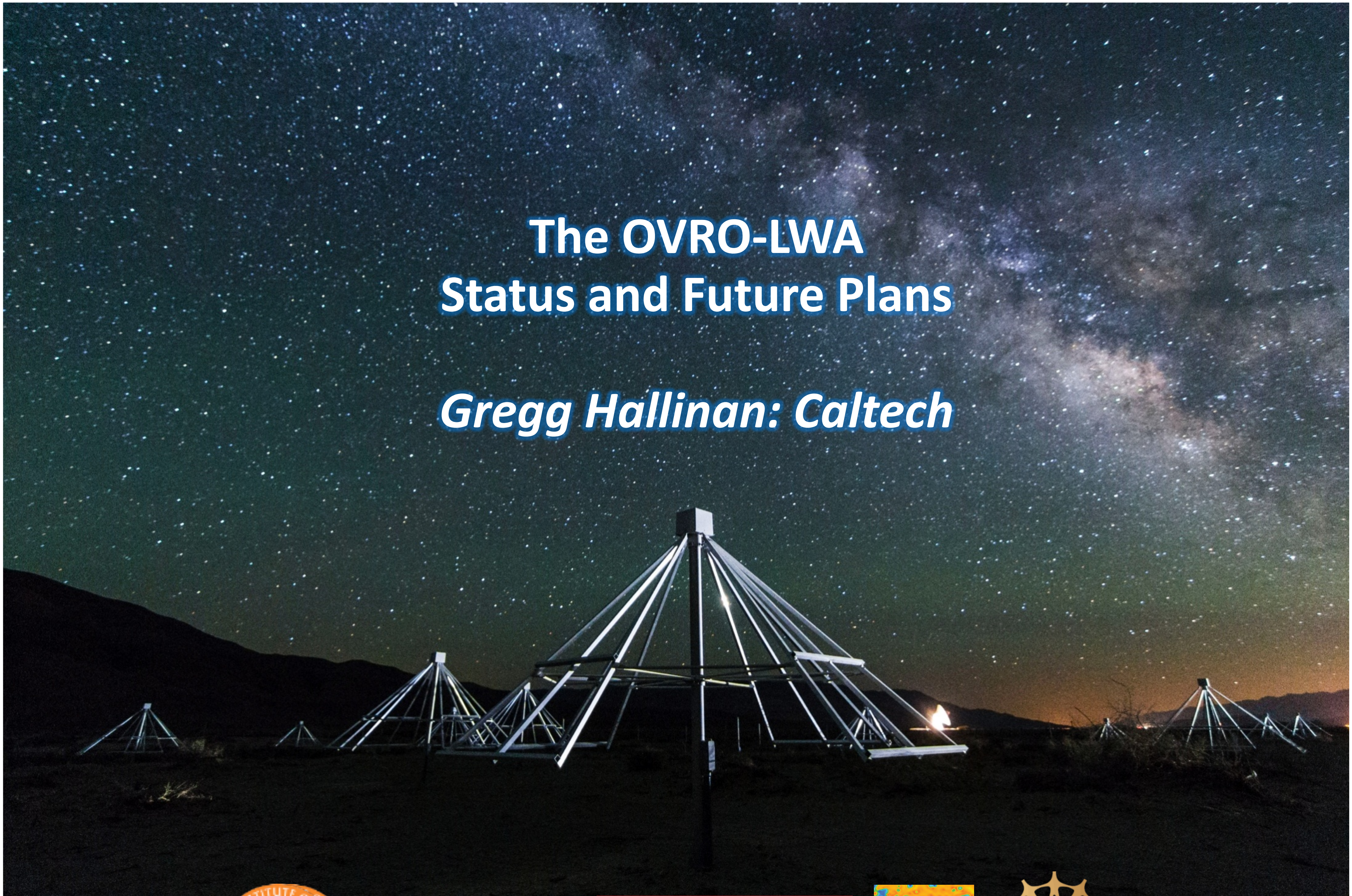
The OVRO-LWA
Status and Future Plans

Gregg Hallinan: Caltech



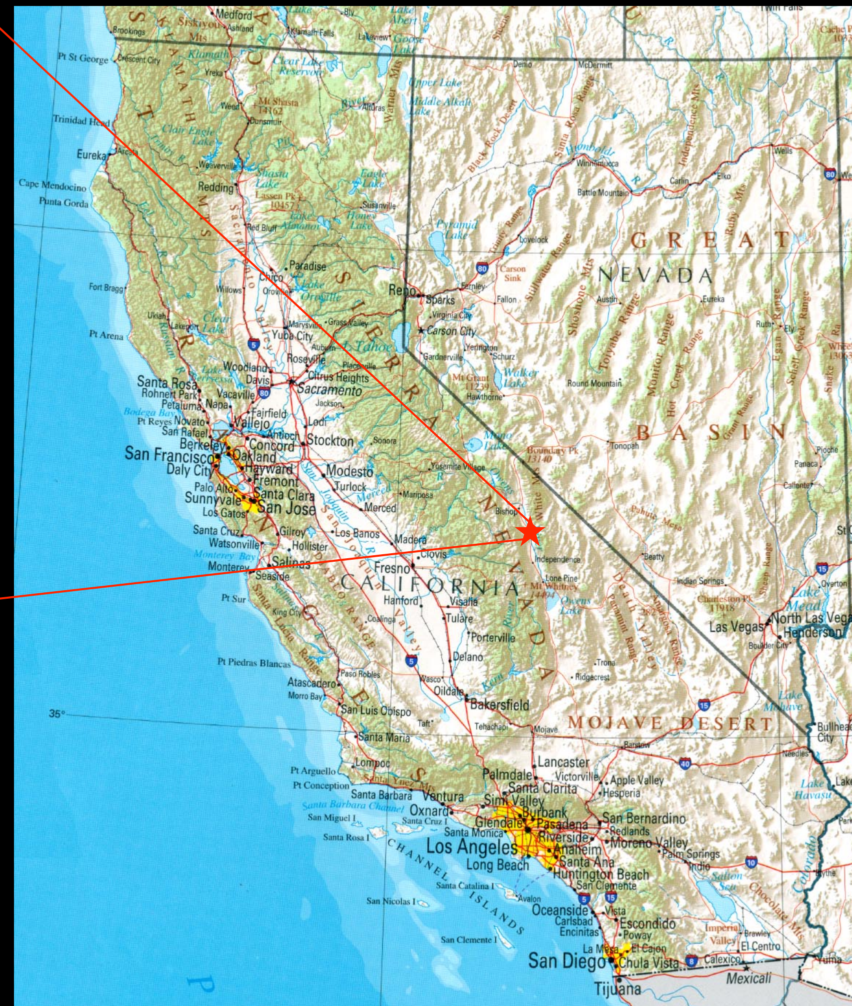
Jet Propulsion Laboratory
California Institute of Technology

Long Wavelength Array

LEDA
Large-Aperture Experiment to Detect the Dark Ages

NSF

Concept



- A full cross-correlation interferometer to image the entire sky continuously from OVRO

- 352 antennas spaced over ~2.6 km
- ~5 arcminute resolution
- ~20,000 degree FOV
- 60 MHz bandwidth
- ~50 mJy rms noise at zenith in 30 seconds
- Imaging in Stokes I and Stokes V

Collaboration

- **Caltech, OVRO & JPL:**
- **Gregg Hallinan, Stephen Bourke, Michael Eastwood, Marin Anderson, Ryan Monroe, Harish Vedantham, Sandy Weinreb, Esayas Shume, Kate Clark**

- **David Woody, James Lamb + OVRO staff**

- **Joe Lazio, Larry D' Addario, Jonathon Kocz, Dave Hawkins, Attila Komjathy, Melissa Soriano**

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

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

All-sky monitoring to target unique science < 100 MHz

- **1) Transient science: initial focus on Stokes V imaging**
  - ***Stellar coronal mass ejections (CMEs)***
  - ***Planetary auroral radio emission***
  - ***GCRT-like events, EM-GW follow-up, serendipitous***

- **2) Cosmic Dawn (redshift ~20)**
  - ***Total power measurement: modified dipoles (LEDA)***
  - ***Power spectrum measurement: interferometry with core array***
  - ***Lunar occultation: interferometry with extended array***

- **3) Dynamic Imaging spectroscopy of the Sun**

- **4) Continuous monitoring of the ionosphere**

- **5) Reflections of Galilean moons**

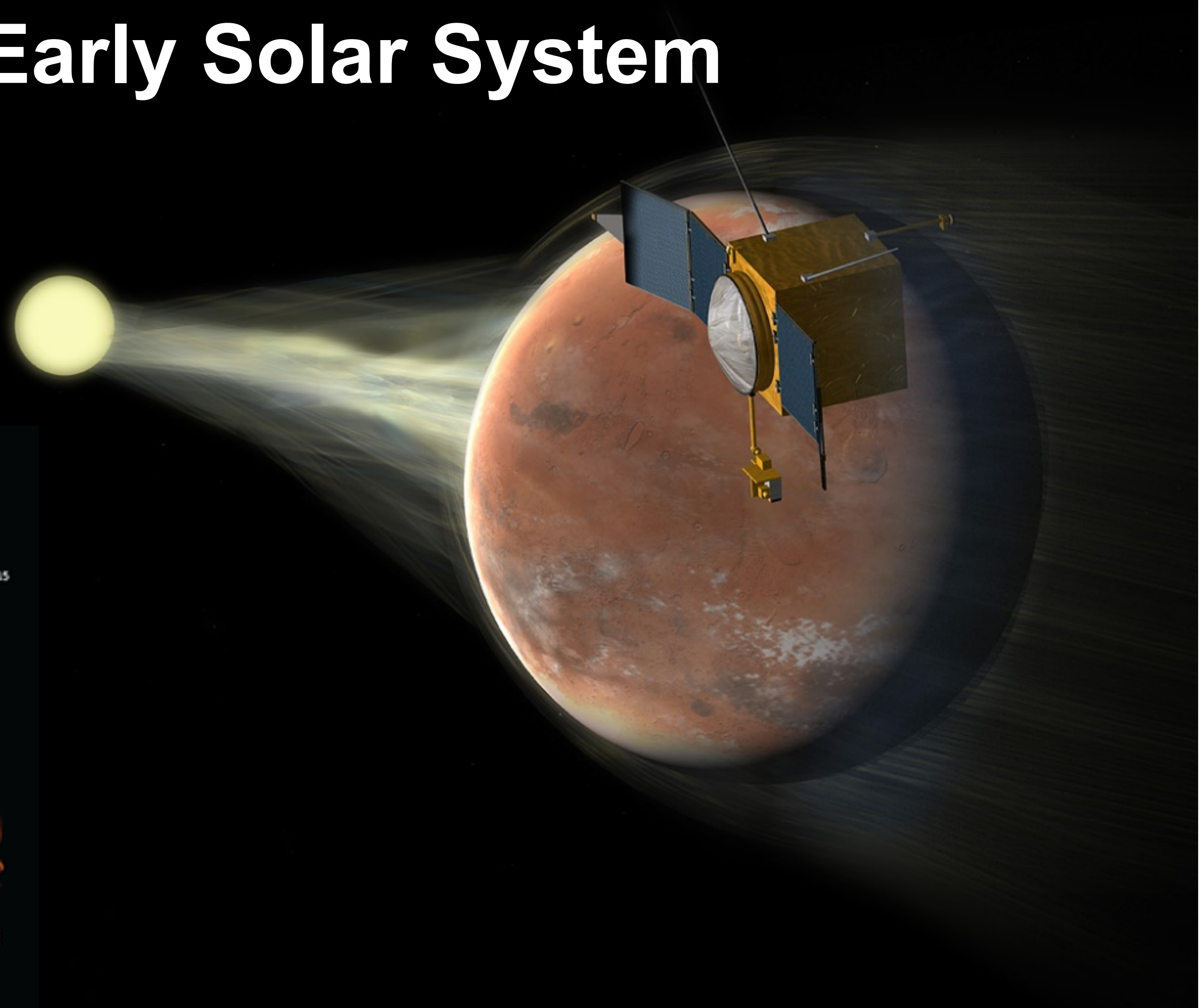
Extrasolar Space Weather

Is magnetic activity important for defining habitability?
Can we directly detect stellar flares, CMEs, planetary aurorae?

