Webinar Plan:

- Two x 15 min presentations
  - ALMA development program
  - NA Study call process
- ~30 minutes of Q/A
- Please post questions in the Q/A box at the bottom of webinar window)

- Webinar presentations are posted to Call website:
https://science.nrao.edu/facilities/alma/science_sustainability/na-alma-develpment-fy2023-call-for-study-proposals

Direct future questions to almadevelopment@nrao.edu

ALMA Development Program, Wideband Sensitivity Upgrade, & FY2023 Call for Studies

Crystal Brogan
(NA Program Scientist, Coordinator NA Development Program)

- Intro to ALMA Development Program
- Overview of the Wideband Sensitivity Upgrade
- FY2023 Call for Study Priorities

ALMA Development Program

- The ALMA Operations Plan includes a vigorous development program, in principle amounting to13M/year including all three executives (NA / EU / EA: ~$5M / $5M / $3.3M)
  - Each Partner administers its own development process as necessitated by the VERY different funding procedures/opportunities of each executive (NA, EA, EU)
  - Executives contribute "Value" to ALMA Development, not a pool of money and contributions should be balanced over time
  - The ALMA Development program began in CY2012

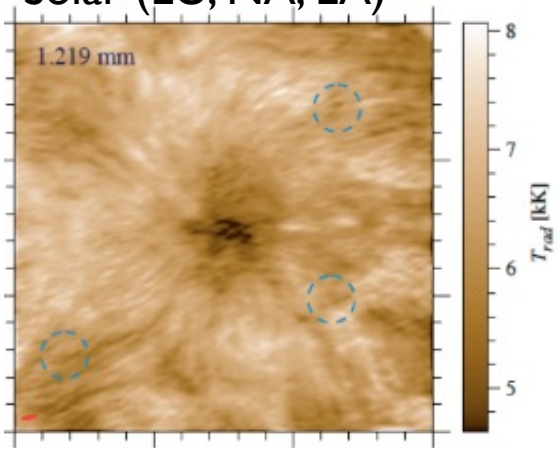
- For NA - NRAO/NA ALMA runs the process: issuing open calls for proposals to the NA community that are independently refereed by (non-NRAO) community members. NSF consents to down-selections.
  - The NA ALMA Development Partnership (includes US & Canada) is separate from the NA ALMA Operations Partnership (includes US, Canada, and ASIAA Taiwan)
    - The NRC contribution is @7.25%
  - NA has spent about $15M on projects since its inception
  - There have been 11 NA-led Projects and 44 NA Studies completed so far, see:

    https://science.nrao.edu/facilities/alma/science_sustainability/alma-develop-history
  - 4 additional projects are in progress or awaiting final ALMA Board approval

ALMA Development Achievements:

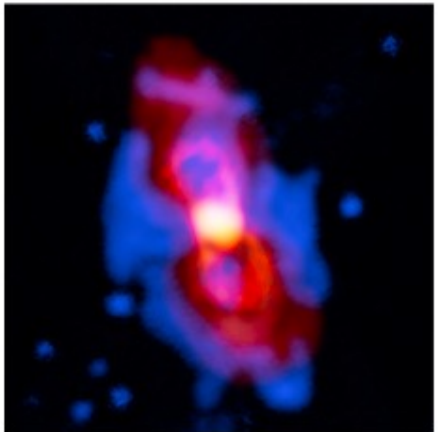
Focused so far on capabilities descoped during ALMA construction due to cost

Solar (EU, NA, EA)



ALMA 1.2mm brightness temperature image of a sunspot (Jafarzadeh 2019).

Band 5 (EU, NA)



Remains of a double-star collision in ^{27}AlF and 1.5 mm dust continuum (Kaminski 2018).

VLBI (NA)

Image of the event horizon of the black hole at the center of M87 (EHT Collaboration 2019). Initiative known as the ALMA Phasing Project (APP).

