The New Landscape of Data Acquisition and Signal Processing for FRB's And The PANOSETI Nanosecond Time Scale Ultra-Wide-Field Transient Search

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SETI@home
The Search for Extraterrestrial Intelligence

CASPER: Collaboration for Radio Astronomy Signal Processing and Electronics Research

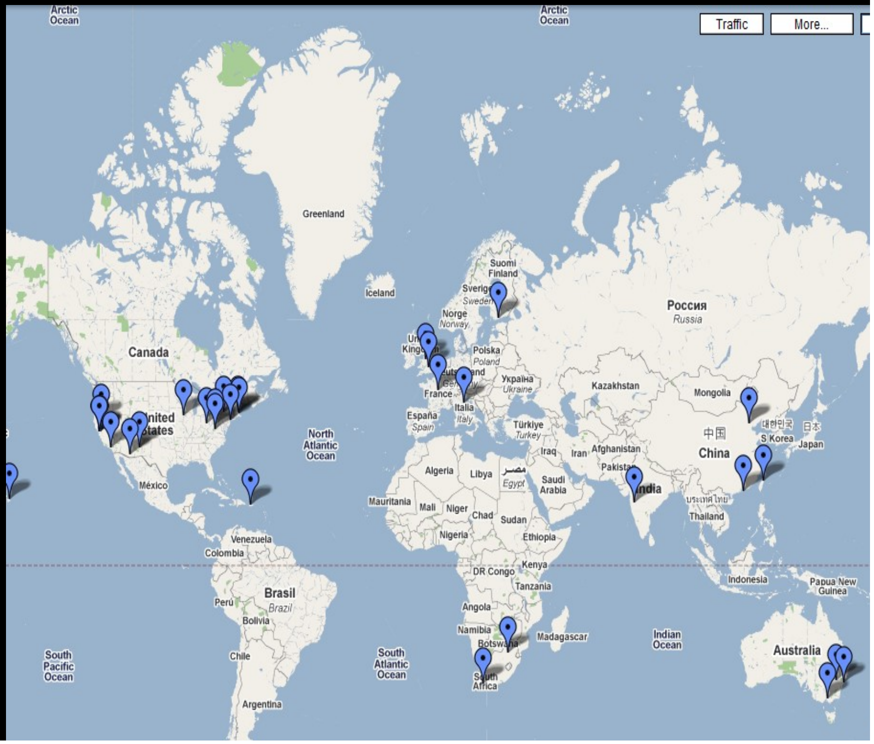
Open Source Hardware, Gateware, GPUware, Software for Instrumentation

Libraries, Tools, Reference Designs, Tutorials, Videos, Workshops

Astronomy, Physics, Electrical and Mechanical Engineering, Medical Research

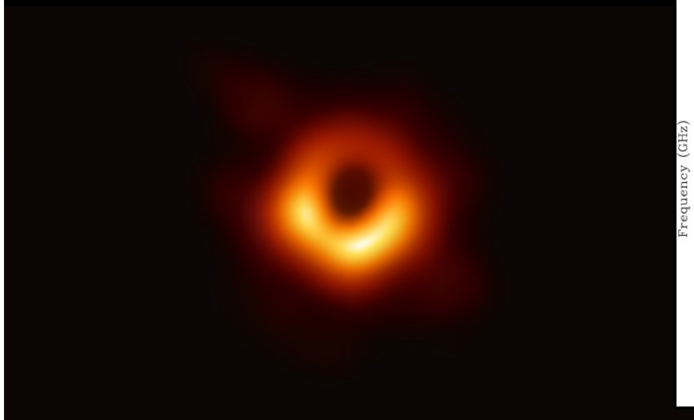
http://casper.berkeley.edu

Xilinx, Intel, Fujitsu, HP, Nvidia, NSF, NASA, NRAO, NAIC,
CFA (Havard/Smithsonian), Haystack (MIT), Caltech, Cornell,
CSIRO/ATNF, JPL/DSN, South Africa KAT, Jodrell Bank,
GMRT (India), Oxford, Institute, UC Santa Barbara;
UC 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
Bologna Univ, Metsahovi Observatory/Helsinki University,
University of California, Berkeley; Swinburne University

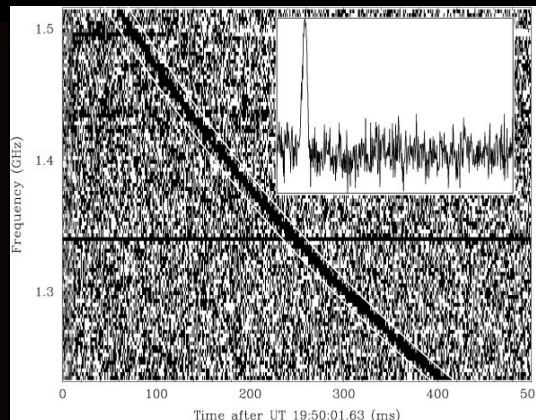


CASPER: Collaboration for Astronomy Signal Processing & Electronics Research
Discoveries Made with CASPER Instrumentation:

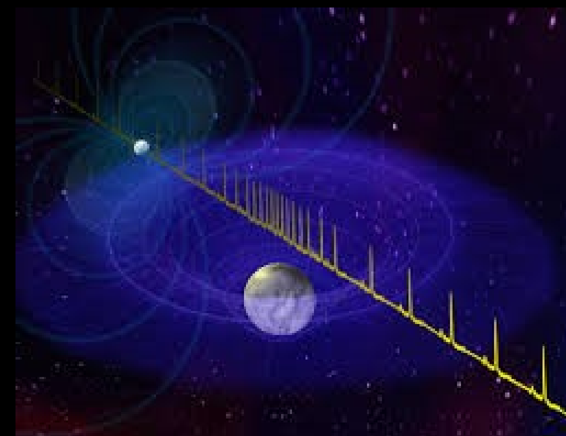
First Image of Black Hole, NSF
The Event Horizon Telescope



