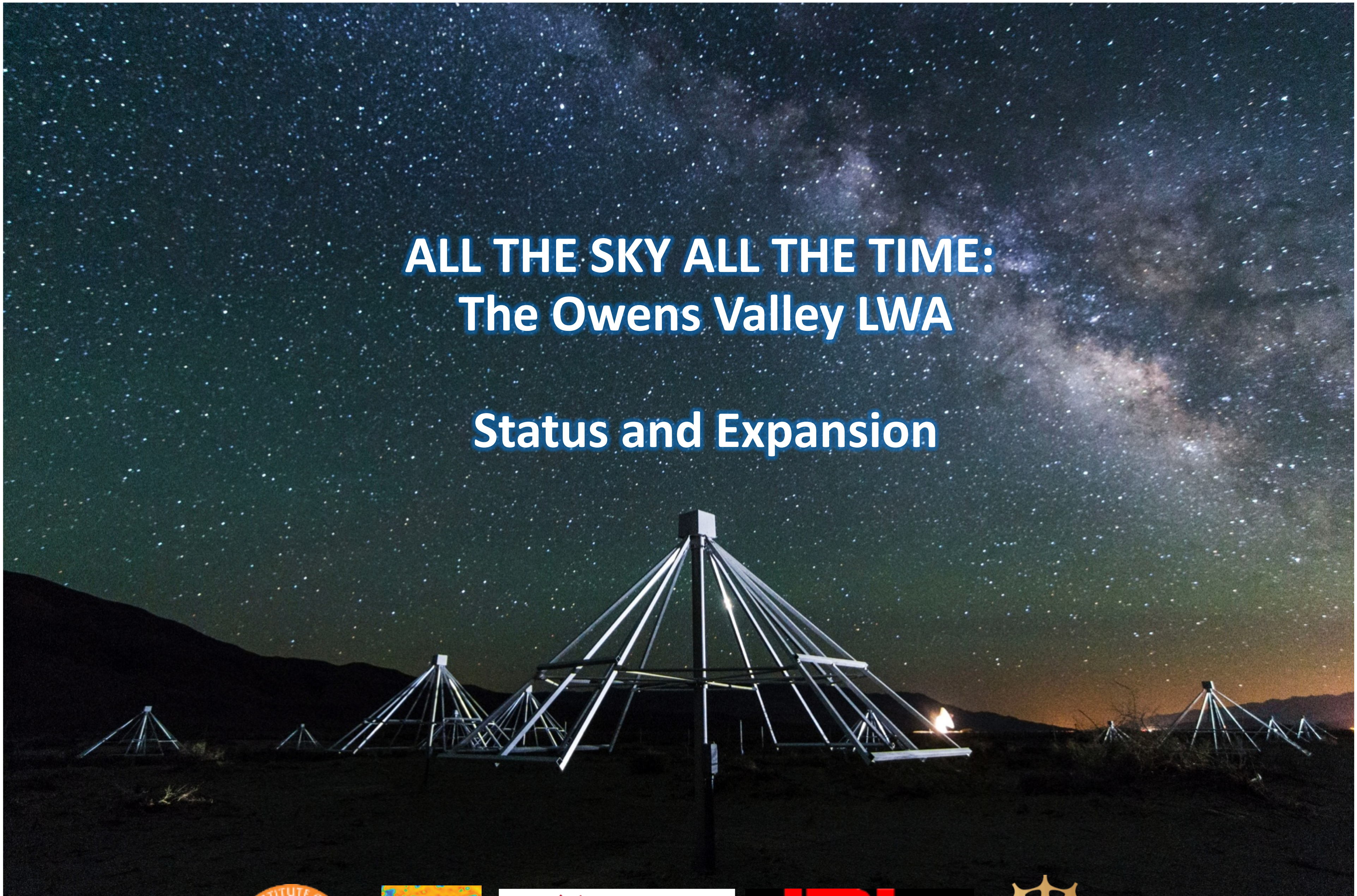
ALL THE SKY ALL THE TIME:
The Owens Valley LWA

Status and Expansion



California Institute of Technology 1891

LEDA
Large-Aperture Experiment to Detect the Dark Ages

LWA
Long Wavelength Array

JPL
Jet Propulsion Laboratory
California Institute of Technology

NSF

Collaboration

- Caltech, OVRO & JPL:
- Gregg Hallinan (PI), Stephen Bourke, Sandy Weinreb, Michael Eastwood, Marin Anderson, Ryan Monroe, Jackie Villadsen, Melodie Kao, Mike Clark (guest)

- David Woody, Dave Hawkins, Russ Keeney + OVRO staff

- Joe Lazio, Dayton Jones, Larry D' Addario, Jonathon Kocz, Chris Mattmann Melissa Soriano, Shakeh Khudikyan, Paul Ramirez

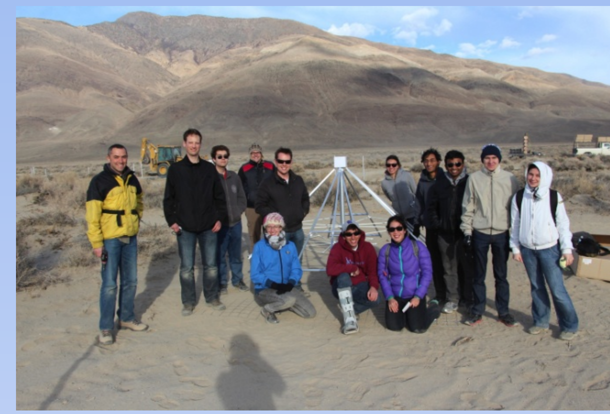
- LWA Collaboration: Greg Taylor, Joe Craig, Namir Kassim, Brian Hicks, Frank Schinzel et al.

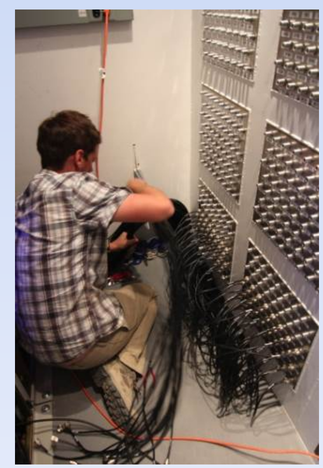
- LEDA Collaboration: Lincoln Greenhill, Greg Taylor, Dan Werthimer, Steve Ellingson, , Danny Price Jonathon Kocz, Ben Barsdell, Frank Schinzel et al.

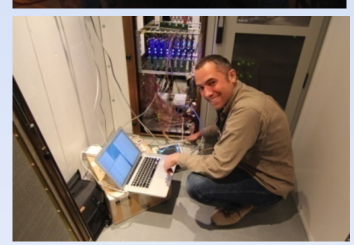
The Owens Valley Radio Observatory

- Suite of facilities operating from 10 MHz – 270 GHz (10^4 range in frequency!)
- CARMA, LWA, 40m Blazar program, Starburst, C-BASS, Owens Valley Solar Array
- Dedicated staff and shared resources on site enable unique science

The Owens Valley LWA







Modified design to facilitate all-sky imaging

- **Core array increased to ~230m diameter - 251 antennas in core array + 5 outliers; 1000 m of fencing, 80,000 m of cables**

- **Antennas positions optimized to minimize sidelobes (-17 dB); minimum antenna spacing of 5m to minimize mutual coupling**

- **Modifications to ARX boards to minimize cost and delivery time**

- **Full cross correlation array, 60 MHz bandwidth instantaneous**

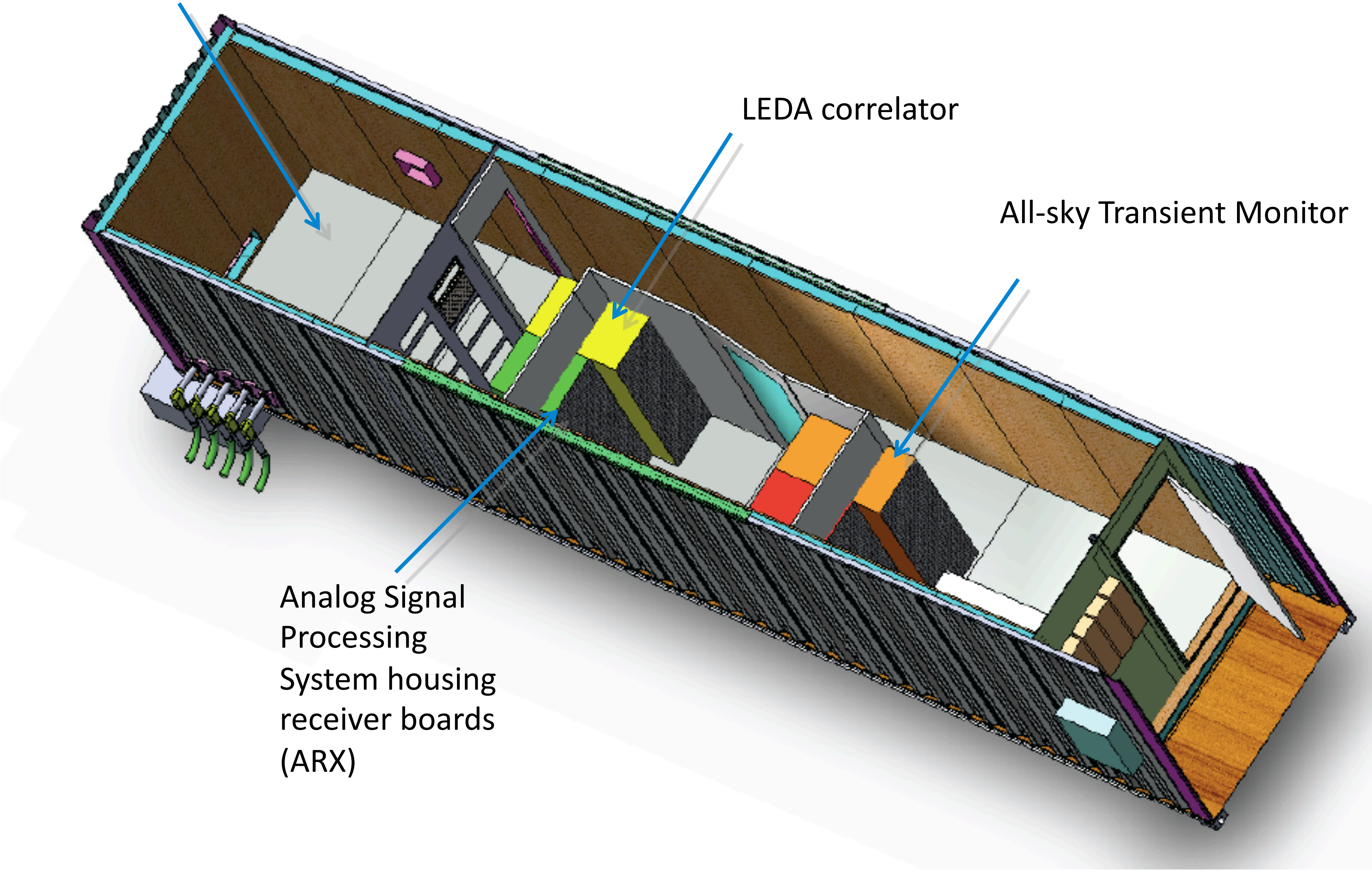
- **New custom built electronics shelter to accommodate increased computational load:**

