ACA Spectrometer Development and Possibility of a Future ACA Correlator based on GPU Technology

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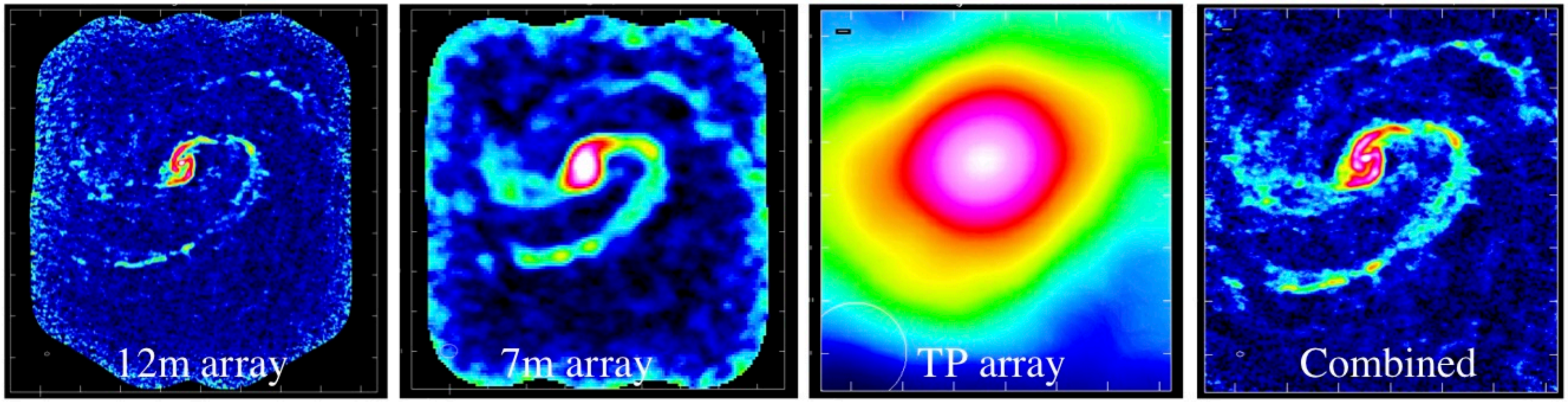
on behalf of ACA Spectrometer Team (led by KASI)

Scientific Motivation

Importance of Total Power



Project Scope

- ✓ Collaboration between KASI (lead) and NAOJ
- ✓ KASI is responsible for designing, developing, procuring, assembling, verifying, shipping and supporting (including warranty repair services) the TP Spectrometer and associated support equipment.
- ✓ NAOJ is responsible for coordination roles with ALMA. NAOJ also contributes on software and hardware developments, system design and interfaces between the TP spectrometer and ALMA.

ACA Spectrometer

Perceived improvements in TP image

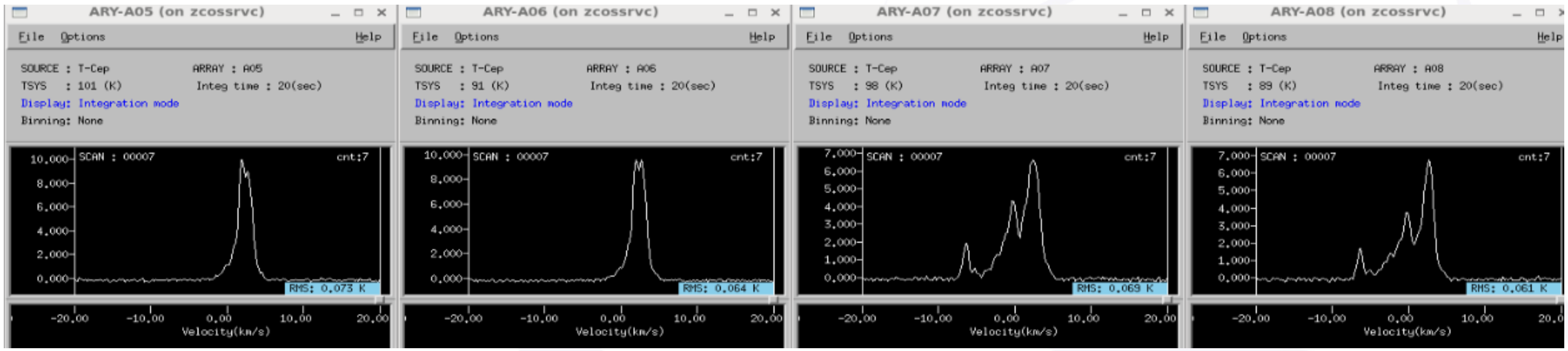
- ✓ Improvements in linearity (and flux accuracy): Current relative flux accuracy ~ 5% w.r.t. 12-m array. High relative flux accuracy between TP and interferometer is important for high fidelity imaging of all extended sources.
- ✓ Improvements in dynamic range: 32-bit FFT/multiplication (Current ACA correlator uses 16-bit)
- ✓ Better spectral response: Signal will be multiplied by a polyphase filter bank before FFT

Expandability

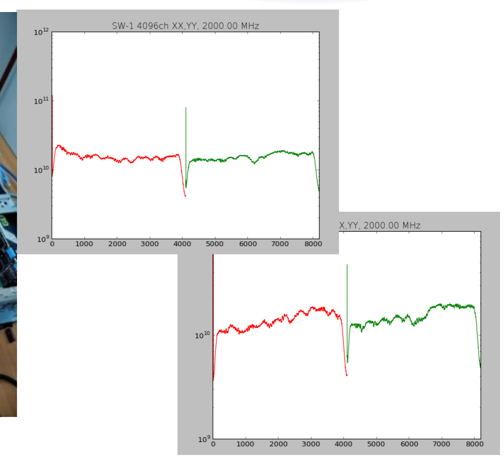
- ✓ Simple architecture and the software nature allows seamless implementation of new capabilities
- ✓ Science case
  - ✓ **Large Bandwidth**: modify DRXP, but software impact is small
  - ✓ **Multi-resolution, multi-band spectra**: currently limited by data transmission in ACA hardware. Easier to implement in GPU.
  - ✓ **Multi-beam**: modify DRXP. Some software impact.