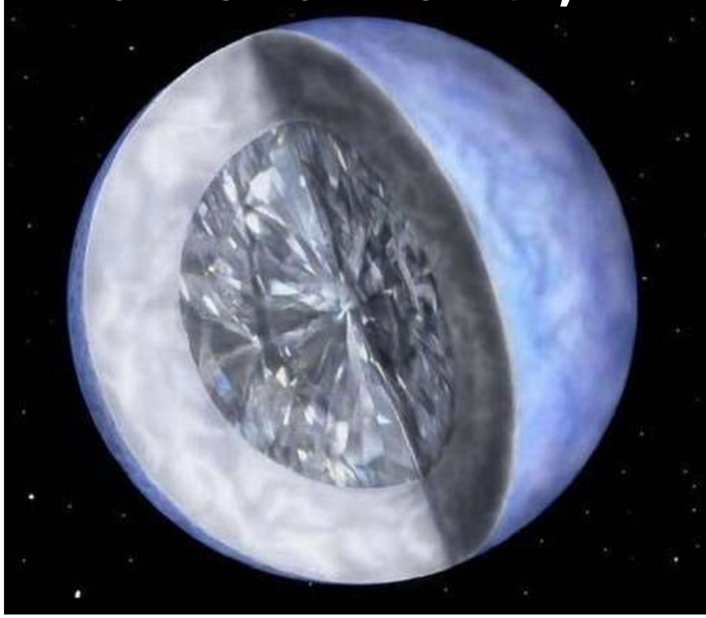
Fast Radio Bursts
Weighing the Universe

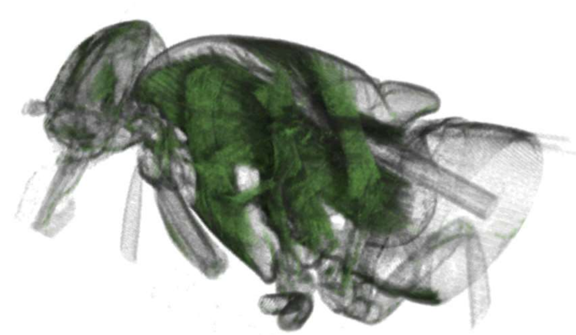


Pulsar Detection & Timing
Gravitational Waves
Equation of State

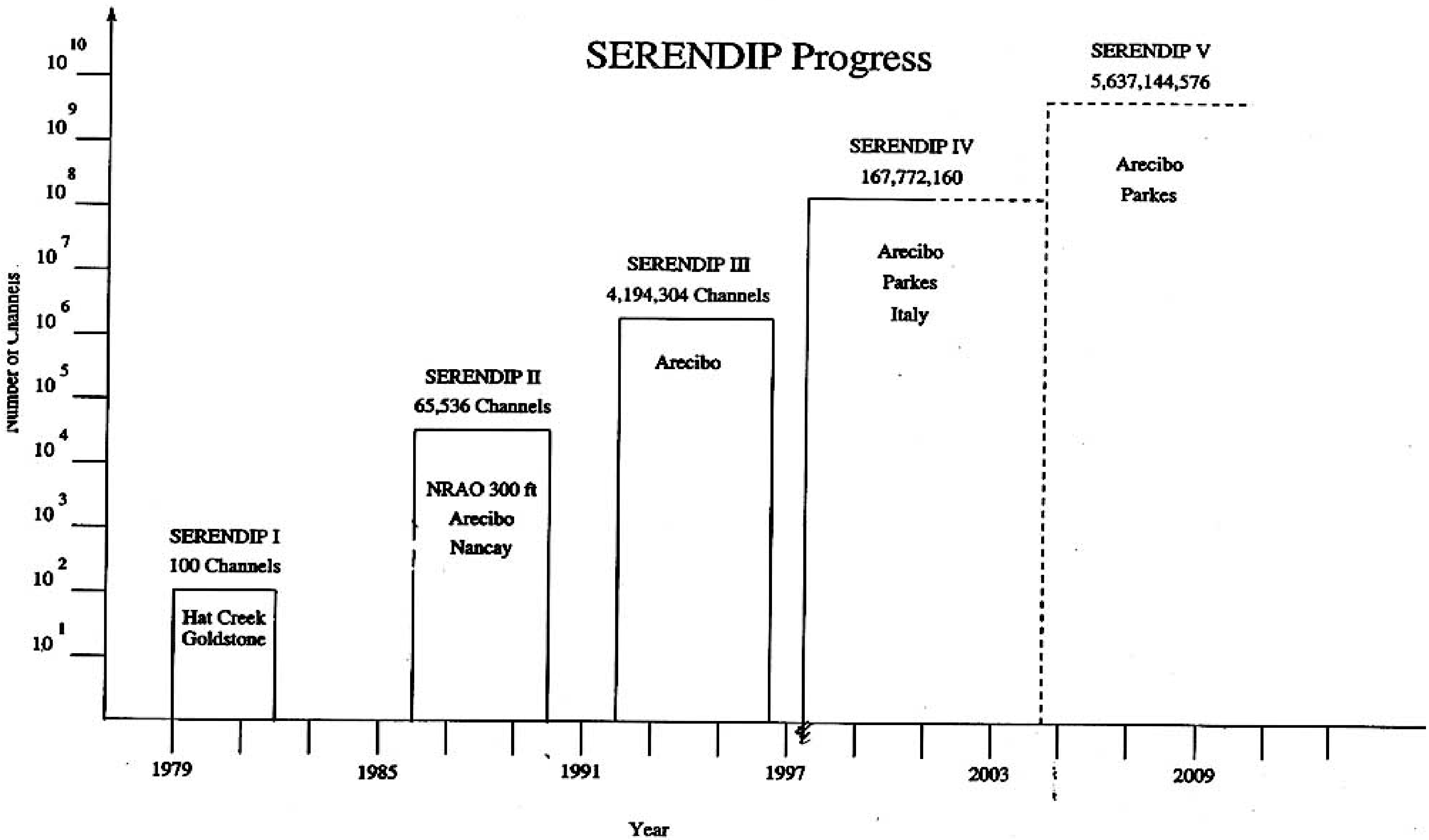


Diamond Planet, Prostheses Control, Neutron Imaging

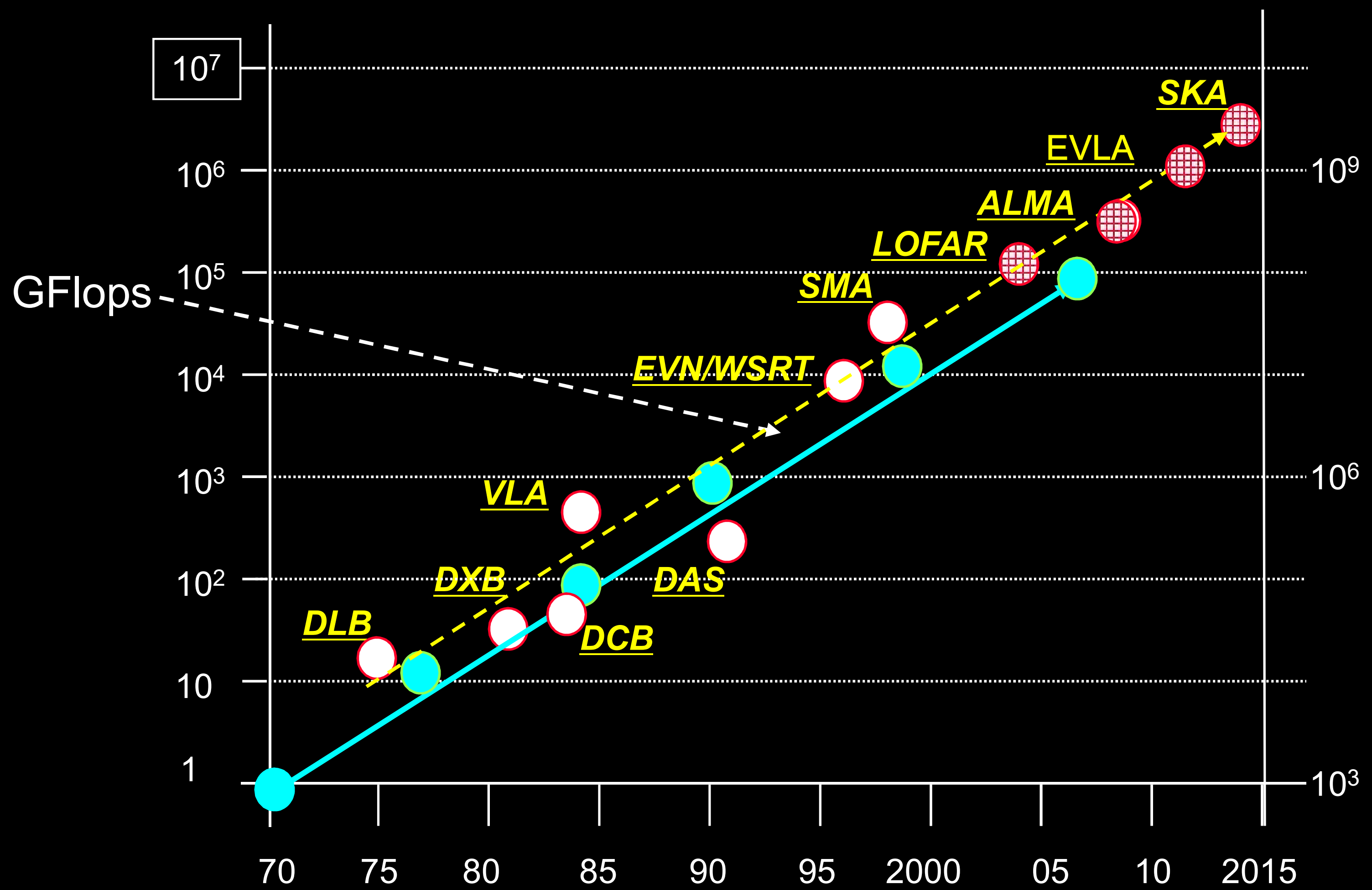




Moores Law – Instruments using FPGA's: 2X per year (1,000,000 over 20 years)



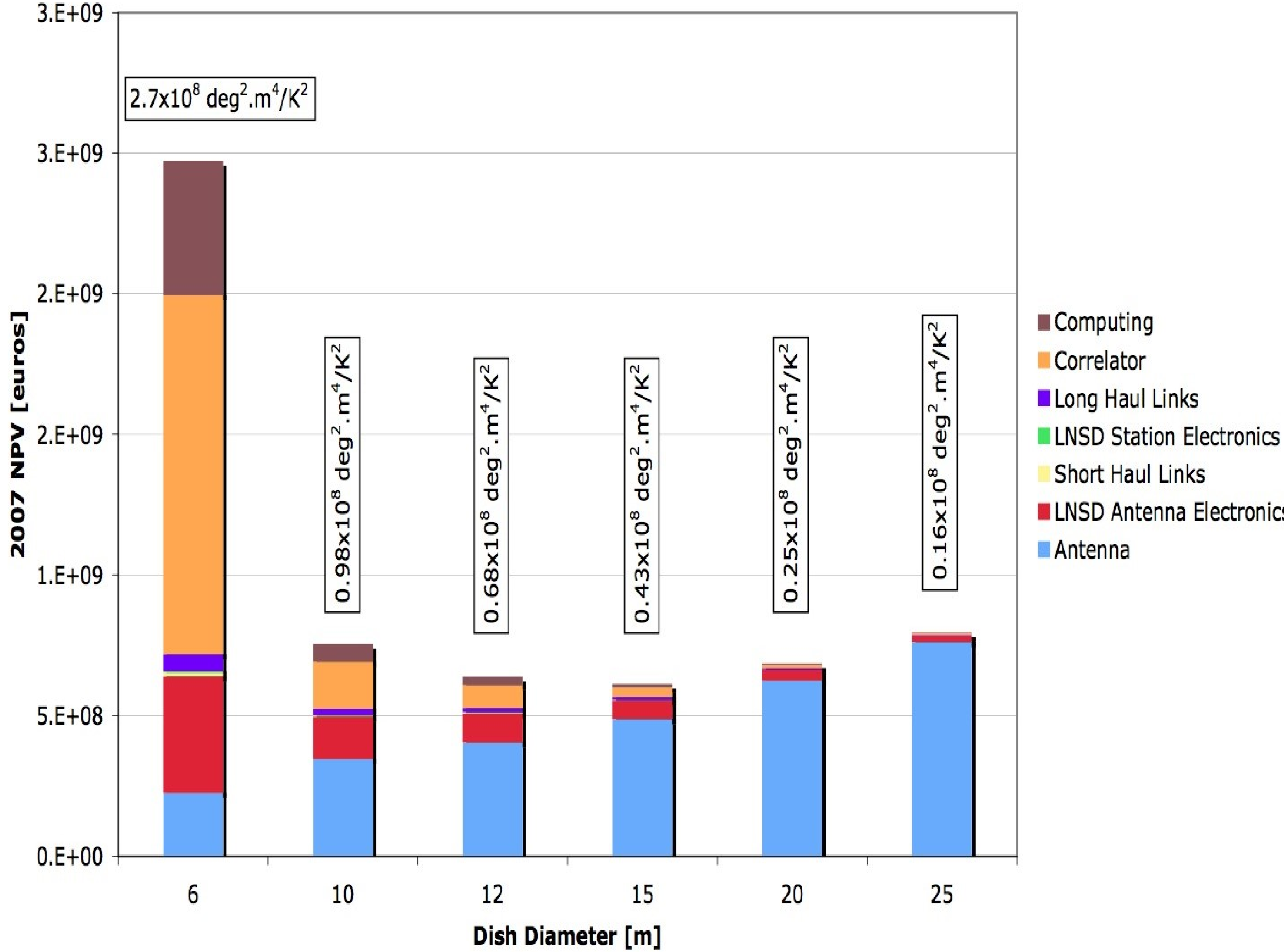
Correlator processing power



source: Arnold van Ardenne

expect (plan for)

- 100 GHz bandwidth
- 1000 to 1M antenna arrays
- 1000 to 1M beams (commensal experiments)
- 6:1 or 20:1 ? Feeds and receivers
- phased array feeds with low Tsys


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

CASPER Philosophy and Religion

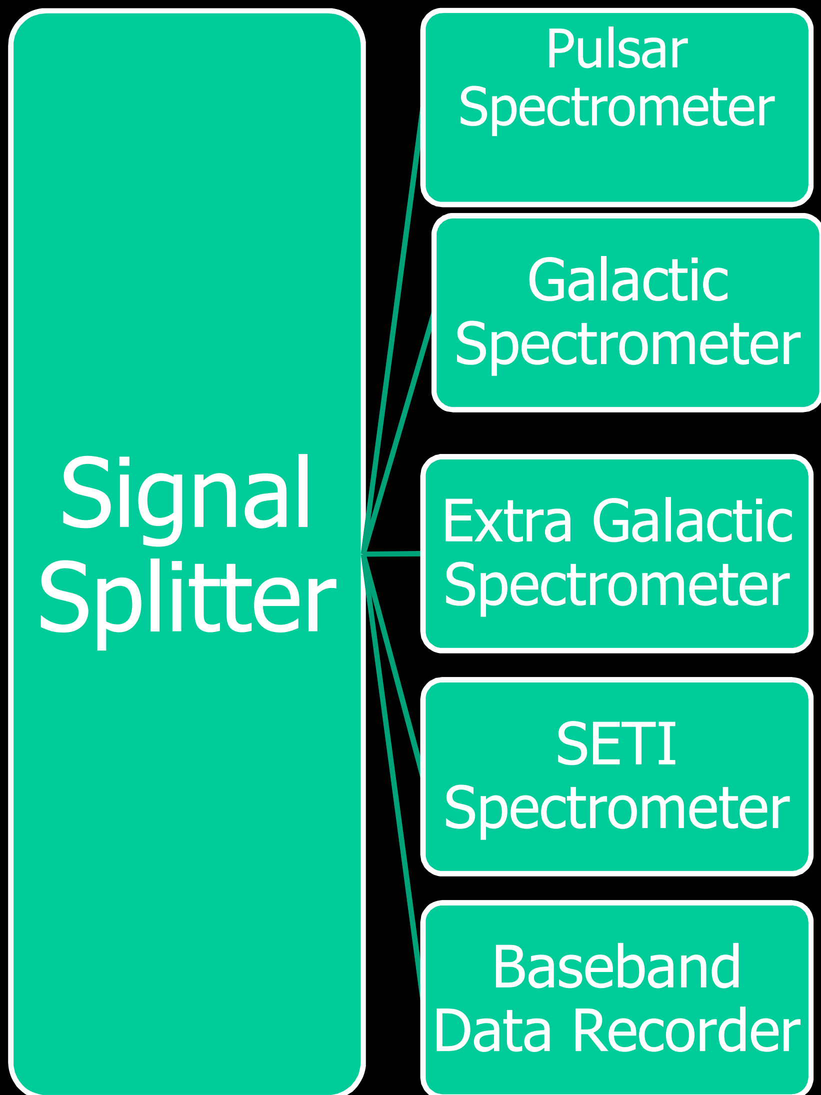
Design Observatories with Plan for Exponential Growth in Digital Processing

