A GPU spectrometer for Radio Telescopes

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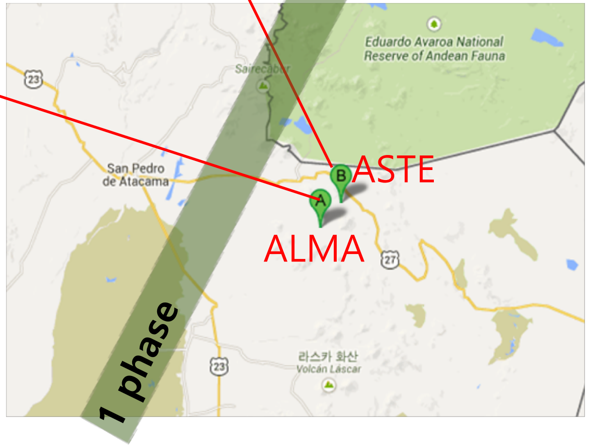
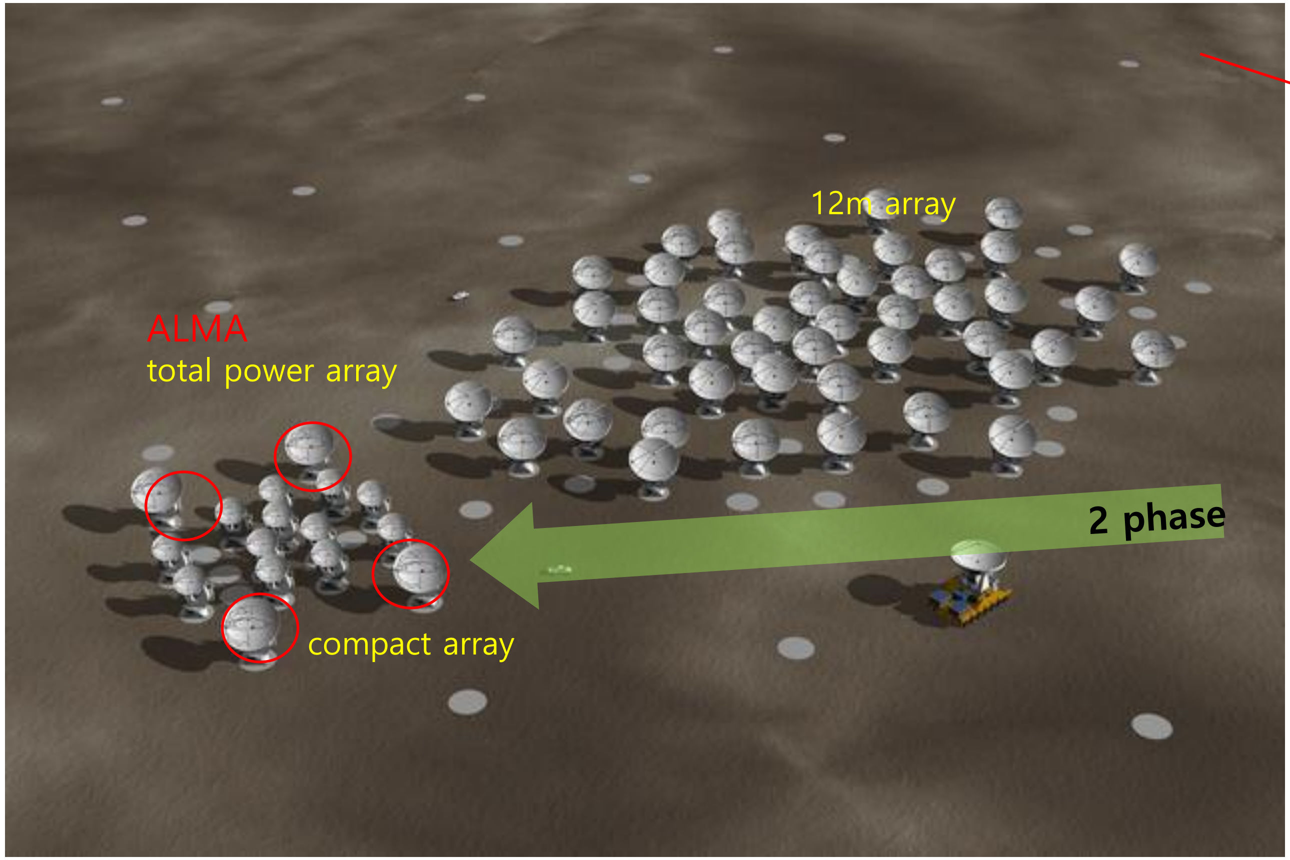
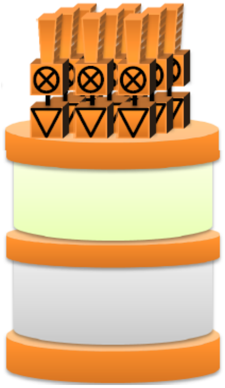
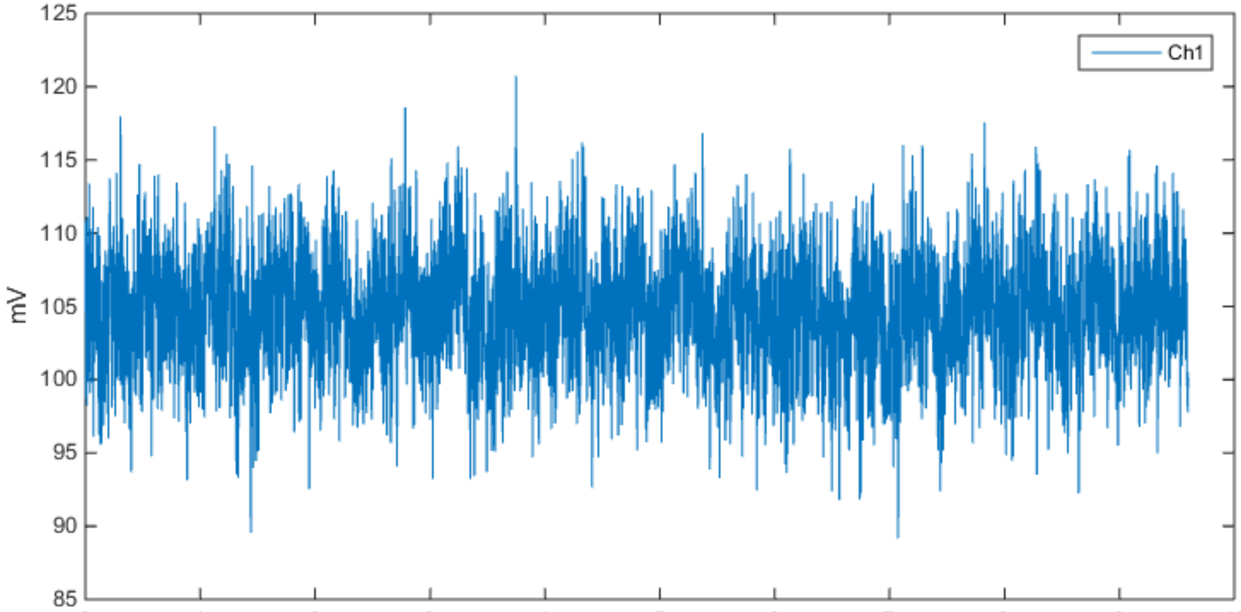
EA-ALMA Development projects in KASI

