Imaging the Sun with The Murchison Widefield Array

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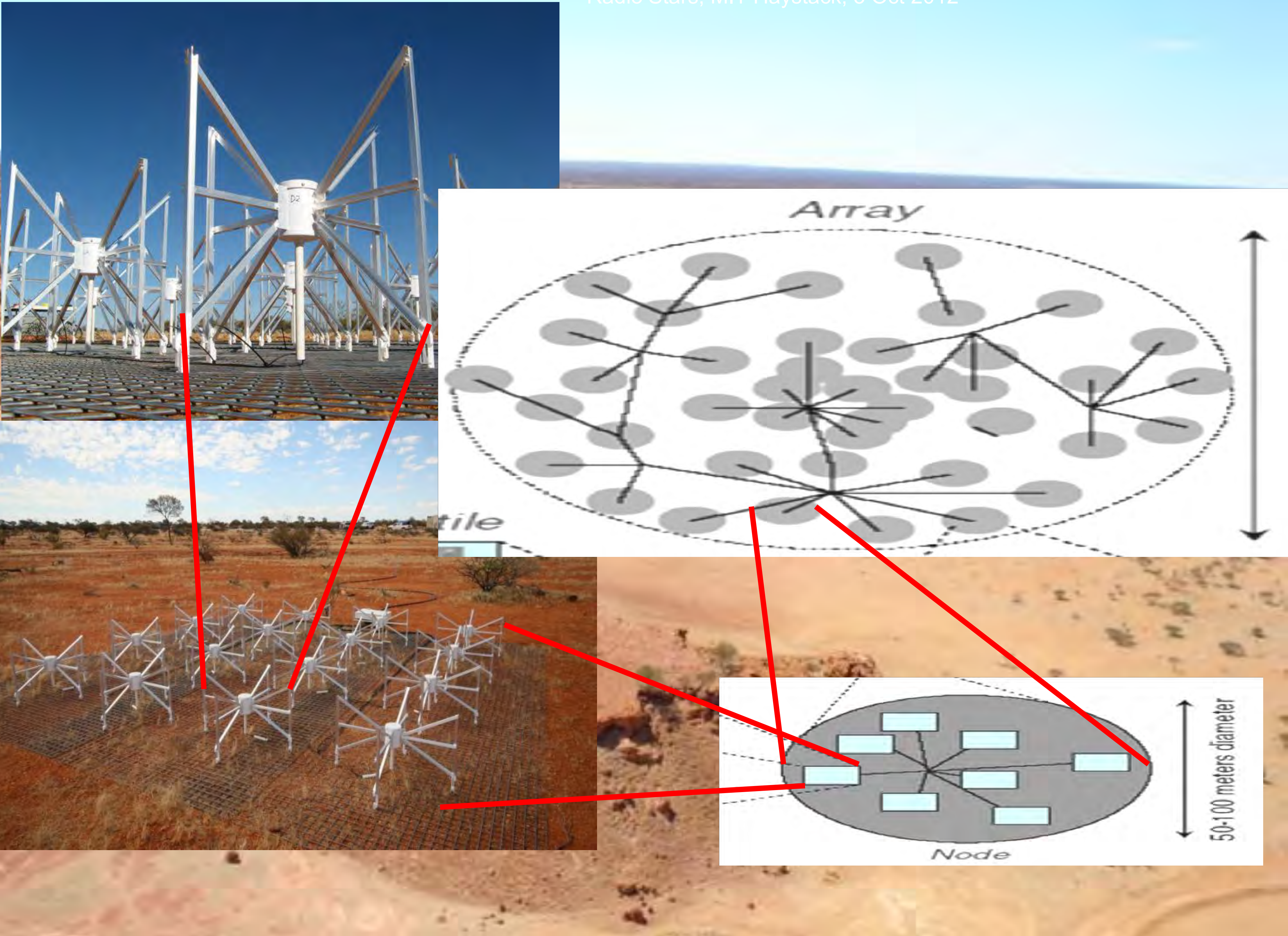
Outline

