Development of Total Power GPU Spectrometer (TPGS) for ALMA Wideband Sensitivity Upgrade (WSU)

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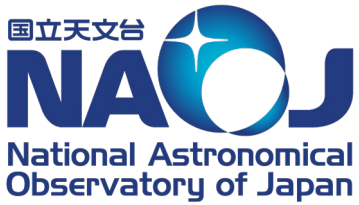
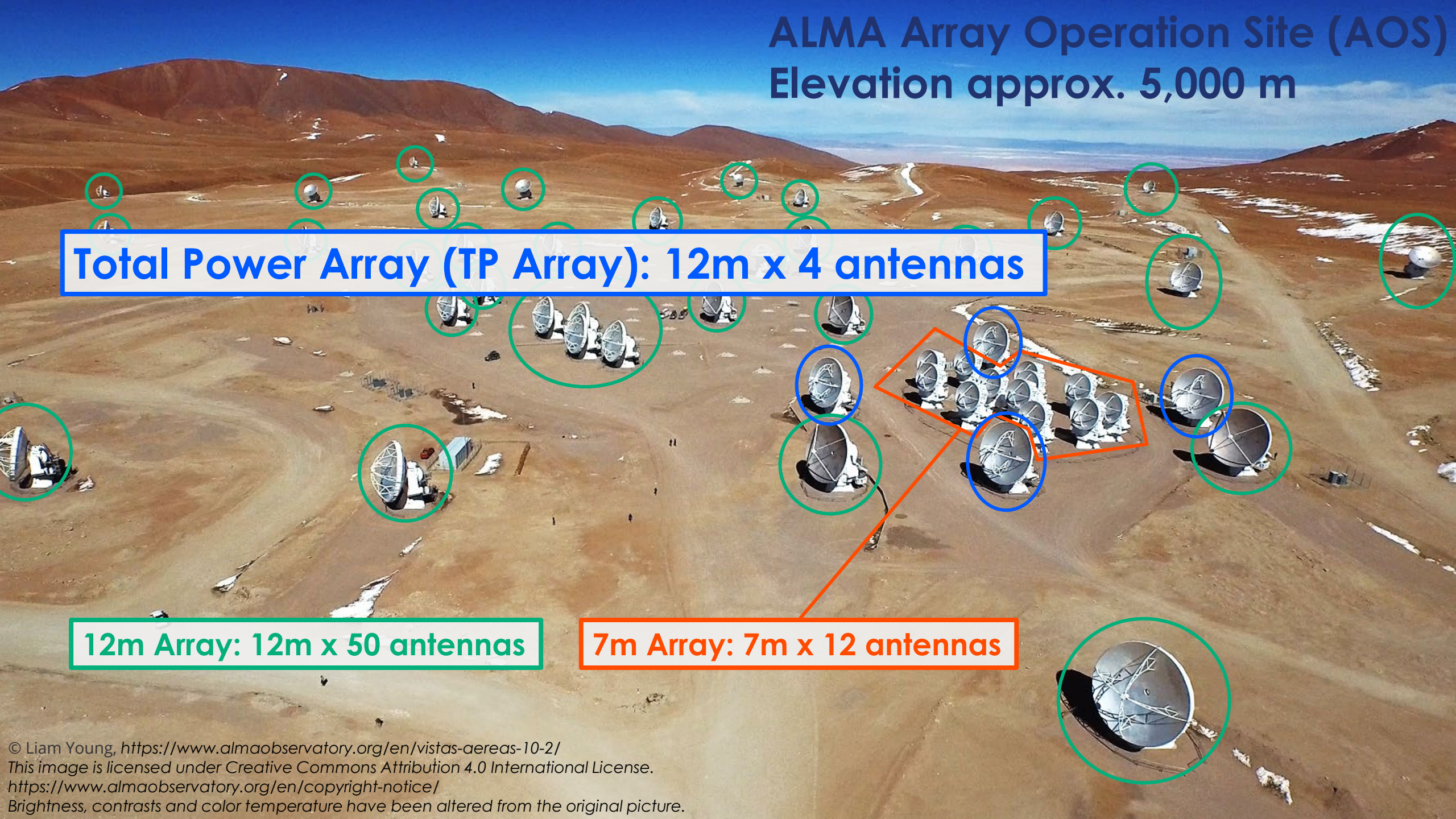
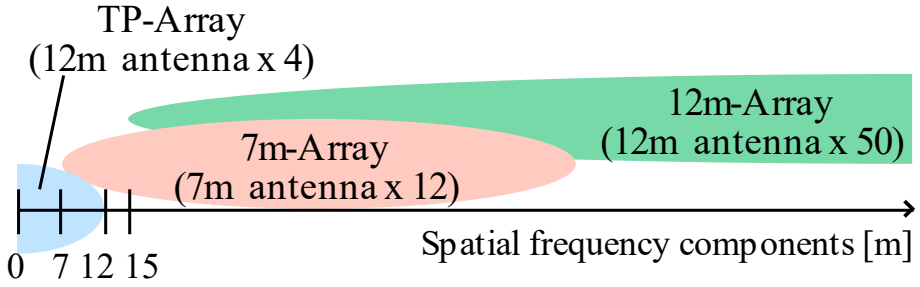
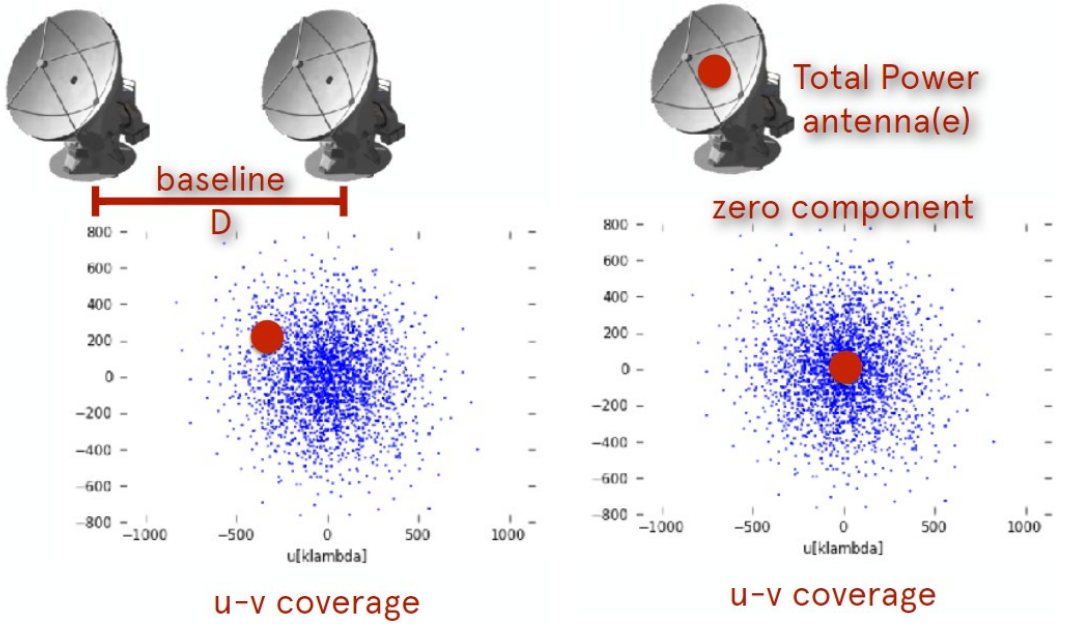






