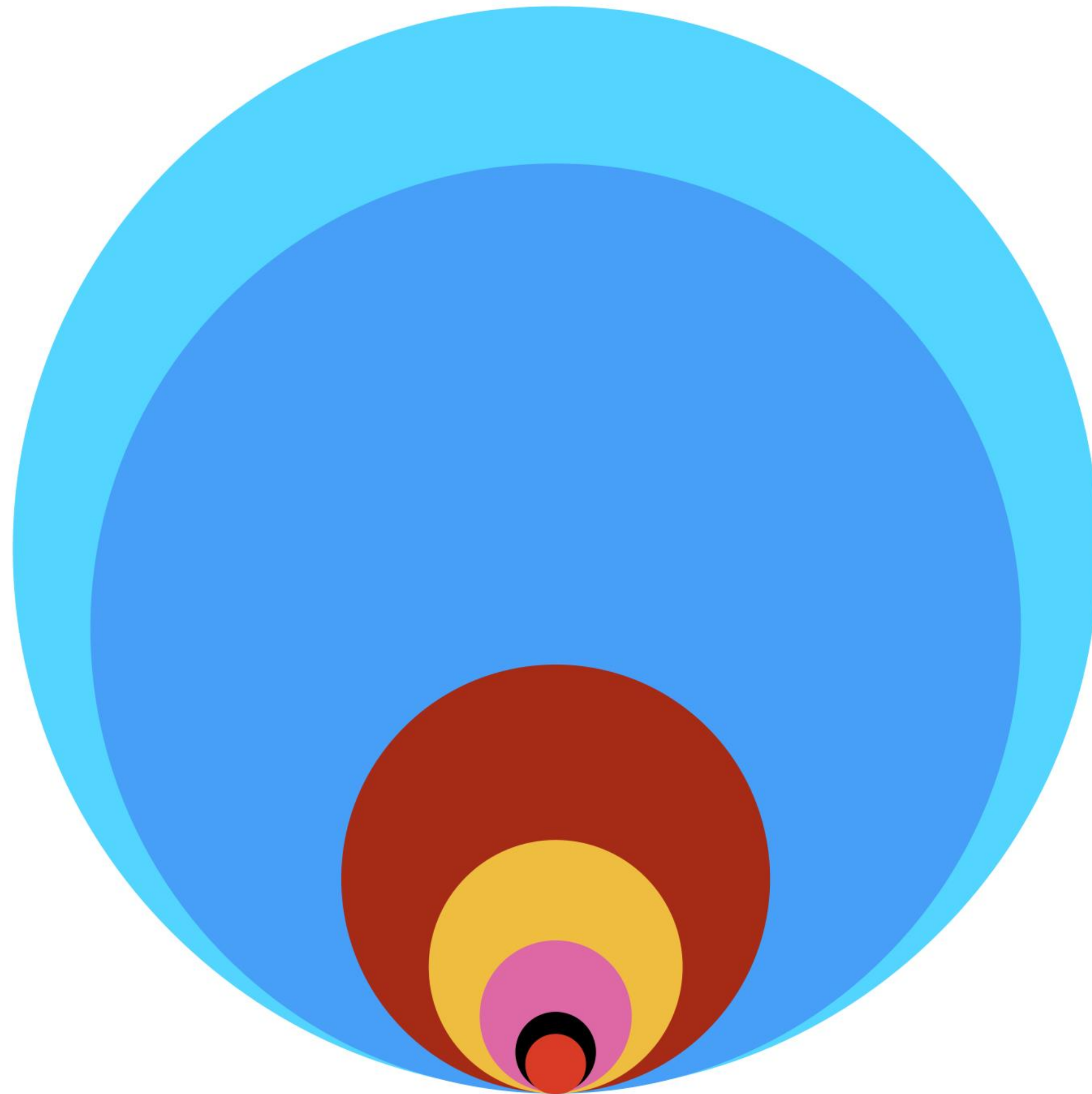
At antenna, one sub channel



Spectral capabilities

- **Spectral resolution:** most demanding case is 0.02 km/s at 100 GHz (Binaries). Already achieved now.
- **Instantaneous bandwidth for highest resolution?** WSU will do 32 GHz down to 0.1 km/s
- **Instantaneous bandwidth:** is 32 GHz enough? (Early Discs, Binaries and GalMolAtlas mentioning ultra-wide bandwidths)
- **Instantaneous multi-band capability** (found critical for time-domain cases and beneficial for practically all cases). Close bands may be better matched for angular scales/sensitivity/operational constraints, but widely-spaced are preferred for time-domain cases. Also requested for Phased-Array mode and VLBI (CosmExpl, Jets, Pulsars and HighResSun)
- **Dynamic sub-arraying** can also provide simultaneous multi-frequency capability for bright targets and in addition:
 - Enables simultaneous calibration during high-cadence campaigns, efficient array use and agile ToO response.
 - Provides a high-sensitivity ground anchor with long up-time for future mm-space-VLBI missions while maintaining a conventional science schedule (that is, if mm-space-VLBI missions require the use of ALMA for the longest baselines, ALMA could provide just a sub-array for that purpose and maintain regular operations for the remaining sub-array).
- **Spectral dynamic range:** current is 10000:1 for measurement of weak lines in presence of strong lines or continuum.

Leap in sensitivity compared to other facilities



ALMA2040 300-array (equiv. 225m dish)

ALMA2040 200-array (equiv. 180m dish)

ALMA 12m array (equiv. 84m dish)

AtLAST & LMT (50m dish)

NOEMA (equiv. 50m dish)

IRAM 30m (30m dish)

SMA (equiv. 15m dish)

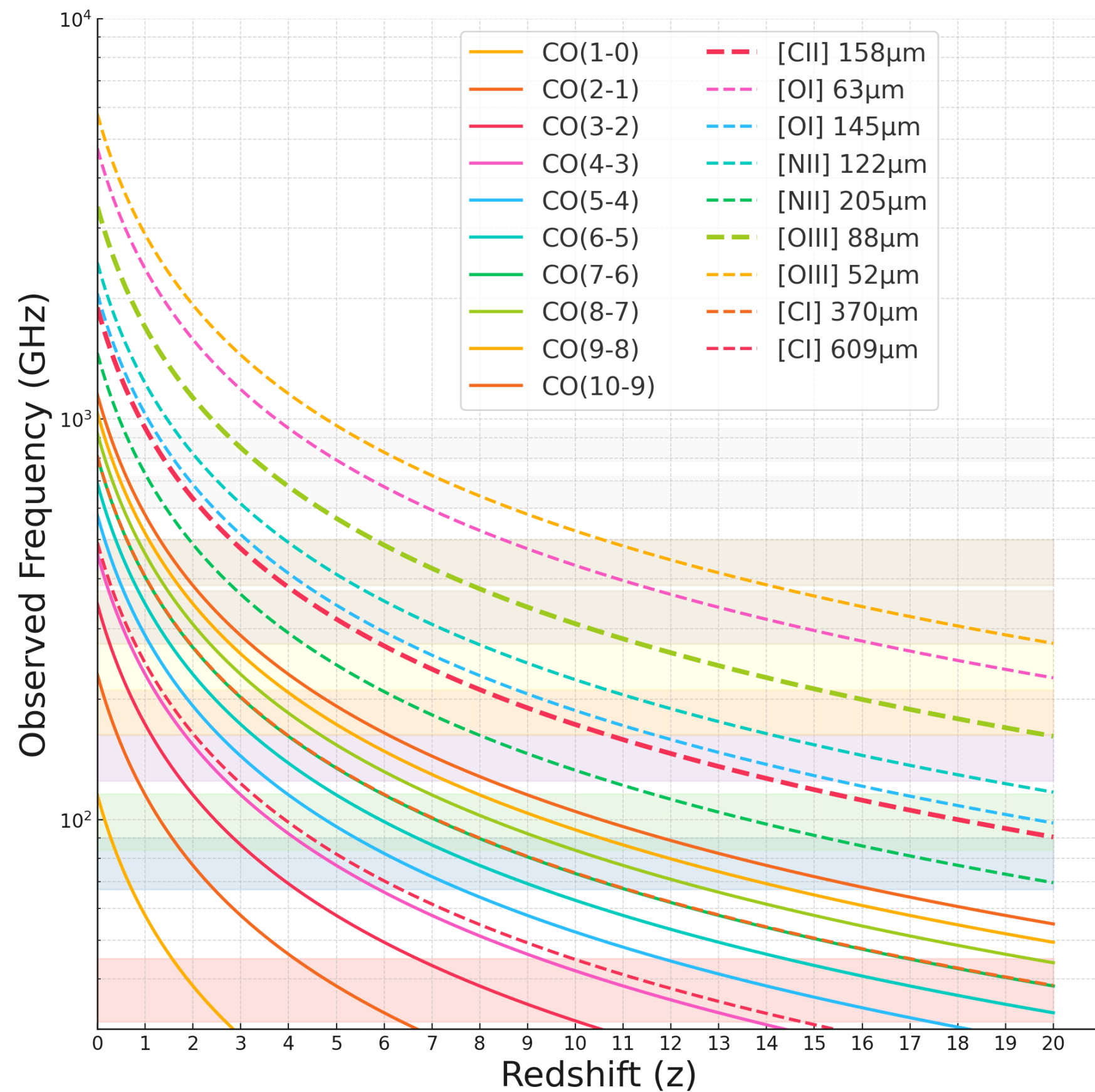
JCMT (15m dish)

Apex (12m dish)

