Peta-Flop Radio Astronomy Signal Processing and the CASPER Collaboration (and correlators too !)

Dan Werthimer and 800 CASPER Collaborators

http://casper.berkeley.edu

Two Types of Signal Processing

1. Embarrassingly Parallel – Low Data Rates

   (record the data and process it later)

   (high computation per bit)

2. Real Time in-situ Processing

   Petabits per second (can not record data)

TYPE 1

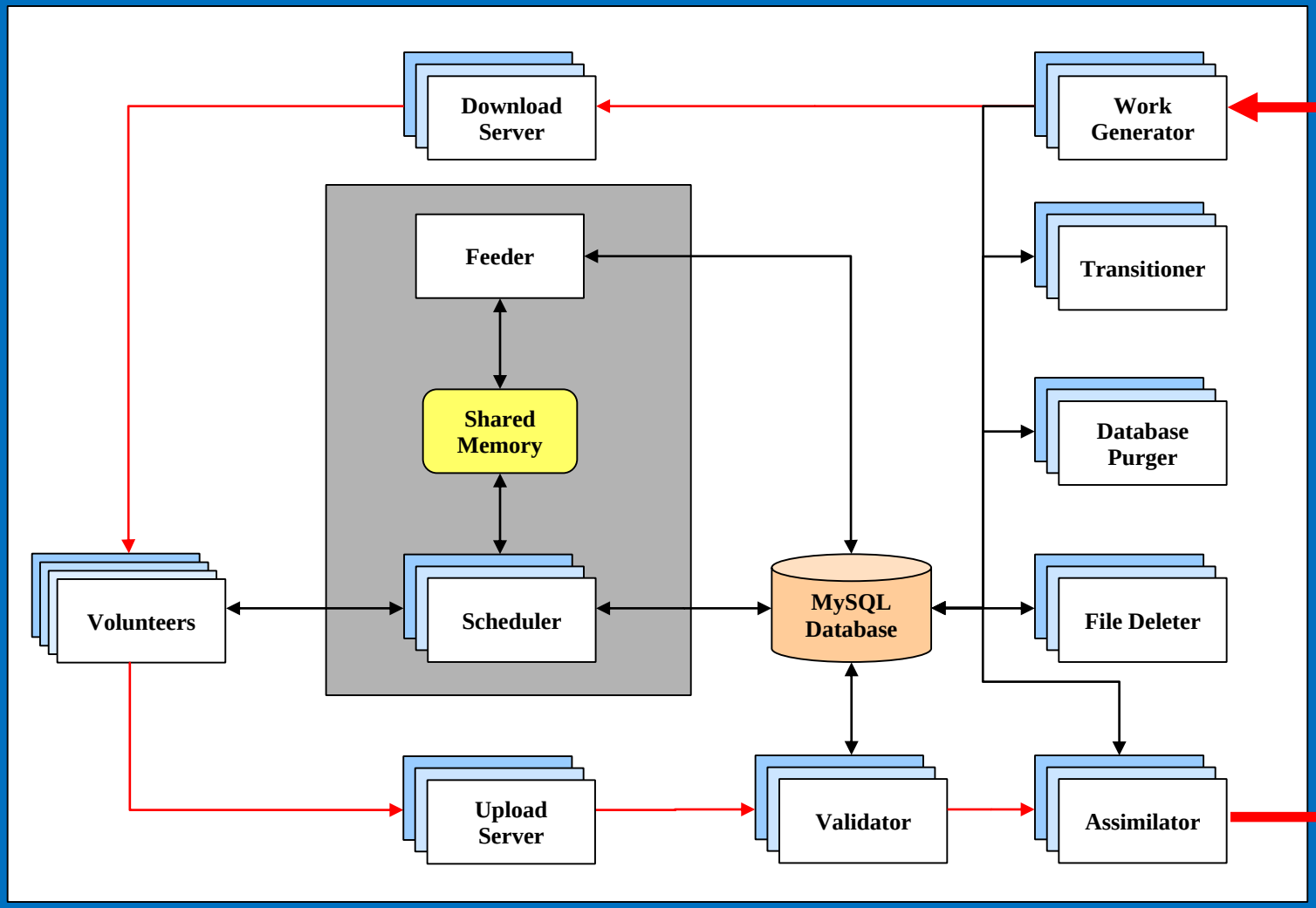
Embarrassingly Parallel – Low Data Rates

(record the data and process it later)

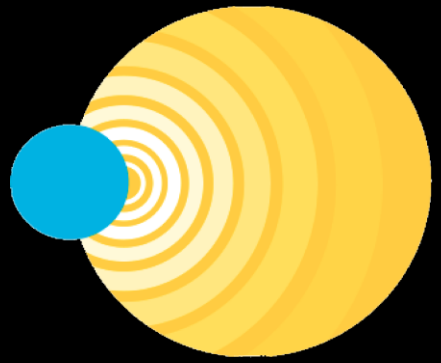
(high computation per bit)

VOLUNTEER COMPUTING

BOINC - Berkeley Open Infrastructure for Network Computing



BERKELEY SETI RESEARCH CENTER



BERKELEY **SETI**

SSL
UNIVERSITY OF CALIFORNIA
Berkeley

CASPER

BWRC

BERKELEY
ASTRONOMY
DEPARTMENT

BERKELEY LAB

THE UNIVERSITY OF CALIFORNIA
LET THERE BE LIGHT
1868

AMERICAN MUSEUM OF NATURAL HISTORY

UW-LA CROSSE

COLUMBIA UNIVERSITY

NRAO

UNIVERSITY OF TORONTO

SETI INSTITUTE

ASTRON

UNIVERSITY OF HAWAI'I

LOFAR

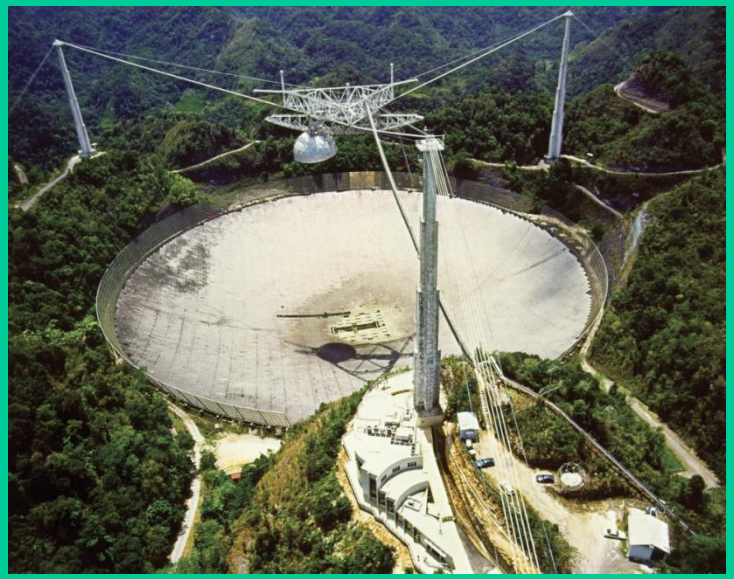
CORNELL UNIVERSITY
FOUNDED A.D. 1865

Berkeley SETI and Volunteer Computing Group

David Anderson, Hong Chen, Jeff Cobb, Matt Dexter, Walt Fitelson, Eric Korpela, Matt Lebofsky, Geoff Marcy, David MacMahon, Eric Petigura, Andrew Siemion, Charlie Townes, Mark Wagner, Ed Wishnow, Dan Werthimer

NSF , NASA, Individual Donors

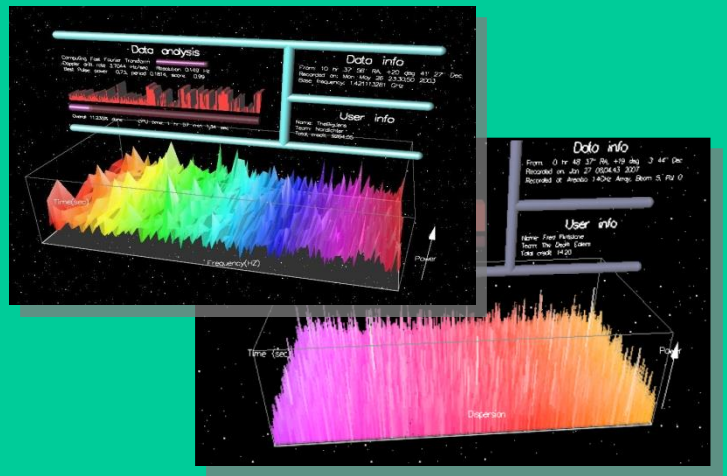
Agilent, Fujitsu, HP, Intel, Xilinx



Arecibo Observatory

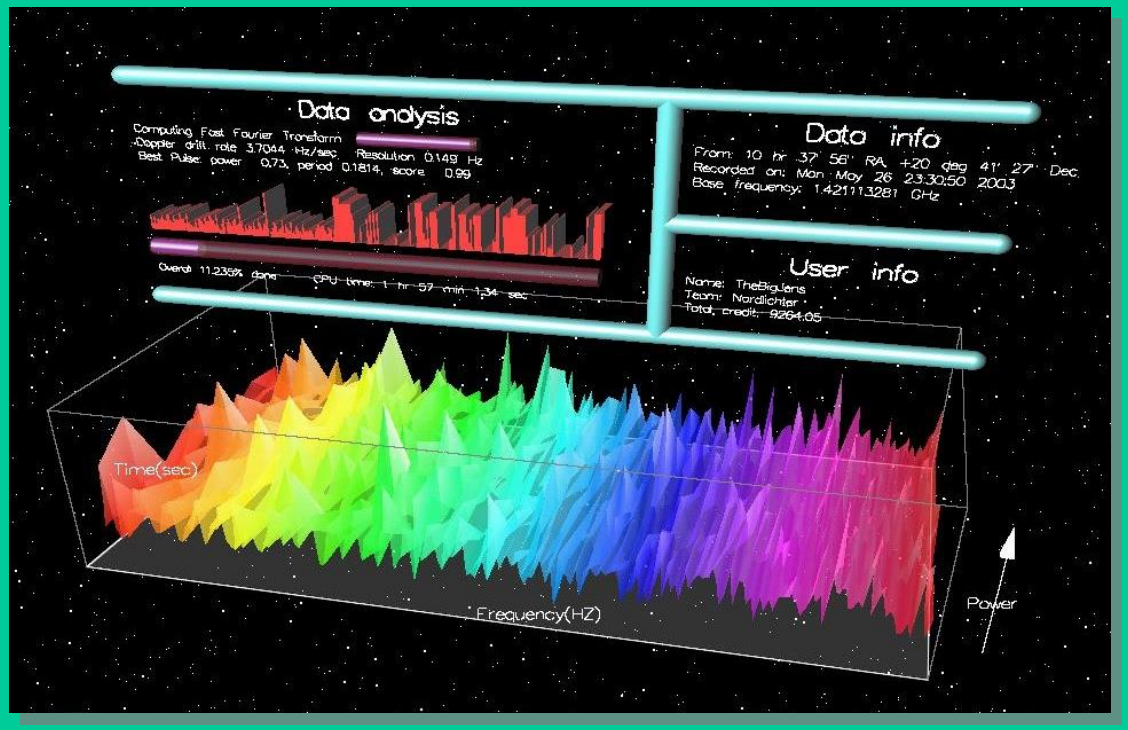
High performance data storage silo

UC Berkeley Space Sciences Lab



Public Volunteers

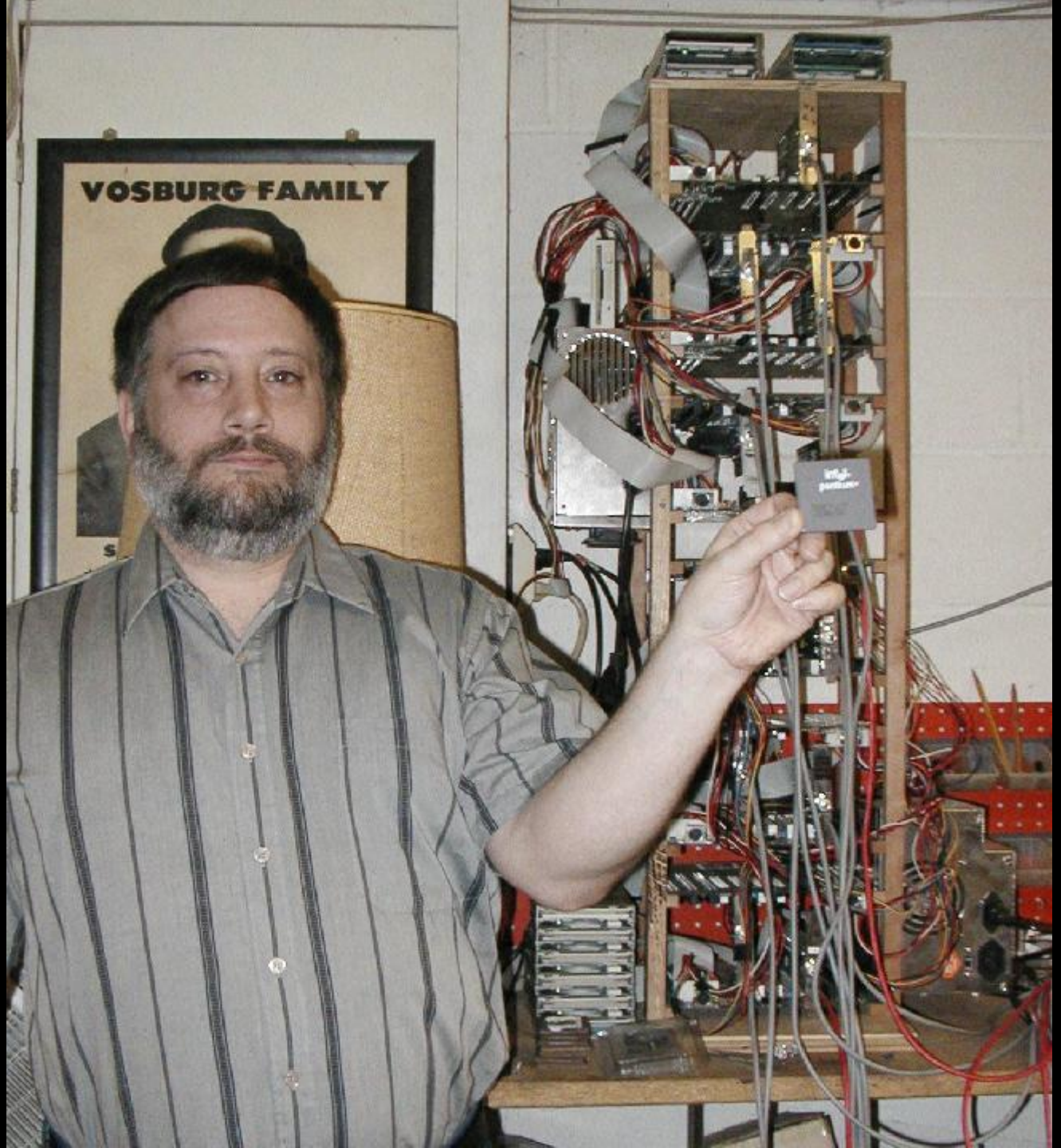
SETI@Home

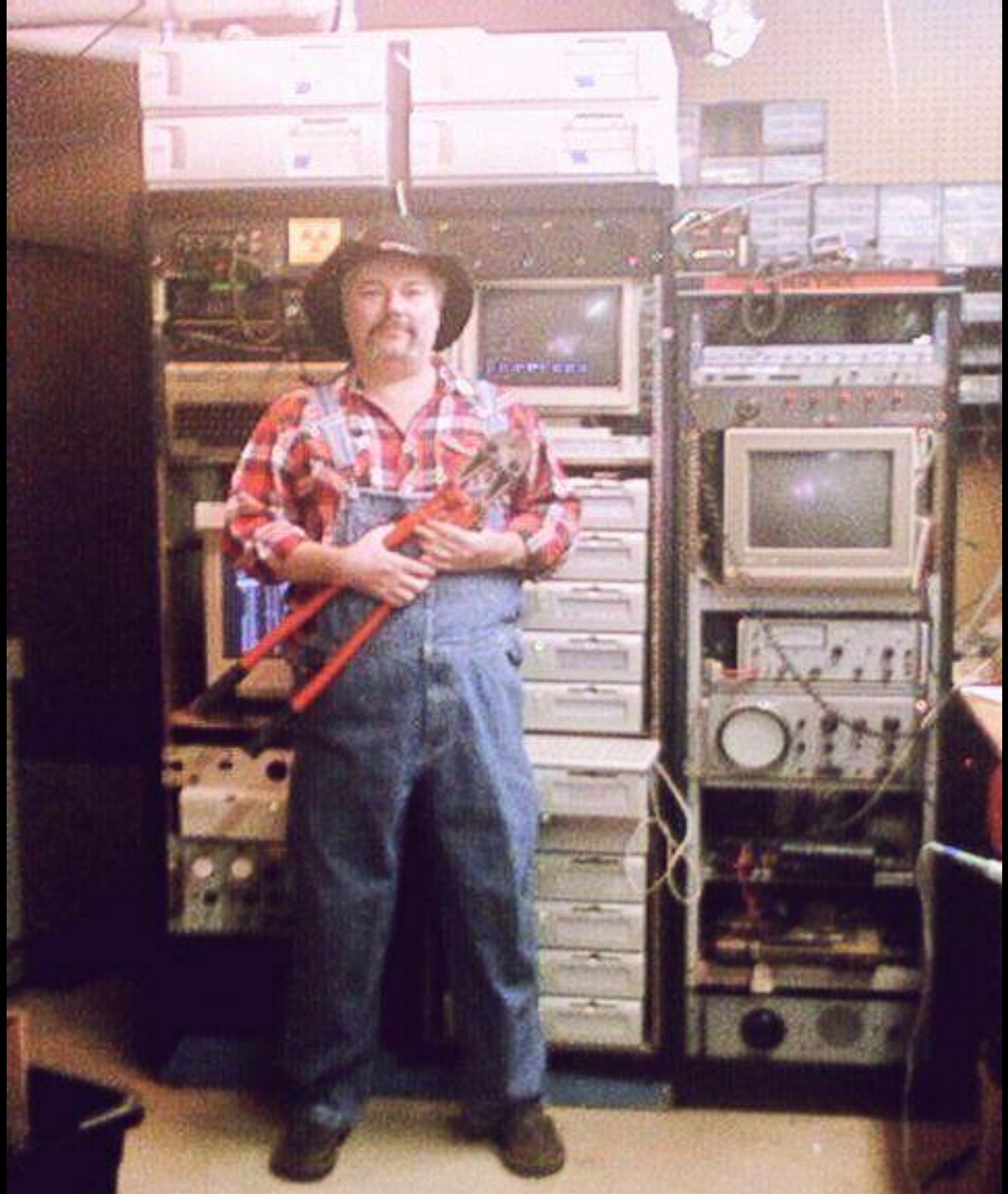


- Polyphase Channelization
- Coherent Doppler Drift Search
- Narrowband Pulse Search
- Gaussian Drift Search
- Autocorrelation
- <insert your algorithm here>

SETI@home Statistics

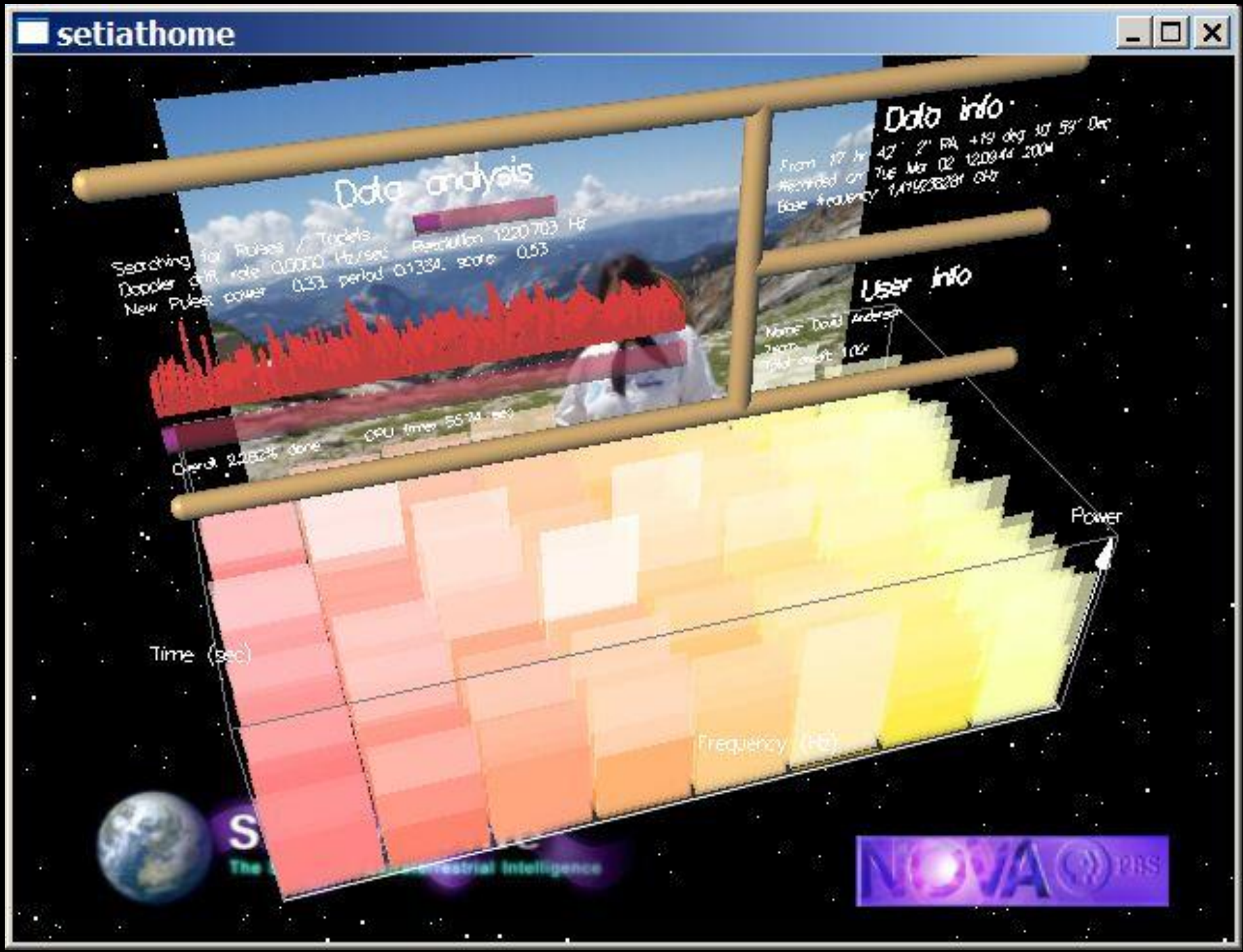
TOTAL	RATE
8,464,550 participants (in 226 countries)	2,000 per day
3 million years computer time	1,000 years per day
$3*10^{23}$ operations	3,000 Tera-flops

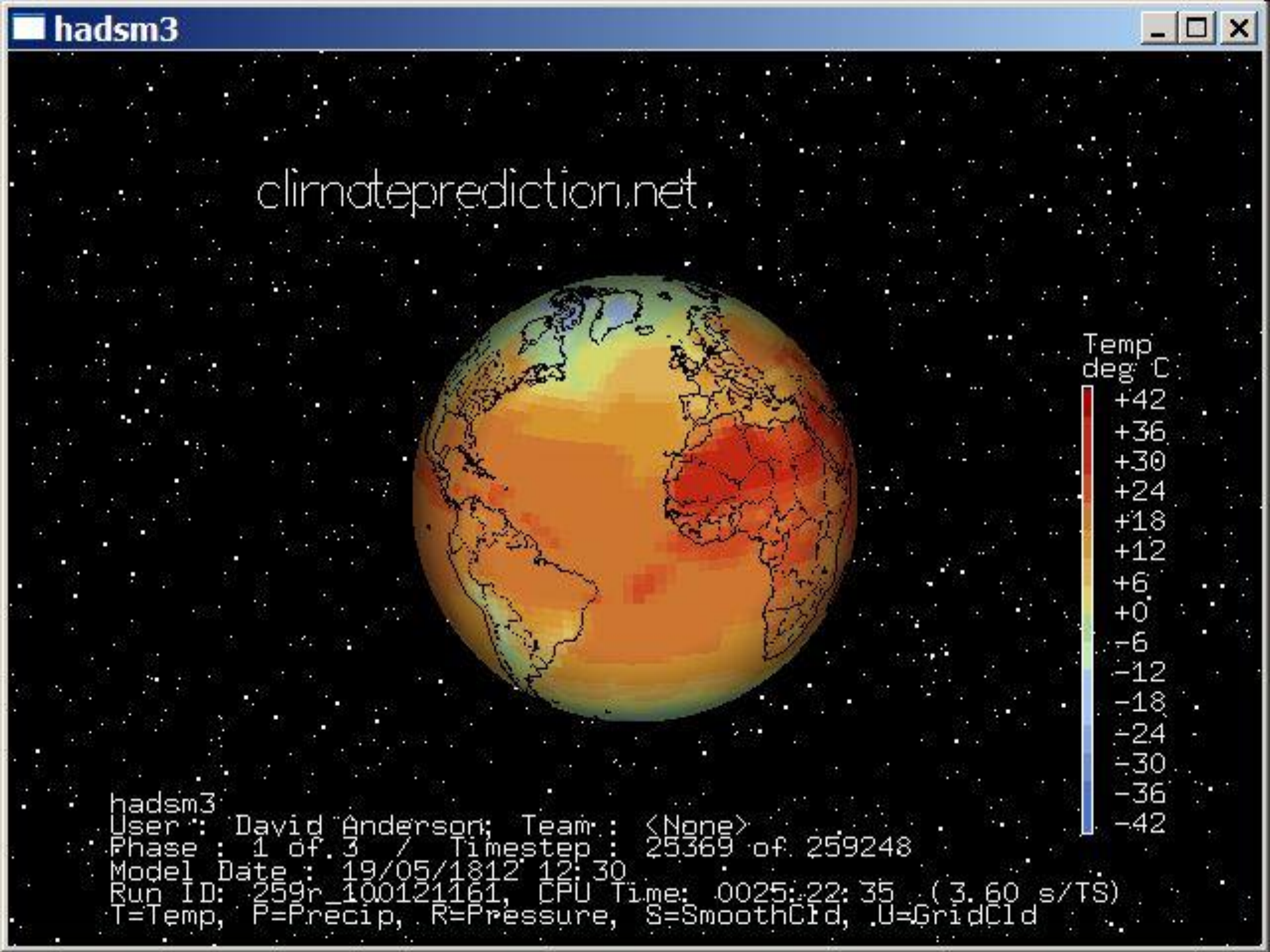

VOSBURG FAMILY

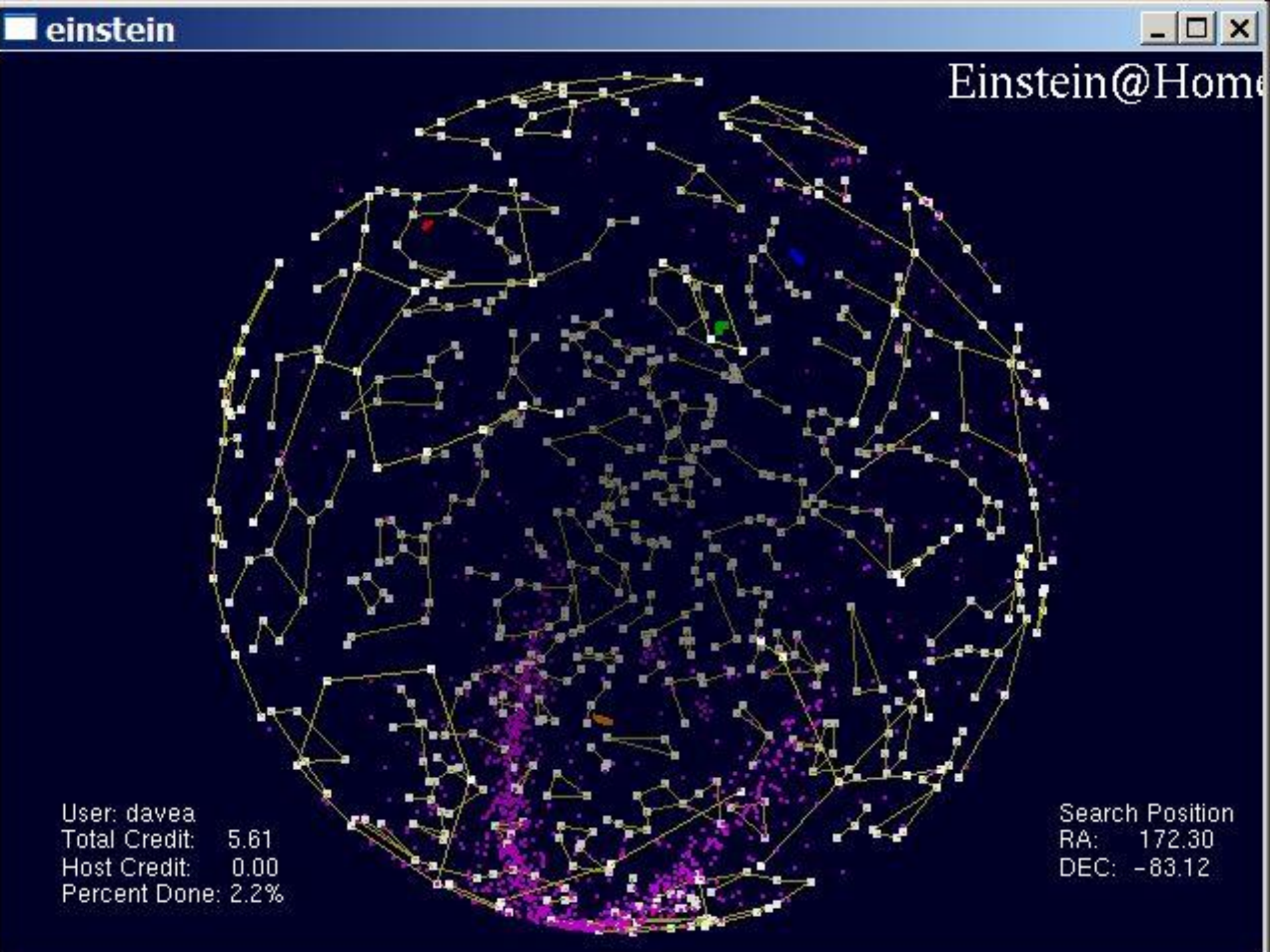


Projects

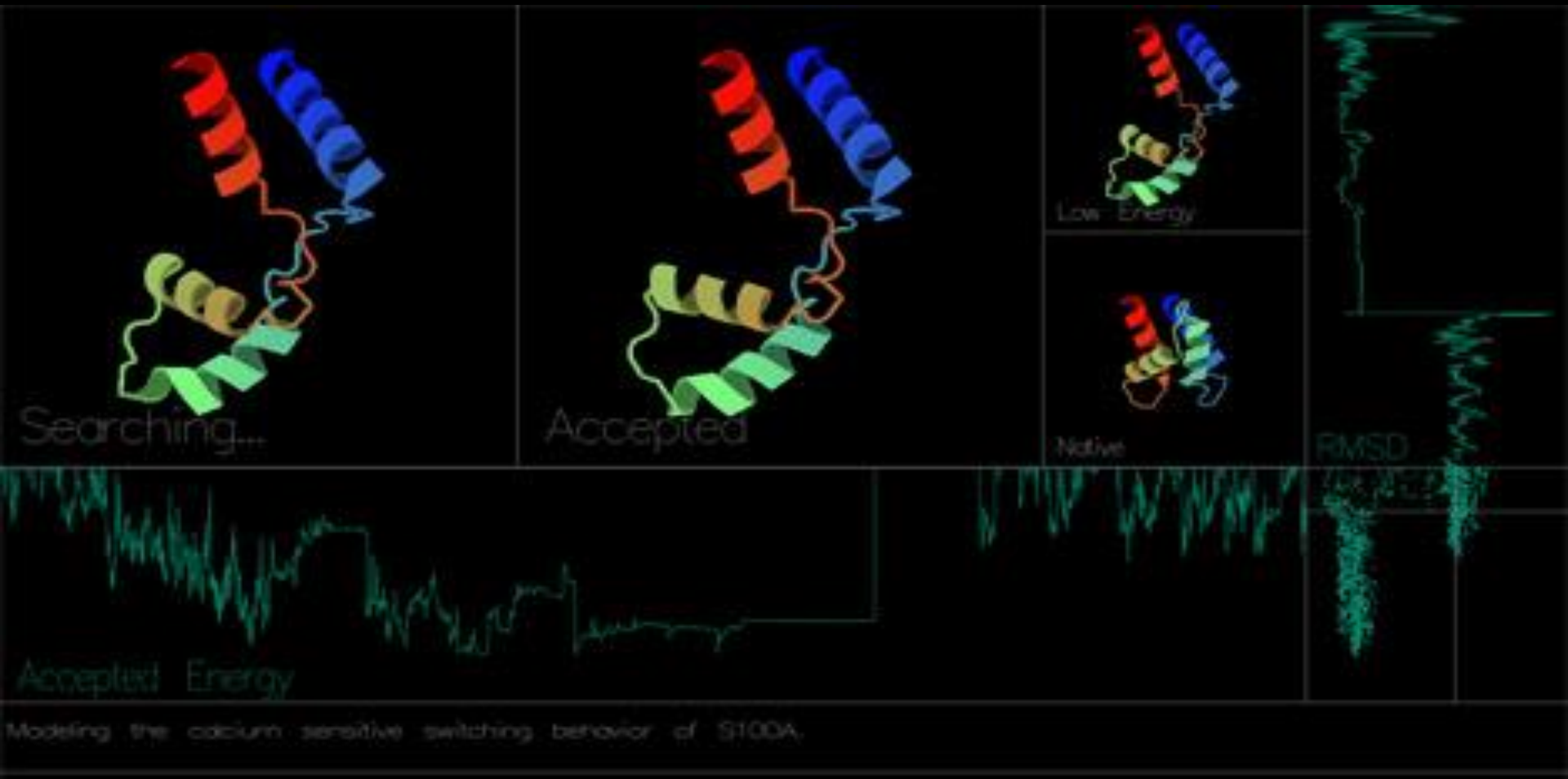
- Astronomy
  - SETI@home (Berkeley)
  - Astropulse (Berkeley)
  - Einstein@home: gravitational pulsar search (Caltech,…)
  - PlanetQuest (SETI Institute)
  - Stardust@home (Berkeley, Univ. Washinton,…)
- Earth science
  - Climateprediction.net (Oxford)
- Biology/Medicine
  - Folding@home, Predictor@home (Stanford, Scripts)
  - FightAIDSathome: virtual drug discovery
- Physics
  - LHC@home (Cern)
- Other
  - Web indexing/search
  - Internet Resource mapping (UC Berkeley)


setiathome
Data analysis
Searching for Pulses / Triplets
Resolution 1220703 Hz
Data info
User info
Power
Time (Sec)
Frequency (Hz)
NOVA
PBS

