RAPID

A Portable and Reconfigurable Imaging Interferometer Array

Colin Lonsdale, Frank Lind

and a team of ~10

MIT Haystack Observatory

Cambridge University Team

Led by Andy Faulkner

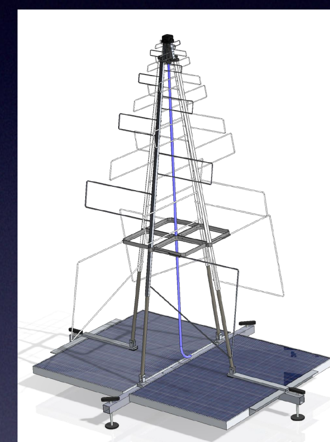
JPL Team

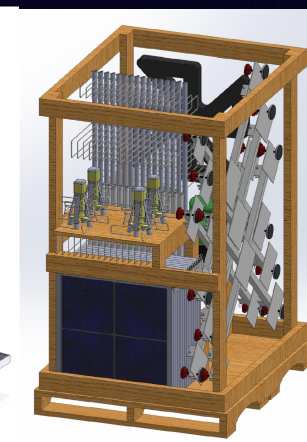
Led by Chris Mattman

RAPID

Radio Array of Portable Interferometric Detectors

- Low frequency radio array, 48-615 MHz
- ~50-75 solar-powered, portable antennas
- No copper <u>or</u> fiber connections
- Local storage of voltage samples at each antenna
- Imaging interferometry performed offline
- Low-cost setup and breakdown
- Highly portable and reconfigurable





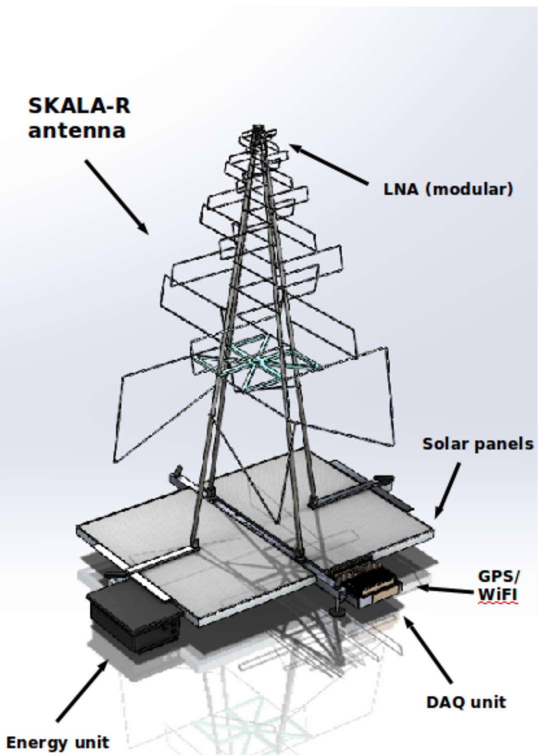
RAPID capabilities

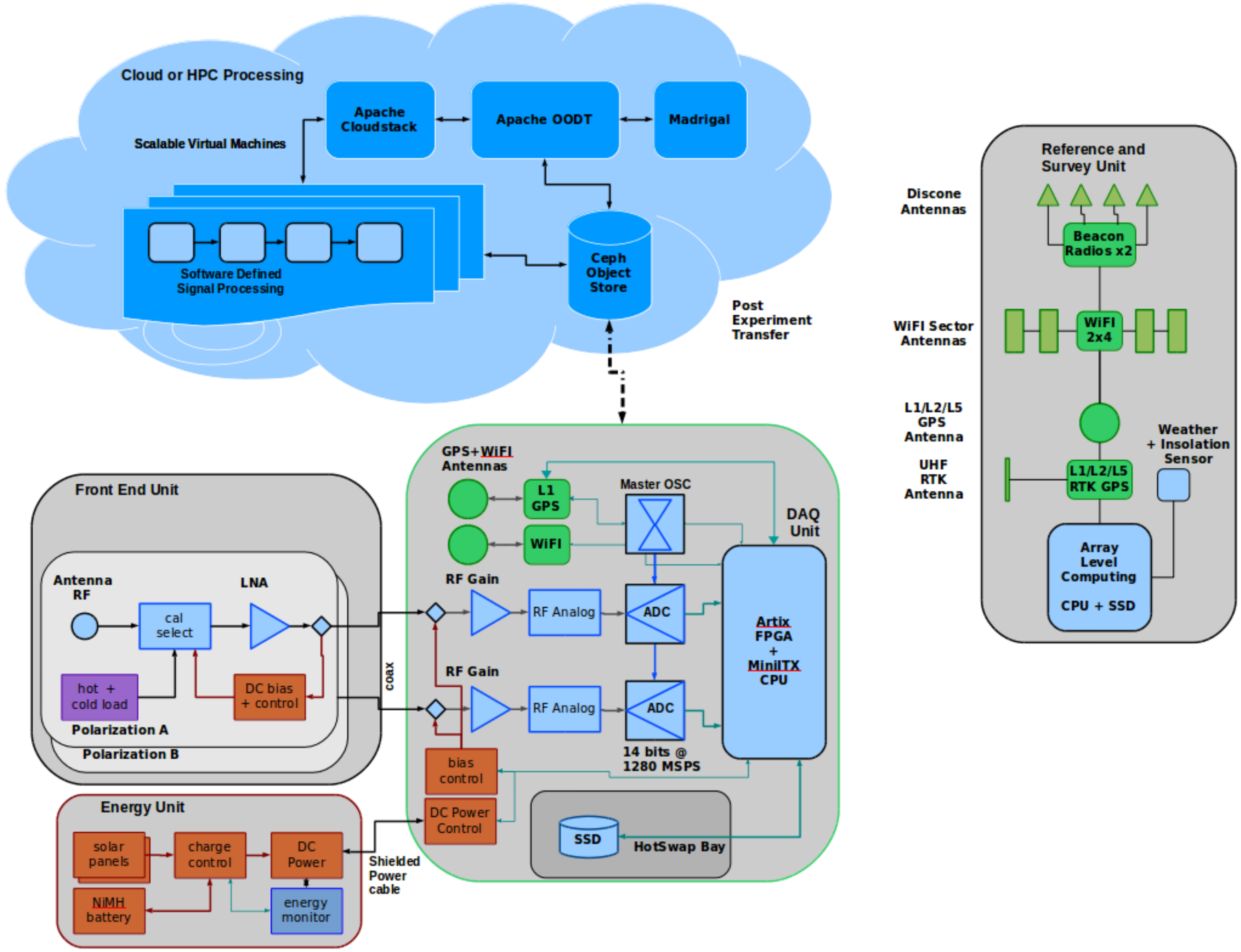
A whole new level of flexibility ...