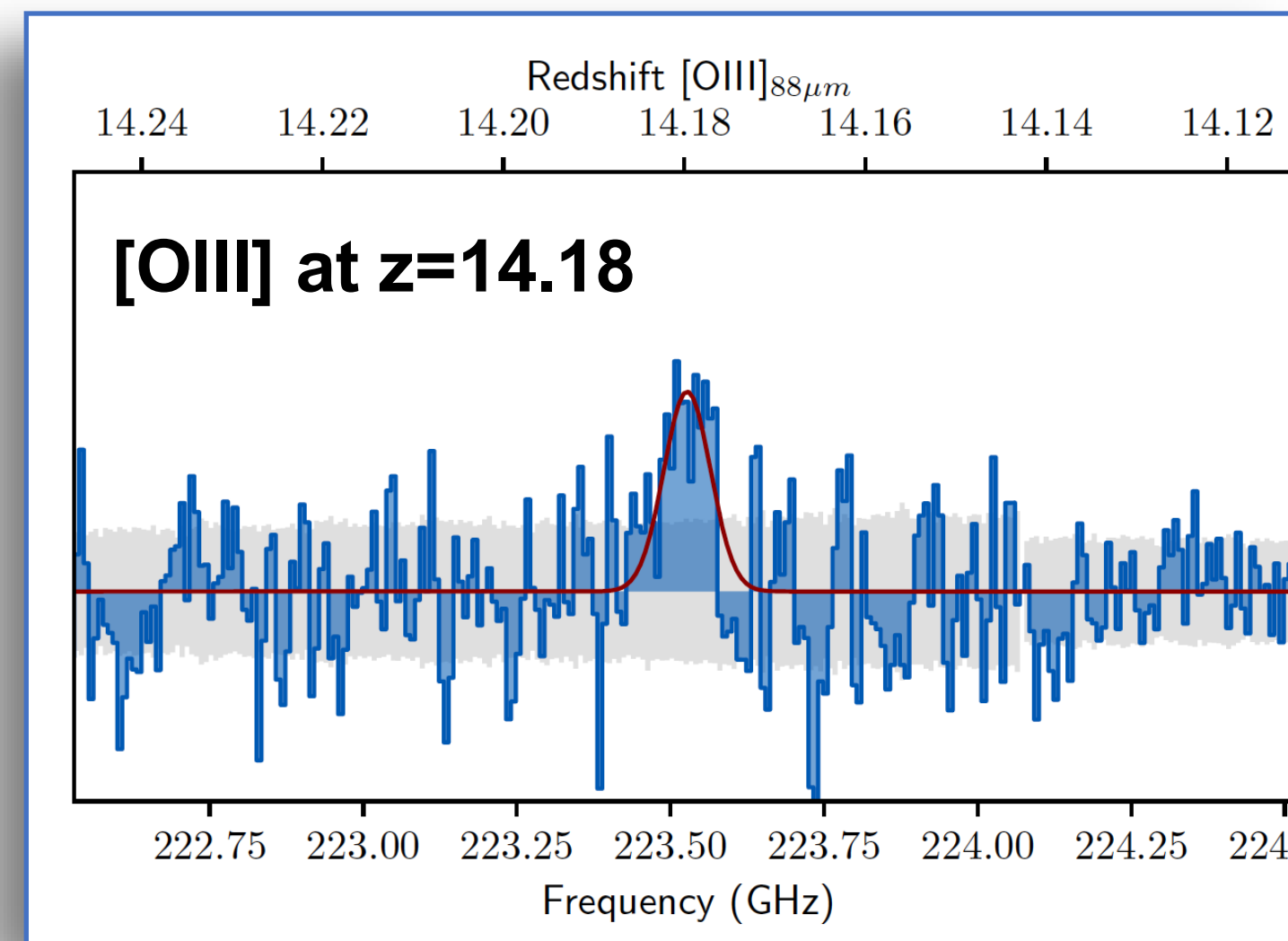
How did the *first galaxies* form their stars?

Breaking the last cosmic frontier

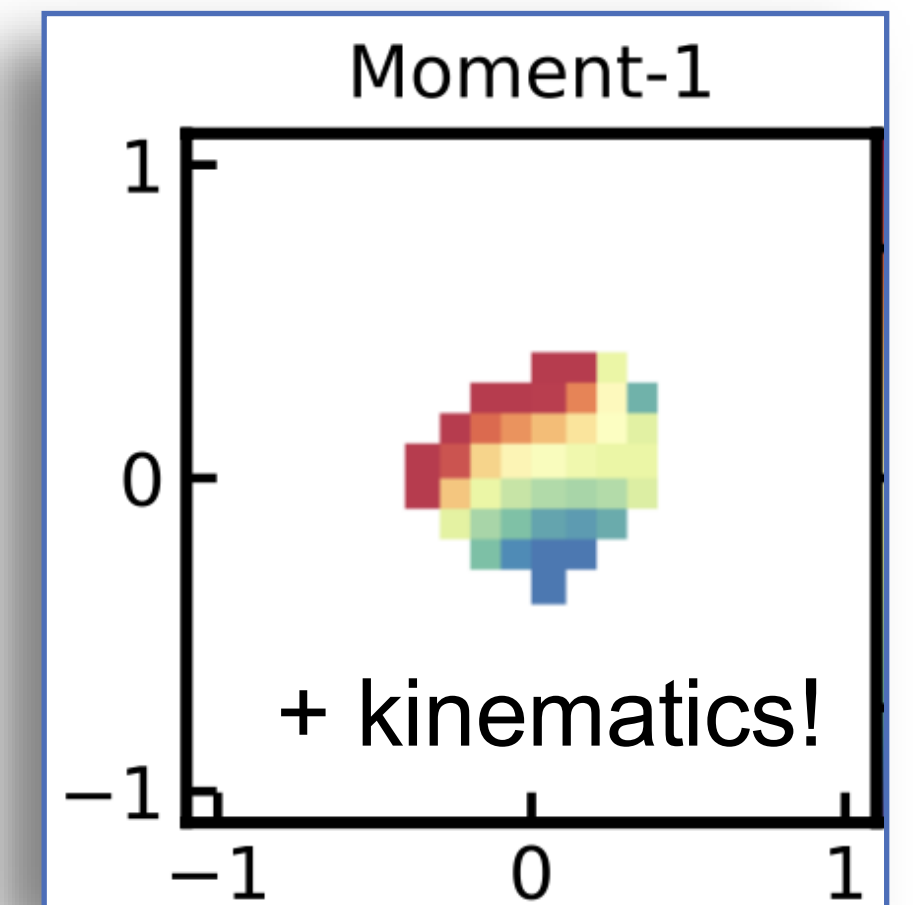
Need to spectroscopically confirm galaxies out to $z \sim 20$



Proof of concept: Spectroscopic confirmation of a galaxy at $z > 14$ (only 300 Myr after Big Bang)



