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The ALMA observatory

Current capabilities and future upgrades

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The ALMA observatory

Current capabilities

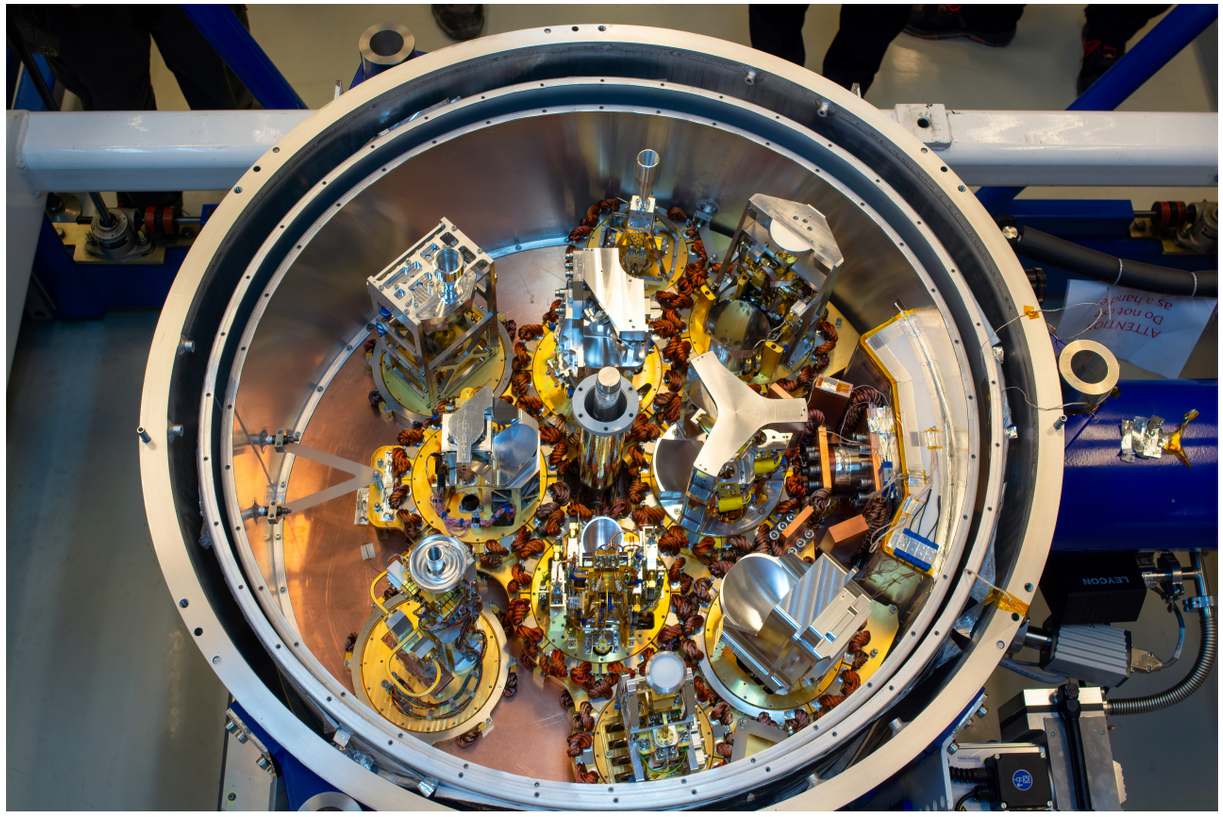
- Located in the Atacama desert (Chile), at an altitude of 5,000 m.
- Main array: Fifty 12 m antennas
- ALMA compact array (ACA) or Morita array:
  - Twelve 7-m antennas
  - Four 12-m antennas (total power)
- Maximum baselines:16 km
- Angular resolution (at 1 mm, last cycle): from ~1.5” down to ~0.03”.

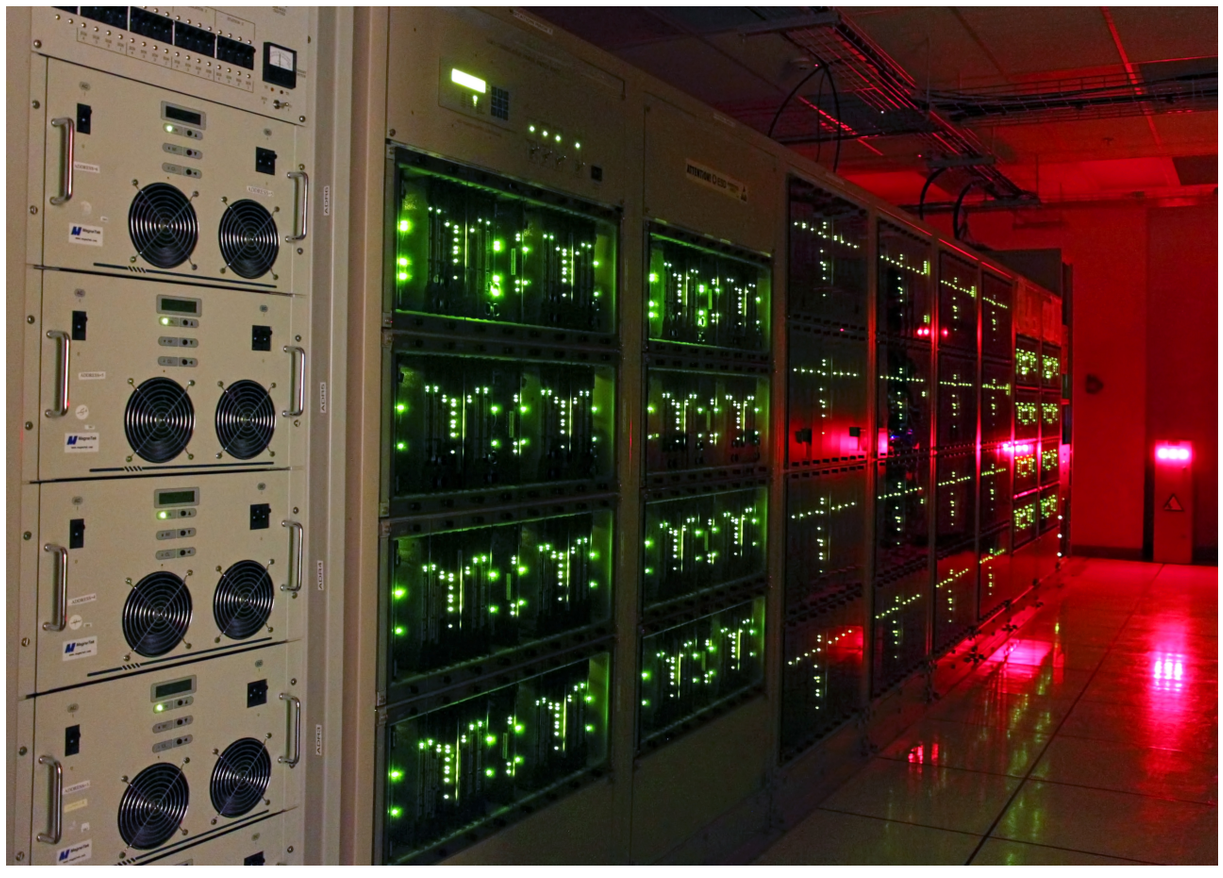
- 9 receivers bands, covering frequencies from 35 GHz to 950 GHz (0.3 mm to 8 mm).