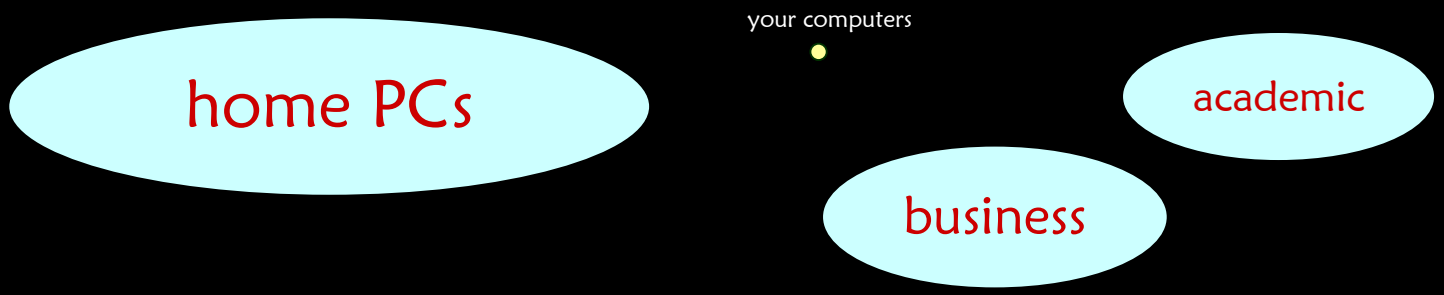

hadsm3
climateprediction.net
Temp
deg C
+42
+36
+30
+24
+18
+12
+6
+0
-6
-12
-18
-24
-30
-36
-42
hadsm3
User : David Anderson; Team : <None>
Phase : 1 of 3 / Timestep : 25369 of 259248
Model Date : 19/05/1812 12:30
Run ID: 259r_100121161, CPU Time: 0025:22:35 (3.60 s/TS)
T=Temp, P=Precip, R=Pressure, S=SmoothCld, U=GridCld


einstein
Einstein@Home
User: davea
Total Credit: 5.61
Host Credit: 0.00
Percent Done: 2.2%
Search Position
RA: 172.30
DEC: -83.12

Rosetta Screensaver



Where's the computing power?



2010: 1 billion Internet-connected PCs

55% privately owned

If 100M participate:

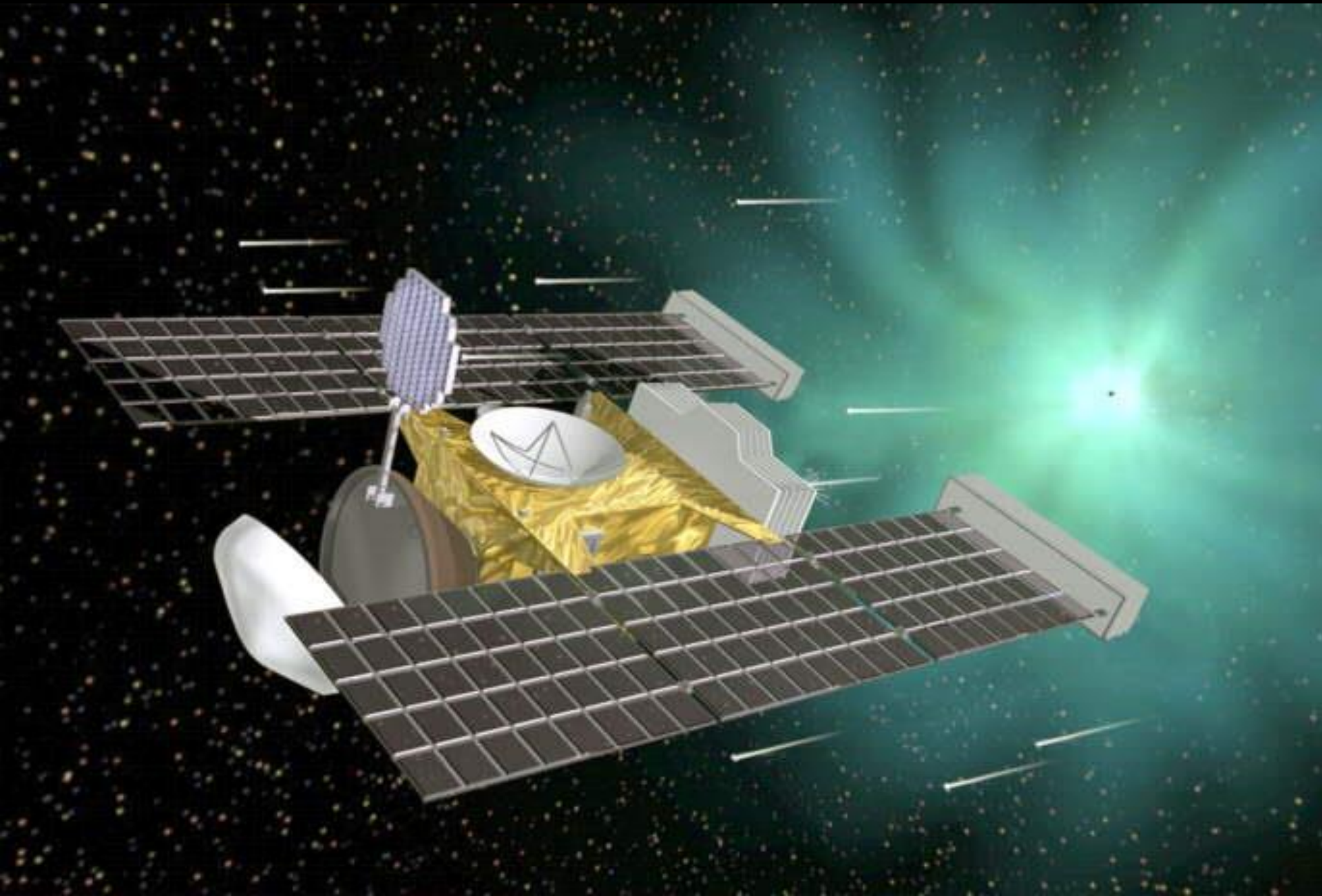
100 PetaFLOPs, 1 Exabyte (10^18) storage

Recently ported to Cell Phones (android) (8 billion)

Thinking@Home

Stardust@home...

Stardust (NASA)



Citizen Science Projects

- SETI@home and Astropulse (UC Berkeley)
- Stardust@home (UC Berkeley)
- SetiQuest (Seti Institute)
- Galaxy Zoo (Galaxy Classification)
- Audubon Society's Christmas Bird Count (1900)
- Community Collaborative Rain, Hail & Snow Monitor Network
- Clickworkers (mars crater identficiation - NASA)
- Ebird, NestWatch, FeederWatch, Urban Birds (Cornell Univ.)
- ParkScan (monitor San Francisco Parks)
- ScienceForCitizens.net
- ENERGY@home

Type 2 Signal Processing

Real Time in-situ Processing

Petabits per second (can not record data)

CASPER

Collaboration for Radio Astronomy Signal Processing and Electronics Research

Some of the CASPER Collaborators:

Xilinx, Fujitsu, HP, Sun/Oracle, Nvidia, NSF, NASA, NRAO, NAIC, CFA (Havard/Smithsonian), Haystack (MIT), Caltech, Cornell, CSIRO/ATNF, JPL/DSN, South Africa KAT, Manchester/Jodrell Bank, GMRT (India), Oxford, Bologna, Metsahovi Observatory/Helsinki University, University of California, Berkeley; Swinburne University (Australia), Seti Institute, University of California, Santa Barbara; University of California, Los Angeles; CNRS (France), University of Maryland Nancay Observatory, University of Cape Town (South Africa), ASTRON (Netherlands), Academica Sinica (Taiwan), Cambridge, Brigham Young University, Rhodes University (South Africa)


Greenland
Iceland
Canada
United States
México
North Atlantic Ocean
Suomi Finland
Sverige
Sweden
Norge
Norway
Россия
Russia
Polska
Poland
Україна
Ukraine
France
Italia
Italy
España
Spain
Türkiye
Turkey
Kazakhstan
Mongolia
中国
China
대한민국
S Korea
日本
Japan
Iraq
Iran
Afghanistan
Pakistan
India
Saudi Arabia
مصر
Egypt
Libya
Algeria
Mauritania
Mali
Niger
Chad
Sudan
Nigeria
Ethiopia
Kenya
DR Congo
Tanzania
Angola
Namibia
Botswana
South Africa
Madagascar
Indian Ocean
ประเทศไทย
Thailand
Indonesia
Papua New Guinea
Australia
New Zealand
Venezuela
Colombia
Brasil
Brazil
Perú
Bolivia
Chile
Argentina
South Pacific Ocean
South Atlantic Ocean

MWA
XNTD
PAPER
FAST
PAST
LAR
LWA

meerkat
karoo array telescope

CARMA
Combined Array for Research in Millimeter-Wave Astronomy

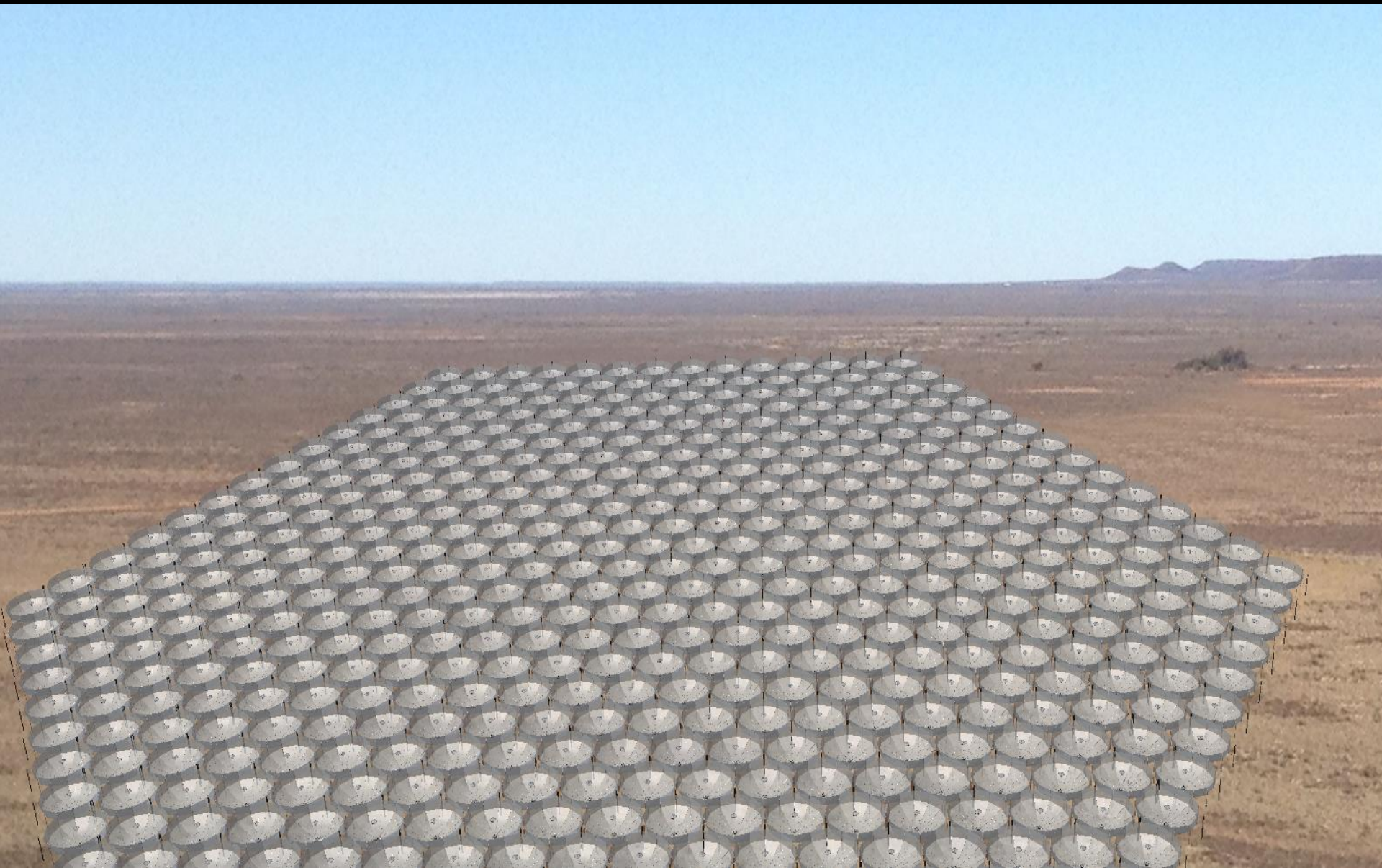
SKA
SQUARE KILOMETRE ARRAY

Expanded
Very Large Array

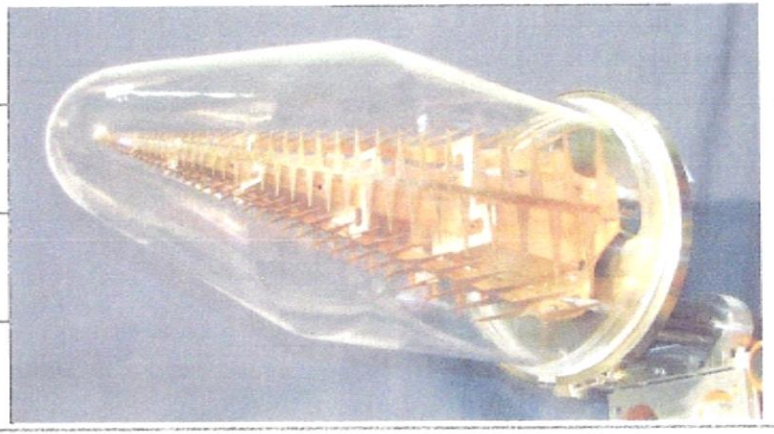
LWA

ALMA
ATACAMA LARGE MILLIMETER ARRAY

HERA Array 547 x 15 meter dishes



Measured Receiver Temperature & Tsys at Zenith
Cooled ATA Feed



Jack Welch, Matt Fleming, Dave DeBoer,
Sandy Weinreb, Rob Spencer

Temperature in K

0 10 20 30 40 50 60 70 80

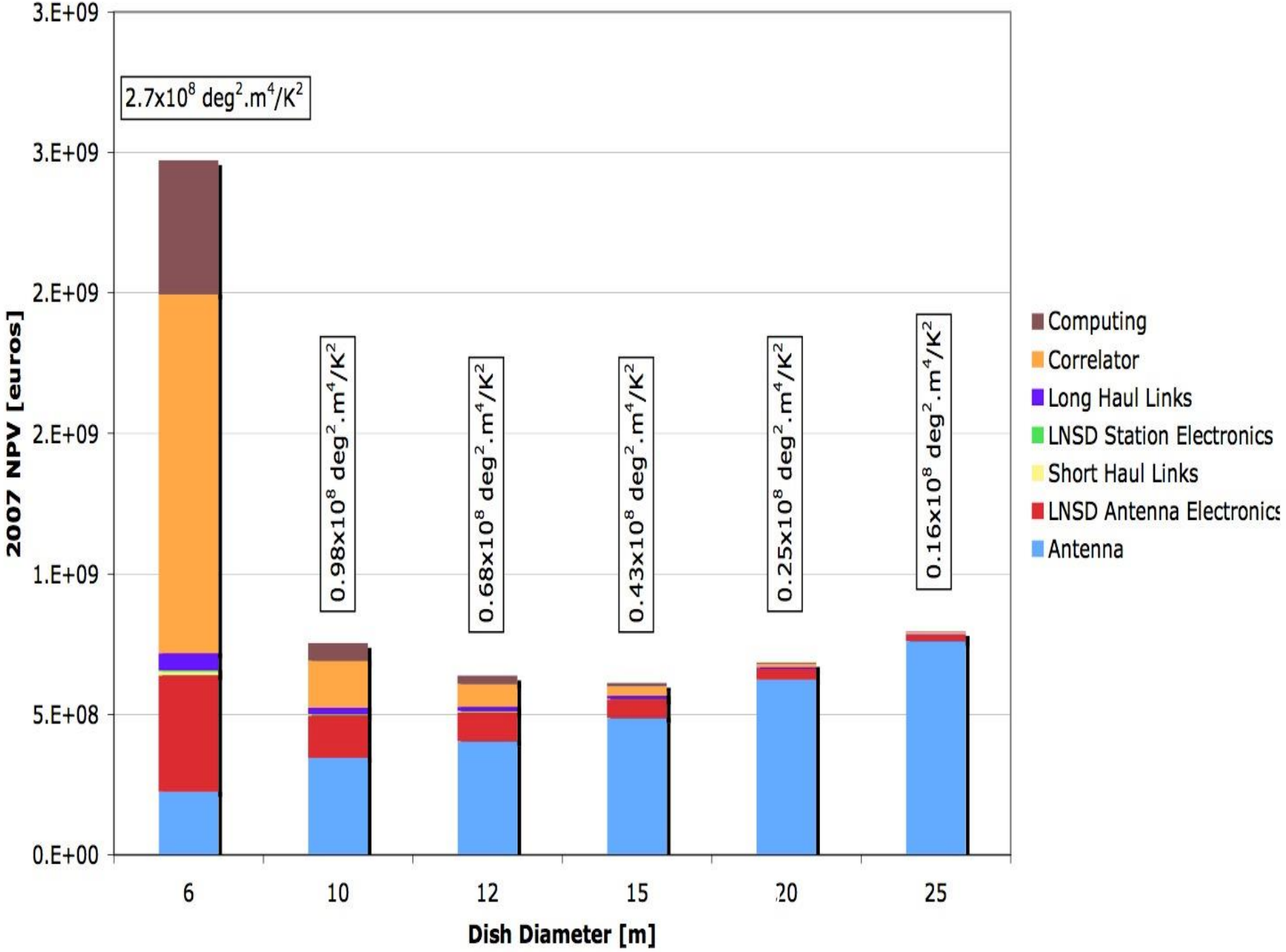
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

Frequency in GHz

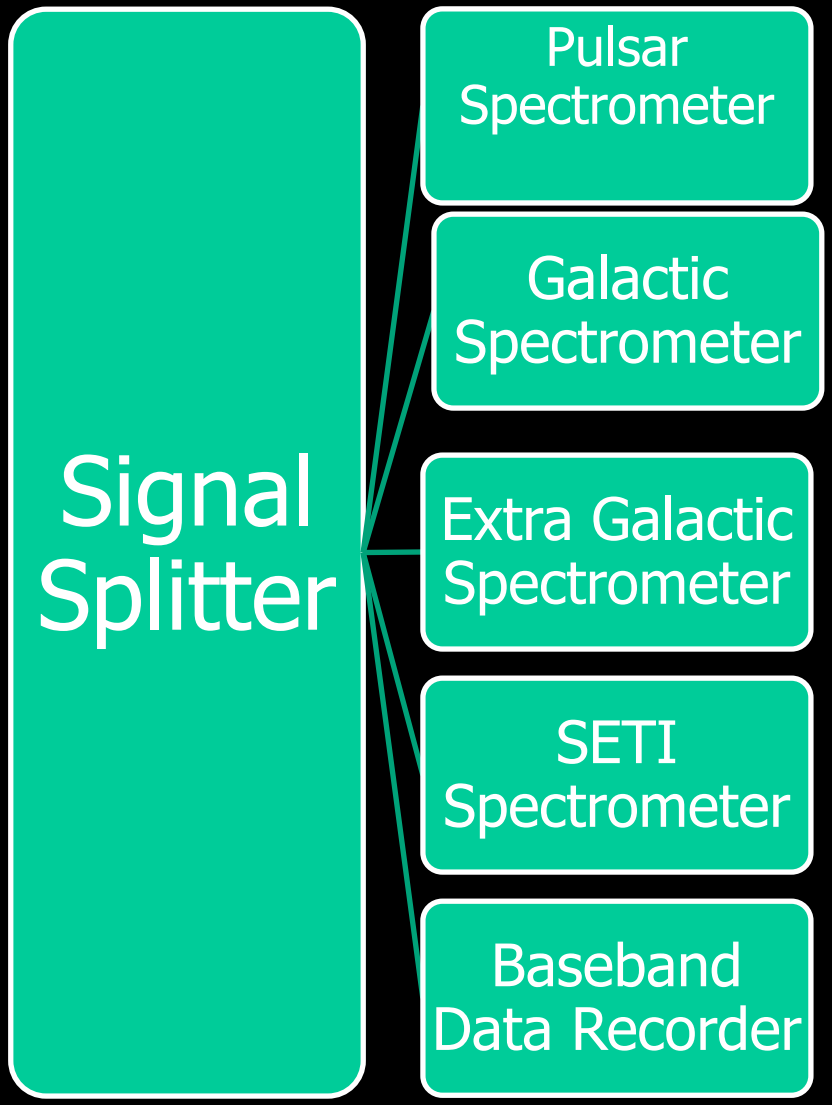
AVG TRx (sky,Tradome=7)
AVG TRx (lab)
Tsys at zenith w. galaxy

Phased Array Feed – 64 beams


xilostudios.com


3.E+09
3.E+09
2.E+09
2.E+09
1.E+09
5.E+08
0.E+00
2007 NPV [euros]
2.7x10^8 deg^2.m^4/K^2
0.98x10^8 deg^2.m^4/K^2
0.68x10^8 deg^2.m^4/K^2
0.43x10^8 deg^2.m^4/K^2
0.25x10^8 deg^2.m^4/K^2
0.16x10^8 deg^2.m^4/K^2
6
10
12
15
20
25
Dish Diameter [m]
Computing
Correlator
Long Haul Links
LNSD Station Electronics
Short Haul Links
LNSD Antenna Electronics
Antenna

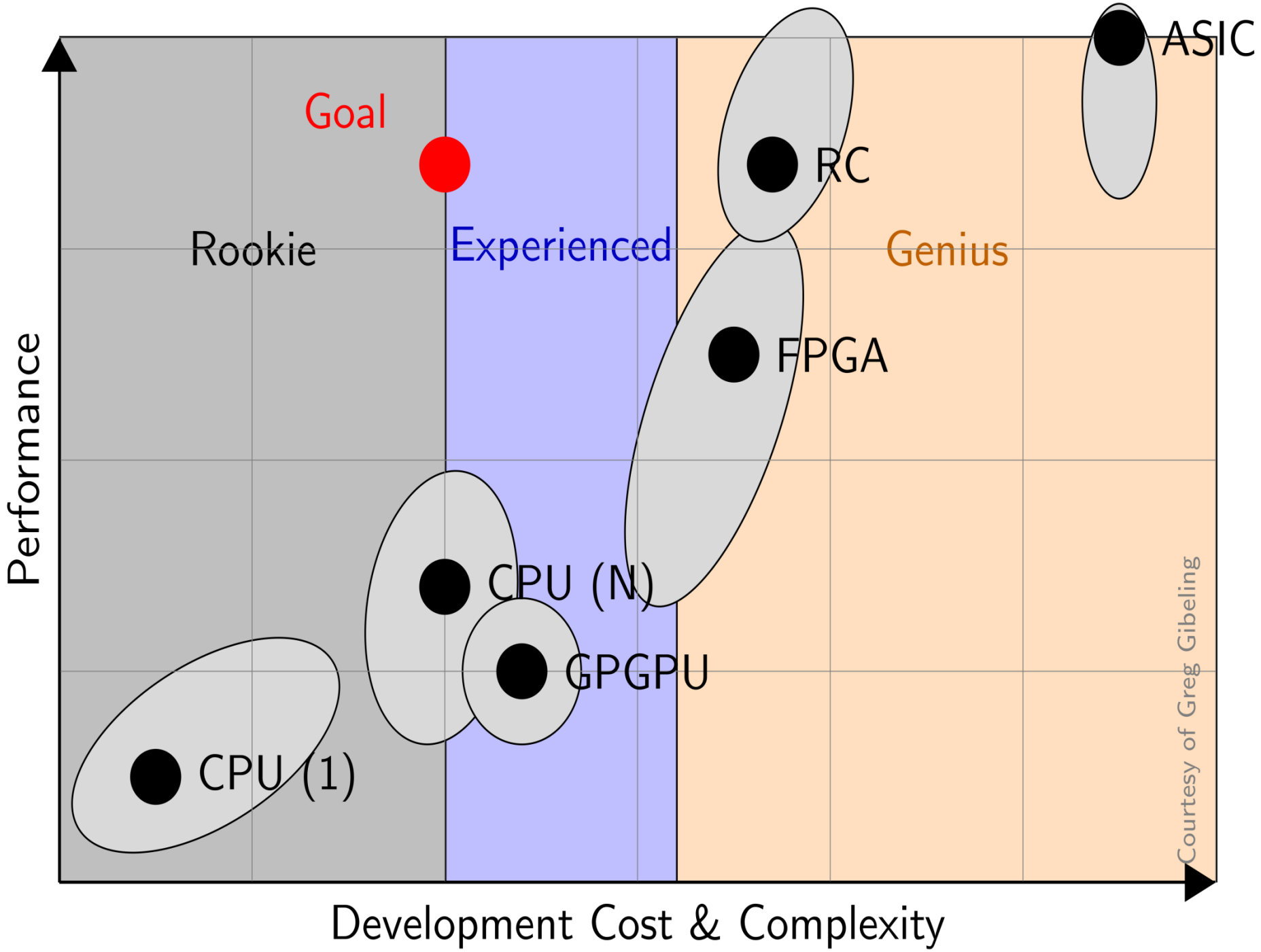
Simultaneous Digital Backends Piggyback, Commensal, Sky Surveys



Analog Power Splitters

or

Digital Data Splitter


Goal
Rookie
Experienced
Genius
ASIC
RC
FPGA
CPU (N)
GPGPU
CPU (1)
Performance
Development Cost & Complexity
Courtesy of Greg Gibeling

FPGA vs GPU

FGPA = synchronous, GPU = asynchronous

eg: ADC input: FGPA to time stamp, packetize

FPGA: 1 Tbit/sec I/O GPU: 18 Gbit/sec

GPU's use more power (3 - 20X FPGA)

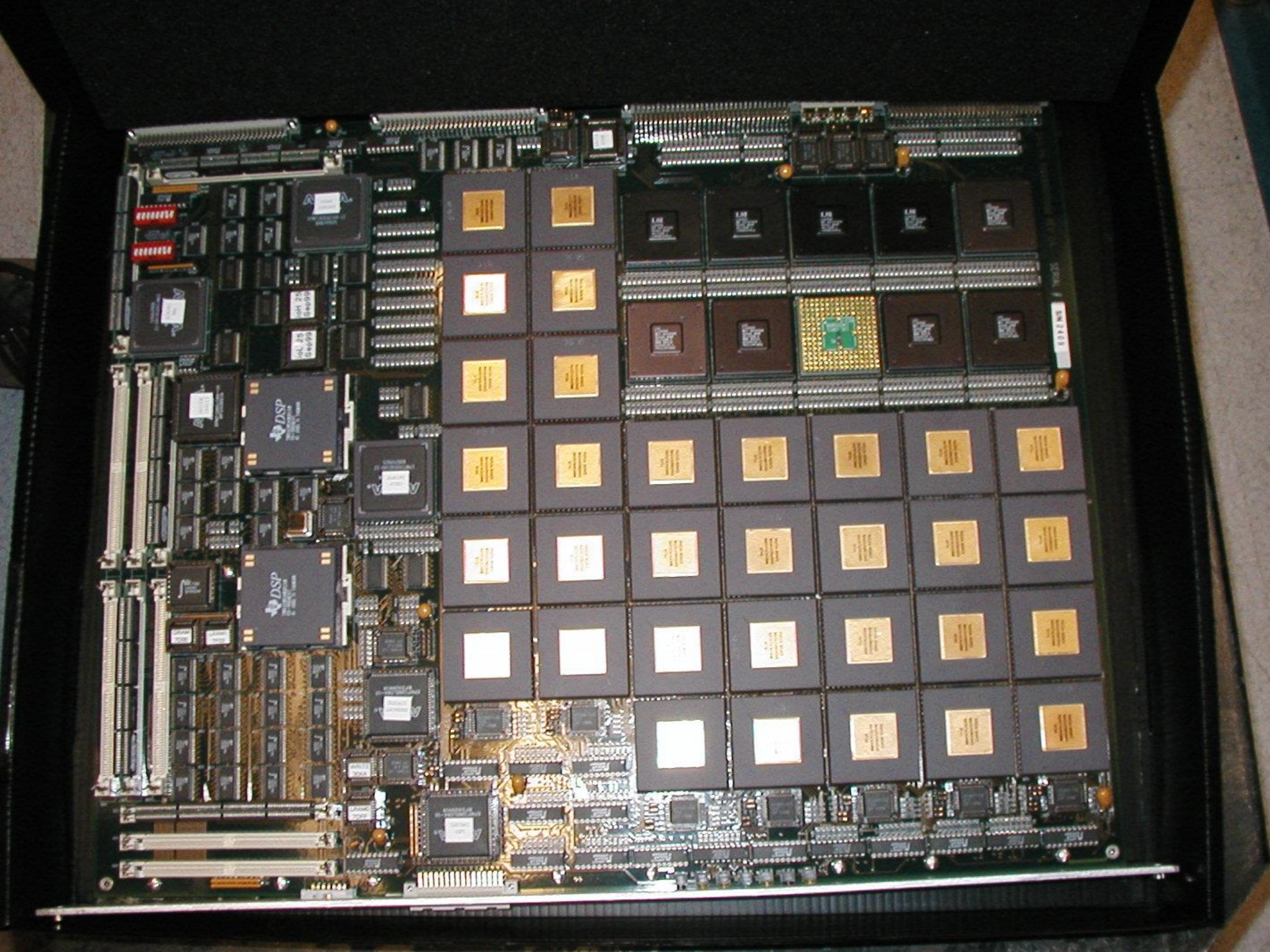
GPU's are easier to program (CUDA)

GPU's are cheaper

GPU's are good at floating point

The Problem with the Traditional Hardware Development Model

- Takes 5 to 10 years
- Cost Dominated by NRE because of custom Boards, Backplanes, Protocols
- Antiquated by the time it's released.
- How to buy the hardware at the last minute?
- Each observatory designs from scratch


DSP
DSP


CAUTION
WERNER

Solution:

Modular General Purpose Hardware

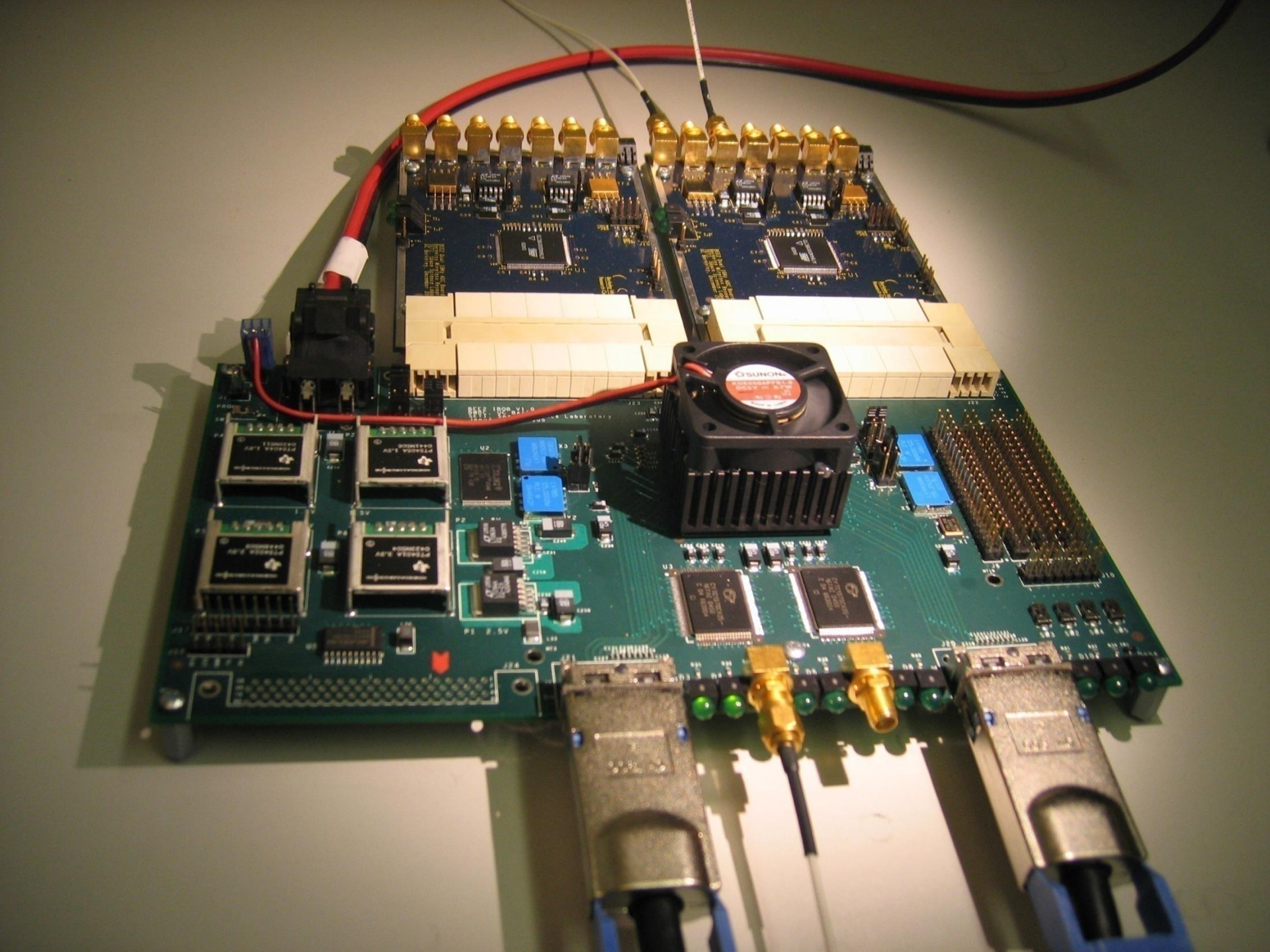
- Low number of board designs
- Can be upgraded piecemeal or all together
- Reusable
- Standard signal processing model which is consistent between upgrades.