Schouws et al. 2025; Carniani et al. 2025
ESO Press Release



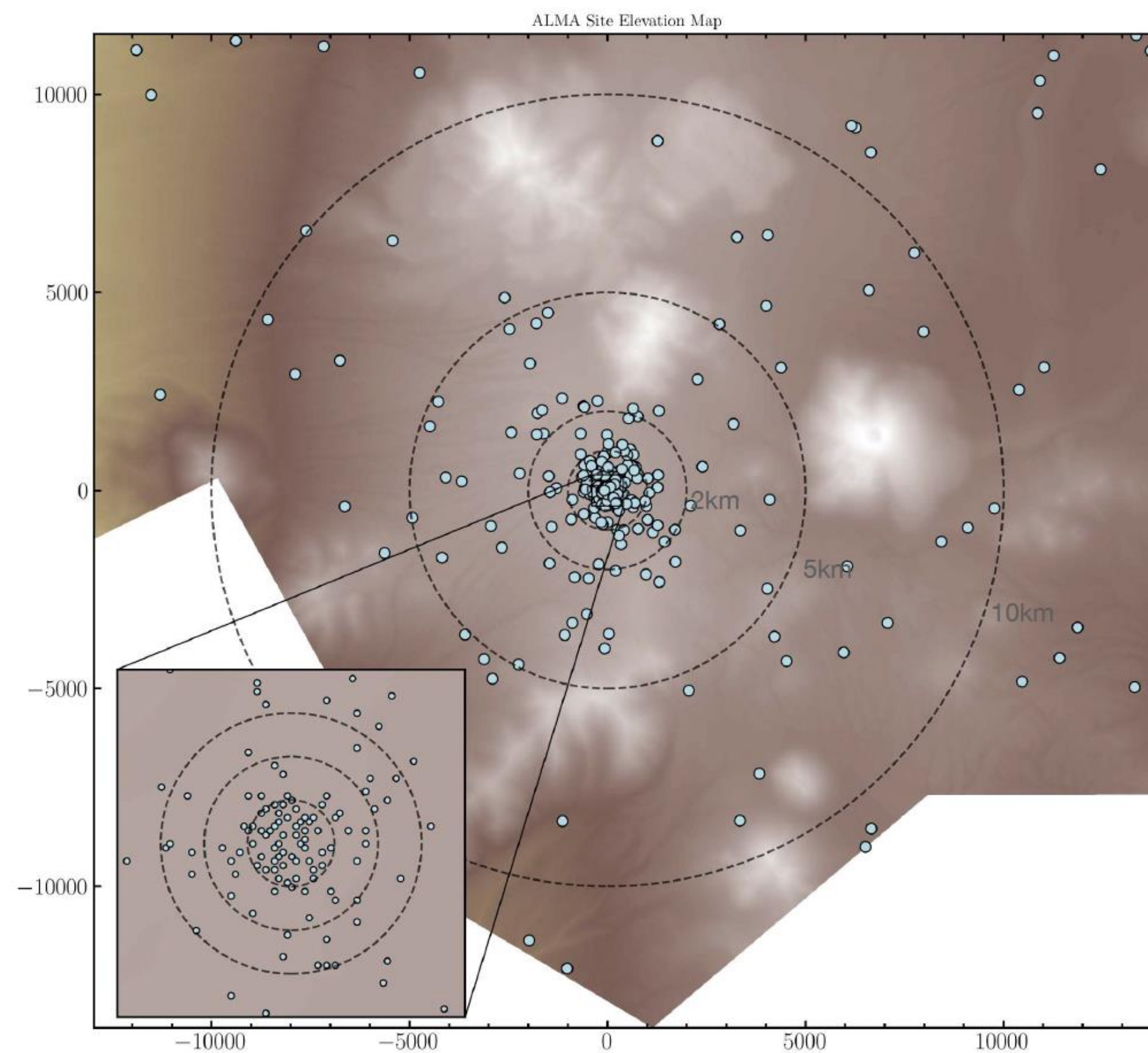
Scholtz et al. 2025

...but only barely probes tip of the iceberg

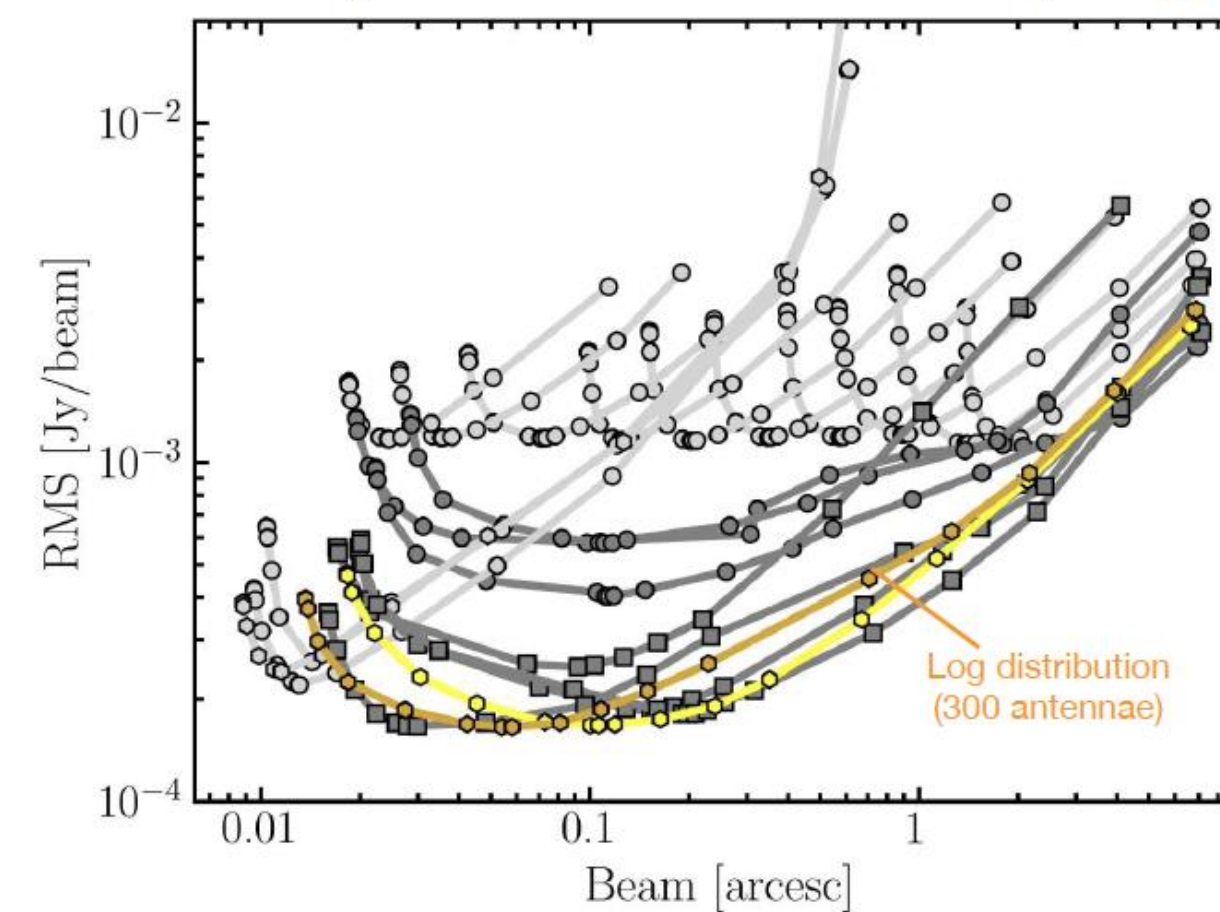
Example of configuration study

Band 6 (230 GHz), 1h observation

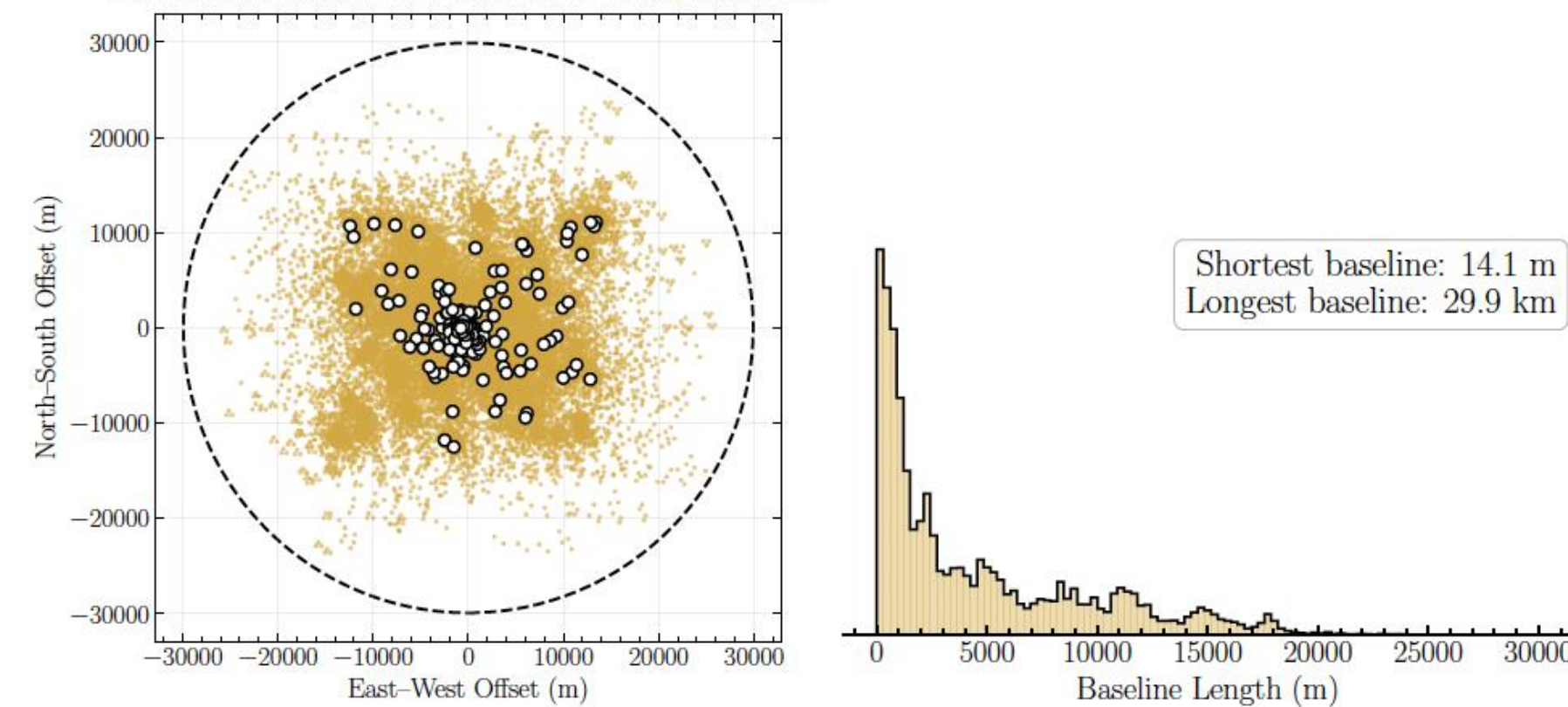
OWN CONFIGURATION #6: LOG-NORM ANTENNA DISTRIBUTION