- Digital Backend should be replaced every 5 years (keep software, toss old - buy new hardware)
- DSP Part of Operating Costs, not construction costs

Instrument Architectures

- Scalable
- Upgradeable
- Flexible
- General and Multi-Purpose
- Fault Tolerant

Simultaneous Digital Backends
Piggyback, Commensal, Sky Surveys



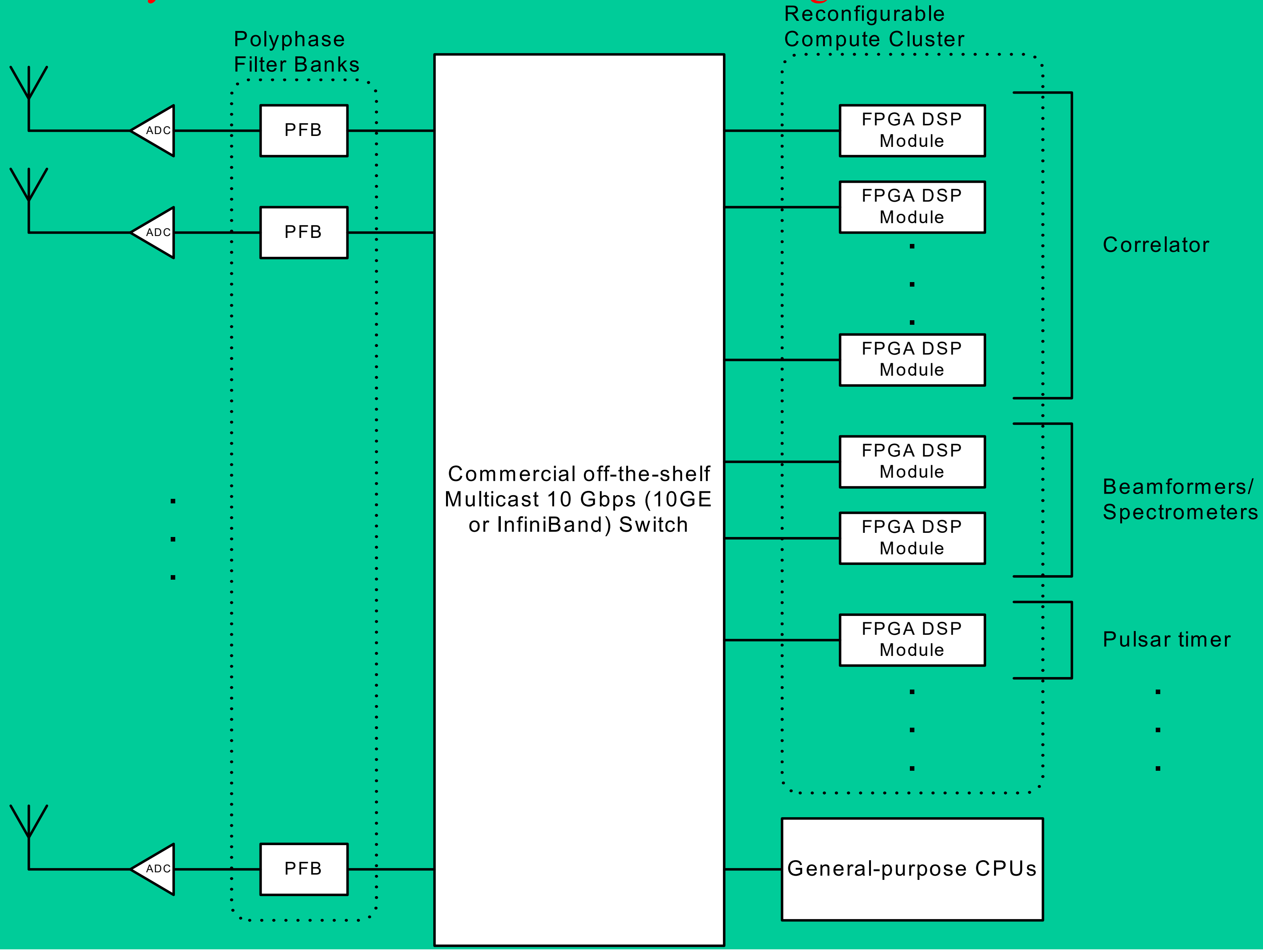
Analog Power Splitters

or

Digital Data Splitter

CASPER General Purpose Architechture "Ethernet Telescopes"

Dynamic Allocation of Resources – Moving GPU Cluster Backends



Board Interconnect - Upgradable

- Problem: Backplanes are short lived

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

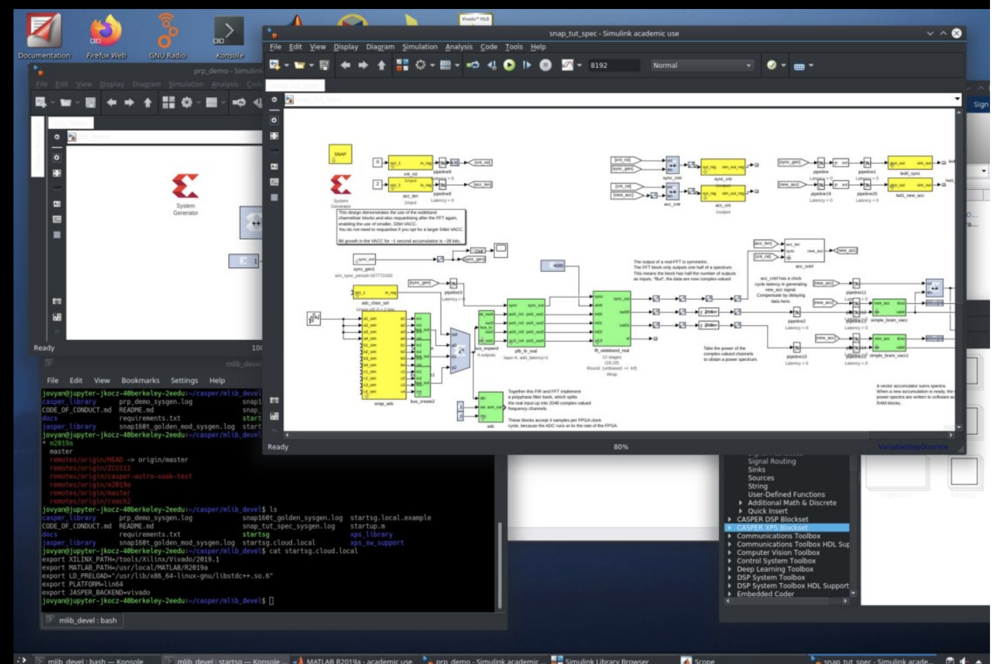
- Solution: 10, 40, 100, 400 Gbit/sec Ethernet

  Ethernet since 1973 – likely to stay around !

  40 Km fiber transceivers: 400 Gbit/s - 10 Tbit/s

Platform-Independent Parameterized Gateware

- Libraries are Independent from Hardware
- Same code ~40 FPGA boards
- Matlab Simulink (graphical)
- Linux I/O and Control



Casper Commandments

Thou Shalt Share thy Knowledge

Thou Shalt Help thy Neighbor Casperite

Thou Shalt Covet thy Ethernet to Connect Everything

Switches are Free

CASPER Tutorials

Introduction to Simulink and CASPER

Using 10/40/100 Gbit/sec Ethernet

Spectrometer (400MHz, 2K channels)

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

Heterogeneous Computing ADC→FPGA→CPU/GPU

Embedding Verilog/VHDL in Simulink

High Speed Data Transport to/from GPU

Yellow Block Creation (ADC/DAC/Other Interfacing)

Annual CASPER Workshops

morning: talks

afternoon: lab training, tutorials, working groups,

get help designing an instrument....

Busy Weeks, Board Porting Workshops,

HELP: Archived Mail List, Slack, Monthly Telecons

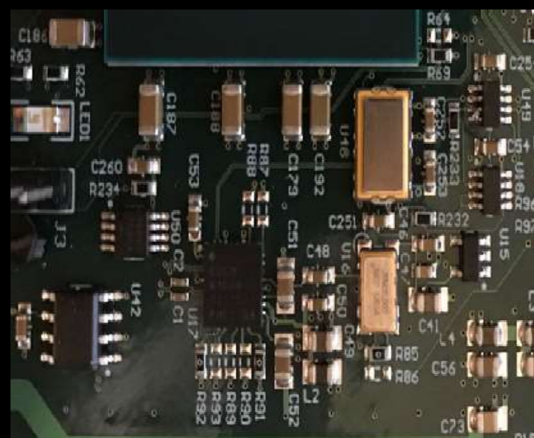
White Rabbit – open hardware/gateware Time and Frequency Transfer over Ethernet

1pps, 10/25/100 MHz,

30 ps time transfer

Open source design/code

$50 hardware, or gateware



Problem: GPU's are I/O bound

Tensor Cores: Correlators,Beamformer,Filters (not FFT)

Data Transport Software for GPUs

HASHPIPE, PSRDADA, BiFROST

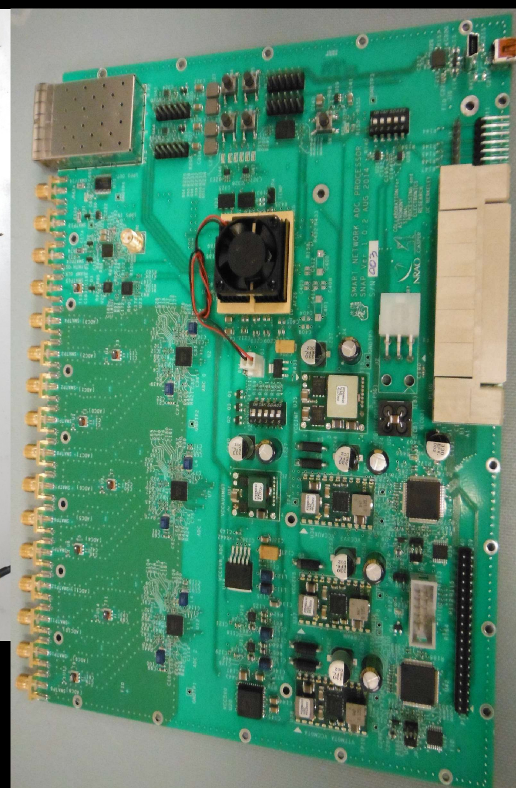
400 Gbit/sec into a GPU (RDMA, ROCE)