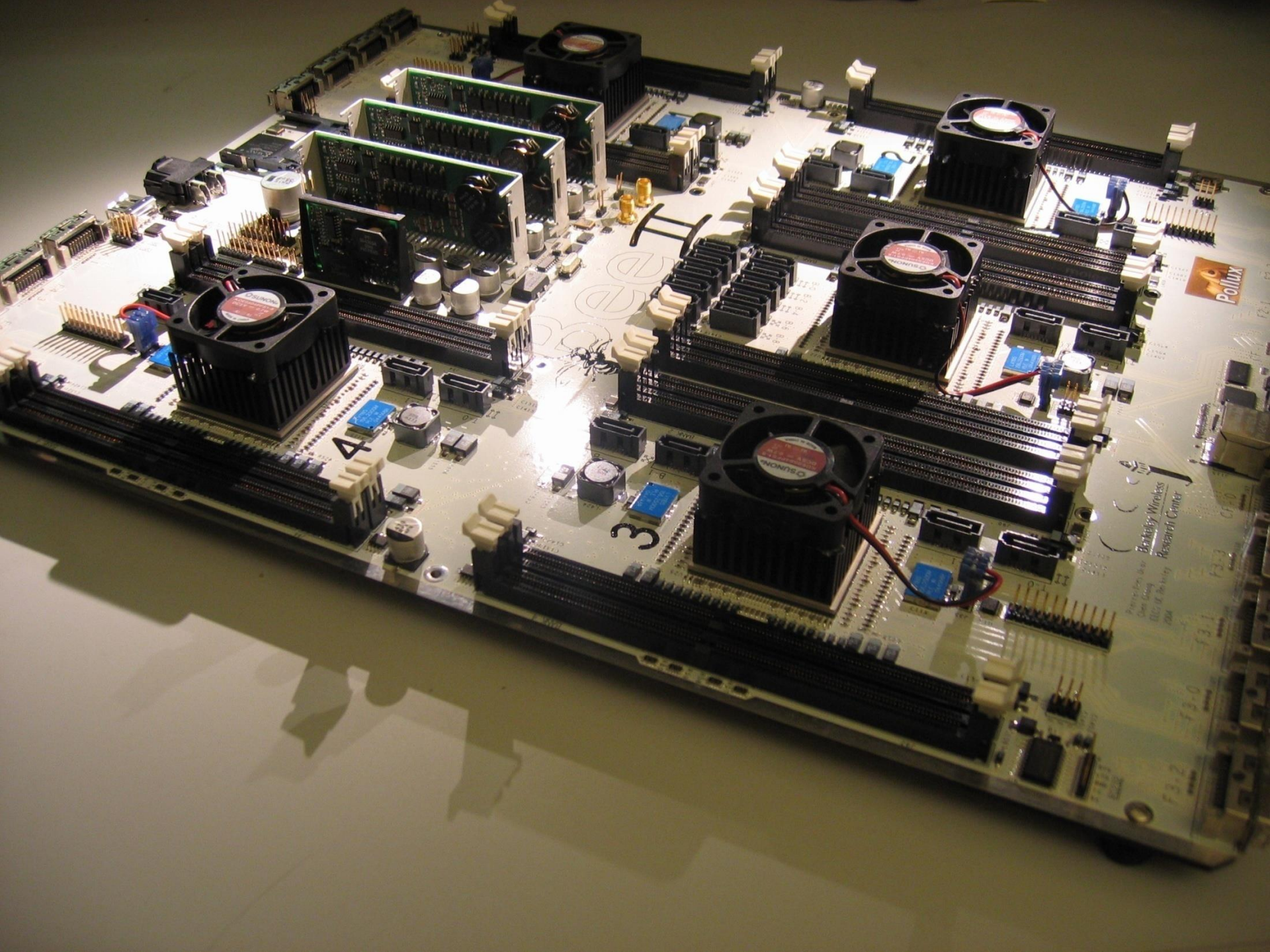
CASPER Real-time Signal Processing Instrumentation

- Low NRE, shared by the community
- Rapid development
- Open-source, collaborative
- Reusable, platform-independent gateware
- Modular, upgradeable hardware
- Industry standard communication protocols
- Use switches to solve correlator interconnect
- Low Cost

Collaboration

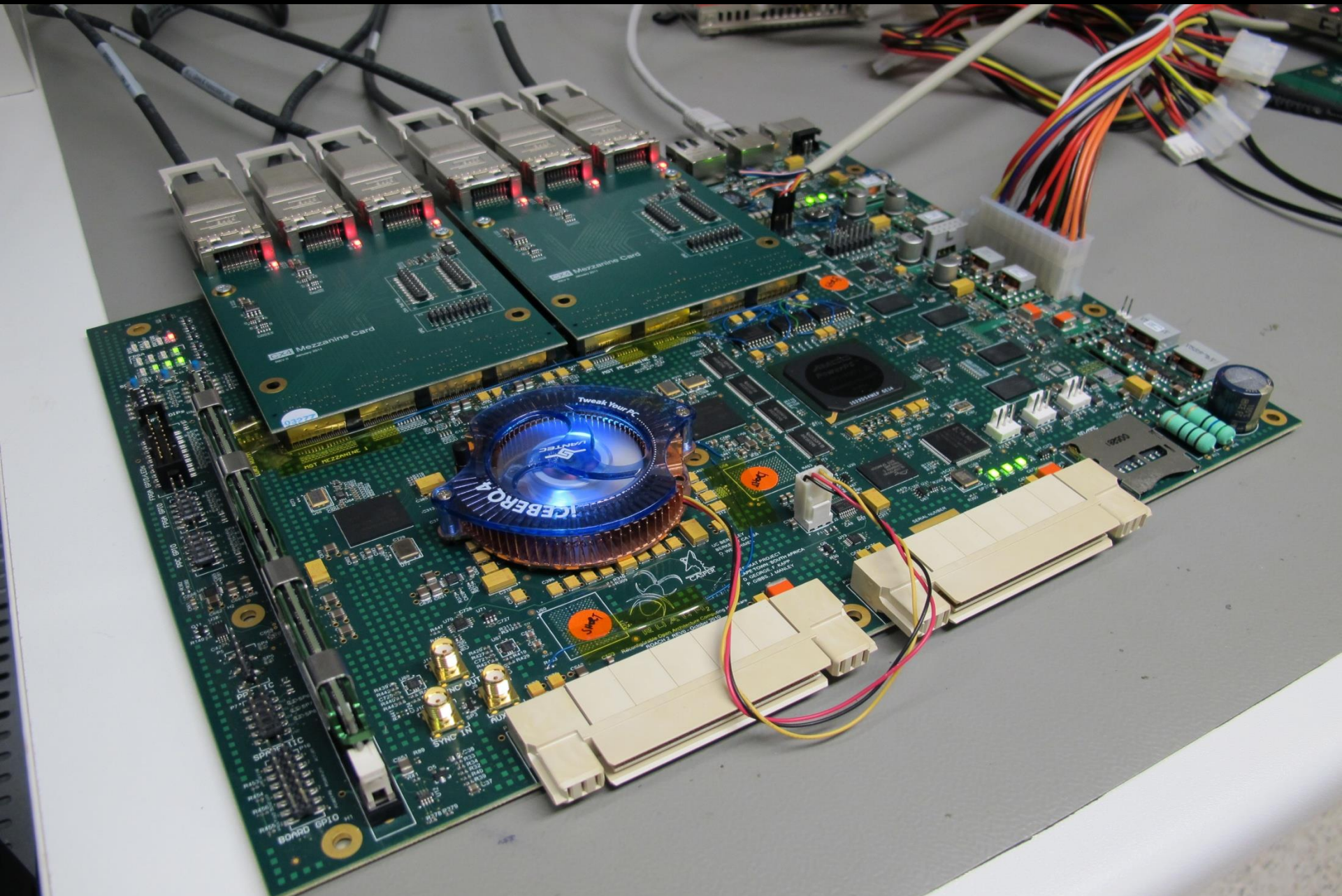
- Share Open Source Libraries
- Workshops
- Video’s and Doc’s on Tool Flow, Libraries
- Wiki, Mailing List
- Open Source Boards (available from vendors)




Pollux
Berkeley Wireless
Research Center

Roach Motel (Roach Nest) (KAT)

Roach II (South Africa KAT)



Current CASPER ADC Boards

ADC2x1000-8 (dual 1GSa/sec, single 2Gsps, 8 bit)

ADC1x3000-8 (3GSa/sec, 8 bit) ADC (6Gsps interleaved)

64ADCx64-12 (64x 64MSa/sec, 12 bit)

ADC4x250-8 (quad 250MSa/sec, 8 bit)

katADC (dual 1.5GSa/sec, 8 bit, with gain, atten, synth)

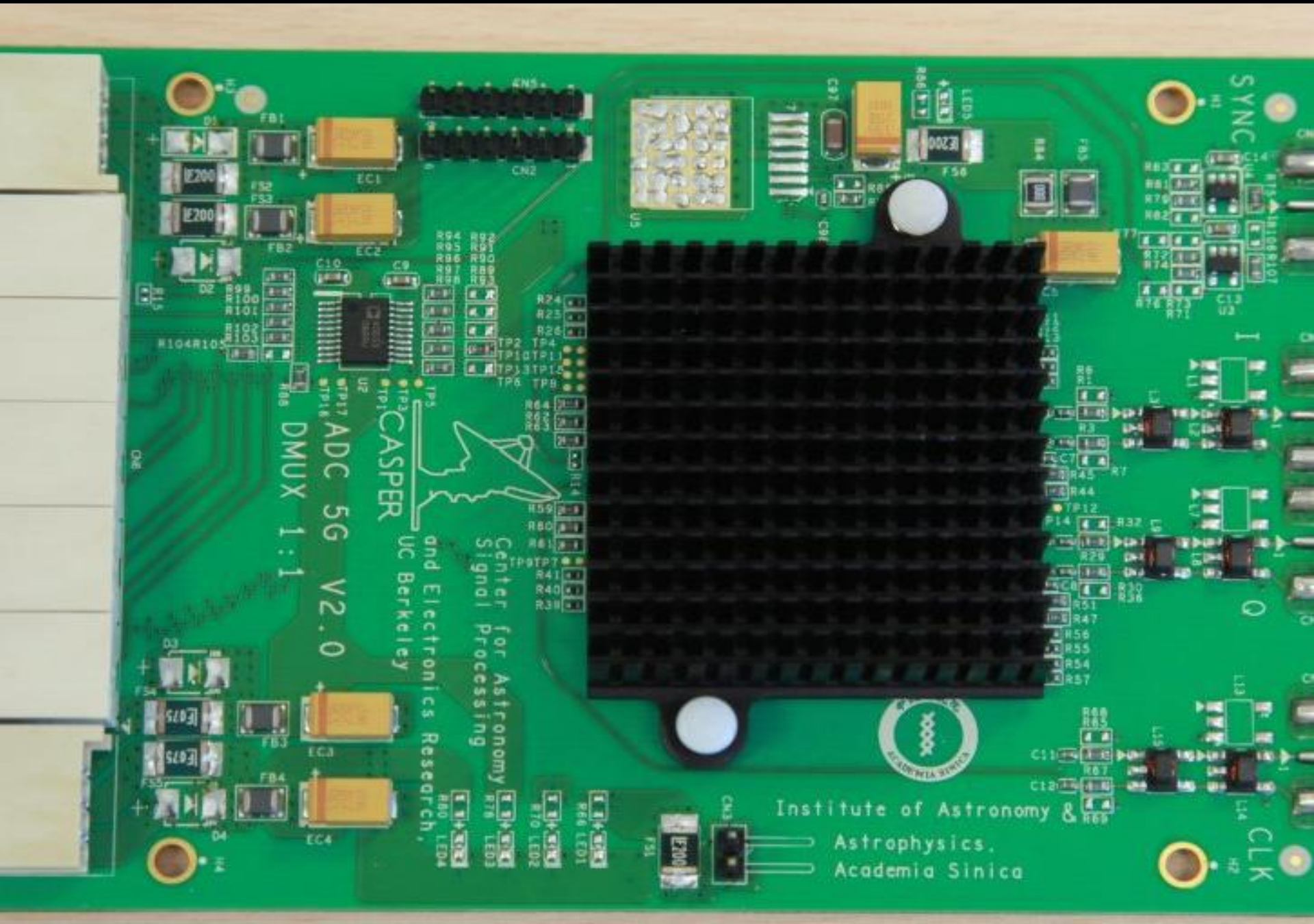
ADC2x550-12 (dual 550 Msps, 12 bit)

ADC2x400-14 (dual 400 Msps, 14 bit)

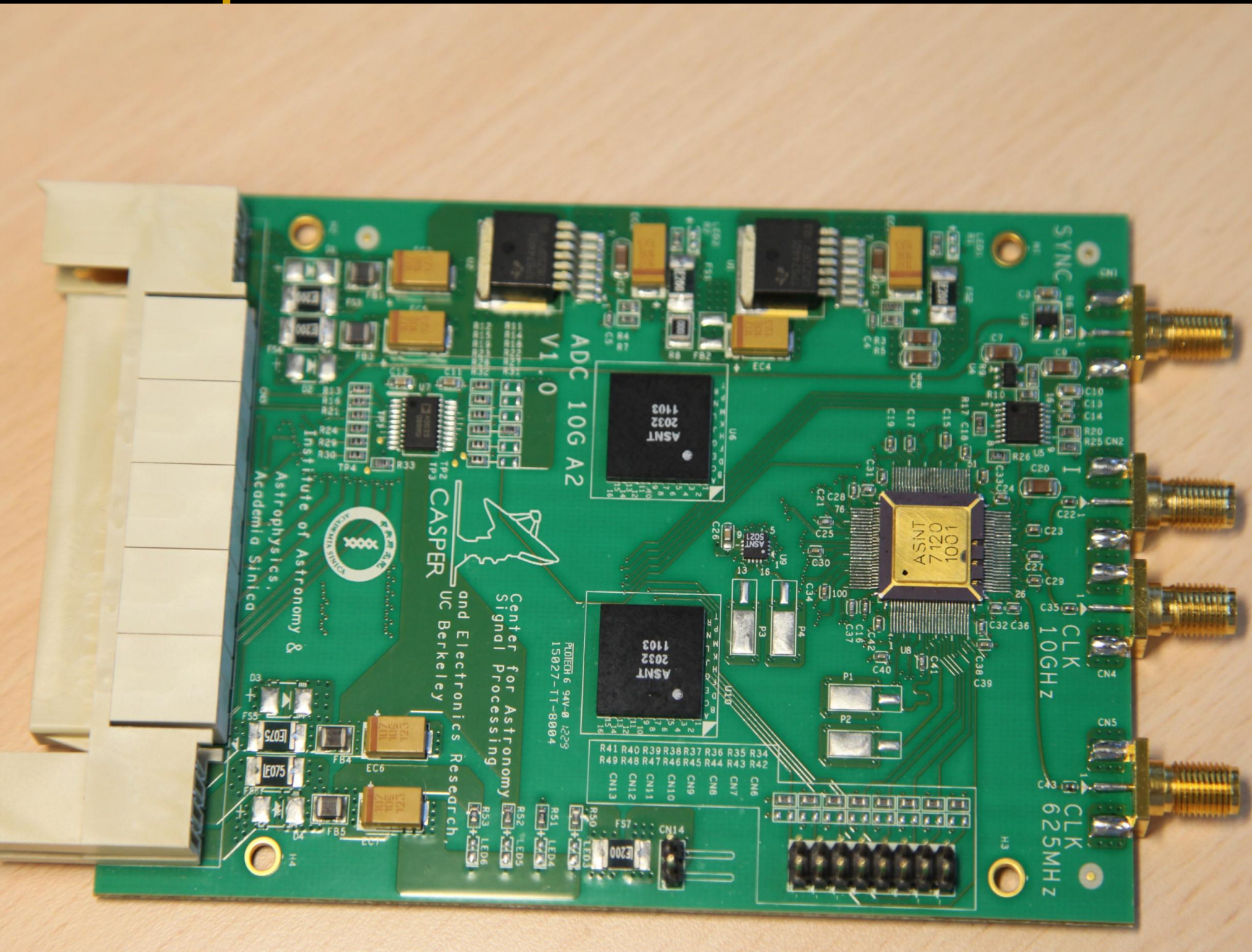
ADC1x5000-8 (1x5Gsps,2x2.5Gsps, ASIAA - Taiwan)

ADC1x1000-12 (optically isolated 12 bit 1Gsps – JPL)

5 Gsps, 8 bit ADC - ASIAA (tested at ASIAA, CFA, NRAO, UCB)



10 Gsps 4 bit ADC: ASIAA Kim Guizino



20 to 60 Gsps ADC's ??

26 Gsps	3.5 bit	Hittite ADC
20 Gsps	5 bit	E2V ADC
60 Gsps	8 bit	Fujitsu
20 Gsps	6 bit	Micram

Board Interconnect - Upgradable

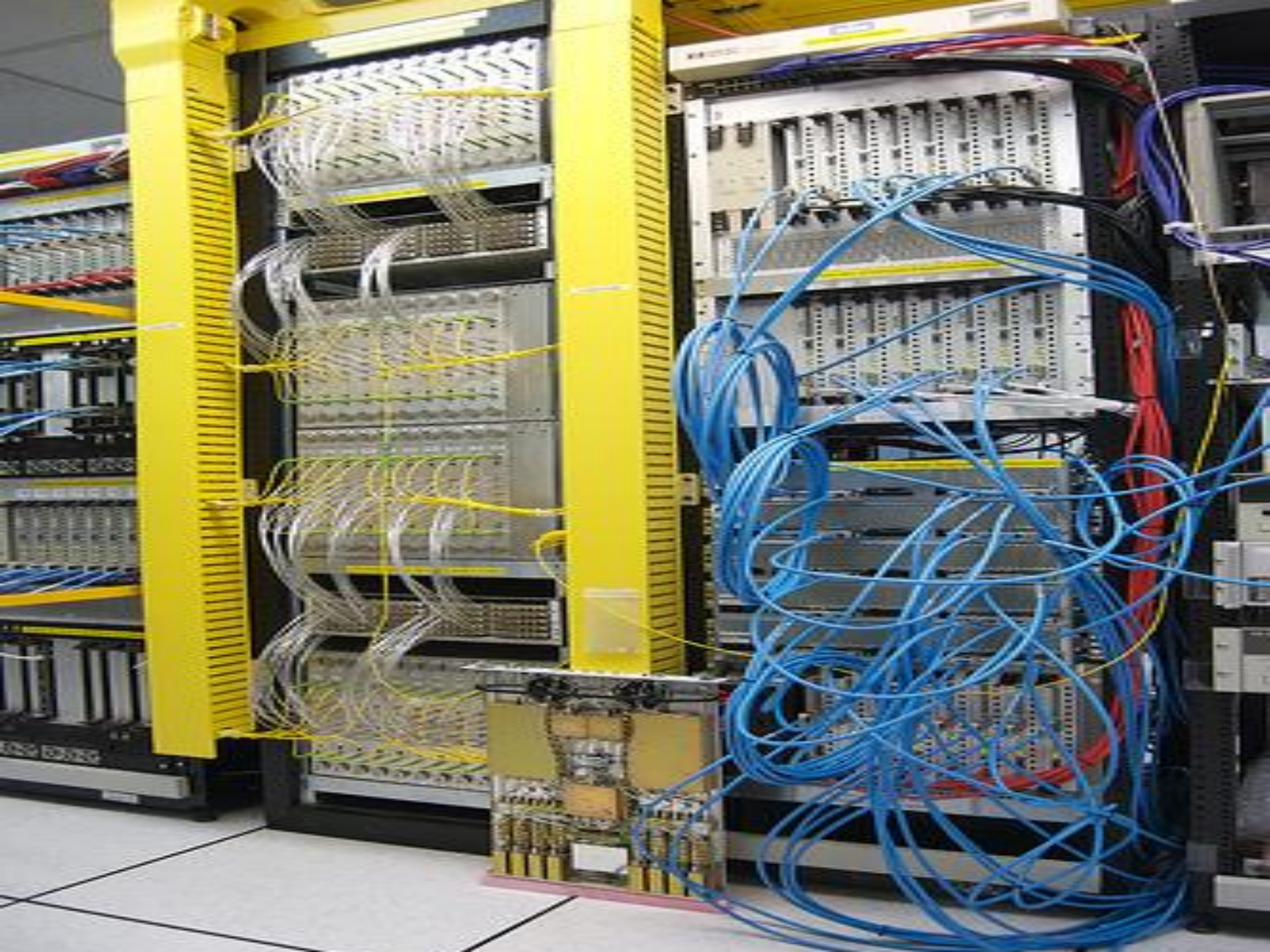
- Problem: Backplanes are short lived

  (S100, Multibus, VME, ISA, EISA, PCI, PCIx, PCIe, PCIe2.0, compactPCI, compactPCIe, ATCA…)

- Solution: Use 10Gbit Ethernet (40/100 Gbe)

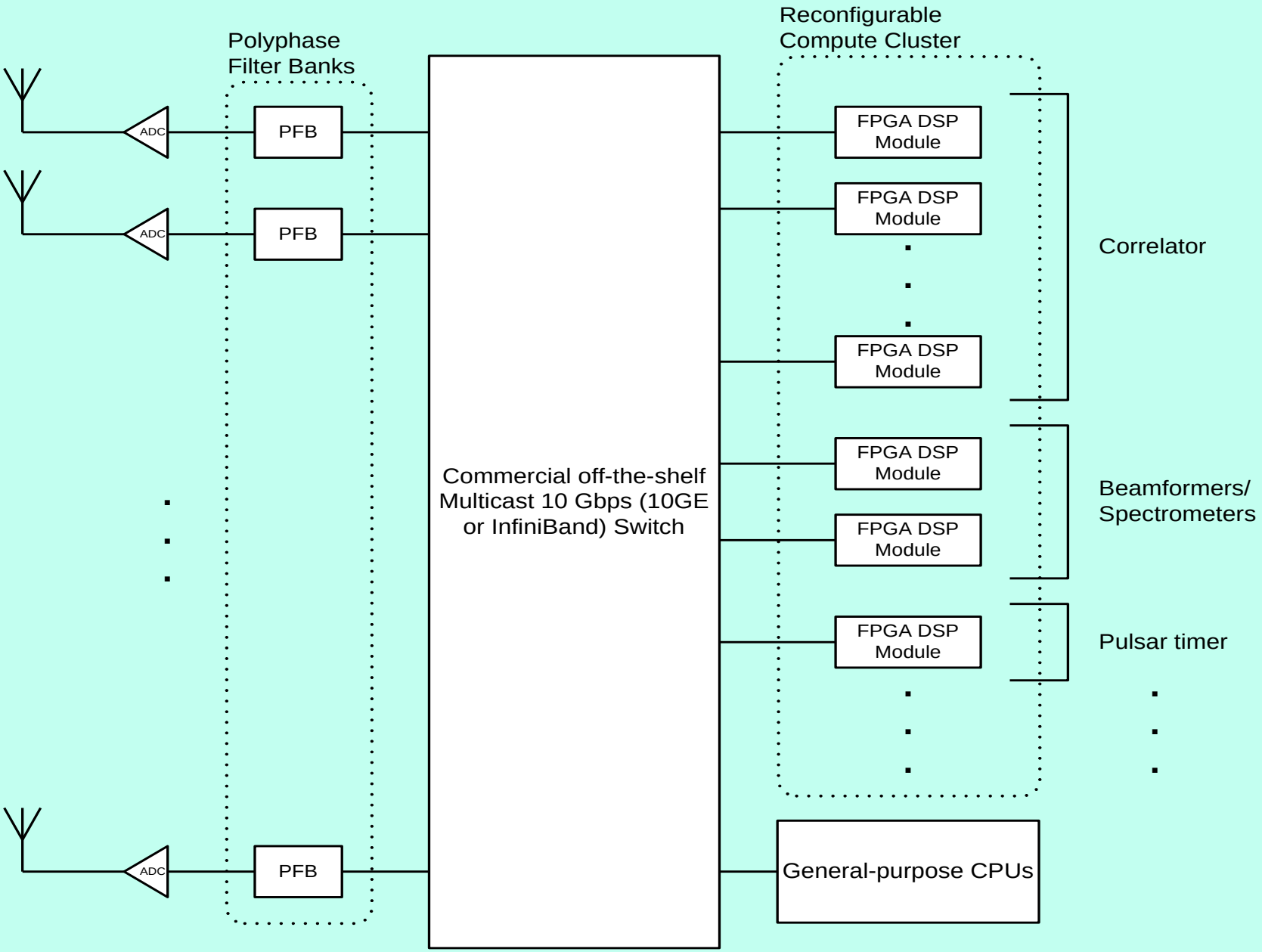
  (10Gbe, Infiniband, Myrinet, Xaui, Aurora)

  Copper CX4/SFP+ (15 meters max) or Optical



Beowulf Cluster Like General Purpose Architechture

Dynamic Allocation of Resources, need not be FPGA based



Serendip VI & ALFABURST (Hemant Shukla, NSF)
UCB, WVU, Oxford, Arecibo (and soon, GBT)

10, 40 Gbit Ethernet Switches, NIC's

Fujitsu, Arista Cisco, Force10, Fulcrum, Extreme Networks, HP, Mellanox… ($85 per port)

CX4 connectors (old), RJ45, SFP+ (standard)

756 10Gbe ports or 300 40Gbe ports
full crossbar, non blocking - available now
(big enough for SKA already, 20 Tbit/sec)

40 and 100 Gbit ethernet switches available now

inexpensive 1U switch: 36x40Gbe or 144x10Gbe

Platform-Independent, Parameterized Gateware

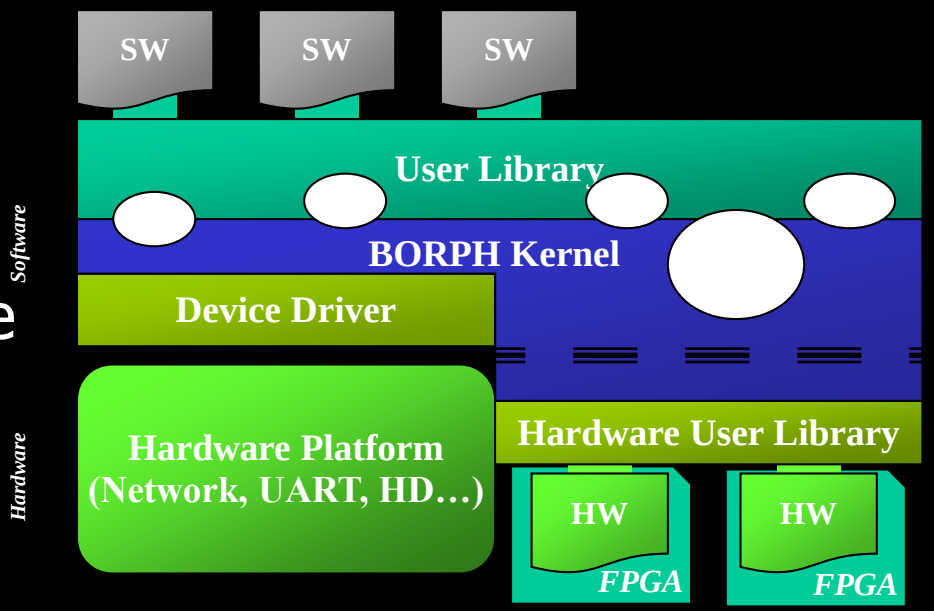
- Libraries for signal processing which don't have to be rewritten every hardware generation.
- Matlab Simulink
- Linux File I/O and Process Control