Reference:
Takeshi Kamazaki et al., Digital Spectro-Correlator System for the Atacama Compact Array of the Atacama Large Millimeter/Submillimeter Array,
Publications of the Astronomical Society of Japan, Volume 64, Issue 2, 25 April 2012, 29



Images: Wedemeyer et al., Solar observations with ALMA
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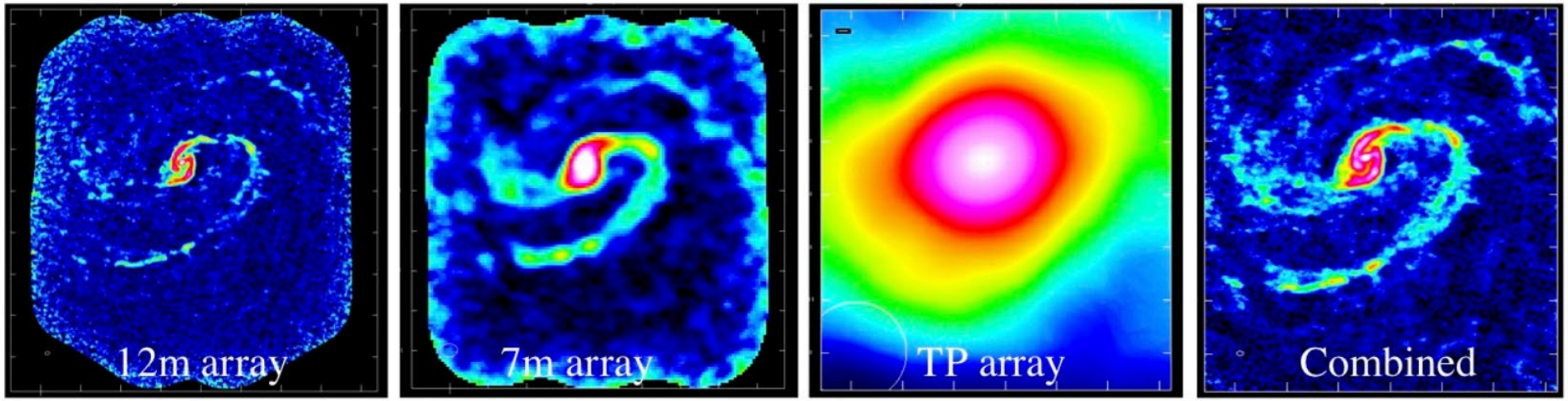
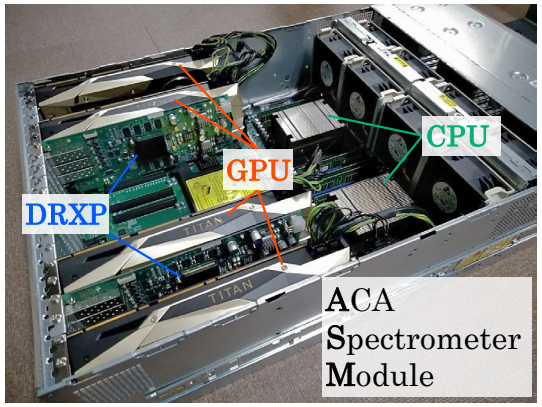


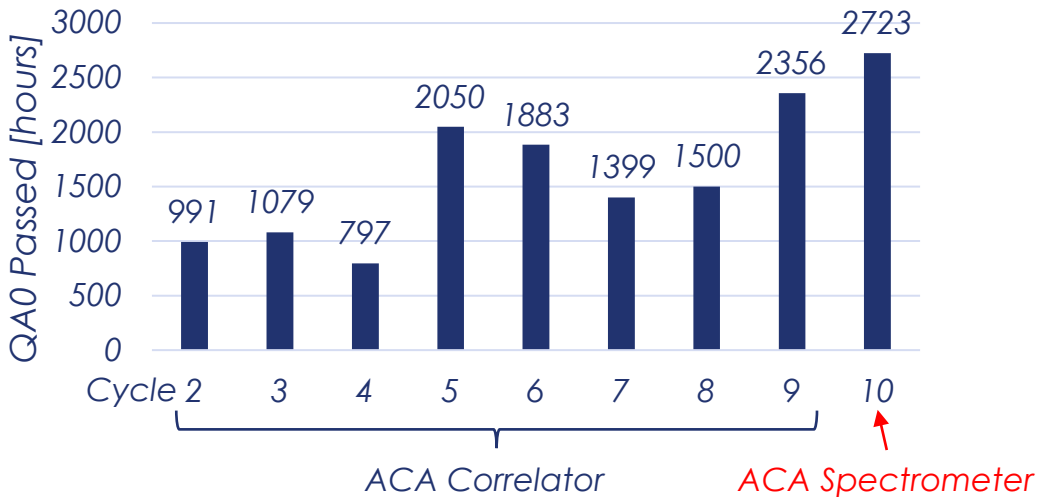
https://safe.nrao.edu/wiki/pub/ALMA/10Jan17Agenda/ACA_Total_Power_Spectrometer_V2.pdf
https://www2.nao.ac.jp/~eaarc/DATARED/presentation_2020Jan/DataReductionTutorial2020_Image_combination_Miyamoto.pdf
https://casaguides.nrao.edu/index.php/M100_Band3_Combine_4.3