- ***Cosmic Dawn:*** **Large Aperture to detect the Dark Ages (LEDA) [Harvard, Berkeley, UNM, VT] - *PI: Lincoln Greenhill***

- ***Transient Science:*** **All-sky Transient Monitor [Caltech & JPL] – focus on extrasolar space weather - *PI: Gregg Hallinan***

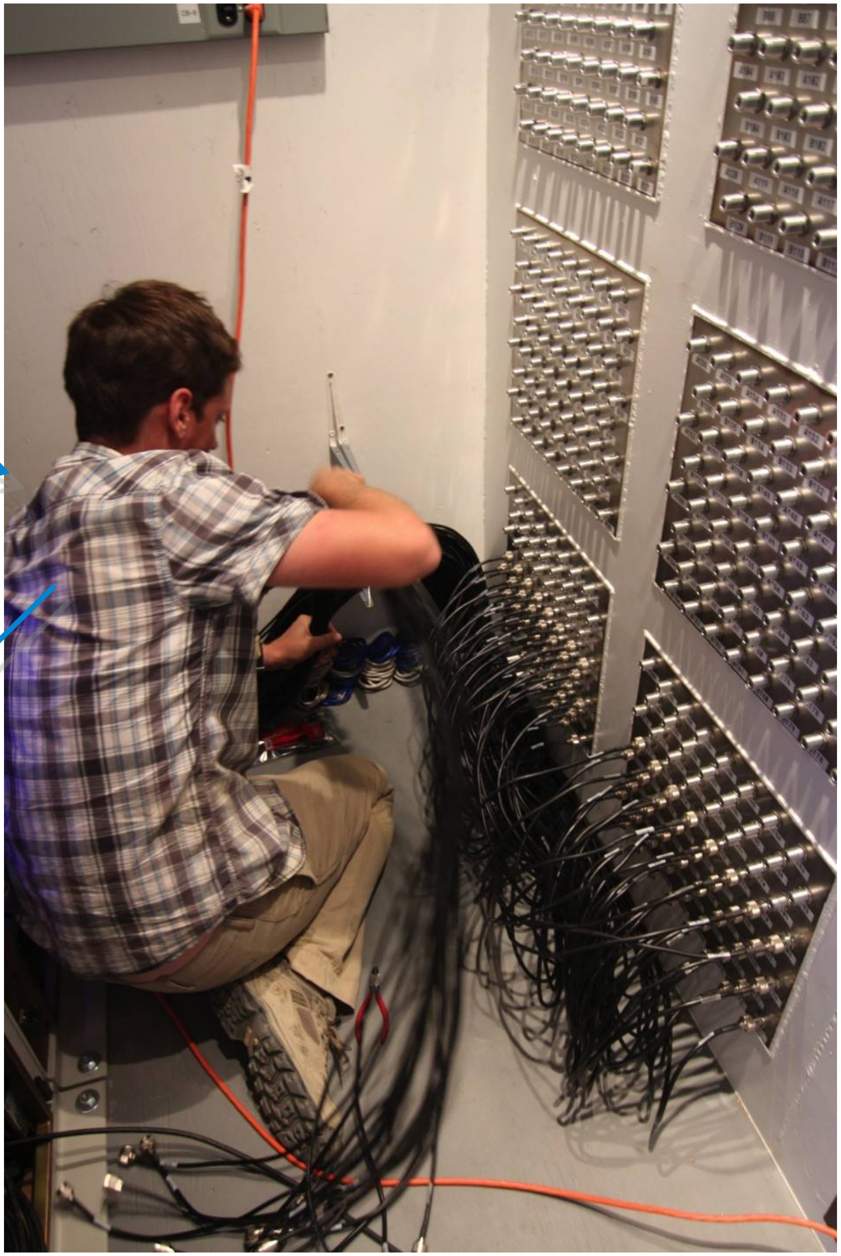
Electronics Shelter

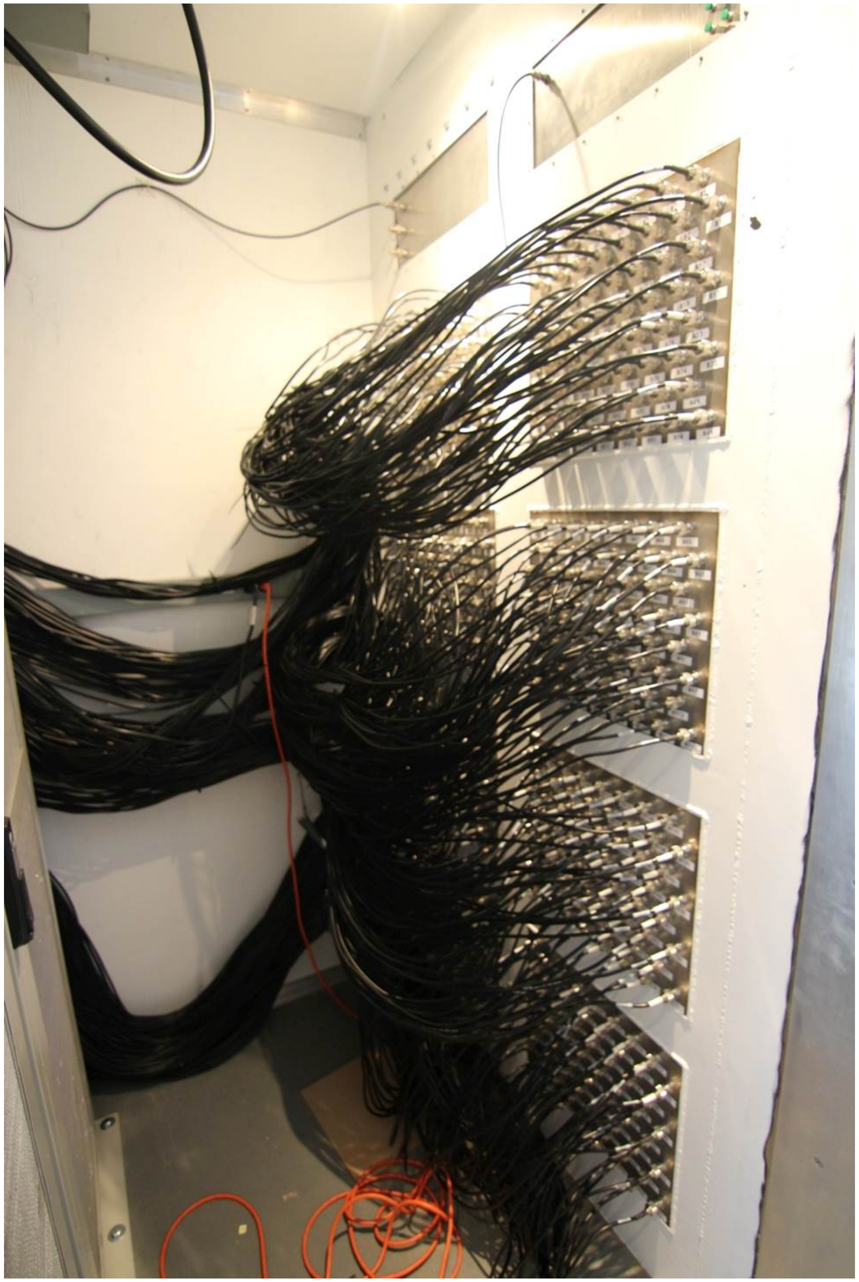
Designed and built by Russ Keeney



Electronics Shelter

Connecting it all together…





Large Aperture Experiment to Detect the Dark Age (LEDA)

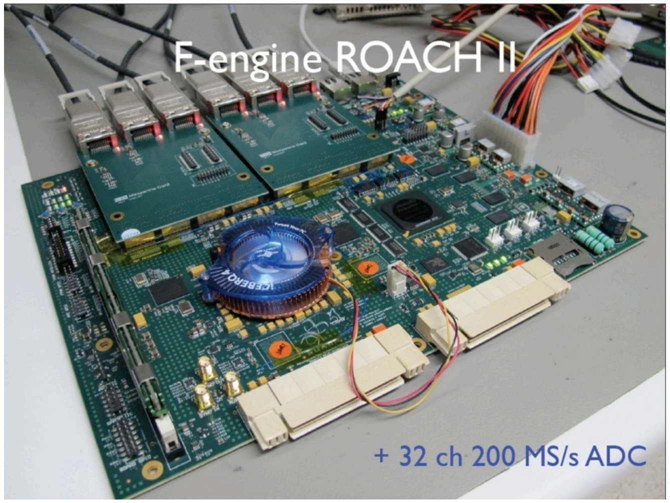
- FX correlator with 512 inputs (PIs: Lincoln Greenhill, Dan Werthimer, Greg Taylor, Steve Ellingson)

- The 512 signals digitized by 16 ADC boards, each containing thirty-two 200 Ms s^{-1}, 8-bit samplers processing a 0-100 MHz baseband.

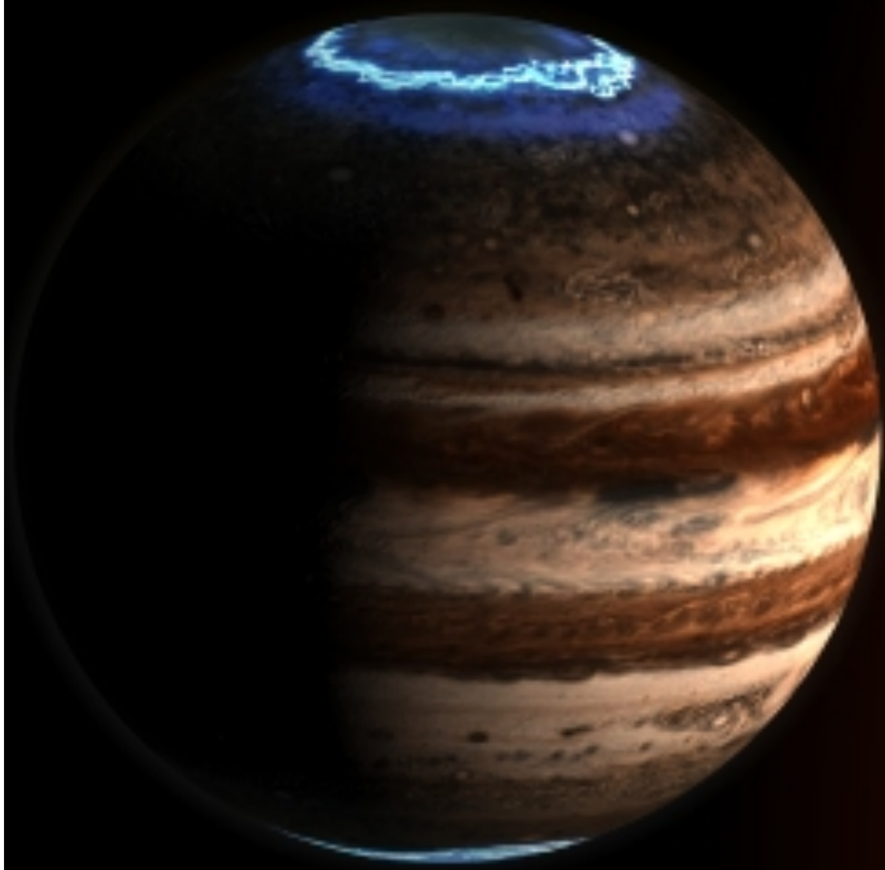
- F-engine - 16 CASPER Roach-II boards used as polyphase filterbank to give 2048 channels (4096 baseband)

- X-engine: 22 GPU-based X-engines will cross-correlate contiguous 2.6 MHz sub-bands, each containing 109 channels.