- GPU Spectrometer for the ALMA TP Array
- Multi-beam receiver for the ALMA TP Array and ASTE

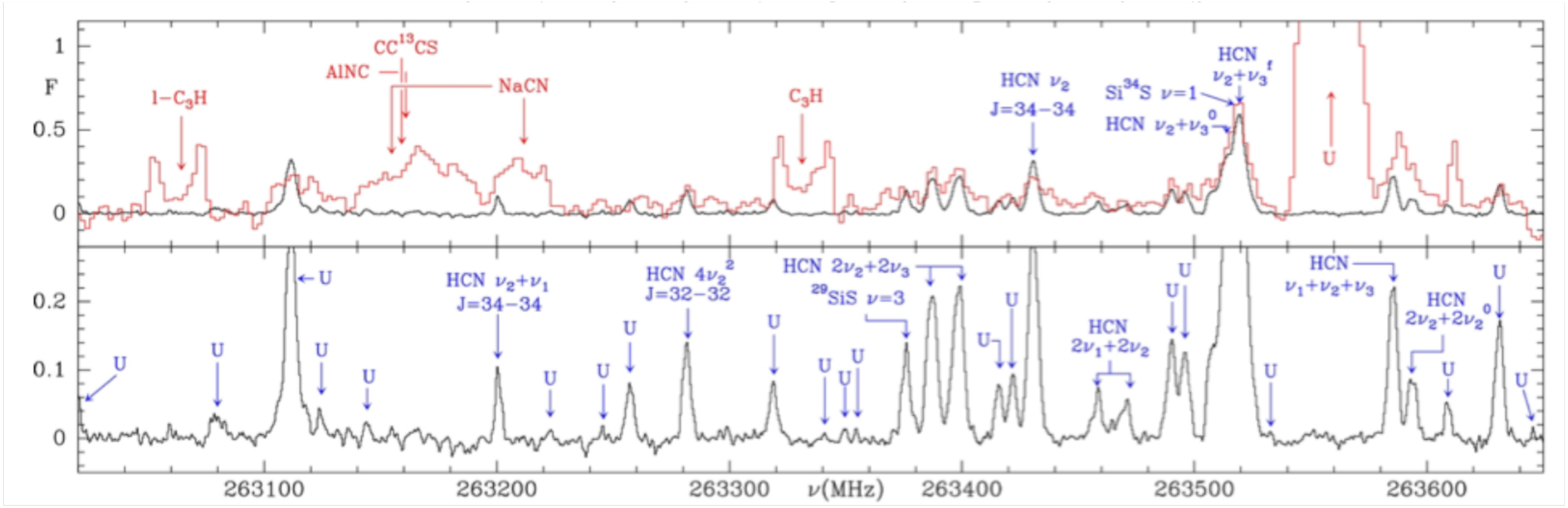




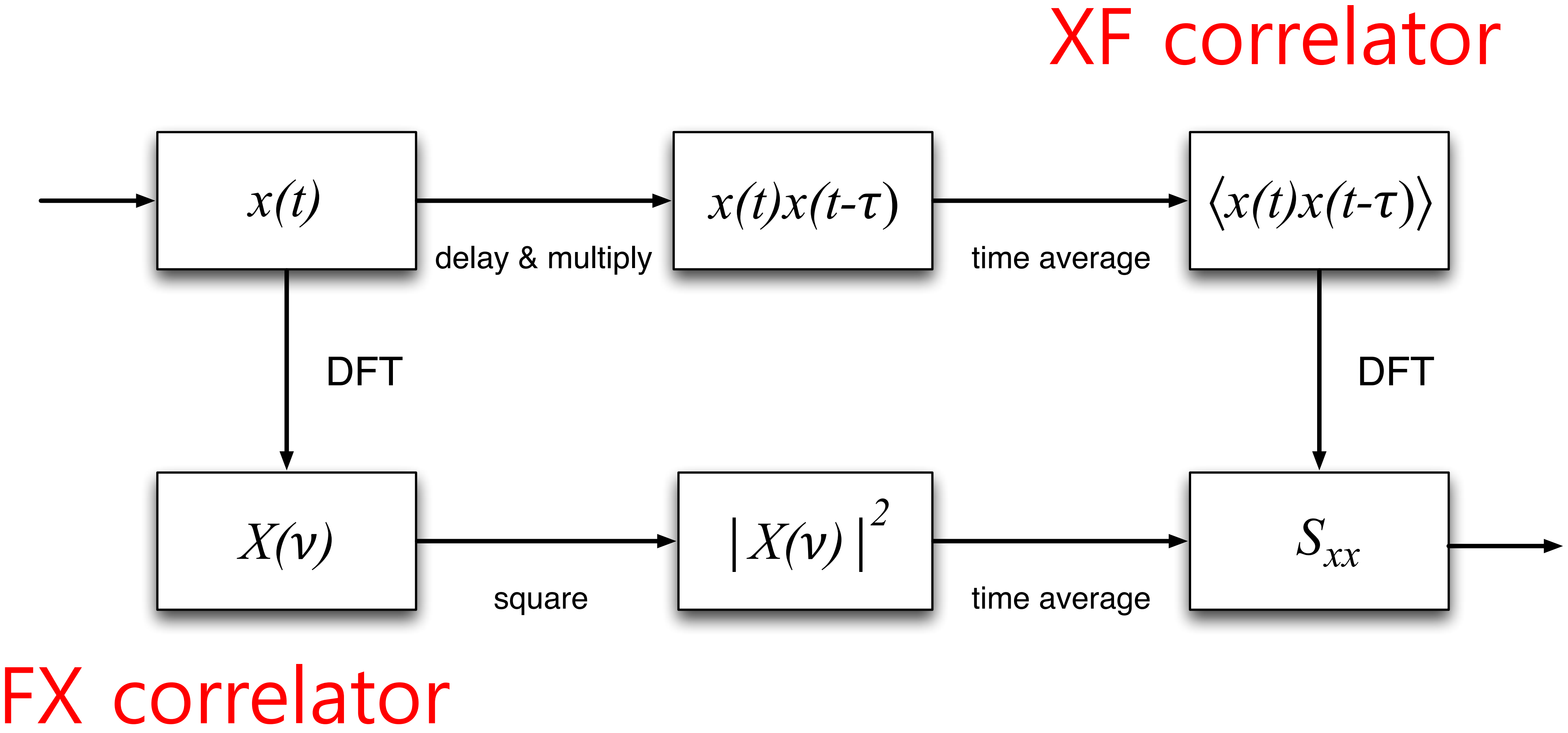




Fourier Transform



Wiener-Khinchin Theorem



Three Technologies for Correlator

- ASIC (Application-Specific Integrated Circuit)
  - Example, ALMA 64-antenna correlator
- FPGA (Field-Programmable Gate Arrays)
  - Example, ALMA ACA correlator
- Software (high level-languages, e.g., C/C++, MPI, CUDA/OpenCL)
  - Example, ALMA ACA spectrometer