M Dwarfs – Implications of Activity

- 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
- Coronal mass ejections (CMEs) – higher stellar wind flux –> can erode atmosphere – eg. ion pick-up of a CO^2-rich atmosphere

The Early Solar System



Extreme Activity: M Dwarfs and Young Solar Analogs

Remote Sensing of CMEs

- Optical:

Remote sensing of coronal mass ejections (CMEs) is difficult

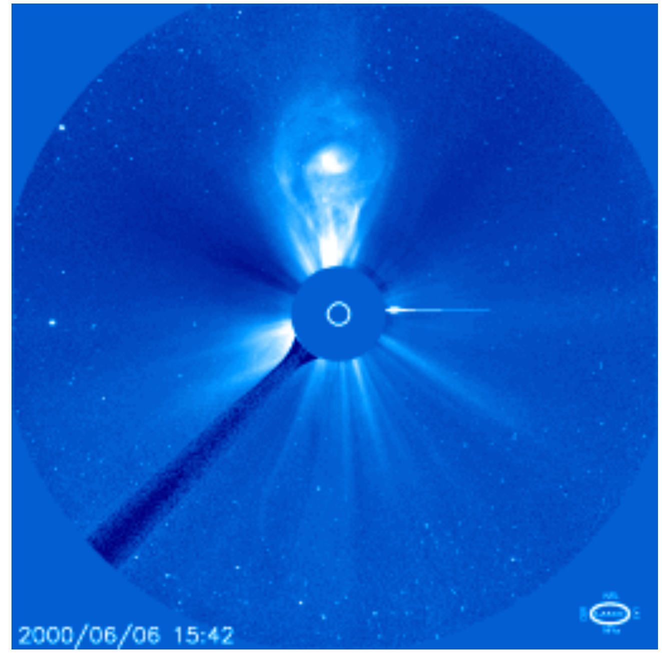
-Space-based coronographs observe Thomson scattered sunlight

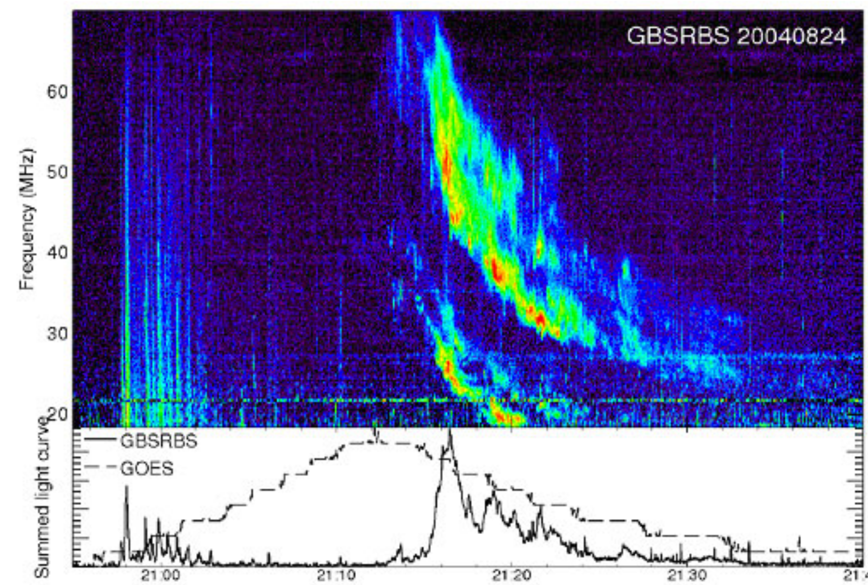
-**Radio:**

- The majority of fast CMEs are accompanied by Type II bursts – often highly circularly polarized

- Allows direct measurement of density, and an indirect measure of height in the atmosphere

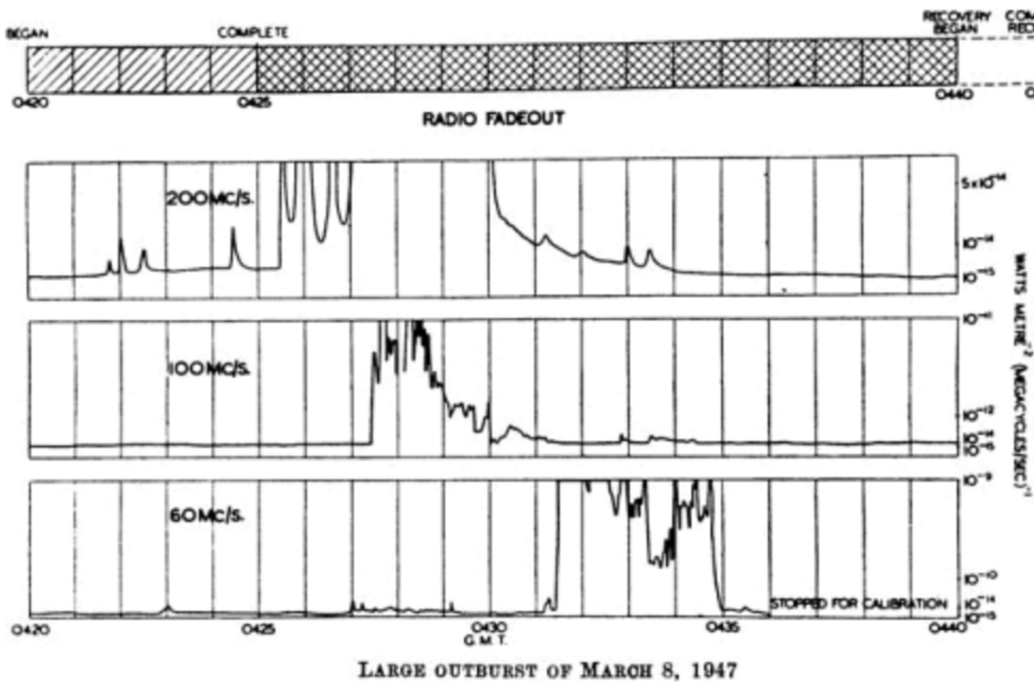
- Mostly observed at frequencies <150 MHz





Credit: Stephen White

Brightest Bursts from the Sun



Payne-Scott et al. Nature, 160, 256 (1947)

via “Under the Radar: The First Woman in Radio Astronomy: Ruby Payne-Scott” – Miller Goss

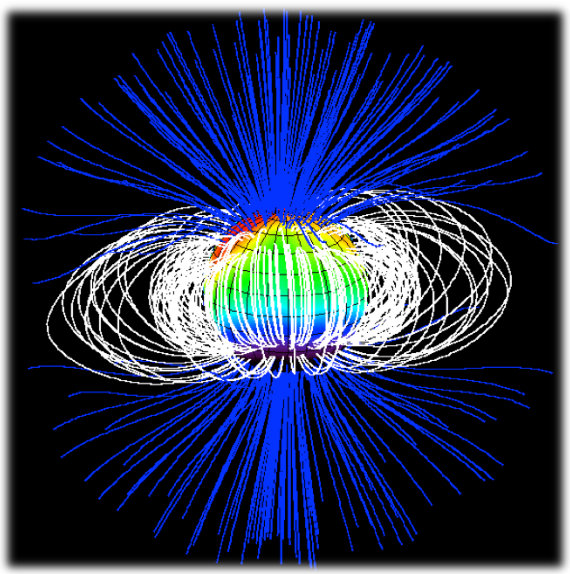
- Giant Type II burst detected in 1947

- >100 mJy at 5 pc!

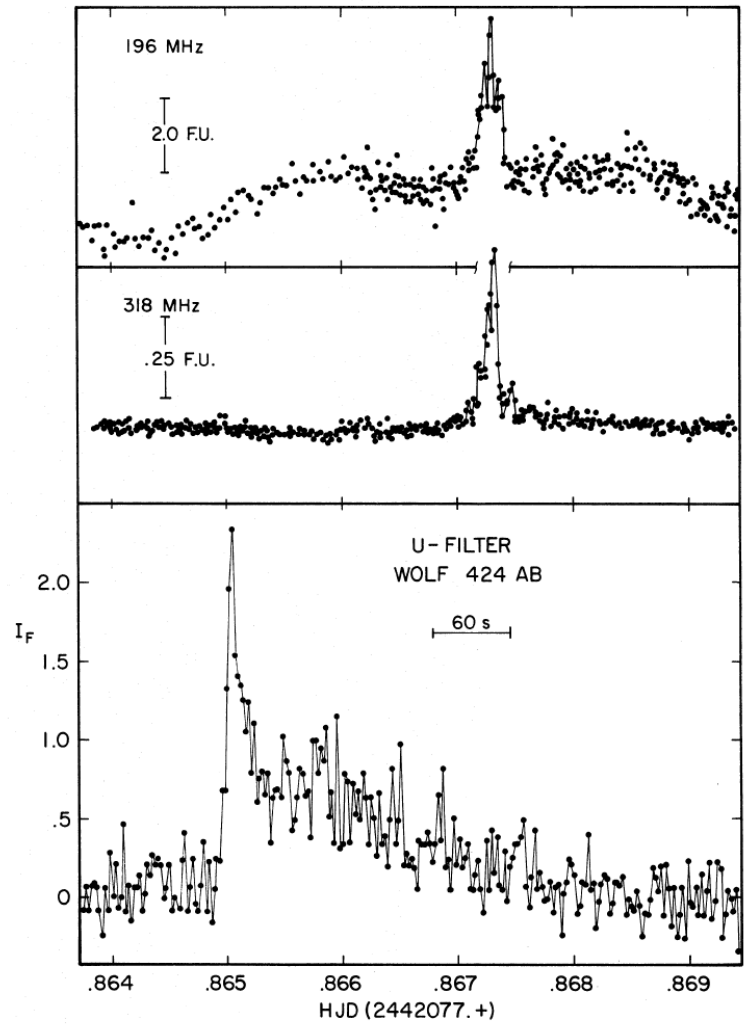
- Rare events

M dwarf radio bursts

- Strong evidence that M dwarfs produce very bright radio bursts
- Signatures of CMEs?
- Need broadband monitoring at low frequencies
- OVRO-LWA should see these bursts in the first 24-hour dataset.