- GPUs achieve exceptionally high computing density and power efficiency – 2 TF per GPU.



All Sky Transient Monitor



Successor to PASI

160 CPU cores, ~20 GPU, 1 TB of RAM

250 TB of high speed Lustre storage

Data will be processed and archived in real time

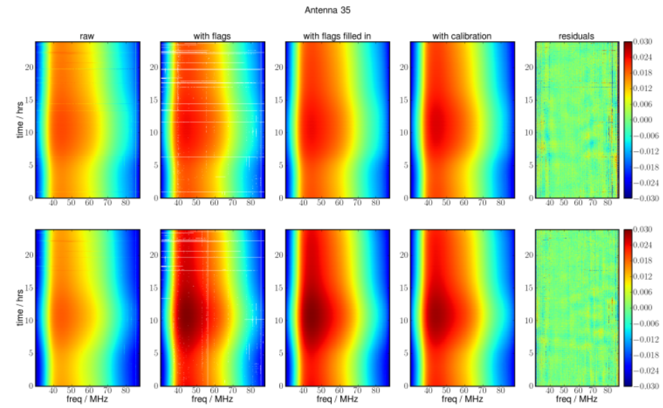
32768 x 4P x 2400 channels (60 MHz) x 32b+32b = 2.7 GB per integration

Resolution ~ 1 degree -> image data ~ 10 MB per integration (Stokes I and V)

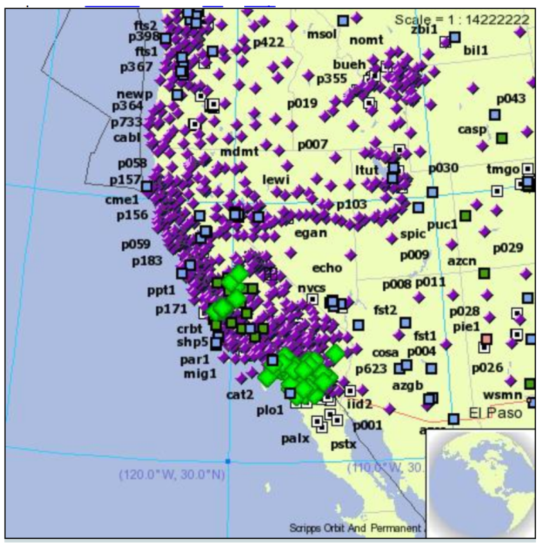
Can monitor the entire hemisphere continuously to detect transients

Ongoing Work

- Development of pipeline -> Calibration, deconvolution, polarization calibration – application of cuWARP (Stephen's talk)

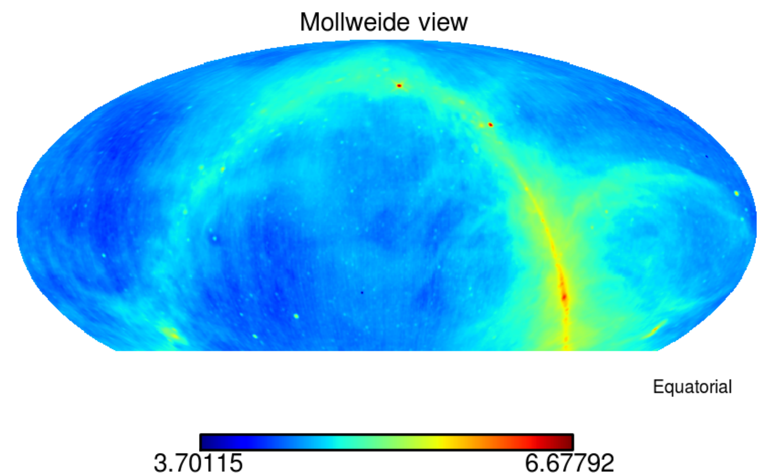


RFI flagging



Ionospheric calibration:

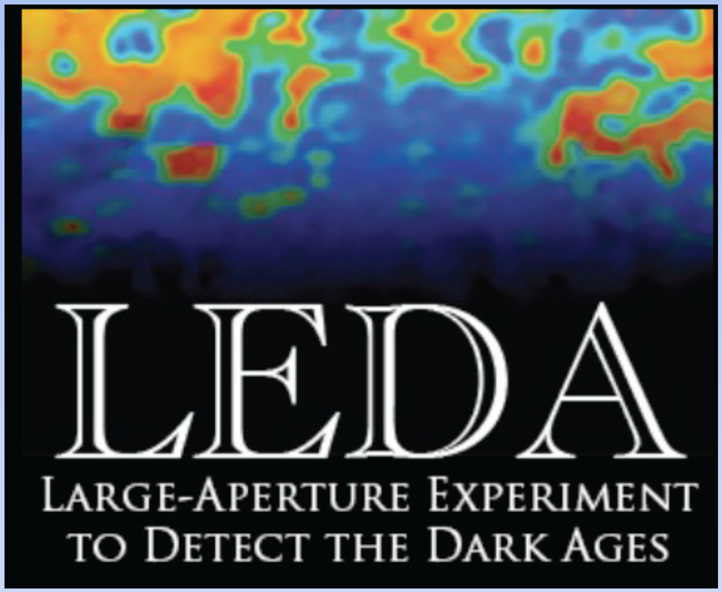
Data from ~1000 GPS stations will provide high spatial/temporal resolution tomography of the ionosphere above OVRO

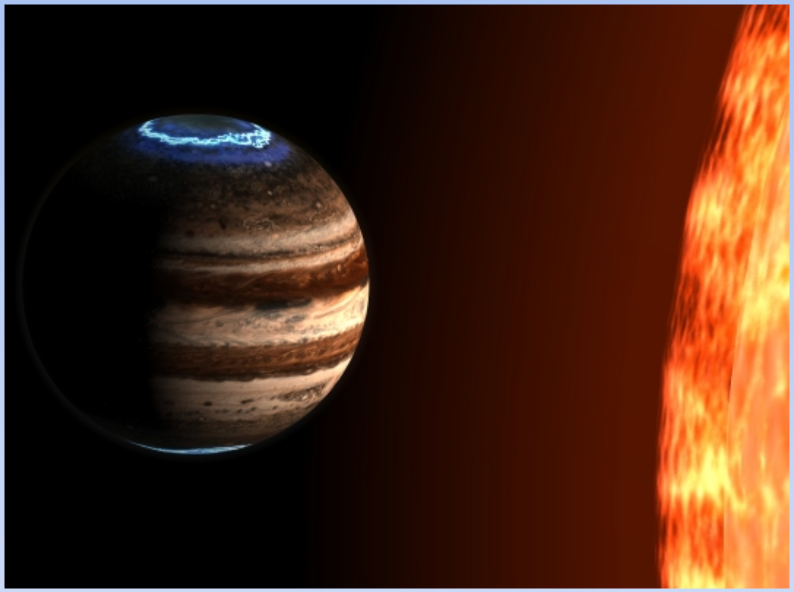


Data will be gridded to the Mollweide projection and stored via the Healpix format

Accessible via web interface

LWA-OVRO Primary Science





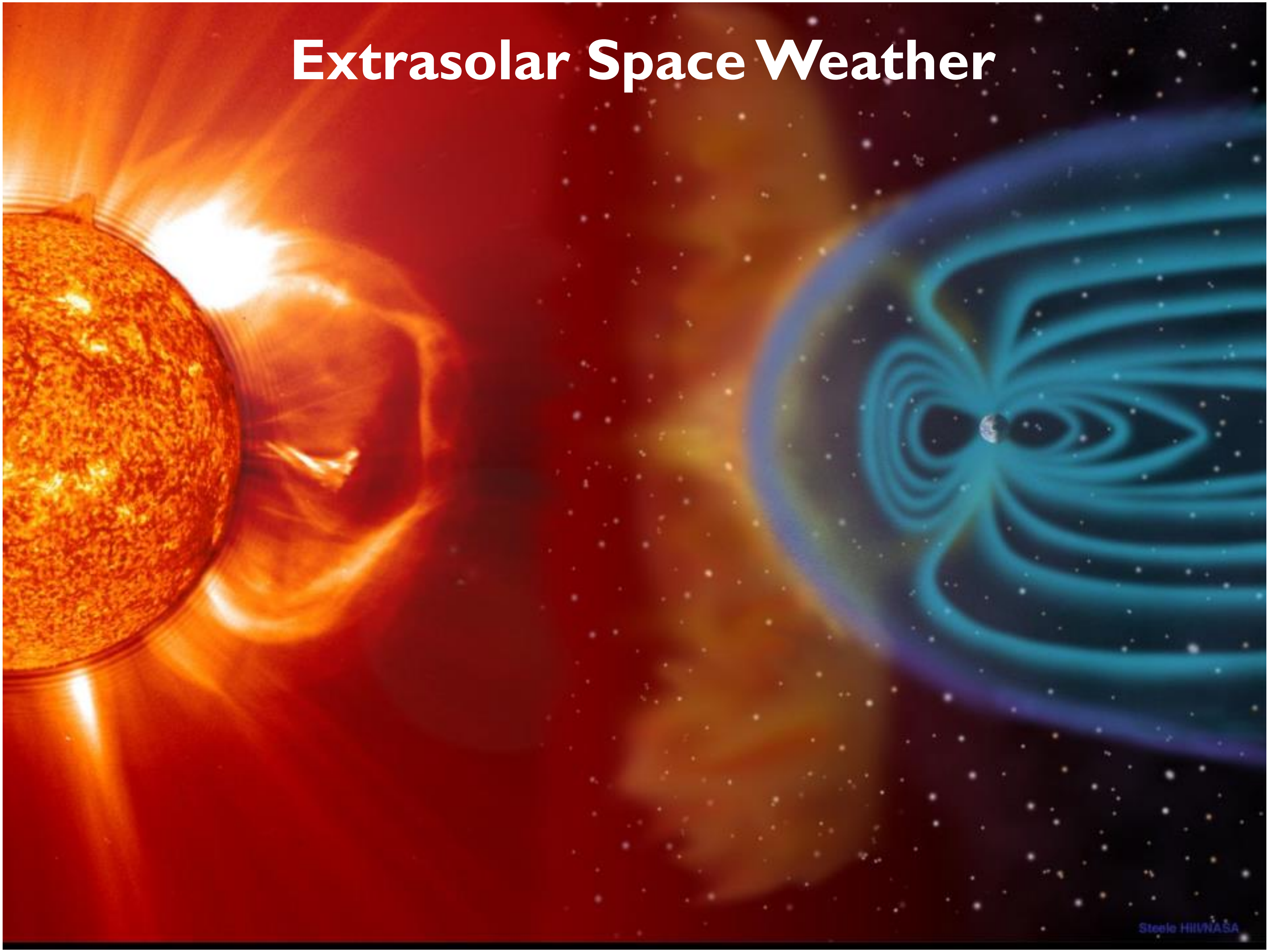
LEDA: Detect sky averaged HI signal at z~20