- A wide range of software initiatives (ADMIT, CARTA, Ari-L, and many more)

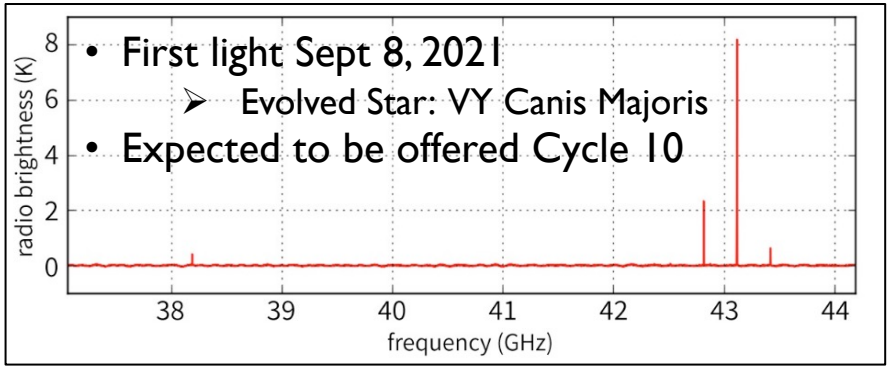
ALMA Development Coming Soon:

❖ ALMA Phasing Project Phase 2 & 3 (NA)

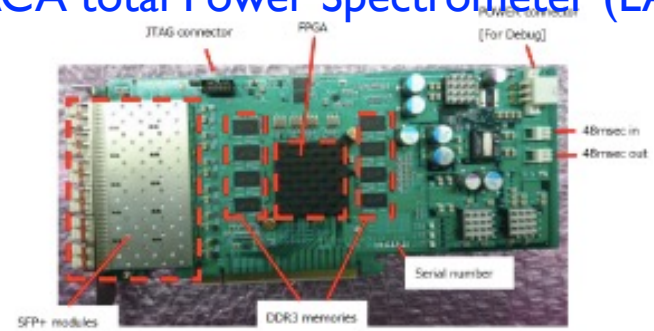
- Improve sensitivity, implement Bands 3, 5 spectral line VLBI, Bands 1 & 7 continuum
- Offering new capabilities Cycle 9 & 10

❖ ALMA Band 1 (EA, NA, EU, CL)

- NA building LNAs and LOs



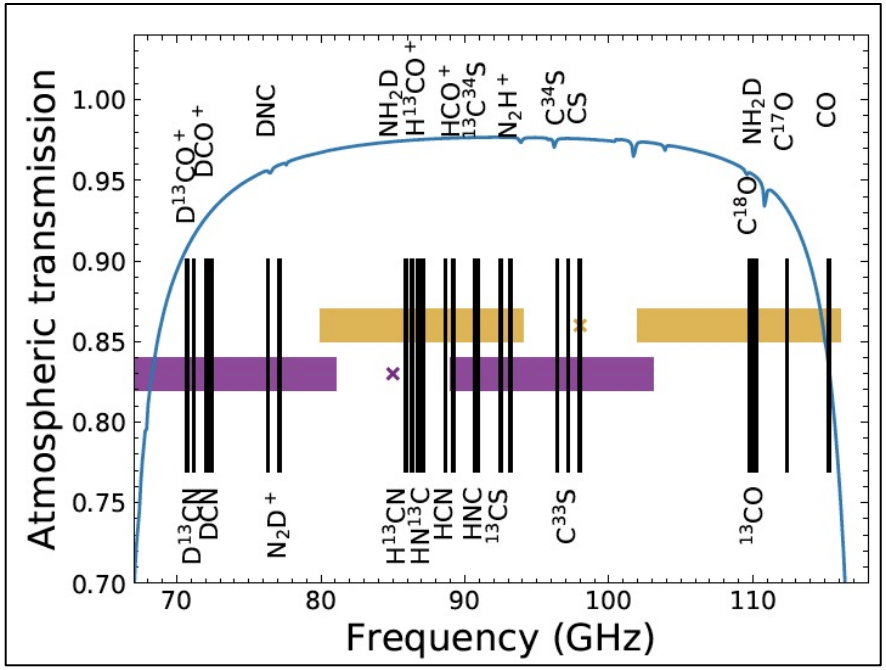
❖ ACA total Power Spectrometer (EA)



- Improved linearity, dynamic range, and spectral response
- Commissioning underway, expect Cycle 10 availability