Current Status

- Conceptual Design Phase:
  - Passed PDR on Feb 2017 / Approved by the Board on Nov 2017
- Detailed Design Phase:
  - Nobeyama 45-m test on Dec 2017, June 2018



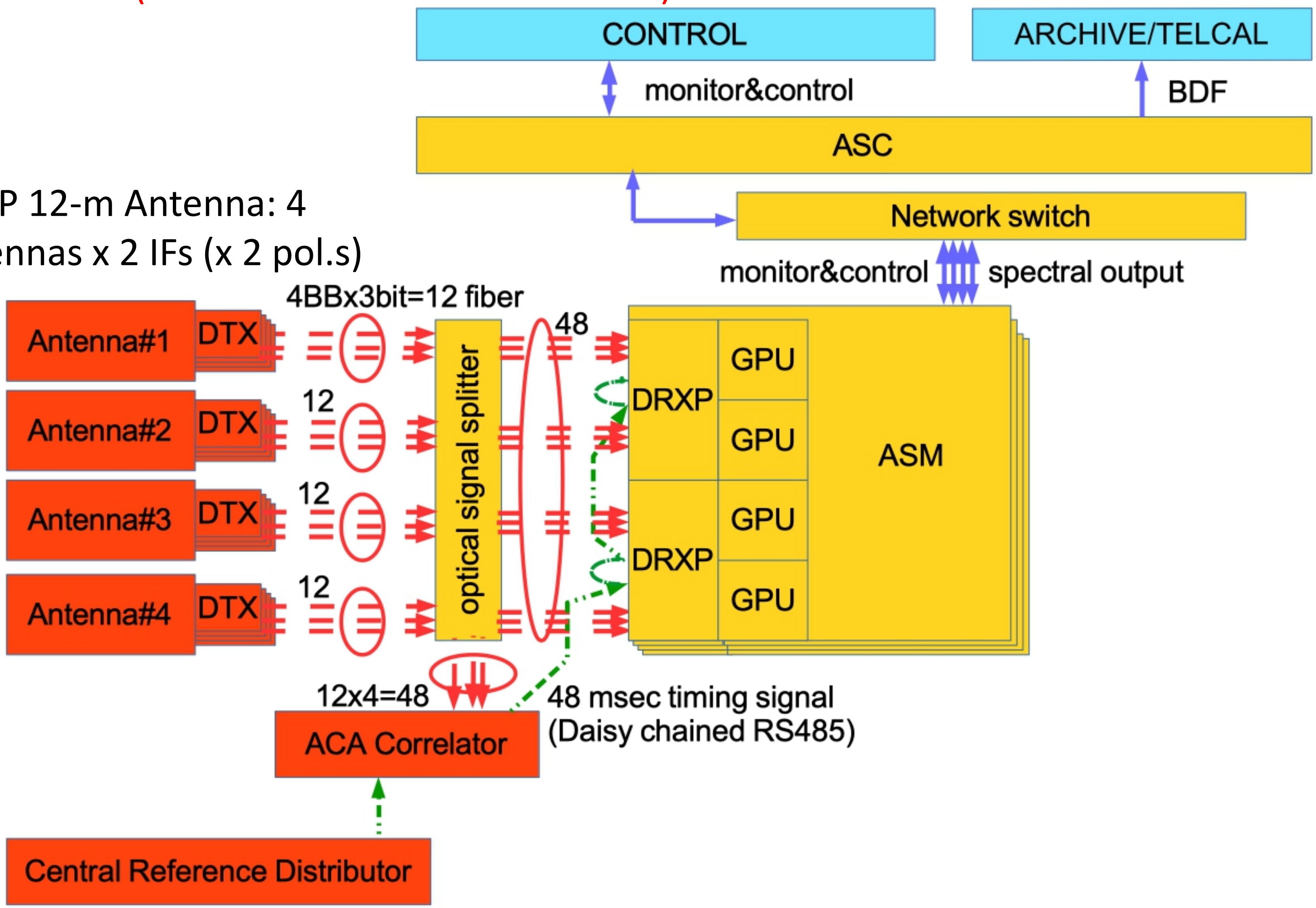
  - AOS on-site test on Feb 2018
  - 1 GPU server / Antenna signal
  - <We are here !!>
  - CDMR on Summer 2019
- Commissioning Phase:
  - Deployment at AOS on Feb 2020
  - Science verification and commissioning from 2020
- Science observations from Cycle 9



ACA Spectrometer

ACA Spectrometer Technical Specifications and Requirements (ALMA-64.00.00.00-0005-A-SPE) is Released

ACA TP 12-m Antenna: 4
4 antennas x 2 IFs (x 2 pol.s)



Nobeyama 45-m Test

- BE: SAM45 = a part of ACA Correlator (Kamazaki et al. 2012)
  - Receive digitized data “ALMA Frame”
  - Calculate spectra
  - 16 IFs (= 8 IFs x 2 pols)