Sensitivity to Scale for Meerkat-like array design



Antenna and 2D Baseline distribution

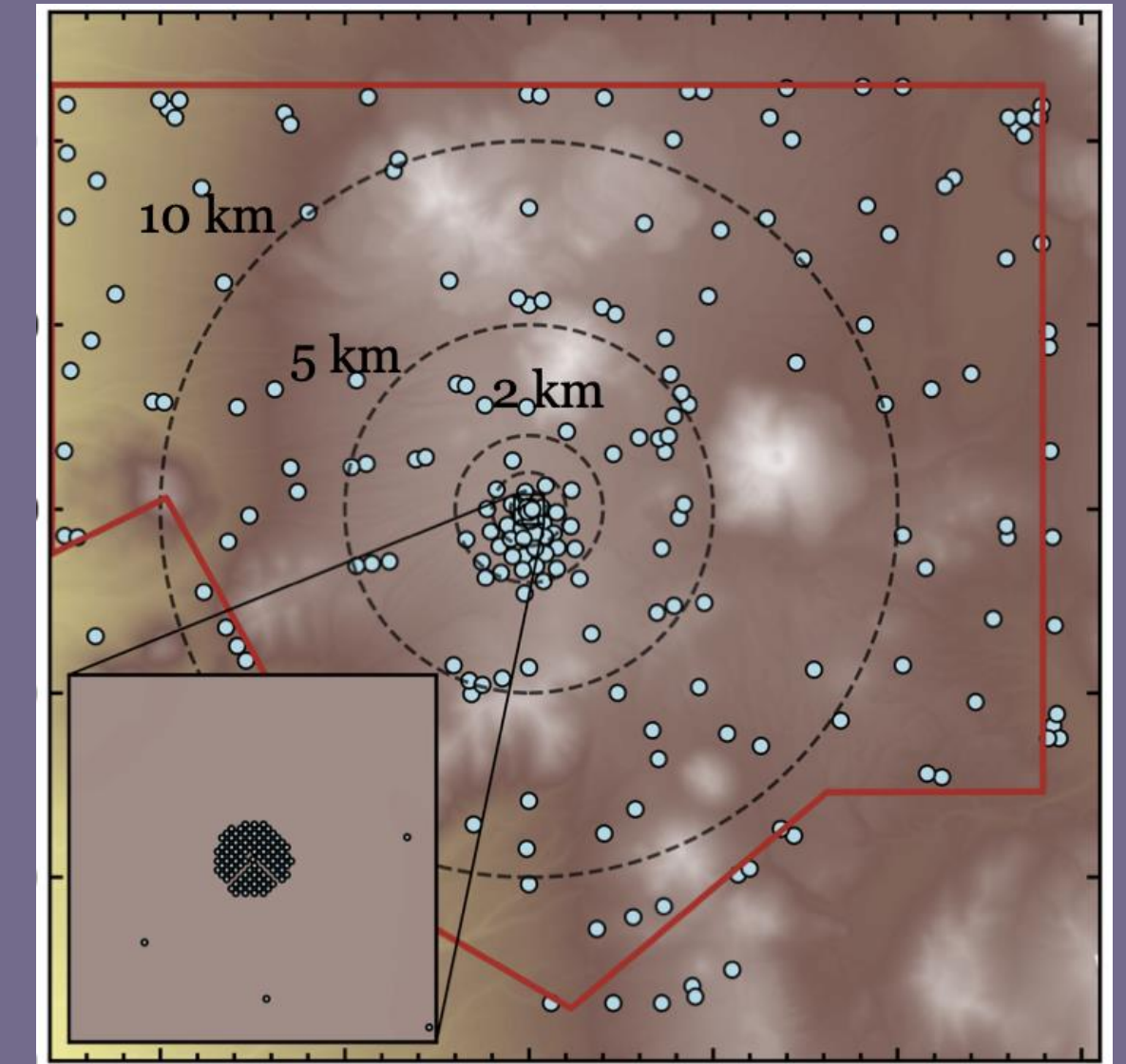


27

Working concept

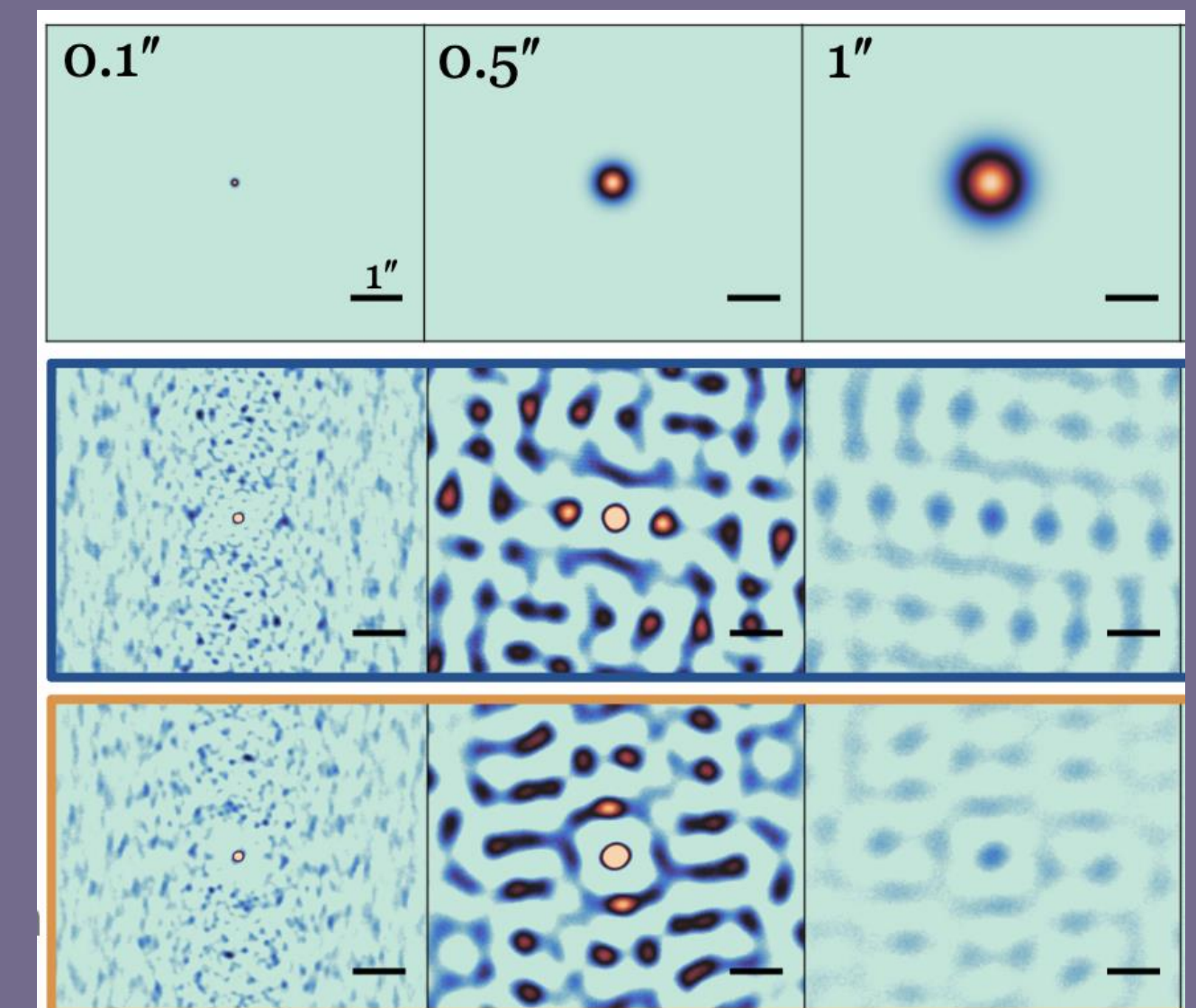
Requirements from consolidated key science goals:

- ~200-300 antennas within the astronomical park
- Short-spacing capabilities
- Covering full (current) frequency range (at least for core)
- FULL instantaneous bandwidth