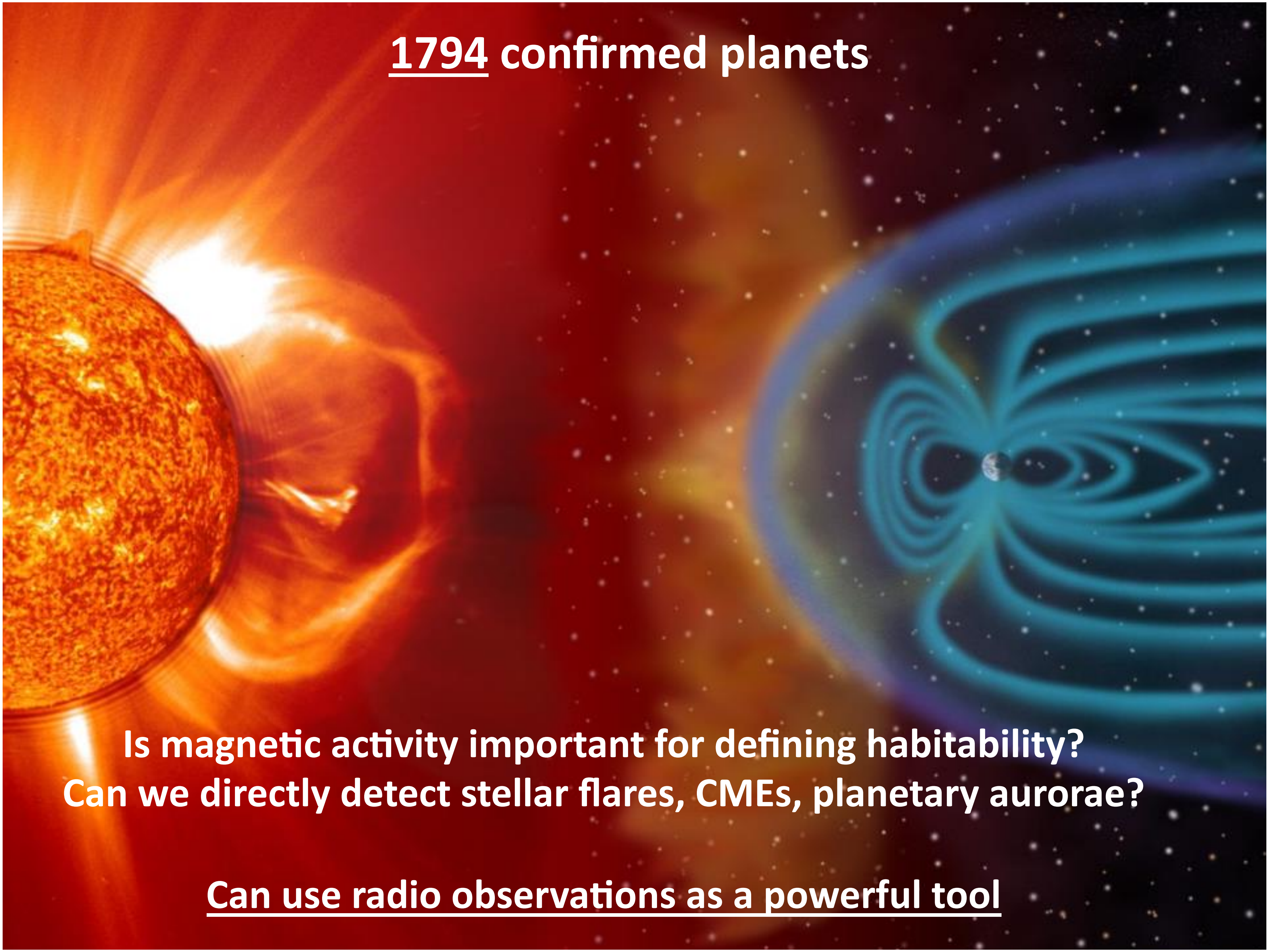
First constraints on HI power spectrum at z~20?

All-sky Transient Monitor: Image the entire viewable hemisphere each second in Stokes I and V

Key objectives include first radio exoplanet detection, stellar CMEs

Extrasolar Space Weather




1794 confirmed planets
Is magnetic activity important for defining habitability?
Can we directly detect stellar flares, CMEs, planetary aurorae?
Can use radio observations as a powerful tool

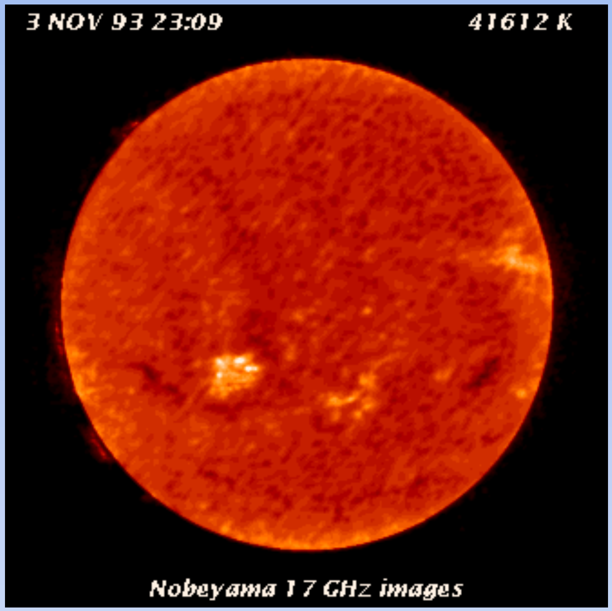
Implications of Activity – e.g. M Dwarfs

- 95% of stars that can host evolved exoplanets (age > 1 Gyr) are M dwarfs
- Kepler has shown that lower mass planets are frequent around M dwarfs (Dressing & Charbonneau 2013)
- *Likely the nearest habitable planet orbits an M dwarf*
- Can be much more active than the Sun and active for much longer –> flares up to 10^4 times more energetic
- Flares – higher X-ray and ultraviolet radiation flux –> photochemical reactions leading to significant atmospheric loss (Segura et al. 2010)
- Coronal mass ejections (CMEs) – higher stellar wind flux –> can erode atmosphere – eg. ion pick-up of a CO^2-rich atmosphere (Lattimer et al. 2007)

Radio Emission from the Sun

Quiet Sun (MHz – GHz)

Free-free emission from thermal atmosphere (10^4-10^6 K)

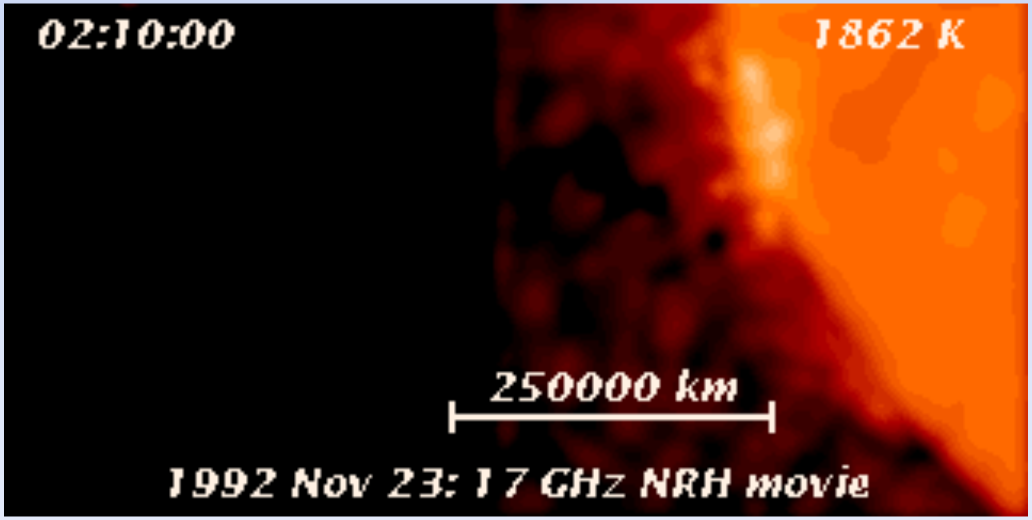


Credit: Stephen White

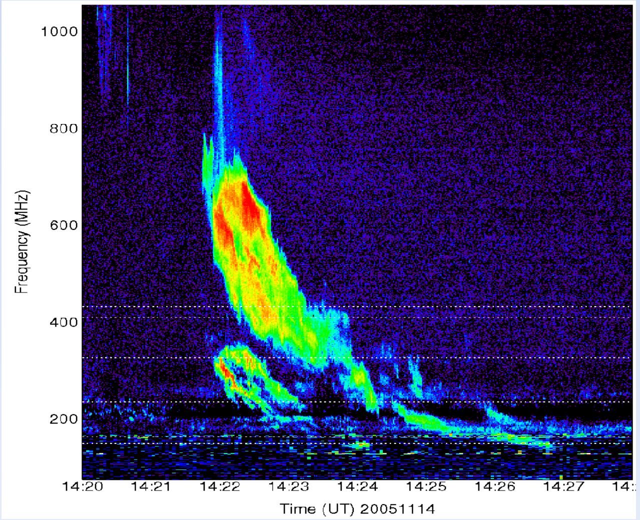
Flaring Sun (MHz – GHz)