- The correlator can process four 2 GHz *basebands* per receiver, with resolutions (at 300 GHz) between:

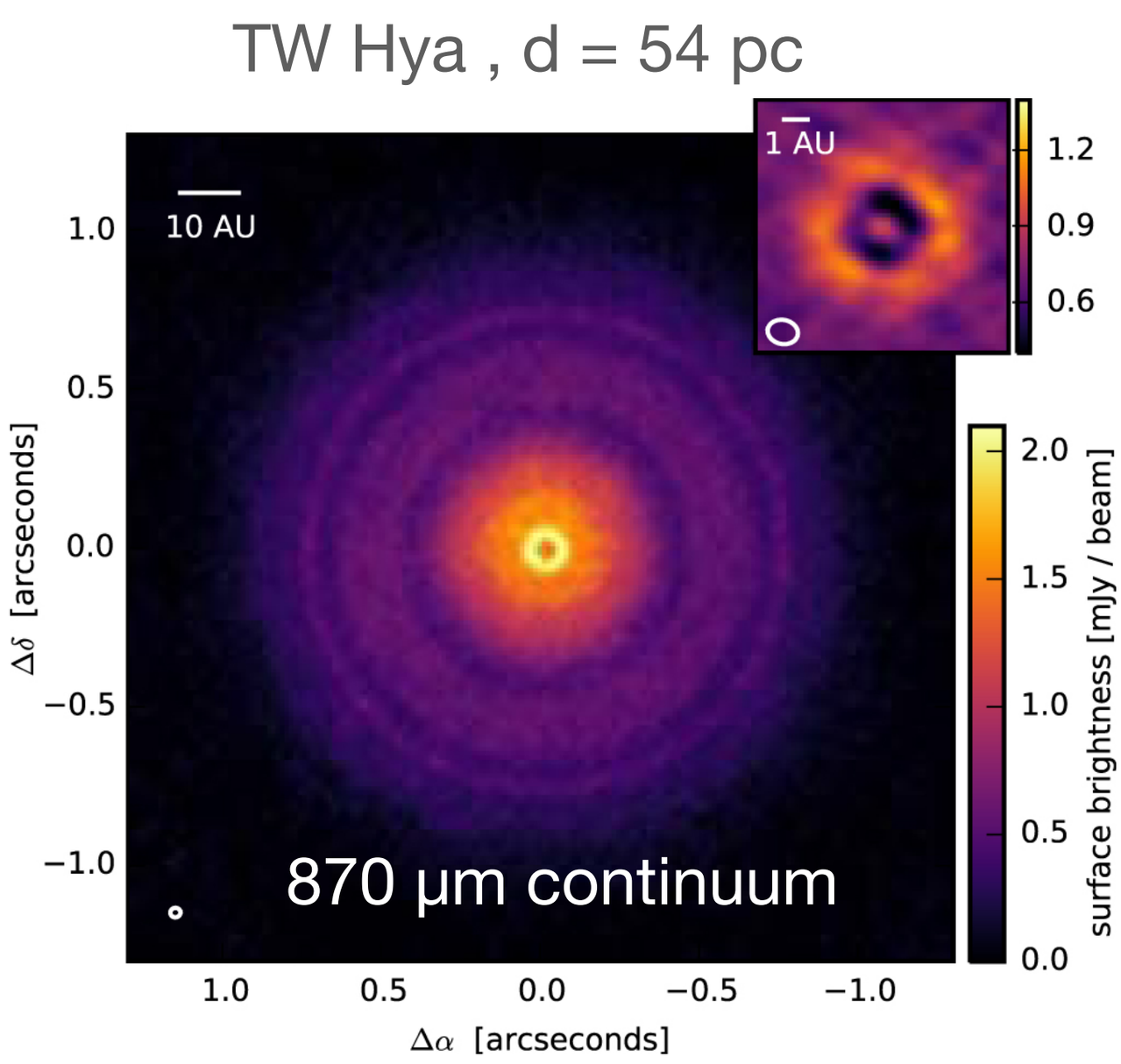
  - 0.03 km/s for a 58.6 GHz bandwidth

  - 0.98 km/s for a 1875 MHz bandwidth





- The first observations (cycle 0) started in 2011.
- After only 5 years of operation, the initial top-level science goal had already been achieved:
  - Ability to detect CO or C+ line emission from a normal galaxy at z = 3, in less than 24 hours of observation.
  - Ability to image the gas in a solar-mass protoplanetary disk at a distance of 150 pc.
  - The ability to provide precise images at an angular resolution of 0.1”.
- The ALMA board appointed a working group to develop a strategic vision for ALMA 2030. This led to a development roadmap, which was approved in 2018.