New IF — OCTAD-A — “ALMA Frame” (on optical fibers) — SAM45 ↔ SAM45-LC

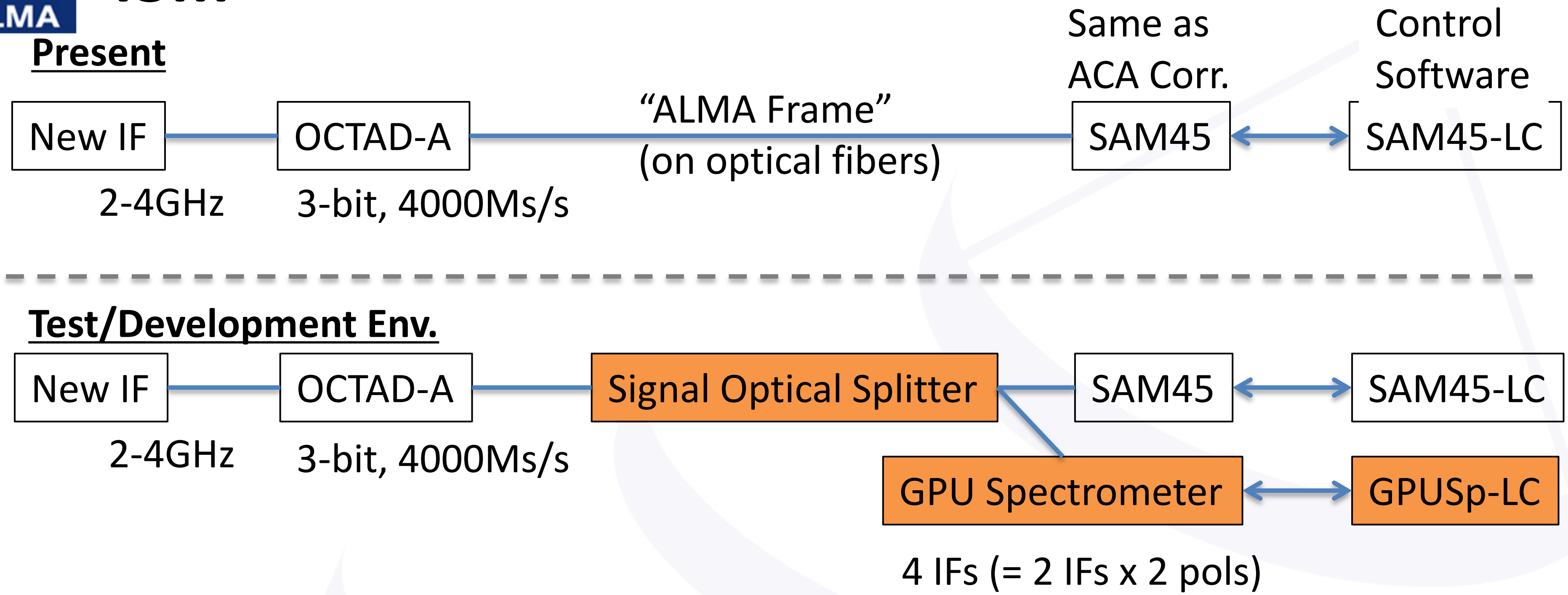
New IF: 2-4GHz

OCTAD-A: 3-bit, 4000Ms/s

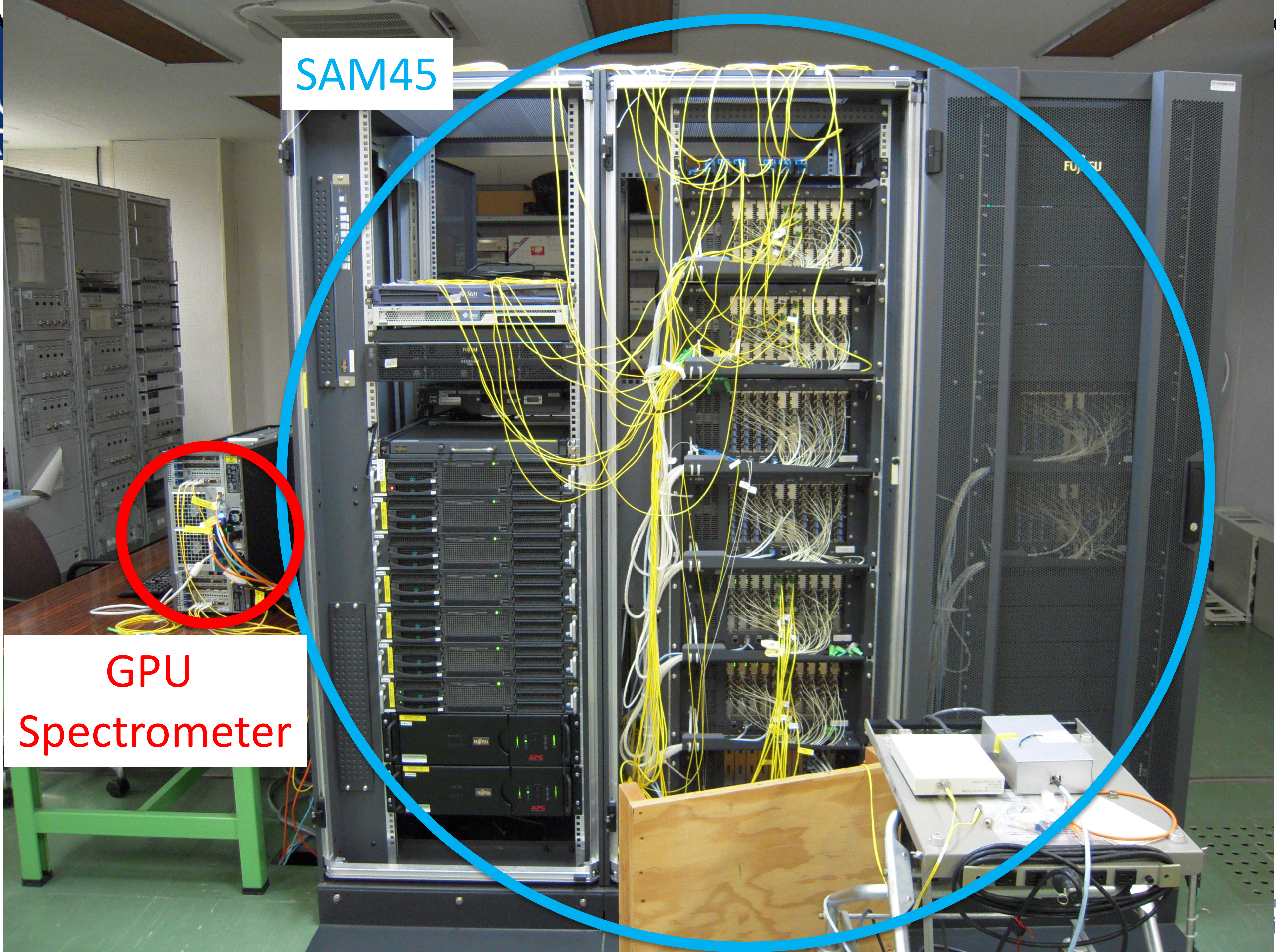
SAM45: Same as ACA Corr.