  Borph – Hayden So

  FPGA device Drivers – Shanly Rajan

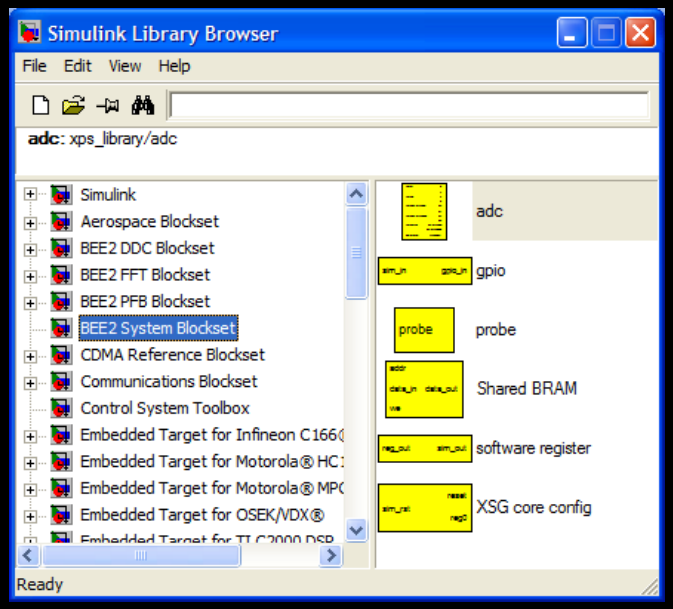
BORPH Operating System – Hayden So and fast FGPA device drivers – Shanly Rajan

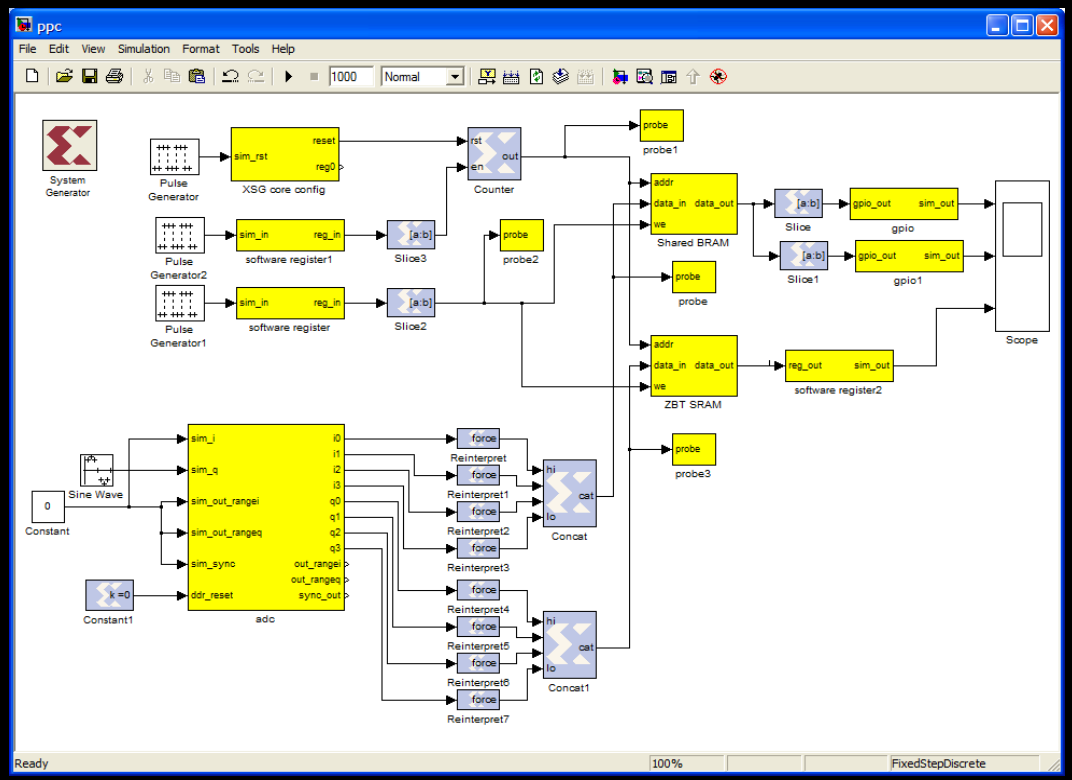
- An extended version of Linux operating system
  - Treats FPGAs = CPUs
- FPGA applications execute as hardware processes
- HW/SW communication
  - UNIX file I/O
- Benefits
  - Easy to understand for novice/experienced users
  - **Remote control+monitor**

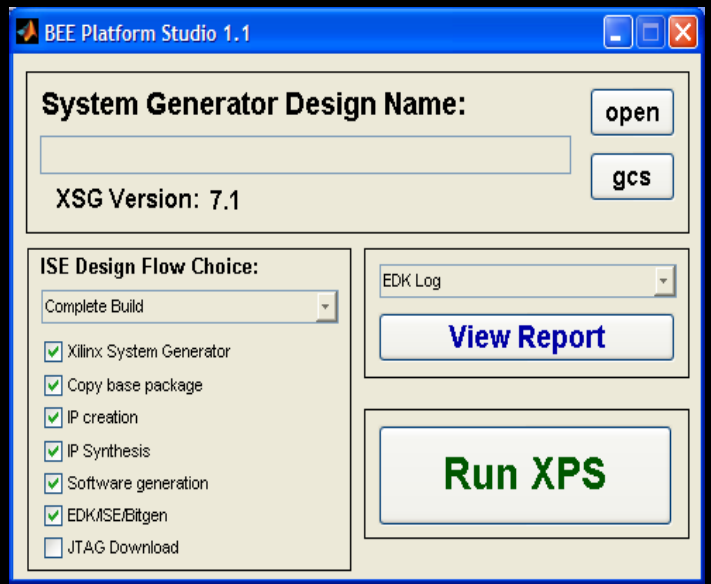


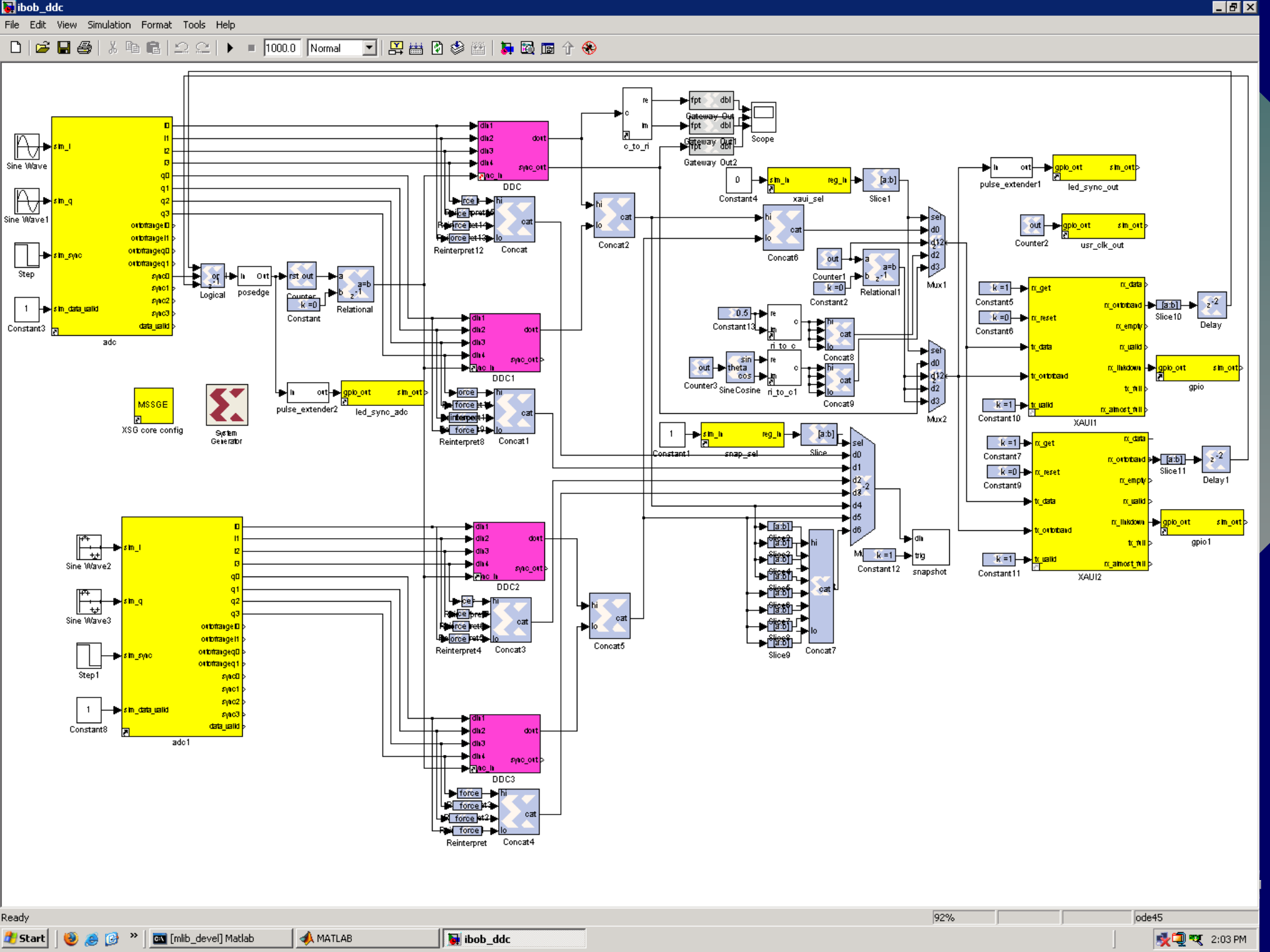
Poster Session 3 P3_09 (11am):
File System Access From Reconfigurable FPGA Hardware Processes in BORPH

Simulink-based Design Tool Flow







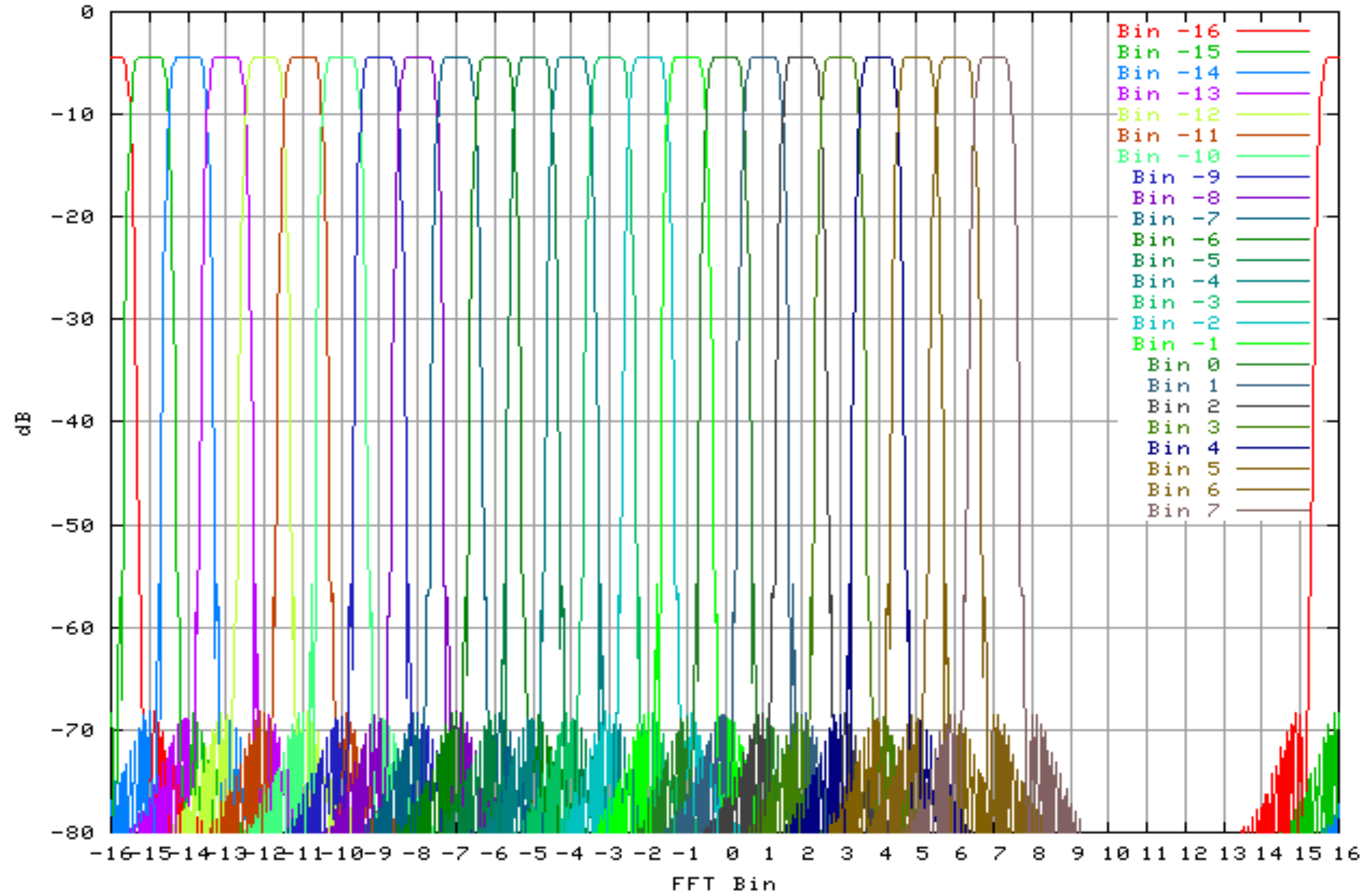

ibob_ddc
File Edit View Simulation Format Tools Help
Normal
Sine Wave
Sine Wave1
Step
Constant3
adc
Logical
posedge
Constant
Relational
DDC
DDC1
DDC2
DDC3
Reinterpret12
Reinterpret8
Reinterpret4
Reinterpret
Concat
Concat1
Concat2
Concat3
Concat4
Concat5
Concat6
Concat7
Concat8
Concat9
c_to_ri
Gateway Out
Gateway Out1
Gateway Out2
Scope
Constant4
xaui_sel
Slice1
Mux1
Mux2
Counter1
Constant2
Relational1
Counter2
usr_clk_out
pulse_extender1
led_sync_out
Constant13
ri_to_c
Counter3
SineCosine
ri_to_c1
MSSGE
XSG core config
System Generator
pulse_extender2
led_sync_adc
Constant1
snap_sel
Slice
Constant12
snapshot
Slice9
Sine Wave2
Sine Wave3
Step1
Constant8
adc1
Constant5
Constant6
Constant10
XAUI1
Slice10
Delay
gpio
Constant7
Constant9
Constant11
XAUI2
Slice11
Delay1
gpio1
Ready
92%
ode45
Start
[mlib_devel] Matlab
MATLAB
ibob_ddc
2:03 PM

FFT controls

Simulink Library

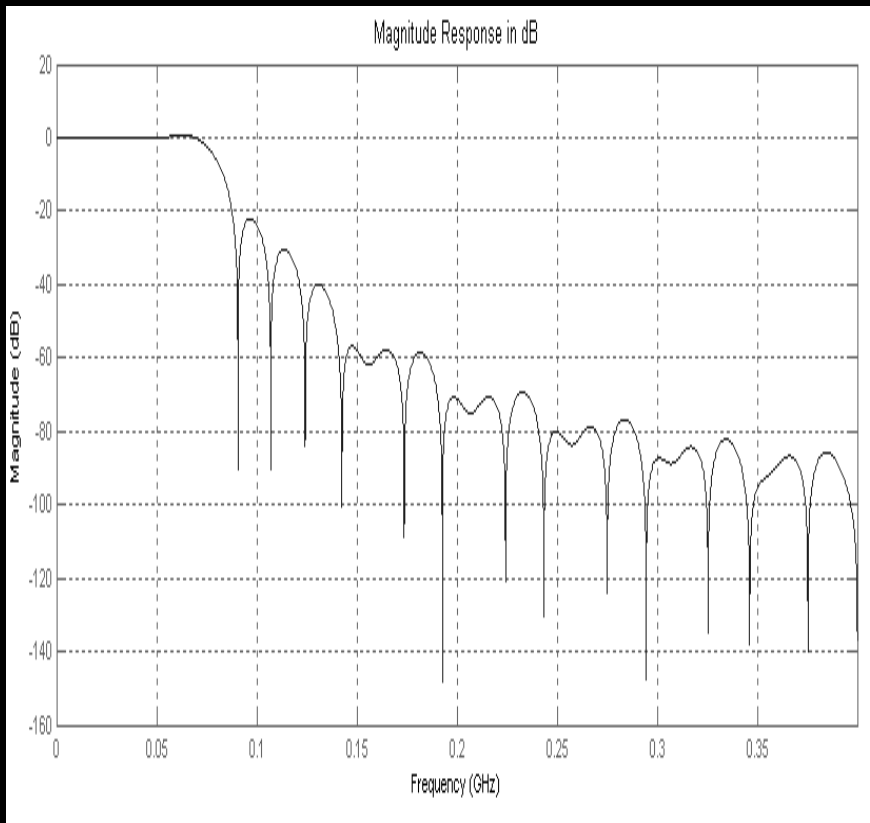
- Transform length
- Bandwidth
- Complex or Real
- Number of Polarizations
- Input bit width and output bit width
- twiddle coefficient bit width
- Run-time programmable down-shifting
- Decimate option

PFB vs. FFT

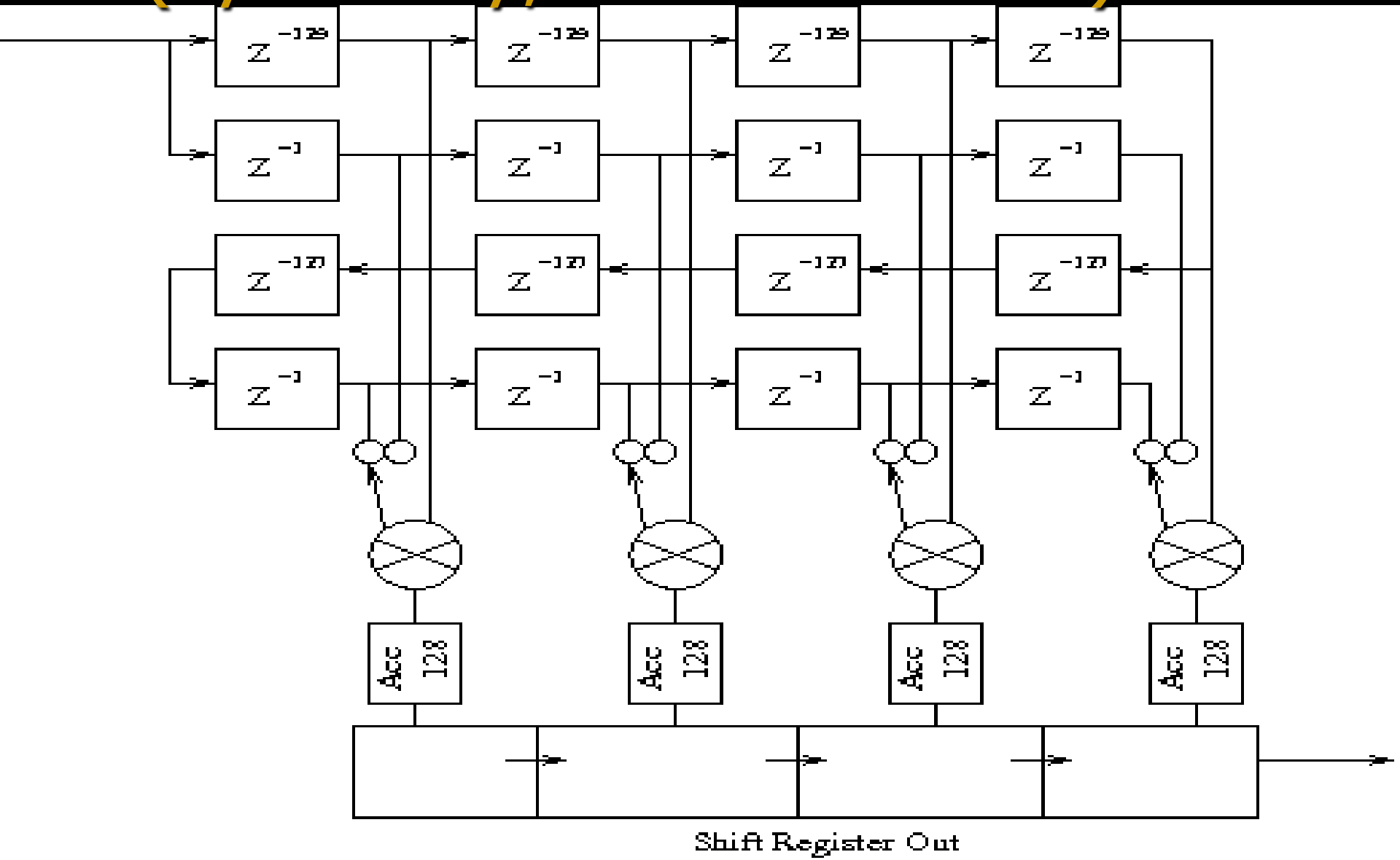

0
-10
-20
-30
-40
-50
-60
-70
-80
dB
-16 -15 -14 -13 -12 -11 -10 -9 -8 -7 -6 -5 -4 -3 -2 -1 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
FFT Bin
Bin -16
Bin -15
Bin -14
Bin -13
Bin -12
Bin -11
Bin -10
Bin -9
Bin -8
Bin -7
Bin -6
Bin -5
Bin -4
Bin -3
Bin -2
Bin -1
Bin 0
Bin 1
Bin 2
Bin 3
Bin 4
Bin 5
Bin 6
Bin 7

Digital Down-Converter

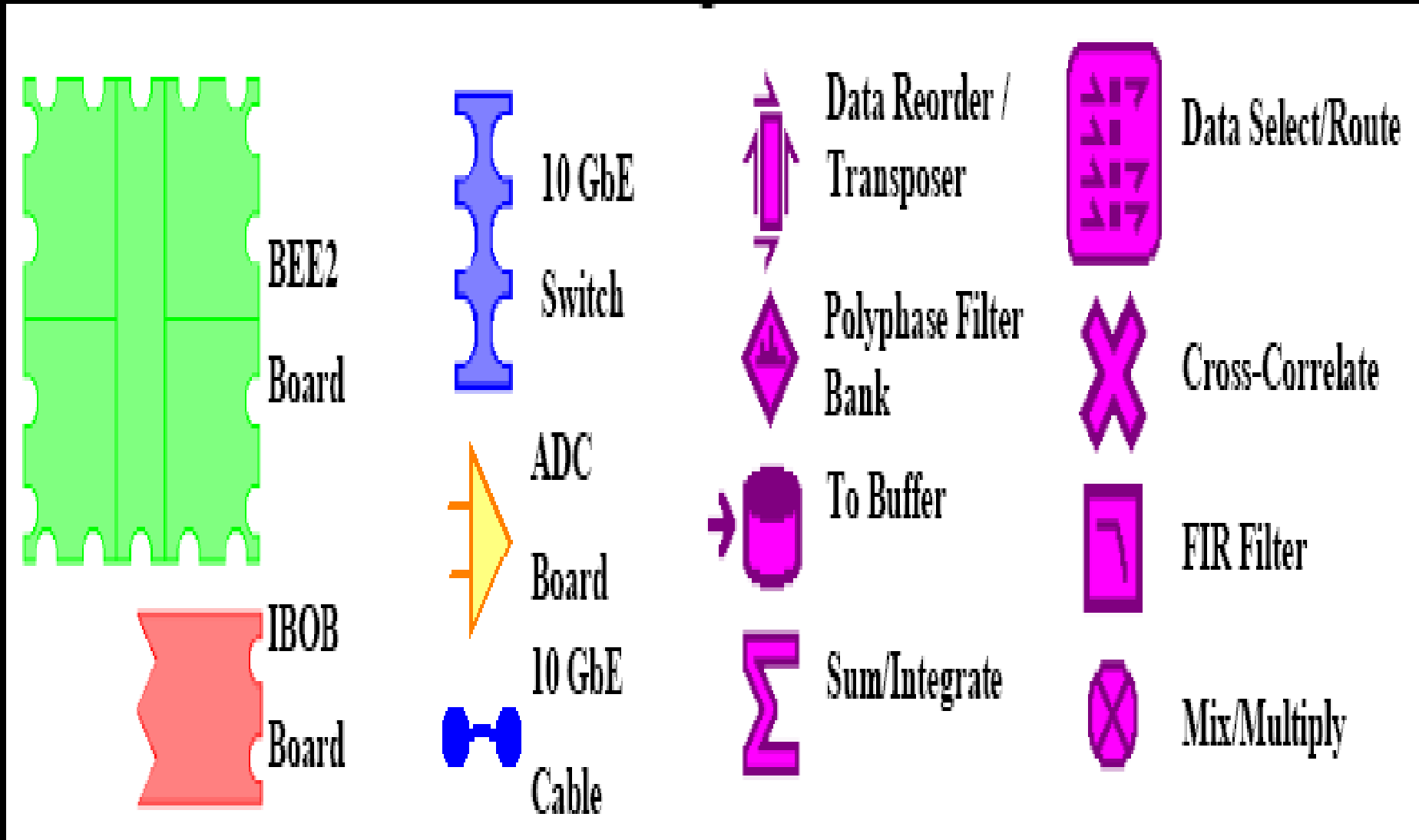
- Selectable # of FIR taps
- On-the-fly programmable mix frequency
- Selectable FIR coeff
- Agile sub-band selection.



X-Engine Correlation Architecture (Lynn Urry, Aaron Parsons)

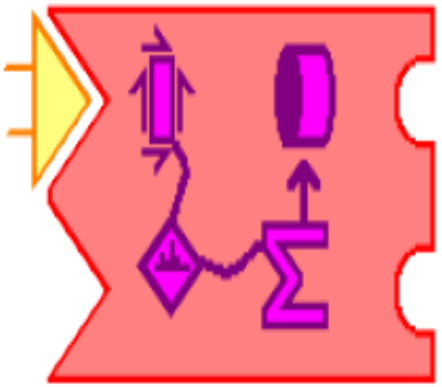


Hardware and Software Libraries legend:

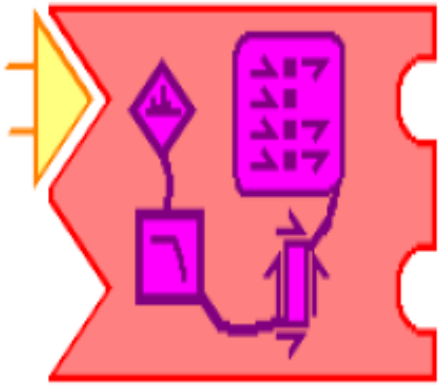


Applications

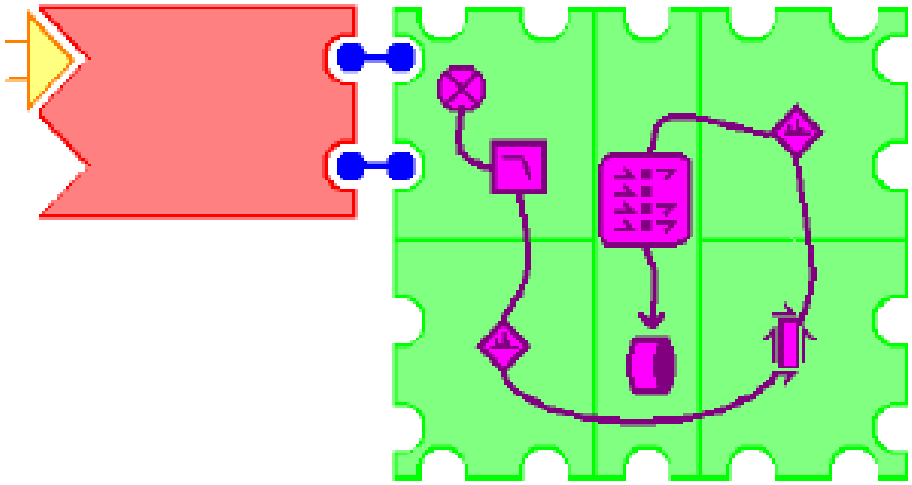
1) Pocket Spectrometer:



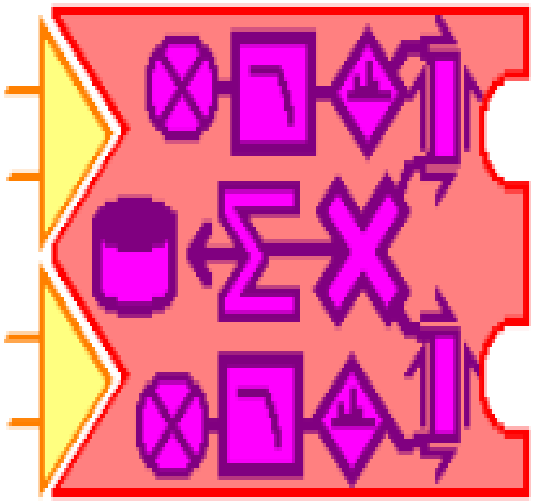
2) VLBI Channelizer:



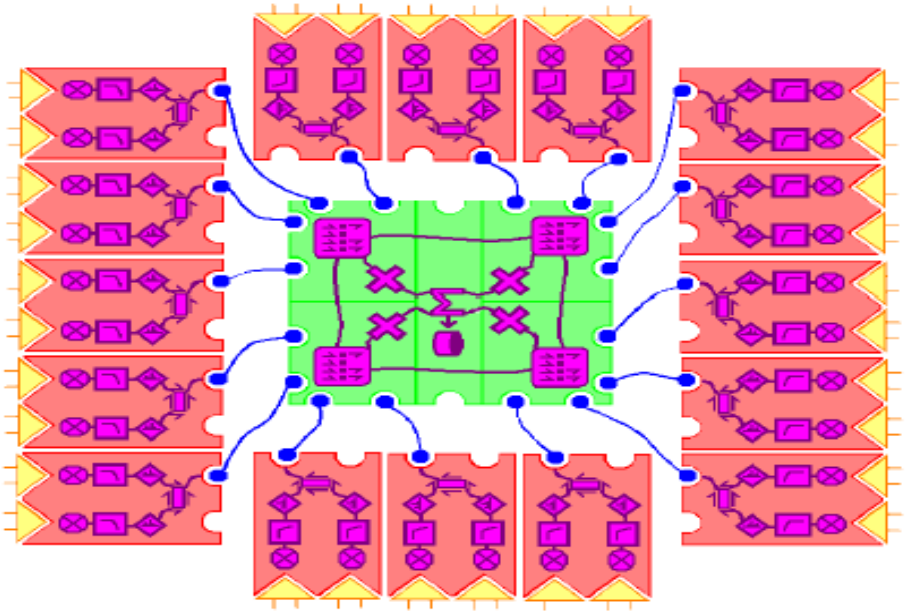
3) SETI Spectrometer:



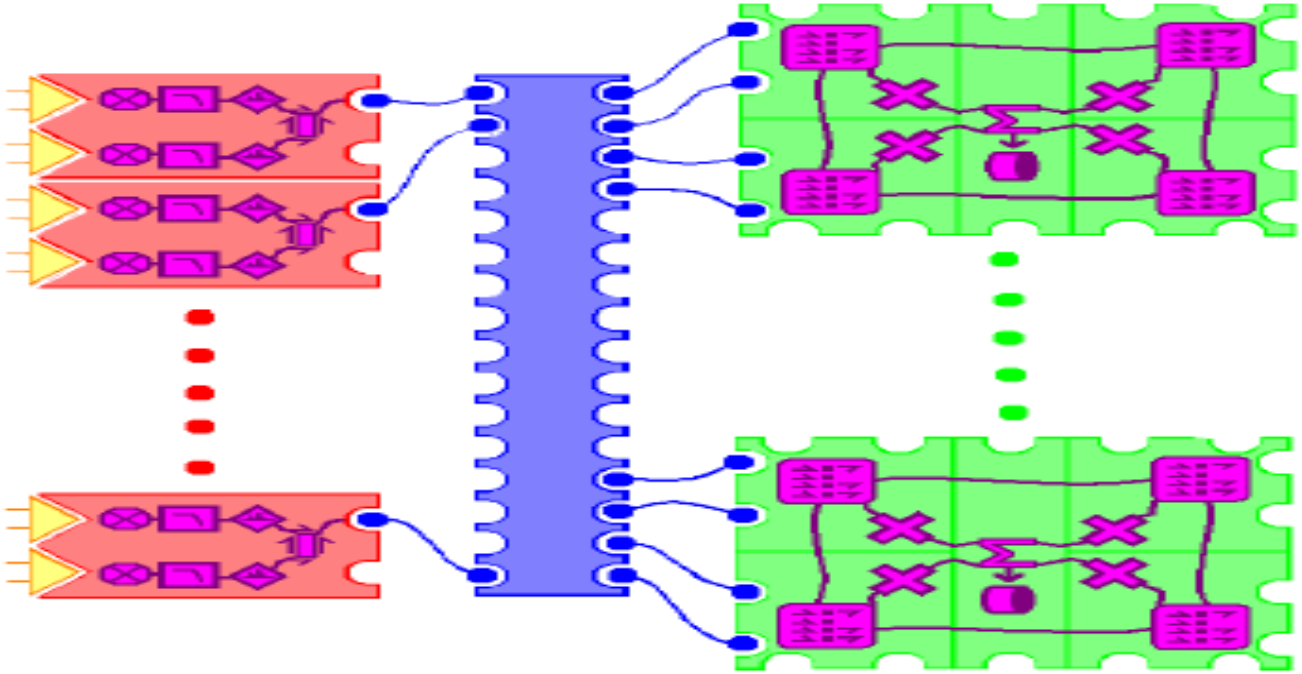
4) Pocket Correlator:



5) 32 Station Correlator:



6) Arbitrary Sized Correlator



Applications

- VLBI /VLBA/eVLBI Mark 5: Haystack, NRAO, CARMA, SMA, Finland...
- Beamforming – ATA, SMA, CARMA, SKADS, MIT
- SETI – Arecibo (UCB), DSN (JPL/UCB), GBT (NRAO/UCB)
- Correlators and Imagers:

  ATA, Oxford (SKADS), MIT (FFT imaging correlator)

  PAPER (Reionization Experiment)

  Carma Next Gen,

  MeerKAT/SKA South Africa

  GMRT next gen correlator ??