Largest Correlators in the world

Price+ 2017

Telescope	Reference	N_{ant}	B (GHz)	Data rate $N_{\mathrm{ant}}B$ (GHz)	# of calculations N_{ant}^2B (GHz)	
CHIME-1024	Vanderlinde *et al.* (2014)	**1024**	0.4	409.6	**419430**	FPGA+GPU
ALMA	Baudry *et al.* (2012)	64	**16.0**	**1024.0**	65536	ASIC
HERA-352	DeBoer *et al.* (in press)	352	0.2	70.4	24781	FPGA (CASPER)
ASKAP	Tuthill *et al.* (2014)	36	0.3	388.8†	13997‡	
eVLA	Perley *et al.* (2009)	27	8.0	216.0	5832	
LEDA	Kocz *et al.* (2015)	256	0.058	14.85	3801	FPGA+GPU
MeerKAT	Jonas (2009)	64	0.856	54.78	3506	
AARTFAAC-12	Prasad *et al.* (this issue)	576	6.25	3.6	2074	GPU
PAPER-128	Cheng *et al.* (2016)	128	0.100	12.8	1638	
SMA	Primiani *et al.* (this issue)	8	**16.0**	128.0	1024	
MWA	Ord *et al.* (2015)	128	0.030	3.84	492	
uGMRT	Reddy *et al.* (submitted)	32	0.4	12.8	410	
EOVSA	Nita *et al.* (this issue)	16	0.6	96	154	
LOFAR	de Vos *et al.* (2009)	48	0.032	1.54	74	

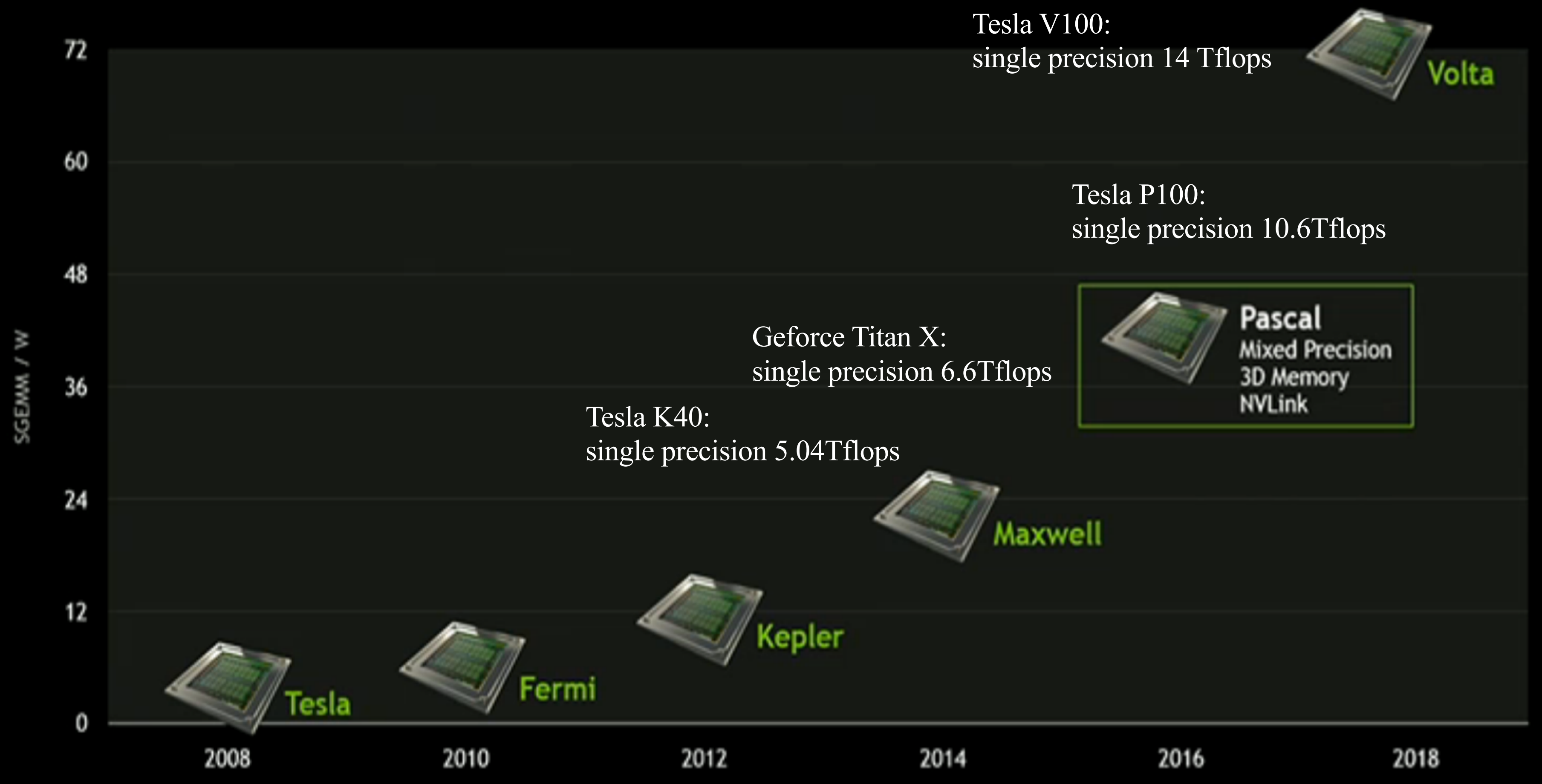
† Computed as $N_{\mathrm{beam}}N_{\mathrm{ant}}B$, with the number of beams N_{beam}=36.

‡ Computed as $N_{\mathrm{beam}}N_{\mathrm{ant}}^2B$ with N_{beam}=36.