SAM45-LC: Control Software

45m



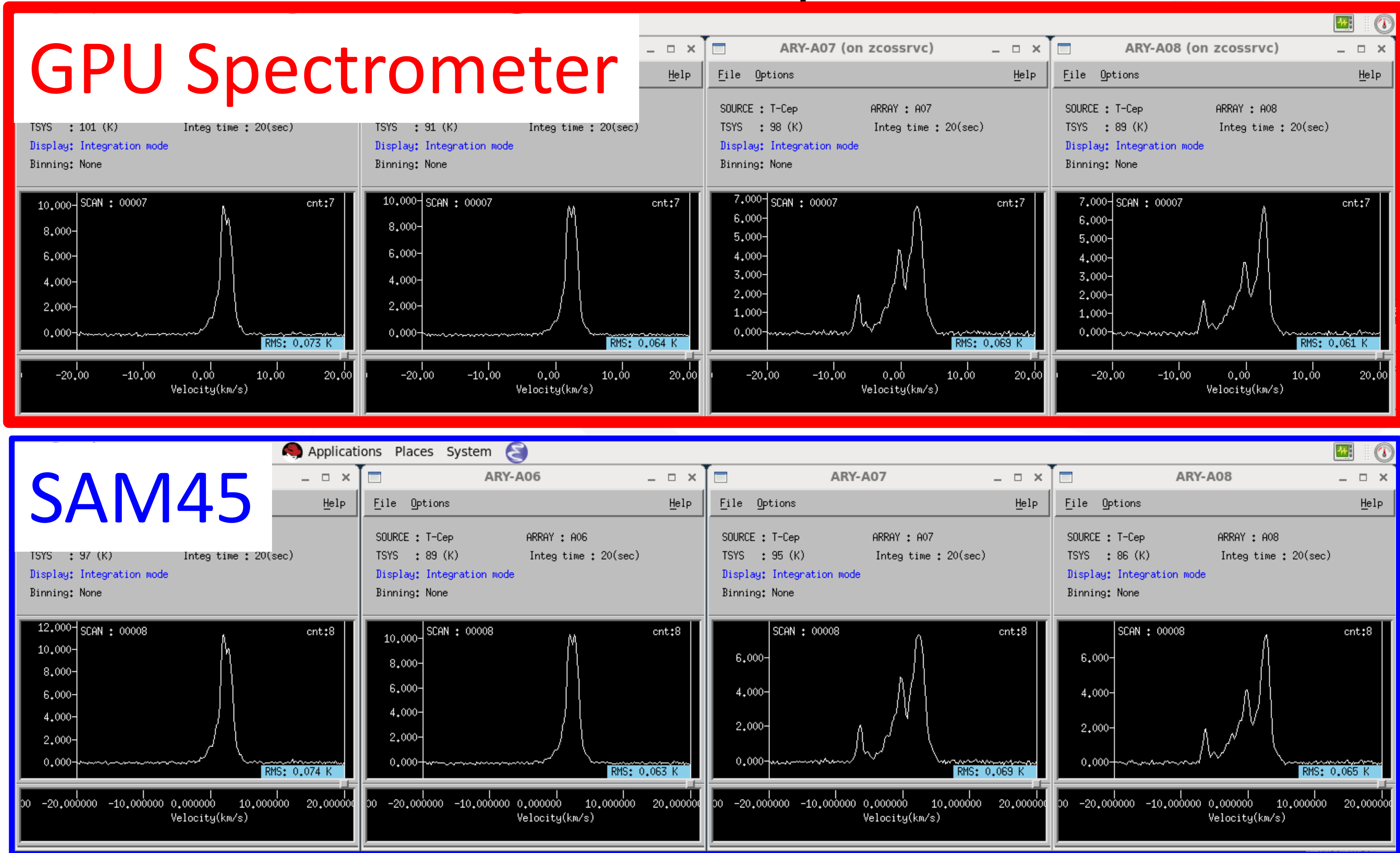
- GPU Spectrometer
  - Server: Dell T630 server
  - GPU card: NVIDIA TITAN Xp (x 2)
  - Proto-type DRXP card (x 2)


SAM45
GPU
Spectrometer

First Spectra with 45-m Telescope

SiO (v=2, J=1-0) @ 42.8GHz

SiO (v=1, J=1-0) @ 43.1GHz



Data taken June 05, 2018

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20180605170746	z4ot0k	5	OTF	100
20180605172244	z4ot1k	1	OTF	100
20180605173752	ircsp0k	5	PoSW	1000
20180605175746	ircsp1k	1	PoSW	1000
20180605181839	ircot0k	5	OTF	100
20180605183417	ircot1k	1	OTF	100

- PoSW / OTF
- Narrow band / Wideband

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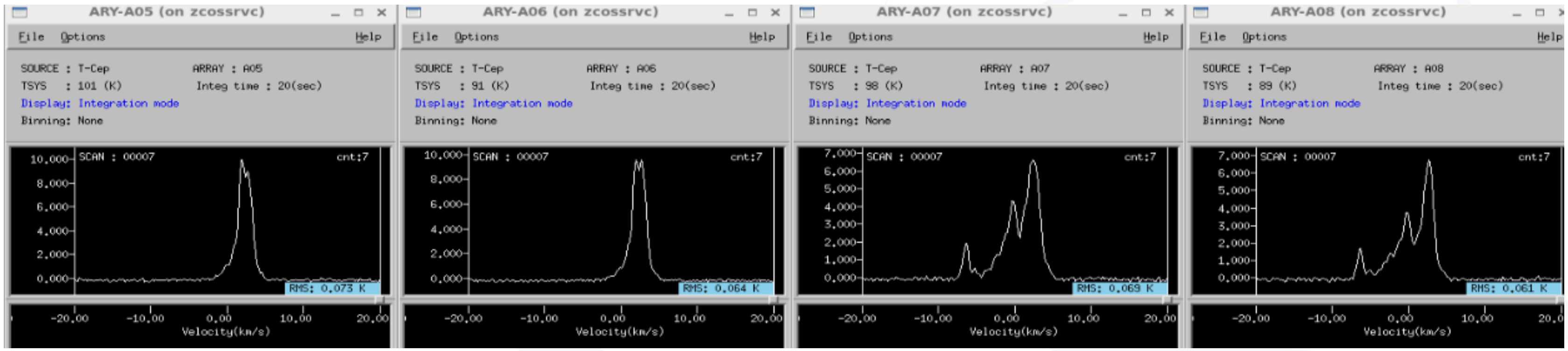