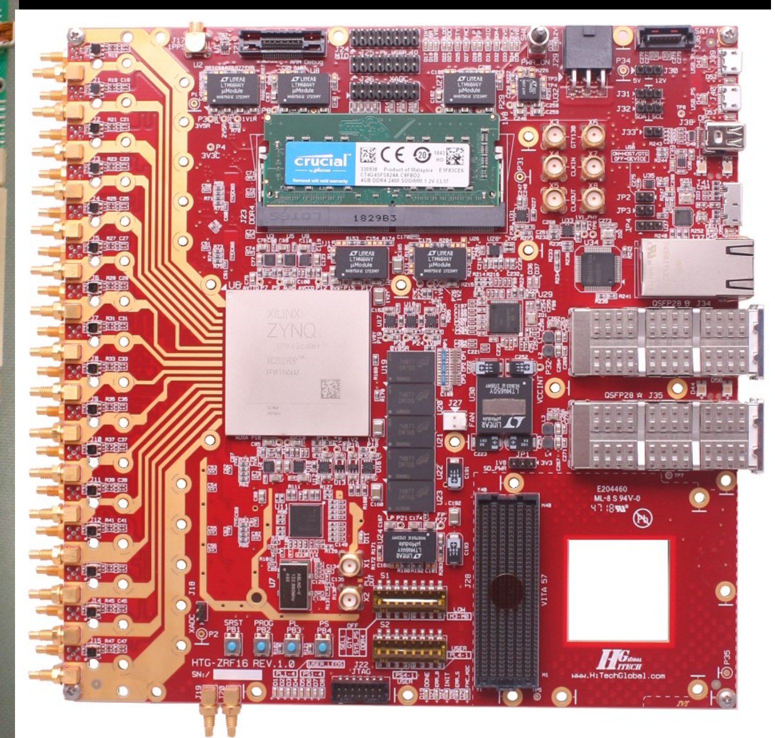
Gbe NIC → CPU → GPU → CPU → DISK

QUAD 16 Gsps ADC board
Ultrascale+ FPGA, 4x100Gbe

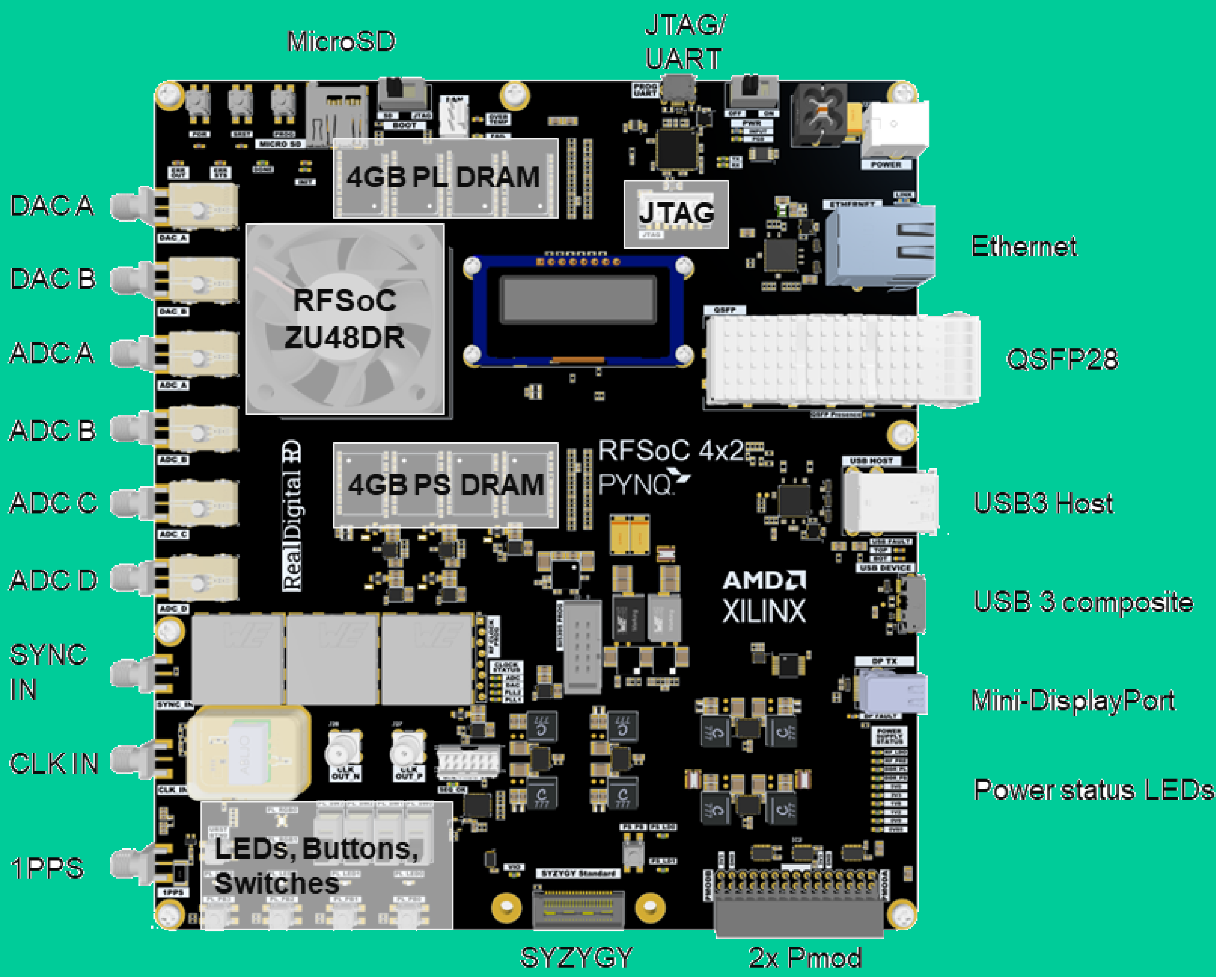
12 ADCs, Synthesizer
$2.5K FPGA Board

RFSOC Boards (many)
5.9 Gsps 14 bit ADCs
10 Gsps 14 bit DACs





$2150 RFSOC4x2 Board
Quad 5 Gsps 14 bit, 100 Gbit ethernet



Sparrow

500/800/900 MSPS ADC

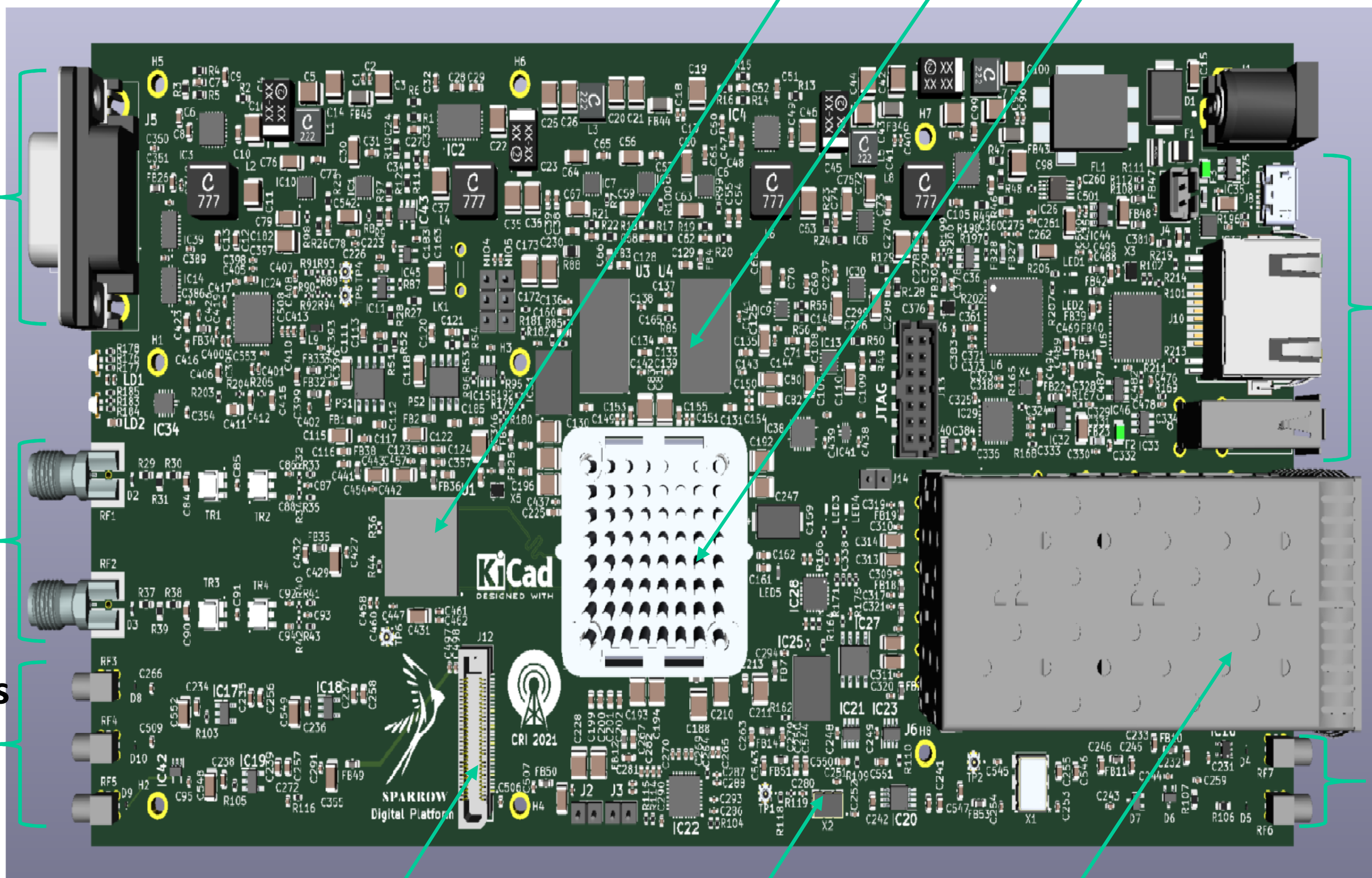
4G RAM

Xilinx ZynQ 7000

DC, GPIB, SPI, I2C

Dual RF inputs

REFCLKs and Trigger



RJ45 Ethernet, USB and SD card

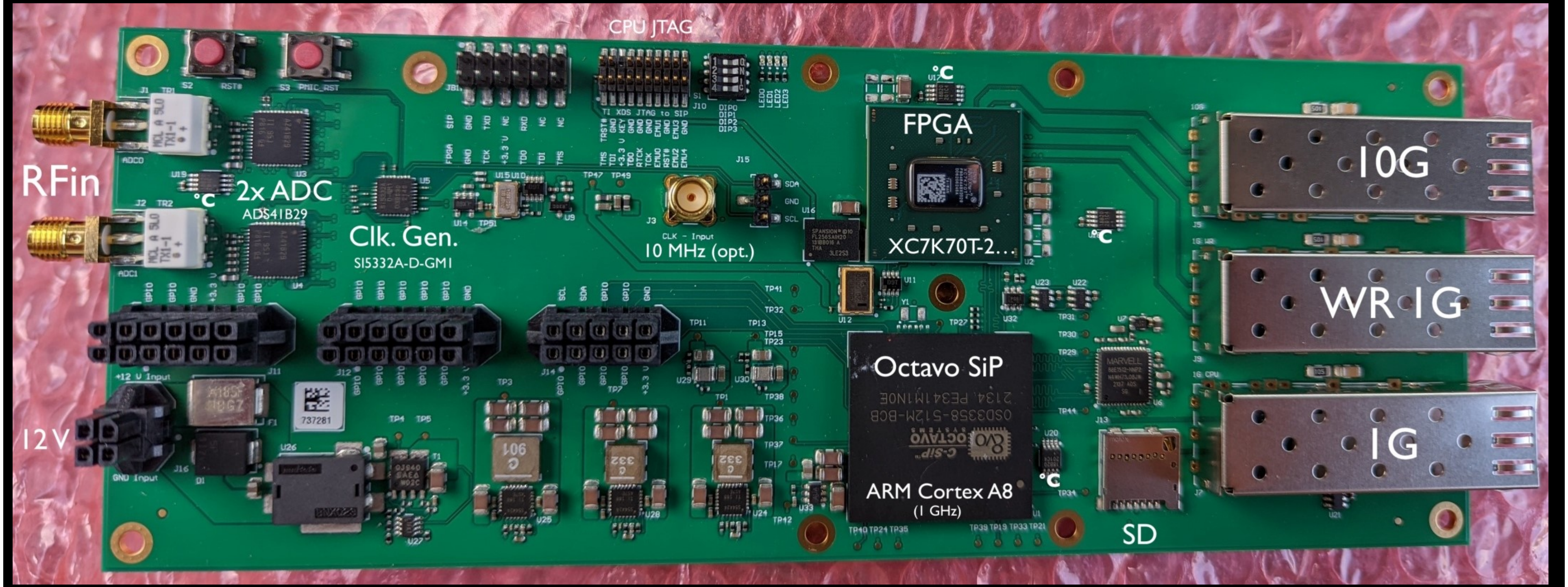