Intensely Bright Radio Emission

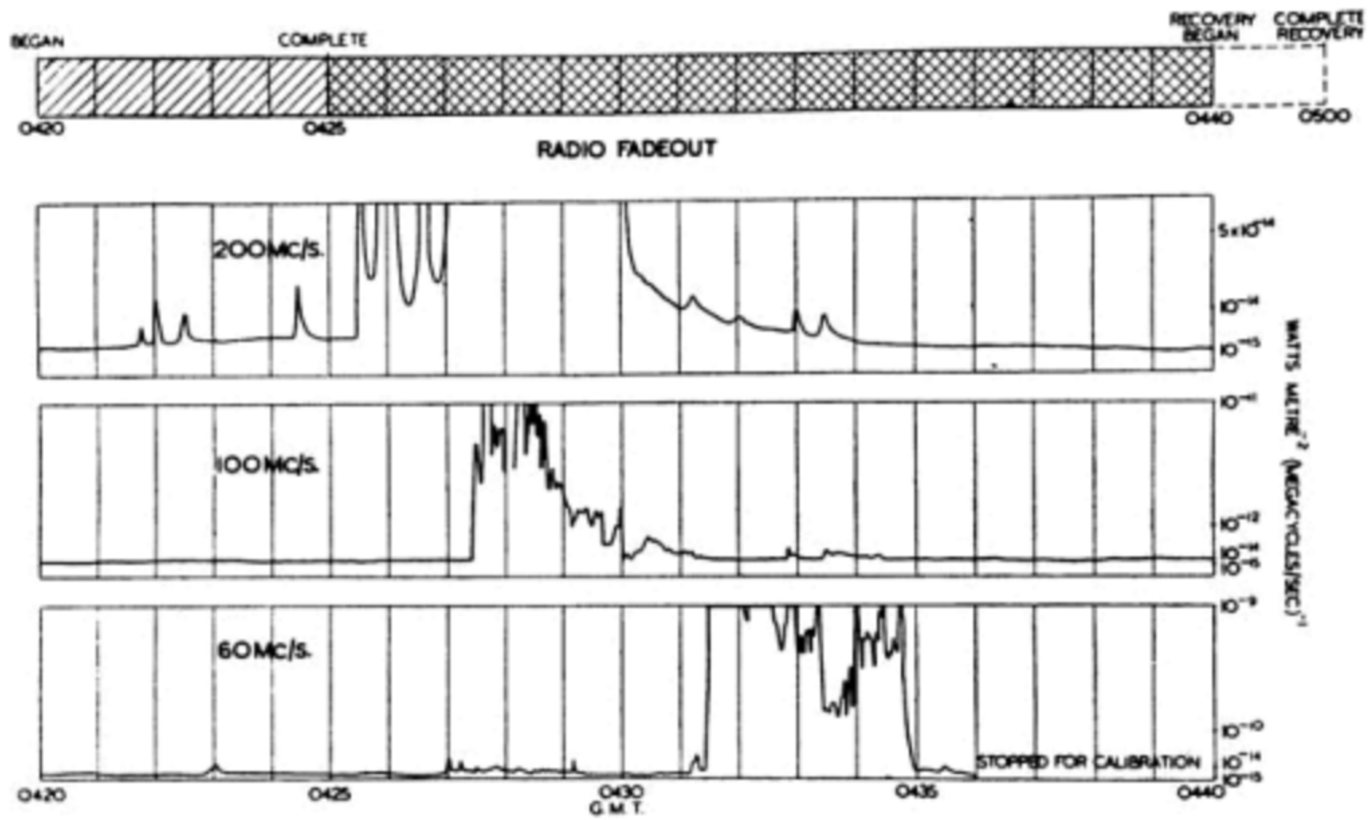
Gyrosynchrotron flares



Coherent bursts (Type II, Type III…)



Brightest Bursts from the Sun

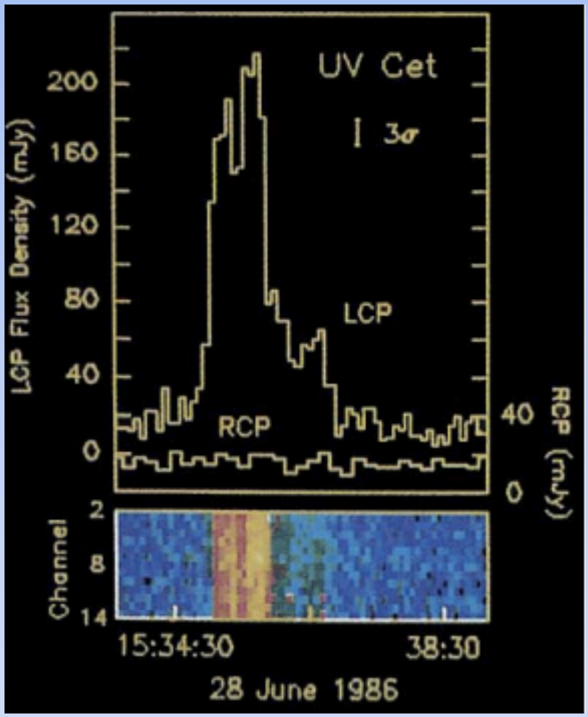


LARGE OUTBURST OF MARCH 8, 1947

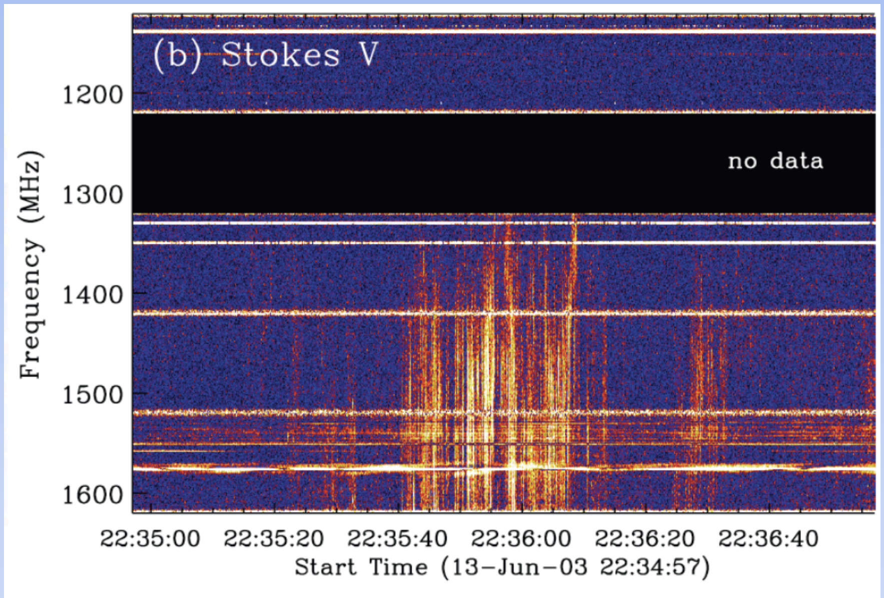
Giant Type II burst detected in 1947 - Possibly as bright as 10^{11} Jy at 60 MHz!

Payne-Scott et al. Nature, 160 (1947), 256, via Goss & McGee 2009

Radio Bursts from Nearby Stars



Bastian et al. Nature (1987)

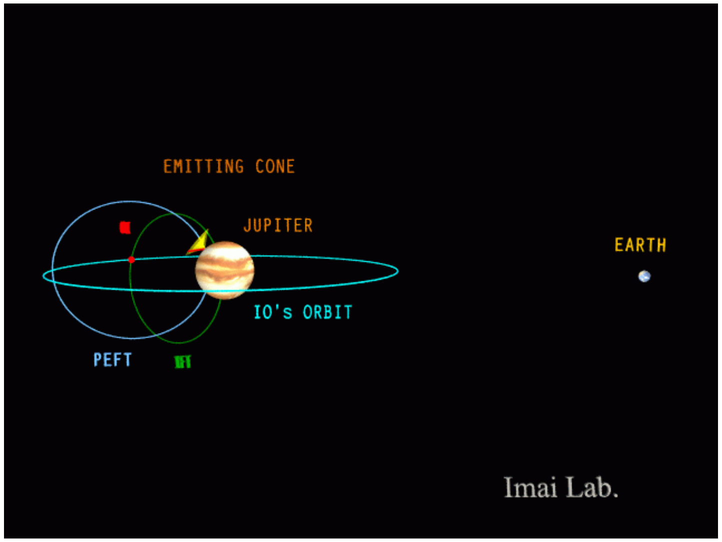


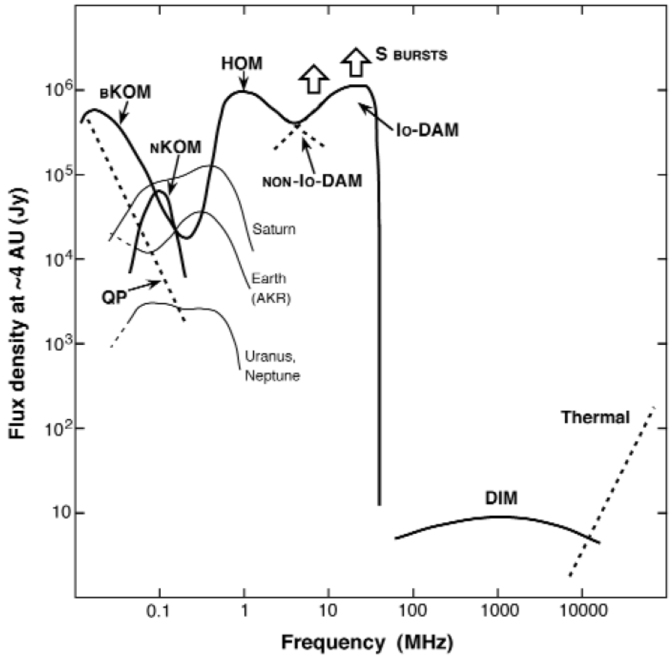
Osten & Bastian, ApJ (2006)

- Active stars flare frequently and intensely
- Very bright bursts have been detected for decades ~ 1 Jy (eg. Lovell 1964)
- Powerful signature of CMEs on nearby stars

Radio Emission from Solar System Planets

- Late 1960s/70s: Earth's polar region also recognized as radio source (10^{14} erg s^{-1}).
- *Voyagers*: Opens up field
- All gas giants and Earth have strong planetary magnetic fields and auroral/polar cyclotron emission.





Zarka (1998)

- Very high brightness temperature (> 10^{15} K)

- Highly circularly polarized

- Electron cyclotron maser emission

- Direct measurement of B…

$$B_{Gauss} = \nu_{MHz} / 2.8$$

Why look for radio emission from exoplanets?

- It's a direct detection

- Allows measurement of rotation rate

- Possible use as a detection method for exoplanets

- The only method currently viable for measurement of magnetic field strengths for exoplanets...

a) Leads to constraints on scaling laws based on magnetic fields of solar system planets

b) Provides insight into internal structure of planet.

Expected Flux…

- Strong correlation between Solar Wind (P & V) and auroral radio emissions.