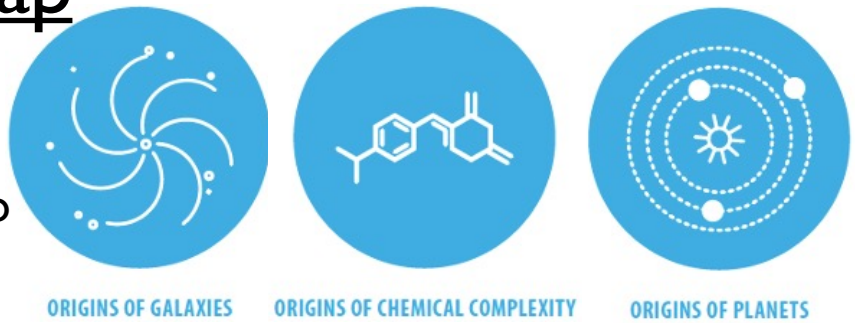
❖ ALMA Band 2 (EU, EA)

- RF Range: 67 – 116 GHz
- 2SB with IF Bandwidth
  - Minimum: 4 – 16 GHz
  - Goal: 4 – 18 GHz
- CDR for Phase 1 held May 2022 (ongoing resolution of deficiencies)
- Phase 2 Manufacturing & Integration expected 2023-2025



ALMA Development Roadmap

- Published 2018 after several years investigation
- Three new key science "themes"
- All require <u>increased bandwidth and sensitivity</u> to keep ALMA at forefront of scientific discovery



<u>Highest near-term priorities this decade</u> (envelope of existing development funding):

1. Increase receiver IF bandwidth and sensitivity
2. Increase the digital sensitivity and widen the correlated bandwidth by at least a factor of 2

=> ALMA2030 Wideband Sensitivity Upgrade (WSU)

- Working Groups convened 2019-2022 to recommend specifications/requirements in major technical areas: FE/Digitizers, Back-end/Data Transport, 2nd Generation Correlator; each sponsoring a Workshop to solicit community feedback
- <u>Ongoing now</u>: Internal review of "WSU Conceptual System Design Description"
- <u>September 2022</u>: External WSU System Requirements Review
- **Goal for completion by ~2030 (upgrade of some receiver bands will come later)**

3. Improve usability of ALMA Science Archive and data products
   - Diverse efforts on both archive and tools across partnership

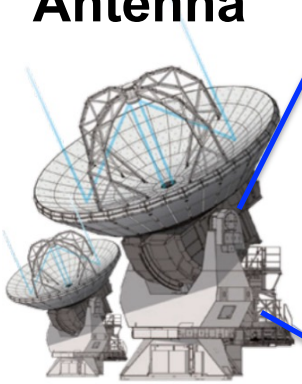
WSU Overview & Capabilities

Wideband Sensitivity Upgrade (WSU)

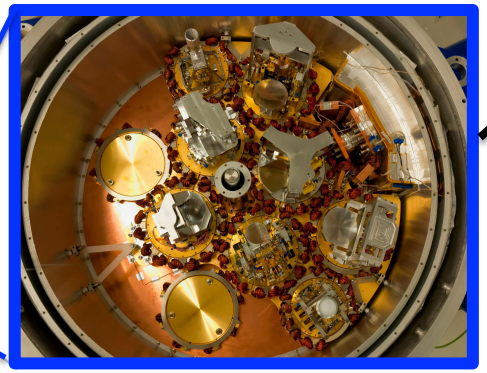
New or Upgraded Components are in blue

Goal: Expand system bandwidth by at least 2x with improved sensitivity

Antenna



Front Ends (Receivers)



Back Ends

- IF Switches & Anti-aliasing filters
- Digitizers & Digital Signal Processing
- Digital Transmission System