ACA Spectrometer
Current Spectrometer for Total Power Array



NVIDIA TITAN V
(16 GPUs in total)

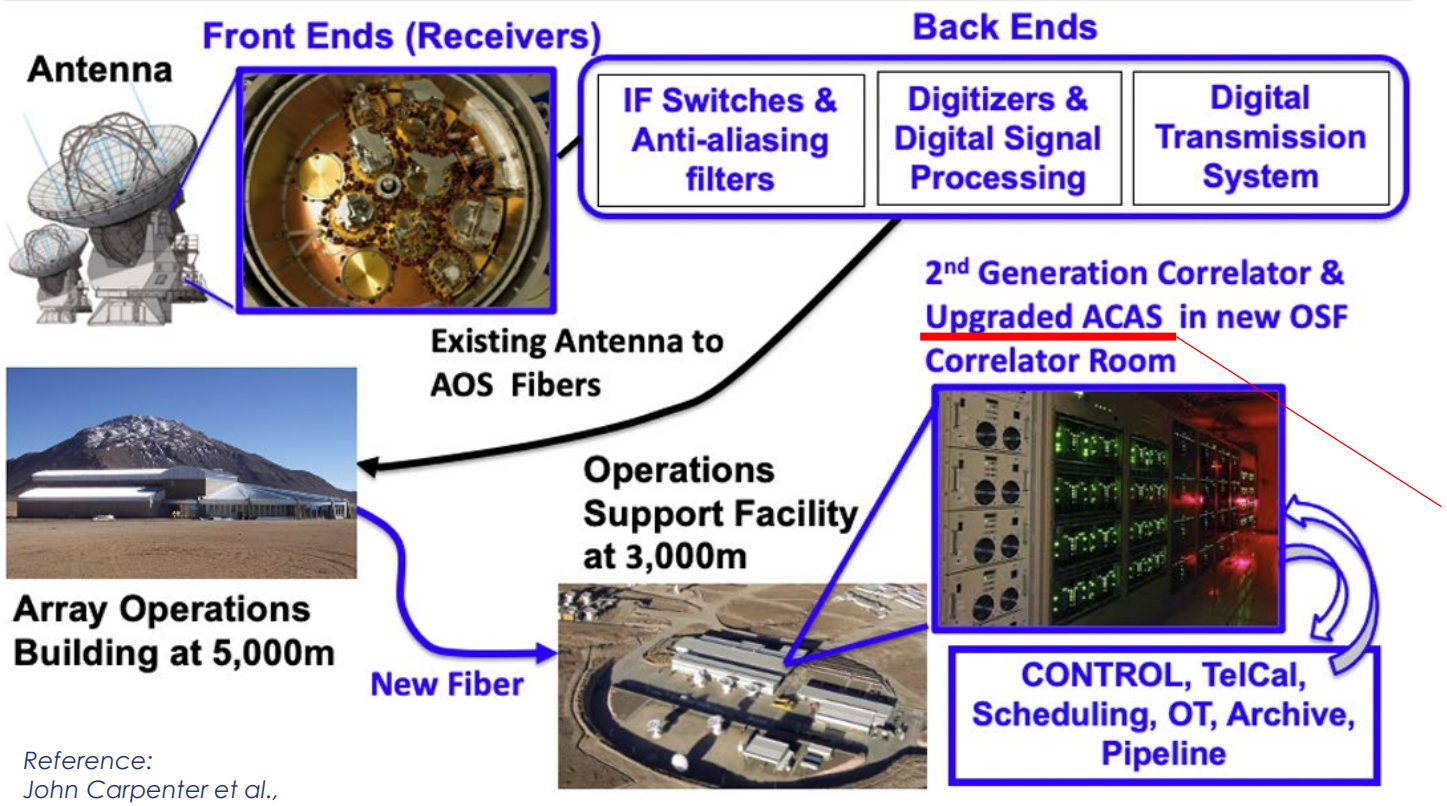
TP Array



- *Developed by KASI and NAOJ using GPU technologies.*
  - *Other ALMA Correlators were using ASIC and/or FPGA.*
- *Started science operation in October 2022 (Cycle 10).*
  - *One cycle = 1 year starting from Oct*
- *TP array achieved the highest observing time in the first cycle!* https://www.almaobservatory.org/en/announcements/alma-achieved-record-number-of-observing-hours-in-cycle-10/
- *Received NAOJ DG Award!* https://alma-telescope.jp/en/news/dgaward-202503.html
- *Will be replaced by Total Power GPU Spectrometer (TPGS) in the Wideband Sensitivity Upgrade (WSU) era.*