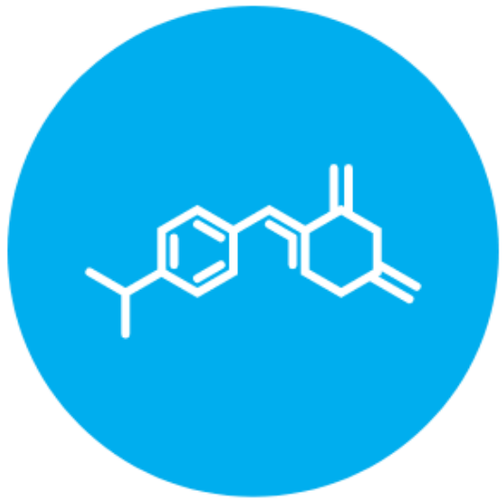
Andrews et al. (2016)

The ALMA development roadmap

3 new fundamental science drivers

ORIGINS OF GALAXIES

Trace the cosmic evolution of key elements from the first galaxies (z>10) through the peak of star formation (z=2–4) by detecting their cooling lines, both atomic ([CII], [OIII]) and molecular (CO), and dust continuum, at a rate of 1-2 galaxies per hour.



ORIGINS OF CHEMICAL COMPLEXITY

Trace the evolution from simple to complex organic molecules through the process of star and planet formation down to solar system scales (~10-100 au) by performing full-band frequency scans at a rate of 2-4 protostars per day.

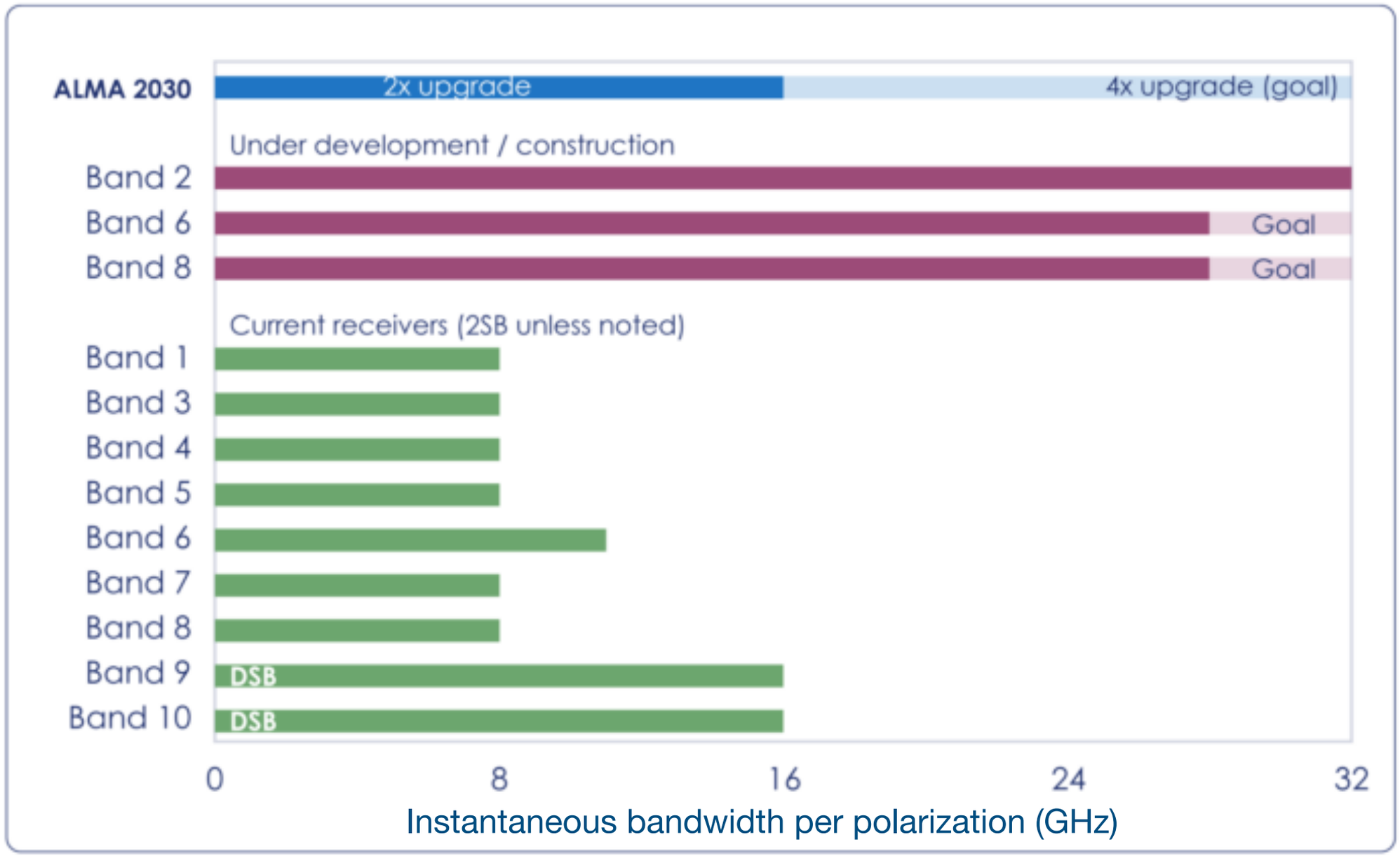
ORIGINS OF PLANETS

Image protoplanetary disks in nearby (150 pc) star formation regions to resolve the Earth forming zone (~ 1 au) in the dust continuum at wavelengths shorter than 1mm, enabling detection of the tidal gaps and inner holes created by planets undergoing formation.