Existing Antenna to AOS Fibers

Array Operations Building at 5,000m

New Fiber

Operations Support Facility at 3,000m

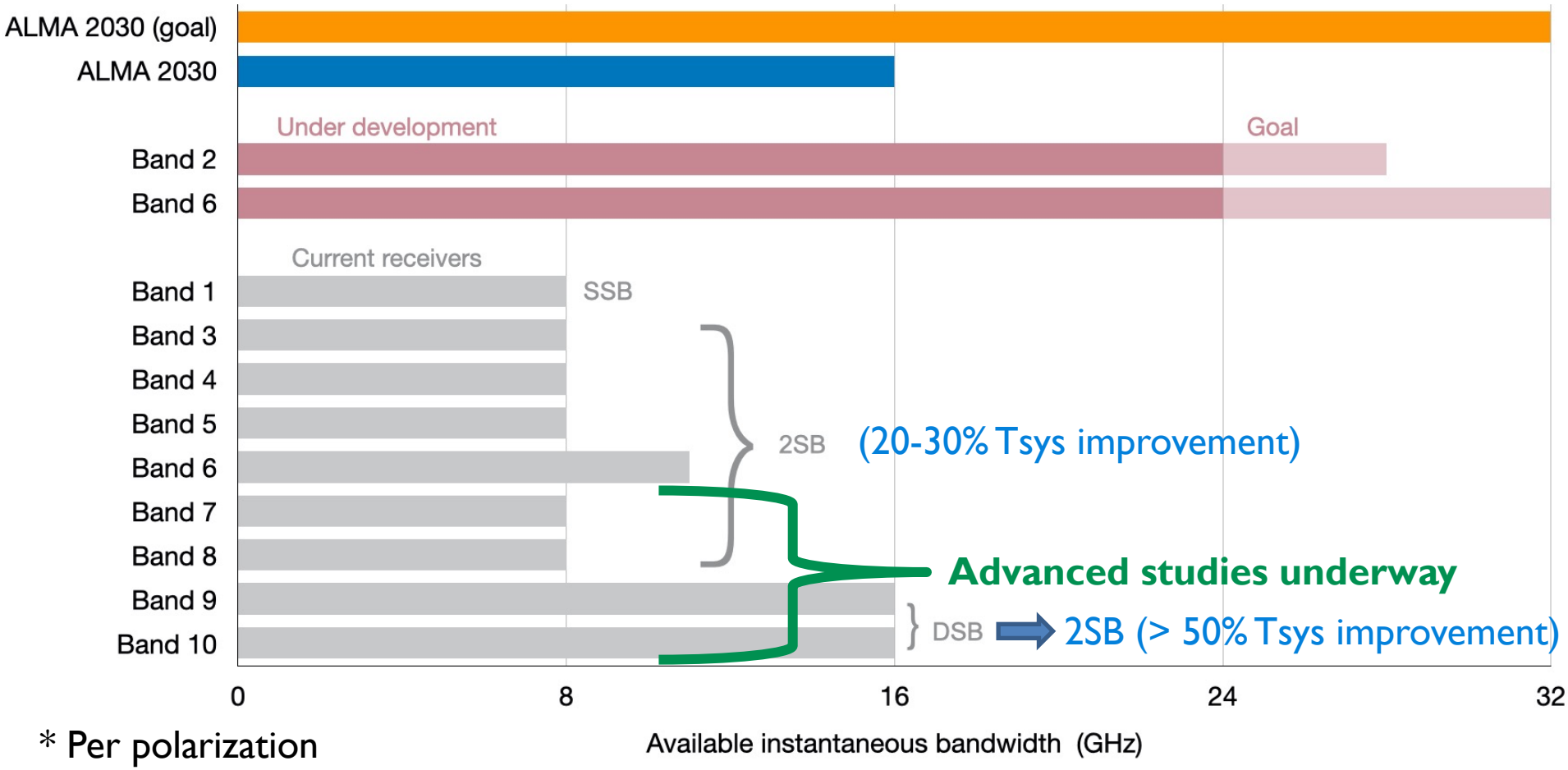
2nd Generation Correlator & Upgraded ACAS in new OSF Correlator Room

CONTROL, TelCal, Scheduling, OT, Archive, Pipeline

Wideband Sensitivity Upgrade: Overview

- **Available receiver bandwidth**
- Correlated bandwidth
- Observing speed

Factor of 2-4 increase in the total (across sidebands) available IF bandwidth.