Wideband Sensitivity Upgrade (WSU)

Available instantaneous bandwidth: factor of 2 to 4 increase (8 GHz to 16 - 32 GHz)
Correlated bandwidth: factor of 4 to 68 increase at high spectral resolution (e.g. 0.1 km/s).
Observing speed: 2.2 – 4.7 times faster for spectral lines, 4.8 times faster for continuum (Band 6v2)



New components or components that will be upgraded are in blue.

Many major components in ALMA will be replaced or upgraded.

TPGS will be installed in OSF, not AOS.

Reference:
John Carpenter et al.,
The ALMA2030 Wideband Sensitivity Upgrade
ALMA Memo 621 (https://library.nrao.edu/public/memos/alma/main/memo621.pdf)

TPGS Key Requirements

Total Power GPU Spectrometer (TPGS) will meet the ALMA Scientific Specifications and Requirements Updated for the ALMA2030 Wideband Sensitivity Upgrade (WSU). Major requirements are shown below.

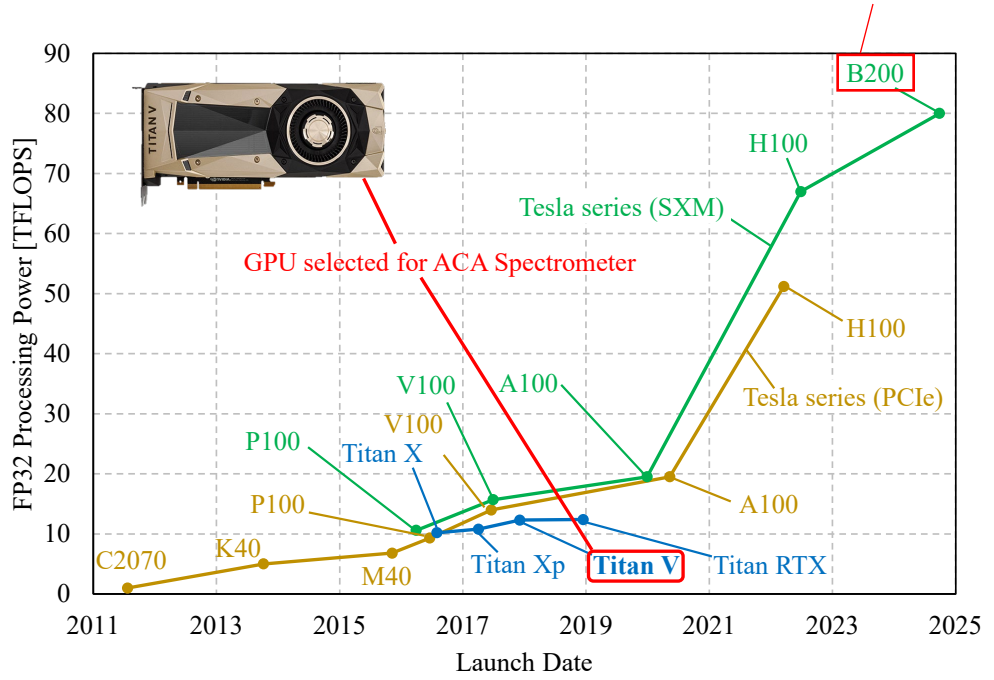
Process data from up to **four antennas**.
Allow observers to **combine images from ATAC and TPGS**. *(ATAC: Advanced Technology ALMA Correlator)*
Shortest integration time of 96 ms at the frequency resolution of 13.5 kHz for a science bandwidth of **32 GHz per polarization** *(x4 IF).*
Shortest integration time of 16 ms *at the coarsest resolution of 5.184 MHz.*
Zoom mode to achieve **the finest channel width of 0.844 kHz** *with less science bandwidth.*
15000:1 *spectral dynamic range.*
0.995 *or better digital efficiency.*
Full polarization *products.*
Interferometric observations *for system calibrations.*