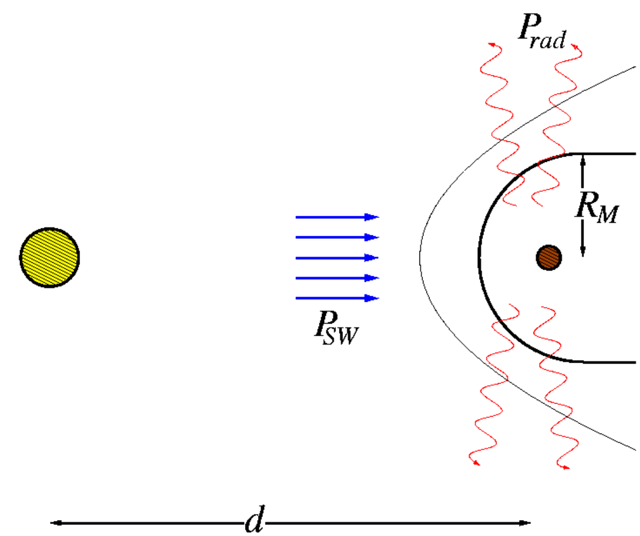
- The emitted power scales with the received stellar wind power - $P_{rad} \propto P_{SW}^{x}$

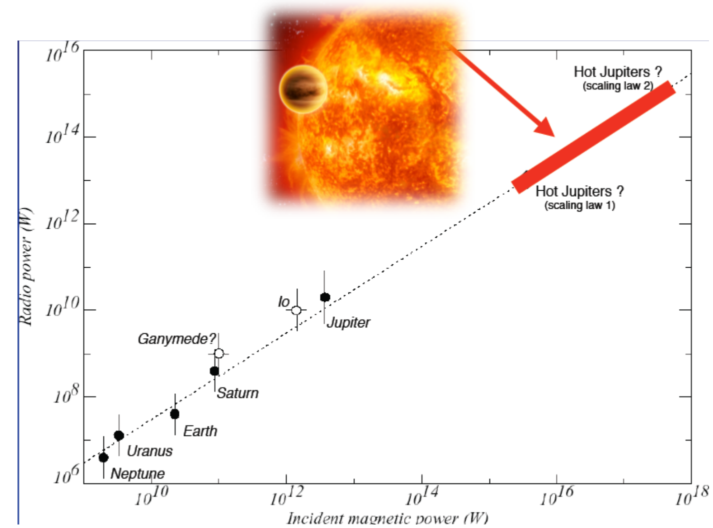
- The received stellar wind power depends on the distance and the cross-section of the magnetosphere – $P_{SW} \propto R_M^2 d^{-2}$

- Close in planets have brighter radio emission

- Higher flux during CMES

- ***Jupiter at 1 AU from solar star at 10pc detectable with ~5,000 dipoles from the ground***





Zarka et al, ApSS. 2001

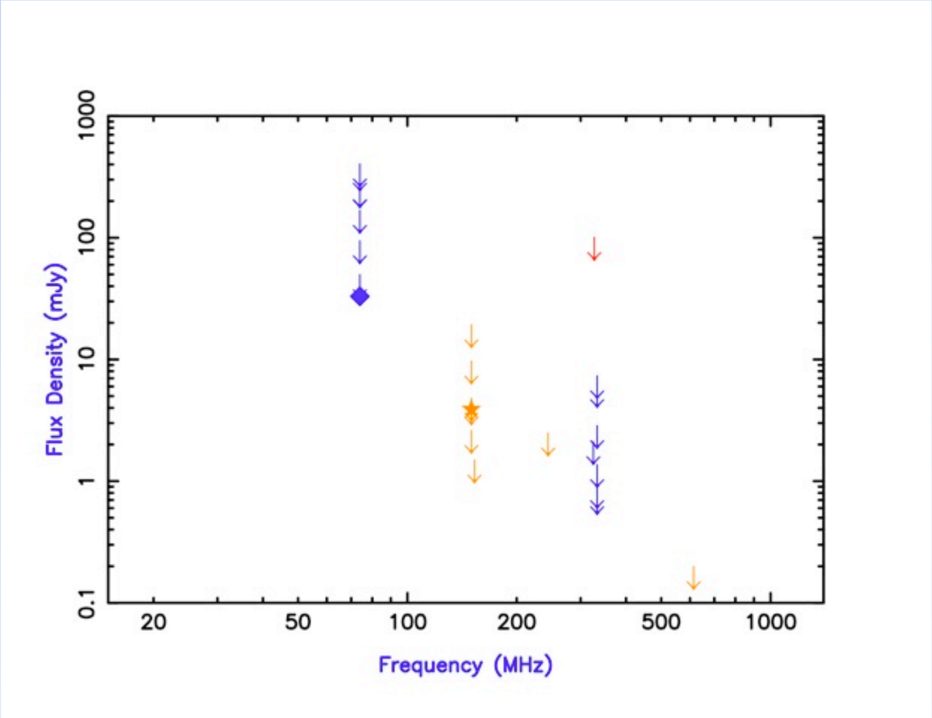
Searches Thus Far...

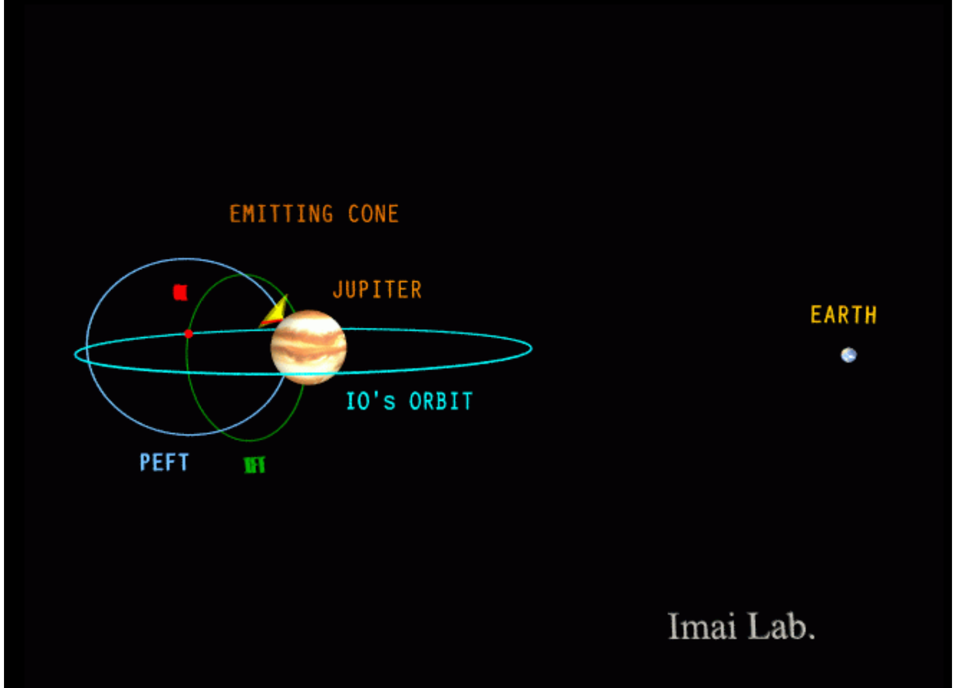
- Searches have been ongoing for > 30 years – no detections

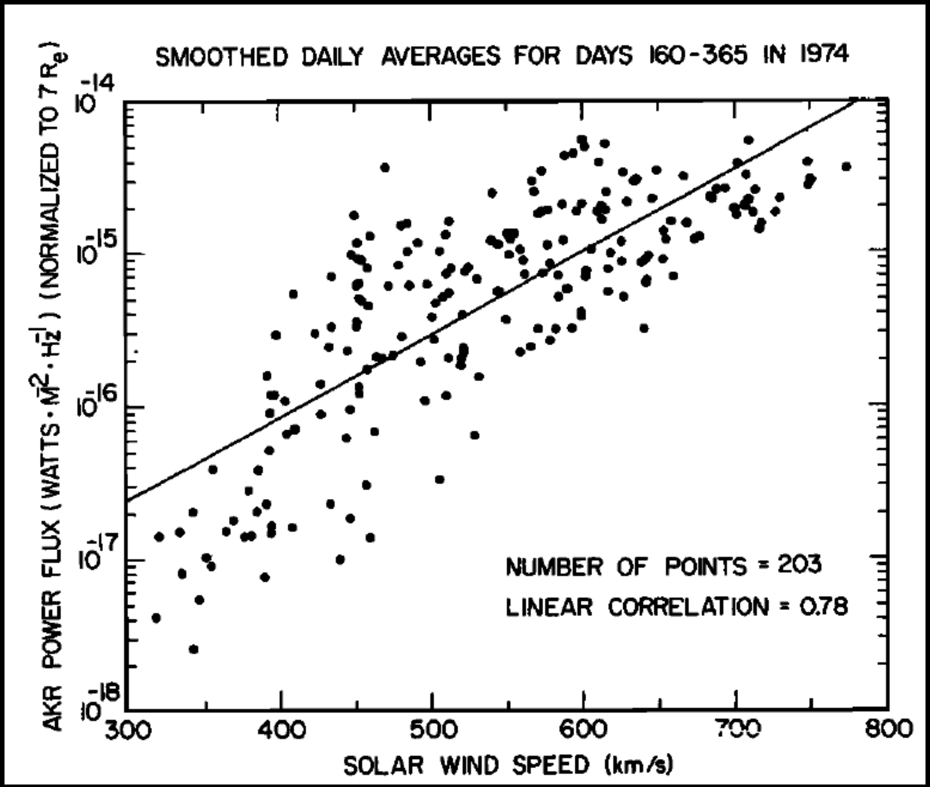
- Involve targeted pointings of small sample of Hot Jupiters (<10)