* Per polarization

Wideband Sensitivity Upgrade: Overview

- Available receiver bandwidth
- **Correlated bandwidth**
- Observing speed

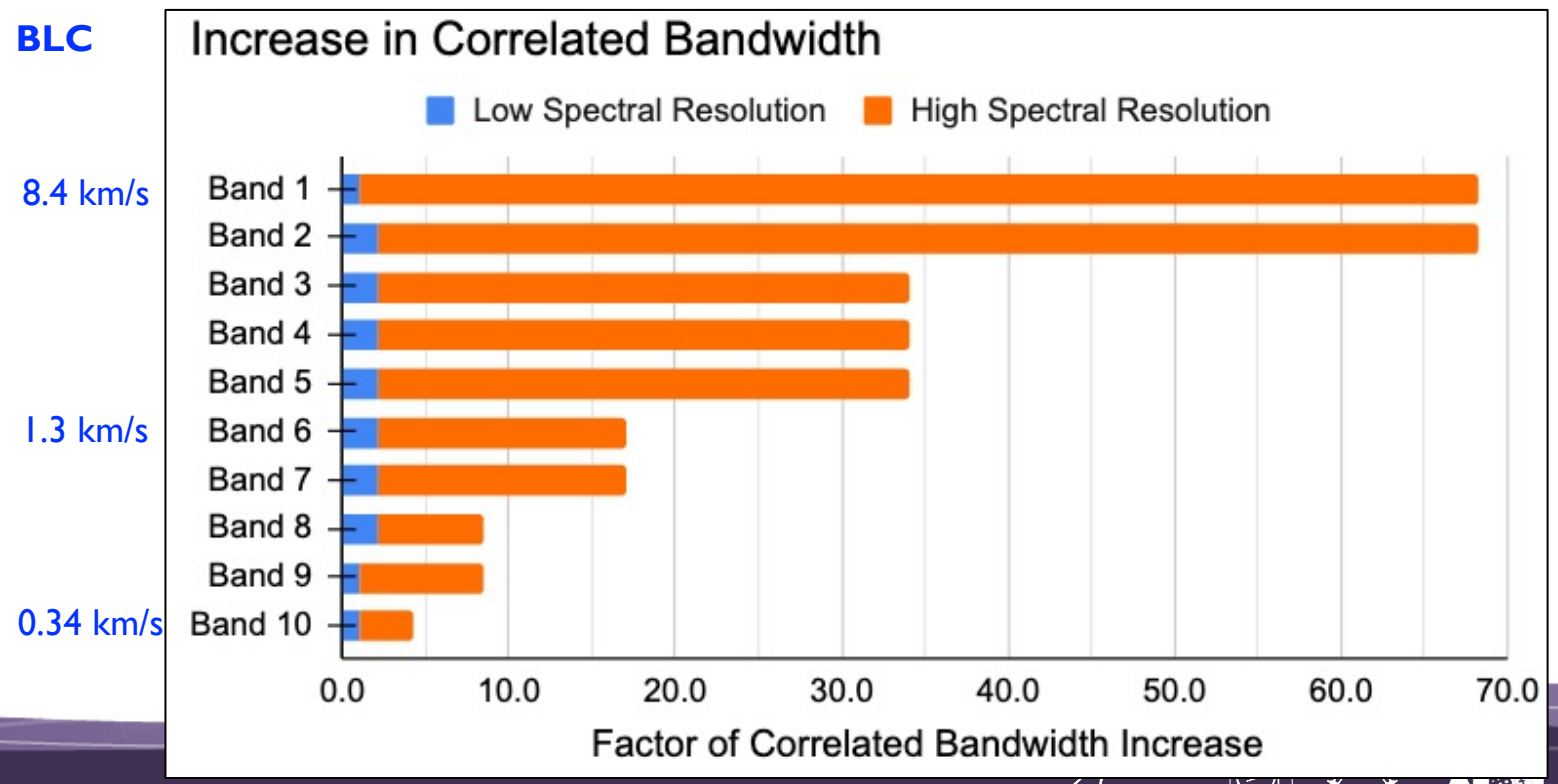
The ALMA2030 WSU requirements recommend:

Spectral resolution ≤0.2 km/s at full correlated BW per polarization at f ≥ 35 GHz (**goal ≤0.1 km/s**) so that it will very rarely be necessary to give up BW for spectral resolution in future

- "High spectral resolution" defined as 0.1-0.2 km/s (cannot presently be done at any ALMA Band)
- "Low spectral resolution" defined by what BLC can do at full correlated BW

37% of Cycle 8 SBs had to give up correlated bandwidth for spectral resolution

Considering only the "Circumstellar Disk" and "Star Formation, ISM, Astrochemistry" science categories, the number grows to 75%



Wideband Sensitivity Upgrade: Overview

- Available receiver bandwidth
- Correlated bandwidth
- **Observing speed**

Example: Increase in Band 6v2 observing speed after WSU

Observing mode	Increase in speed over current system*
Continuum	4.8x (with goal of 9.6x)
Spectral line	2.25-4.7x

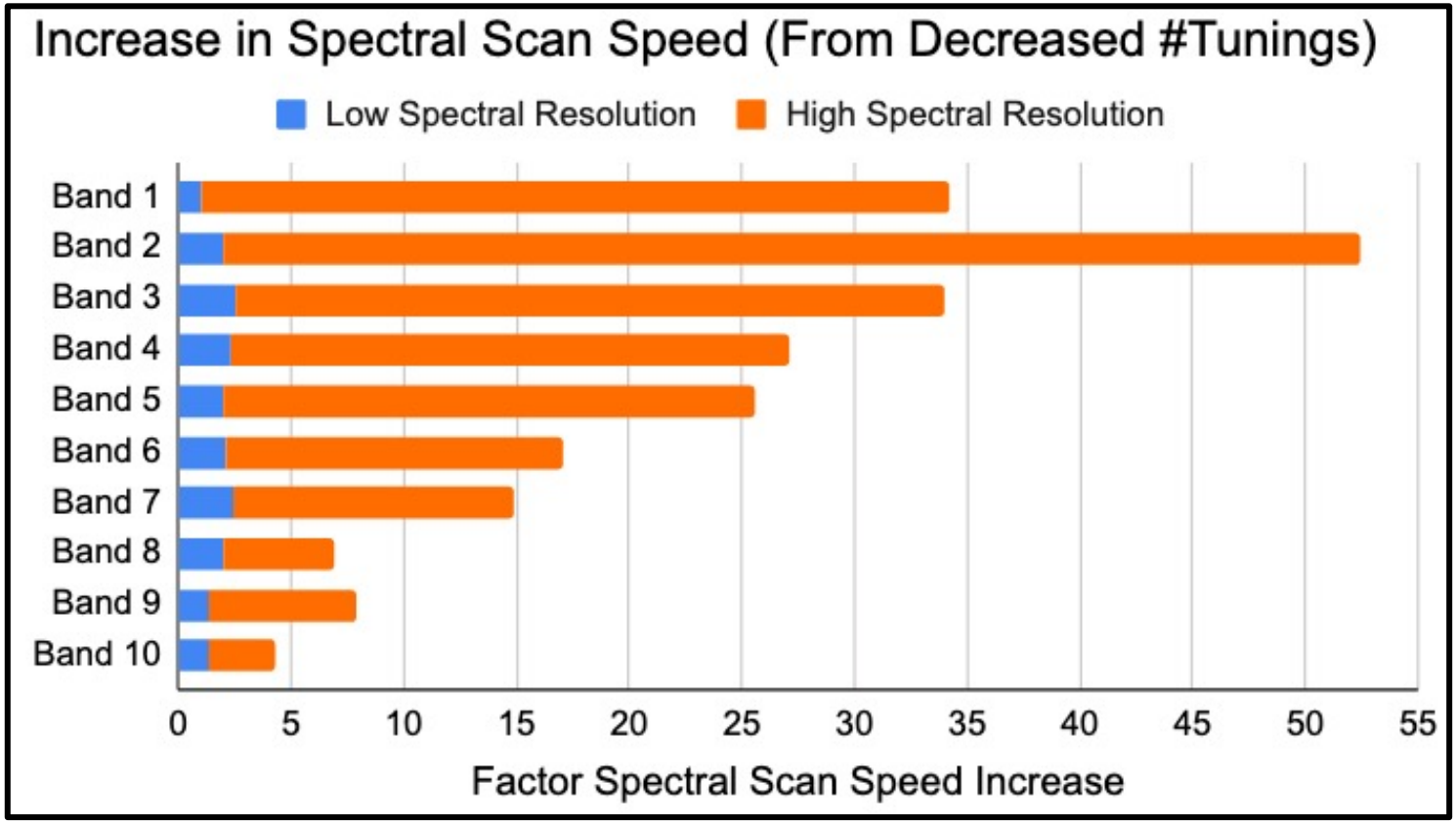
* To reach same sensitivity as current system with single tuning