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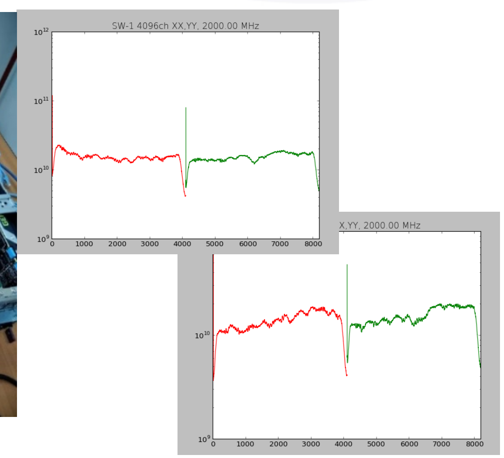
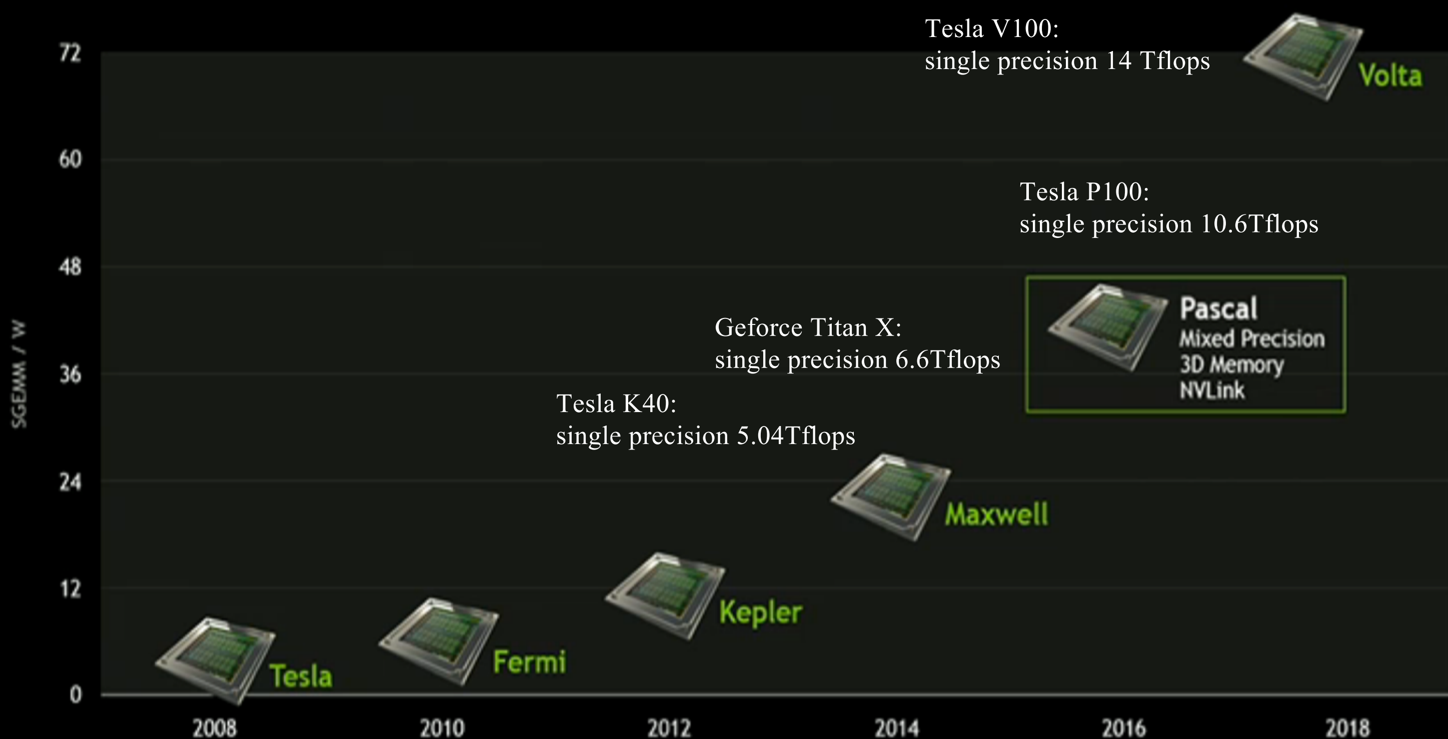
- Science observations from Cycle 9 or 10



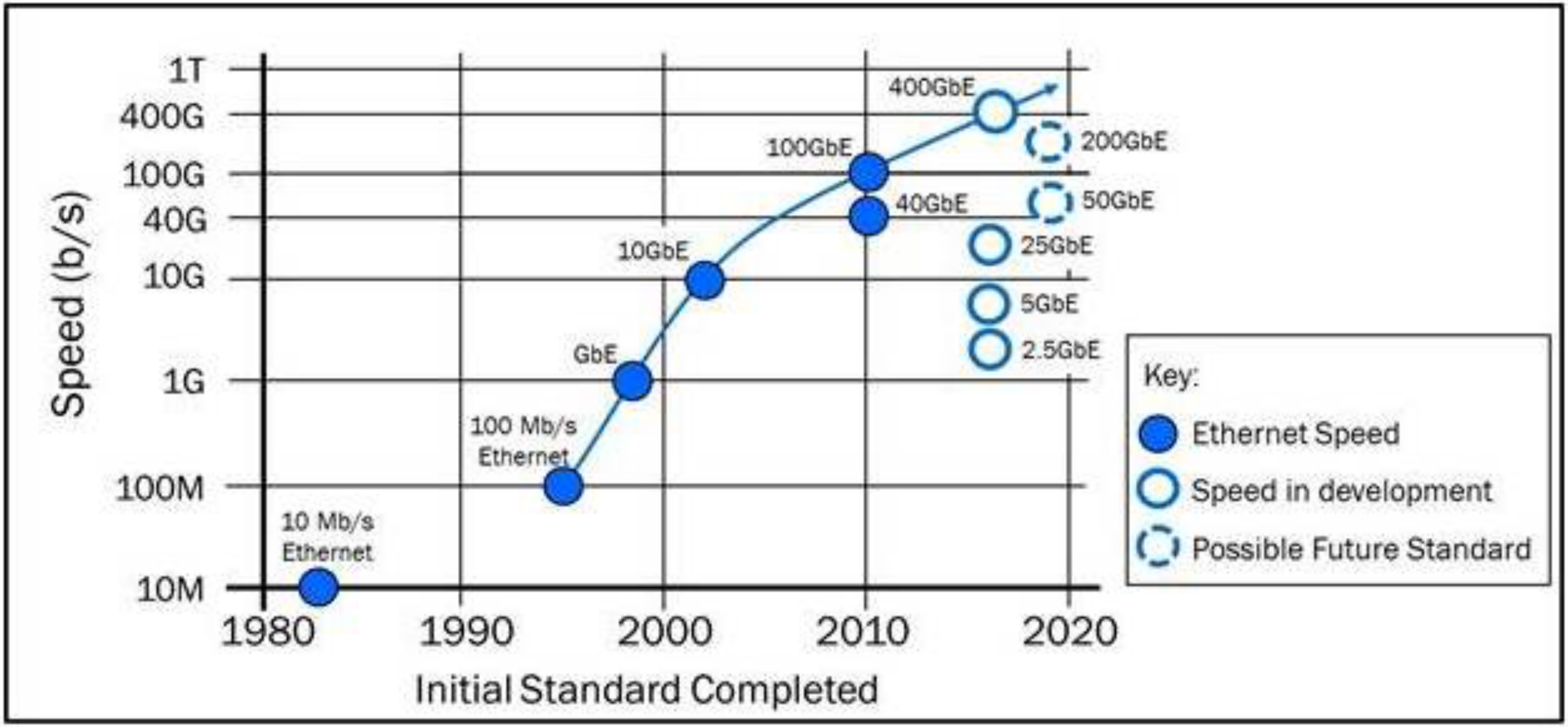
Possibility of a Future ACA Correlator based on GPU Technology