  Bologna (SKA), FASR ??

  Pulsar Timing and Searching, Transient

  Green Bank, Arecibo, Allen Telescope Array, VLA,

  Swinburne (Parkes), meerKAT, Nancay, Effelsburg

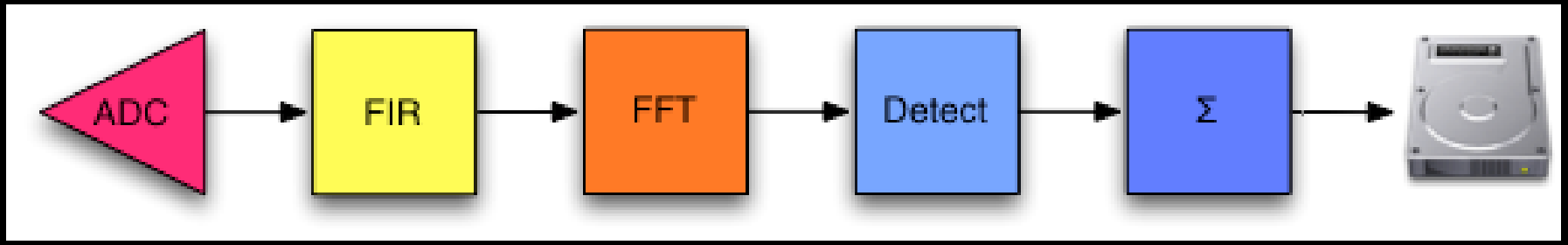
SETI Spectrometers

- Parkes Southern SERENDIP
- ALFA SETI Sky Survey (300 MHz x 7 beams)
- JPL DSN Sky Survey (eventually 20 GHz bandwidth)

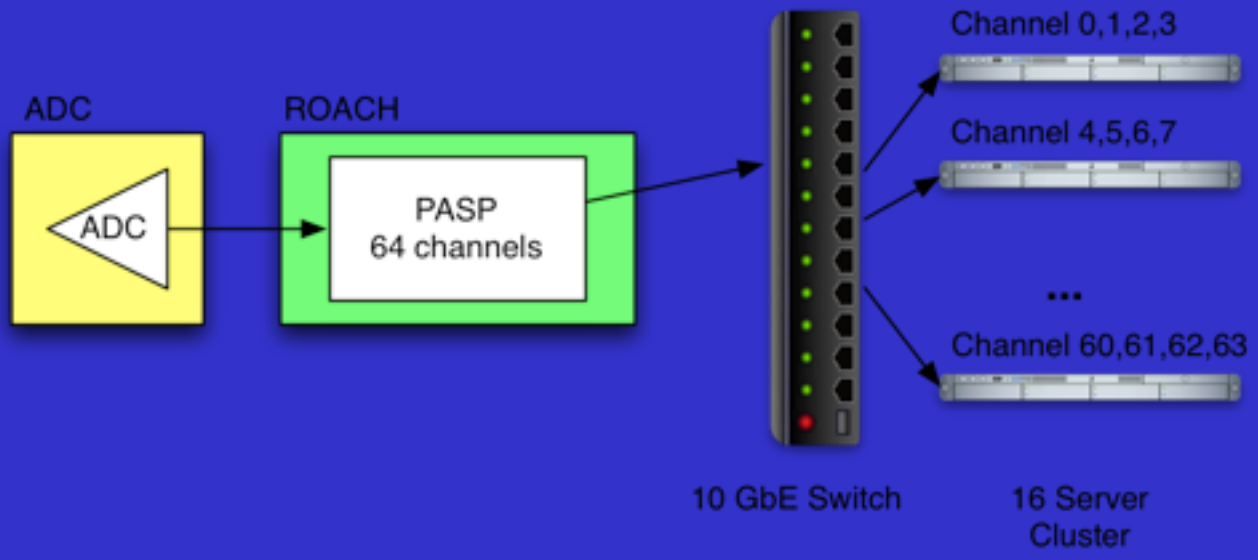
Radio Astronomy Spectrometers

- GALFA Spectrometer – Arecibo Multibeam Hydrogen Survey
- Astronomy Signal Processor – ASP – Don Backer, Ingrid Stairs, et al(pulsars)
- Antenna Holography, ATNF, China
- Gavert (DSN education, outreach) – 8 GHz BW –G. Jones
- CMB Bolometer Readout – Caltech, UCB
- Fast Readout Spectrometers (Parkes, NRAO, ATA...)

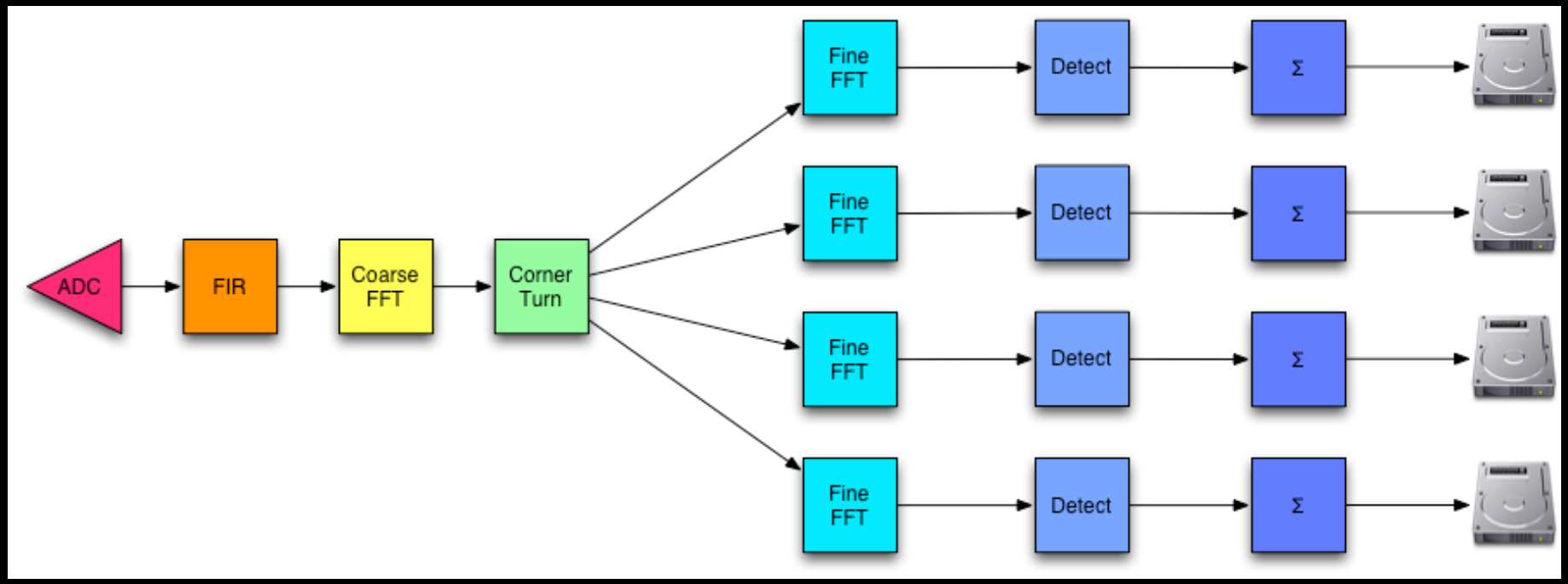
Spectrometer (1 beam, 1 pol)



Spectrometer using CPU/GPU

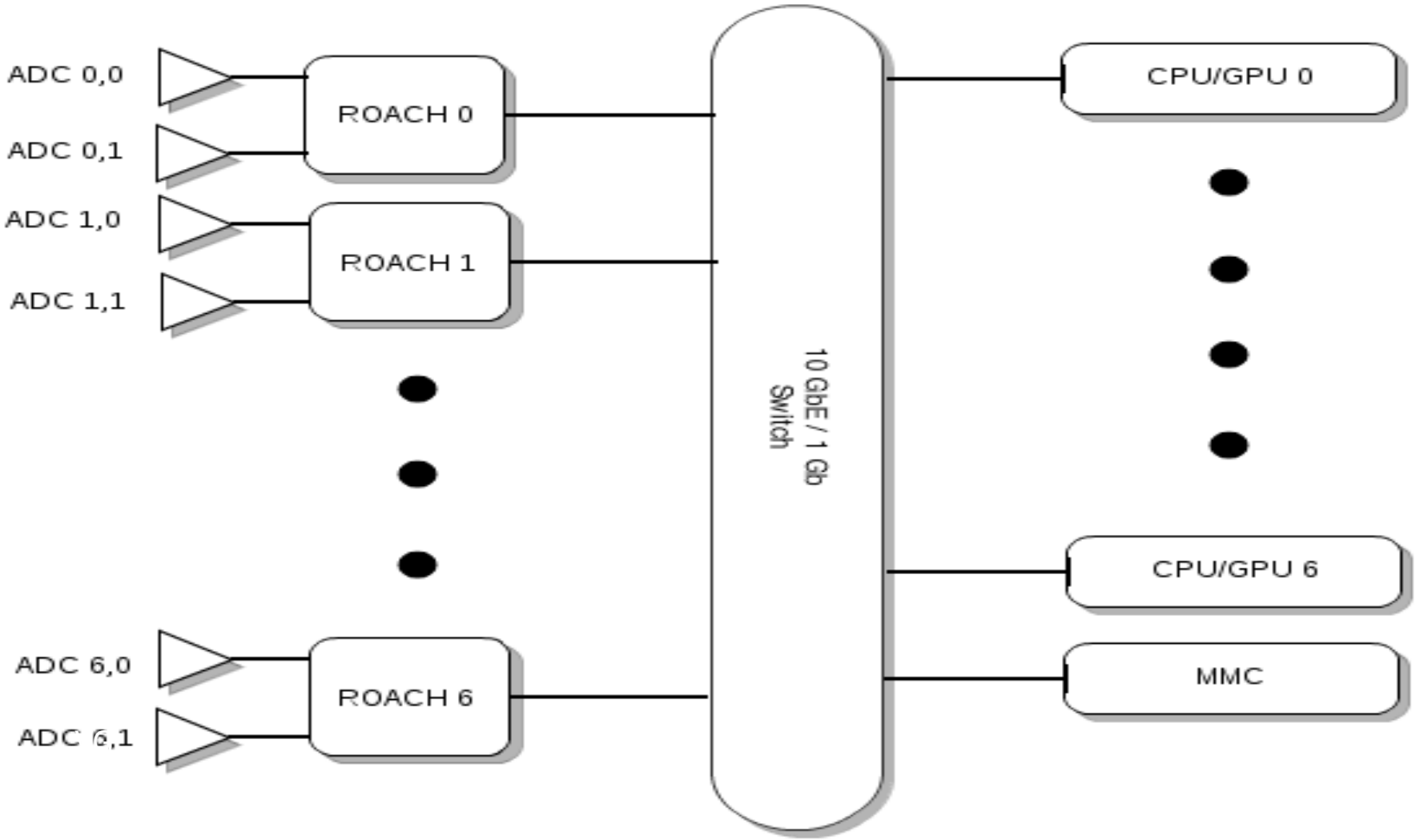


High Resolution Spectrometer

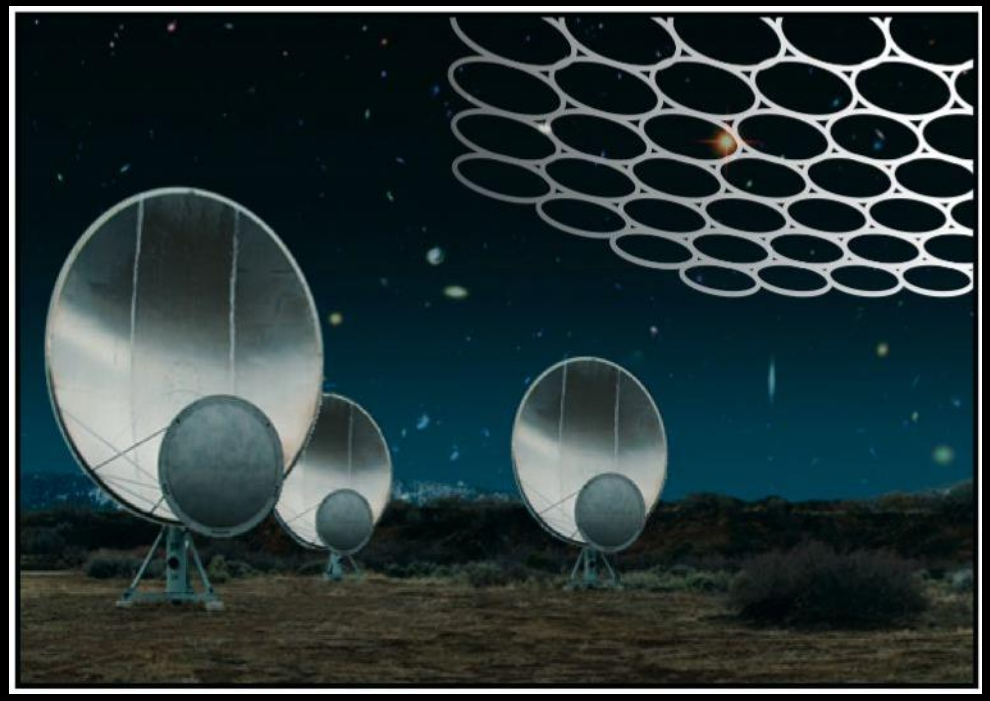



ZAMBELLI

VEGAS Multi-beam Spectrometer
John Ford et al

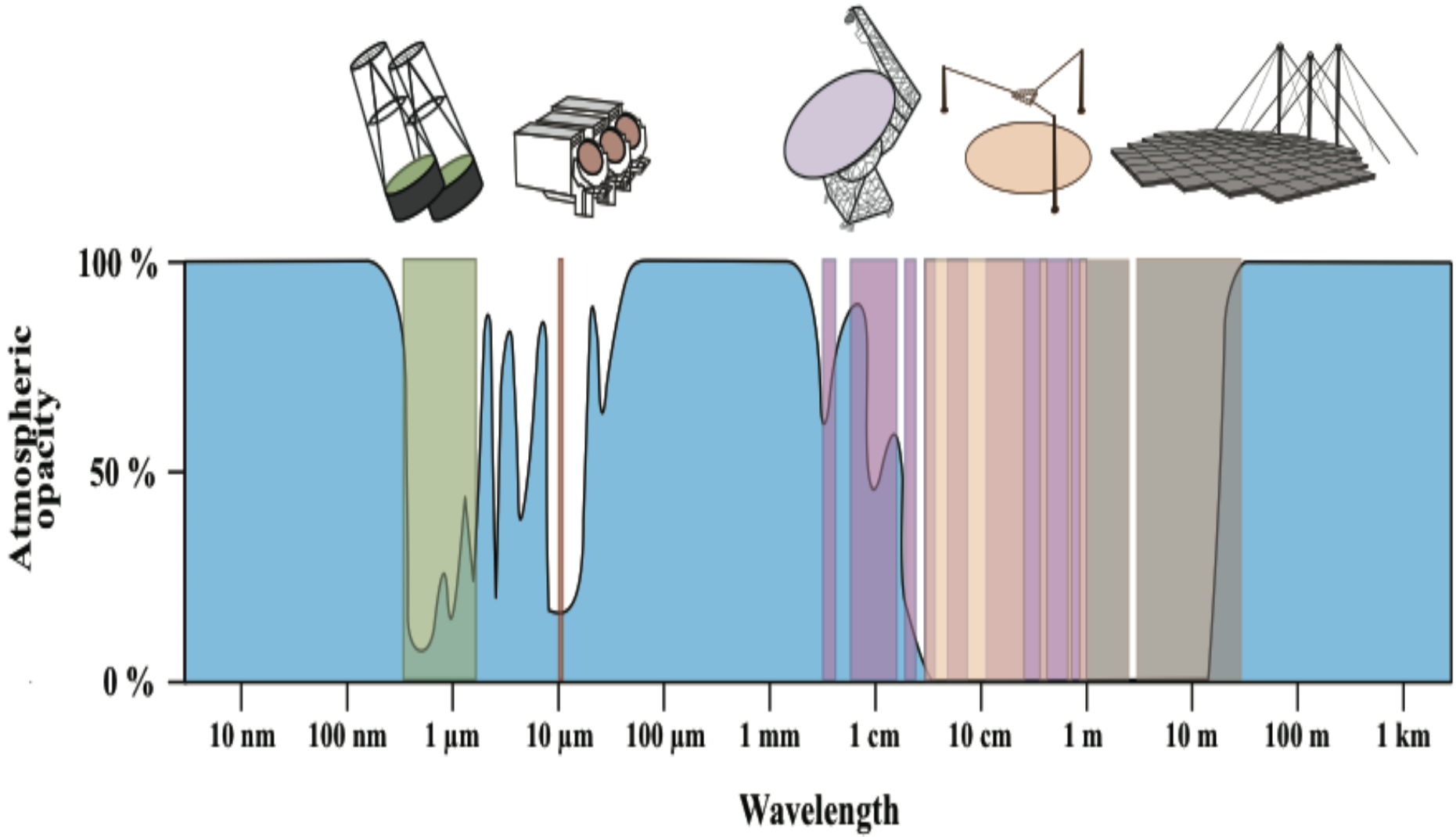


ATA Fly's Eye Transient Instrument
44 fast readout spectrometers
3 weeks to build



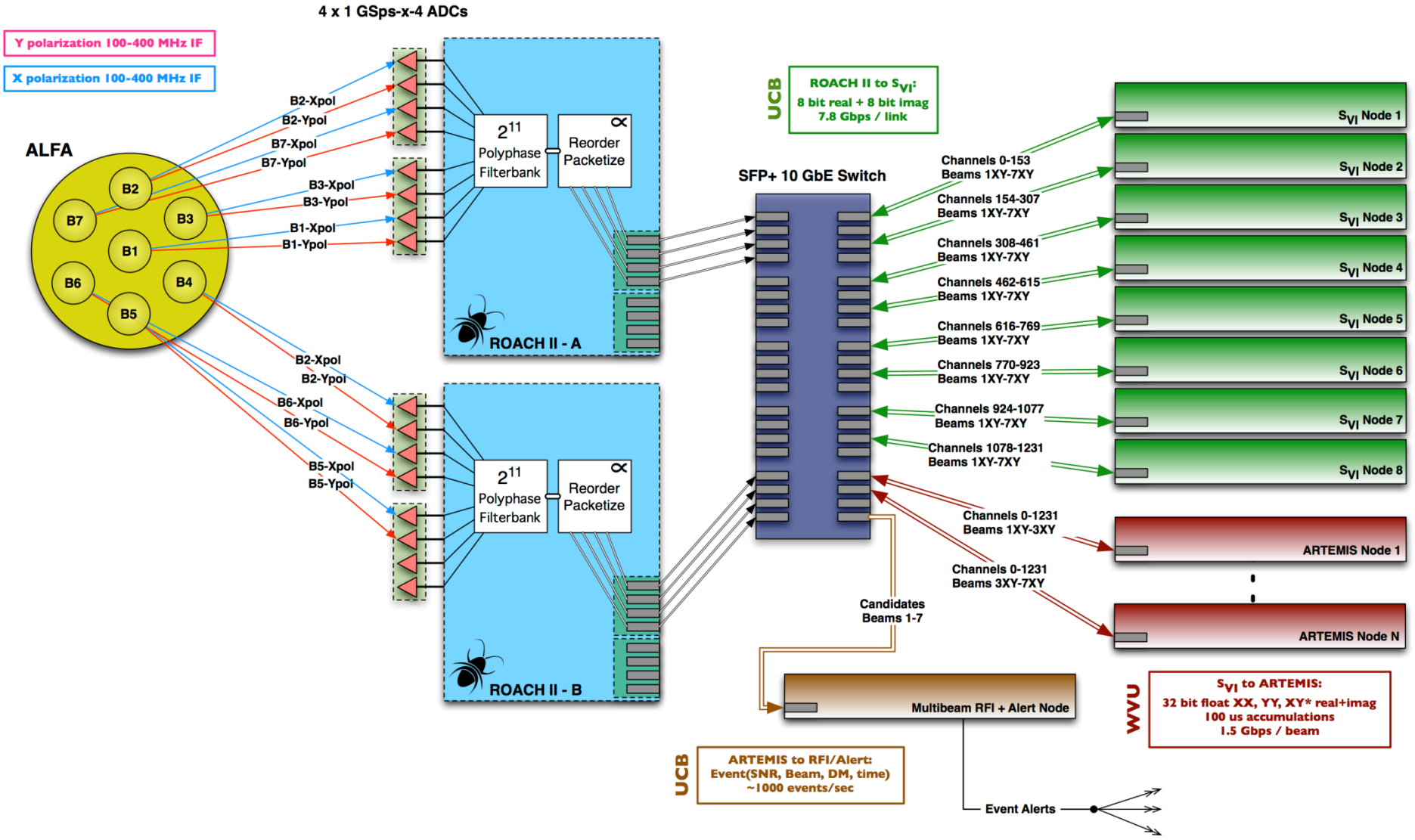
Geoff Bower, Jim Cordes, Griffin Foster, Joeri van Leeuwen, Peter McMahon, Andrew Siemion, Mark Wagner, Dan Werthimer

SETI Instruments (IR, Vis, Radio)

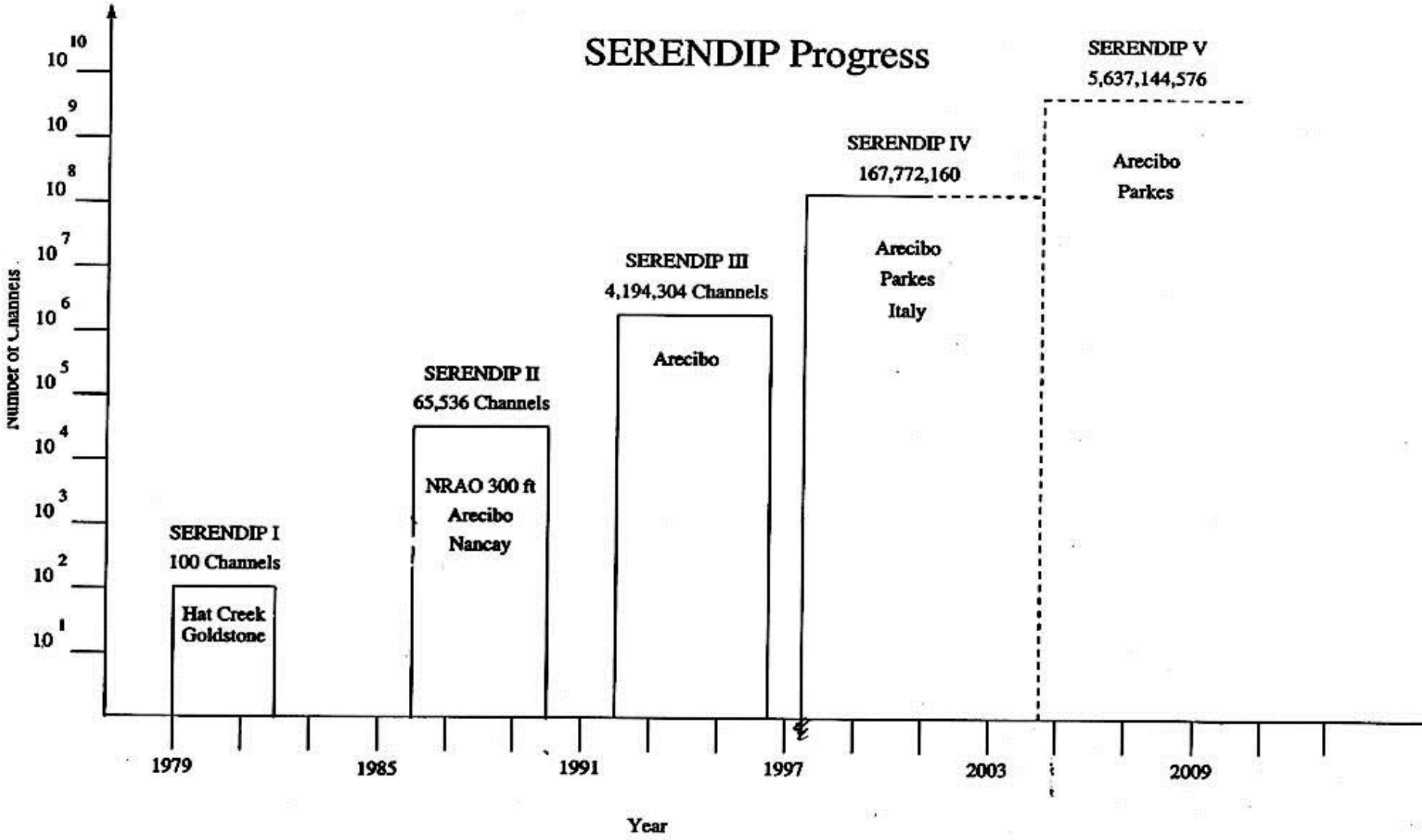


SETI and FRB search at Arecibo/GBT
SERENDIP VI and ALFABURST

Lorimer, Werthimer, Siemion, MacMahon, Dexter, Cobb, Chennamangalam, Armour, Karastergiou

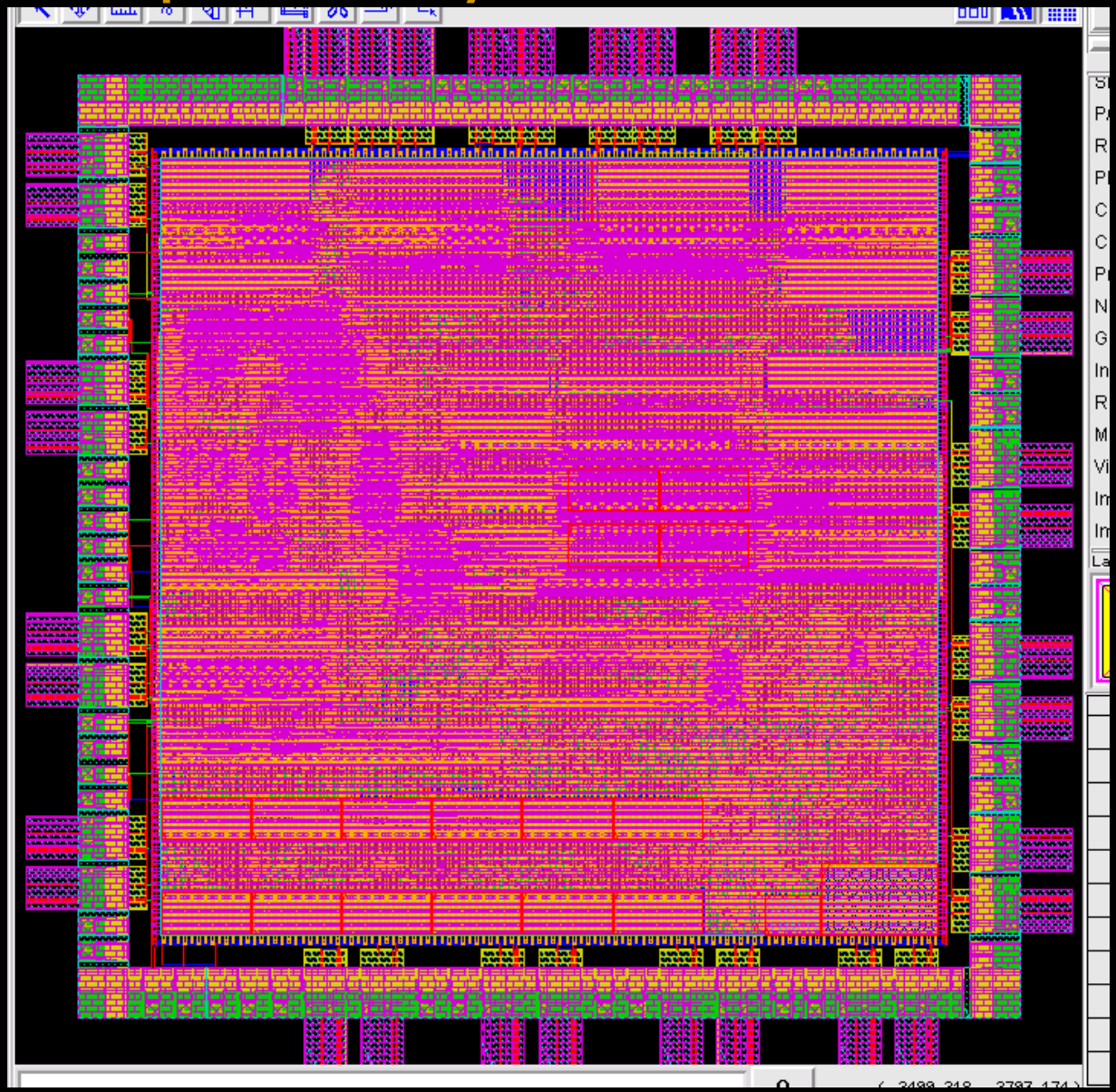


Moores Law – Instruments using FPGA's: 2X per year (1,000,000 over 20 years)