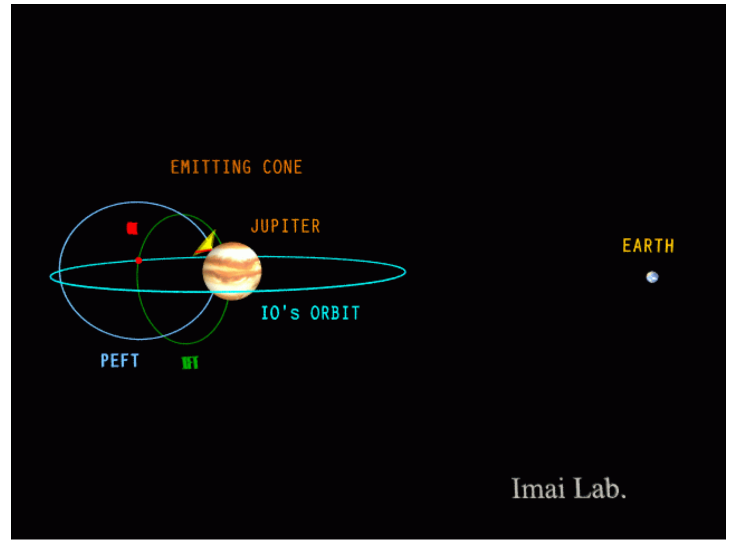
Donati et al. Science (2006)

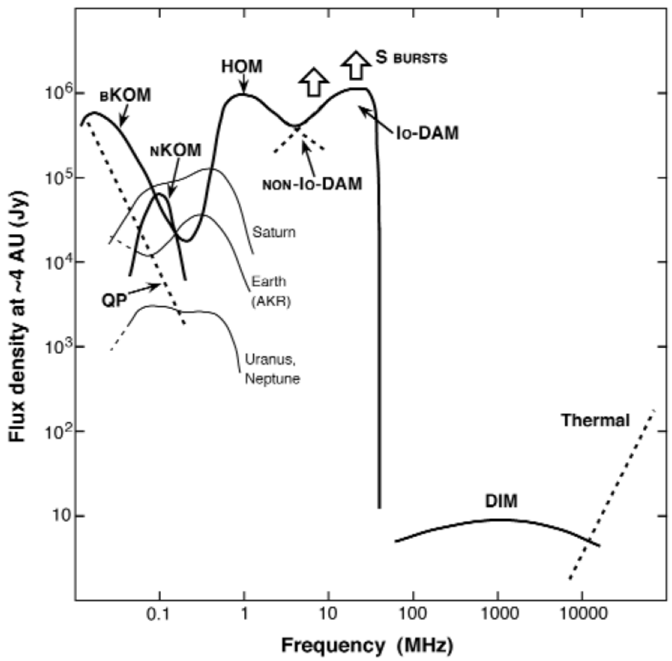


Spangler et al. (1976)

Radio Emission from Solar System Planets

- Jupiter detected as radio source in 1955
- 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?

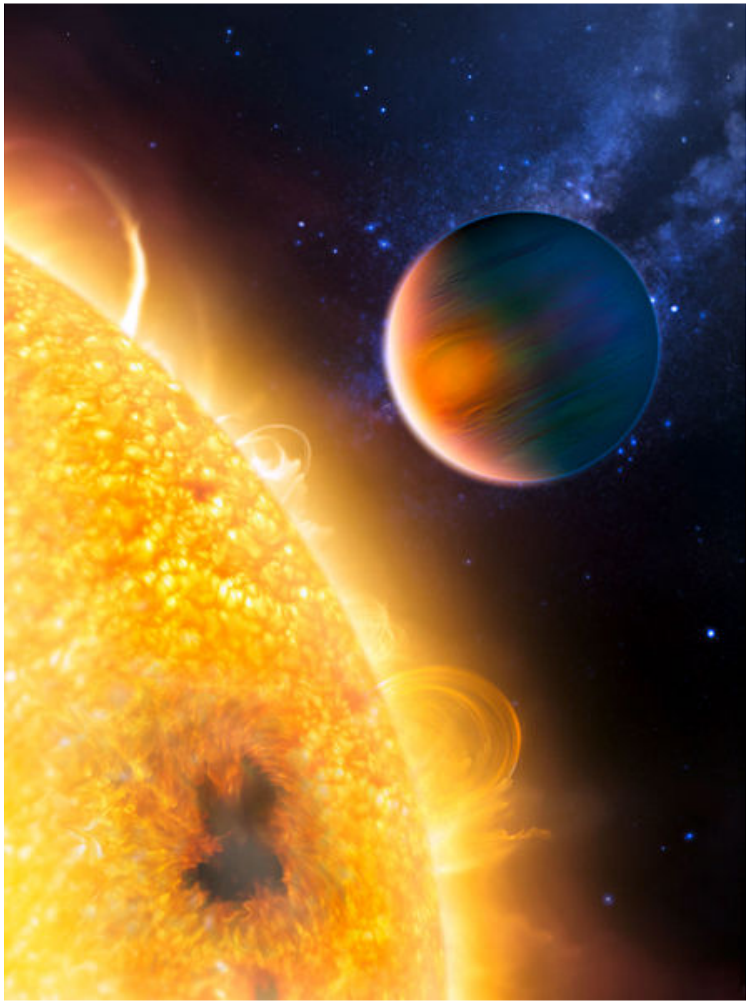
- The only method currently viable for measurement of magnetic field strengths for exoplanets.

- Allows measurement of rotation rate

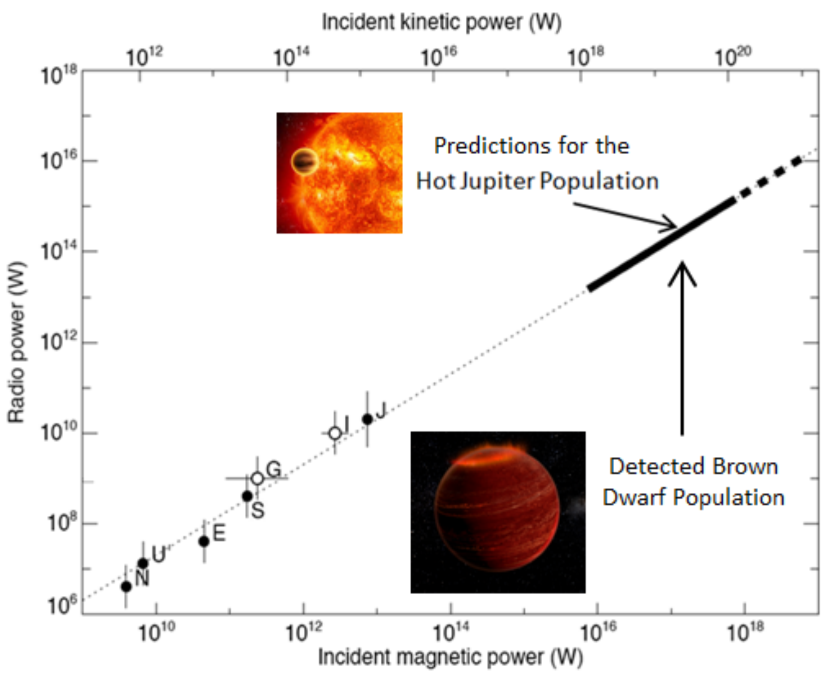
- Possible use as a detection method for exoplanets

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

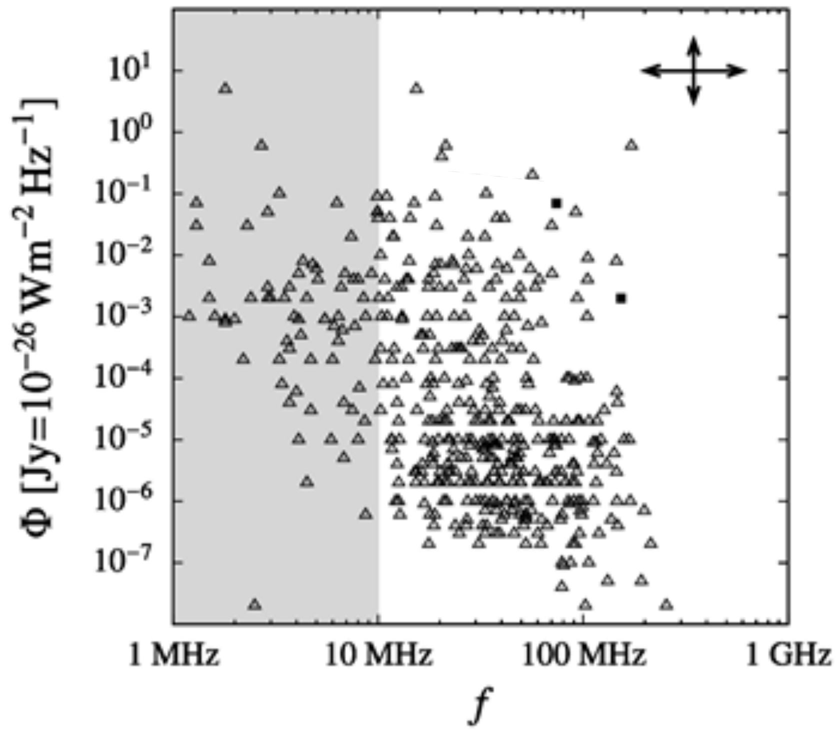
b) Provides insight into internal structure of planet.



Can we Detect Exoplanets?

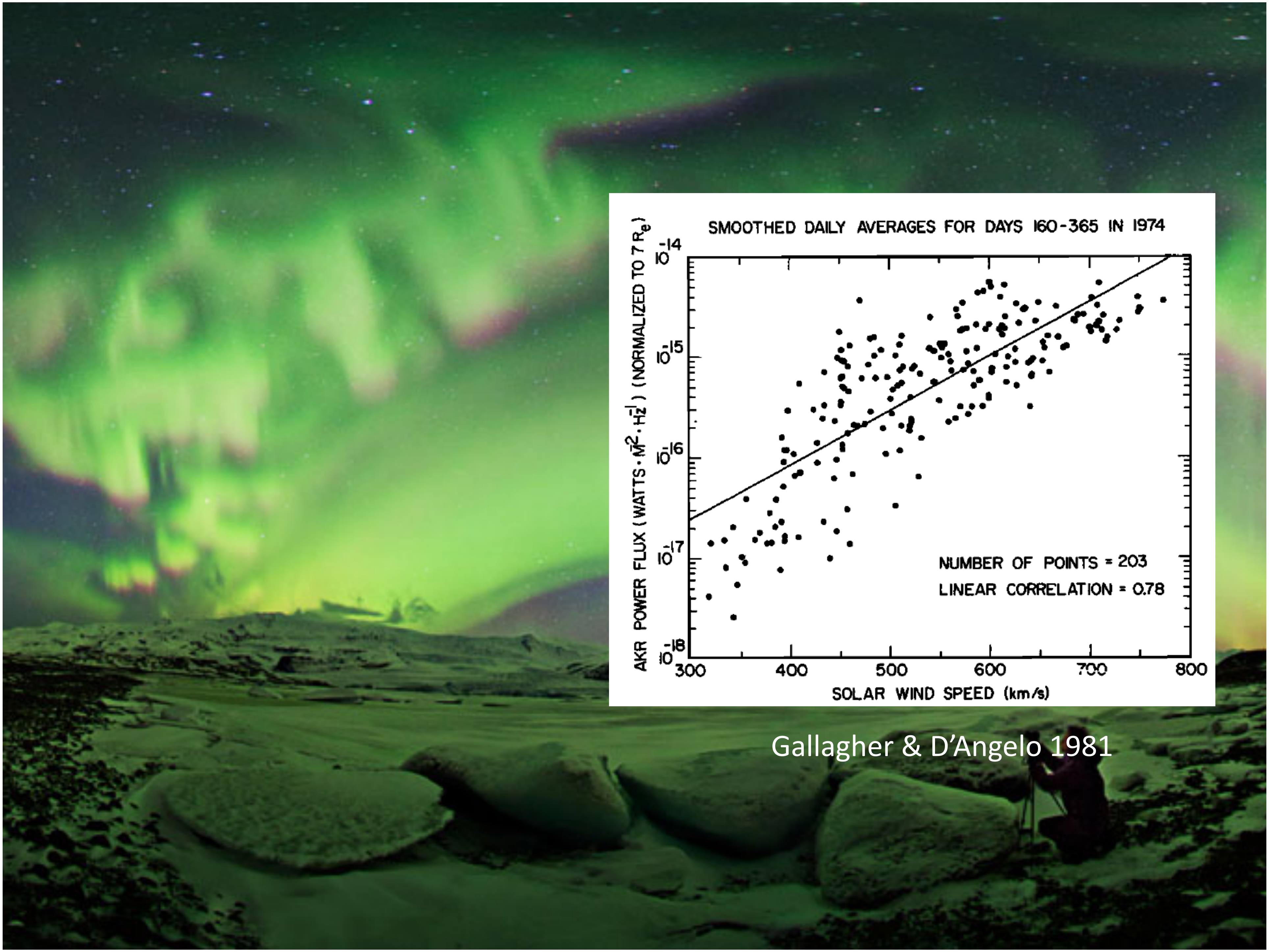


Adapted from Zarka (2007)