REFCLK, 1PPS

60-pin High speed Mezzanine

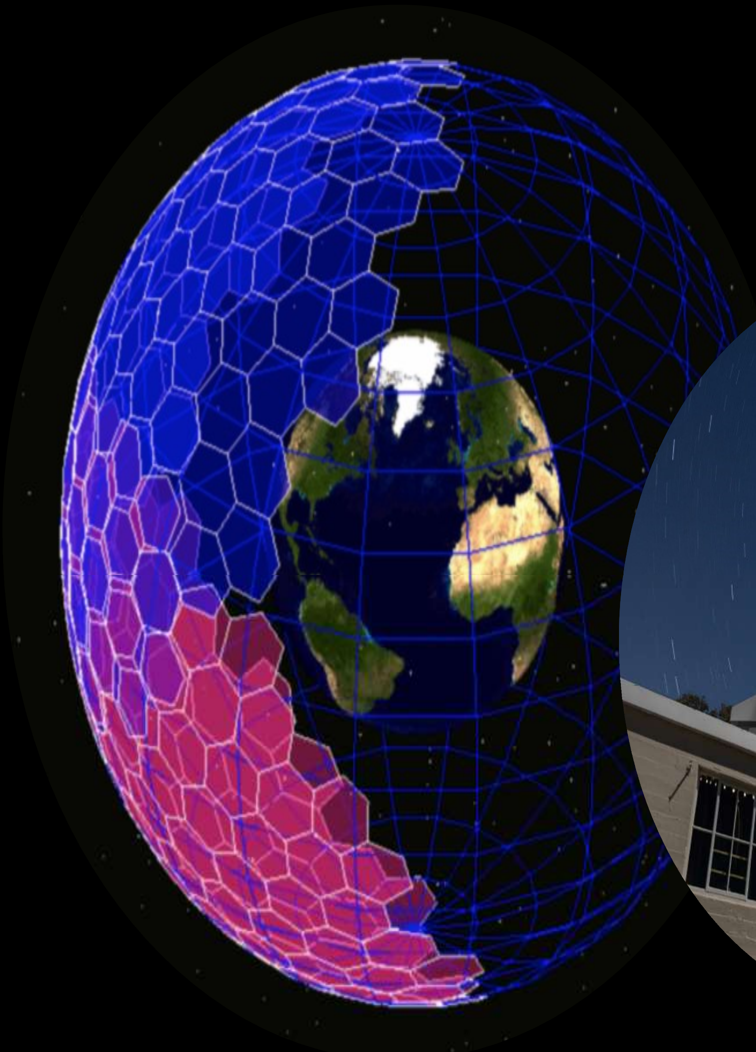
WR circuits

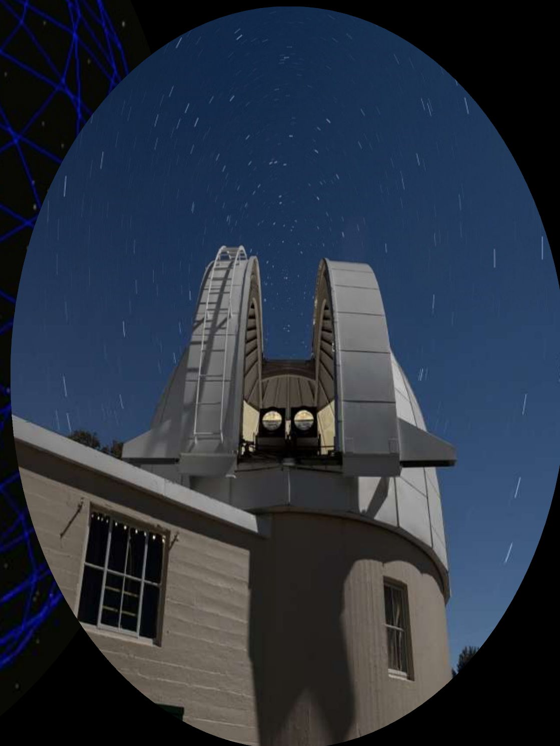
3x10Gb data output + WR

Pika Board, 10 Watts, dual 250 Msps, 12bit ADC; Lincoln Green Hill, CFA

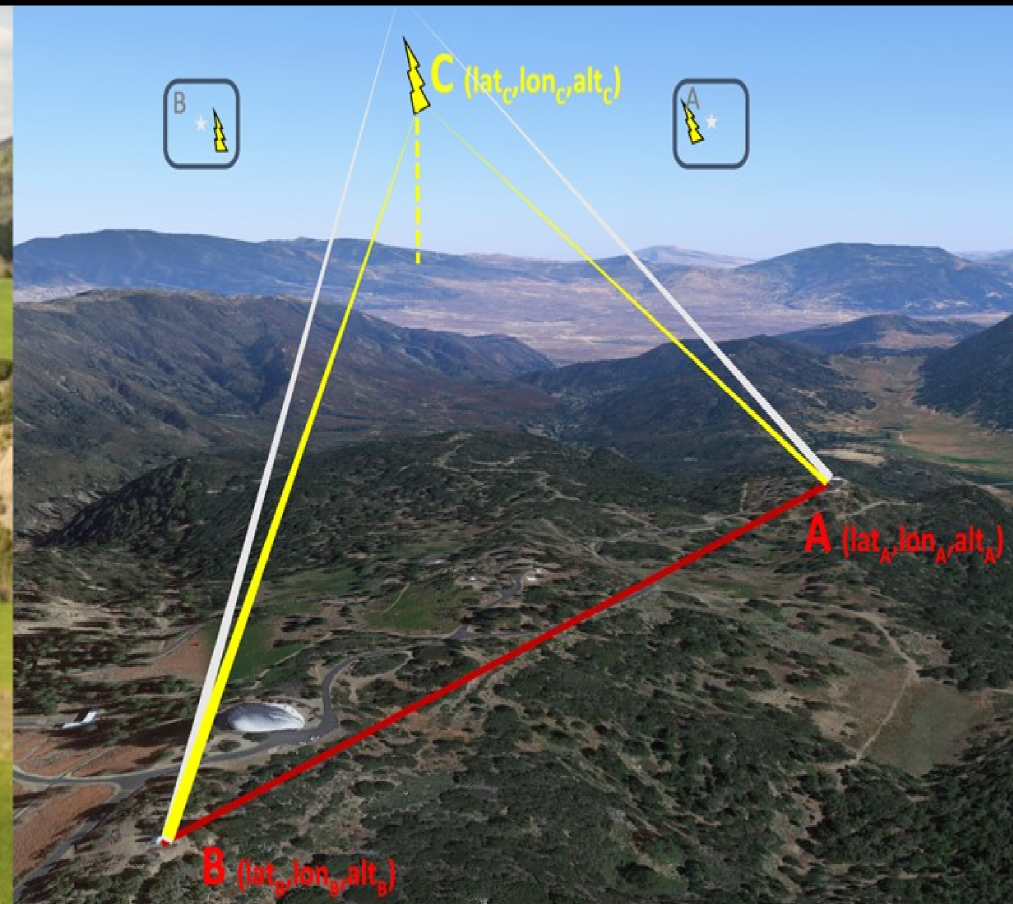


THE PANOSETI IR/VIS TRANSIENT SEARCH





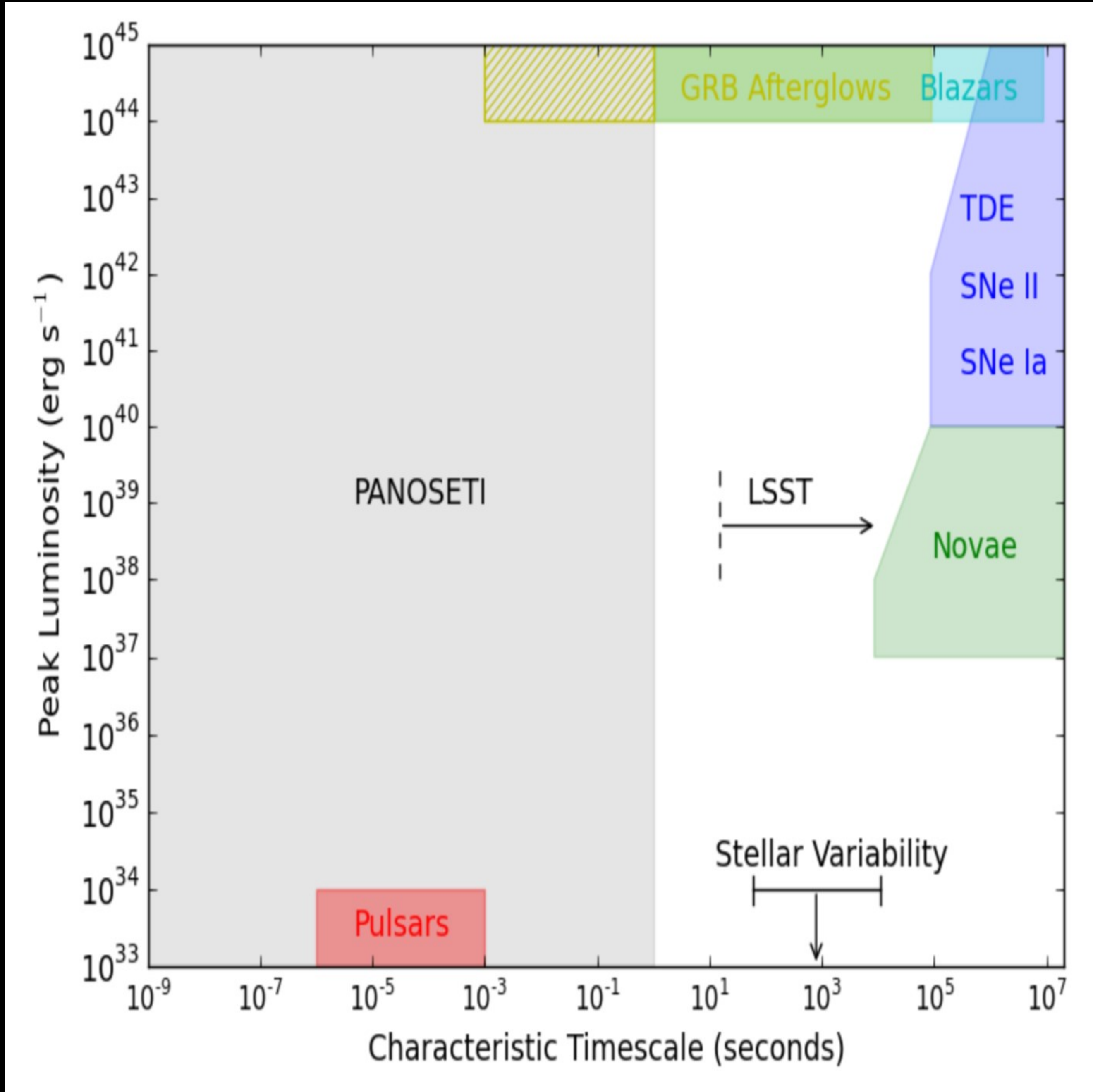
David Anderson, Nico Rault-Wang,
Franklin Antonio, Aaron Brown,
Frank Drake, Andrew Howard,
Paul Horowitz, Ryan Lee, Wei Liu,
Jerome Maire, Rick Raffanti,
Dan Werthimer, James Wiley
Shelley Wright