- Ship array to best site for the science goals
  - Zero site infrastructure required
- Set up complete array in a day or two
  - Goal - 20 person minutes per element
- Reconfigure the array in a few hours
- Collect data as needed
  - over hours, days or weeks
  - in multiple configurations if required
- Pack up in a day or two and ship out
- Process offline with complete flexibility

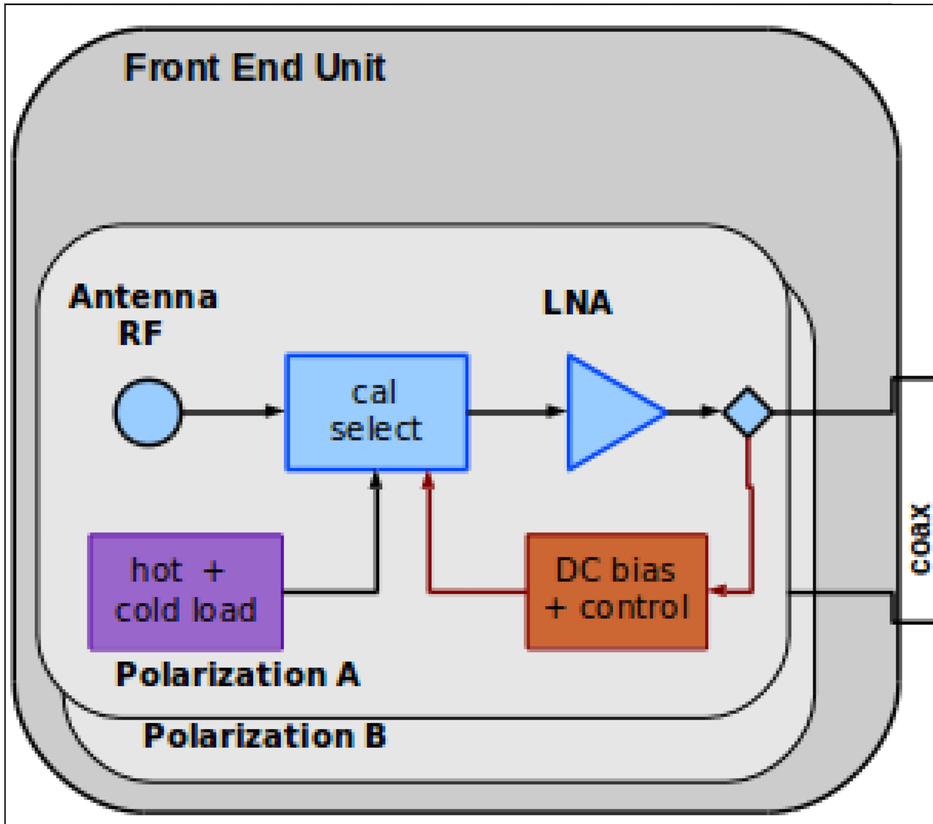
The RAPID System

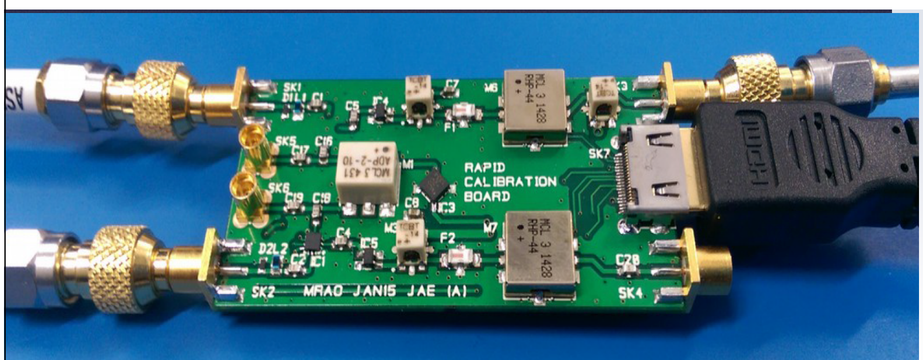
RAPID Field Unit



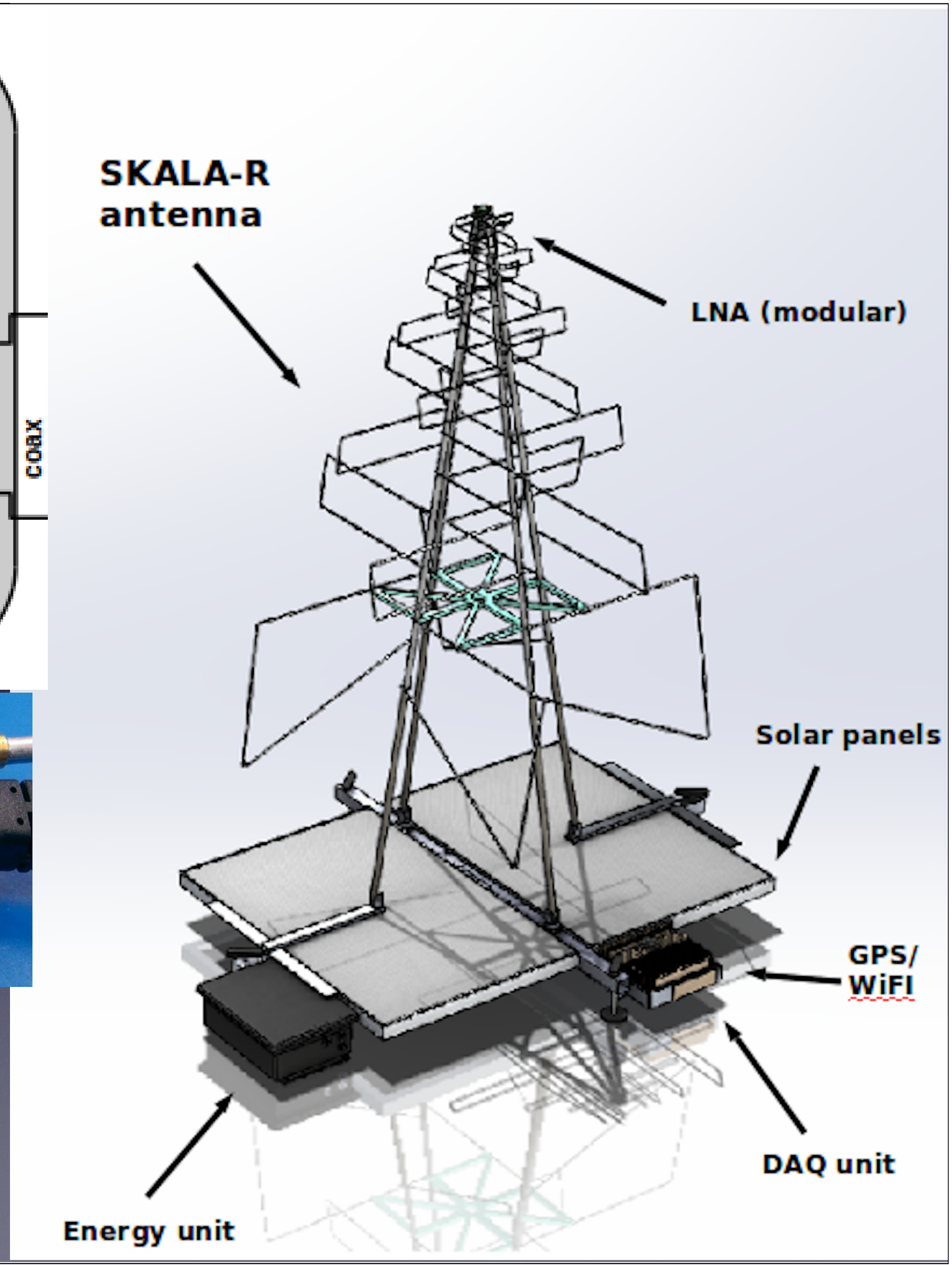


SKALA-R



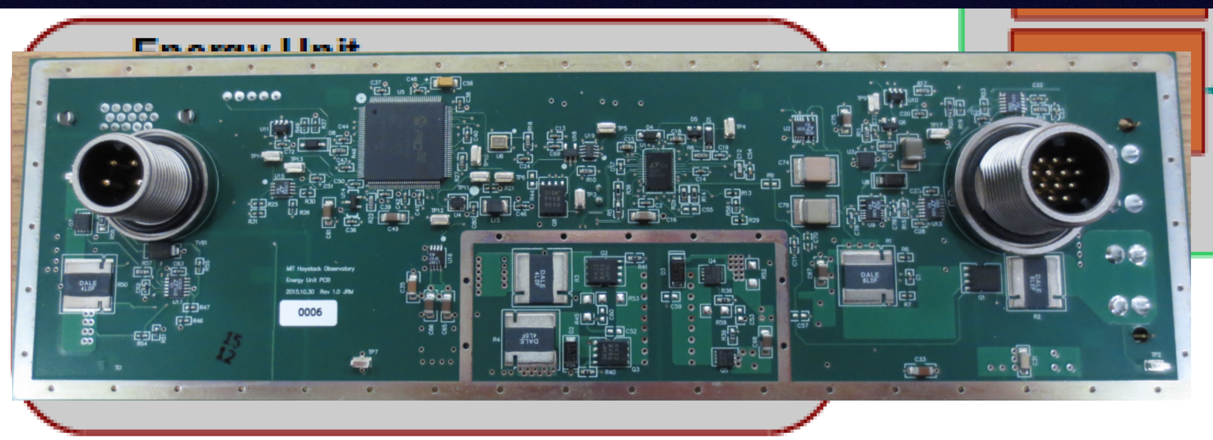


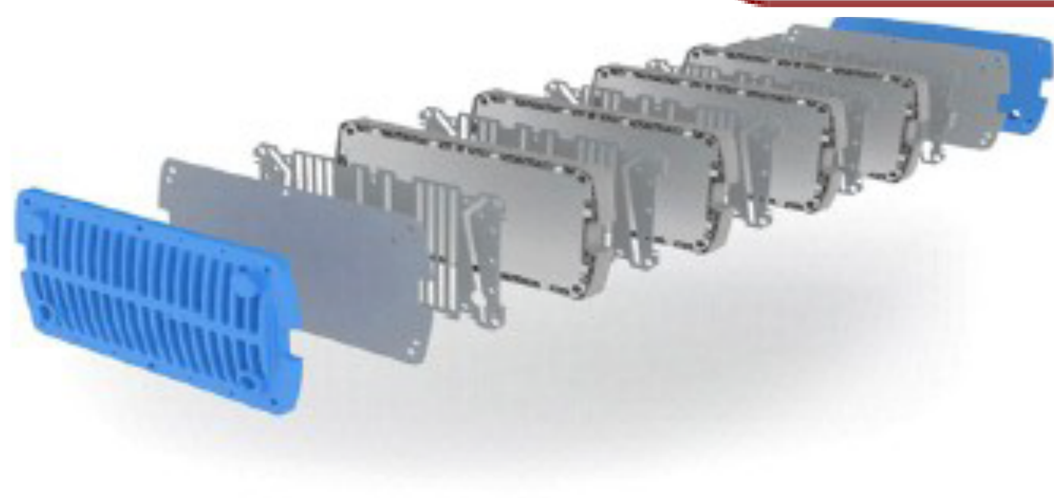
- **Modular LNA**
  - Precision calib. version
  - Low noise version (SKA)