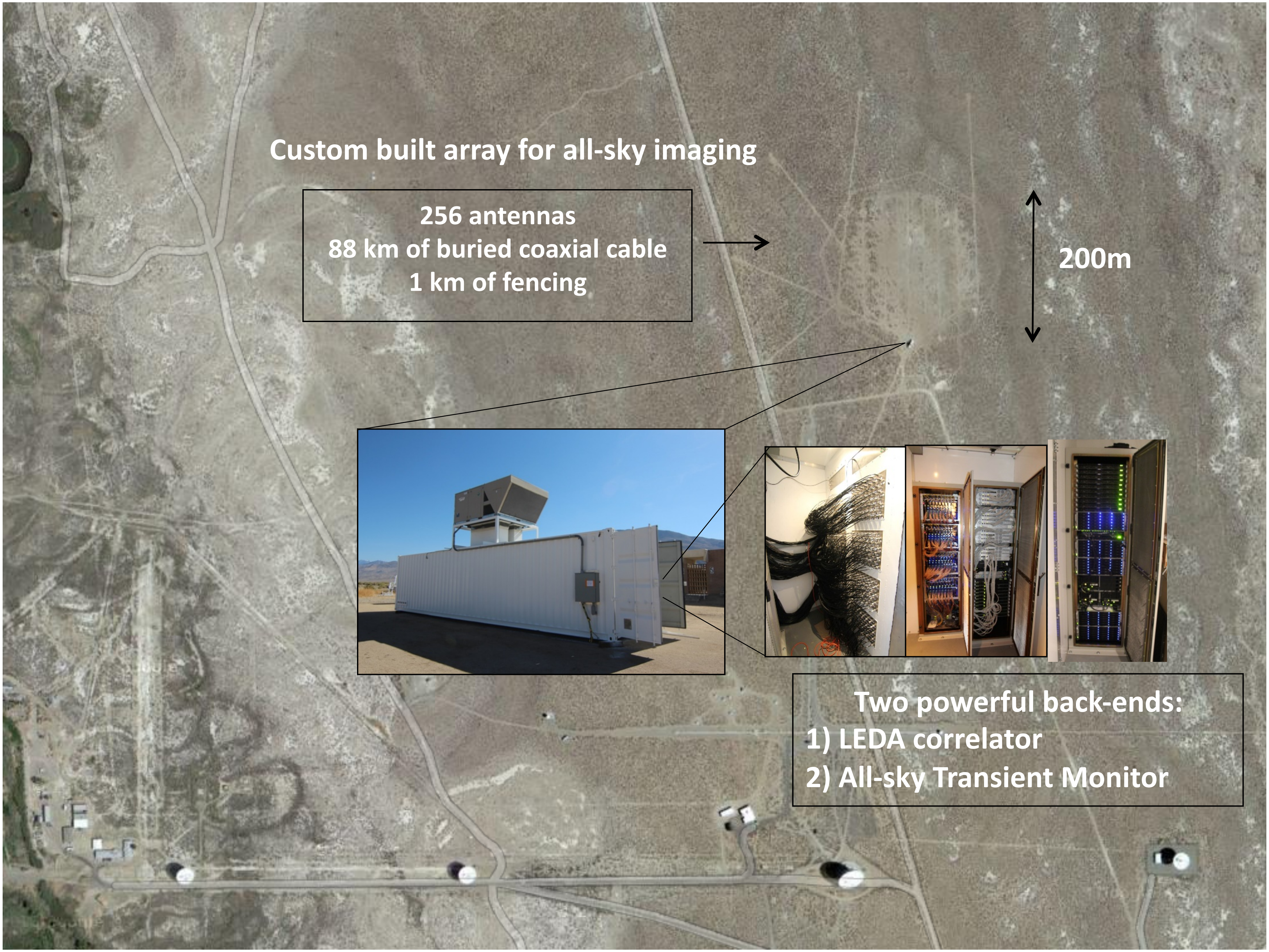


Greissmeier et al. (2007)

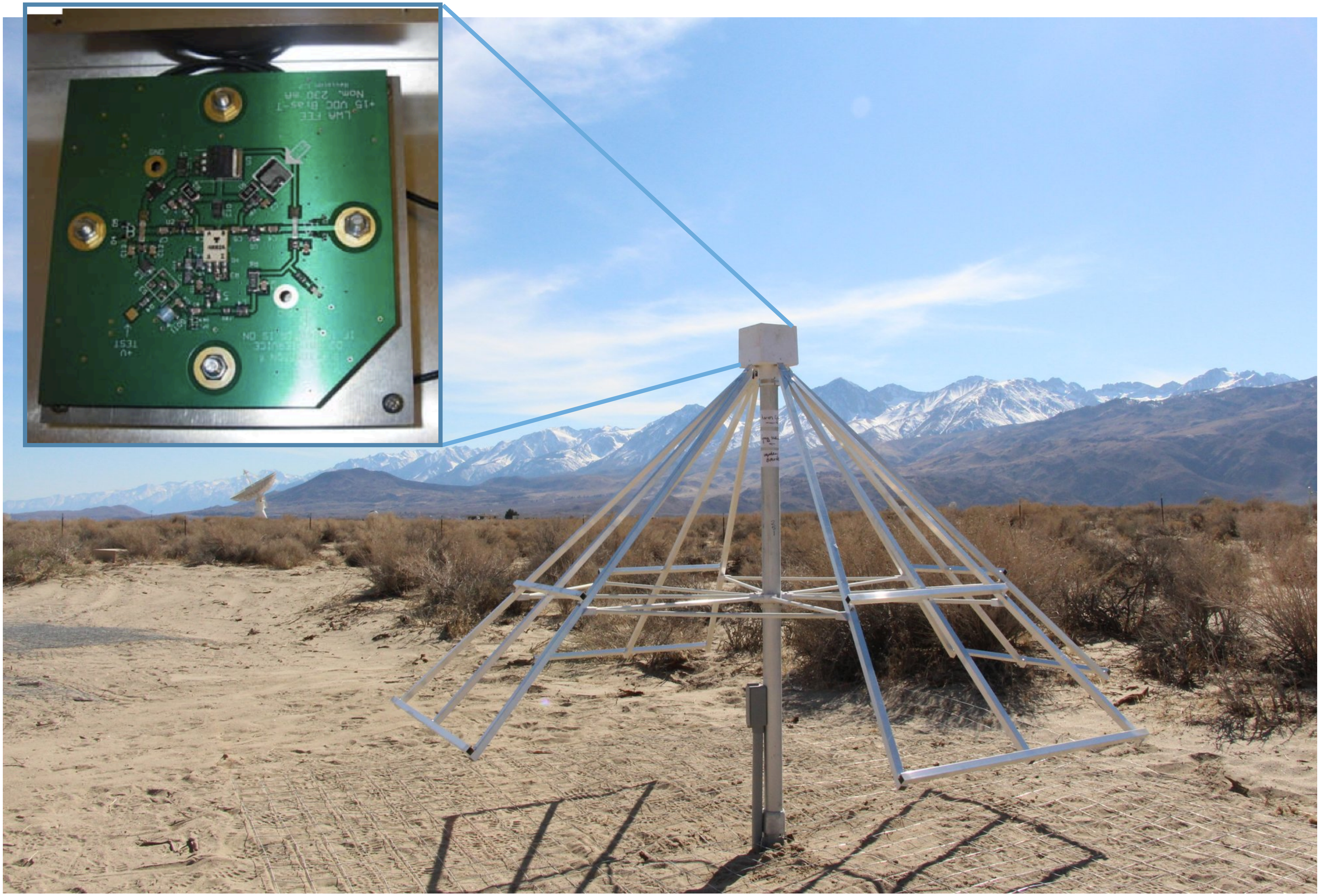
Searches have been ongoing for > 30 years – no detections