- Stage 1: ACA Spectrometer
  - Meet the current specification of the ACA Correlator
  - Composed of 4 GPU servers, 4 GPU cards per server, 2 DRXP (data acquisition) cards per server, and 12 optical splitters per server
  - Will be installed on February 2020
- Stage 2: ACA Correlator
  - Aligned with the upgrade plan of the 64-antenna ALMA Correlator
    - Resolution upgrade: 8x more channels
    - Sampling bit upgrade: 3bit → 4bit
    - bandwidth upgrade: 2GHz → 4 GHz
  - Composed of 4 GPU servers, 16 GPU cards per server, 8 DRXP cards

NVIDIA GPU Roadmap

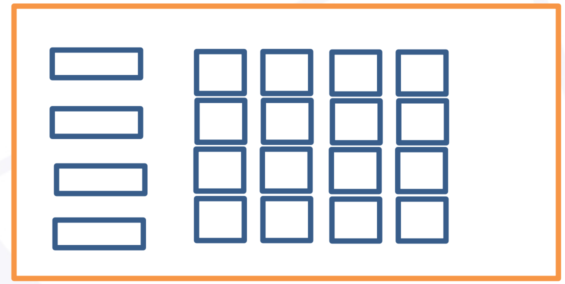


Ethernet Roadmap

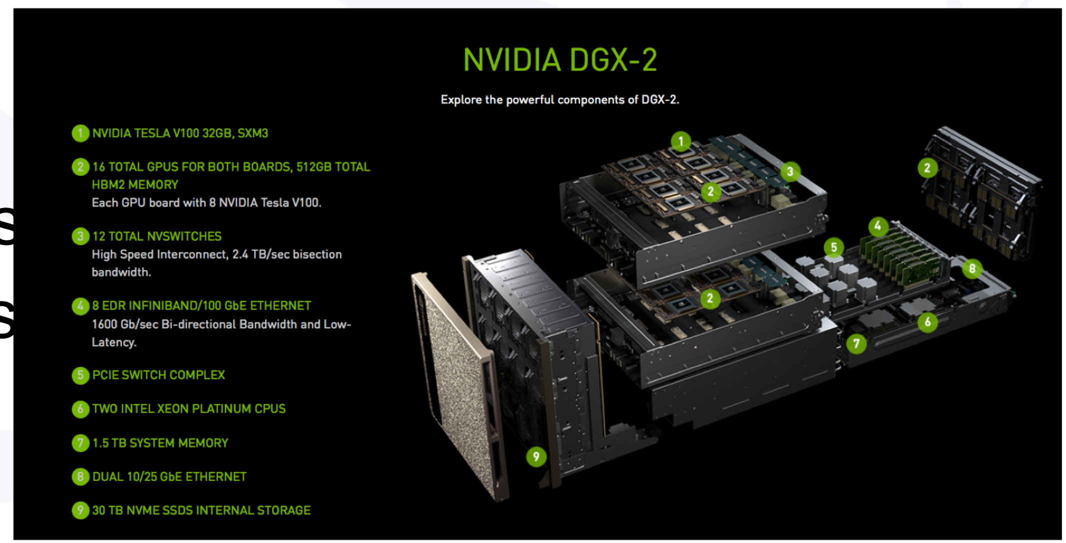


Conceptual Design of an GPU ACA Correlator

- Composed of 4 GPU servers, 16 GPUs/server, 8 DRXP cards/server
- Data rates to one server:
  - Per one IF: 2GHz * 2(Nyquest) * 3(sampling bit) * 2(dual pol)=24 Gb/s
  - 16 antennas: 16*24 Gb/s = 384 Gb/s