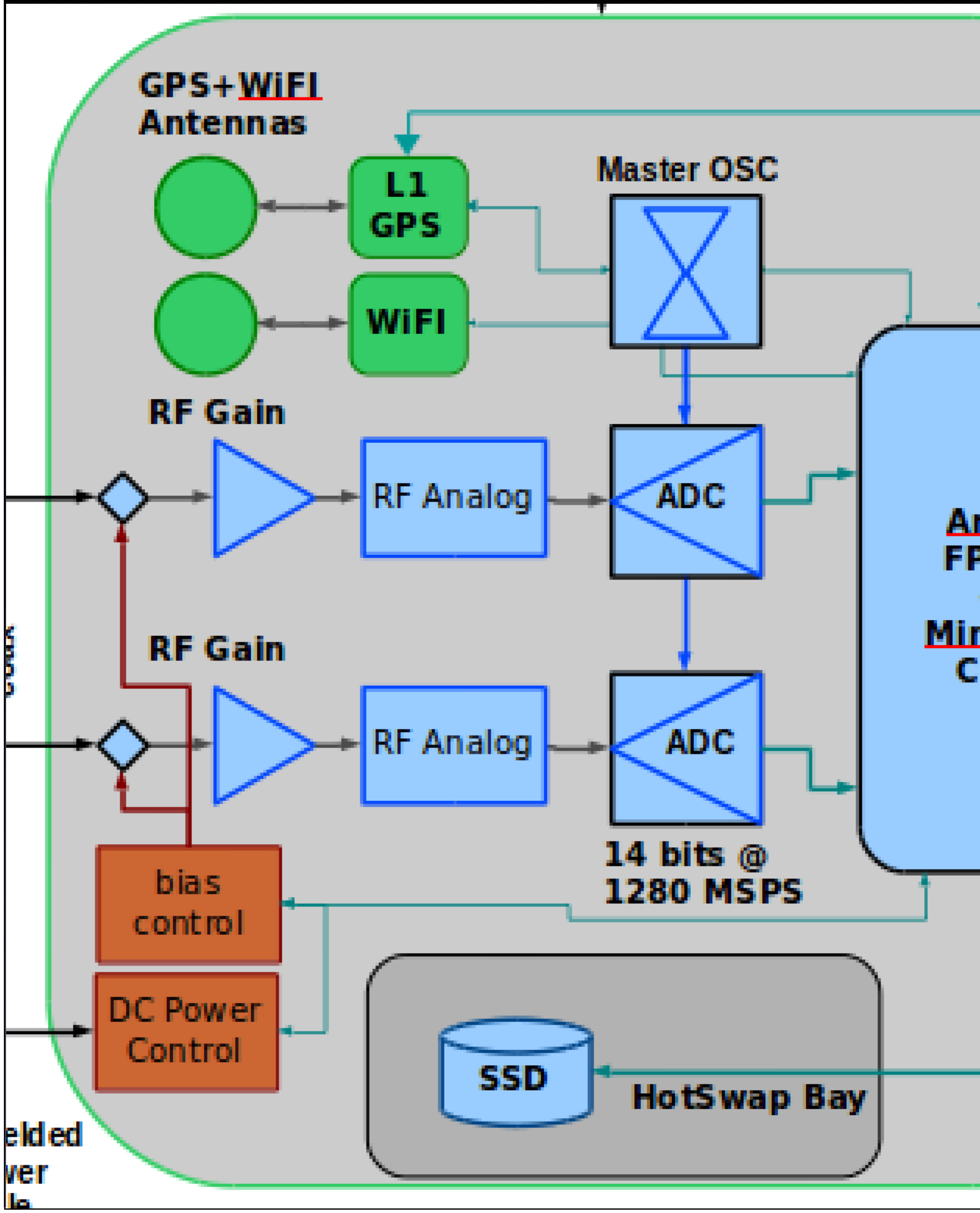
Energy Unit

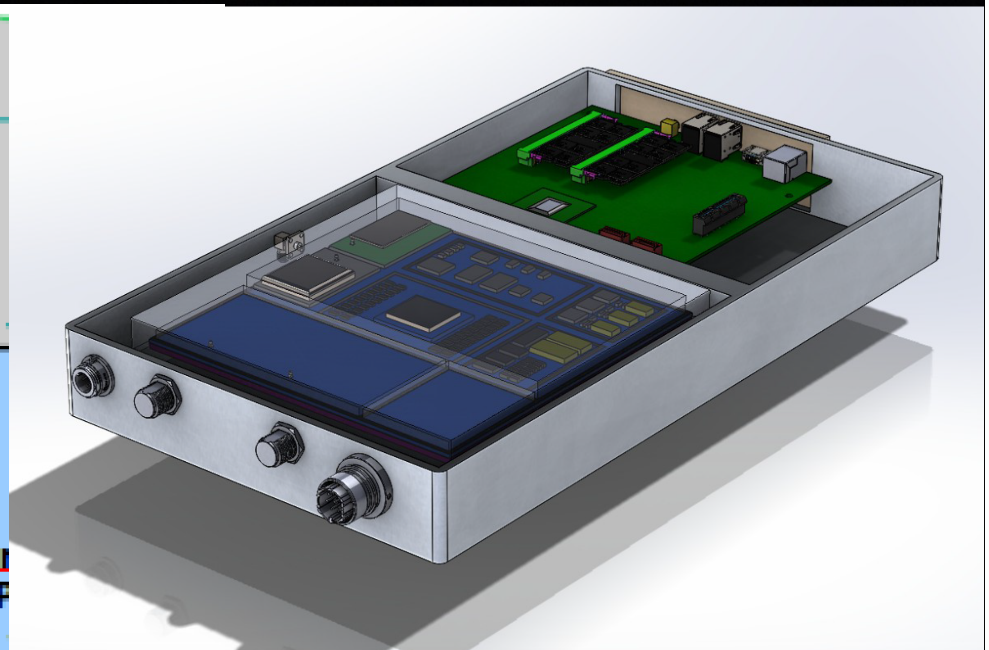
- **Can use Li Ion or NiMH**
- **Choice depends on**

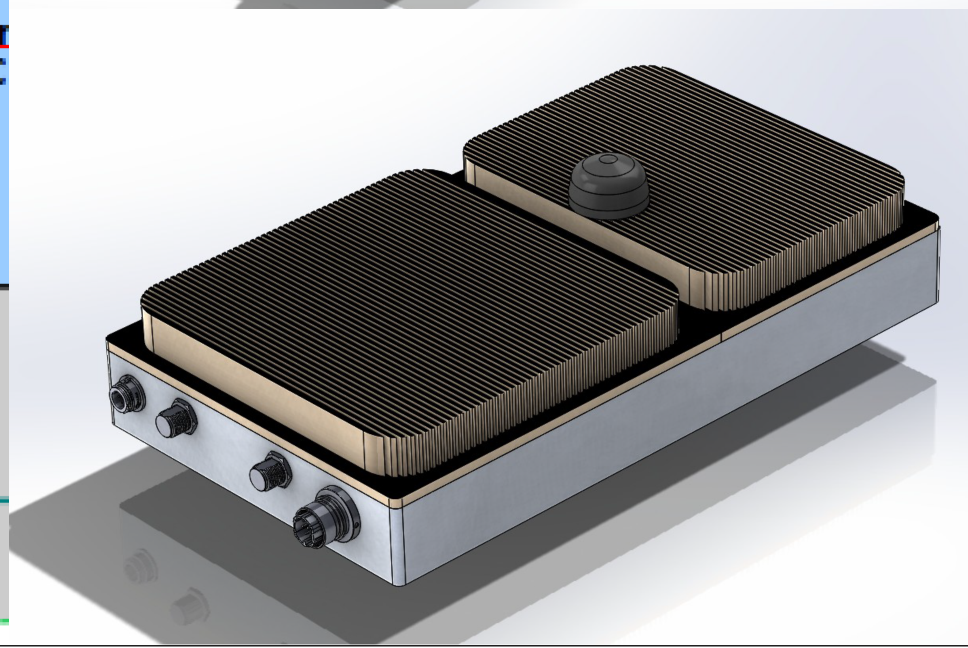




DAQ Unit