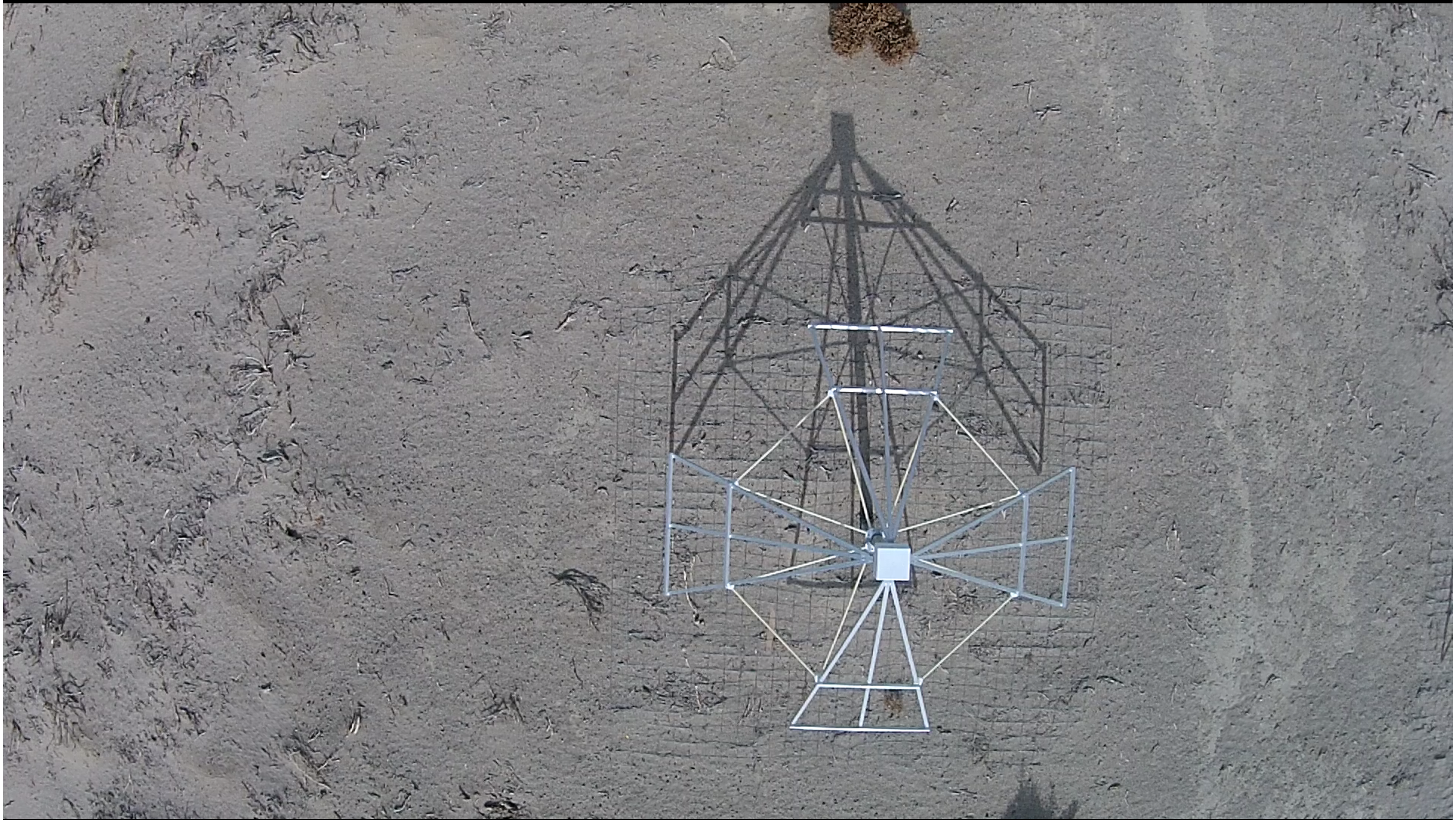


Gallagher & D'Angelo 1981

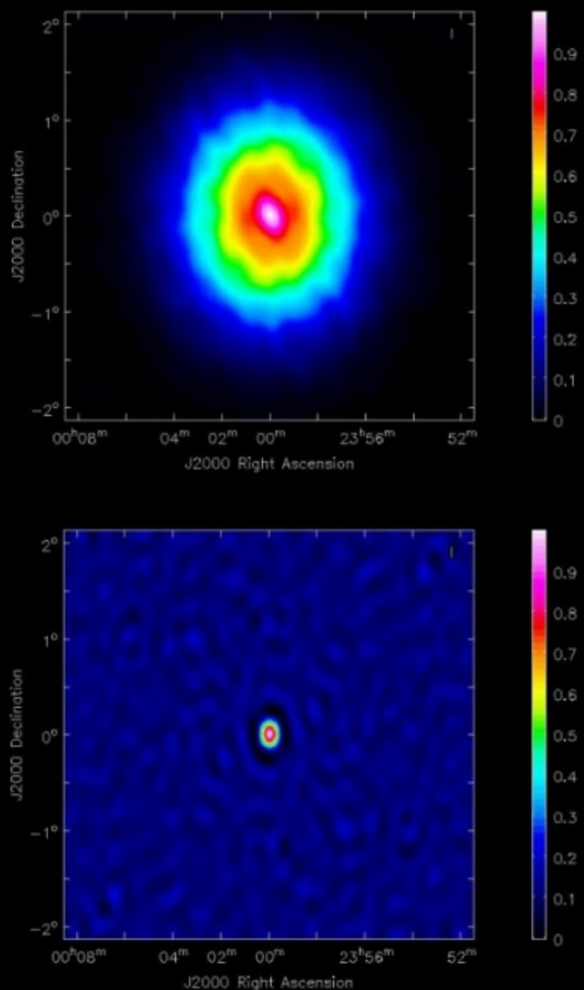

Custom built array for all-sky imaging
256 antennas
88 km of buried coaxial cable
1 km of fencing
200m
Two powerful back-ends:
1) LEDA correlator
2) All-sky Transient Monitor

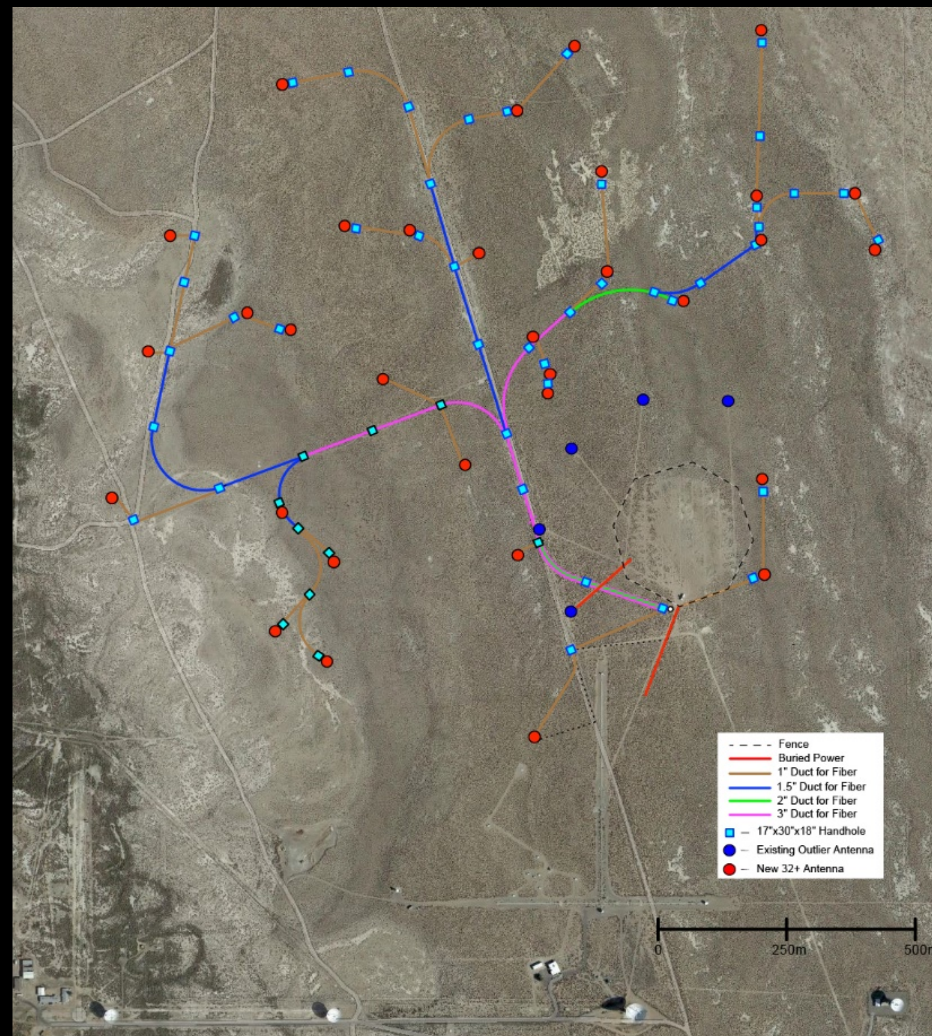
Antenna and Front-end



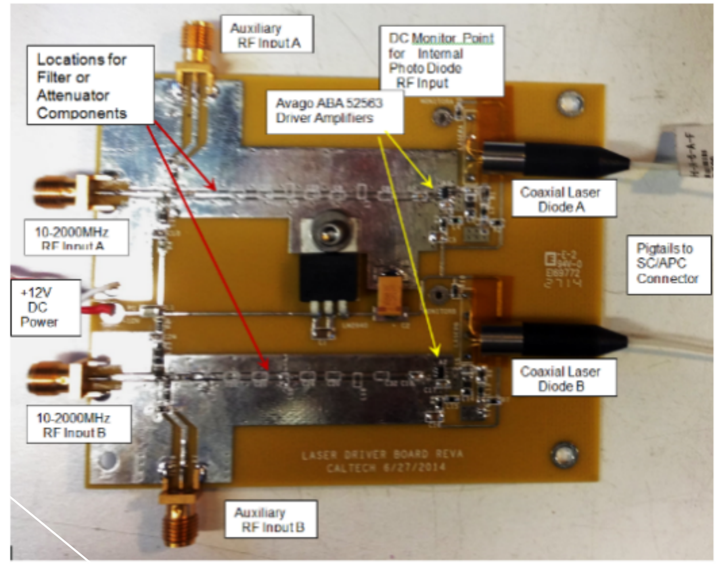


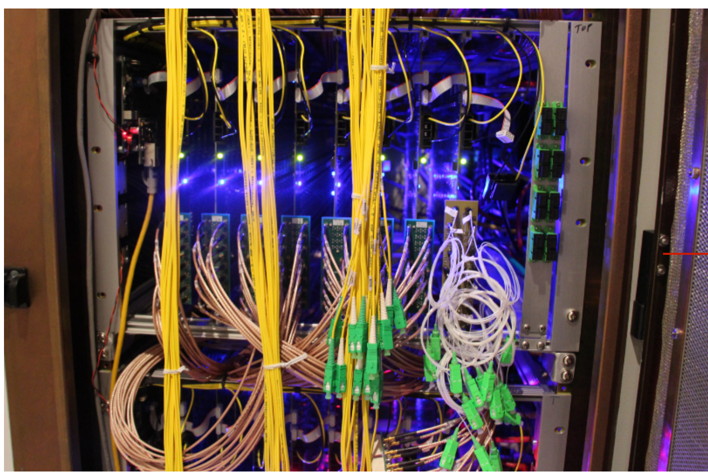
Longer baselines – 2015

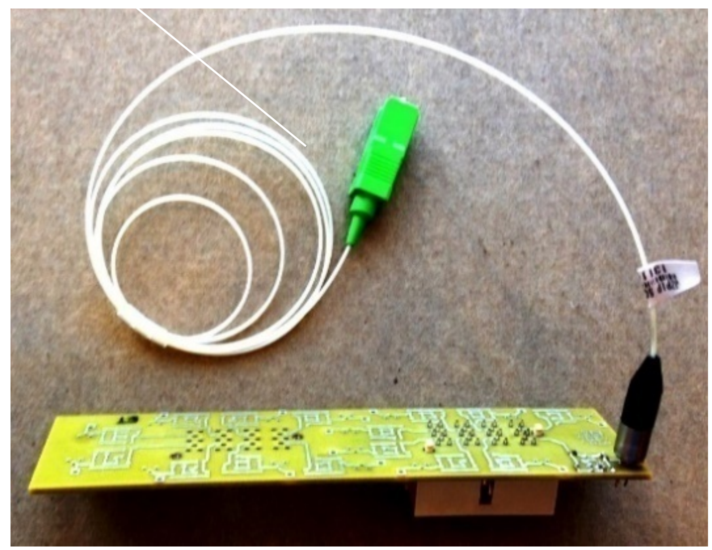




Longer baselines – 2015







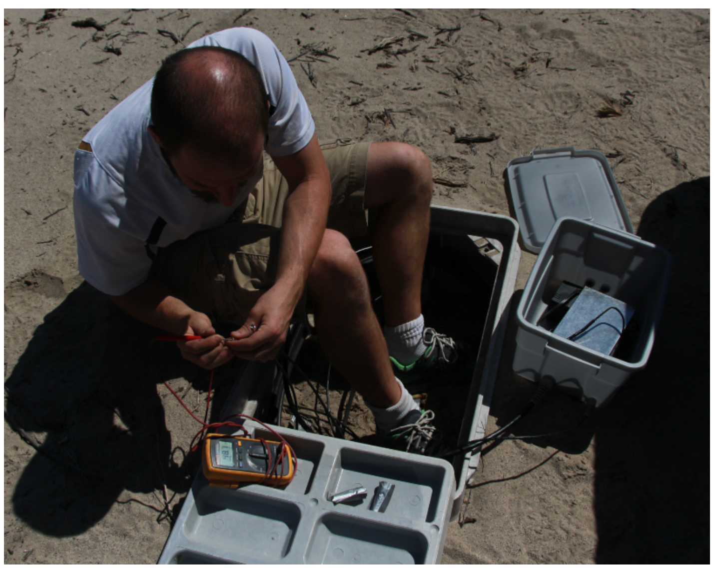
Custom fiber links designed by Sandy Weinreb and his group
– cost per antenna now <$100 (vs $2000 for commercial hardware)