A GPU server with 4 PCI4 and 16 GPUs



Performance requirements for one server

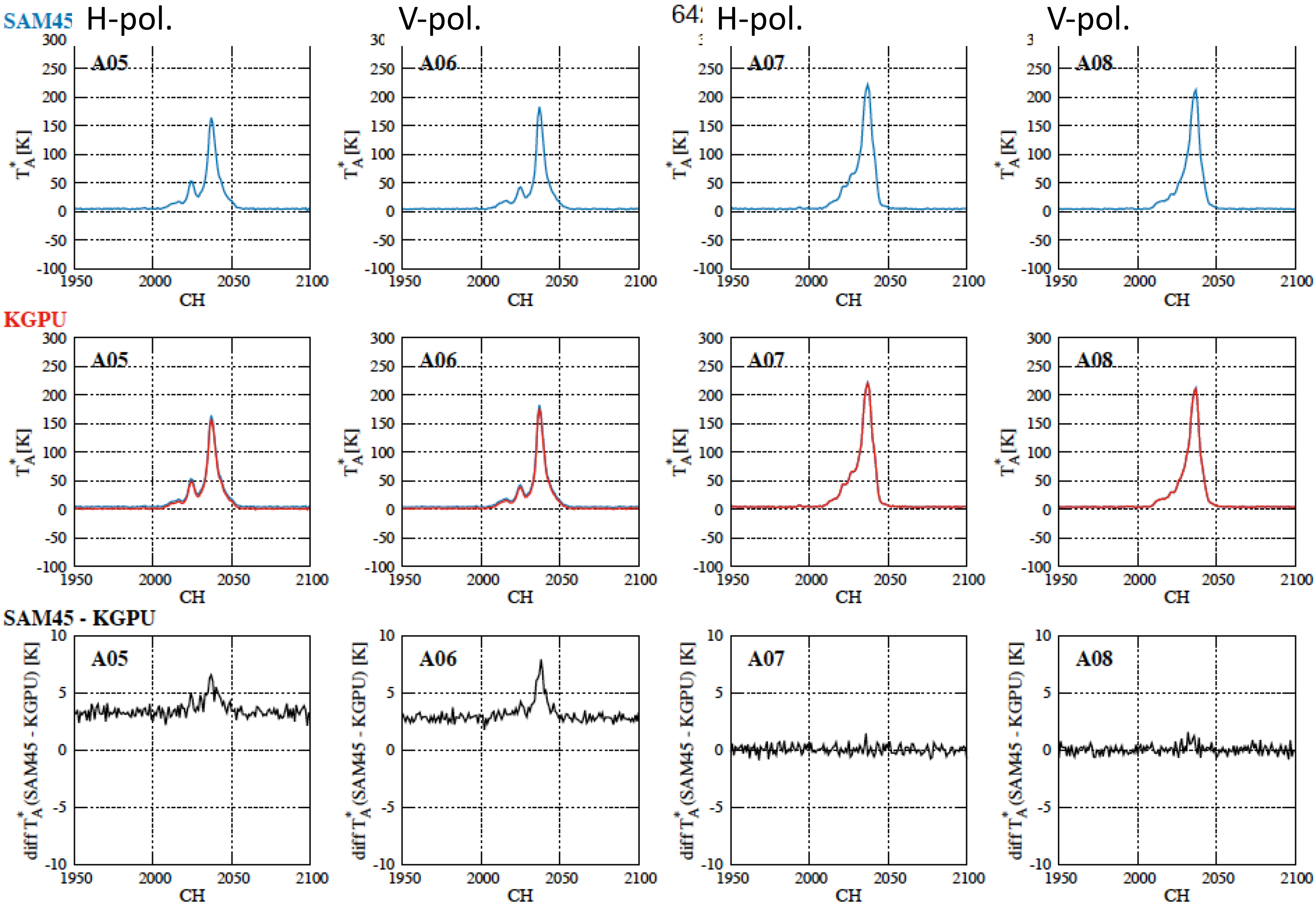
- F-step
  - Assuming a server gets one BB (dual pol) from 16 antennas
  - $N=2^{20}$, dual pol, 16 antenna
  - Flops= 4e9/N*5*N*$\log_2(N)$ * 2 (dual) * 16 (antenna) = 12.8 Tflops
- X-step
  - Assuming that a server collects fft data from 16 antennas
  - cross-correlations: 120 x 8 operations (complex multiplications) x 2e9 = 1.92 Tflops
  - # of auto-correlations: 16 x 4 operations x 2e9 = 0.128 Tflops
- Theoretical performance of one NVIDIA Tesla V100
  - Single precision (32bit): 15 Tflops x 16 = 240 Tflops