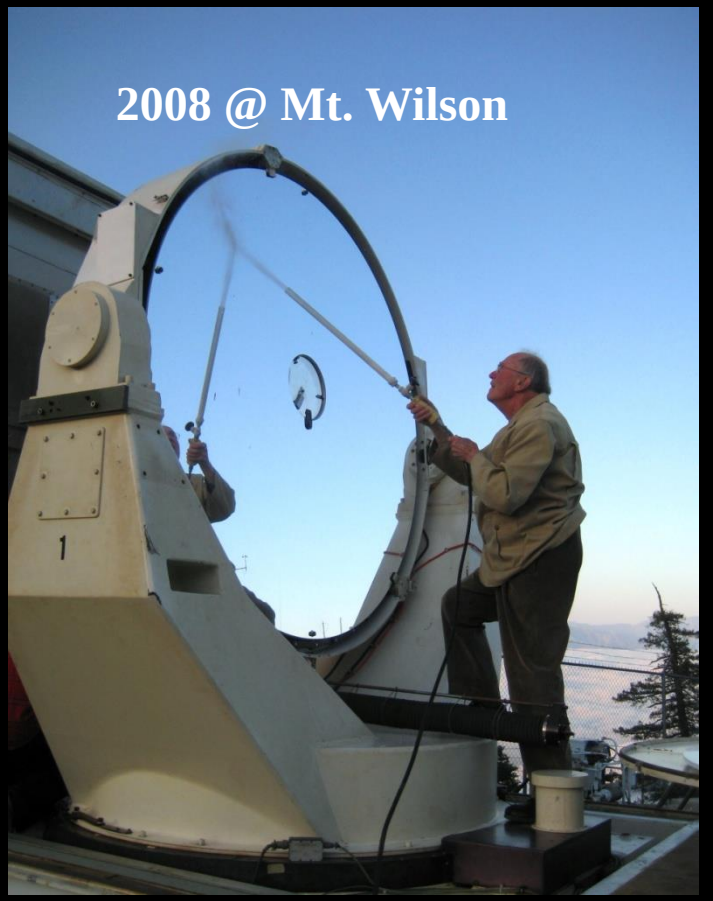


4096 channel Mars spectrometer

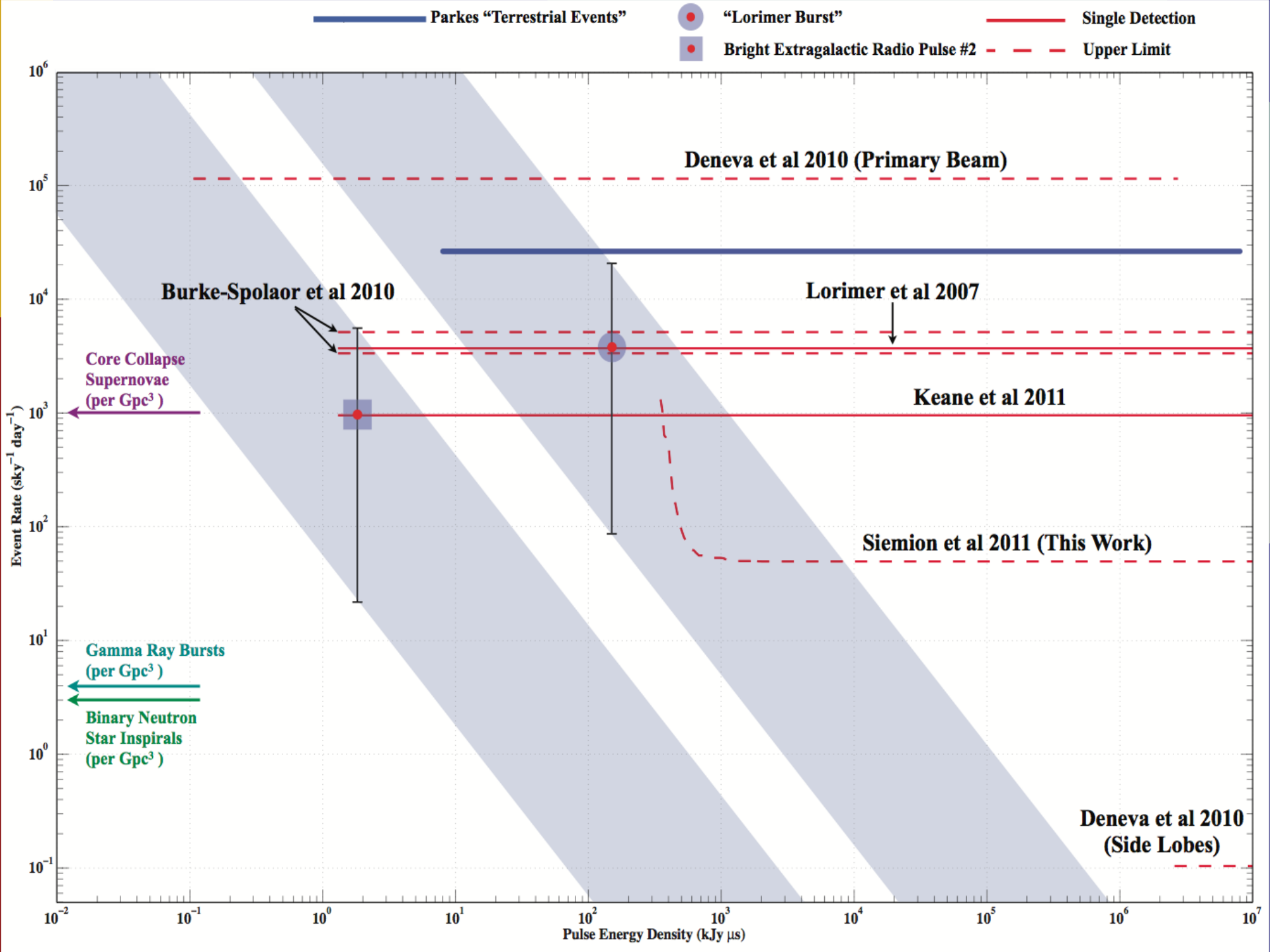
"Chip in a day" FPGA to ASIC



Infrared Spatial Interferometer
heterodyne detection at 27 THz w/ CO2 laser LOs



Mt. Wilson, CA
3 telescope system 4,8,12m early 2006
Currently ~35m triangular baselines


Parkes "Terrestrial Events"
"Lorimer Burst"
Single Detection
Bright Extragalactic Radio Pulse #2
Upper Limit
Deneva et al 2010 (Primary Beam)
Burke-Spolaor et al 2010
Lorimer et al 2007
Core Collapse Supernovae (per Gpc³)
Keane et al 2011
Siemion et al 2011 (This Work)
Gamma Ray Bursts (per Gpc³)
Binary Neutron Star Inspirals (per Gpc³)
Deneva et al 2010 (Side Lobes)
Event Rate (sky⁻¹ day⁻¹)
Pulse Energy Density (kJy μs)

4 September 2008 | www.nature.com/nature | £10

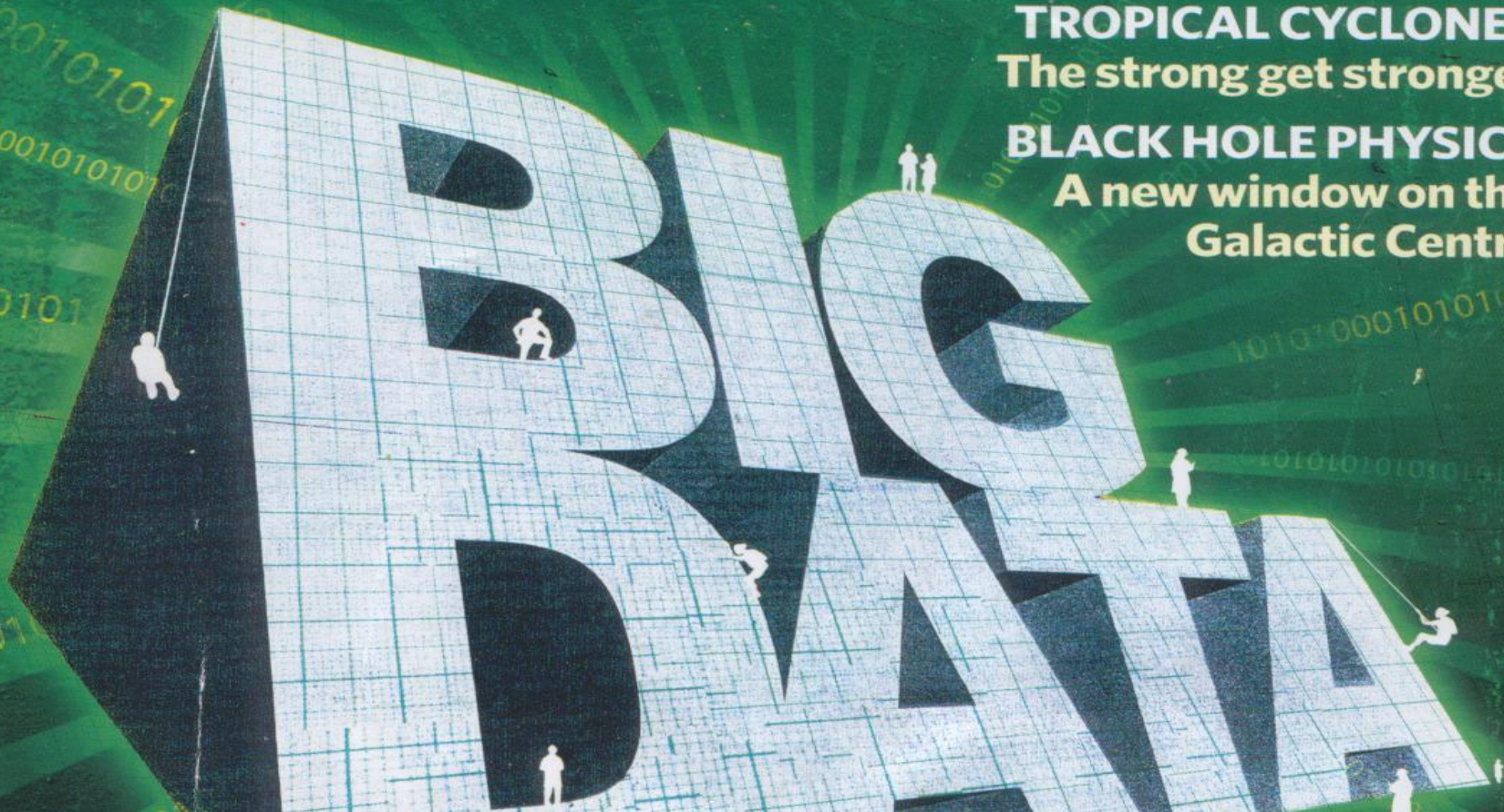
THE INTERNATIONAL WEEKLY JOURNAL OF SCIENCE

nature

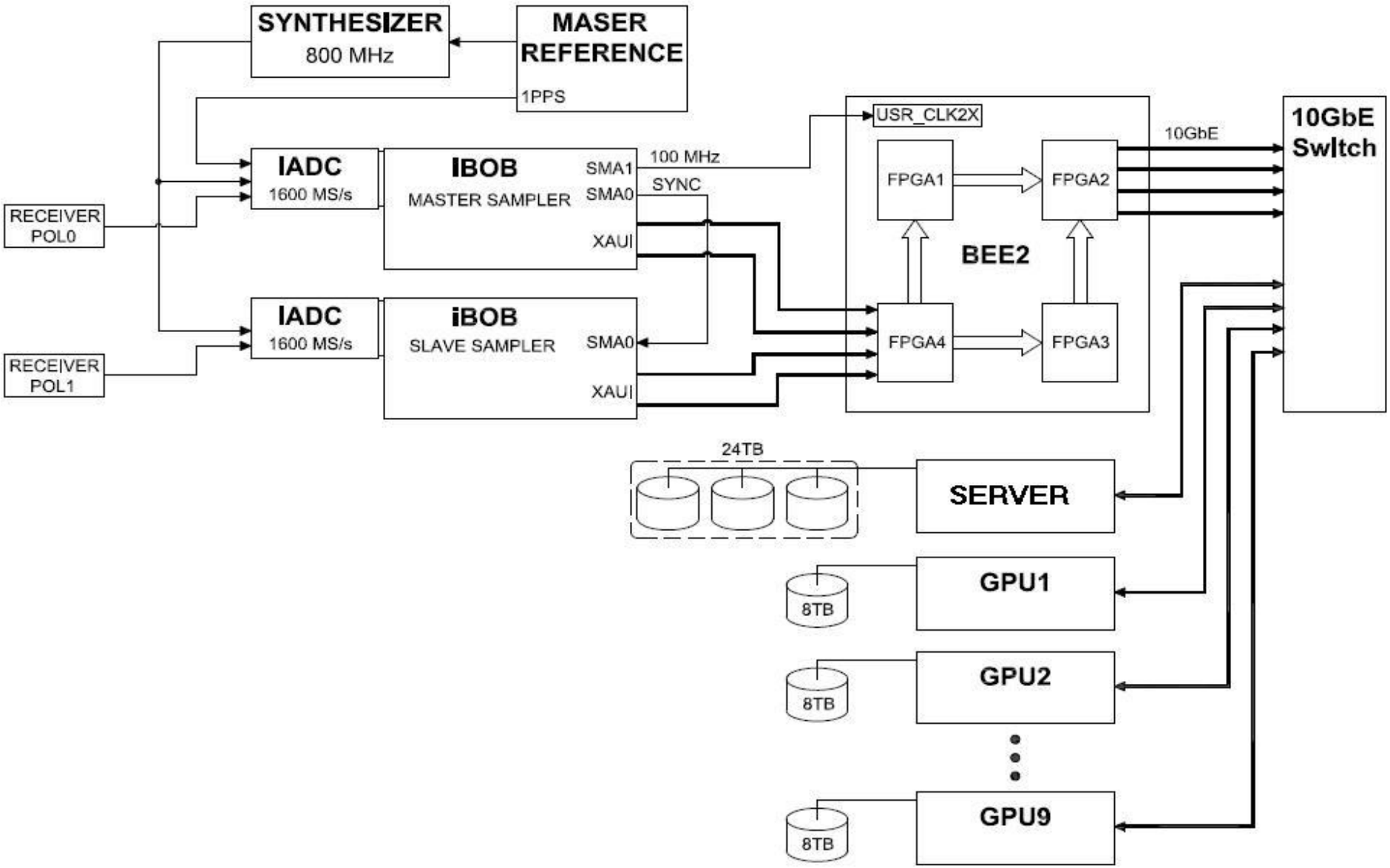
THE BITER BIT
Viral infections for viruses

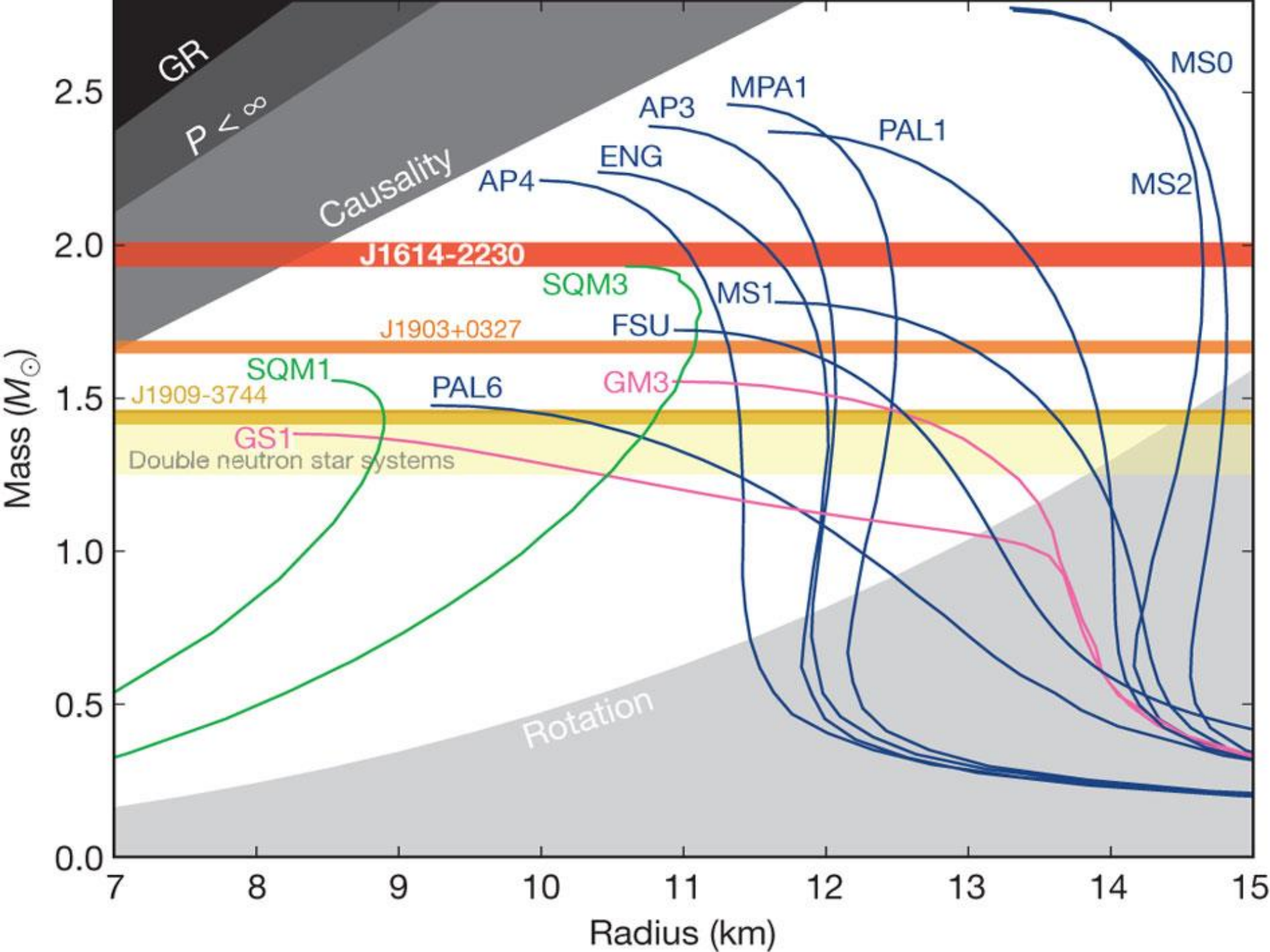
TROPICAL CYCLONES
The strong get stronger

BLACK HOLE PHYSICS
A new window on the Galactic Centre

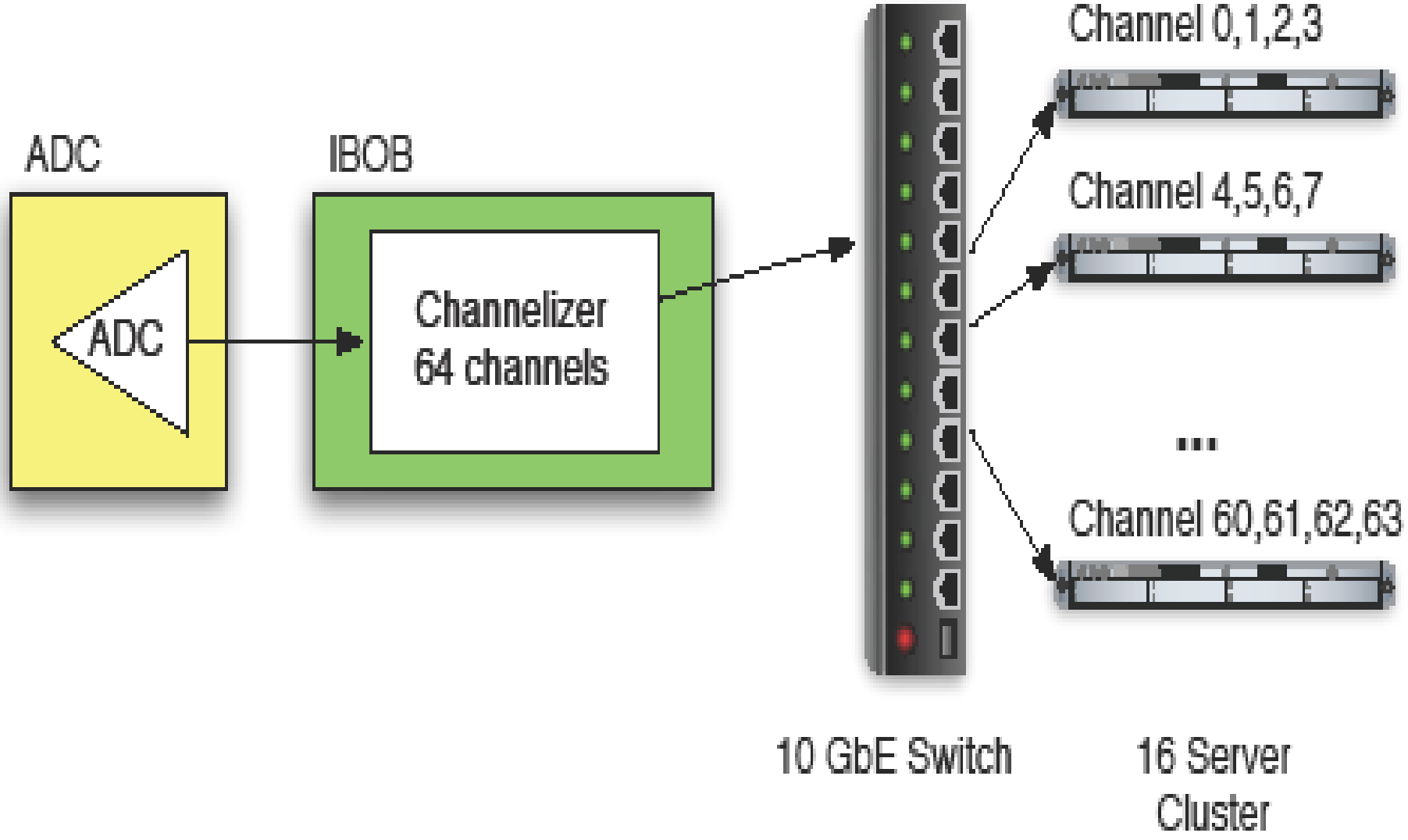


GUPPI Pulsar Machine: NRAO (Arecibo)
John Ford, Paul Demorest, et al

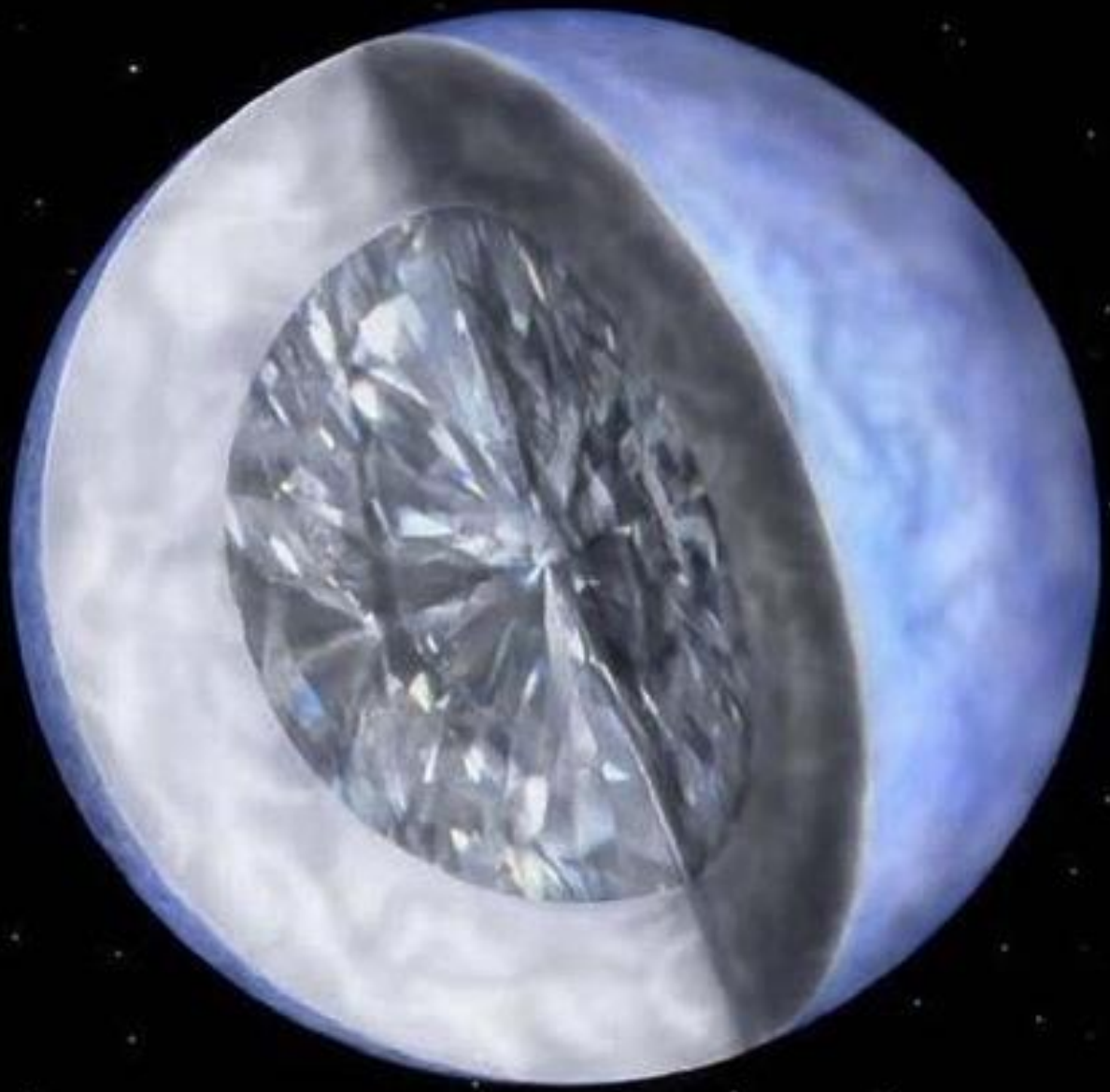



GR
P < ∞
Causality
Rotation
J1614-2230
J1903+0327
J1909-3744
Double neutron star systems
MS0
MPA1
AP3
PAL1
ENG
AP4
MS2
SQM3
MS1
FSU
SQM1
PAL6
GM3
GS1
Mass ($M_\odot$)
Radius (km)
0.0
0.5
1.0
1.5
2.0
2.5
7
8
9
10
11
12
13
14
15

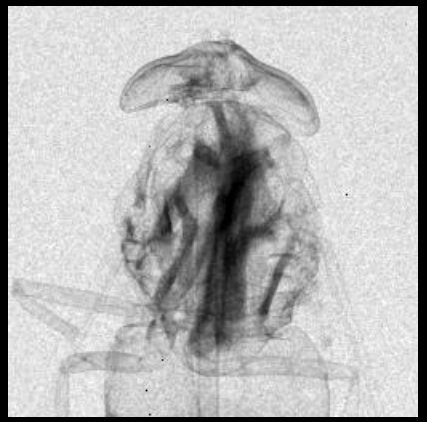
Astronomy Signal Processor
Terry Filiba, Peter McMahon



Diamond Planet: Matthew Bailes et al



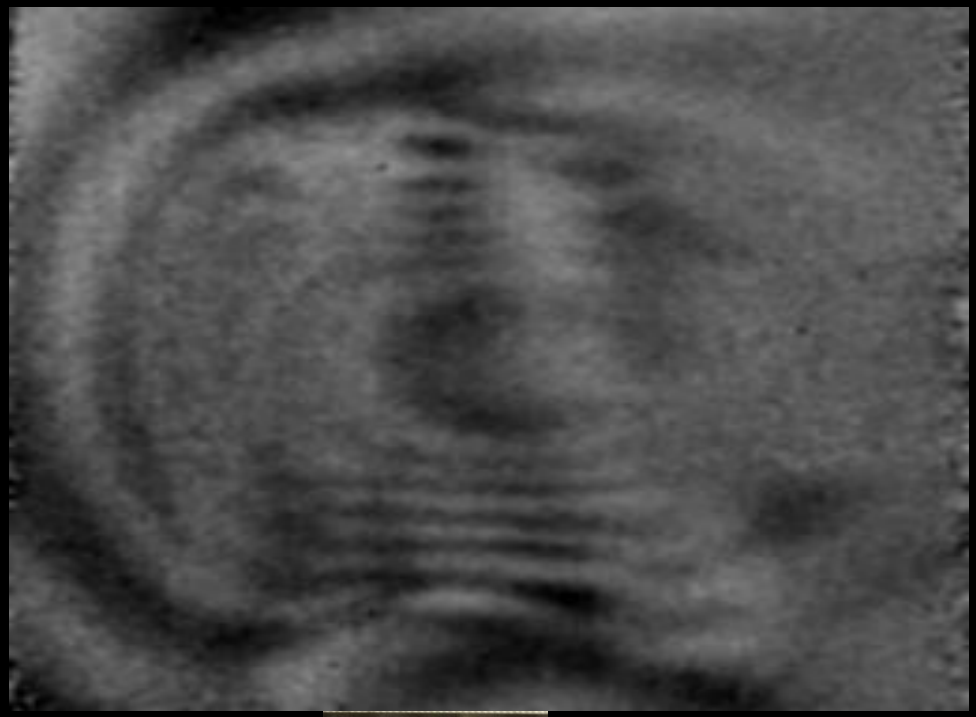
Neutron radiography : MCP, Roach



ICON beamline.

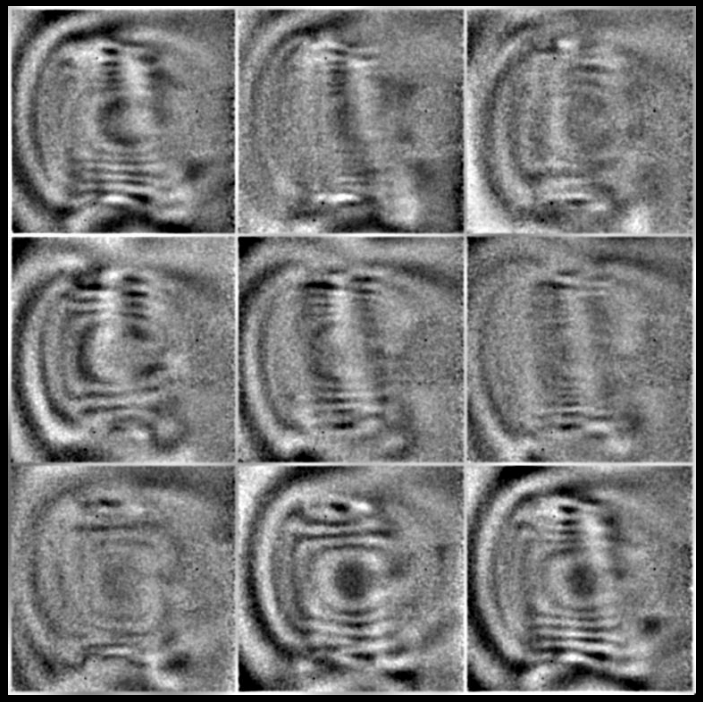
Tissues with different neutron absorption coefficient are depicted by different colors. 201 tomographic projections taken with 140 s image acquisition time each.

Dynamic magnetic field imaging:



Magnetic field produced by 3 kHz AC current in a coil imaged

3 kHz filed: 10A AC current
10 us time slices



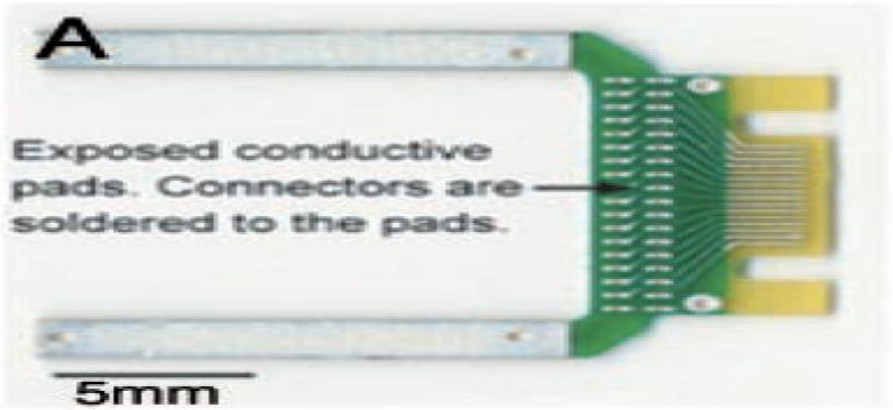
Brain Readout using Roach and Casper Tools

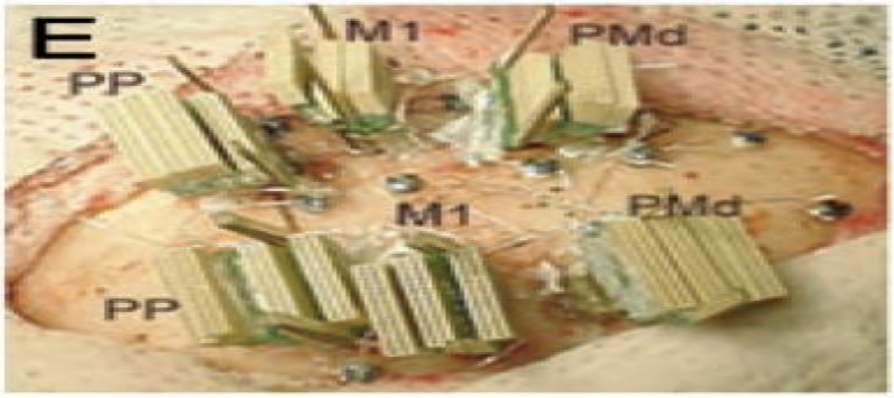
10 Mbit/sec - (Borg?)