- MWA – A quick overview
- Key design aspects
  - Suitability for solar imaging
- Current status and near term plans
- A flavor for MWA solar data
  - The 32T MWA Prototype
  - The Alpha Array commissioning data
- Some solar science snippets from these data

Murchison Widefield Array

- A radio interferometer
- 80-300 MHz
- Located in Murchison region of the Western Australian Outback
- 128 elements
- Heavily centrally condensed array layout, max. baseline ~3km
- 30.72 MHz bandwidth (24 * 1.28 MHz)
- Nearing completion


Array
tile
Node
50-100 meters diameter

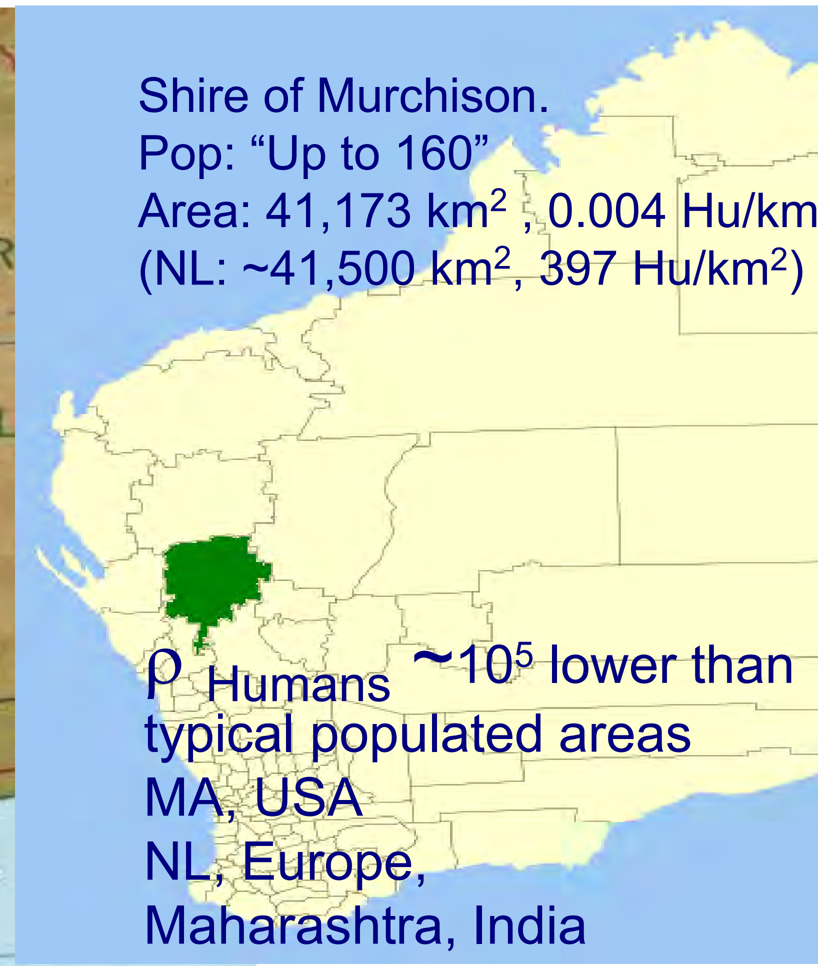
MWA: Key Science Projects

- Epoch of Reionization
  - 21 cm hyperfine transition line of neutral hydrogen, red-shifted to frequencies below 200 MHz
  - Flagship science application, very challenging
- Galactic and Extra-galactic Science
  - Confusion limited all-sky survey with full polarimetry and good spectral resolution
- Time domain astrophysics
  - Known and not yet known transients
- Solar, Heliospheric and Ionospheric Science
  - Spectroscopic solar imaging
  - IPS and Faraday rotation studies of the Heliosphere
  - Ionospheric propagation effects

MWA: Design Philosophy

- Exploit the advances in digital signal processing and affordability of computing
- Optimize the design for a few key science areas
- Emphasis on quality calibration
- Reduce the complexity of the problem
  - Small array footprint
  - Start at higher end of the low frequency band
  - Low RFI environment
  - ‘Simple’ hardware design
  - Stable system performance