On-going dialogue with industry to assess cost trade-offs of the antennas

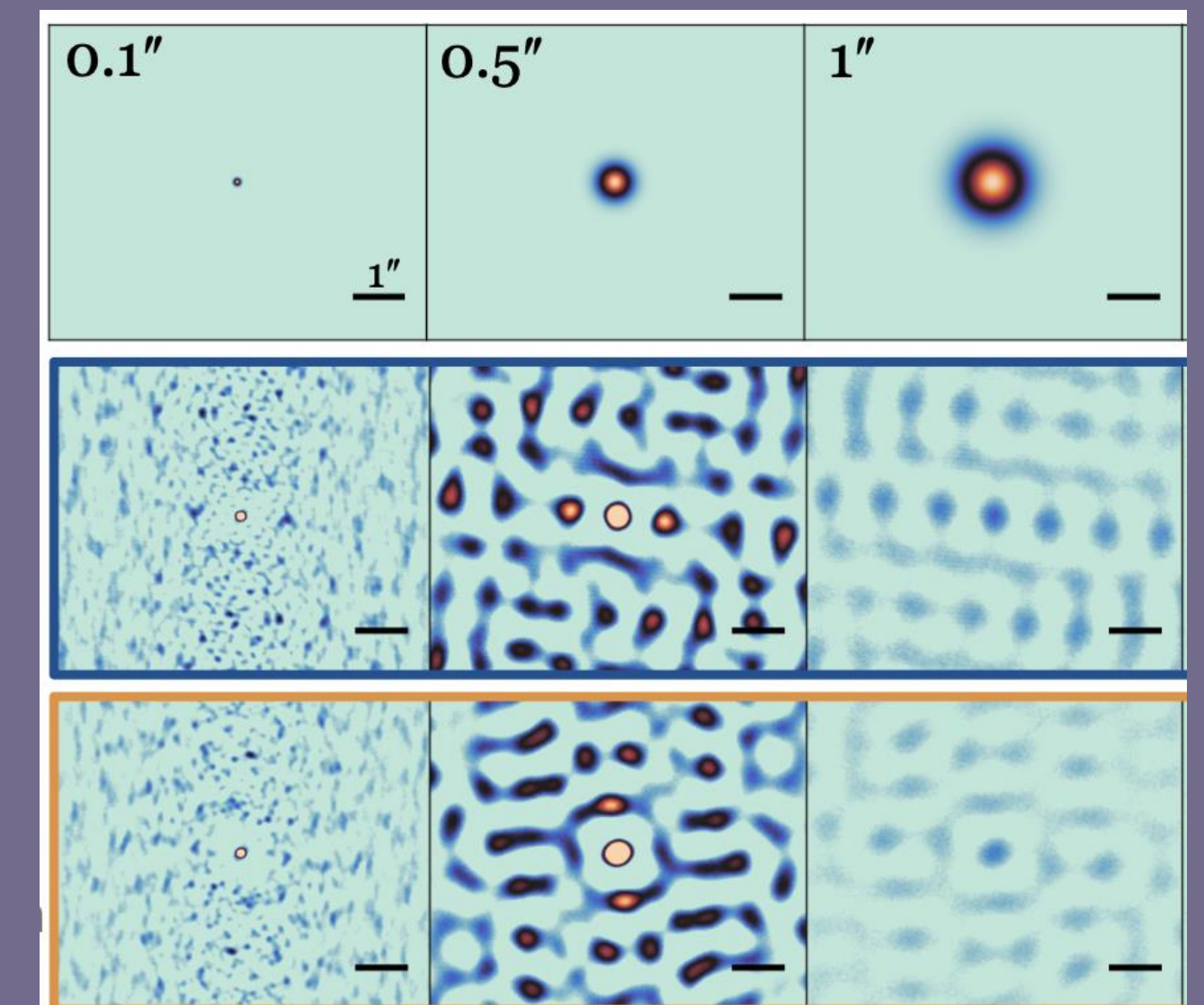
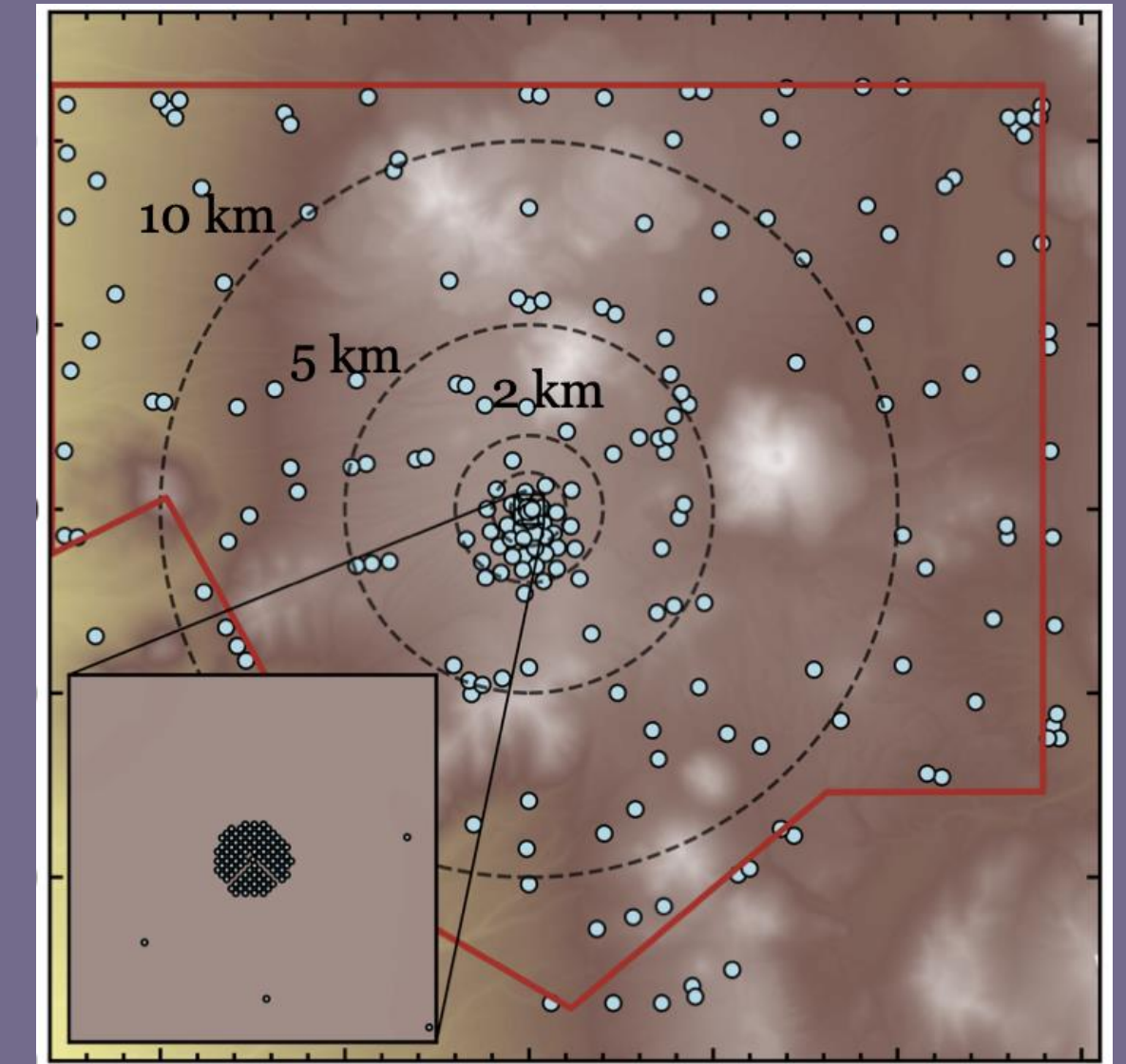
On-going work on overall sustainability with dedicated experts (meeting later this month)



Working concept

Requirements from consolidated key science goals:

- ~200-300 antennas within the astronomical park
- Short-spacing capabilities
- Covering full (current) frequency range (at least for core)
- FULL instantaneous bandwidth
- Solar observing capabilities
- Strict polarization purity
- ToO capabilities (including for VLBI) — within minutes
- Coordination with multi-messenger facilities
- Sub-arraying capabilities
- Real-time calibration