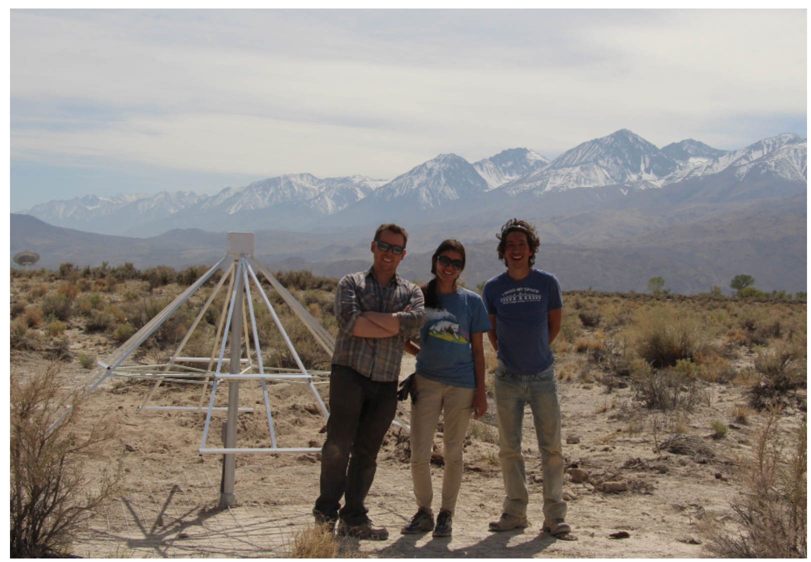
Longer baselines – 2015

- Large network of conduit holding 43 km of optical fiber

- 6 fibers at each “station”

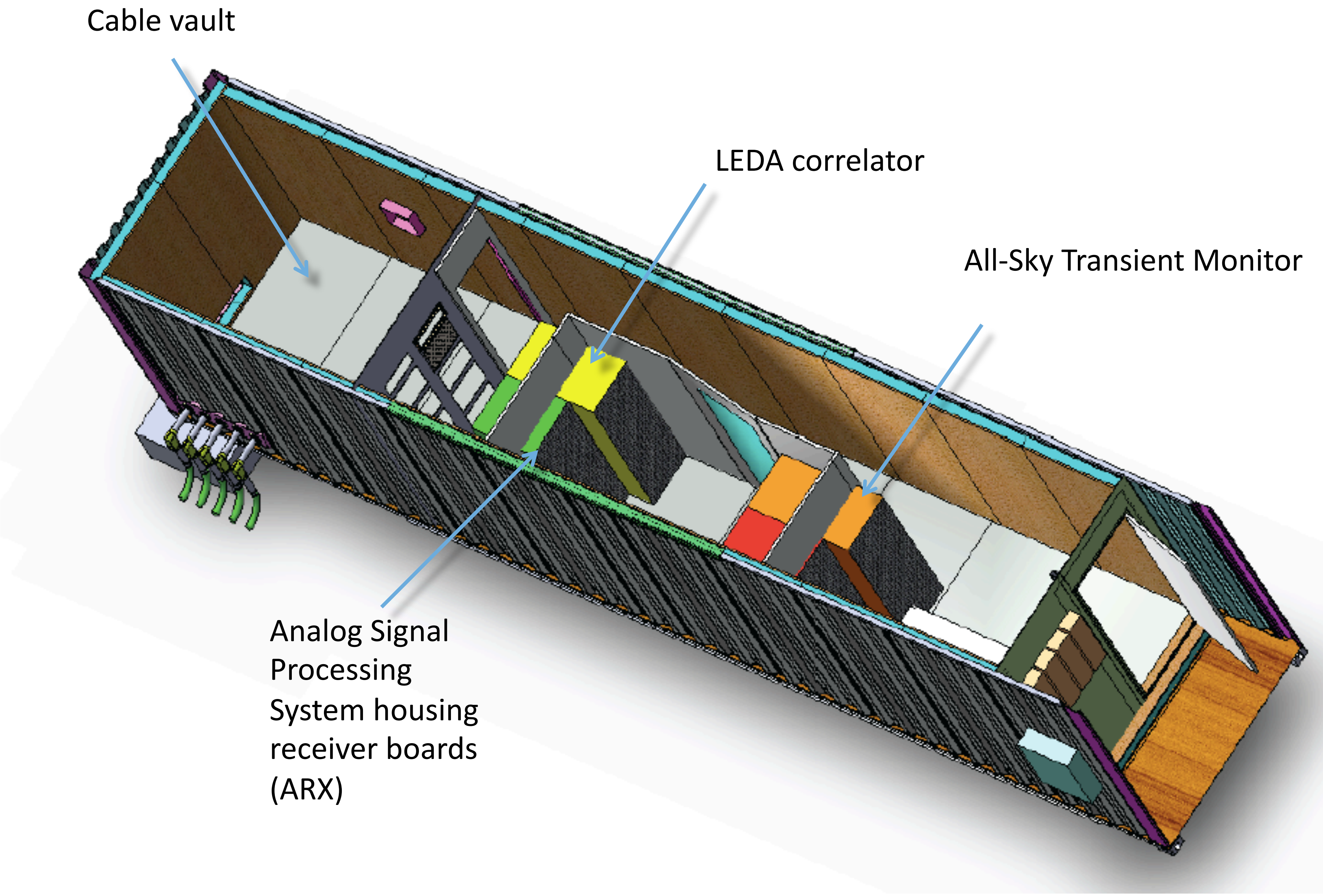
Longer baselines – 2015



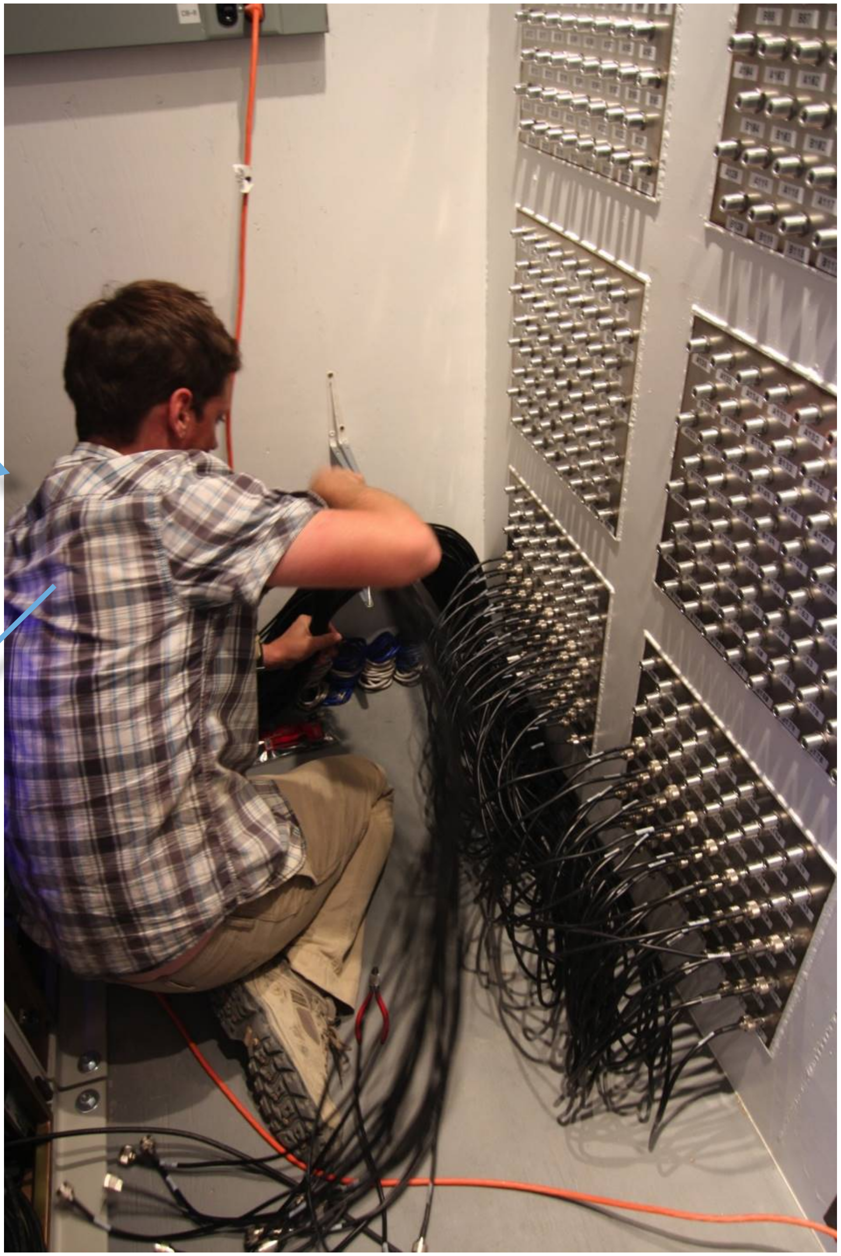


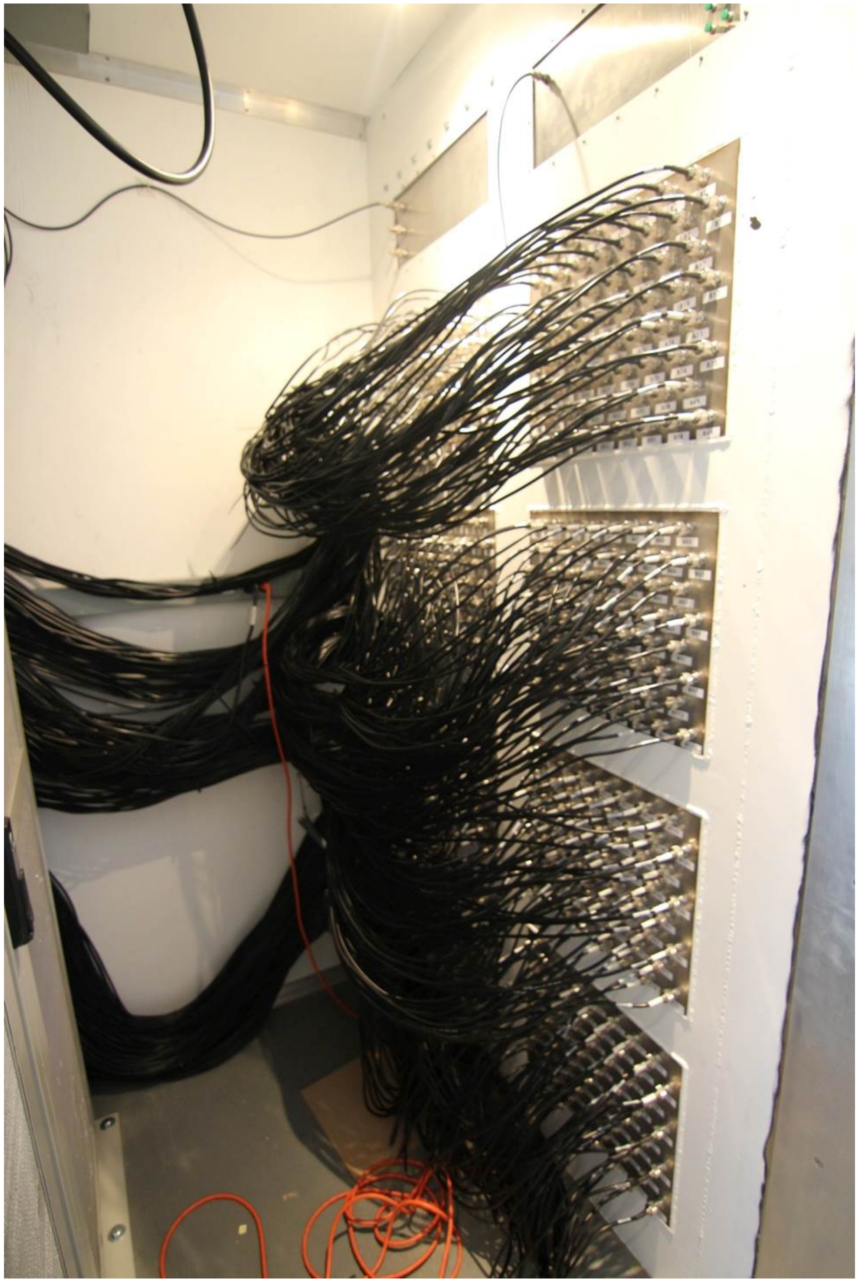
Electronics Shelter

Electronics Shelter



Connecting it all together…





Large Aperture Experiment to Detect the Dark Age (LEDA)

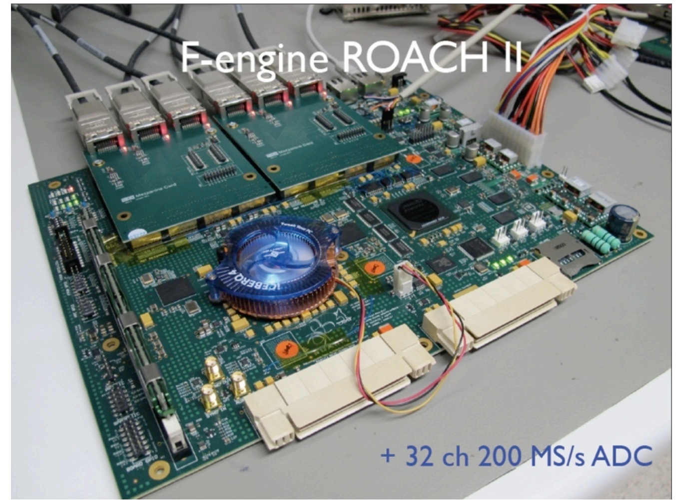
- FX correlator with 512 inputs (PIs: Lincoln Greenhill, Dan Werthimer, Greg Taylor, Steve Ellingson)

- 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.