TPGS Key Technical Specifications and Technology Choices

Items	ACA Spectrometer	TPGS
Sampling rate and number of inputs per antenna	*4 Gsps x 4 BB x 2 pol*	*40 Gsps x 2 SB x 2 pol*
Number of bits per sample	*3 bits*	*6 bits*
Total input data rate	*384 Gbps*	*3.84 Tbps*
Maximum correlator bandwidth (CBW) per pol	*8 GHz*	*32 GHz*
Channel width at max CBW (full pol)	*976 kHz*	*13.5 kHz*
Finest channel width (full pol)	*61.04 kHz*	*0.844 kHz*

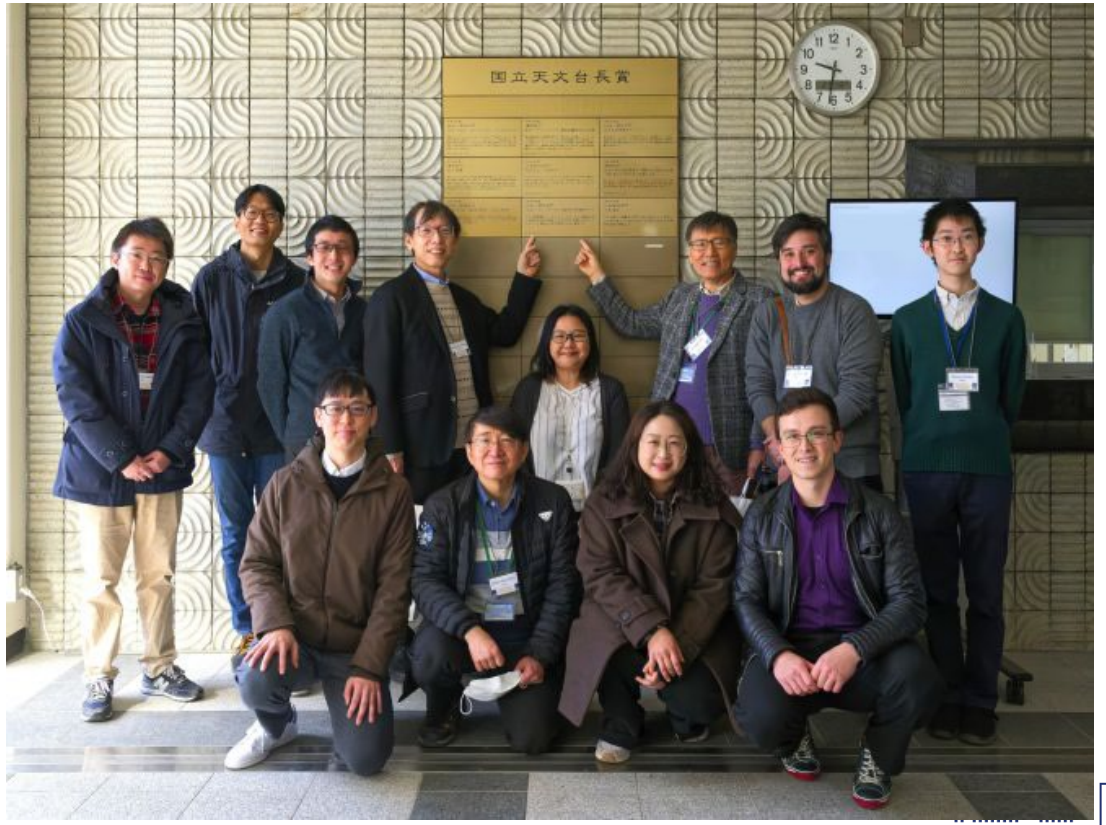
Fully utilize up-to-date GPU and 400 GbE technologies to achieve the high input data rate, the high bandwidth, and the fine channel resolutions.

TPGS will use Blackwell GPUs or beyond.