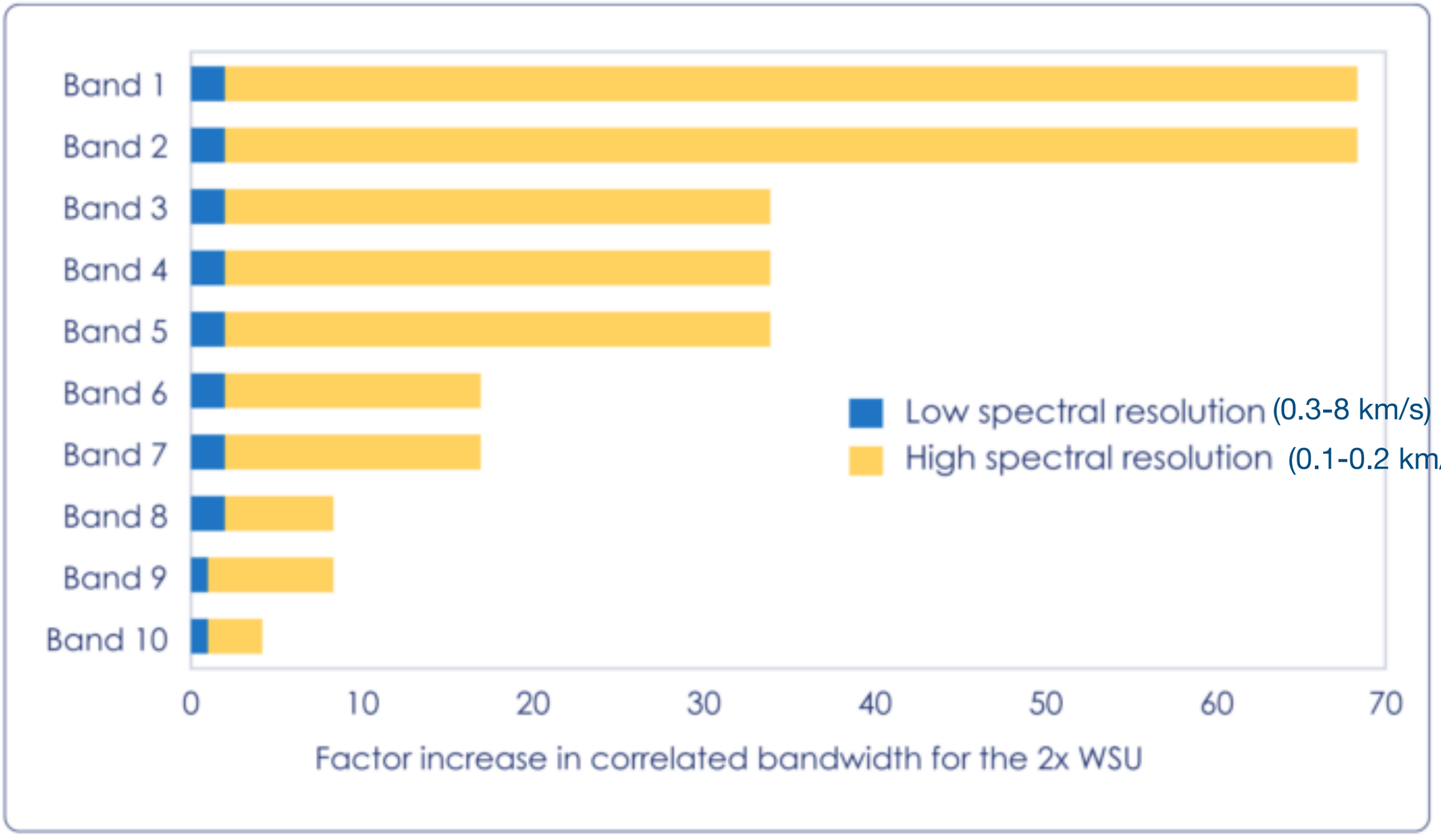
- This new science goals require technical upgrades.
- Main recommendation: broaden the IF bandwidth and increase the data throughput (ALMA Wideband Sensitivity Upgrade, or WSU).

Wideband sensitivity upgrade (WSU)