The All-Sky Transient Monitor

- **208 CPU cores, 1 TB of RAM, 288 TB of high speed storage**

- **Each snapshot with LWA is 2.7 GB data!**

- **9 second integrations -> 27 TB/day**

- **How do we handle this fire hose of data?**

- ***There are key advantages over other arrays***

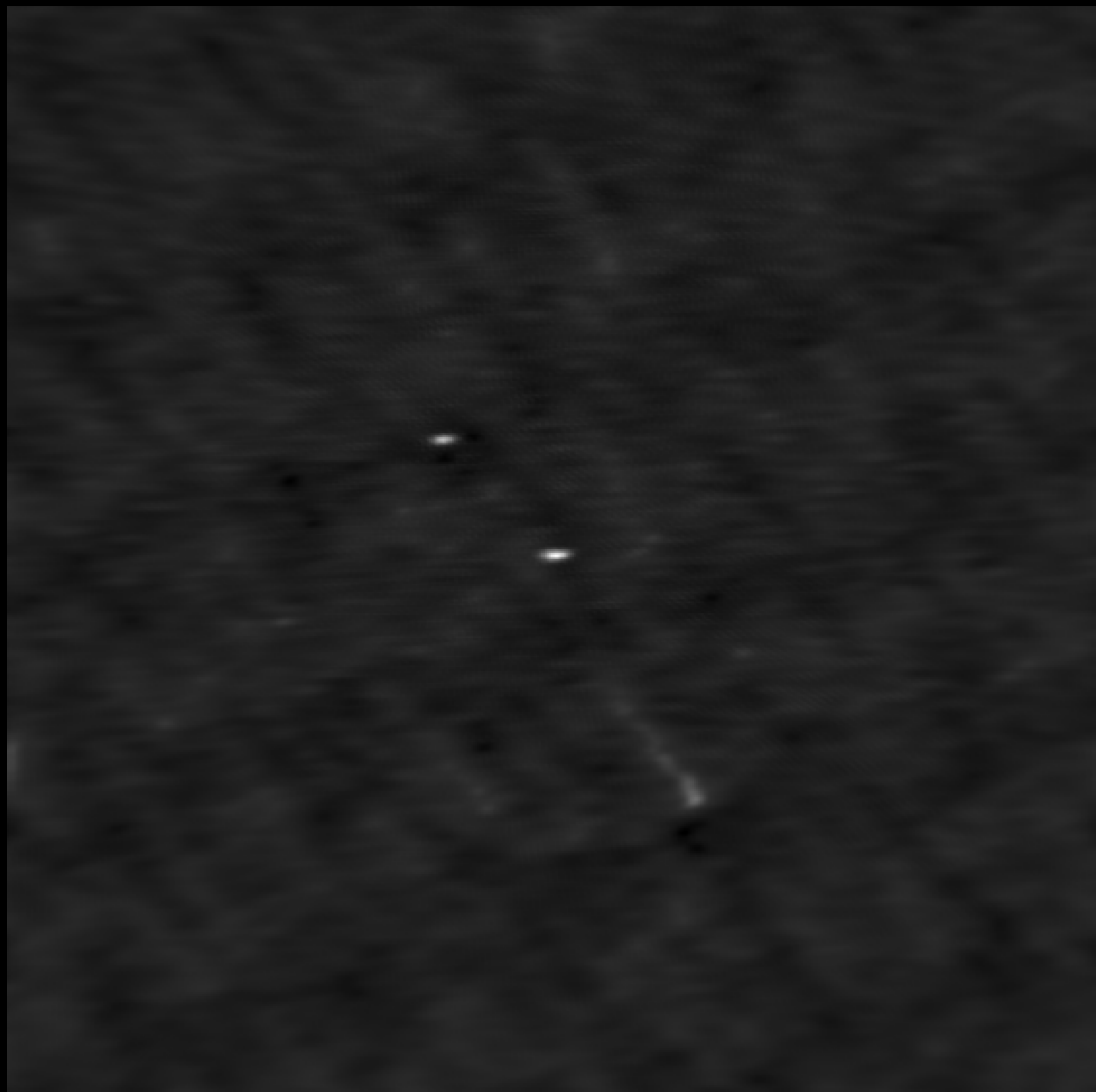
- ***Array is compact***

- ***Array is stationary***

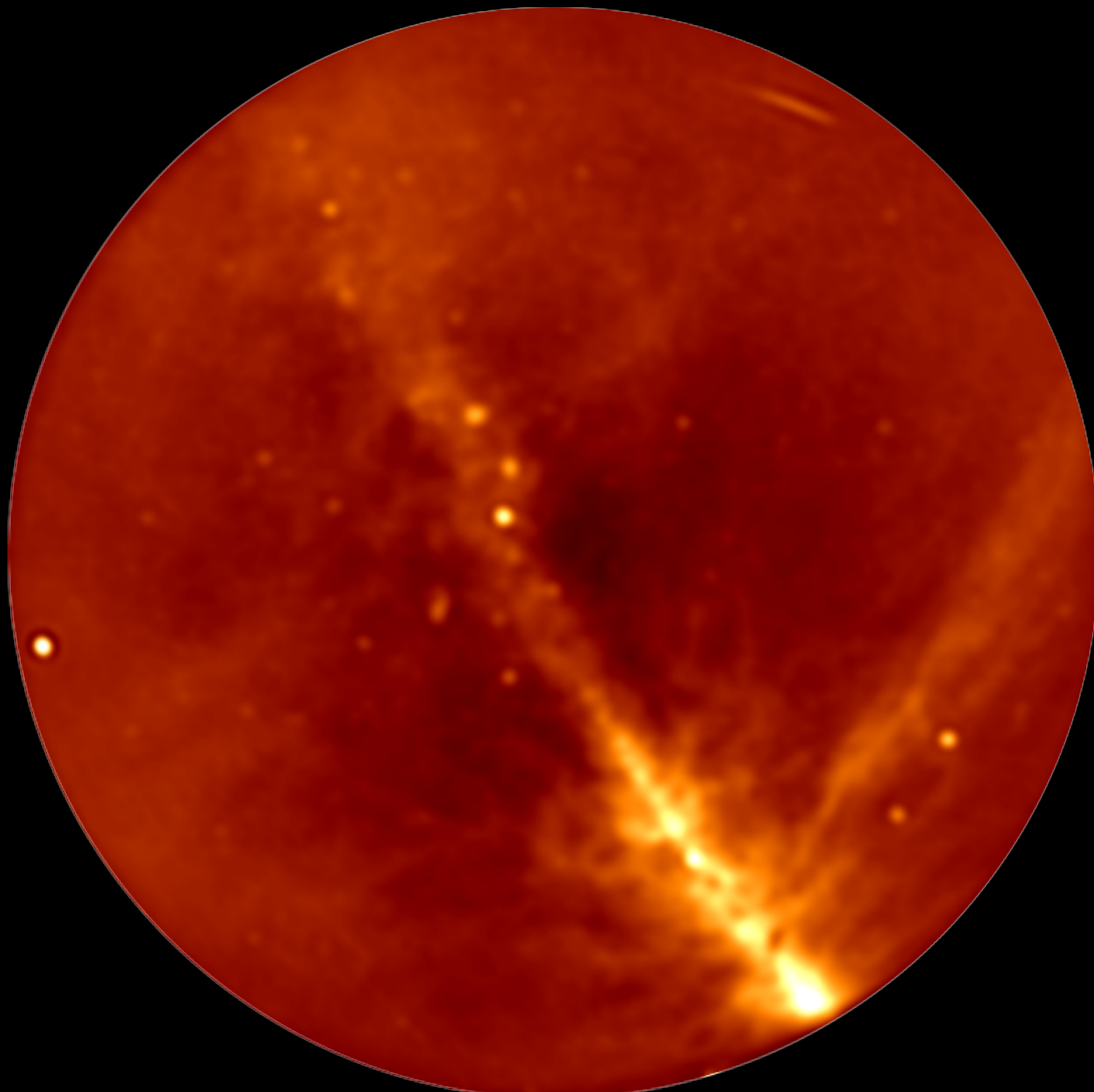
- ***Data is homogeneous***

- ***Most calibration parameters are either non-varying (antenna beam), varying very slowly (electronic gain) or varying sidereally (sky), aside from ionosphere!***