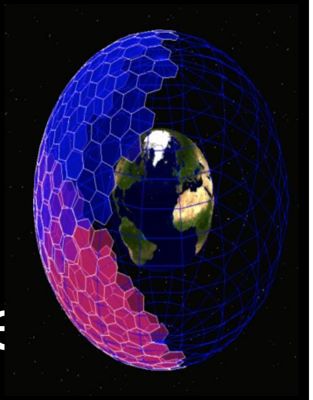
Two sites are critical for unambiguous detection

- PANOSETI will be built at Palomar Observatory on two sites separated by 1 km
- Capable of distinguishing Cherenkov showers by parallax and timing

PANOSETI exploring new time domains over large sky coverage with a long cadence



PANOSETI exploring new phase space



- Extending wide-field searches to the desirable ne
- Investigating the entire “observable” sky, increasing field coverage by a factor of 30,000 (Harvard –wide field) and 3,000,000 (APF-targeted)
- Increasing the fraction of time observed on *any* given source by a factor of 100,000
- Enlarging number of observed sources to 100’s of millions stars
- Observations of transient astrophysical sources and coordinating with multi-messenger progams

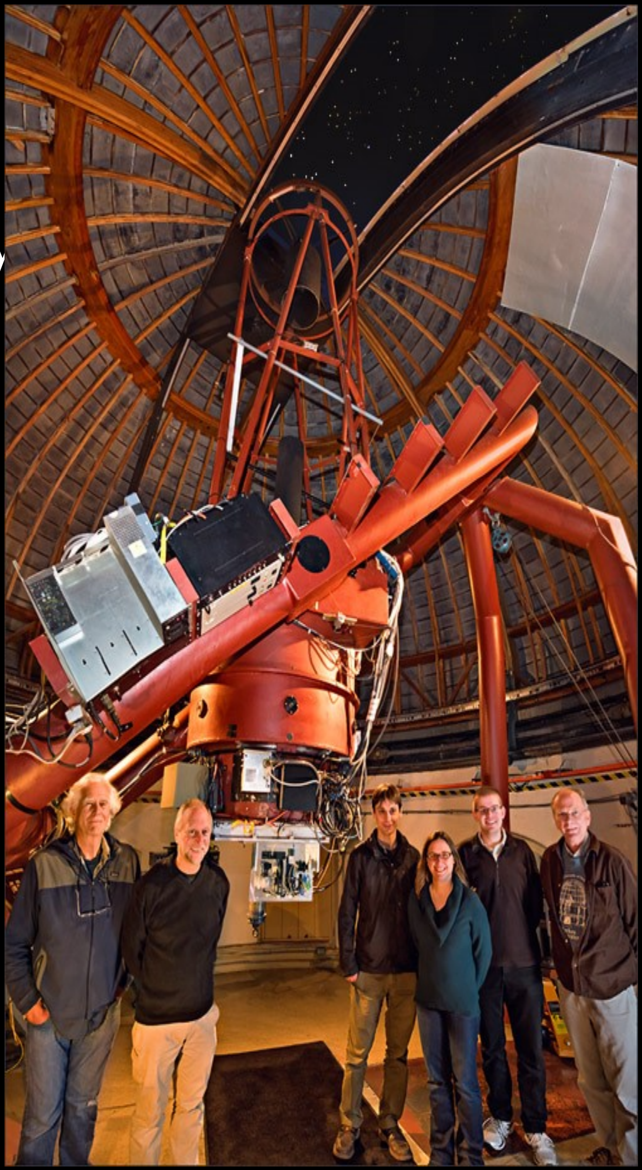
Near-infrared SETI search at Lick Observatory

Targeted search

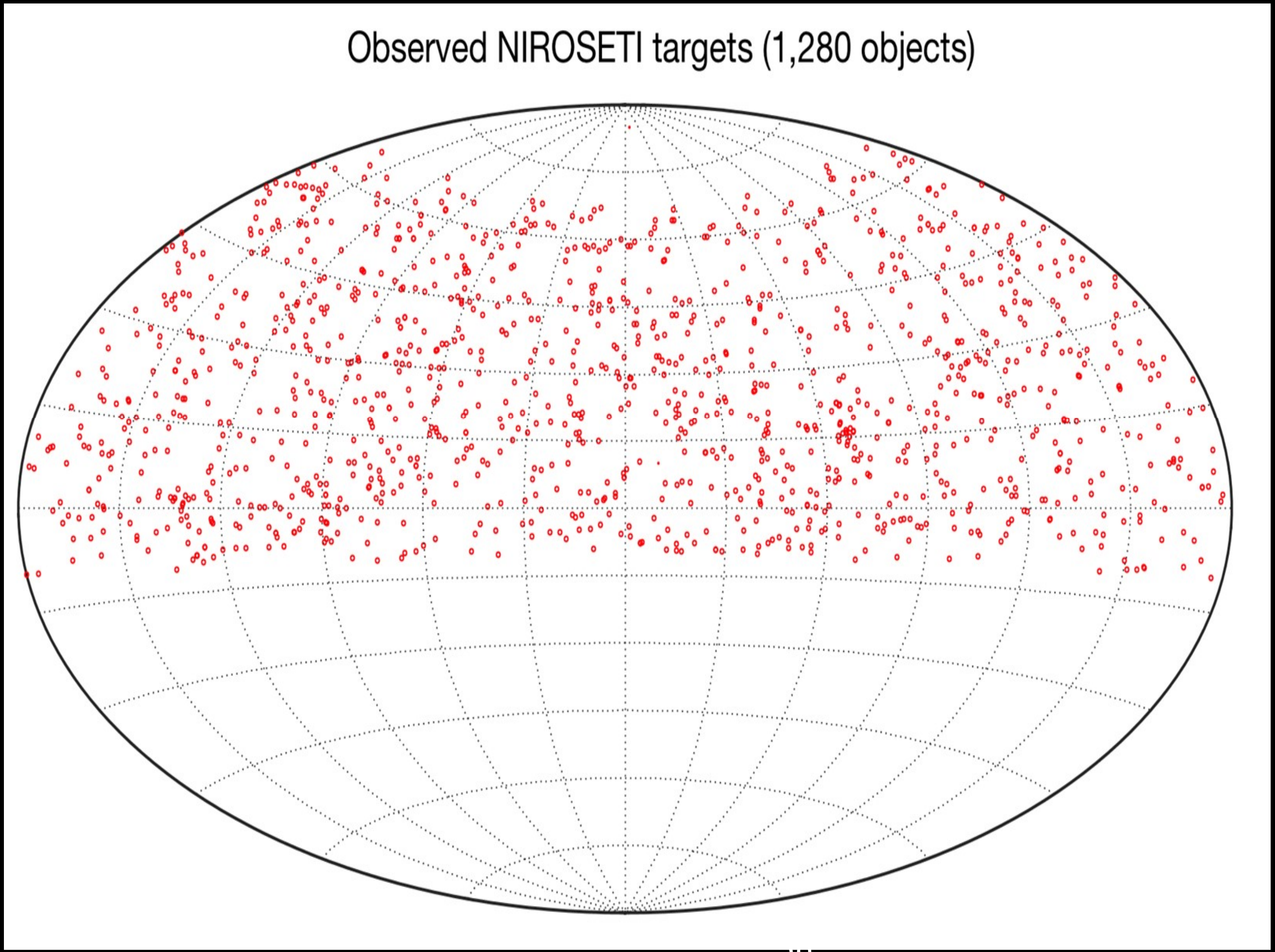
- **1,000s of stars!**
- **At larger distances in the Milky W**

Targeting other phenomena:

black holes and neutron stars

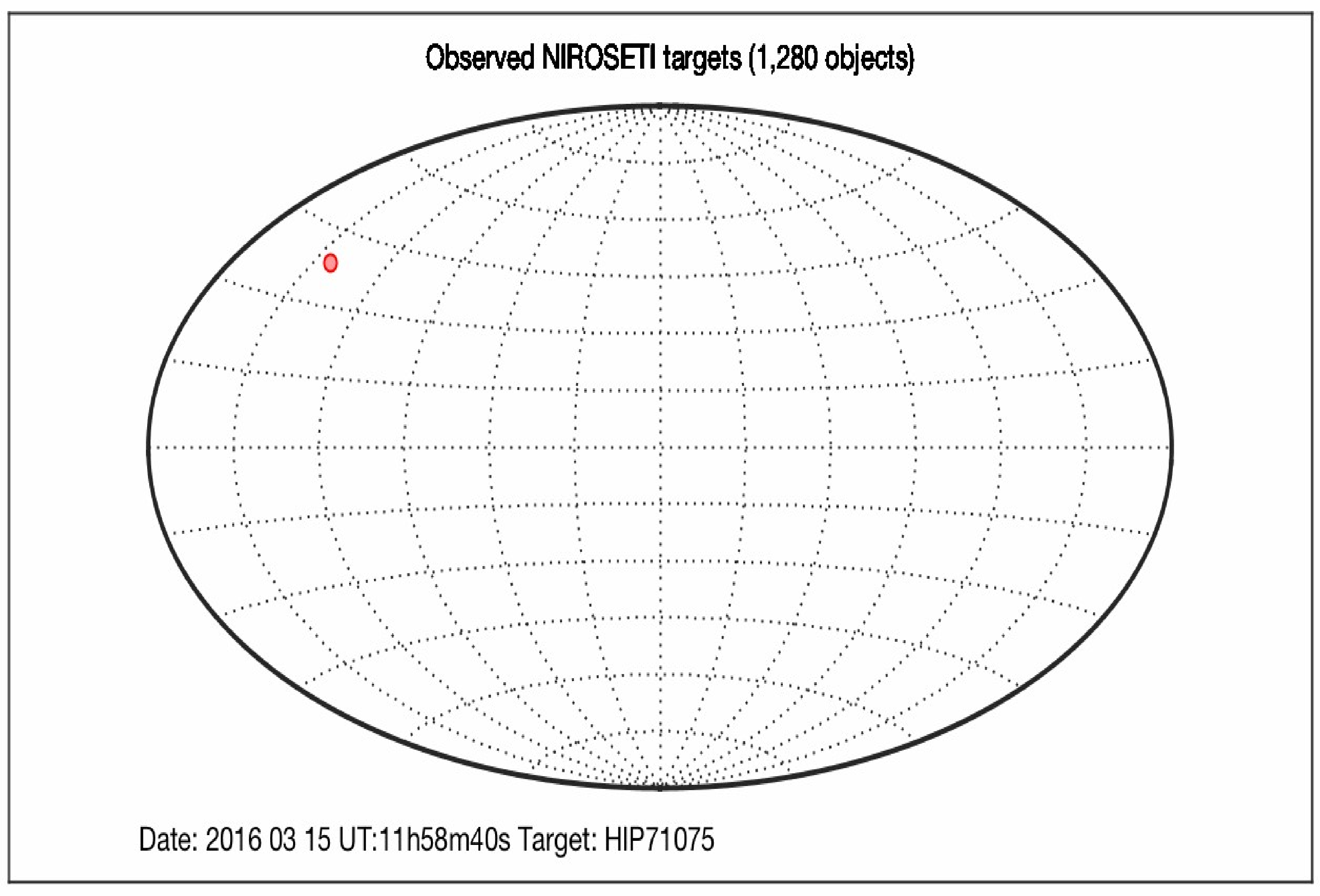


Near-infrared Optical SETI (NIROSETI)