A major increase in the instantaneous bandwidth

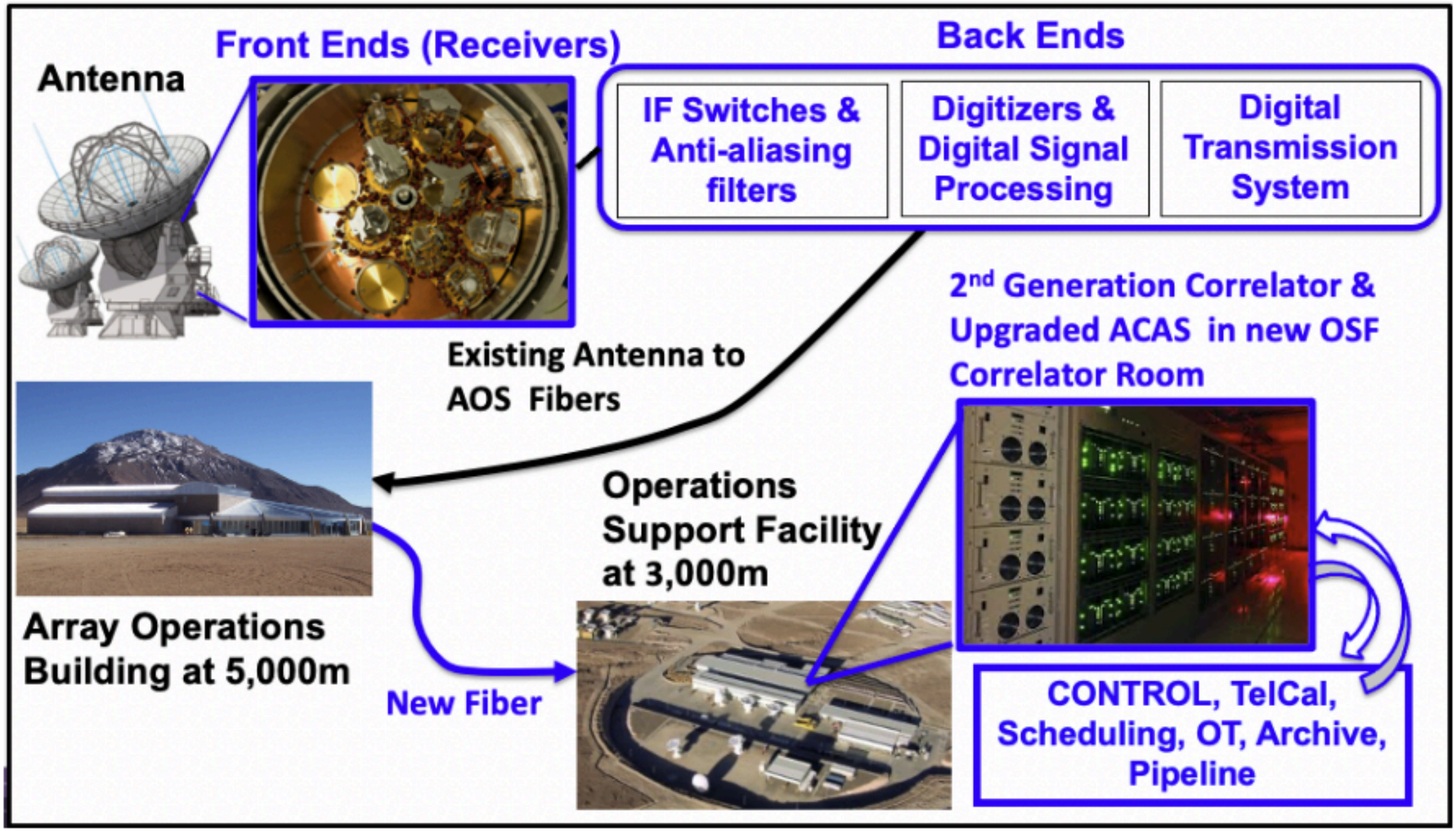


Carpenter et al. (2022)



Carpenter et al. (2022)

- The full receiver band can be covered at high spectral resolution (0.1-0.2 km/s). No more trade-offs between resolution and bandwidth.



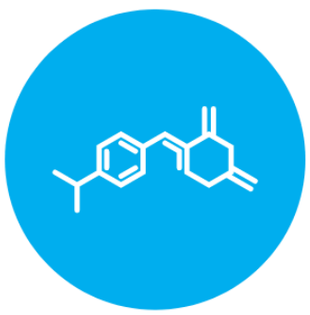
Carpenter et al. (2022)

- The first elements of the WSU will be available before 2030, including a Band 2 receiver, an upgrade to Band 6 (6v2), new digitizers and digital transmission system, and a new correlator.

The scientific impact of the WSU

Benefits of the WSU will impact all observations

- The WSU will provide:
  - A factor of 70 increase in spectral scan speed increase for 0.1 km/s resolution in Band 2.
  - A factor of (at least) 3 increase in continuum imaging speed (bandwidth increase, lower receiver noise).
  - A factor of (at least) 2 increase in spectral line imaging speed (better receiver noise).
  - Access to ultra-high spectral resolution: 10 m/s.
- All 3 main science drivers will benefit from this upgrade.