Core First Light

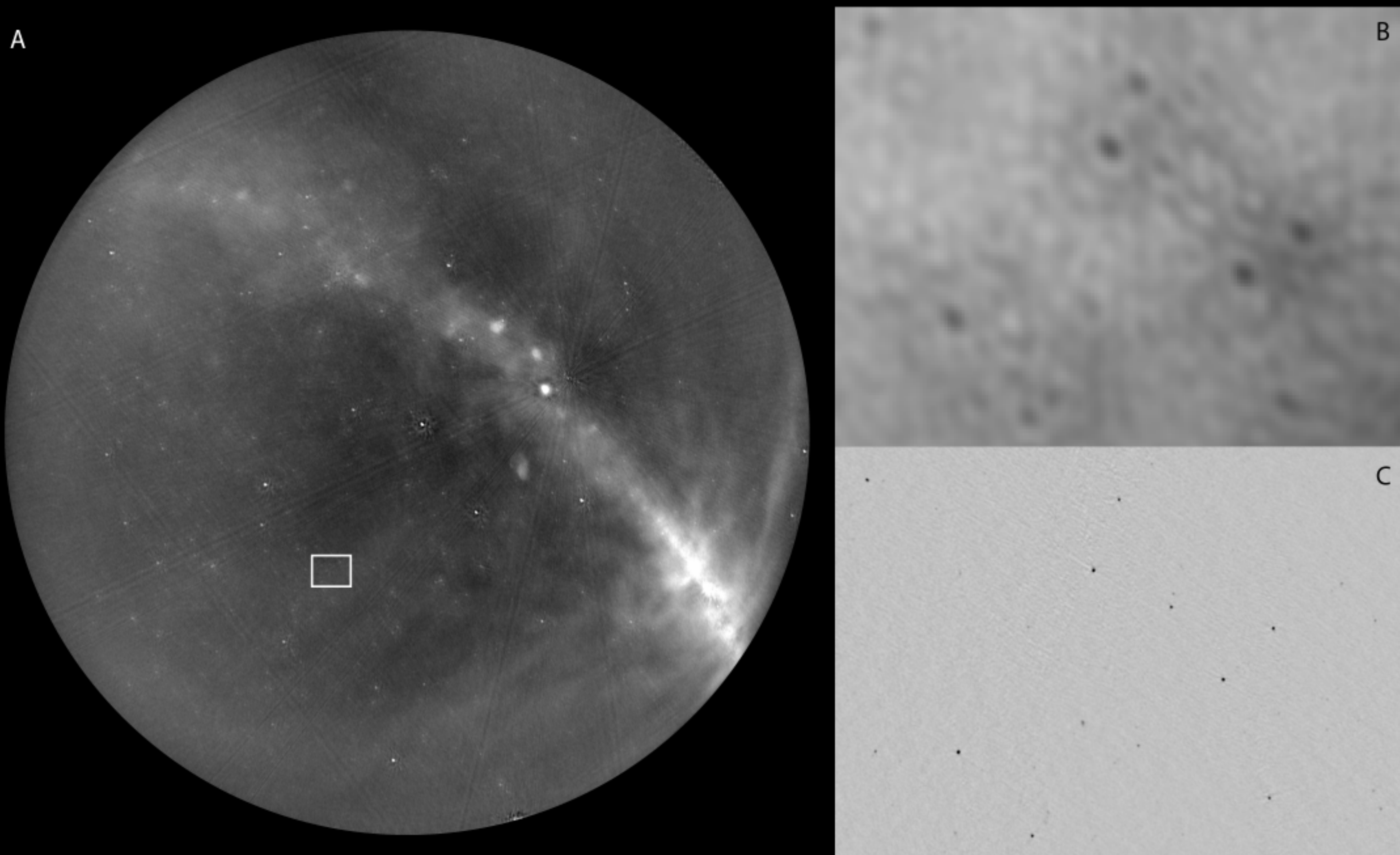


Current Core Imaging Capability



- 30 second snapshot with ~40 MHz bandwidth
- Confusion limit is ~few Jy
- Thermal noise is ~ 70 mJy
- Reach confusion noise in <0.1 seconds!

Long Baselines First Light!

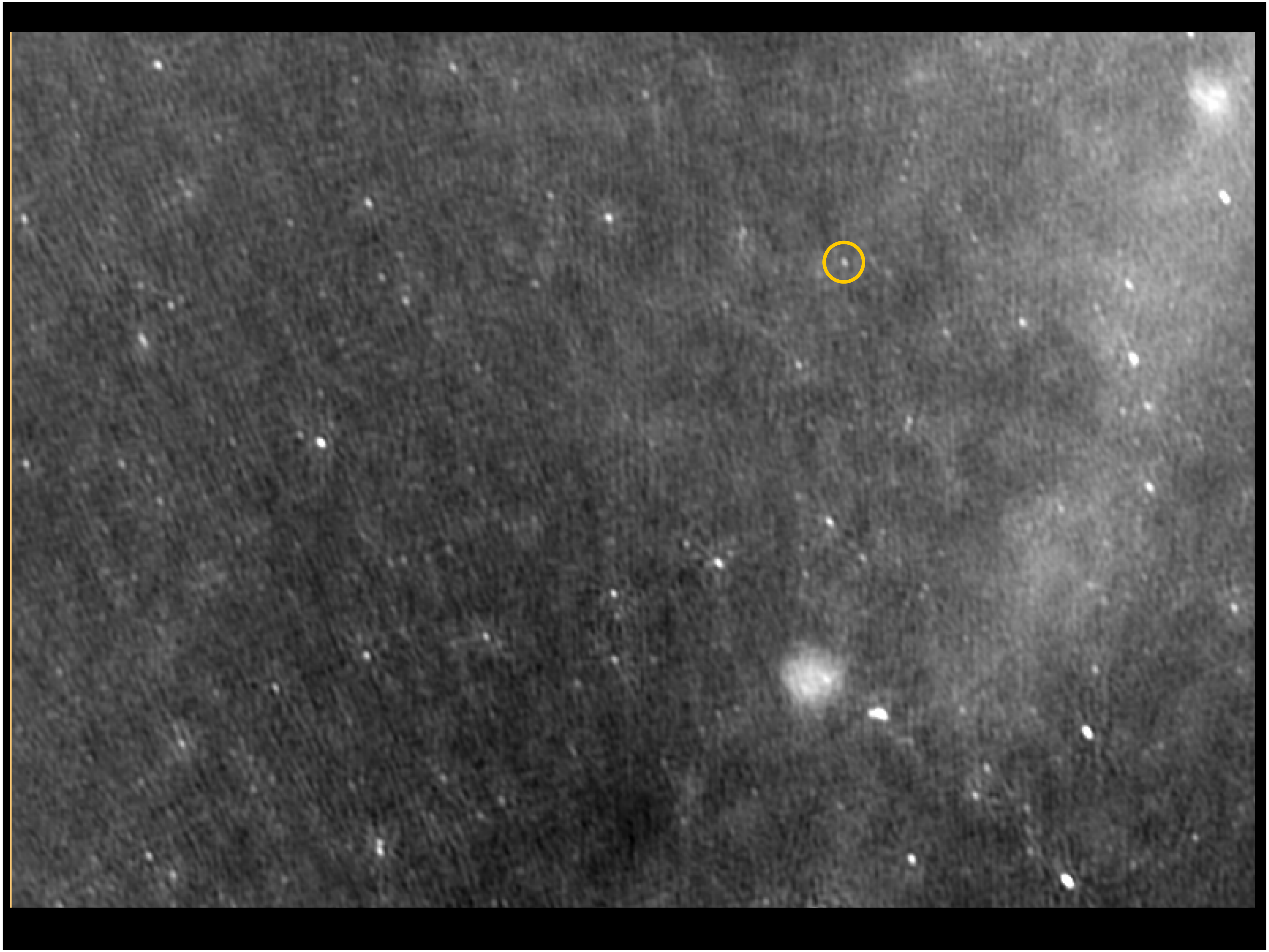


LOFAR MSSS: Detection of a low-frequency radio transient in 400 hrs of monitoring of the North Celestial Pole

A. J. Stewart,[1,2⋆] R. P. Fender,[1,2] J. W. Broderick,[1,2,3] T. E. Hassall,[1,2] T. Muñoz-Darias,[4,5,1,2]

ABSTRACT

We present the results of a four-month campaign searching for low-frequency radio transients near the North Celestial Pole with the Low-Frequency Array (LOFAR), as part of the Multifrequency Snapshot Sky Survey (MSSS). The data were recorded between 2011 December and 2012 April and comprised 2149 11-minute snapshots, each covering 175 deg^2. We have found one convincing candidate astrophysical transient, with a duration of a few minutes and a flux density at 60 MHz of 15–25 Jy. The transient does not repeat and has no obvious optical or high-energy counterpart, as a result of which its nature is unclear. The detection of this event implies a transient rate at 60 MHz of $3.9^{+14.7}_{-3.7} \times 10^{-4}$ day^{-1} deg^{-2}, and a transient surface density of 1.5×10^{-5} deg^{-2}, at a 7.9-Jy limiting flux density and $\sim$ 10-minute time-scale. The campaign data were also searched for transients at a range of other time-scales, from 0.5 to 297 min, which allowed us to place a range of limits on transient rates at 60 MHz as a function of observation duration.



Summary and Status

- 288-antenna Owens Valley LWA is complete

- Produces all-sky images every 9 seconds with ~10 arcminute resolution

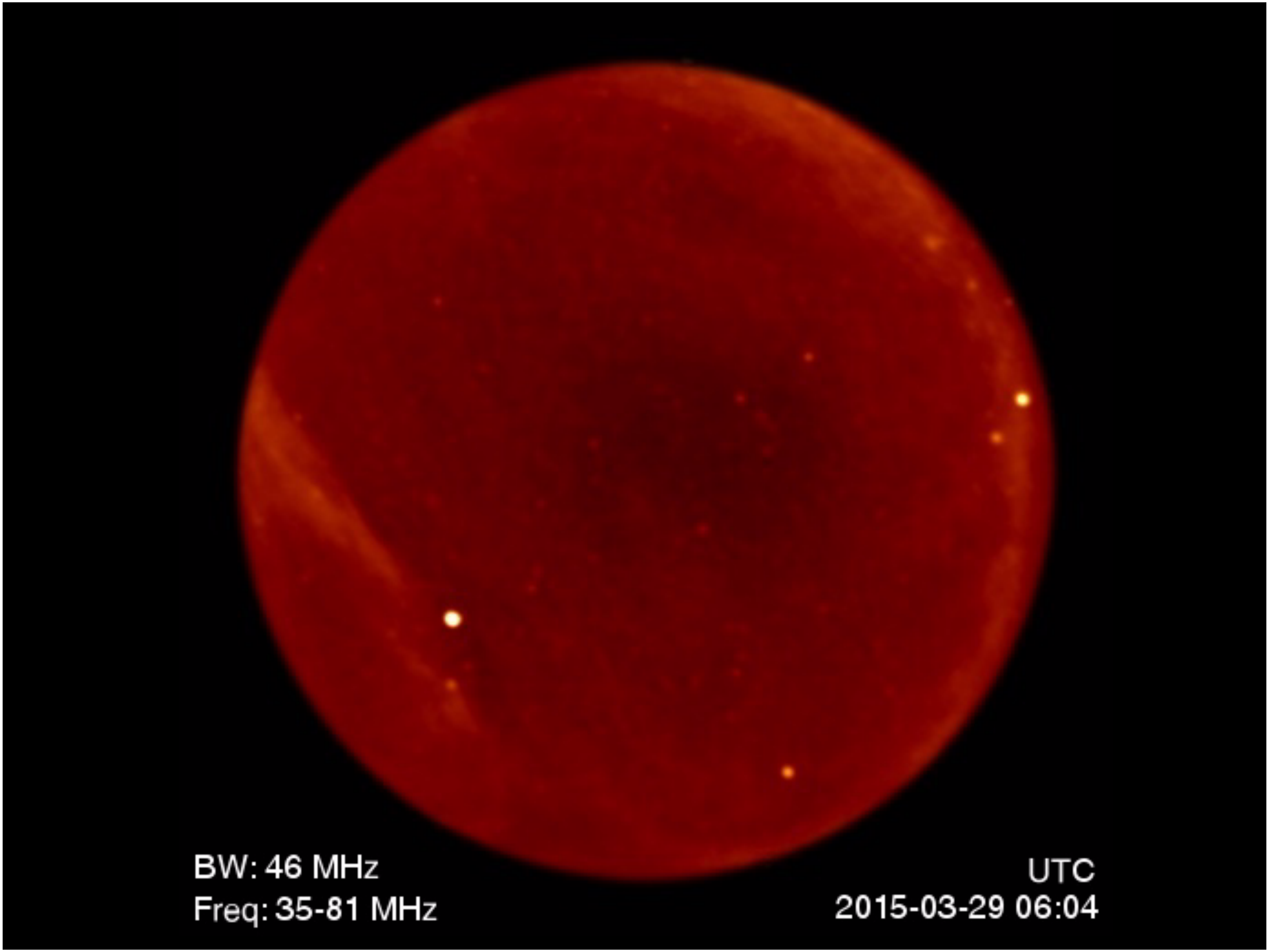
- Remaining 64 antennas proposed via NSF ATI in 2015

-10-day survey with core array completed in July 2015

- 3-day survey with full array completed in September 2015

- Instrument paper and early science coming in early 2016!

- Continuous observations commence in January 2016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Freq: 35-81 MHz
UTC
2015-03-29 06:04