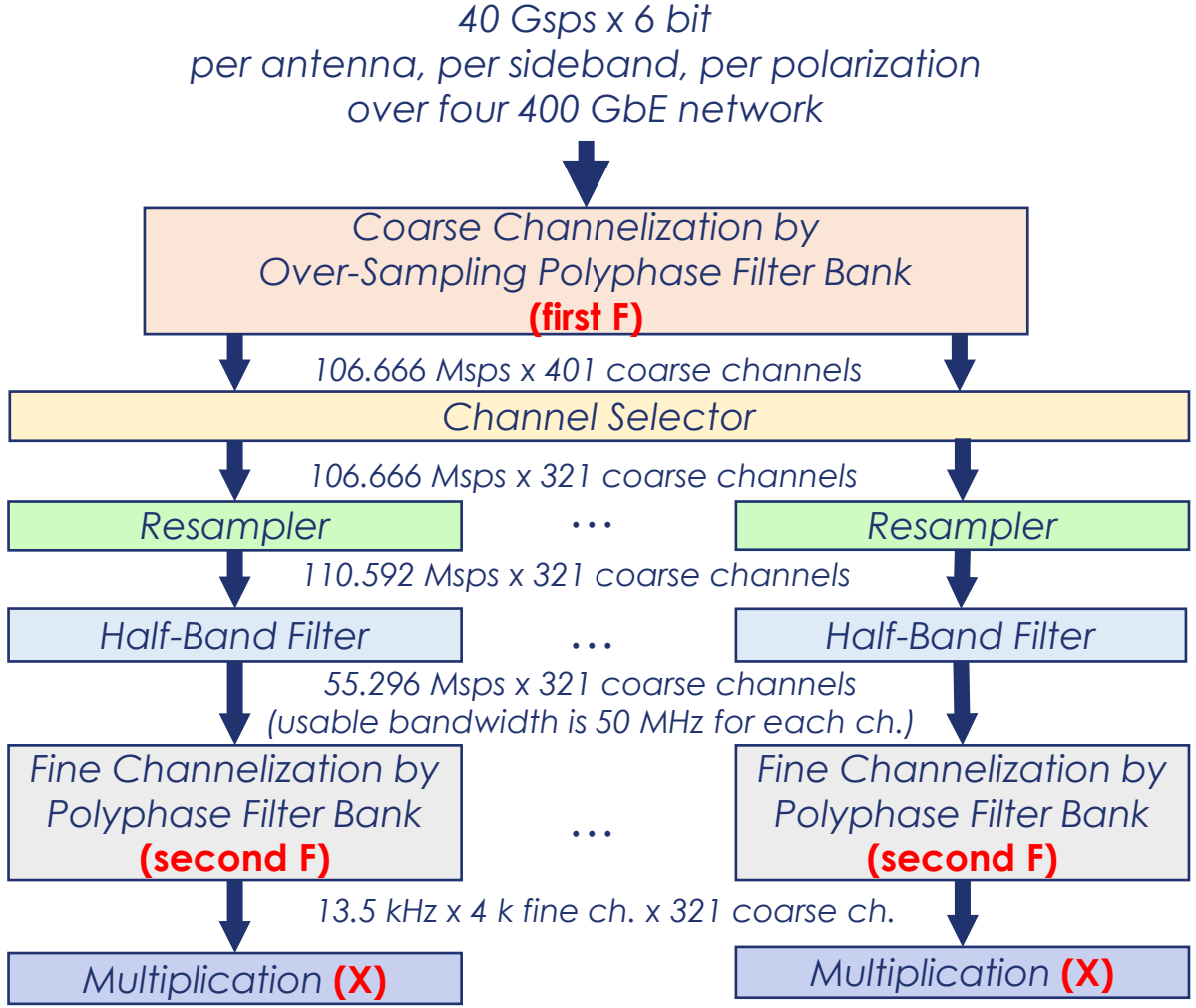


Project Team

- *Joint team of researchers & engineers from Korea Astronomy and Space Science Institute (KASI) and National Astronomical Observatory of Japan (NAOJ).*
  - *The same team as ACA Spectrometer development.*
- *Project management, engineering, software development and administration will be all conducted in-house.*
- *The team passed Conceptual Design Review (CoDR) and Subsystem Requirements Review (SRR) in Nov 2024.*
- *The TPGS project was approved by ALMA Board last week! We are in Preliminary Design Phase now.*