1,280 targets observed; pencil-beam surveys

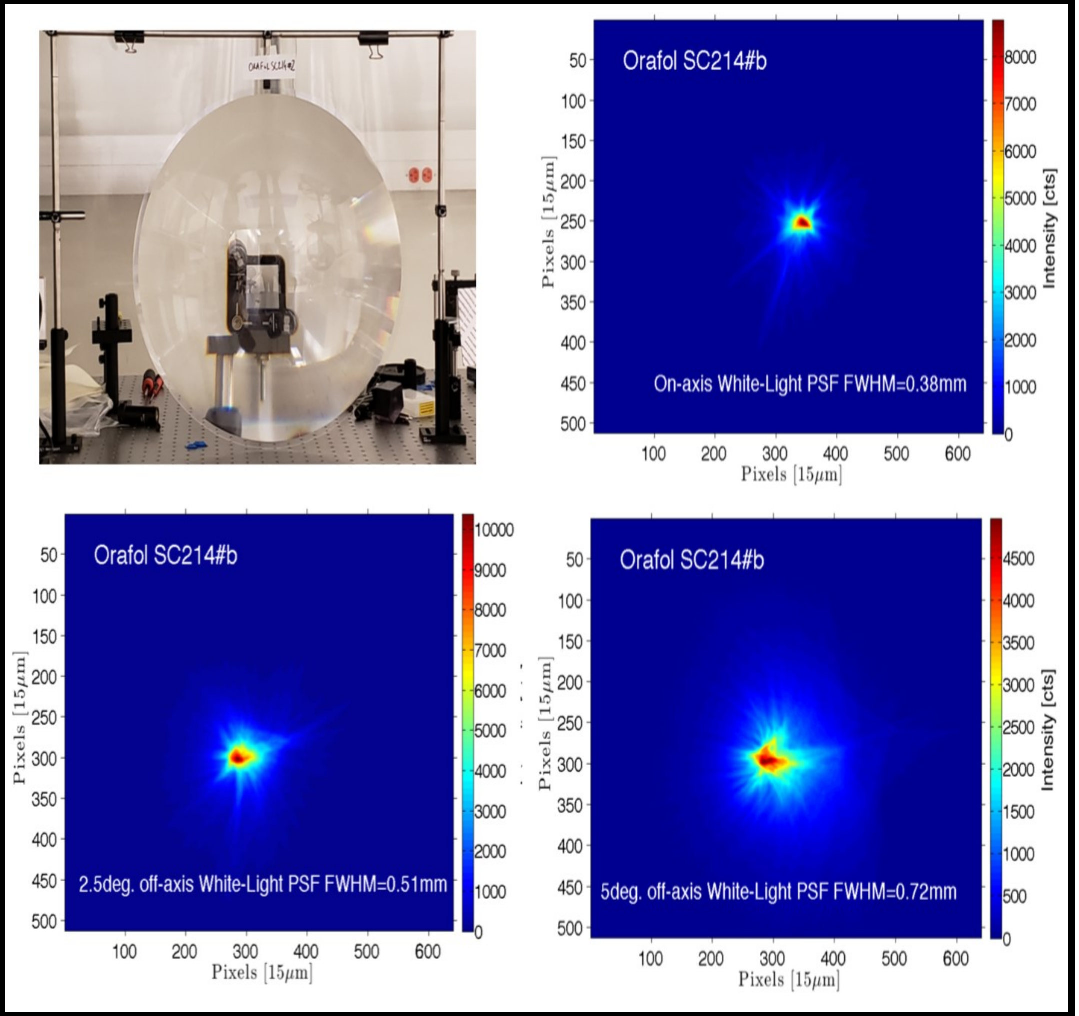
Target search Cadence: NIROSETI



1/24th second = 300 seconds on source

Using multiple Fresnel lenses as an efficient light collecting apertures

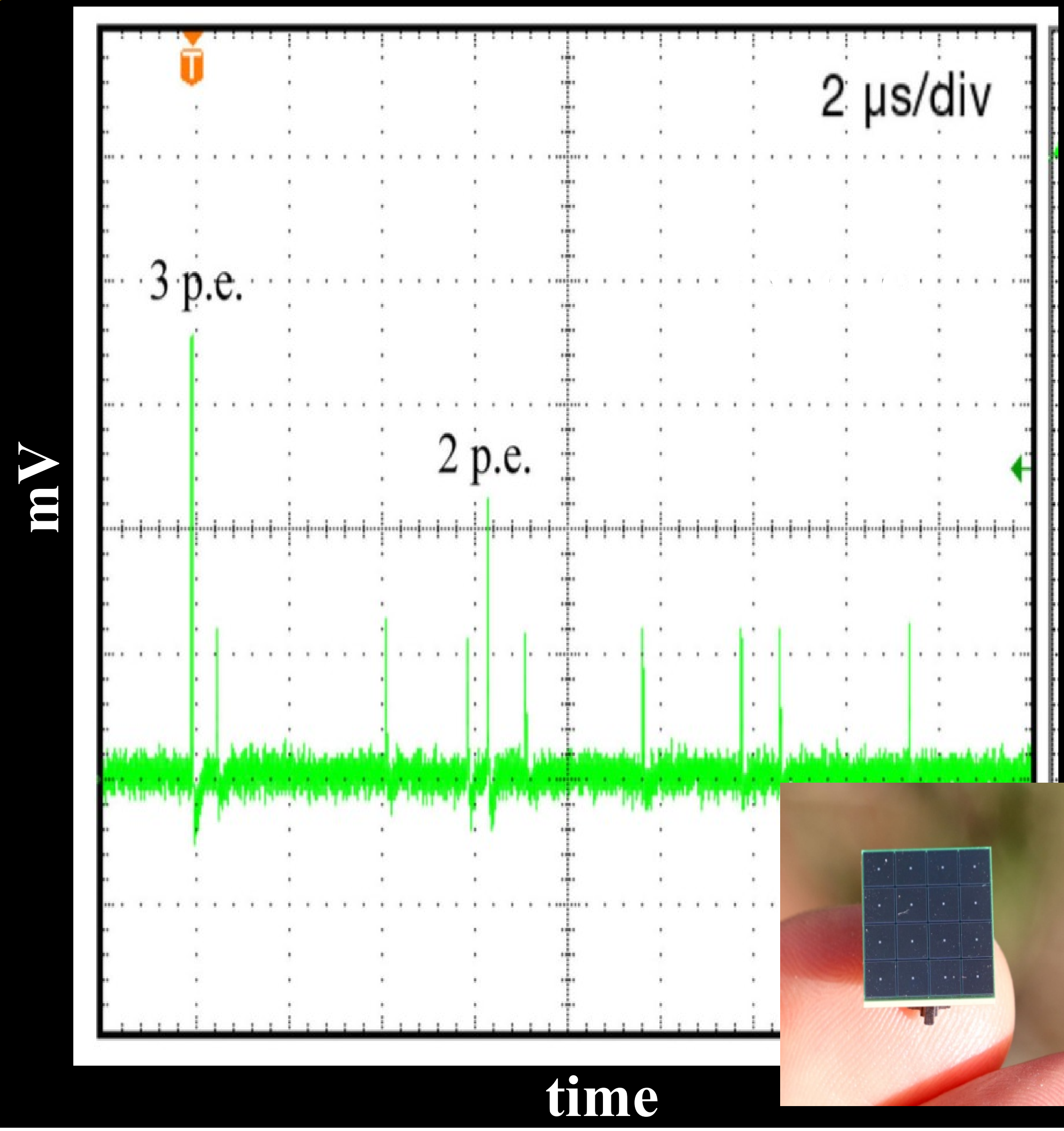
- Lightweight lenses
- Fast focal lengths (f/1)
- Low cost production