- See Lazio et al. 2009 for review – 2010 Decadal Survey White Paper

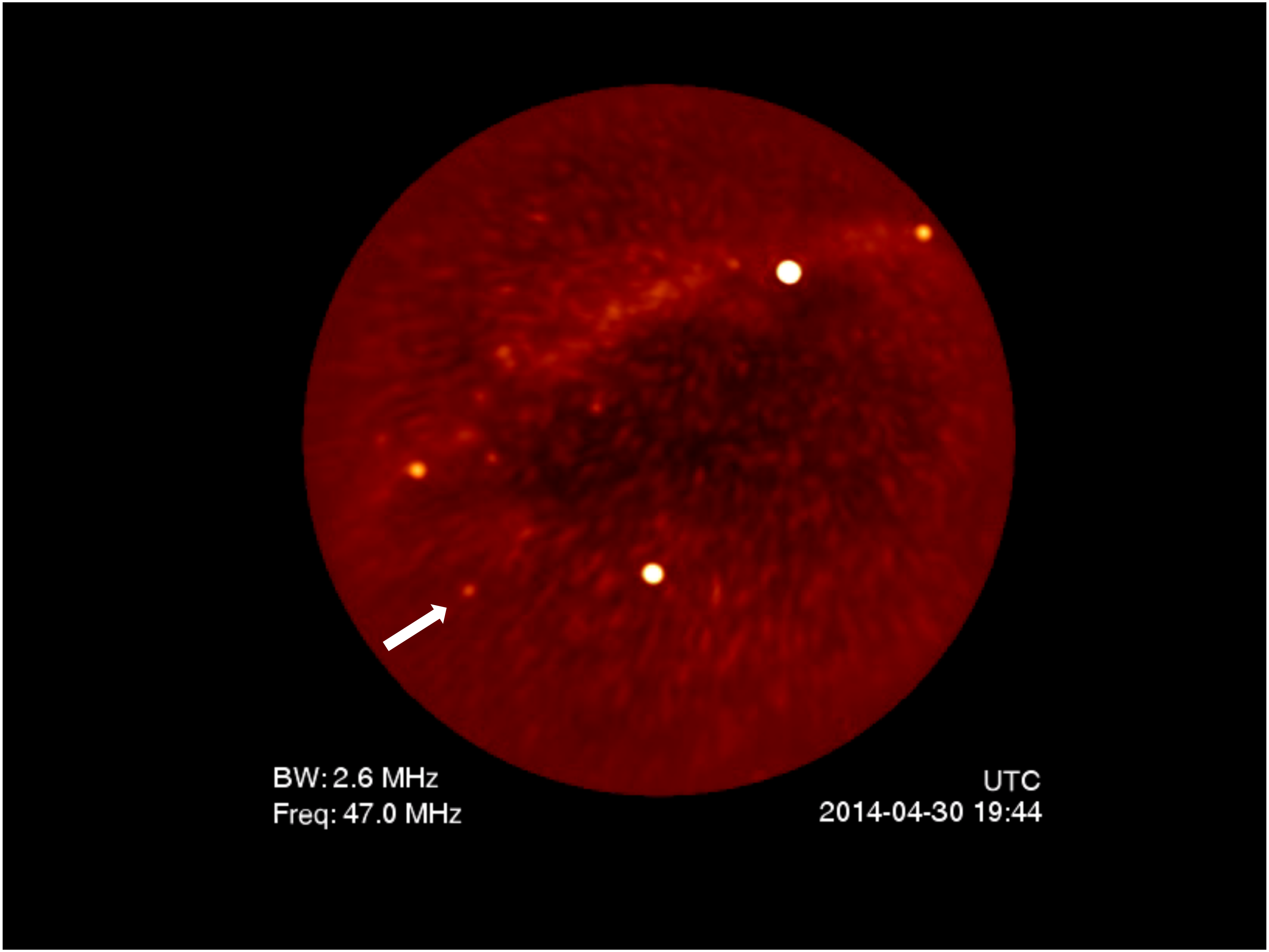
- Need to observe large sample at low frequencies (< 100 MHz) to overcome geometrical selection effects