The COMPASS large program

Spectral surveys of young protostars

ORIGINS OF CHEMICAL COMPLEXITY

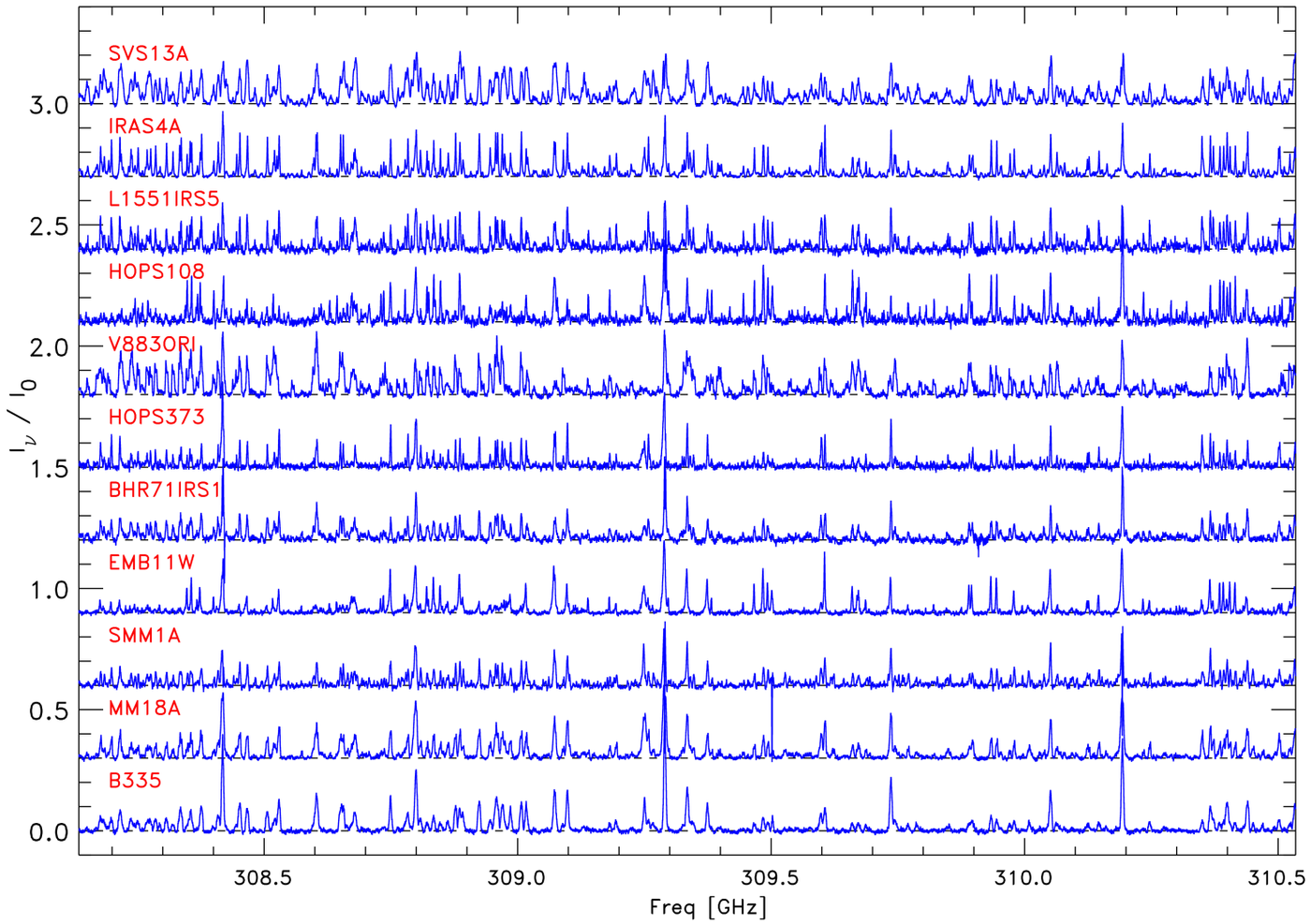
- ALMA cycle 9 large program, P.I. Jes Jørgensen (NL)

- Main goal: comprehensive inventory of the complex organic molecules (COMs) composition in a large sample of young protostars.

- 33 GHz frequency window in Band 7 at 0.5 km/s spectral resolution, 9 frequency settings.

- With the WSU 2x, the same range could be covered in 2 settings, at 0.1 km/s resolution ! (x4 faster)

- Reducing and analyzing such a large volume of data is a challenge.



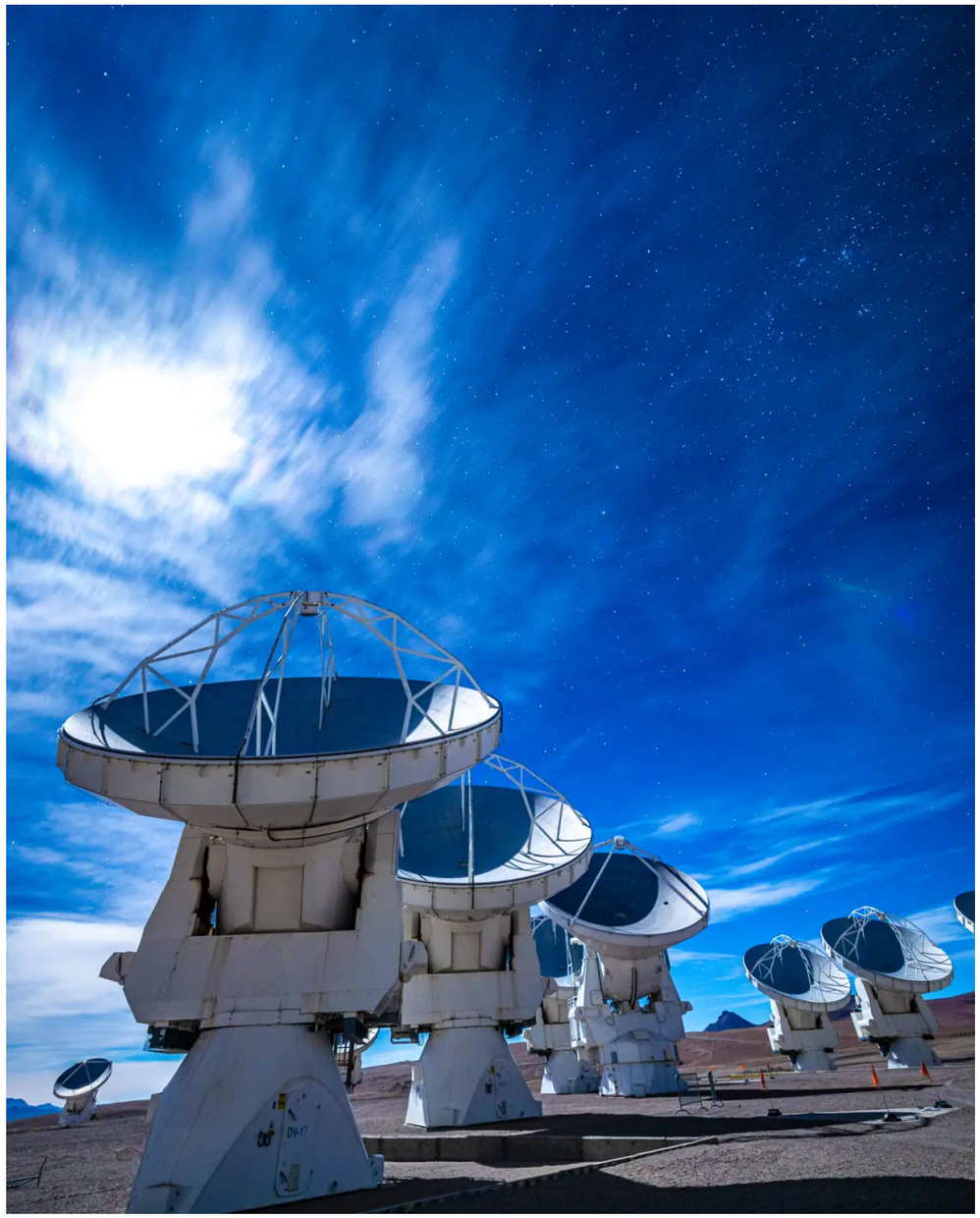
Jørgensen et al. (in prep.)