Increased observing speed results from:

- Improved receiver temperature
- Increased digital efficiency (applies to all bands even before they are upgraded)
  - All digital processing stages ≥ 6-bits
  - Factor 1.2 noise improvement, 1.44 in speed
- Wider bandwidth 2x, goal 4x (continuum, spectral grasp)

More BW & Channels = Efficient Spectral Scans

(Super efficient at high spectral resolution)



Tunings to cover band 2x BW WSU
2
4
2
3
4
4
7
9
8
10

With 2x BW AT.CSP, with 8 GHz per sideband (per pol) of science quality, there will be no gaps

=> The ability to <u>efficiently</u> do spectral scans at high spectral resolution will be unprecedented.

Summary: ALMA2030 WSU will benefit all observations

Capability	Improvement
Instantaneous Bandwidth	• Factor of 2 to 4 increase in the *available* instantaneous bandwidth (8 to 16 GHz per sideband per polarization) compared to existing receivers.
Correlated bandwidth	• Factor of 4 to 68 increase in the *correlated* bandwidth at high spectral resolution (0.1-0.2 km s^{-1}), with larger gains in the lower frequency bands. • Observers will no longer need to trade off high spectral resolution for bandwidth.
Spectral scan speed	• Increase of least a factor of 2, and up to a factor of 4 (Band 10) to 54 (Band 2) for spectral resolution $0.1 - 0.2$ km s^{-1}.
Spectral line imaging speed	• Increased spectral line speed from lower receiver noise temperatures (~20-30%), improved digital efficiency (~20%), and upgrade to 2SB mixers (Bands 9 and 10 only). • Net gain in spectral line imaging speed ~ of 2.
Continuum imaging speed	• Increase by at least a factor of 3.1 with 2× bandwidth increase and at least 6.1× for 4× bandwidth, including digital efficiency improvements. • Additional gains from improved receiver temperatures.
Ultra-high spectral resolution	• Provide for the first time unique access to ultra-high spectral resolution observations – better than 0.01 km s^{-1} at all ALMA frequencies.

Significant challenges remain:

- Time alignment of upgrades and detailed plan for deployment that minimizes impact to science operations
- Downstream subsystems: high data rates impacts on archiving, data processing, data analysis

Hope to complete digital upgrades and and several receiver bands by late this decade

Priorities for FY2023 Call for Development Studies

Of particular interest to the NA ALMA Partnership for the FY2023 Call are **Studies** that aim to explore improvements to:

- ALMA data processing and/or data analysis for the wider bandwidth data that will be produced by the WSU (~two orders of magnitude more channels will be available for high spectral resolution observations)
- Receiver sensitivity at wide IF bandwidth
- The ALMA Science Archive / data mining
- Longer baseline lengths (2-3x) in the form of a detailed science case (including simulations) that demonstrates the potential for significant science gains. Any ALMA science topic is welcome, apart from dust in protoplanetary disks which have already been studied

Additionally, compelling Studies on any ALMA-related development topic are welcome. Funded studies and projects from previous calls are summarized including their abstracts and final reports:
https://science.nrao.edu/facilities/alma/science_sustainability/alma-develop-history

See next talk on process and see the Call website at
https://science.nrao.edu/facilities/alma/science_sustainability/na-alma-develpment-fy2023-call-for-study-proposals

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