Exquisitely Radio Quiet Site



Shire of Murchison.
Pop: “Up to 160”
Area: 41,173 km^2 , 0.004 Hu/km^2
(NL: ~41,500 km^2, 397 Hu/km^2)

ρ_{Humans} ~10^5 lower than typical populated areas
MA, USA
NL, Europe,
Maharashtra, India

The Challenge of Solar Imaging

Nature of the problem

- Large angular size and complex morphology
- Large range in inherent brightness temperatures of features (~10^5 K -10^{12} K)
- Time variability on very short time scales (~10s of ms)
- Spectral structure and variability on scales (~10s of kHz)

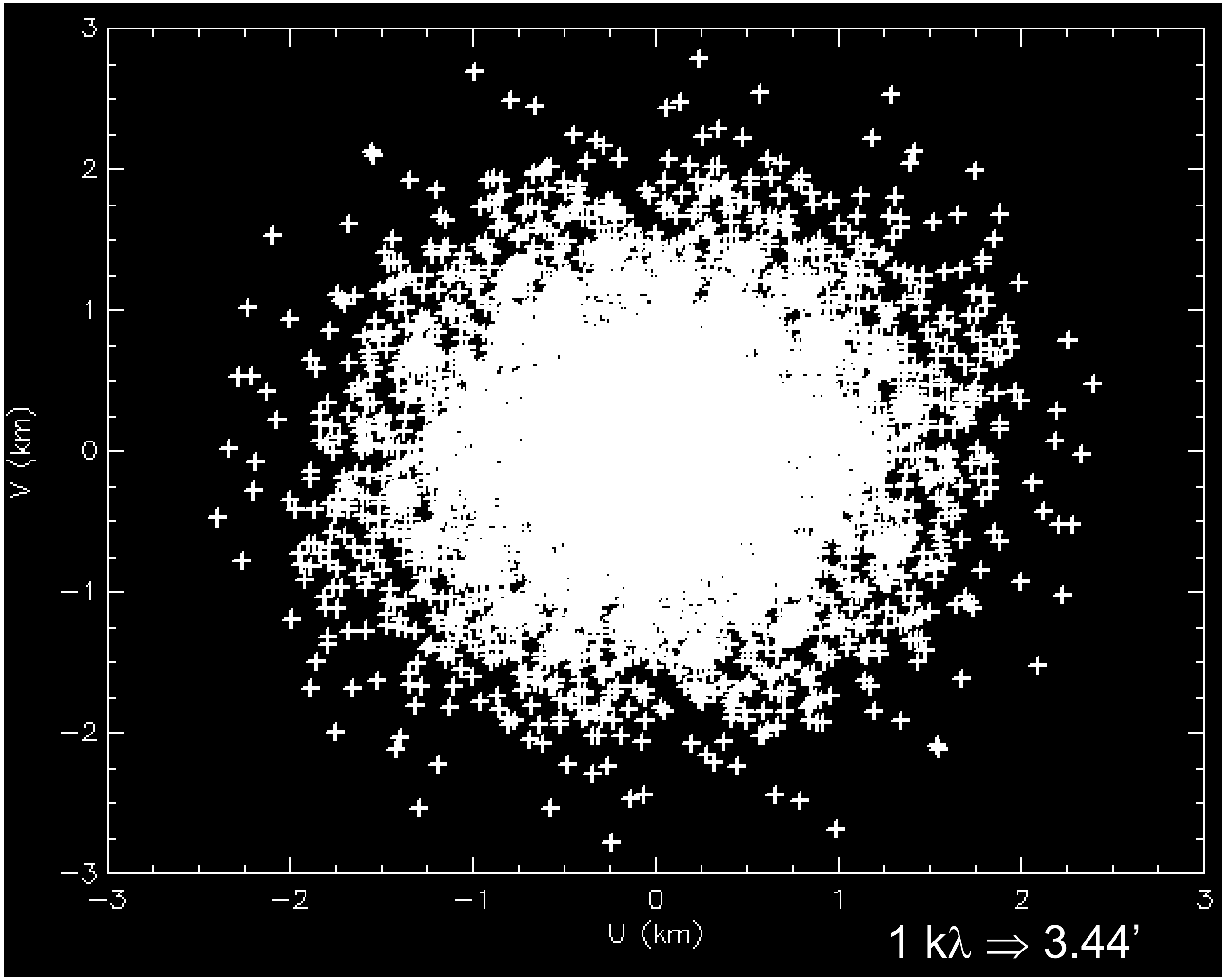
Performance requirements

- High fidelity, high dynamic range imaging over a broad observing band with high time and frequency resolution