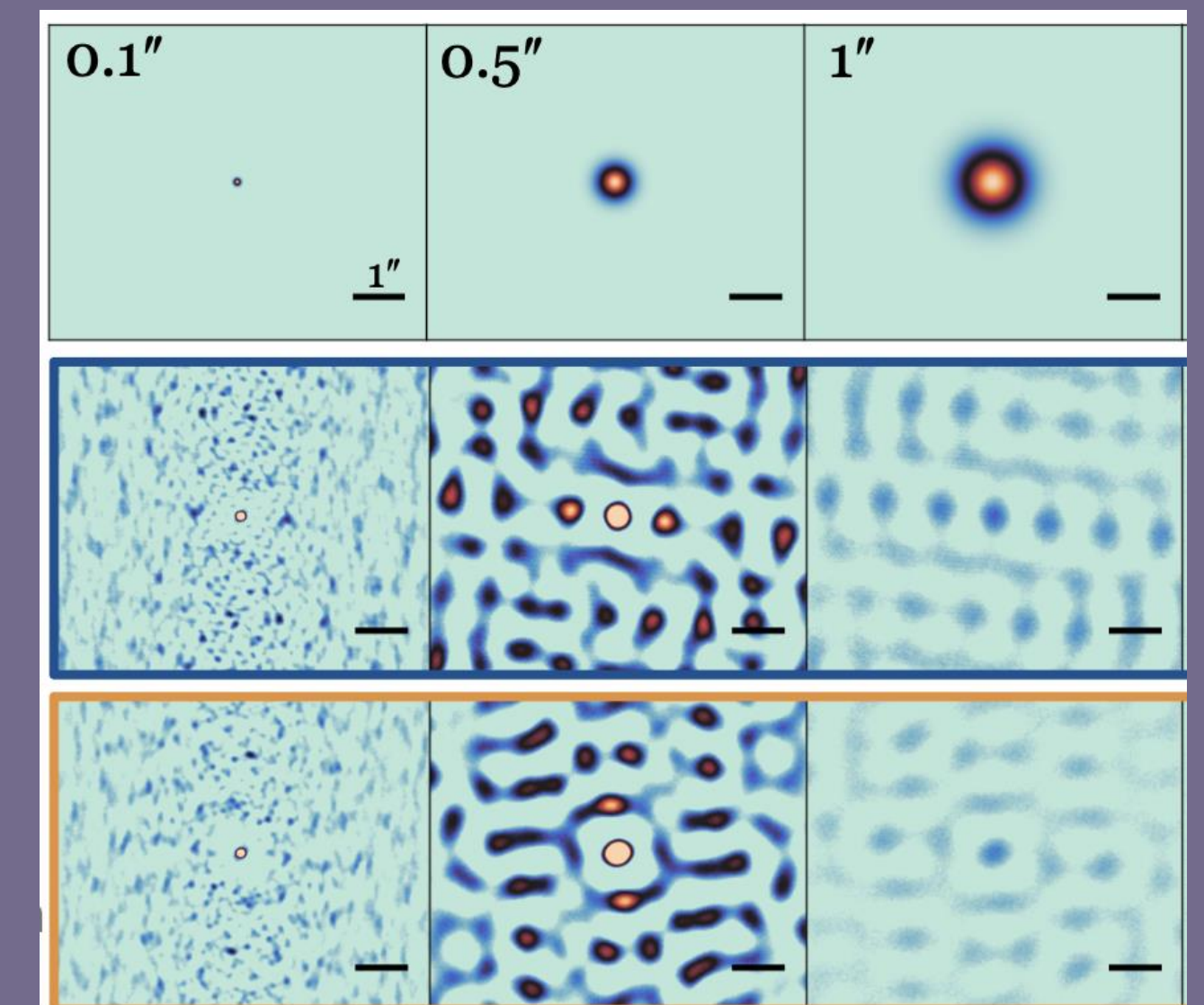
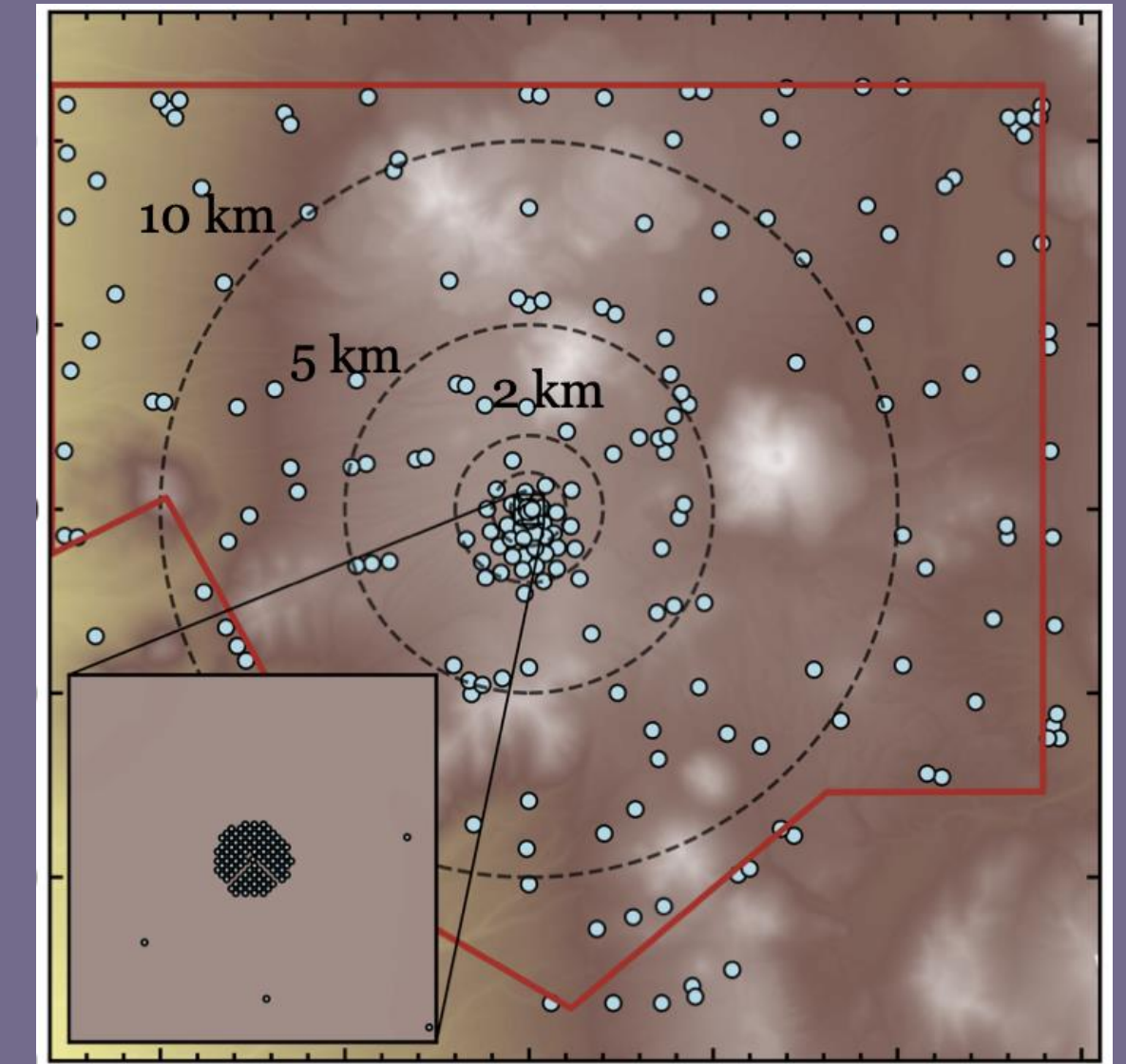
Working concept

Requirements from consolidated key science goals:

- ~200-300 antennas within the astronomical park
- Short-spacing capabilities
- Covering full (current) frequency range (at least for core)
- FULL instantaneous bandwidth
- Solar observing capabilities
- Strict polarization purity
- ToO capabilities (including for VLBI) — within minutes
- Coordination with multi-messenger facilities
- Sub-arraying capabilities
- Real-time calibration

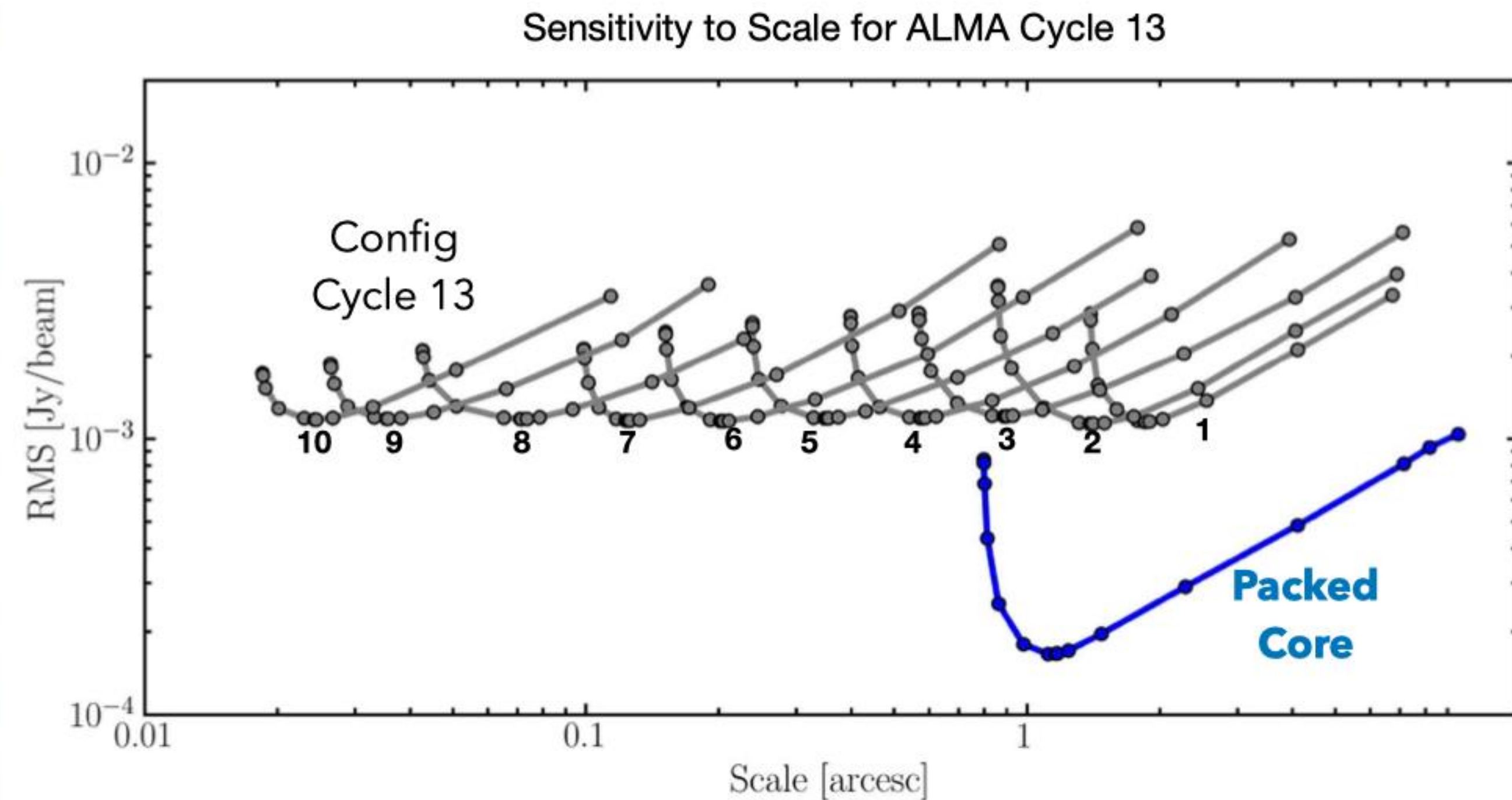
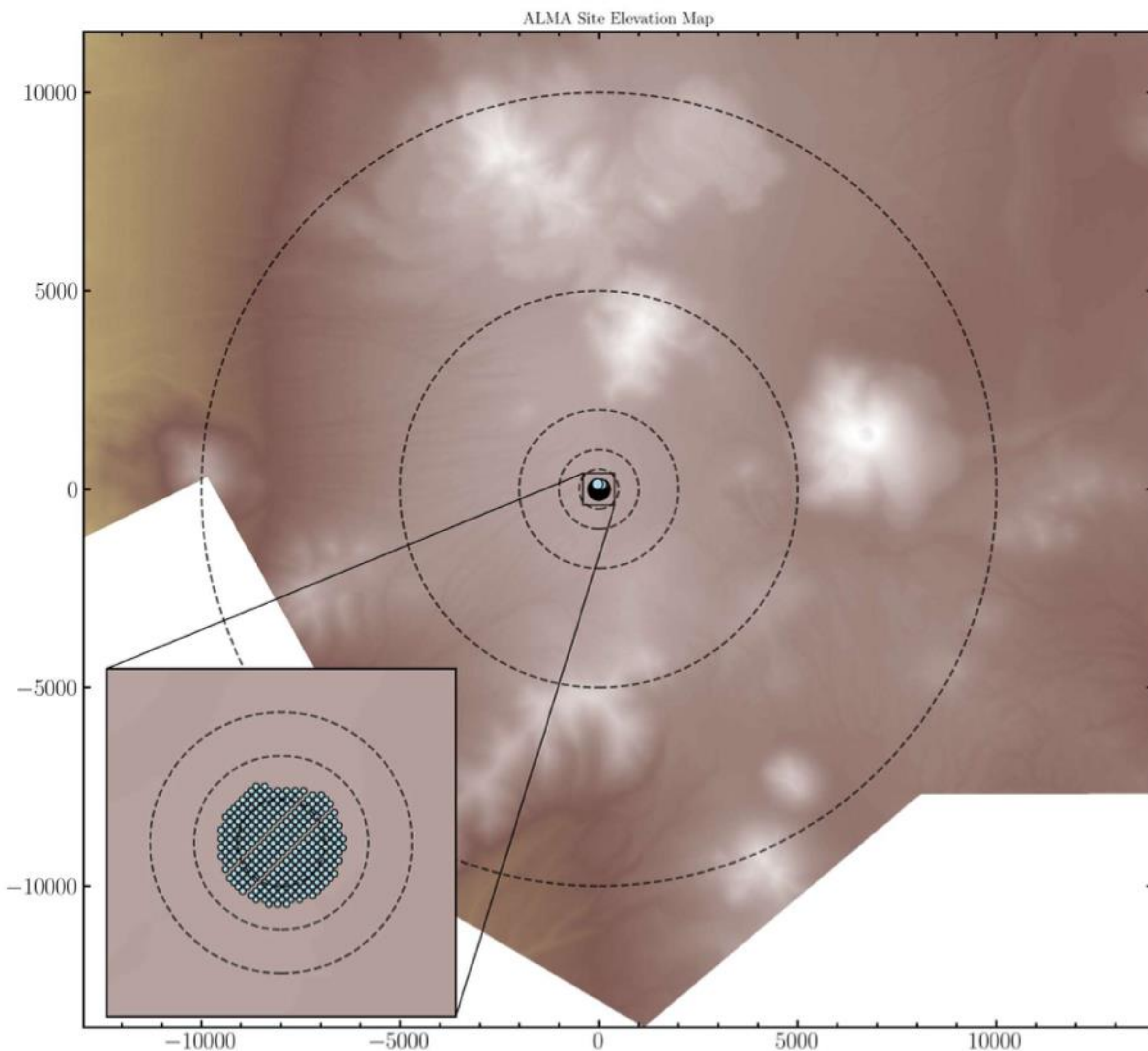
Still under discussion