Prostheses Control

A.L.

Microwire Neural Implants





Correlators and Beamformers

Correlator Ops and Bits

CMAC/sec = bandwidth x Nantenna^2

= 1 GHz x 3000^2

= 1E16 CMACS per beam

Bits/sec = bandwidth x Nantenna x 16 bits

= 1 GHz x 3000 x 16

= 50 Tbit/sec per beam

Correlator References

Thompson, Moran, Swenson, 2nd edition

Interferometery and Synthesis in Radio Astronomy

Parsons, A Scalable Correlator Architecture Based on Modular FPGA Hardware and Data Packetization

http://casper.berkeley.edu/wiki/Papers

http://casper.berkeley.edu/

CASPER Correlator Collaboration

Allen Telescope Array (90 uS imaging)

PAPER (Epoch of Reionization)

Carma Next Generation

MeerKAT/SKA South Africa

GMRT next gen

Bologna

ISI (Infrared) – 6 Gsps (3 GHz)

SKADS (Oxford)

SMA next gen (CFA, ASIAA)

MIT FFT direct imaging correlator

FASR?, Baryon Acoustic Oscillation ?

LEDA (CFA GPU X engine)

Berkeley Correlator Team

- Dan Werthimer (28 years correlator design)
- Matt Dexter (20 years correlator design)
- David McMahon (10 years correlator design)
- Aaron Parsons (6 years correlator design)
- Rick Raffanti (ADC and RF/analog board designer – 30 years)
- Dave Deboer (project manager)
- Terry Filiba (EE grad student – F engine)
- Andrew Siemion (Astr grad student – correlators, transient, pulsars, SETI)
- Suraj Gowda (EE grad student – high speed FGPA tools)
- Hong Chen (Astr. Undergrad – parameterized FPGA designs)

- Mark Wagner (staff scientist – instrument designer)

Correlator Technologies

Software Correlators (DiFX – Adam Deller)

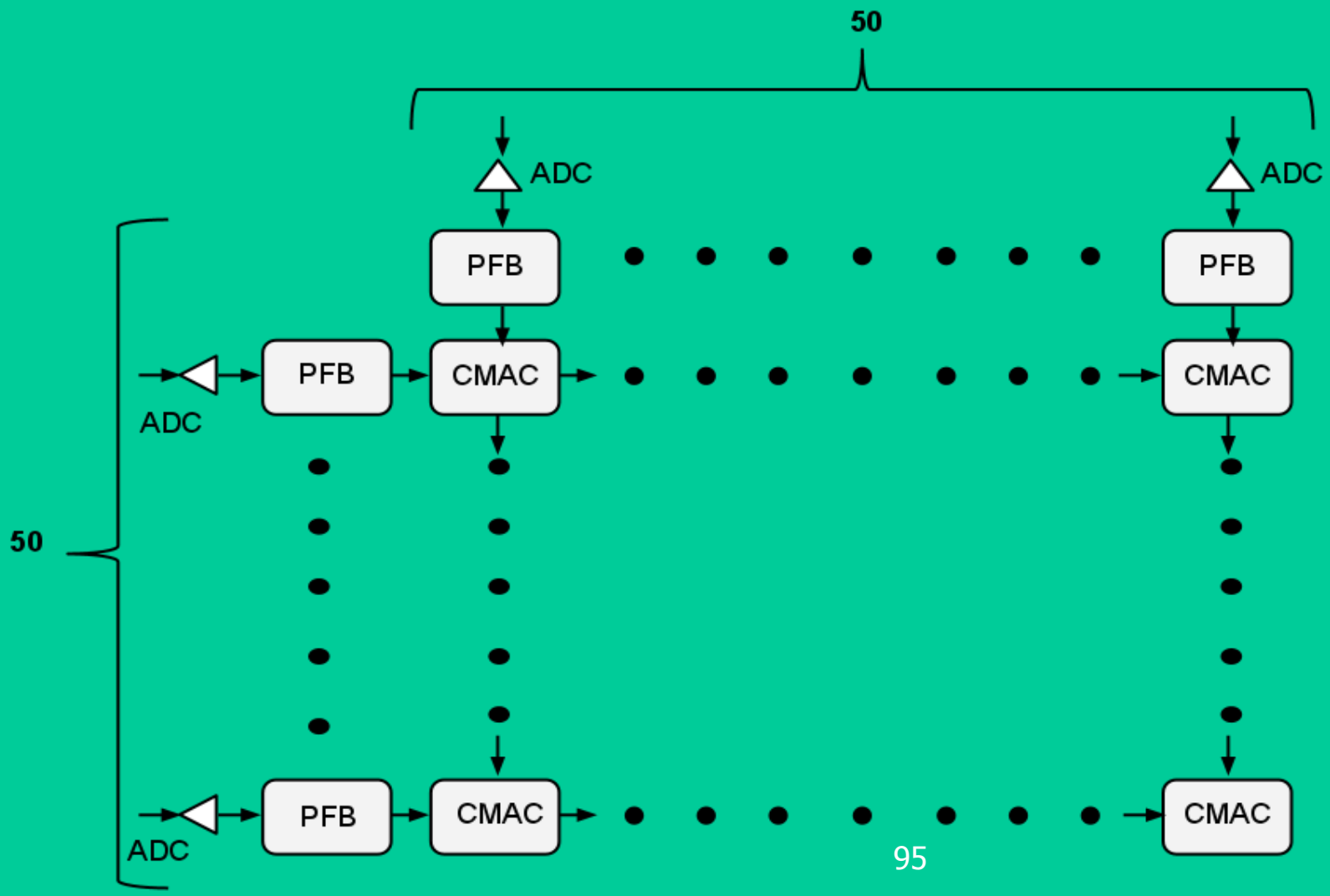
GPU Correlators (CASPER, Xgpu – Mike Clarke)

FGPA Correlators (CASPER, F and X engines)

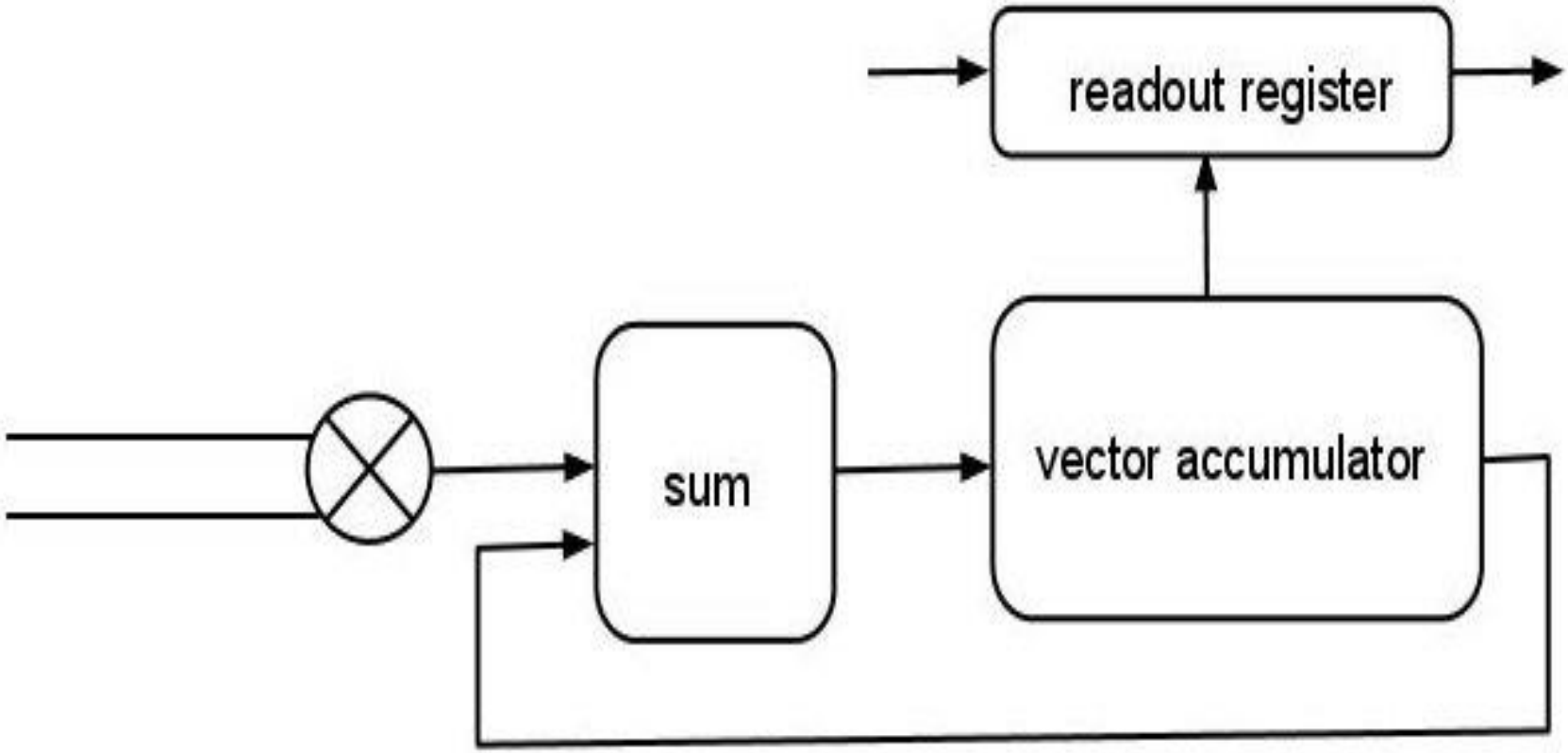
ASIC Correlators (NRAO, DRAO, JPL…)

What ELSE ??? (Intel Phi??)

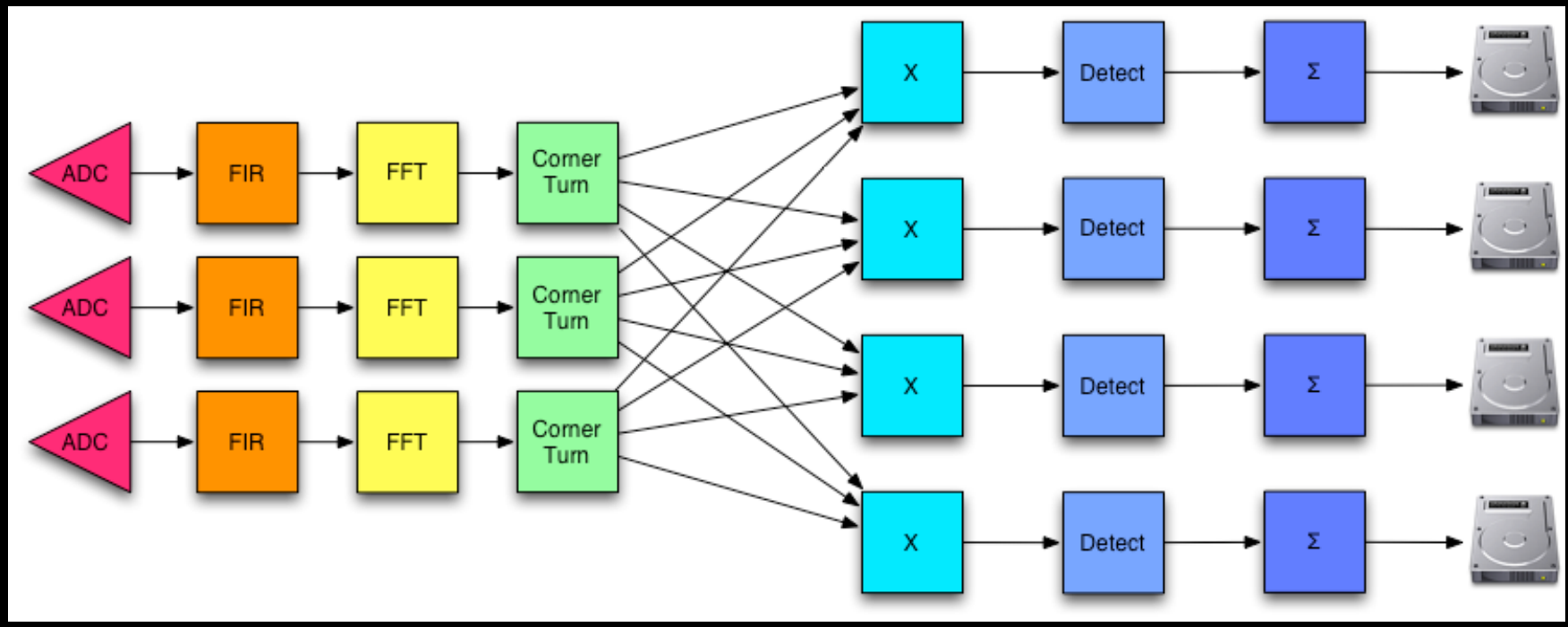
Small Correlator (one board)

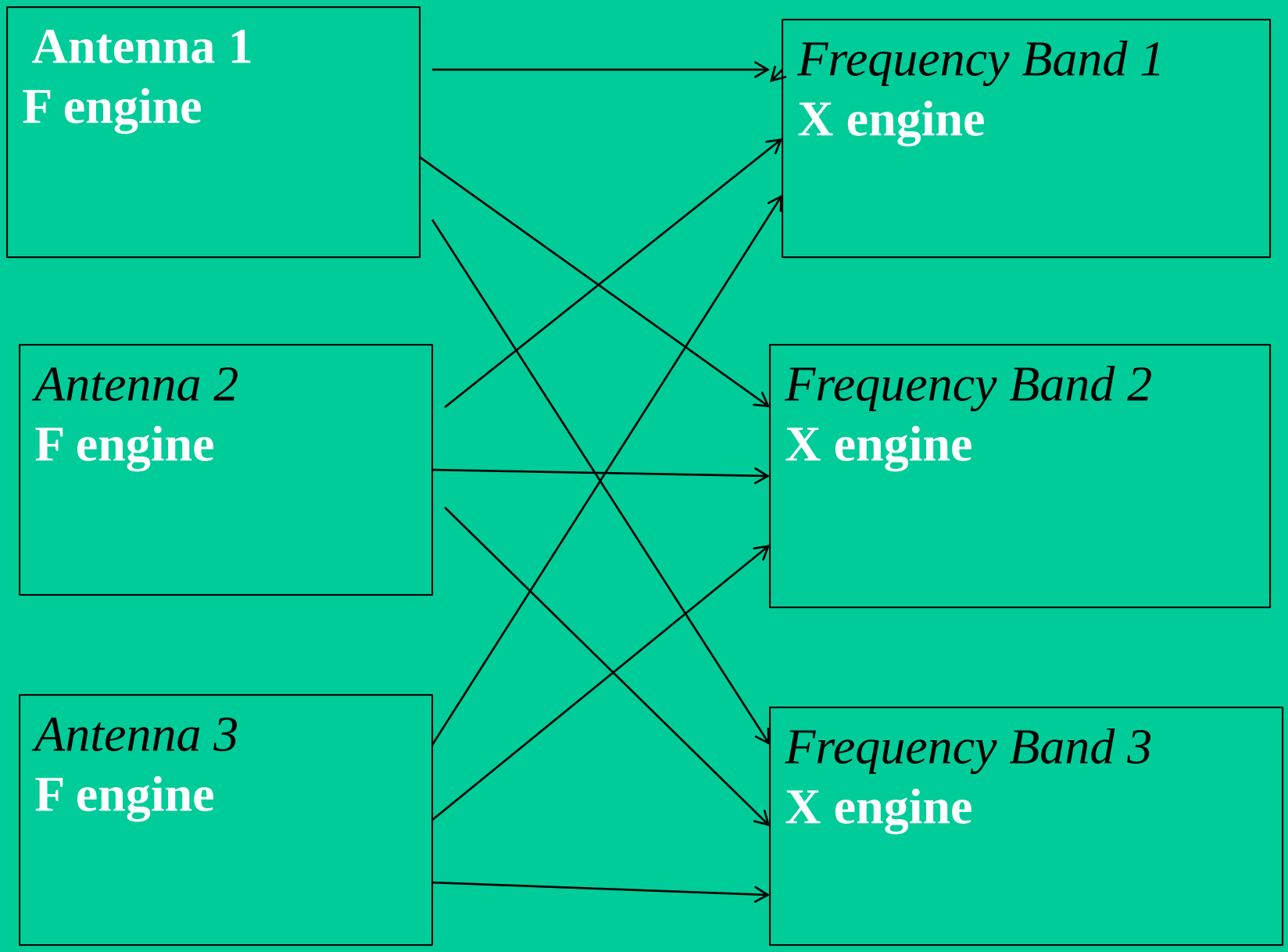


CMAC Complex Multiplier Accumuator

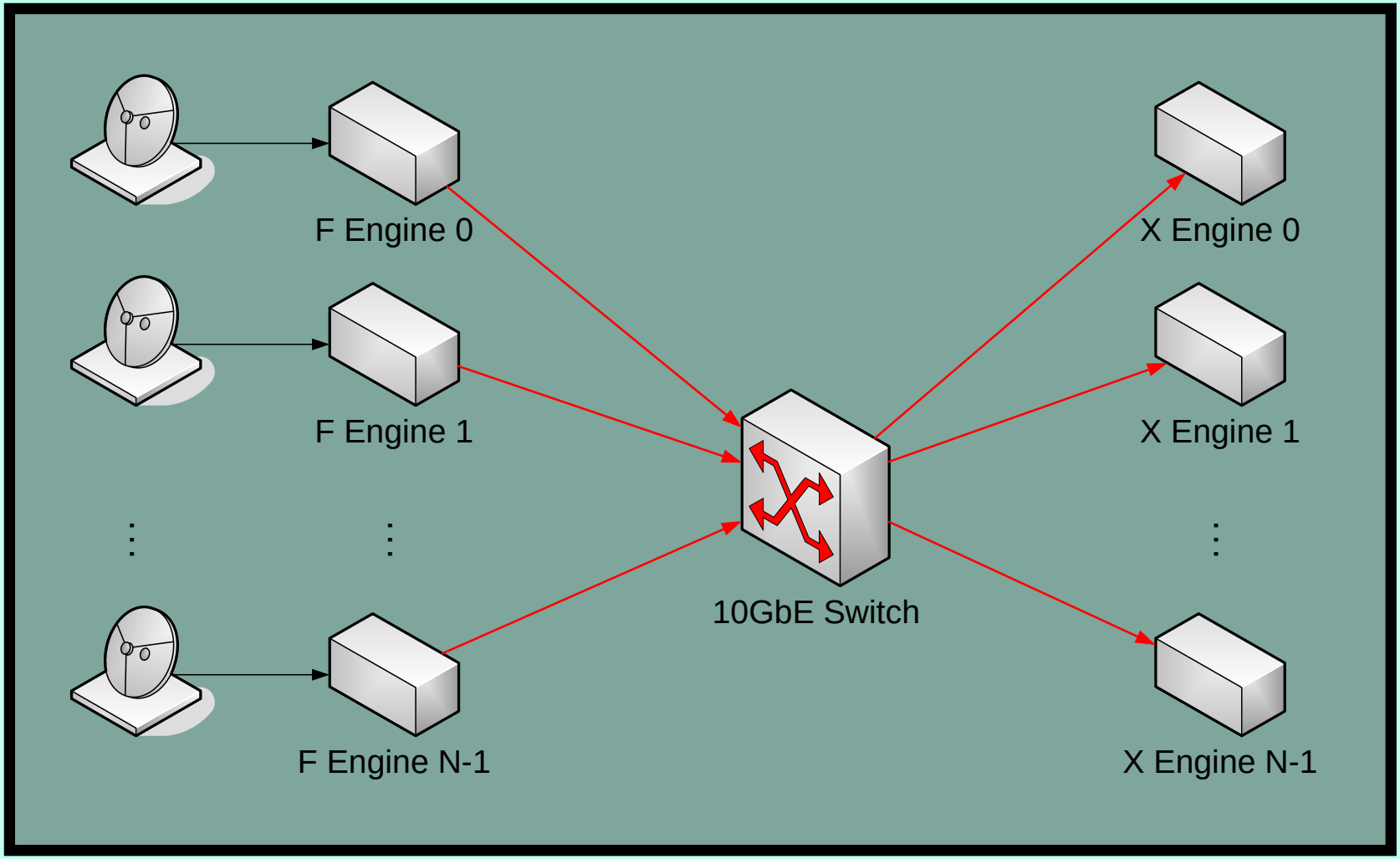


FX Correlator

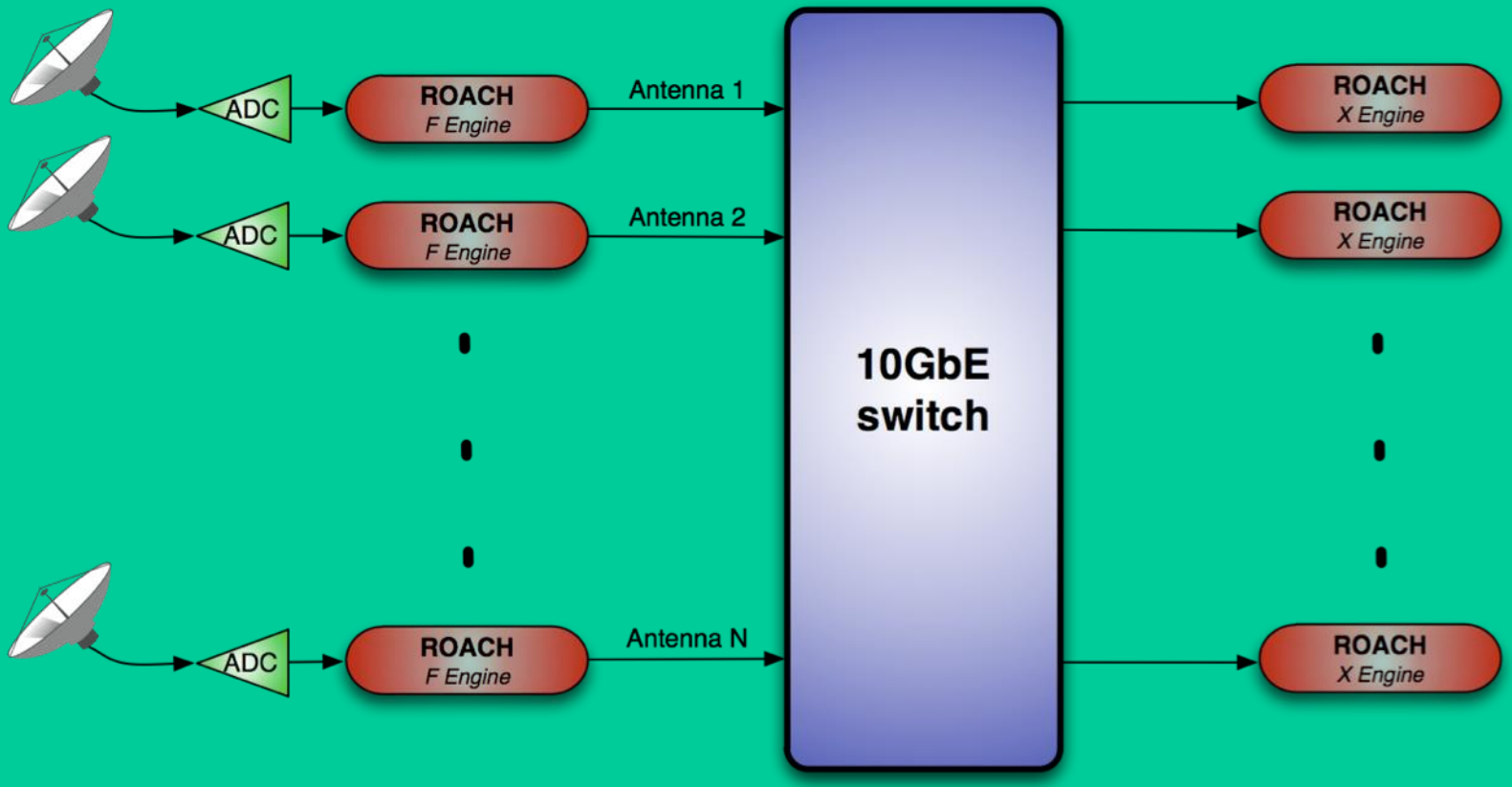


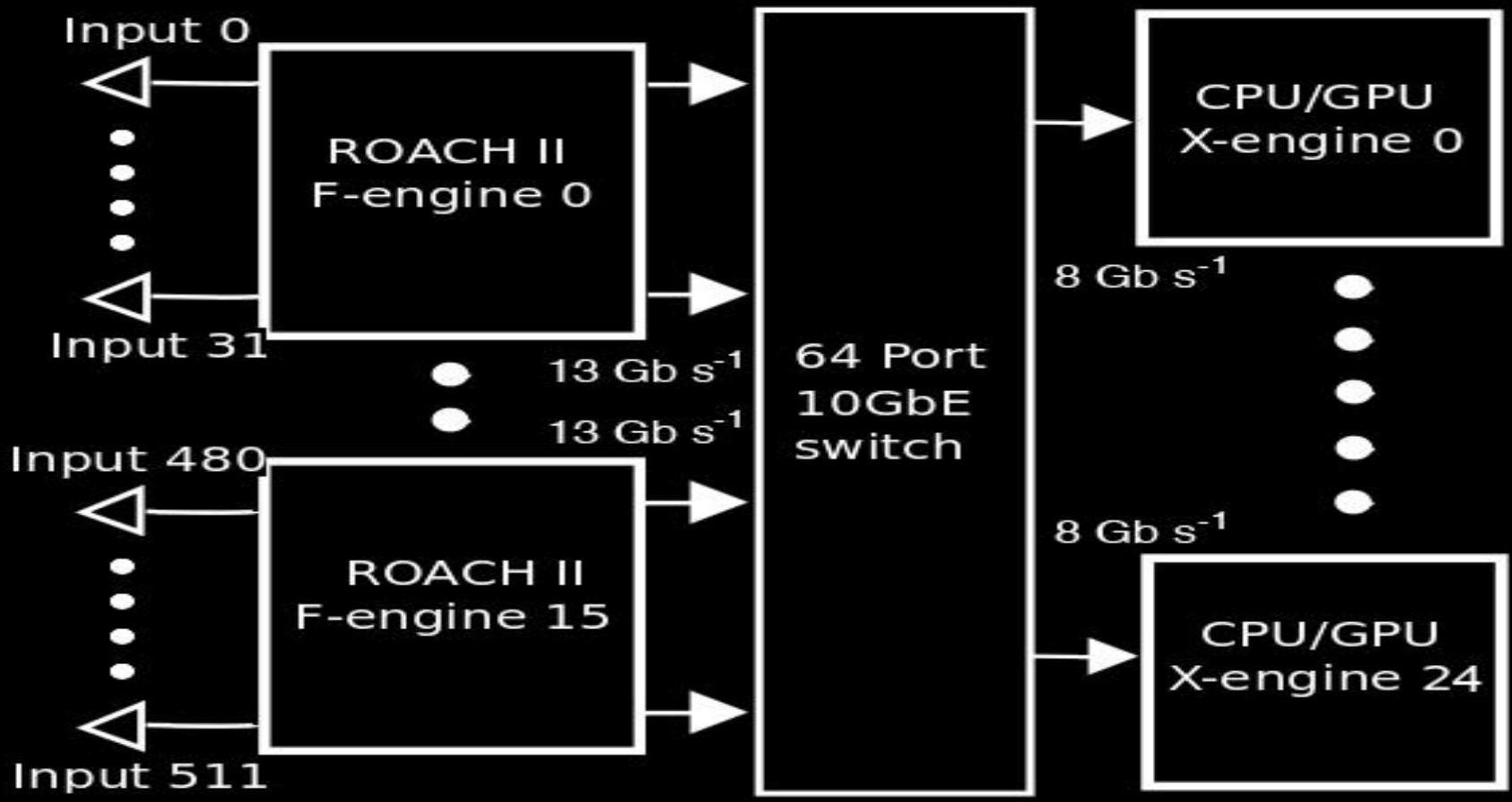

Antenna 1
F engine
Antenna 2
F engine
Antenna 3
F engine
Frequency Band 1
X engine
Frequency Band 2
X engine
Frequency Band 3
X engine

CASPER FXB Correlator/Beamformer
(correlator needed to calibrate beamformer)