FFX Architecture and Design of Digital Signal Processing

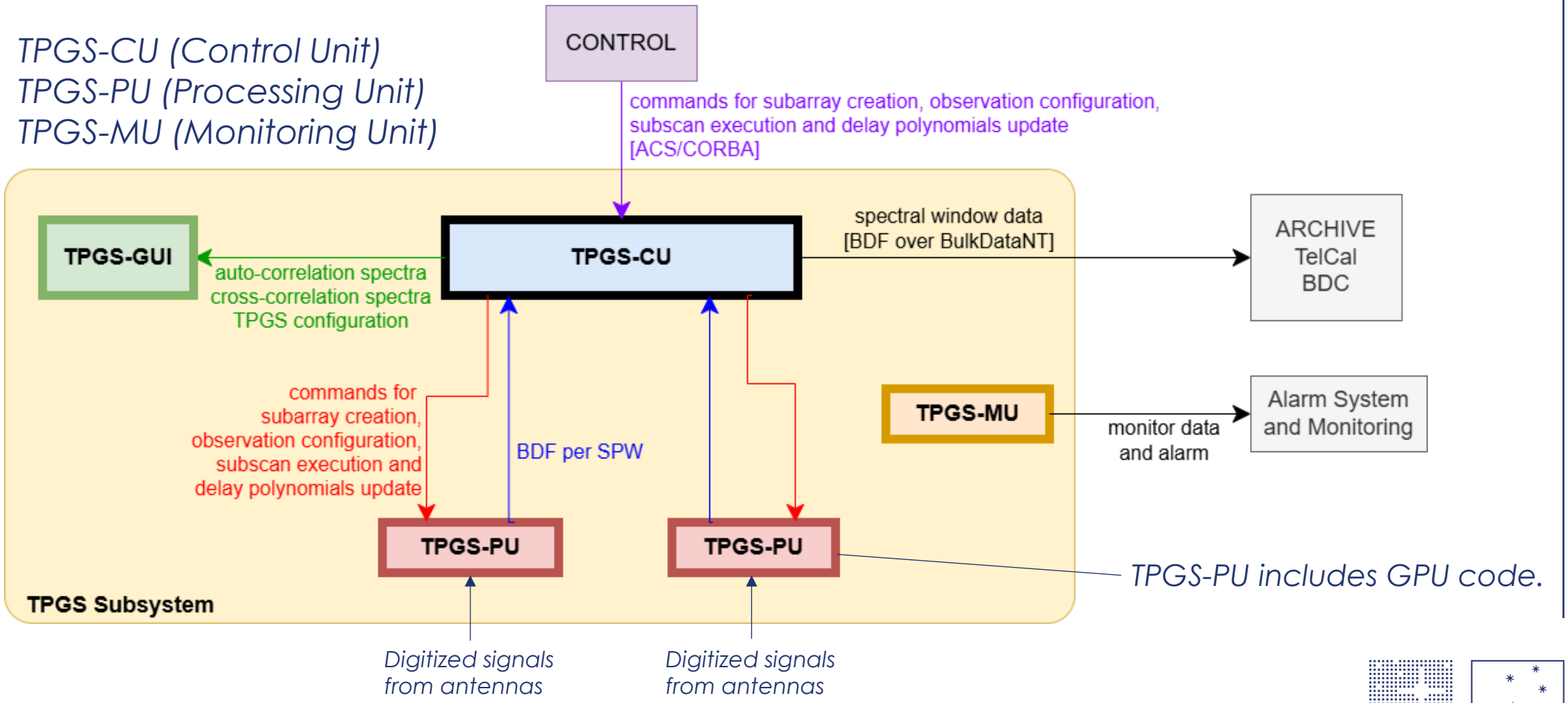


- *Digital signal processing design similar to ATAC (FPGA-based). Our design has been and will be optimized for GPU implementation.*
- *TPGS will use 32-bit floating point calculation.*
- *Use of Polyphase Filter Bank to meet the channel response requirement.*
  - *FFT with a conventional window function cannot fulfill the requirement.*

Note: Design is subject to change.

TPGS Software Architecture

TPGS-CU (Control Unit)
TPGS-PU (Processing Unit)
TPGS-MU (Monitoring Unit)



Note: Design is subject to change.

Major Engineering Challenges

- *Receive high volume of input data (240 Gbps x 2 sideband x 2 polarization x 4 antennas) over 400 GbE.*
  - *Prototyping of data receiver is on-going using DPDK.*
- *Real-time data processing using GPU.*
  - *Prototyping of GPU code is on-going.*
- *A lot of coordination with other subsystems, systems engineers, science operation and many other groups under a tight schedule. Not only TPGS, but many other ALMA subsystems will be upgraded in parallel for WSU.*

Thank you for your attention.