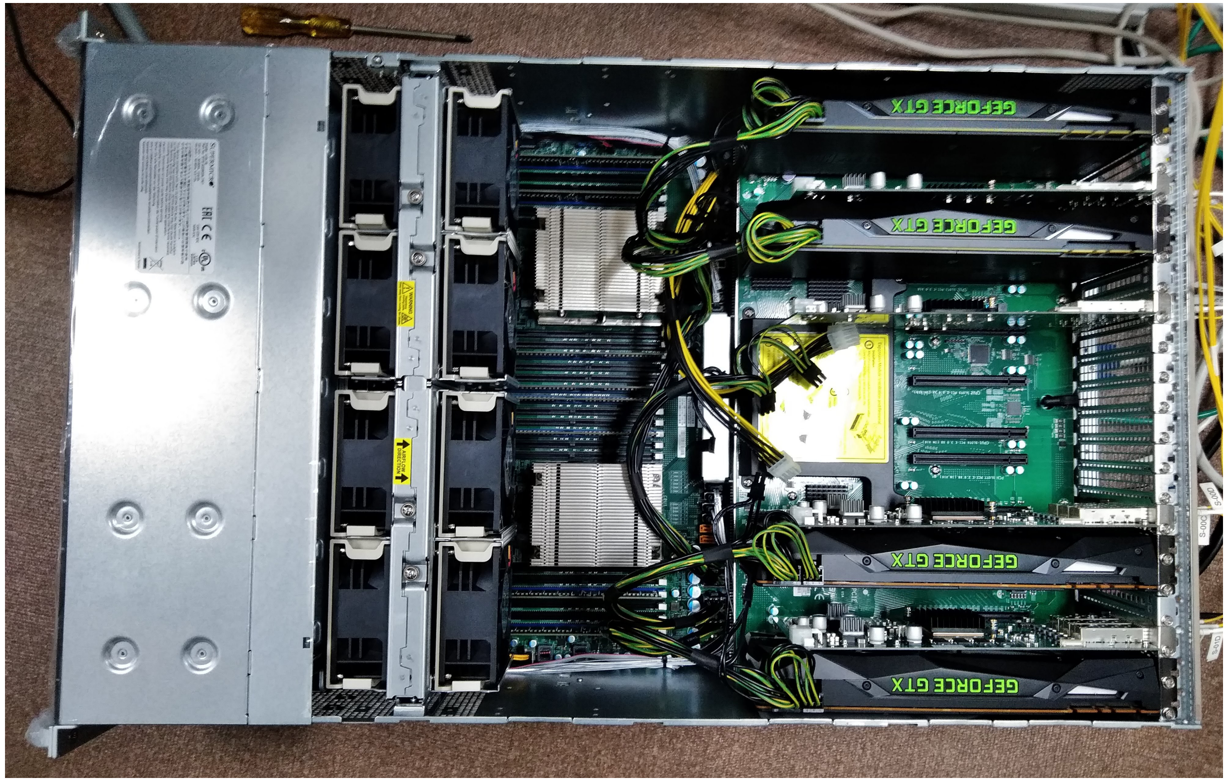
Pros/Cons of Software Correlator

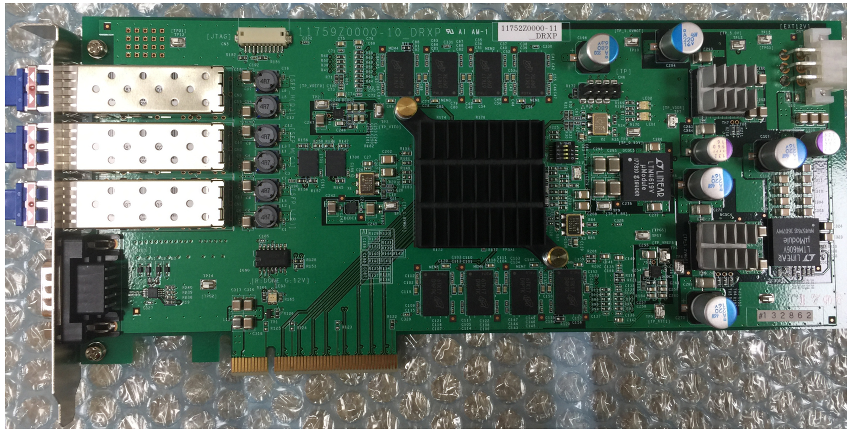
- Pros of software spectrometer
  - rapid and easy development
  - flexibility (e.g., RFI) and expandability
  - 32bit floating point operations (high-precision)
  - Commodity Off-The-Shelf Technology (COTS)
- Disadvantages of software spectrometer
  - low performance/Watt