Possible upgrades beyond the WSU

Additional antennas

- Would benefit all programs by increasing the sensitivity and the uv coverage, especially for the longest baselines (16 km).

- Additional benefits:
  - More calibrators available, and hence better atmospheric phase correction (especially at high frequency).
  - Self-calibration would also be improved (more baselines).



Possible upgrades beyond the WSU

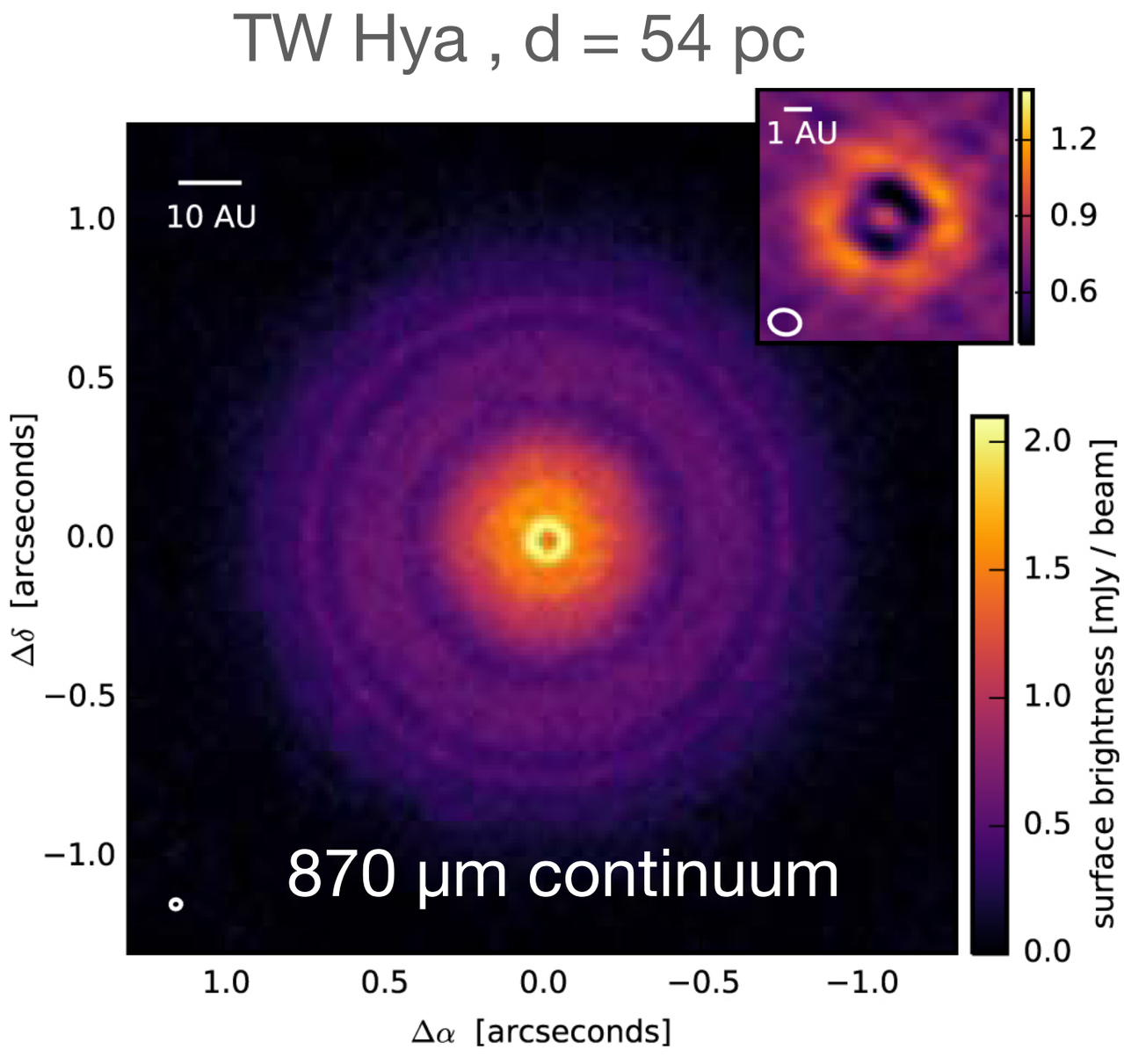
Extended baselines

- Observing disks in the closest star-forming regions at 1 au resolution (Taurus, Ophiucus, and Lupus) would require extending baselines by 2-3x (30 to 50 km).