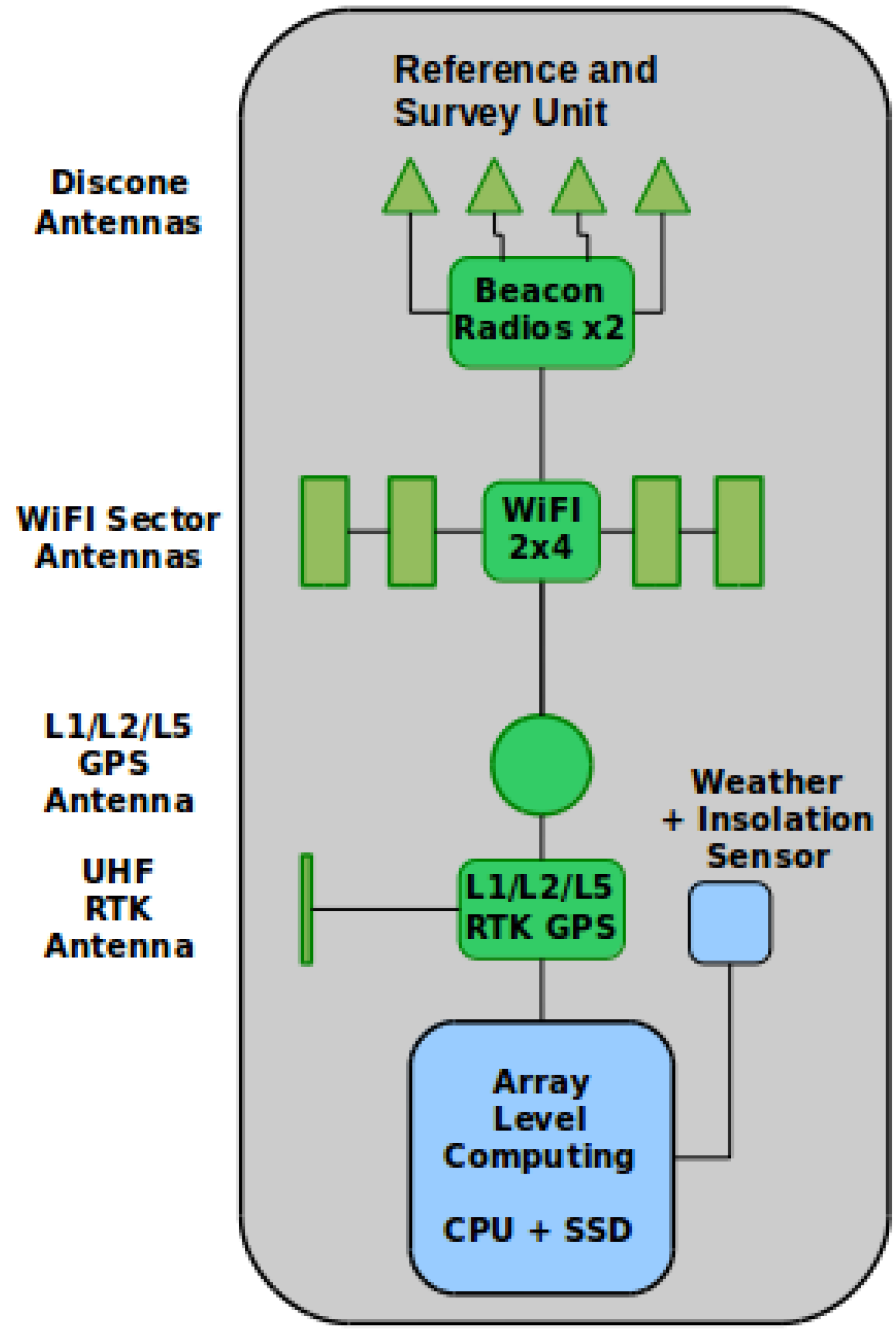

GPS+WiFI
Antennas
L1
GPS
WiFI
Master OSC
RF Gain
RF Analog
ADC
RF Gain
RF Analog
ADC
14 bits @
1280 MSPS
bias
control
DC Power
Control
SSD
HotSwap Bay