- Fixed or movable array
- Optimal configuration



THEORETICAL OPTIMUM: FULLY PACKED 300 ANTENNA CORE

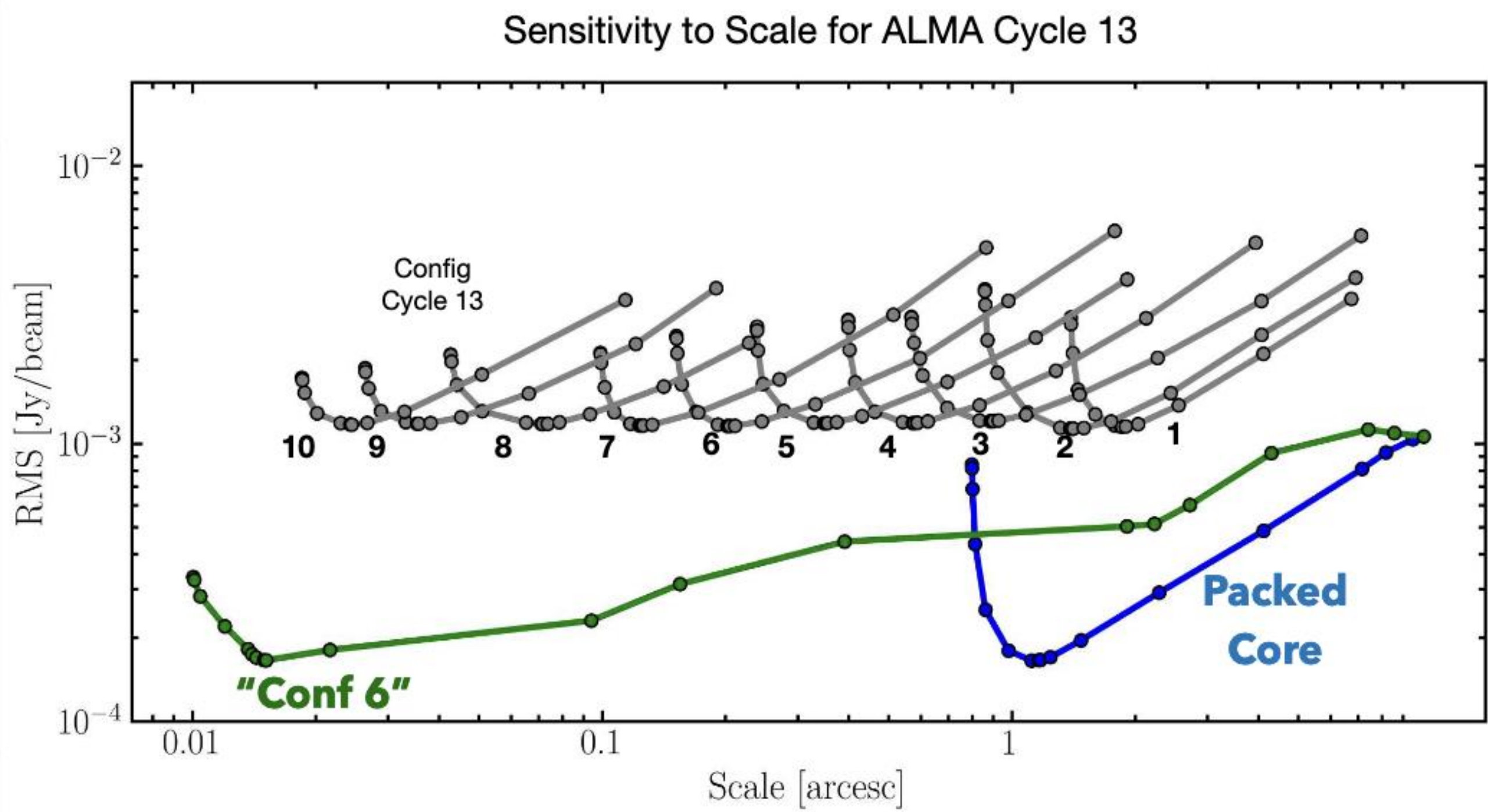
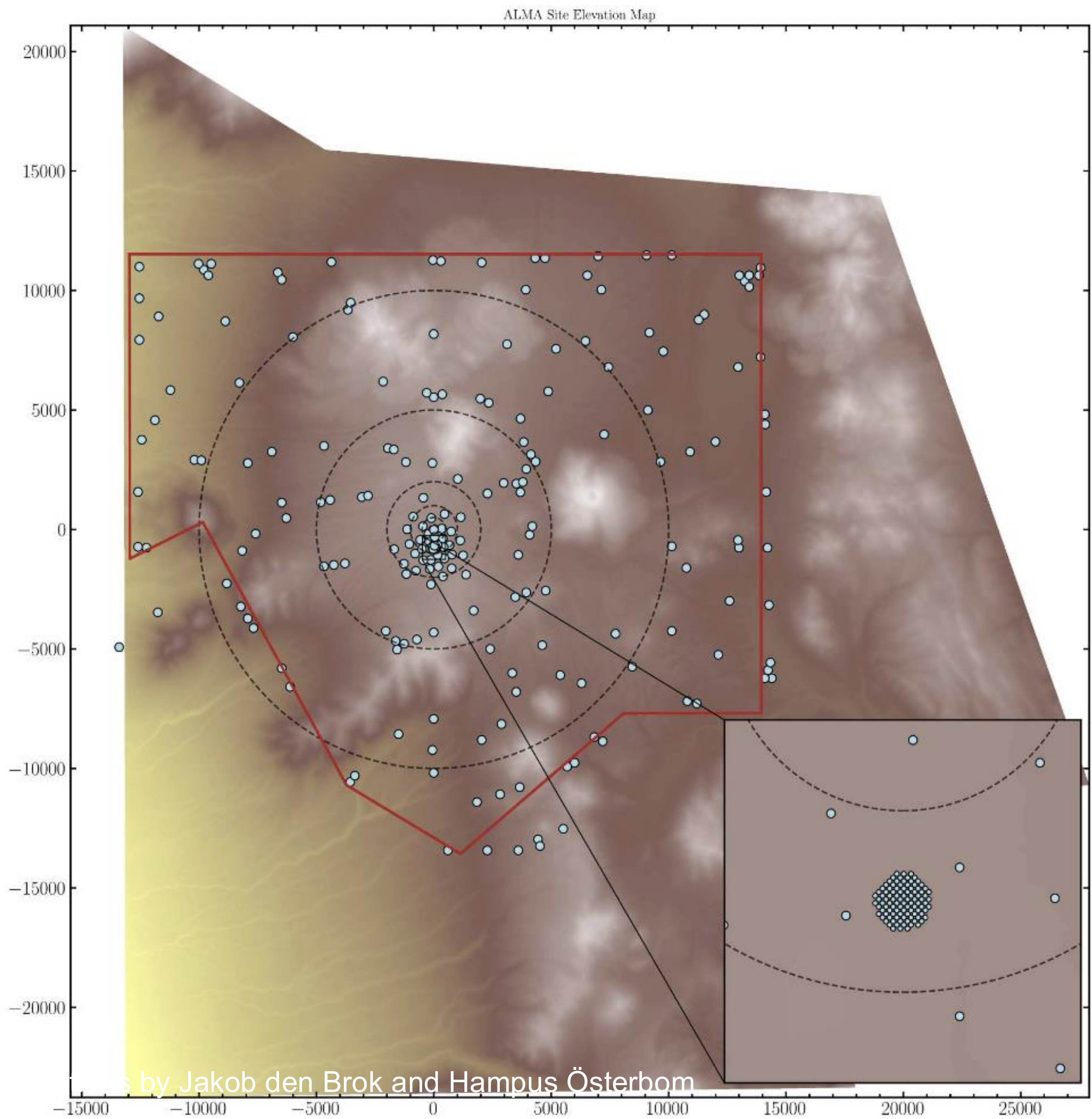
Band 6 (230 GHz), 1h observation



Packing 300 antennas in a compact core to illustrate maximal improvement of sensitivity at larger scales. Any real configuration (with a dense core) will have less dense packing and thus shift this sensitivity curve to smaller scales.