- 2 options:

  - Outside the current concession, with antennas permanently stationed on distant stations (moving them outside the current concession would be unfeasible).

  - Inside the current concession, at the operation support facility (3000 m, ~ 15 km away from the observatory), but limited to lower frequencies.



Andrews et al. (2016)

Possible upgrades beyond the WSU

Focal plane arrays

- Would increase ALMA wide-field mapping speed to survey large regions of molecular clouds, image nearby galaxies, and deep-field cosmological surveys.

- 4-16 pixels receivers could be accommodated at the focal plane.

- Requires a larger correlator.

- Such arrays are being tested at the 30m (c.f. Karl's talk).

Conclusions

What can we expect from ALMA in the coming years?

- The WSU is a major upgrade of the ALMA, that will impact all observations.

- The first elements of this upgrade (Band 2 and 6, new correlator) will be available by 2030. Other bands will follow.

- On longer timescales (2040), additional upgrades (longer baselines, additional antennas, focal plane arrays…) are under consideration.

- The European community is preparing a science case for these upgrades (« ALMA2040 »), following the ESO Expanding Horizon call.

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

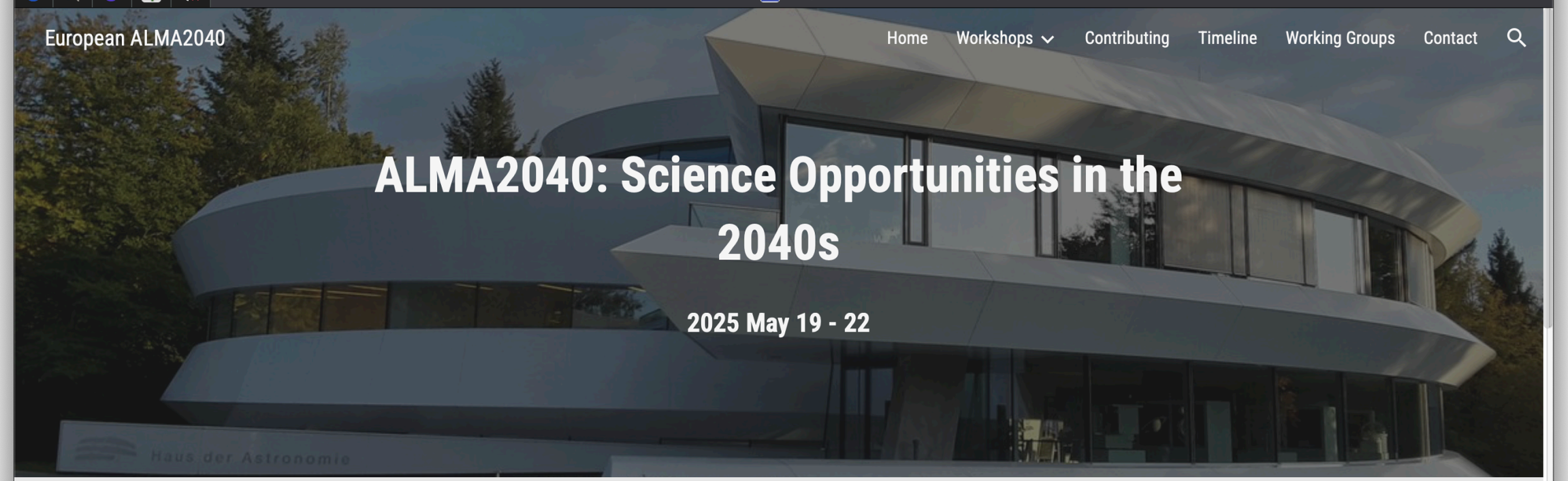
Towards a radical upgrade of ALMA

Following the announcement from ESO about the start of the search for its next astronomical ground-based programme for the 2040s (ESO Expanding Horizons), the community is getting organized to prepare the science case for a new millimeter/sub-millimeter facility in the 2040s ("ALMA2040") which builds upon the successes of the current ALMA Observatory.

A series of workshops will take place in Europe in 2025 to discuss the scientific interest of the ESO community in such a facility, identify the key scientific questions to be addressed, and ultimately define the needed technical capabilities. ESO will issue a Call for Ideas in Q3/2026 with a deadline of 2027 June 1 (and a deadline of 2026 December 1 for Letters of Intent).

Here we aim to help coordinate the interests of the millimeter/sub-millimeter community.

http://euroalma2040.com



ALMA2040: Science Opportunities in the 2040s

2025 May 19 - 22

what? Discuss science ideas for a disruptive upgrade to ALMA and identify key science cases driving the requirements defining such an ALMA2040.

where? Haus der Astronomie (HdA) on the MPIA Campus, Heidelberg, Germany

when? From Monday 2025 May 19 lunch time until the end of the business day on Thursday 2025 May 22

Logistics

registration fee: 150 Euro (plus 8 Euro processing fee) to help cover costs for lunches, coffee breaks, bus transfer

hotels: there are a number of hotels and also Airbnb options in Oldtown Heidelberg -- please visit Booking.com or airbnb.com

getting to the workshop site: we are looking into having a dedicated bus transfer from Monday evening to Thursday morning, with stops close to Peterskirche and Bismarckplatz.

online attendance: the number of (invitation-only) in-person participants is limited due to venue size, but (free) online attendance for the plenary presentations (indicated in **green** below) is highly encouraged and open to all -- please register at this link: **REGISTER TO ATTEND ONLINE**

Agenda

ALMA2040 HdA workshop Schedule : Sheet1

http://euroalma2040.com