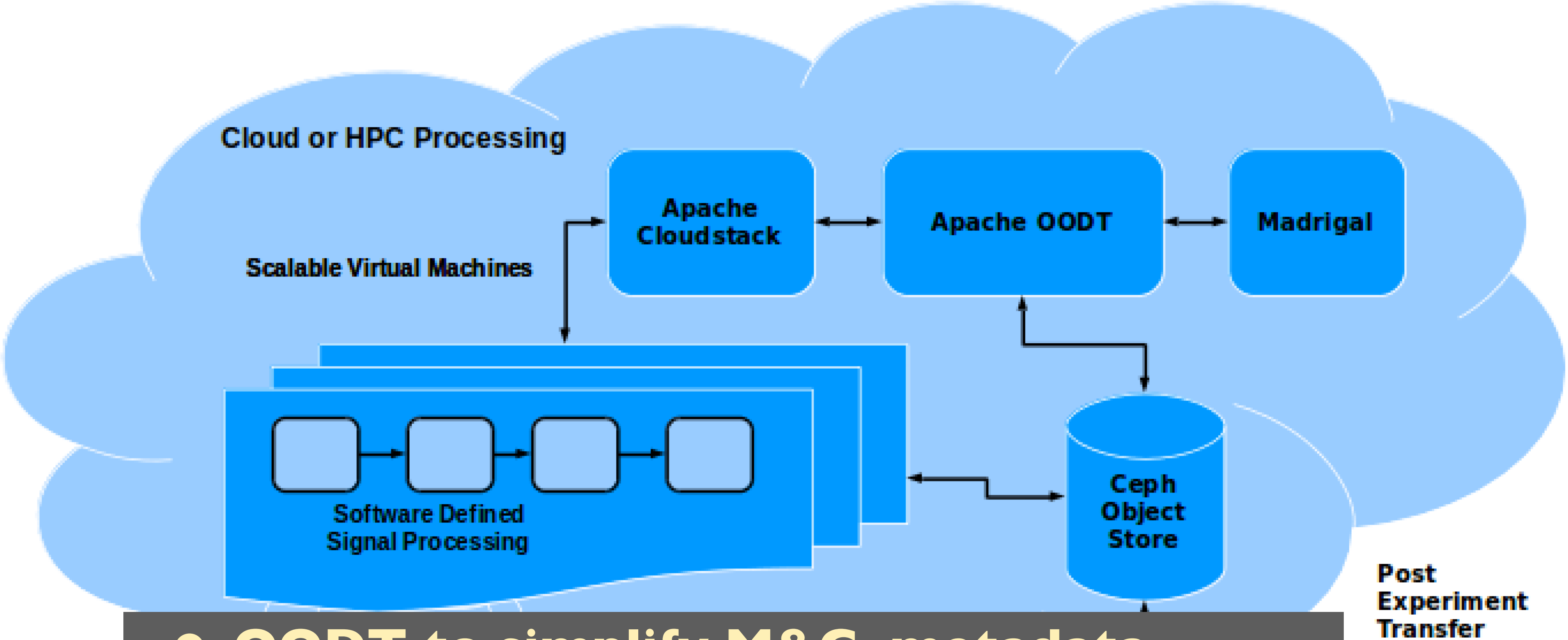


Mobile support infrastructure

- **Array layout measurement**
- **Intra-array communication**
- **Quick look data capture, functional checks, event response, ...**
- **Environmental data**
- **Backup phasing beacon**

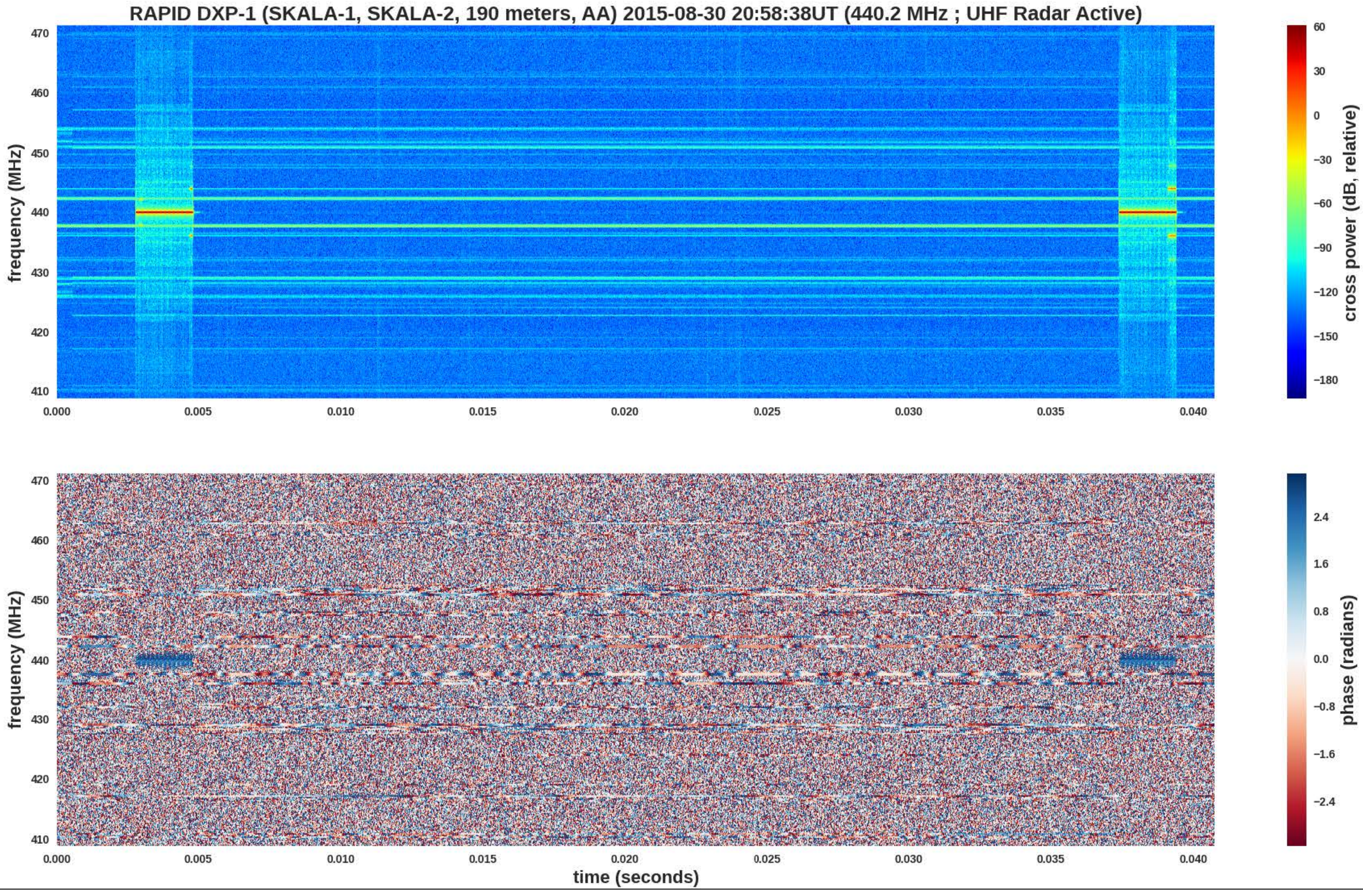


Offline Data Processing



- **OODT to simplify M&C, metadata handling**
- **Modular, highly scalable processing**
  - Correlation, and various other signal processing tasks
  - Developed with evolving processor architectures in mind