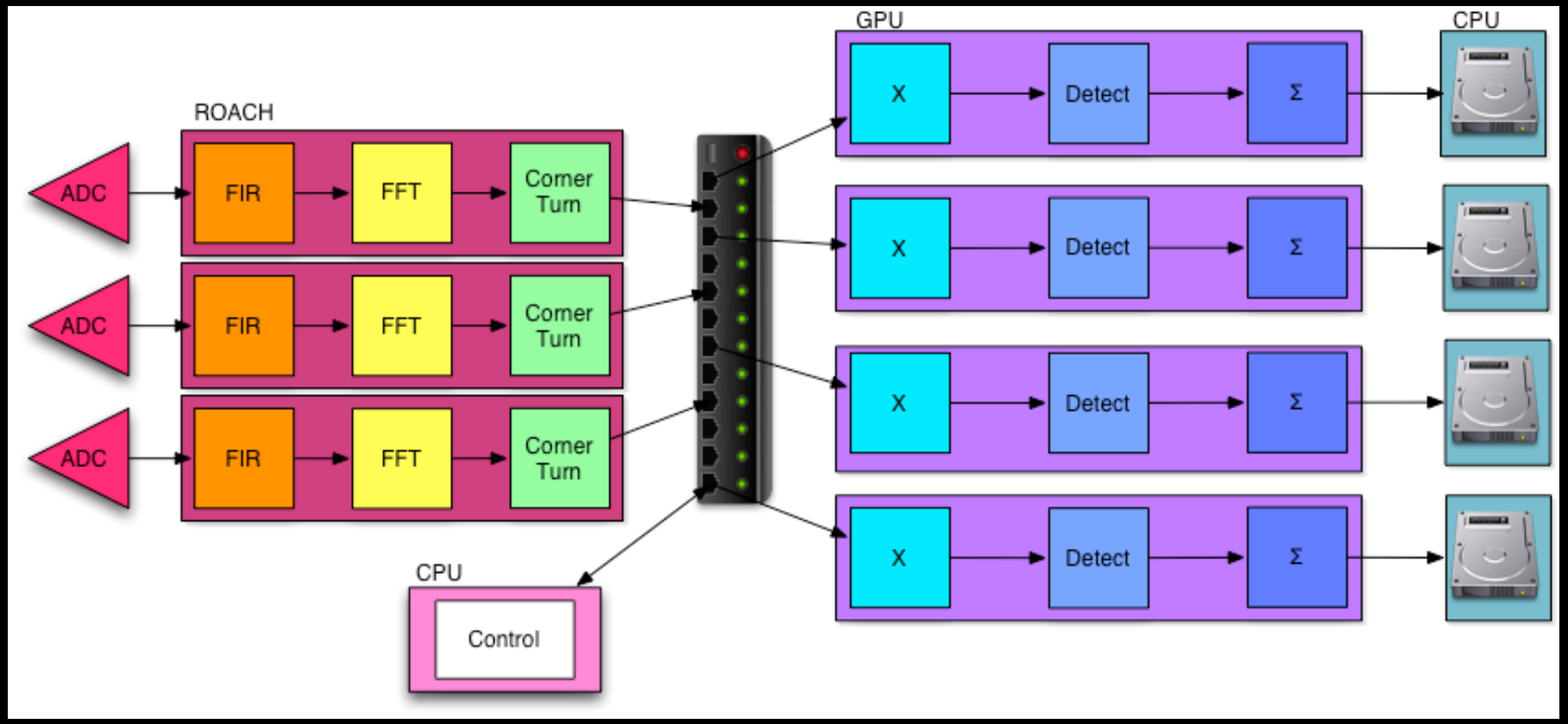


CASPER FPGA Packetized Correlator

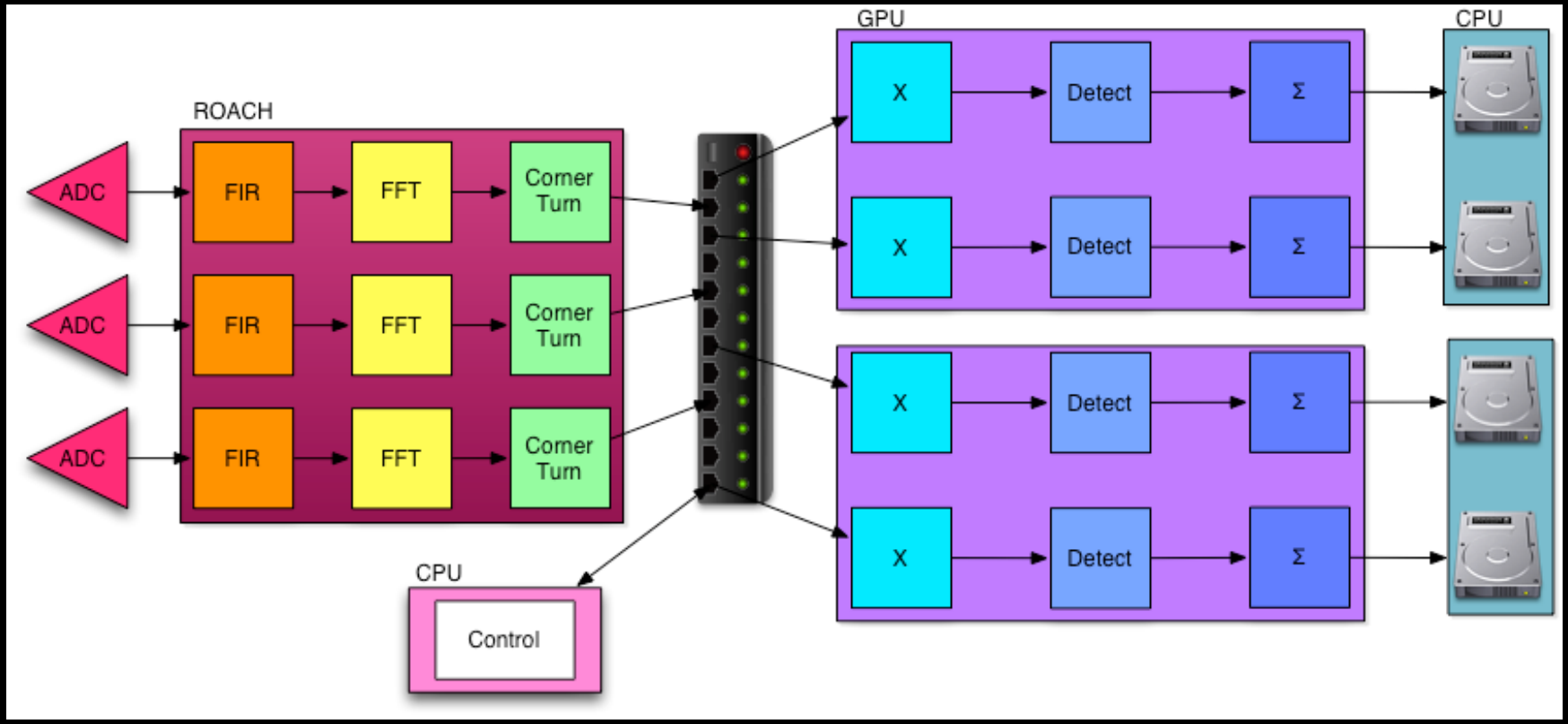



Input 0
ROACH II
F-engine 0
Input 31
13 Gb s-1
13 Gb s-1
Input 480
ROACH II
F-engine 15
Input 511
64 Port
10GbE
switch
CPU/GPU
X-engine 0
8 Gb s-1
8 Gb s-1
CPU/GPU
X-engine 24

Packetized FX Correlator



Heterogeneous Correlator



Data Transport Software for Heterogeneous Instrumentation

PSRDADA – Australia, Kocz et al

HASHPIPE – NRAO, UCB, D. MacMahon

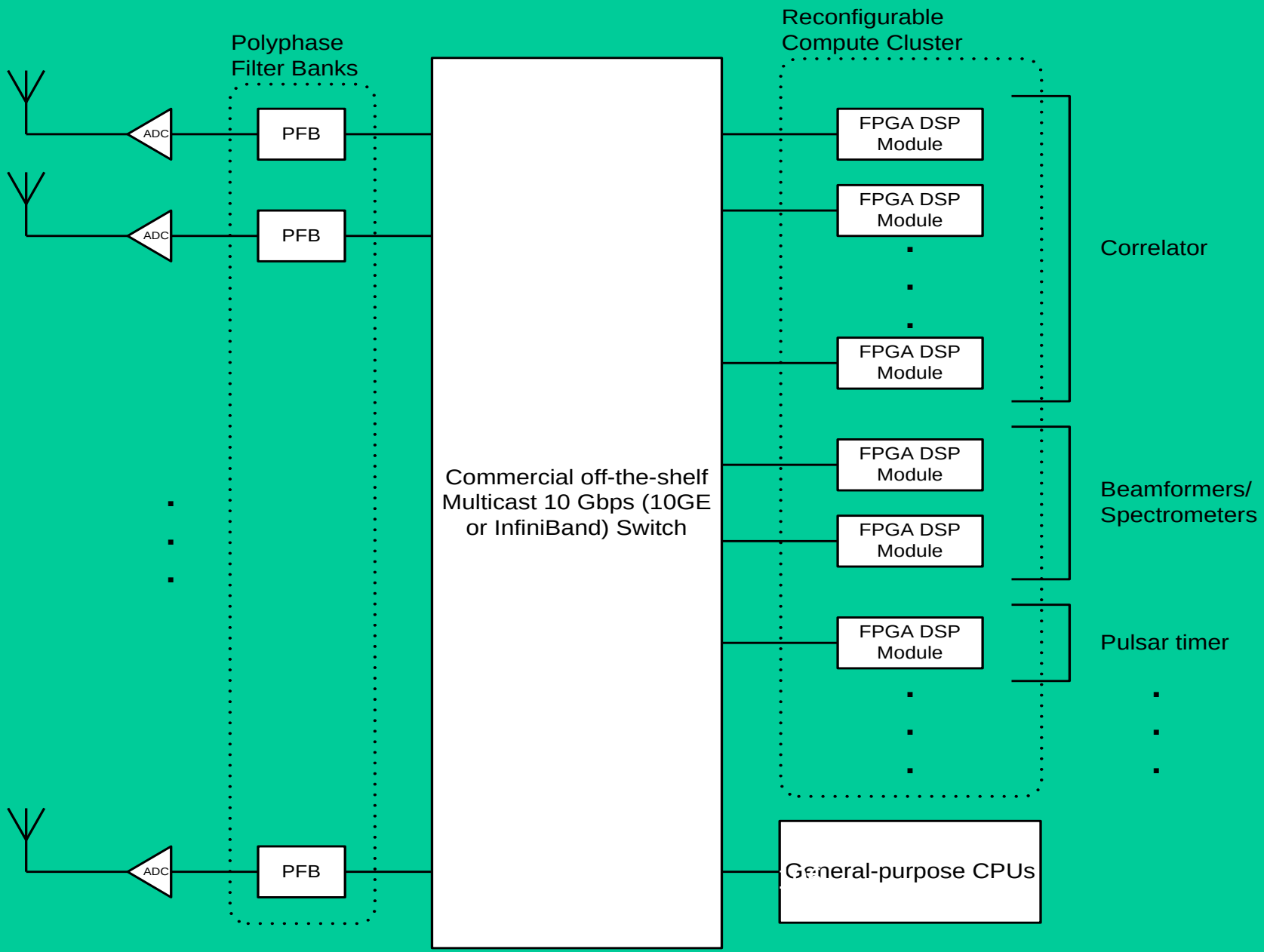
10Gbe NIC → CPU → GPU → CPU → DISK

Correlators and Beamformers

- Globally Asynchronous (like a computer cluster)
- Data is time stamped with 1 PPS at ADC
- Locally Synchronous, Globally Asynchronous
- Solve problem of correlator/beamformer interconnect problem by using 10 Gbe switches (for both interconnect and fast readout)
- No need for high density complex boards
- Use Fifo's to align data before correlation or beamforming…

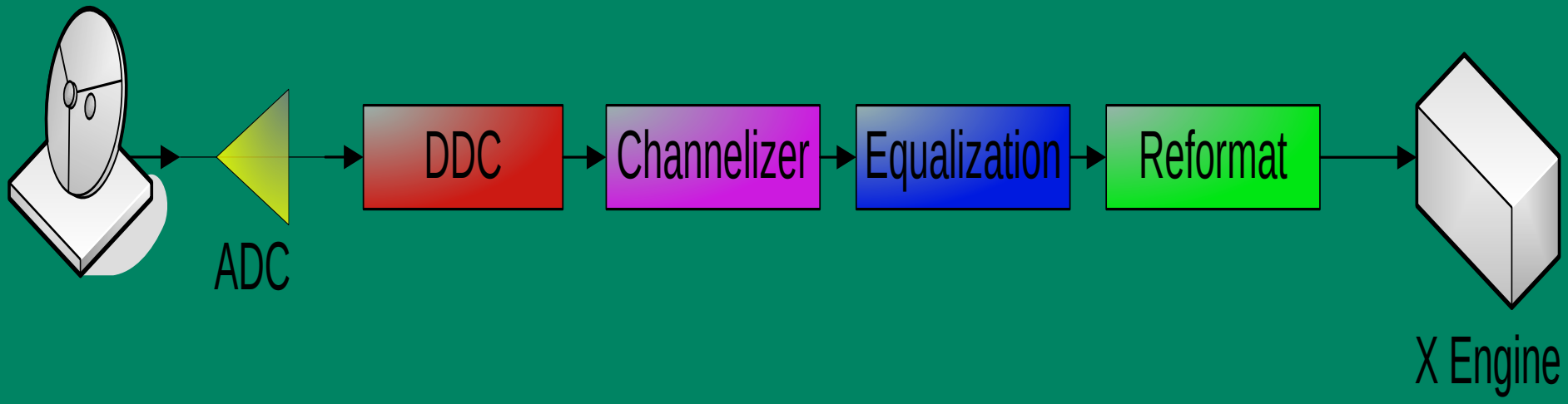
Beowulf Cluster Like General Purpose Architechture

Dynamic Allocation of Resources, need not be FPGA based

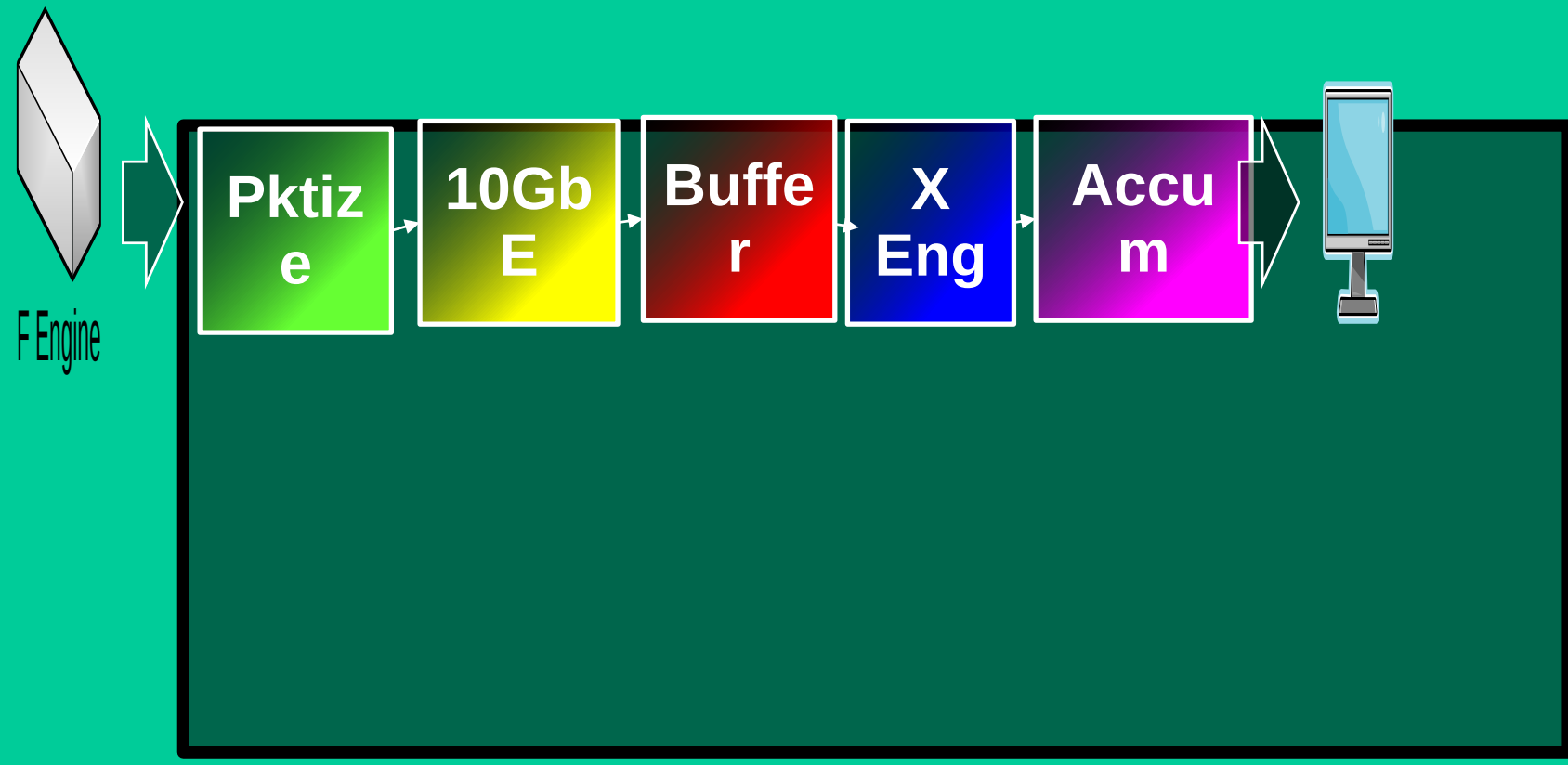


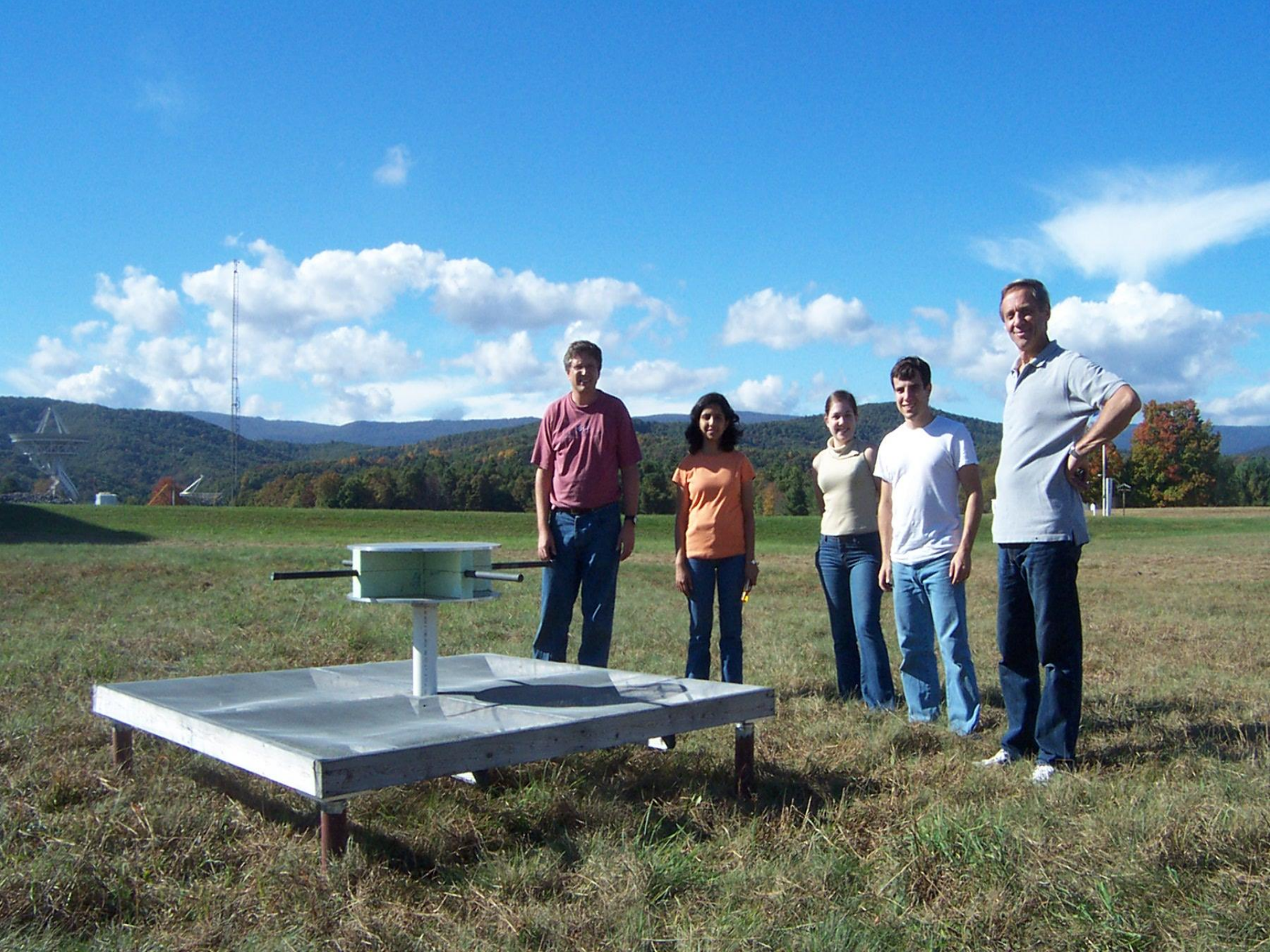
F Engine Overview

- Dual polarization design



X Engine Overview

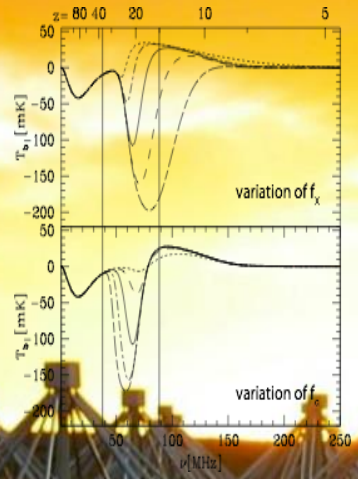




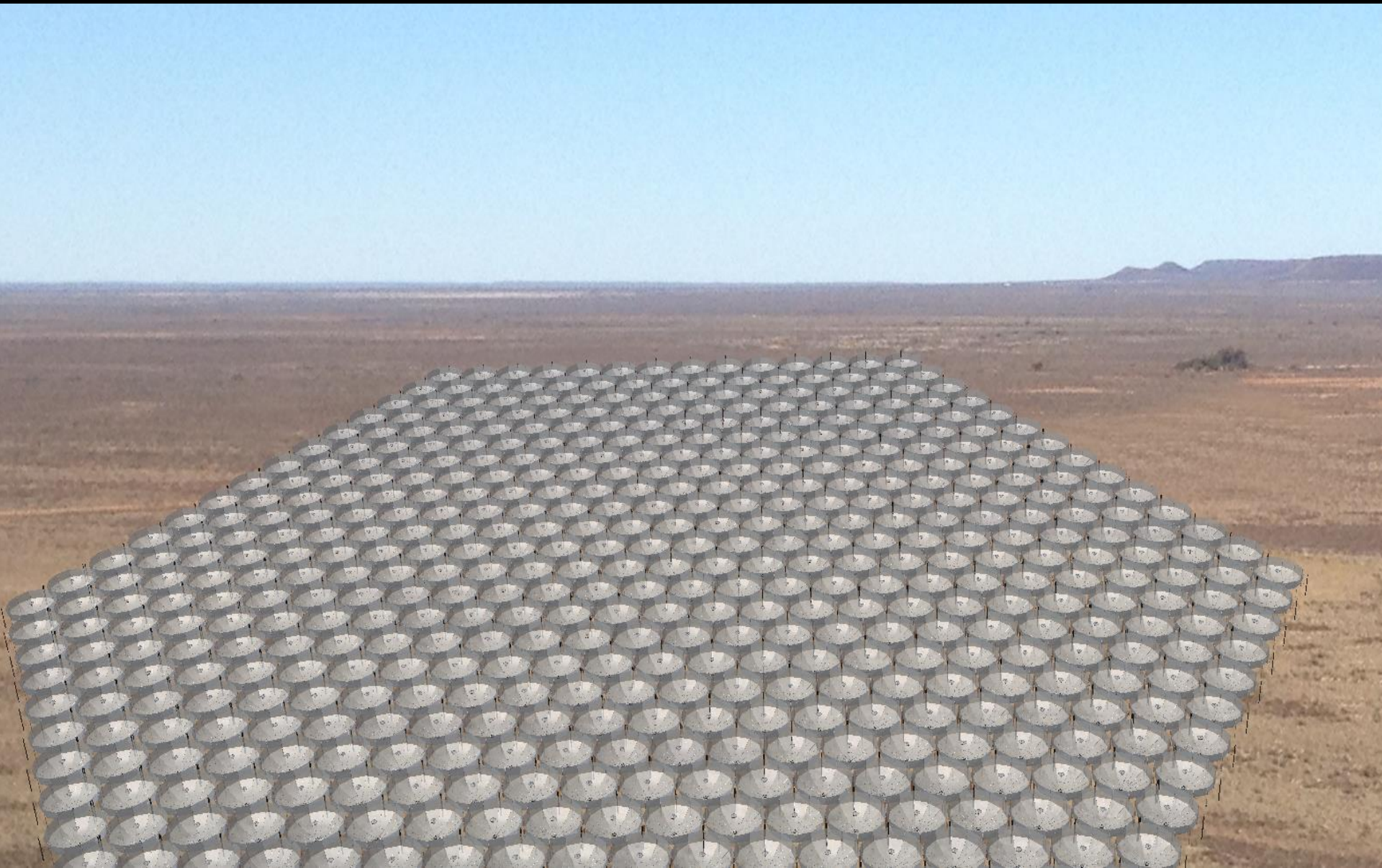

09C
CHARLOTTE PIPE
09B
09C
09B
09
BA

EWA - EDA

New Mexico, Owens Valley



HERA Array 547 x 15 meter dishes

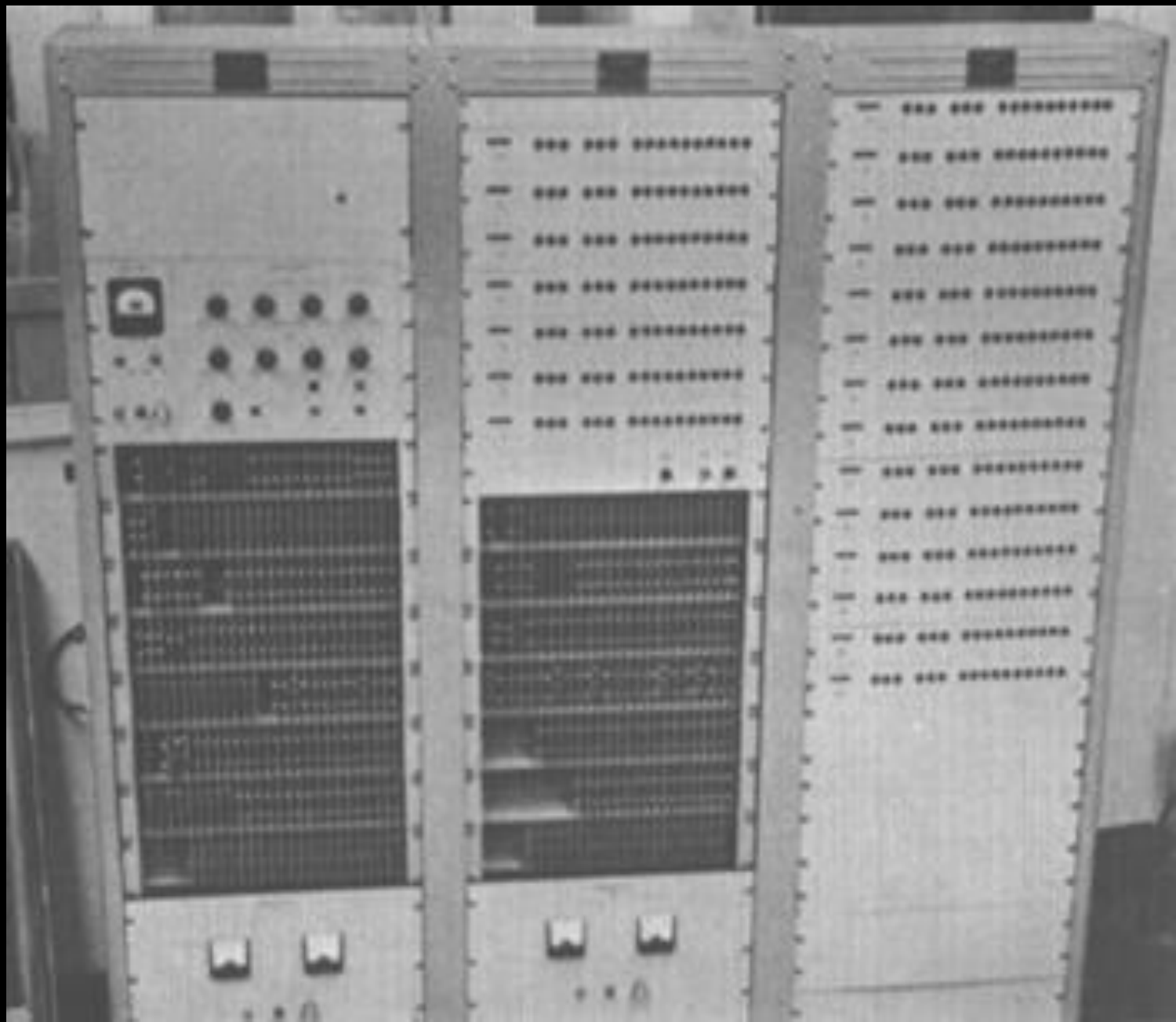


1960 – First Radio Astronomy Digital Correlator

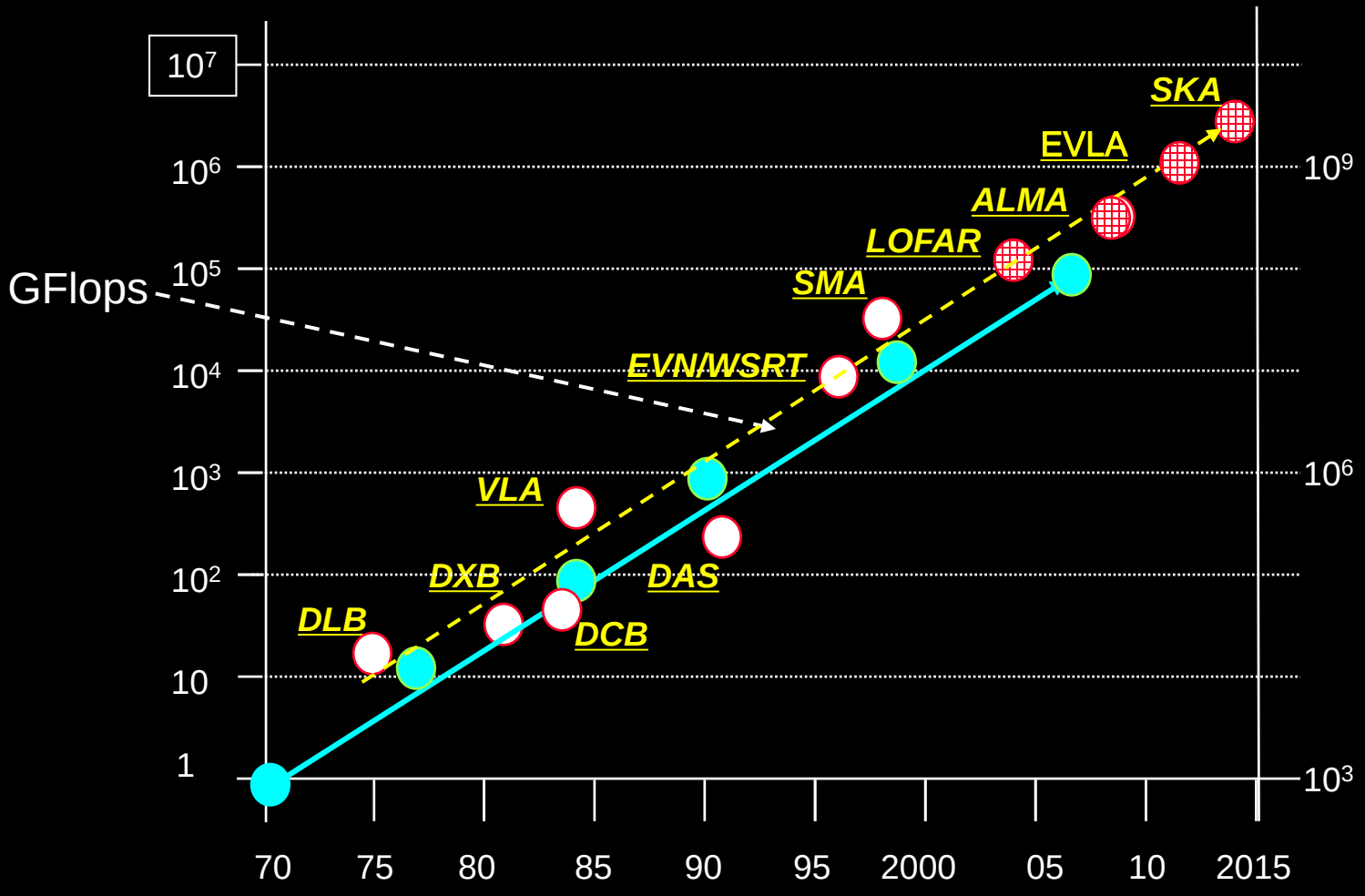
21 lags
300kHz clock
discrete transistors

$19,000

Sandy Weinreb



Correlator processing power



source: Arnold van Ardenne

Ray Escoffier

“With correlator performance having gone up by a factor of 922,000 over the last 30 years, its only fair that correlator design engineers' salaries should have gone up by a similar factor!!”

Correlator Projects

- Communications - $100M/SKA

  RDMA 10/40Gbe NIC to GPU

  CWDM, DWDM, 40/100Gbe, BIG Switches

- Help us design HERA Correlator

  (600 antenna, 250 MHz, South Africa)

- New Platforms – Intel Phi?, FGPA, ASIC?, Next Gen GPU, CPU Arrays,
- Optimize Code (FPGA, GPU…)
- Design Study (power(t), cost(t)…)
- New Architectures (Upgradable, Scalable…)
- Build a Prototype Correlator and improve it

CASPER the Friendly GHOST

- Group Helping Open-source Signal-processing Technology (GHOST?)
  - Goal to help develop signal processing instrumenation and libraries for the community.
  - Open source hardware, gateware, and software.
  - Mail list for collaborators helping each other
  - Provide training and tutorials
  - Promote Collaboration

Tutorials (Monika Obracka, Jack Hickish, et al)

Introduction to Simulink and Roach (blink an LED)

Using 10 Gbit Ethernet

Spectrometer (400MHz, 2k channels)

Correlator (4 input, 400MHz, 1k channels)

Heterogeneous Computing ADC→ROACH→CPU/GPU

Intro to embedding Verilog/VHDL in Simulink

Yellow Block Creation

Invitation to Tenth Annual CASPER Workshop

Berkeley

Monday June 9 through Friday June 13, 2014

morning: talks

afternoon: lab training, tutorials, working groups,

get help designing an instrument….