UPDATED "CONFIG 6": CONF 3 + DENSE CORE

Band 6 (230 GHz), 1h observation

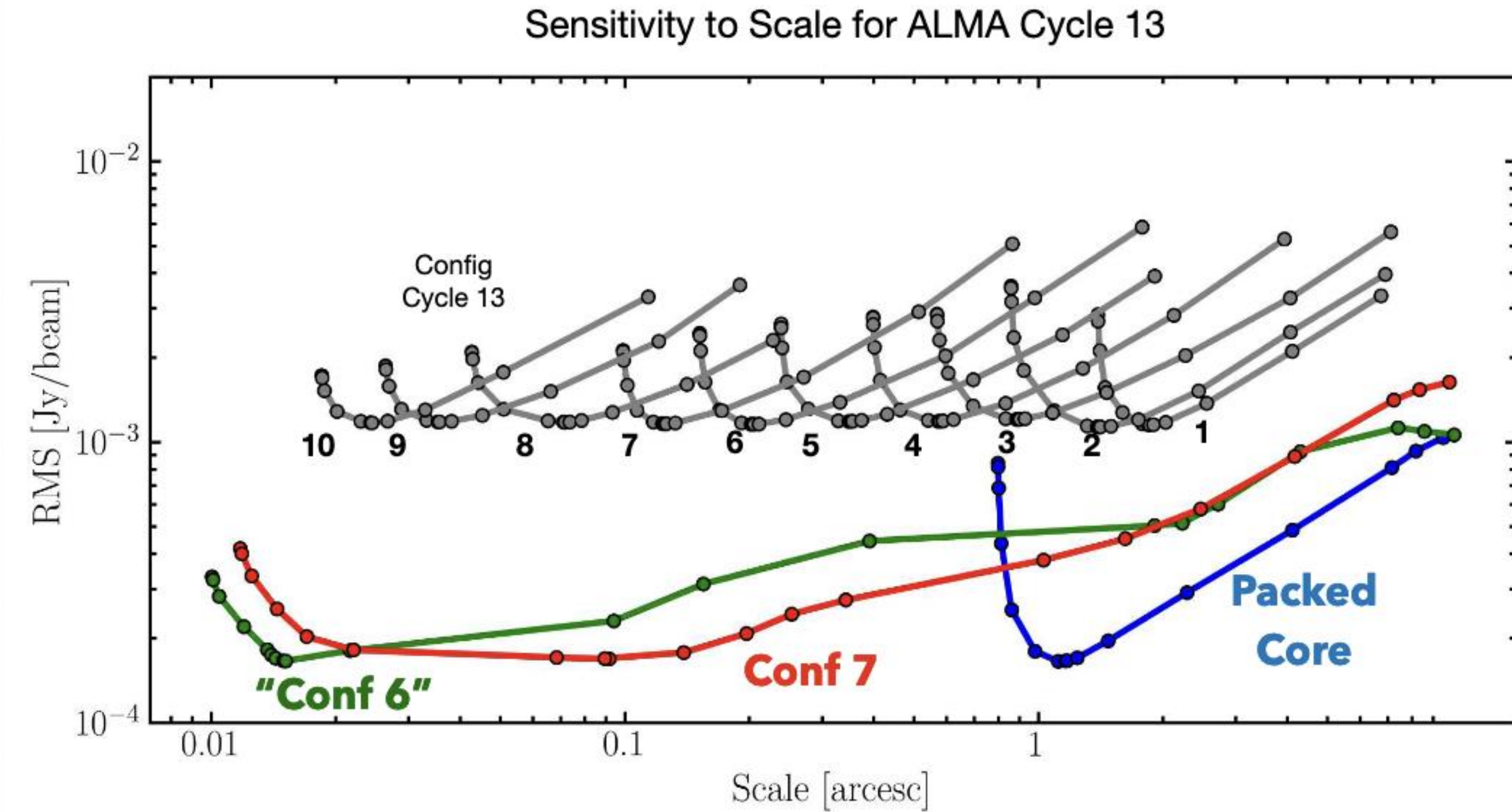
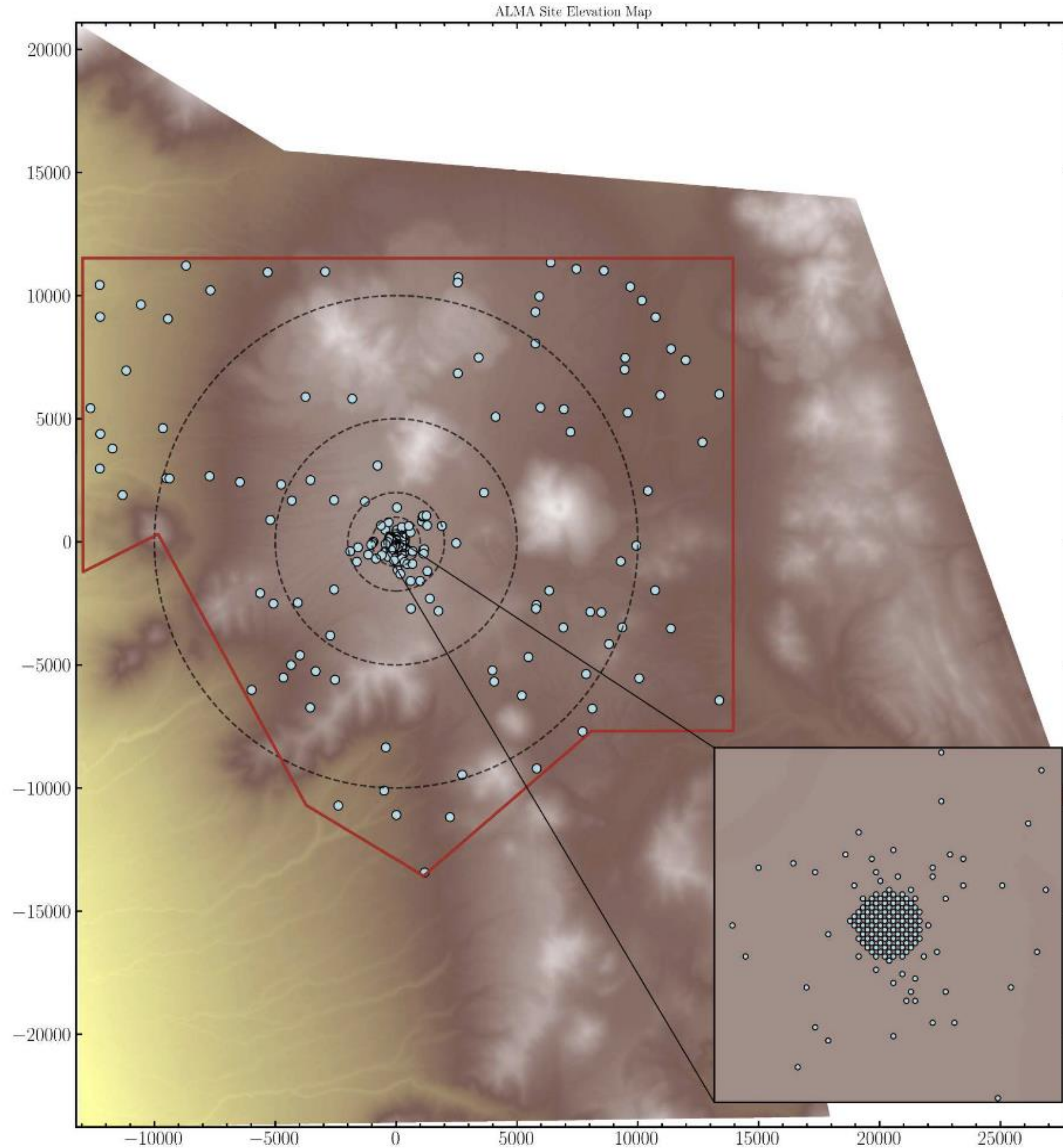


The core has moved to better connect to surrounding antennas of the extended configuration.

Simulations by Jakob den Brok and Hampus Österbom

CONF 7: PACKED CORE + DENSE MID RING + EXTENDED

Band 6 (230 GHz), 1h observation



A new configuration that combines three arrays:

1. 100 antenna packed core
2. 100 antenna placed out to 2km with log-distribution
3. 100 antenna placed randomly beyond 2km

Simulations by Jakob den Brok and Hampus Österbom

Shifting resolution with robust & tapering