NVIDIA GPU Roadmap

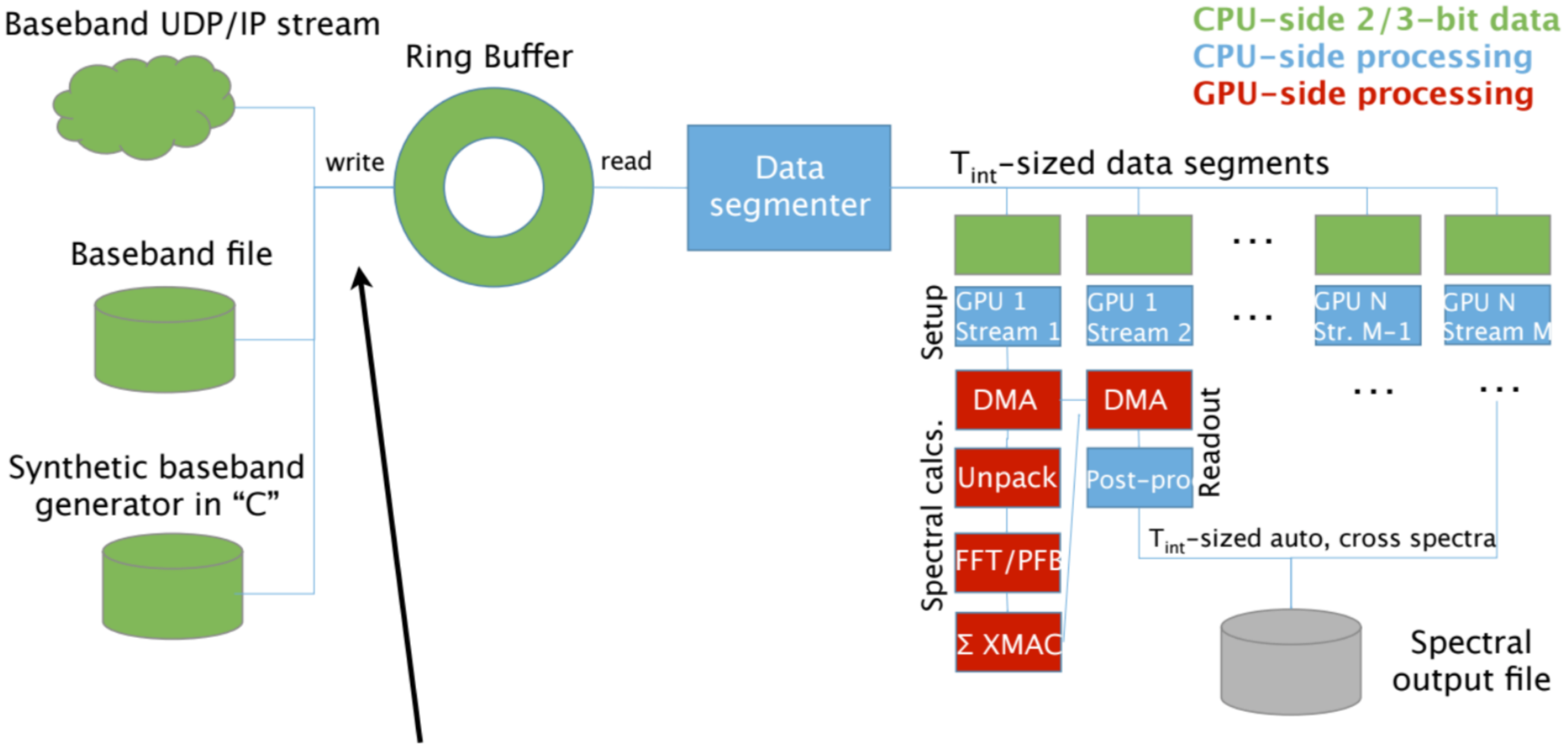


Prototype GPU spectrometer



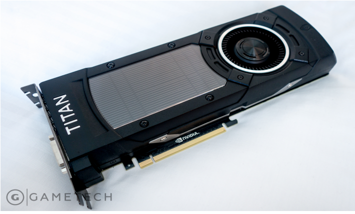


Data Flow in Spectrometer



Input data are in VDIF format or in a yet to be specified ACA TP DXRP PCIe format. Sources: network, file, on-the-fly synthetic generator.

GeForce Titan X



- Maxwell architecture
- CUDA cores: 3072
- base and boost clocks: 1000, 1075MH z
- performance: 6.14~6.6 Tflops single pr ecision
- memory Bandwidth: 336.5 GB/sec
- memory: 12GB

GeForce GTX 980

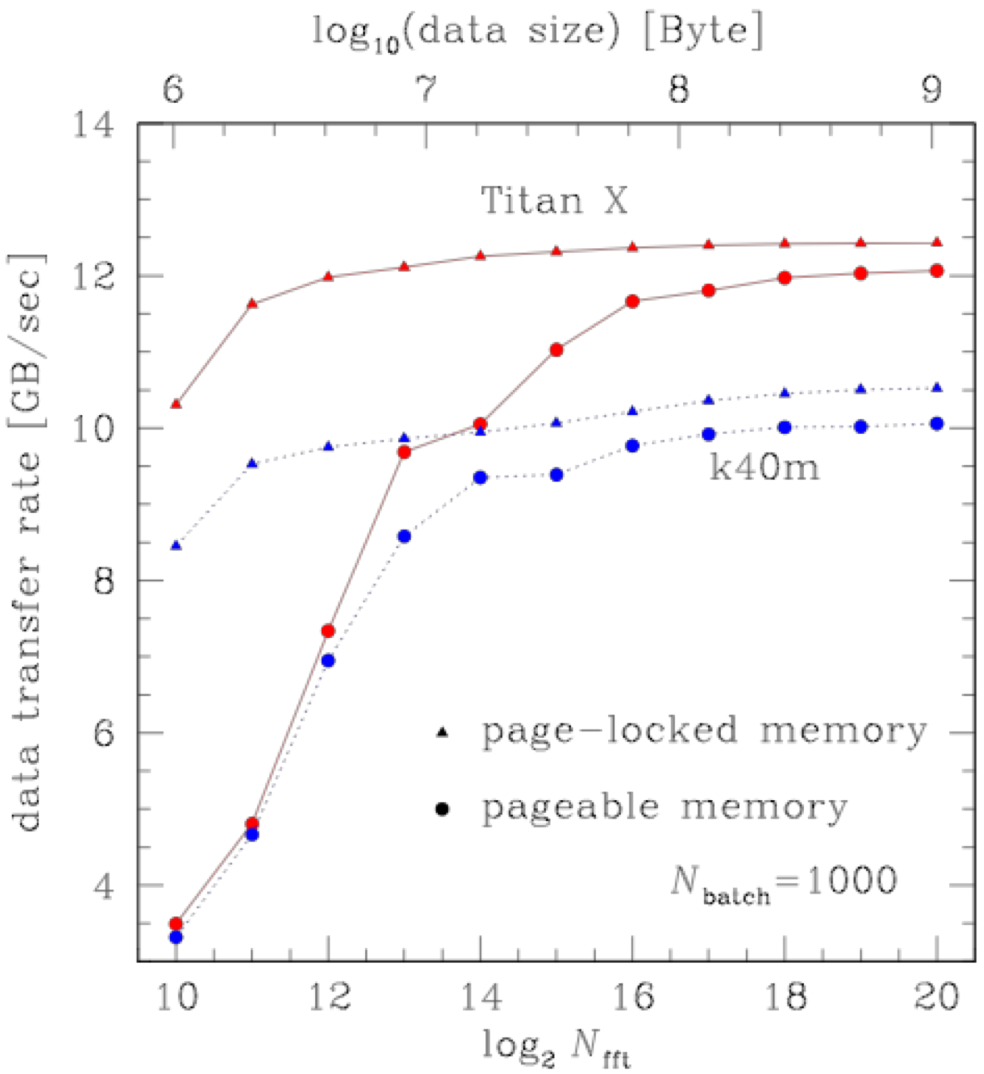
- Maxwell architecture
- CUDA cores: 2048
- base clock: 1064 MHz
- performance: 4.36 Tflops single precision
- memory Bandwidth: 224 GB/sec
- memory: 4 GB

Tesla K40m

- Kepler architecture
- cores: 2880
- base, boost clocks: 745 MHz, 810 MHz an d 875 MHz
- performance: 4.29~5.04 Tflops single preci sion
- memory bandwidth: 288 GB/sec
- memory: 12 GB