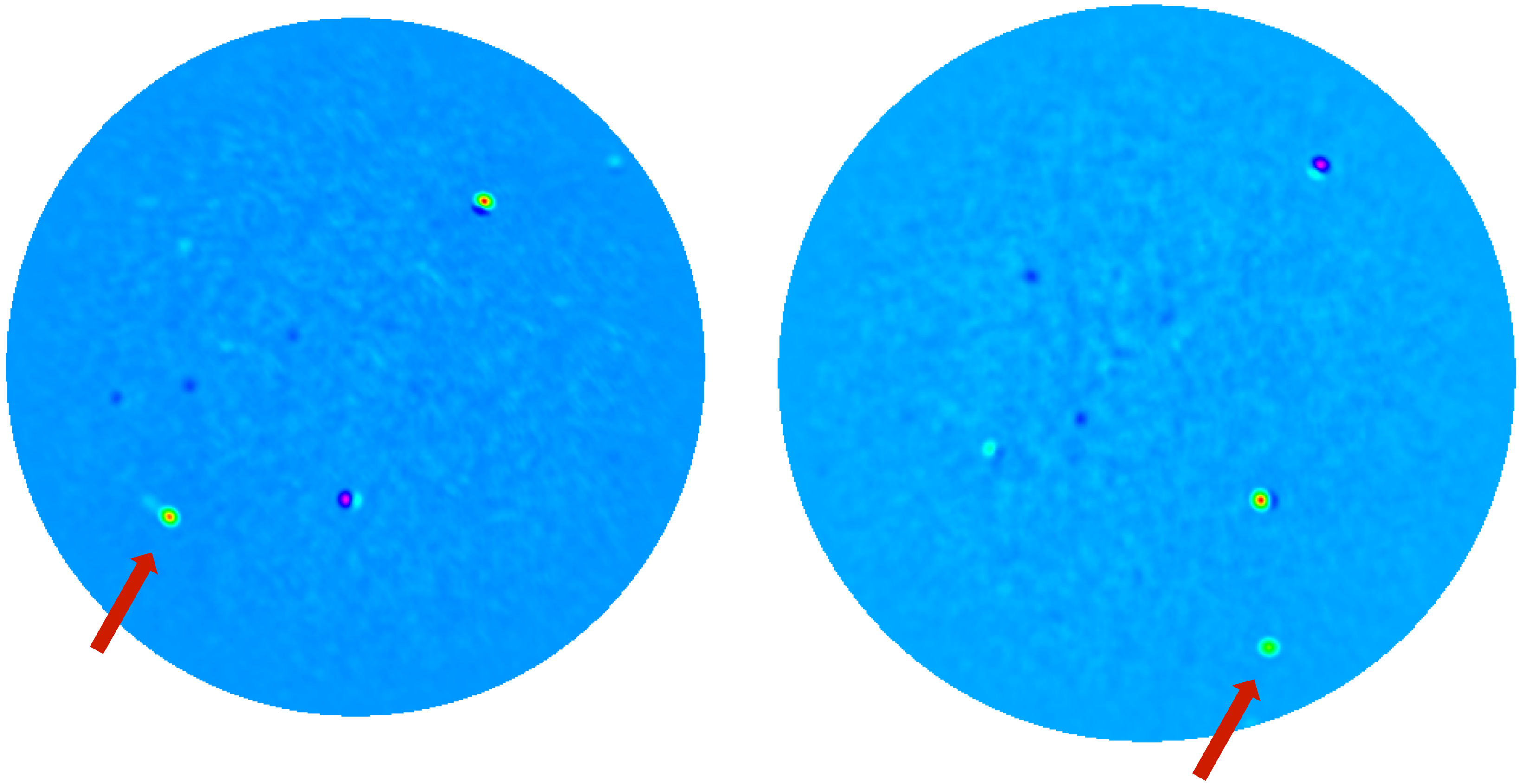






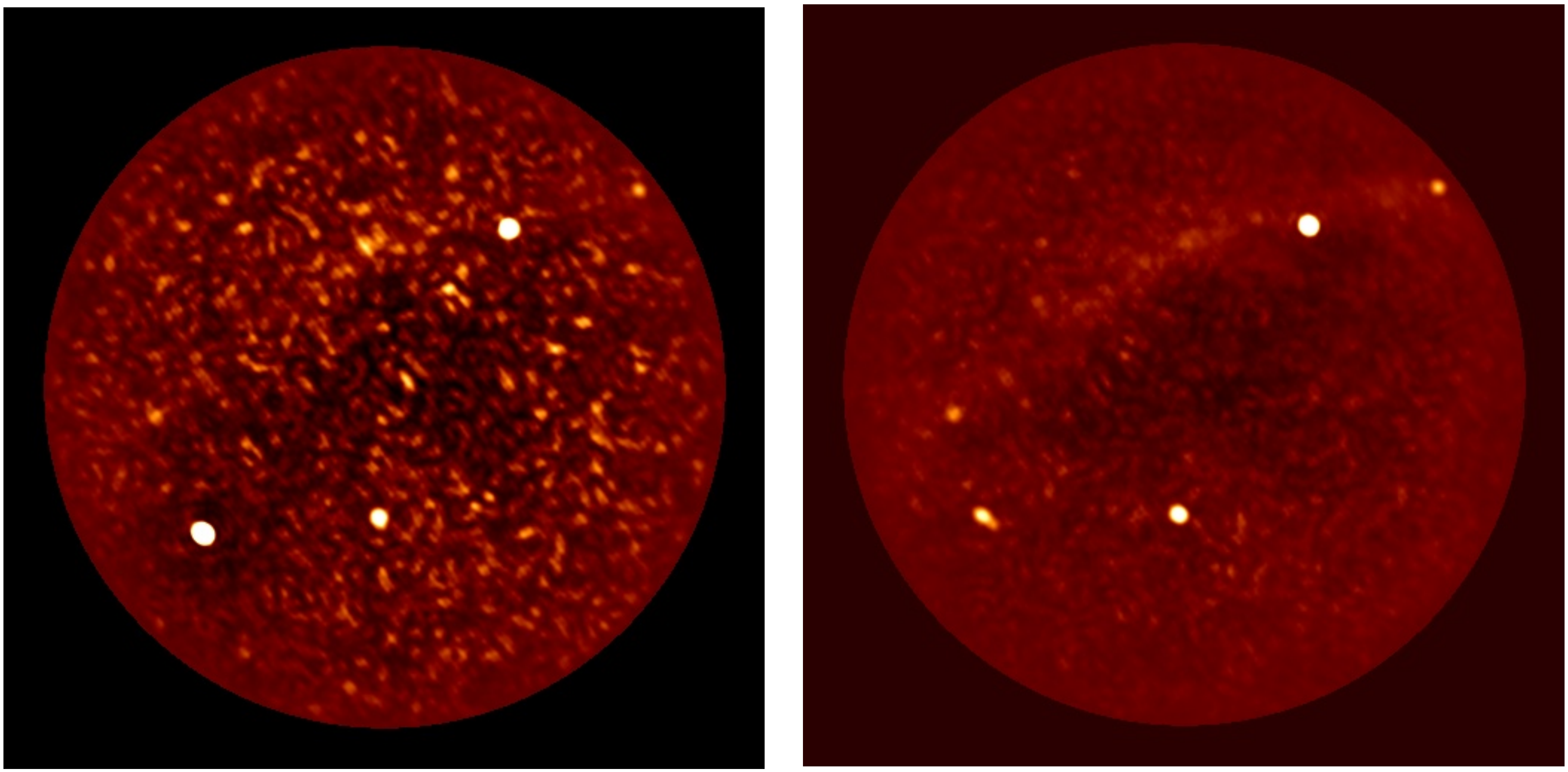
Gallagher & D'Angelo 1981


BW: 2.6 MHz
Freq: 47.0 MHz
UTC
2014-04-30 19:44



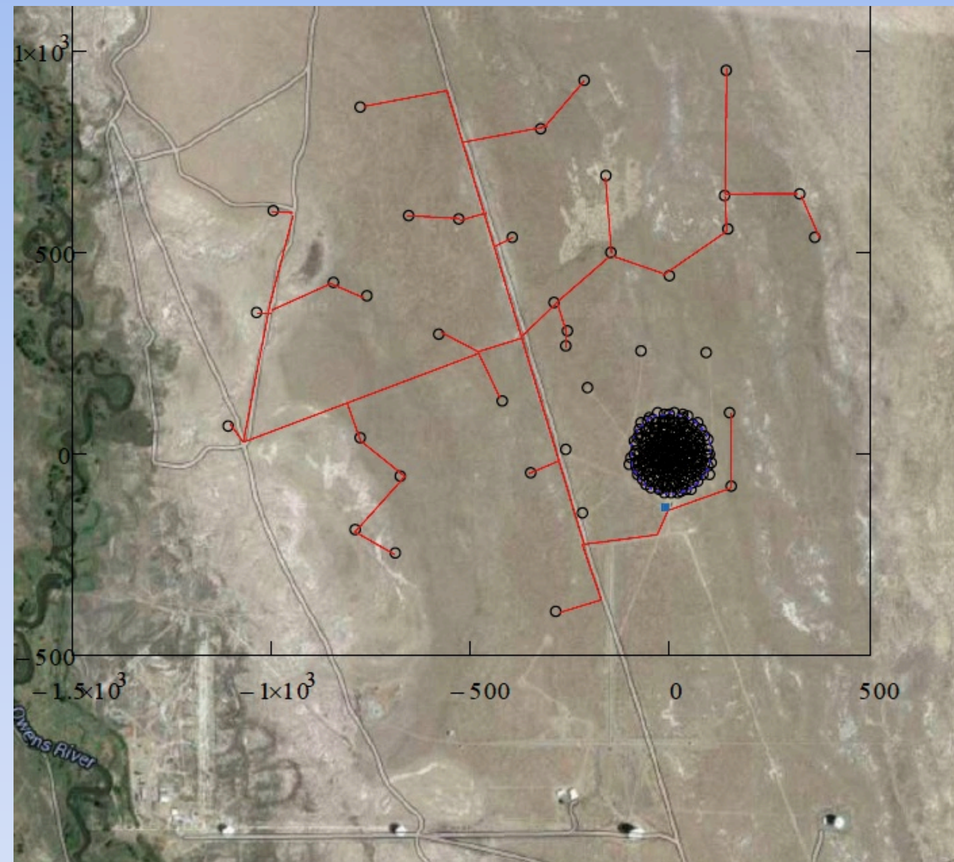
- RMS thermal noise per 11 sec frame (2.6 MHz BW is ~750 mJy)

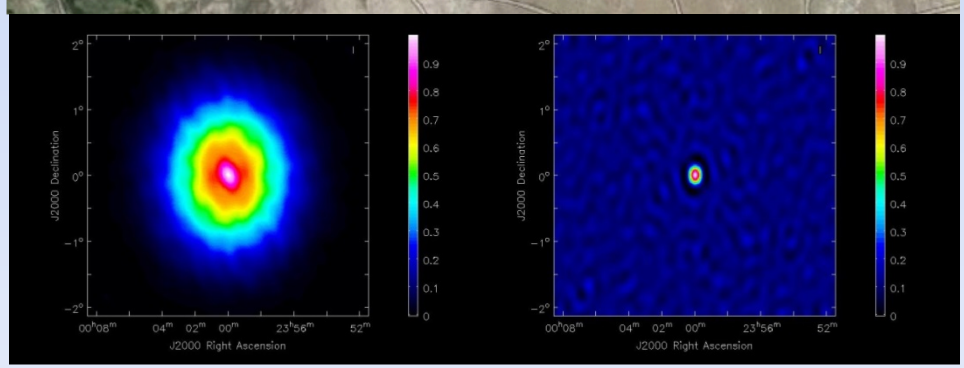
- 15 mins and 30 MHz BW -> 25 mJy



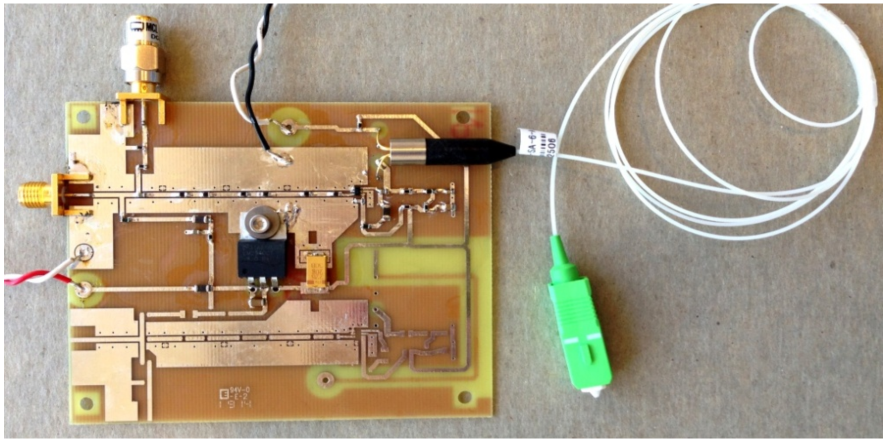
LWA 32 Antenna Expansion

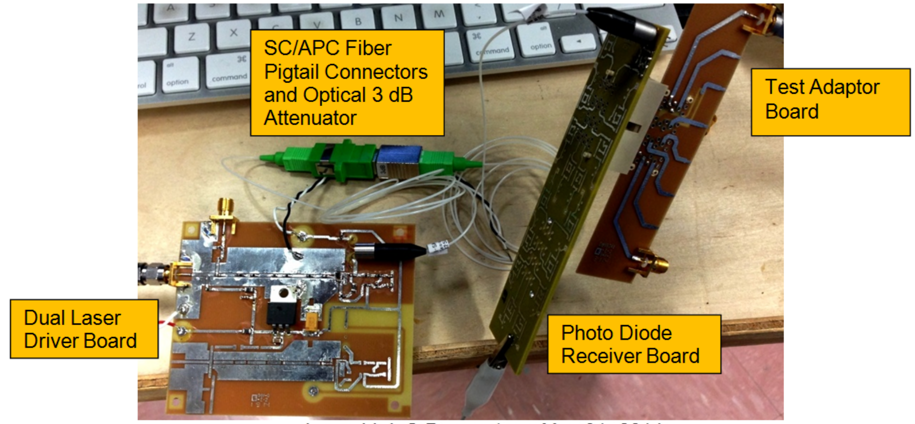
- Antennas powered by solar panels with data transport via optical fiber
- Completion by ~Sept 2014
- Better localization of transients
- A higher resolution all-sky catalog
- Solar dynamic imaging spectroscopy observations
- Longer baselines for calibration
- Resolution of ~7 arcmins at the top of the band
- 41,000 baselines
- Each image will be ~10 Mpix

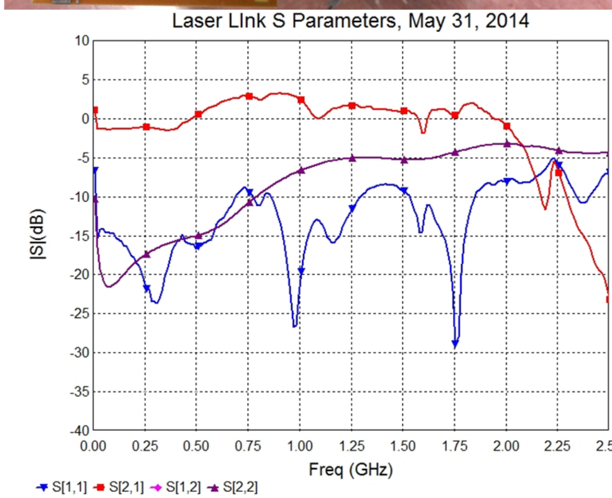




Fiber links (Sandy Weinreb)







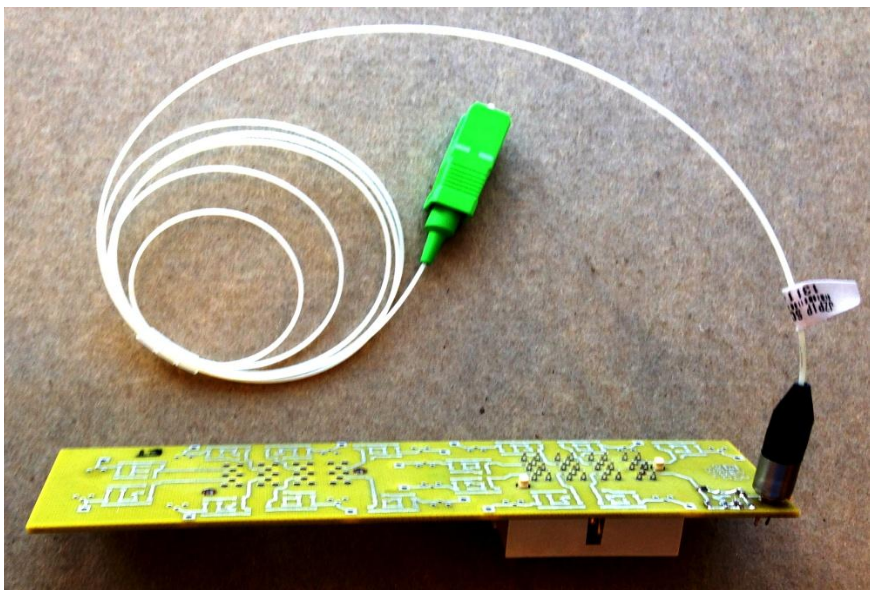


Figure 1 - RF input to RF output S parameters of the laser diode to photo diode optical link shown in the photo above. This is with 3 dB optical attenuation. The link gain is -1dB +/- 0.5 dB from 20 MHz to 400 MHz and is 1 +/- 2dB from 10 MHz ot 2000 MHz. The link input 1 dB gain compression power is -10dBm and link NF is 13 dB. Details for construction and tests follow in this report.

Cost per antenna reduced from $1600 to <$100

The Cosmic Dawn Array

- Funded 2013-2015 for a technology development at Caltech (Hallinan+) and JPL (Lazio+) for a much larger (2000 dipole) full cross-correlation array (>10^6 baselines)

- Work underway includes
  1) migration to data transport via optical fiber
  2) Trade study of correlator architectures (ASIC vs FPGA vs Hybrid)
  3) solar-powered antennas and data processing nodes (digitization at the antenna)
  4) extended RFI surveys at and near OVRO
  5) data processing and archiving capabilities

- **Will serve as a survey instrument for a multi-station LWA**

- **Key science:**

- **1) Power spectrum measurement of red-shifted HI at z~20 (Visbal et al 2012; McQuinn & O'Leary 2012)**

- **2) Detection of Jovian planets orbiting at 1 AU out to 10 pc**