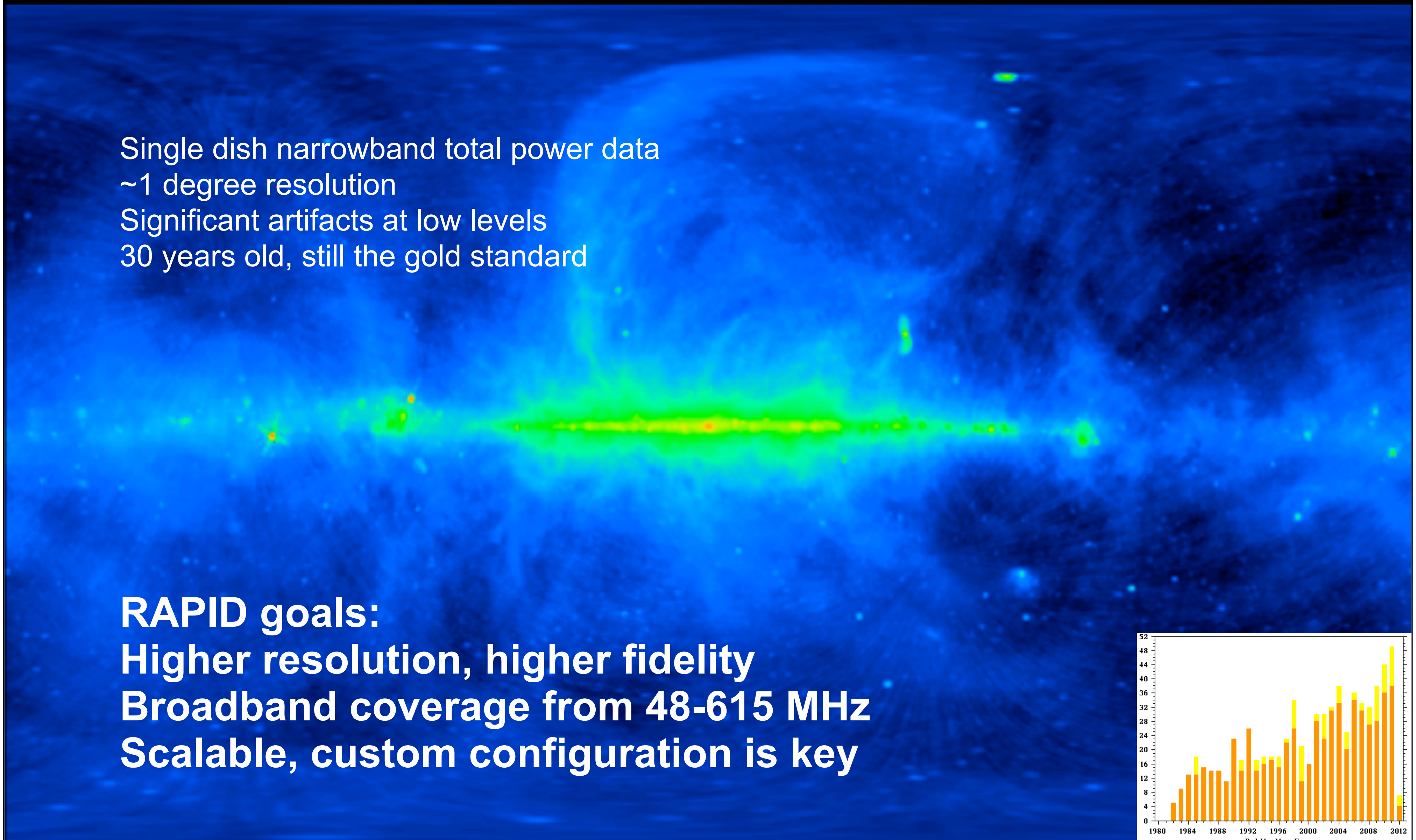
Interferometry Demonstration



Current Status

- **Sustained 8 Gbit/sec, antenna to SSD**
  - Peak power draw ~30W, production unit ~20W
  - Meets or significantly exceeds all requirements
  - Primary project risk retired
- **Several major components complete**
  - SKALA-R antenna system
  - Energy unit
  - All essential software and firmware
- **DAQ unit integration in progress**
  - Production prototype early 2016
- **Production run, commissioning in 2016**

Galactic synchrotron imaging



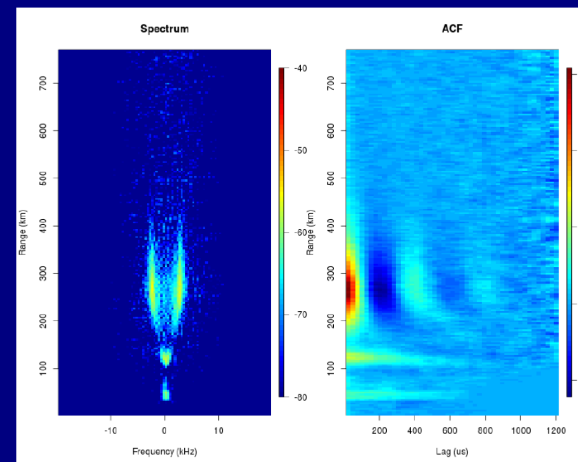
Single dish narrowband total power data
~1 degree resolution
Significant artifacts at low levels
30 years old, still the gold standard

RAPID goals:
Higher resolution, higher fidelity
Broadband coverage from 48-615 MHz
Scalable, custom configuration is key

408 MHz sky, Haslam et al., 1981

Citations per year

Advanced Radio Apertures



[McKay-Bukowski, et al., 2014]