data copy from CPU to GPU

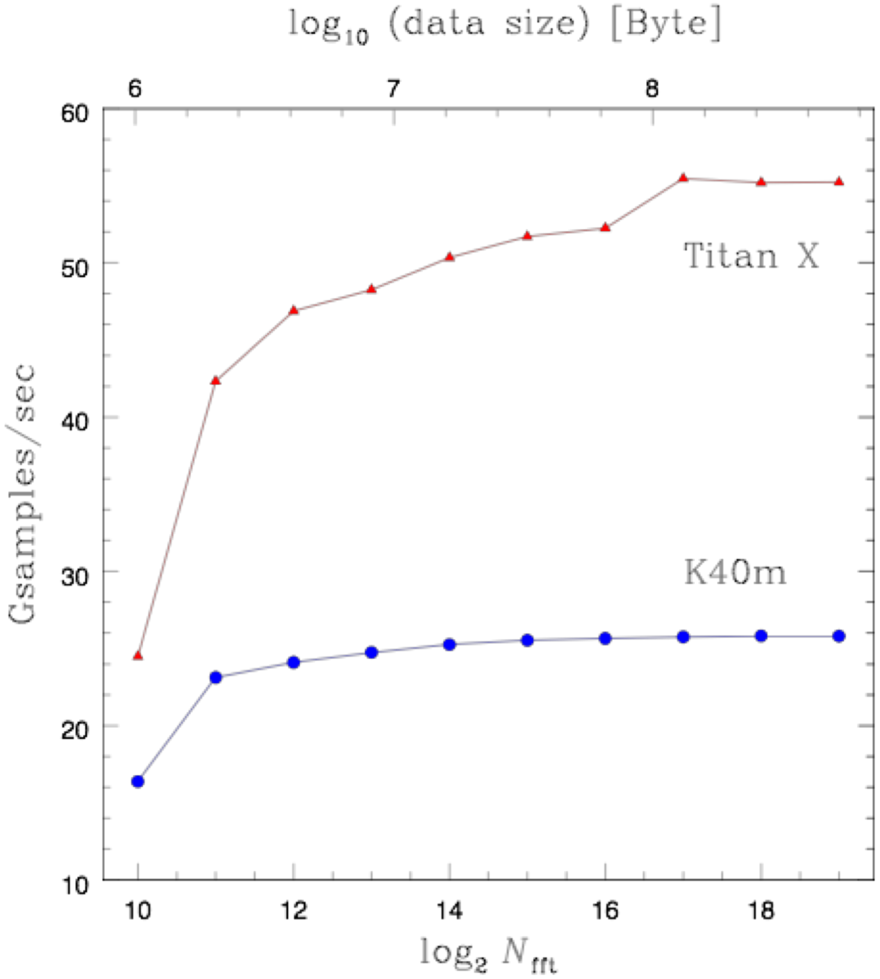
- converges to 12.5 GB/sec < 16GB/sec (PCIE 3)
- 2 bits/sample: 12GB/sec —> 48 G samples/sec (24 GHz bandwidth)
- 3 bits/sample: 12GB/sec —> 32 G samples/sec (16 GHz bandwidth)
- 4 bits/sample: 12GB/sec —> 24 G samples/sec (12 GHz bandwidth)



1024 16384 1048576

Data bit conversion (2 or 3 bits to 32bits)

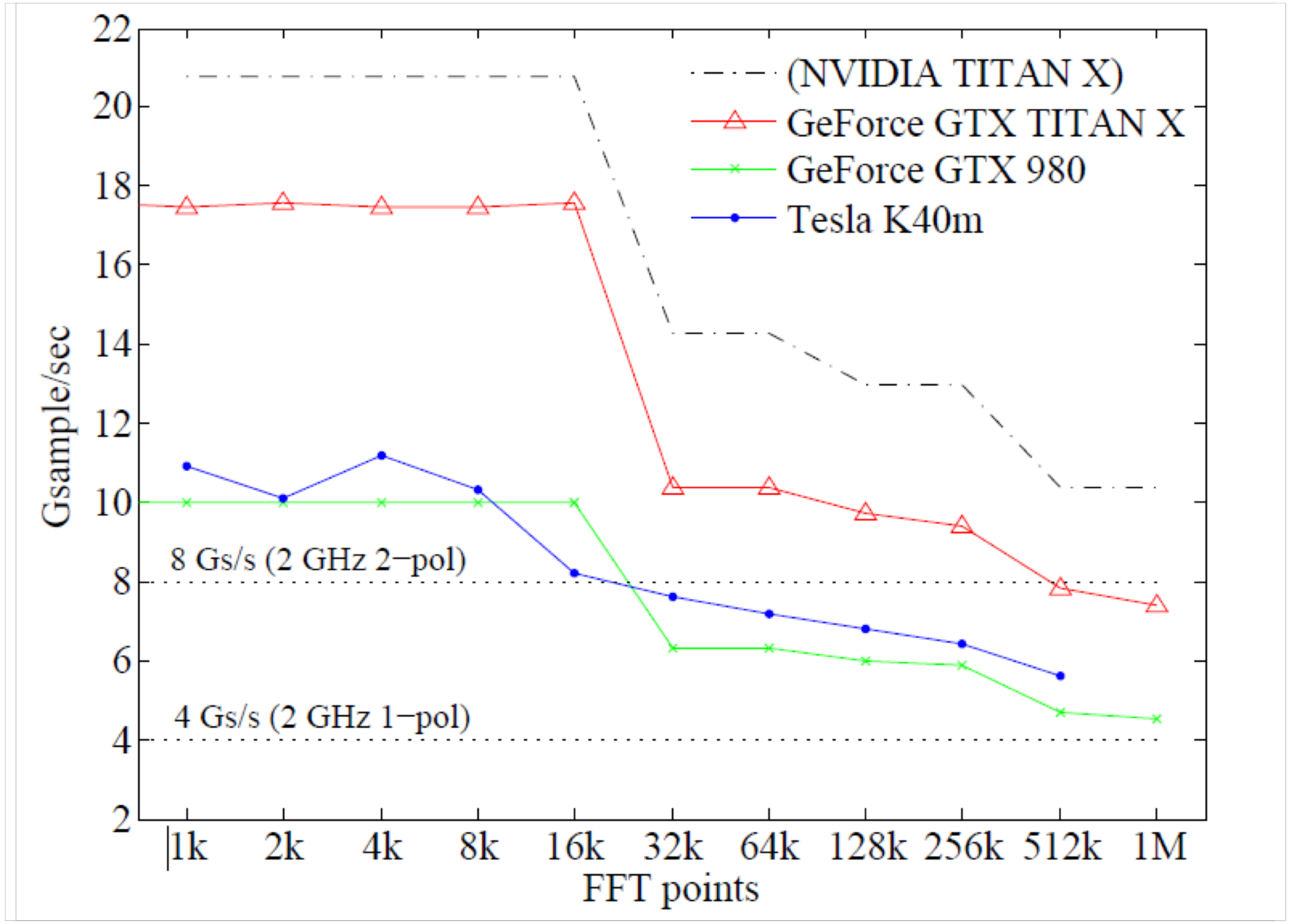
- lookup table for a 2 bit
  - {-3.3359, -1.0, +1.0, +3.3359}
- lookup table for a 3 bit sample
  - {-7.0f, -5.0f,-1.0f, -3.0f, +7.0f, +5.0f, +1.0f, +3.0f}
- ~ 50 Gsamples/s for 2bit and 3bit samples with GTX Titan X