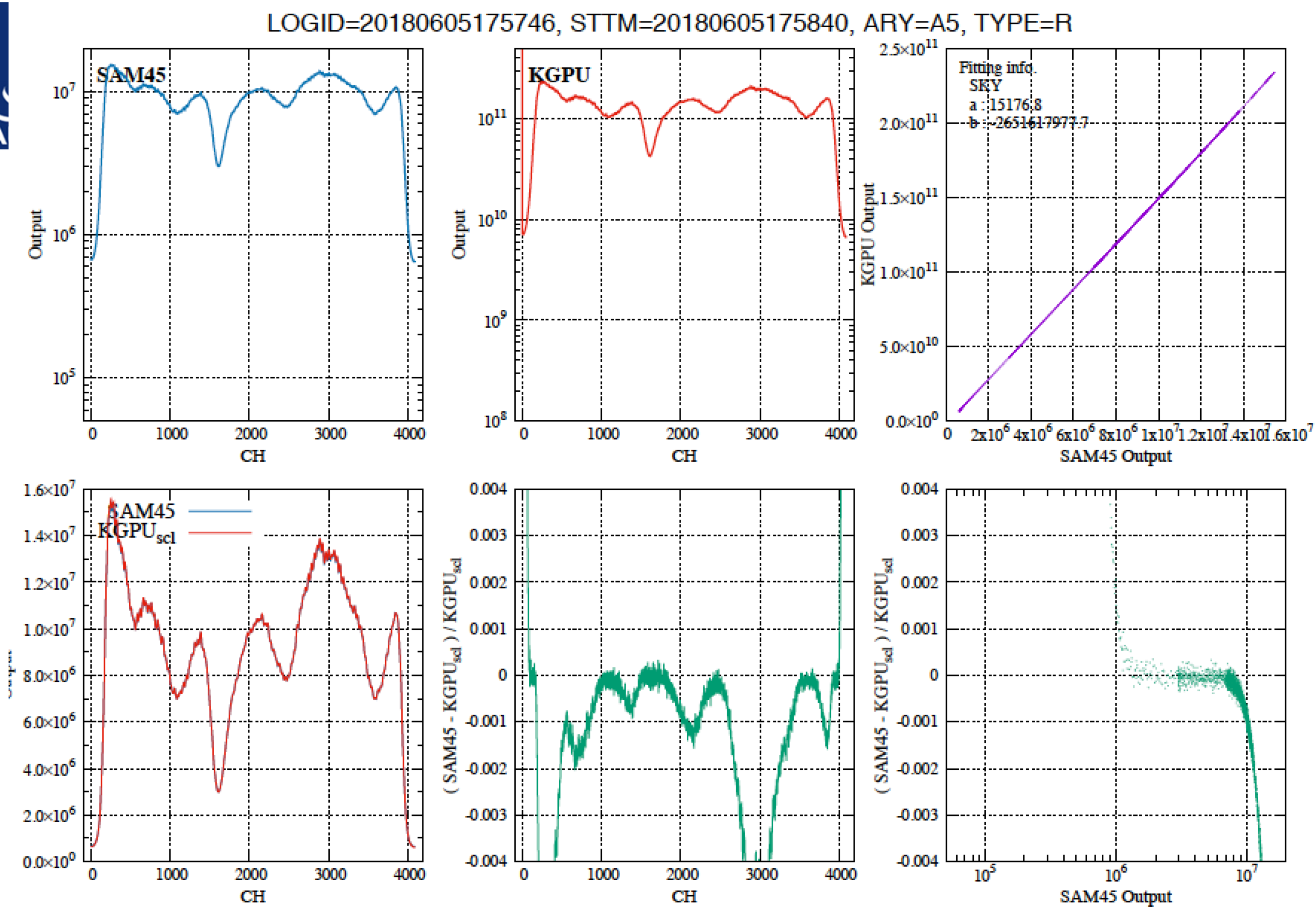
Summary

- The development of the ACA Spectrometer based on the GPU technology is on-going by the KASI and NAOJ.

- GPU technology is promising for future ALMA Spectrometer and Correlator.

SiO 42.82057 GHz H-pol. | SiO 42.82057 GHz V-pol. | SiO 43.12209 GHz H-pol. | SiO 43.12209 GHz V-pol.





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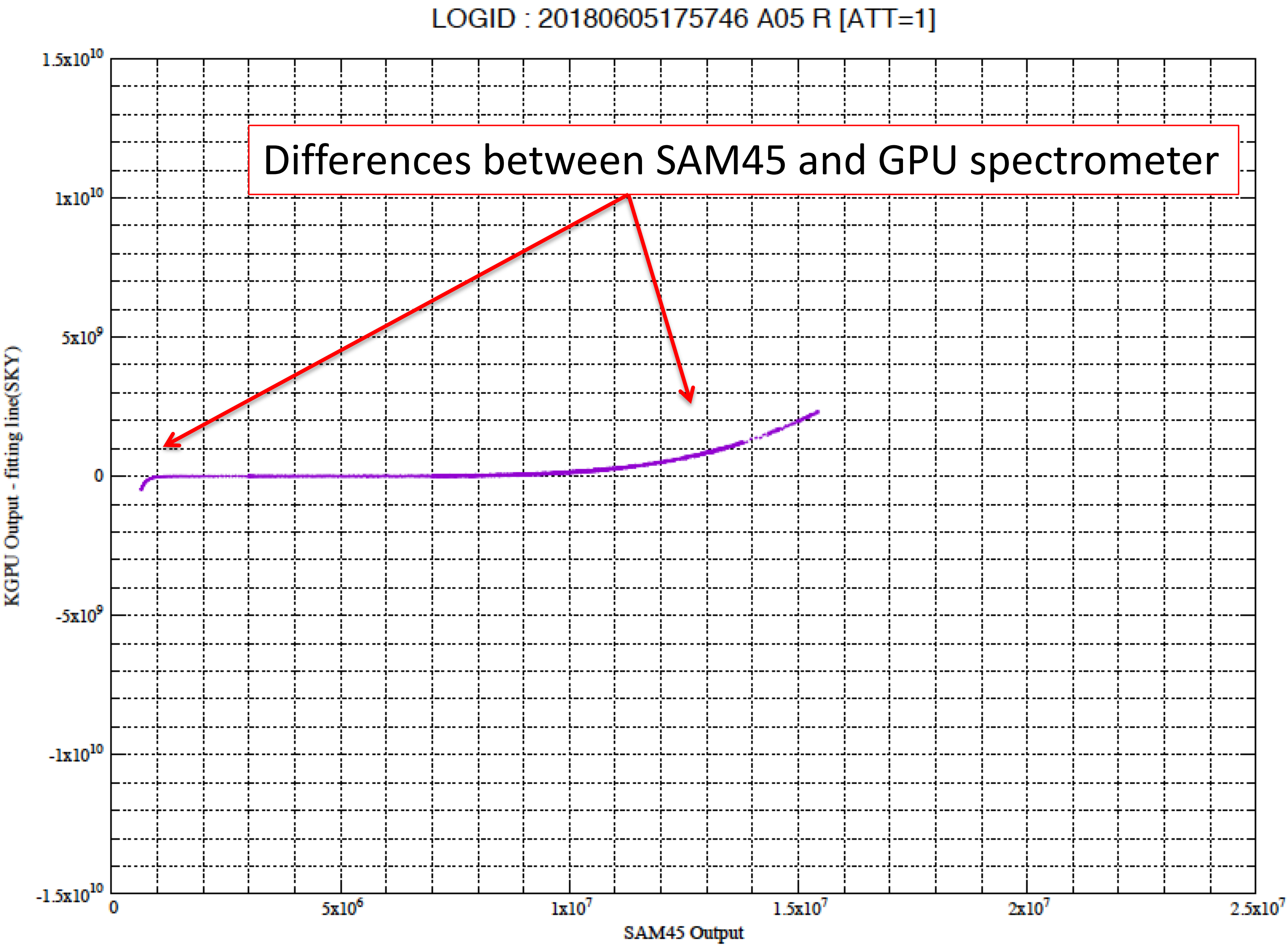
SAM45
KGPU
Output
CH
Fitting info.
SKY
a : 15176.8
b : -2651617977.7
KGPU Output
SAM45 Output
SAM45
KGPU_scl
(SAM45 - KGPU_scl) / KGPU_scl



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Differences between SAM45 and GPU spectrometer
1.5x10^10
1x10^10
5x10^9
0
-5x10^9
-1x10^10
-1.5x10^10
KGPU Output - fitting line(SKY)
0
5x10^6
1x10^7
1.5x10^7
2x10^7
2.5x10^7
SAM45 Output