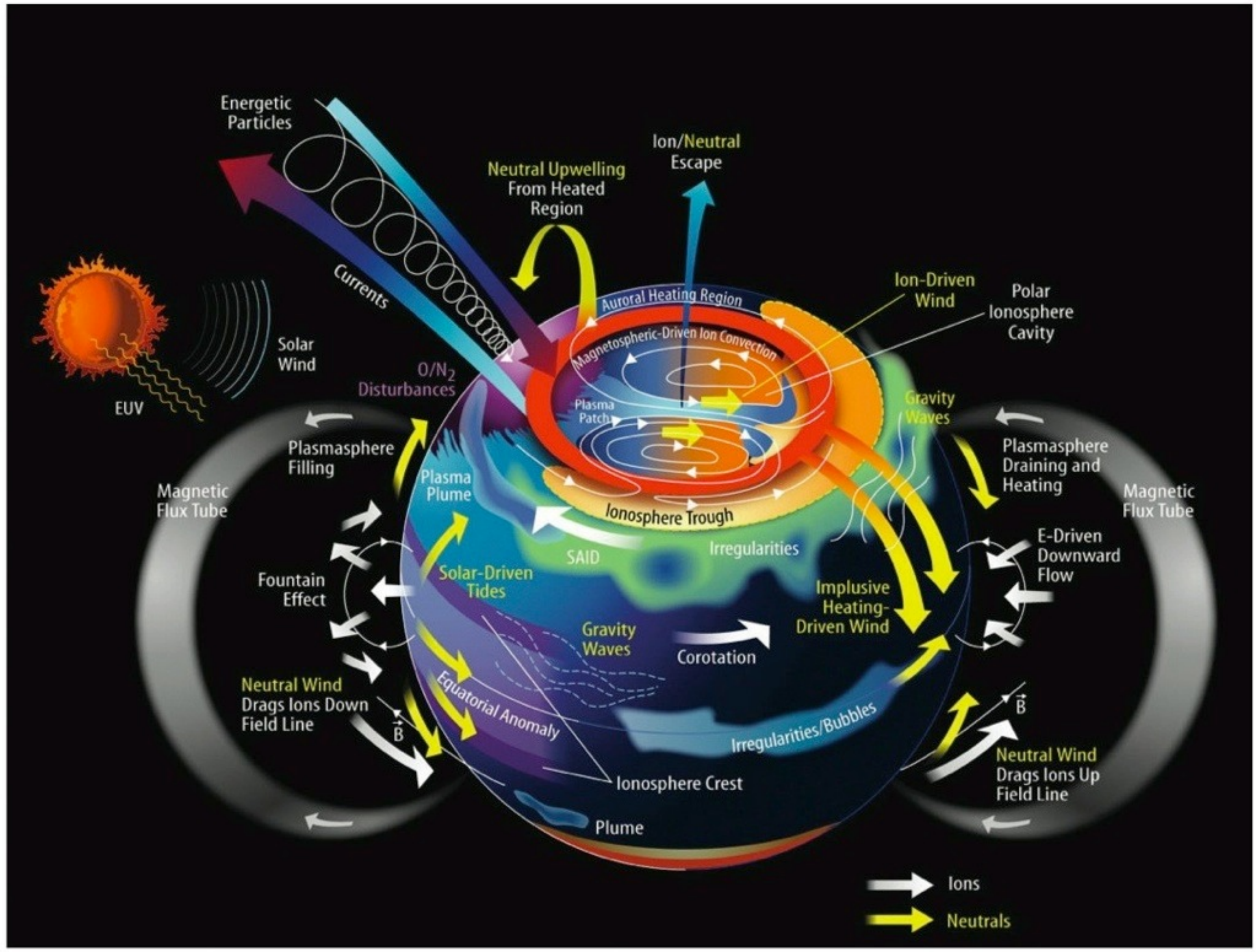
The Astronomy Community has invested heavily in Low Frequency Radio Array Technology Development

Enabled by software radio

Just Add a Transmitter...

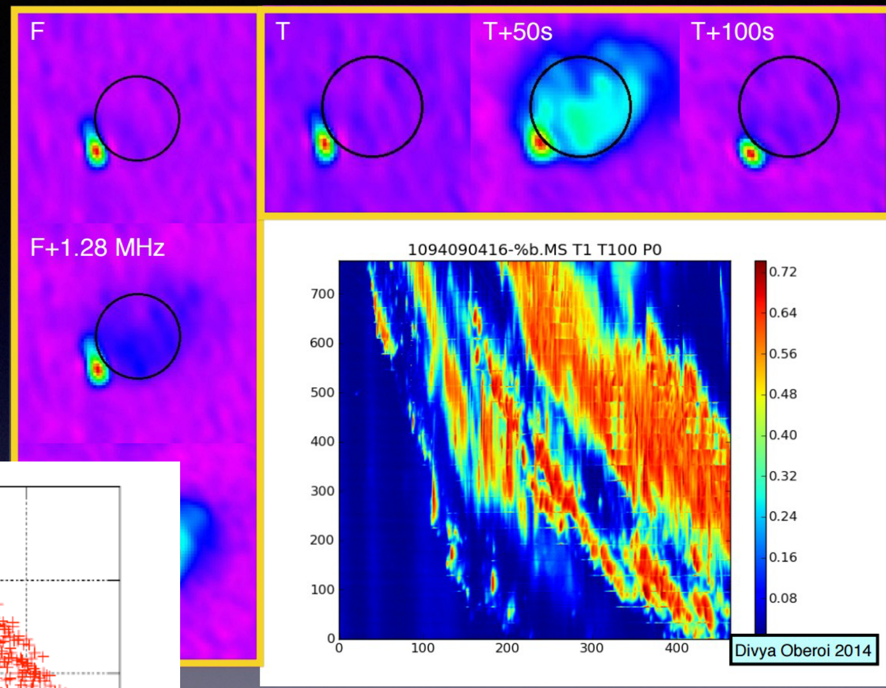
Rich Geospace Science

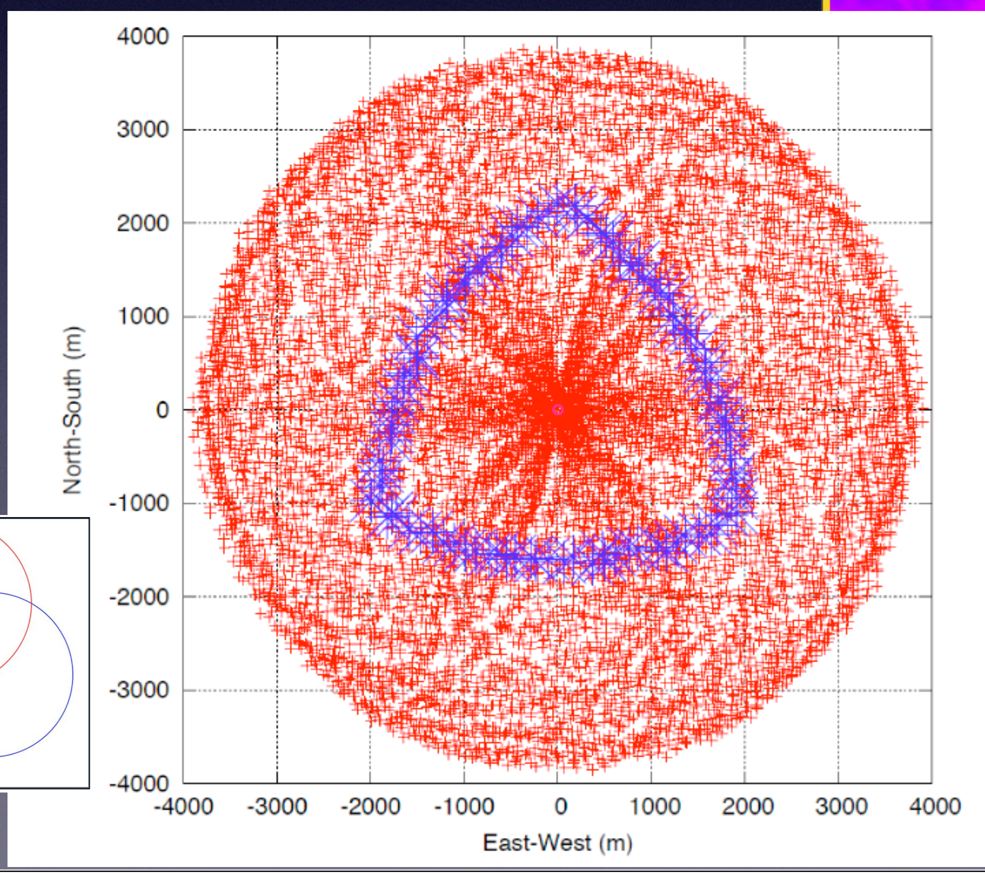
"Photosphere to Mud"