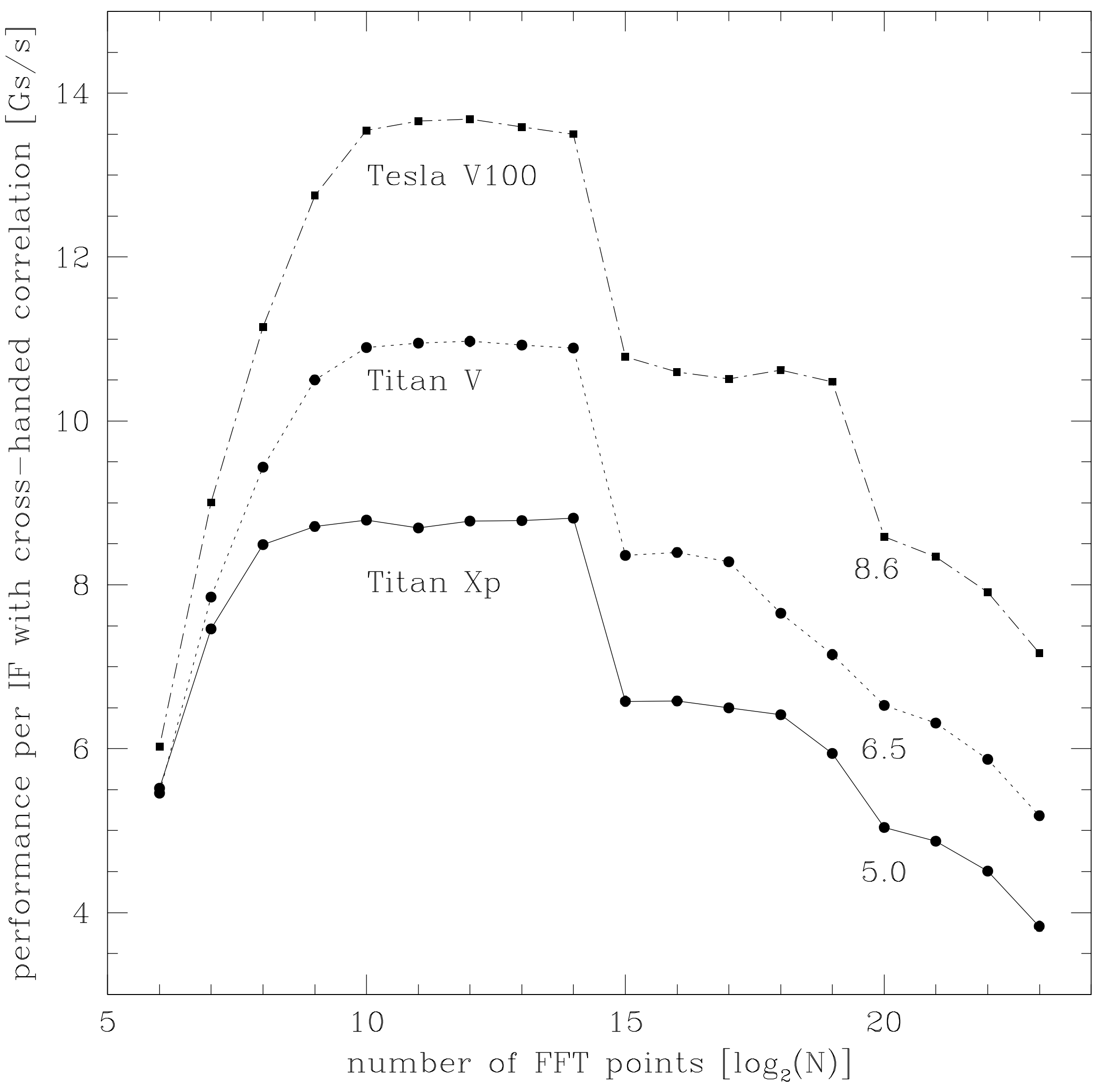
cuFFT

```
cufftPlanMany(….);
cufftExecR2C(plan, idata, odata)
```

- total number of samples: 250*2^20
- 7.5~17.5 Gsample/sec (3.8~8.8 GHz in single polarization)
- ACA correlation used 2^20 point FFT
- for a given number of samples, FFT performance is higher at small fft points