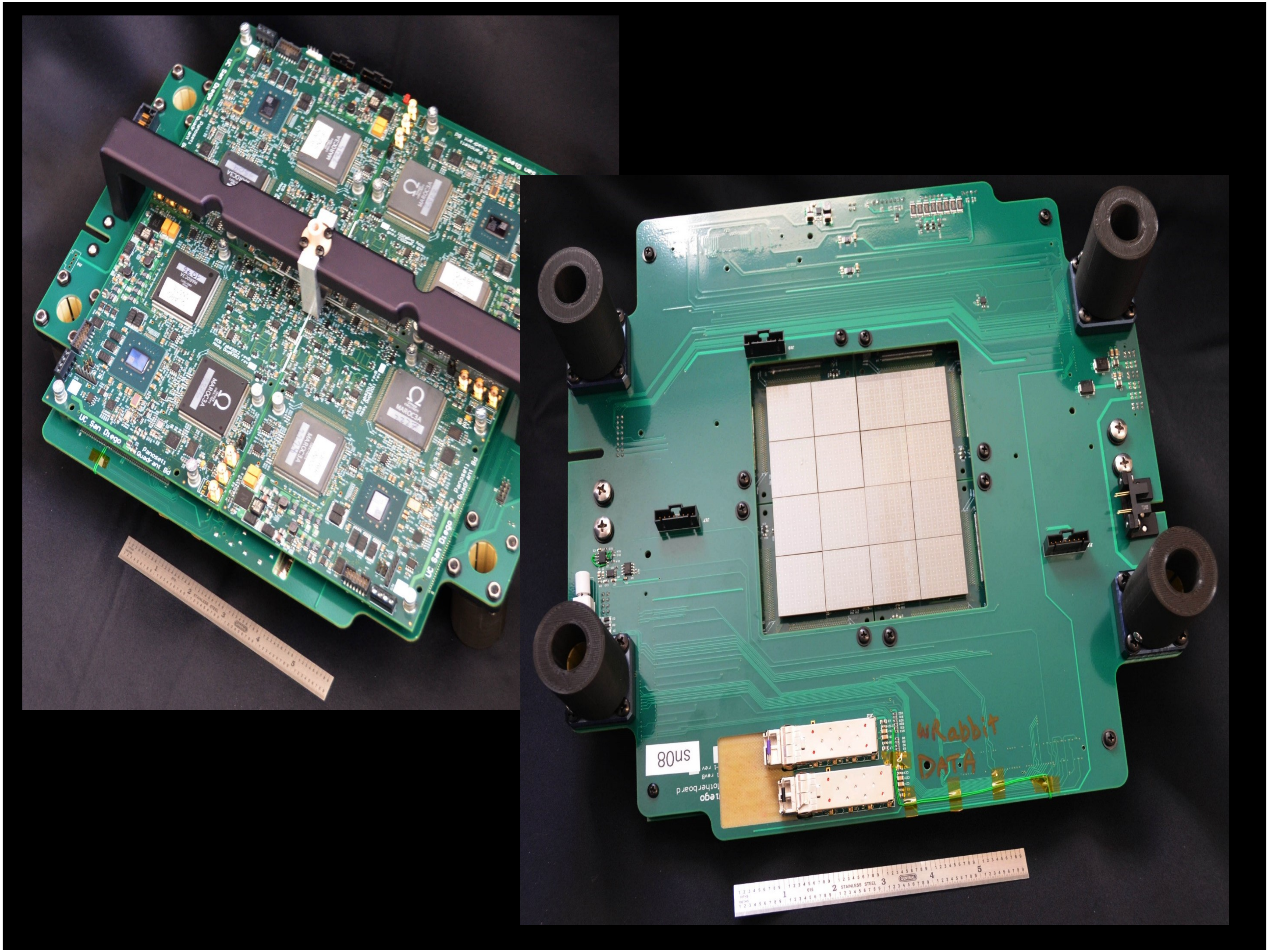


Maire et al. 2018

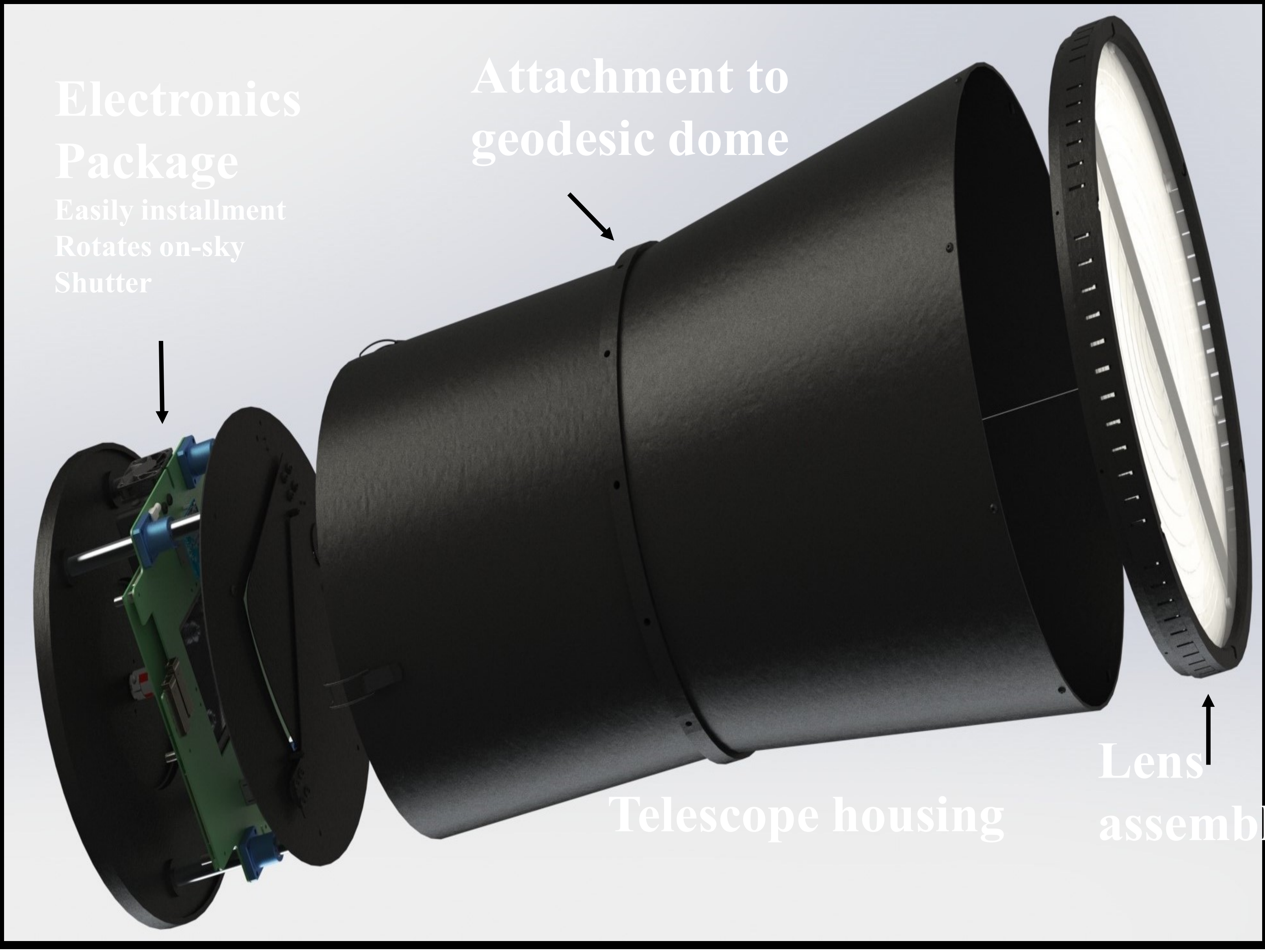
Fast-response optical arrays are now available

- Hamamatsu GHz Optical Multi-pixel photon counting (MPPC)
- Si Avalanche Photodiodes
- 300-850nm
- 14,400 25 µm subpixels per 3mm pixel




UC San Diego
MAROC3A
80us
wRabbit
DATA

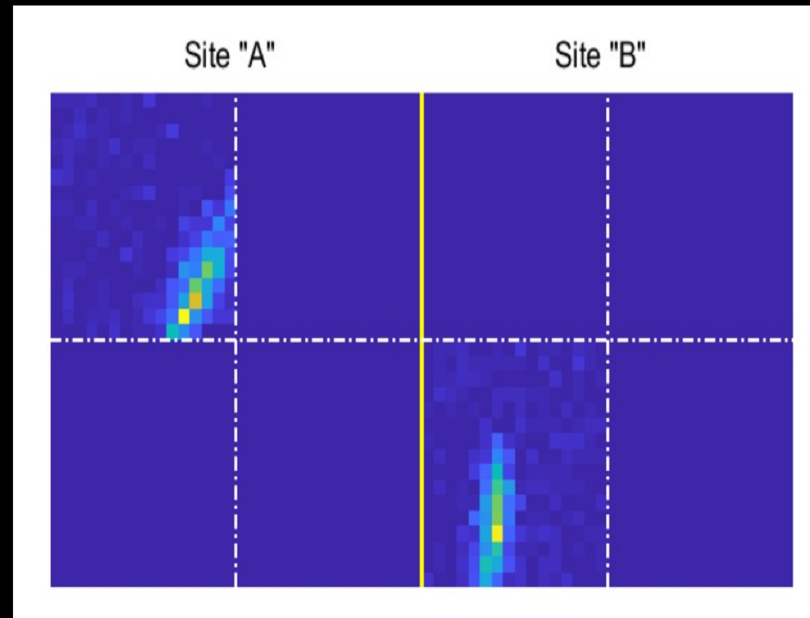
Production telescopes

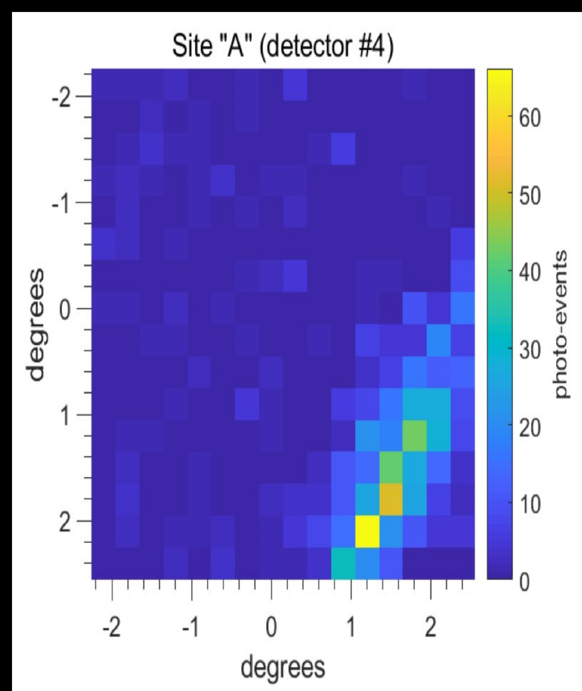


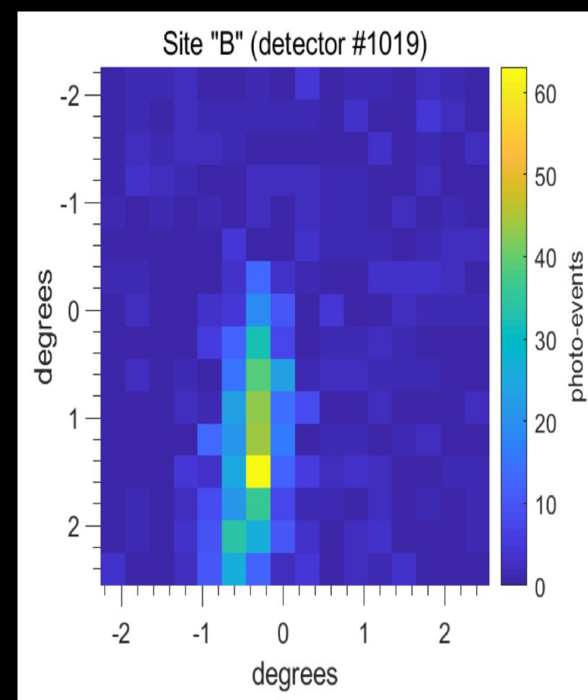

Two PANOSETI prototype system installed in
Astrograph @ Lick February 2020


San Antonio Valley Rd
Kepler Peak Rd
130
United States
Postal Service
Lick Observatory
Mt Hamilton Rd
600,00 m
400,00 m
200,00 m
797,01 m
Mesurer une distance
Cliquez sur la carte pour ajouter la ligne au trajet.
Distance totale : 797,01 m (2614,87 ft)

Cherenkov event between two Panoseti telescopes at Lick Observatory <u>separated</u> by 1km







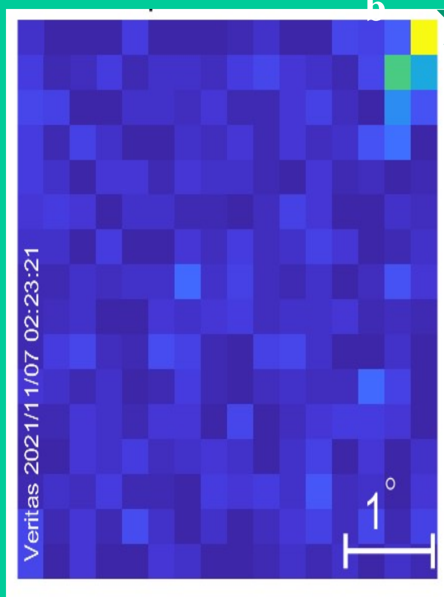
Parallax = 4.7 degrees

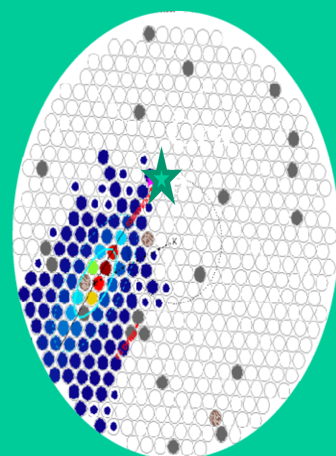
PANOSETI Wide Field Array for Extreme Energy Gamma Rays Search 10Tev – >1Pev

PANOSETI

VERITAS T4

Cra
b





15 TeV Gamma-ray

- 2 PANOSETI telescopes operated at VERITAS for five days in November 2021.
- Analysis shows that they can detect gamma-rays with energies greater than ~10 TeV
- This technology has *enormous* potential to explore the extreme Universe.