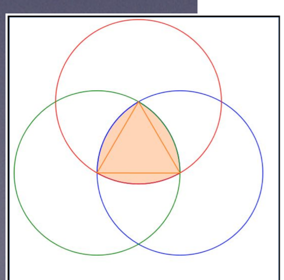


RAPID configuration for solar imaging

- **Need:**
  - Excellent monochromatic instantaneous coverage
  - No very short baselines
  - High angular resolution







⇒ extraordinary uv plane sampling, high DR imaging at optimum resolution

RAPID deployments for Radar

- Jicamarca, Peru
  - 49 MHz high power transmitter
  - Rich equatorial ionospheric phenomenology
- Poker Flat, Alaska
  - AMISR illuminator
  - Rich auroral phenomenology
  - Simultaneous Mahali GPS campaign
  - Data fusion

RAPID deployment for UHECR

- Ship to location of particle detector array
  - Use particle detectors to trigger radio capture
  - Avoid false positive problem (RFI)
  - Cyclic memory buffer, relaxed response time to events

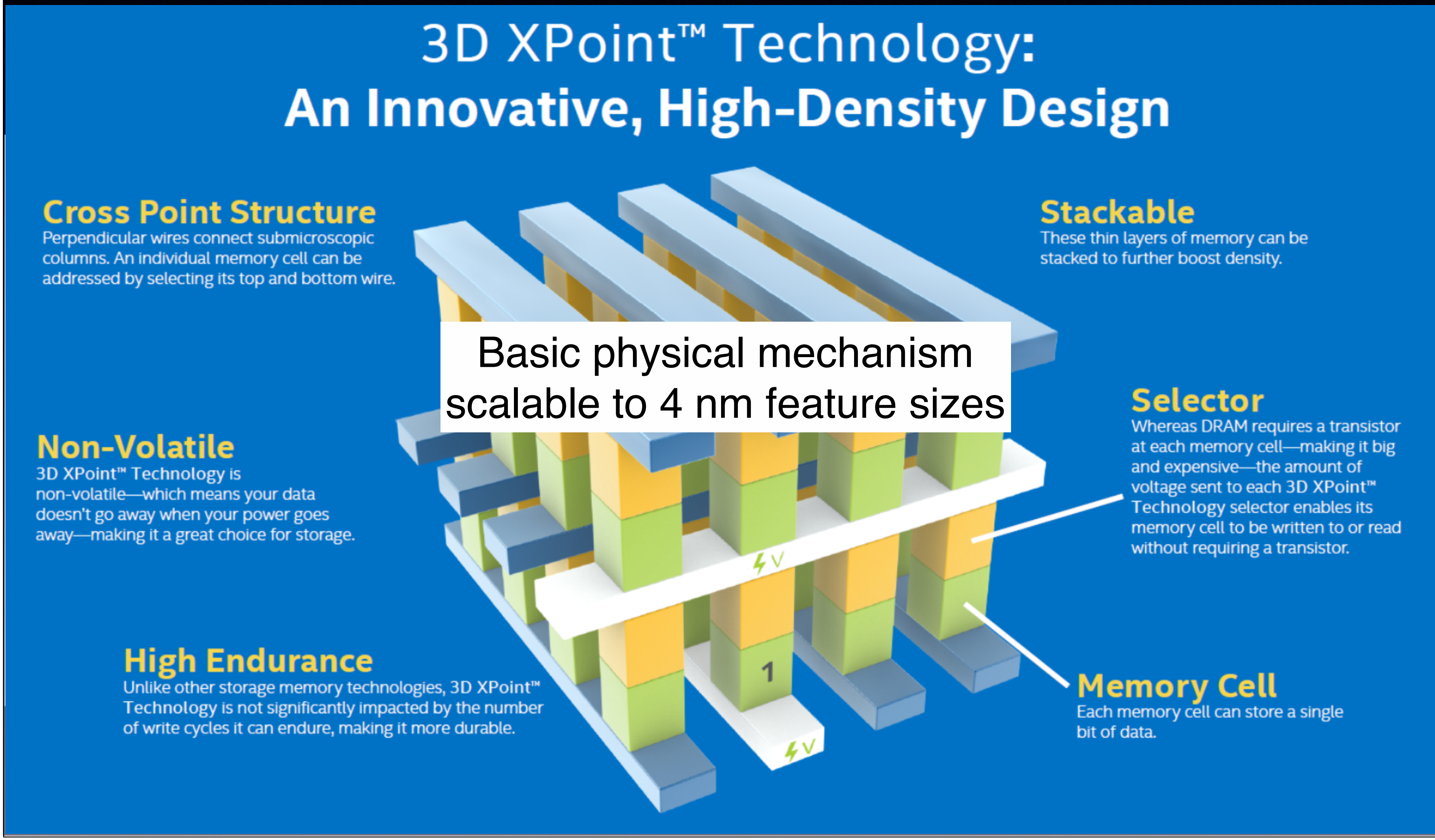
- Tailor configuration to goals, e.g.
  - For energetic, rare events, cover large area
  - For detailed study of weaker, frequent events, sample the "footprint" densely
  - and anything in between

“Future” Aspects

- **Direct RF digitization, no analog mixing**
  - Increasingly prevalent in radio astronomy
  - ADC technology advancing rapidly
- **Voltage recording, offline processing**
  - Minimal compromises at observe time
  - Anticipates affordability of massive memory
  - Minimizes custom engineering for real time data handling
  - Development of a software processing ecosystem
  - Delayed information destruction - process as/how needed
- **Autonomous units, reduced infrastructure dependence**
  - Very low power systems; cheap accurate frequency standards
  - Greater freedom in placement, configuration

“Deep memory” is coming

Store ***and keep*** all voltages



Handling Data Volumes

- **Modular, scalable software infrastructure**
  - Exploit new machine architectures quickly/efficiently
  - Minimize lag relative to Moore's law industry progress
- **Data ⇒ Information ⇒ Patterns ⇒ Understanding**
  - Distillation process, ending in scientific understanding
  - Early stages are quickly growing beyond human cognitive capacity
  - Machine role in discovery process must migrate to the right …
- **RAPID is a testbed**
  - Up to ~0.5 Tbit/sec, petabyte-level acquisition per campaign
  - Strong signal targets, high information per bit

Summary

- **RAPID version 1 is nearing completion**
  - Uniquely flexible in location and configuration
  - Highly modular for different applications
  - Designed with diverse future variants in mind
- **Emphasis on anticipating technological trends**
  - Seek architecture that spans technology cycles
  - Exploit new, better devices with minimum development
  - Software whenever possible, not hardware or firmware
- **Future plans**
  - Scientific use of the array - collaborations enthusiastically welcomed
  - Experiments in conjunction with LWA, LOFAR, MWA
  - Translation of technologies to radars, space-based arrays, …
  - RAPID 256, RAPID 1000, RAPID versions 2, 3, …