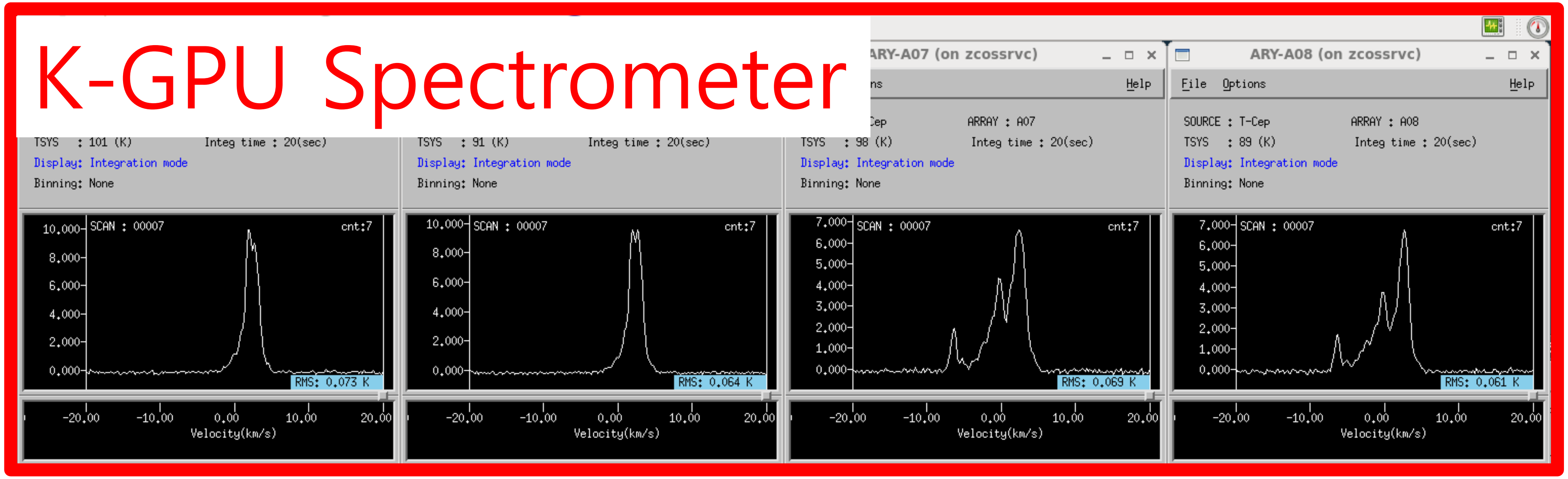
FFT performance of different GPU cards

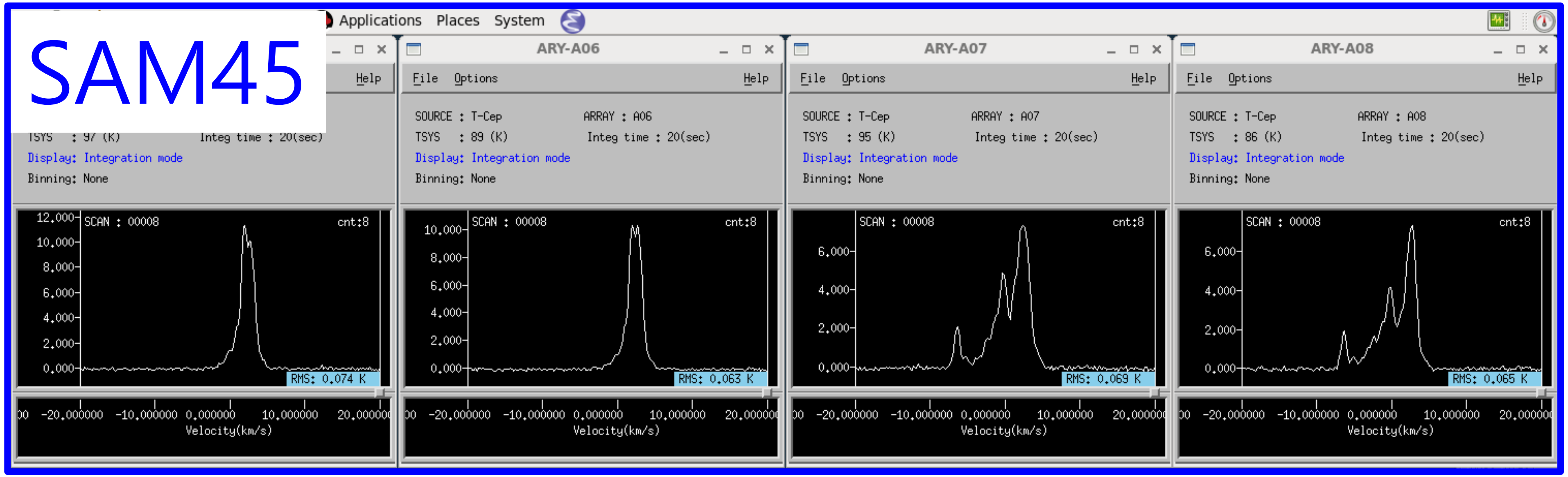


Test results of using the NRO 45-m antenna

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

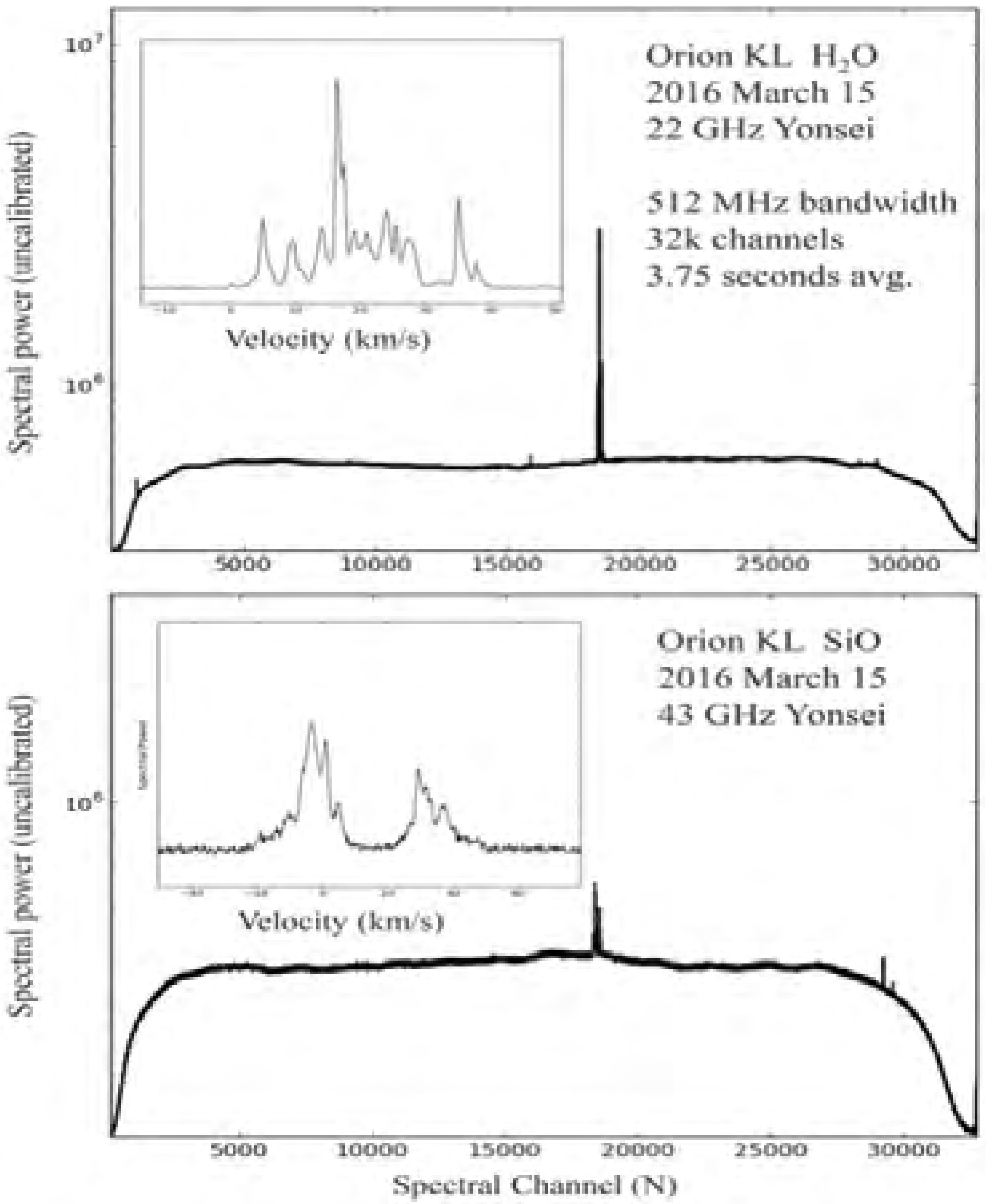
SiO (v=1, J=1-0) @ 43.1GHz





Results of test observation using KVN Yonsei antenna

Orion KL
H2O and SiO maser lines



Conclusions

- The performance of GPU is good enough to make a spectrometer for a single dish antenna or a correlator for an array with modest number of antennas.
- A GPU spectrometer (one server with four GPU cards) could process data streams of 32Gsamples/s from one ALMA antenna in real time.
  - The most time-consuming part is FFT, but cuFFT (in CUDA FFT library) is fast enough for our spectrometer.