MWA characteristics

- Large N design and small footprint $\Rightarrow$ High fidelity imaging capability
- Time resolution ~0.5 s
- Frequency resolution ~40 kHz
- Spectroscopic imaging capability over 30.72 MHz, can be distributed over the 80 to 300 MHz band in 24 chunks of 1.28 MHz each
- Voltage capture and offline correlation

MWA *uv* coverage



MWA: Current Status

Instrument re-scoped to 128 tiles (~early 2011)

Status as of June 2012

- Site infrastructure
  - ☑ Site survey for marking tile locations and trench paths
  - ☑ Trenching
  - ☑ Laying power and optical fiber cables
  - ☑ Building receiver pads
- Hardware installation
  - ☑ Tiles - all 128
  - ☑ Beamformers – all 128

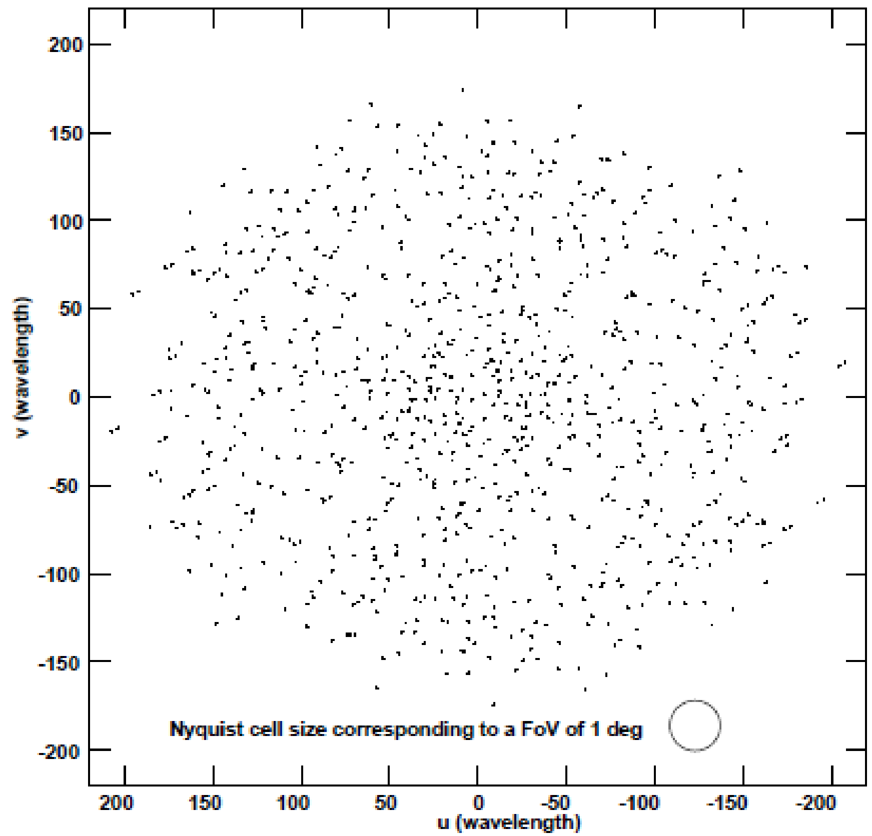
Near Term Plans

- The 128 tile system is being deployed in groups of 32 tiles and 4 receivers each
- They have been christened α, β, γ, δ and ε arrays
- The schedule calls for the deployment of a new array every month
- First 2 wks – cabling up, engineering tests and debugging
- Next 2 wks – gathering science commissioning data
- Complete deployment of all field hardware by the end of the year
- 128T array expected to be operational early next year
- The β array has seen its first light and has also made some solar observations

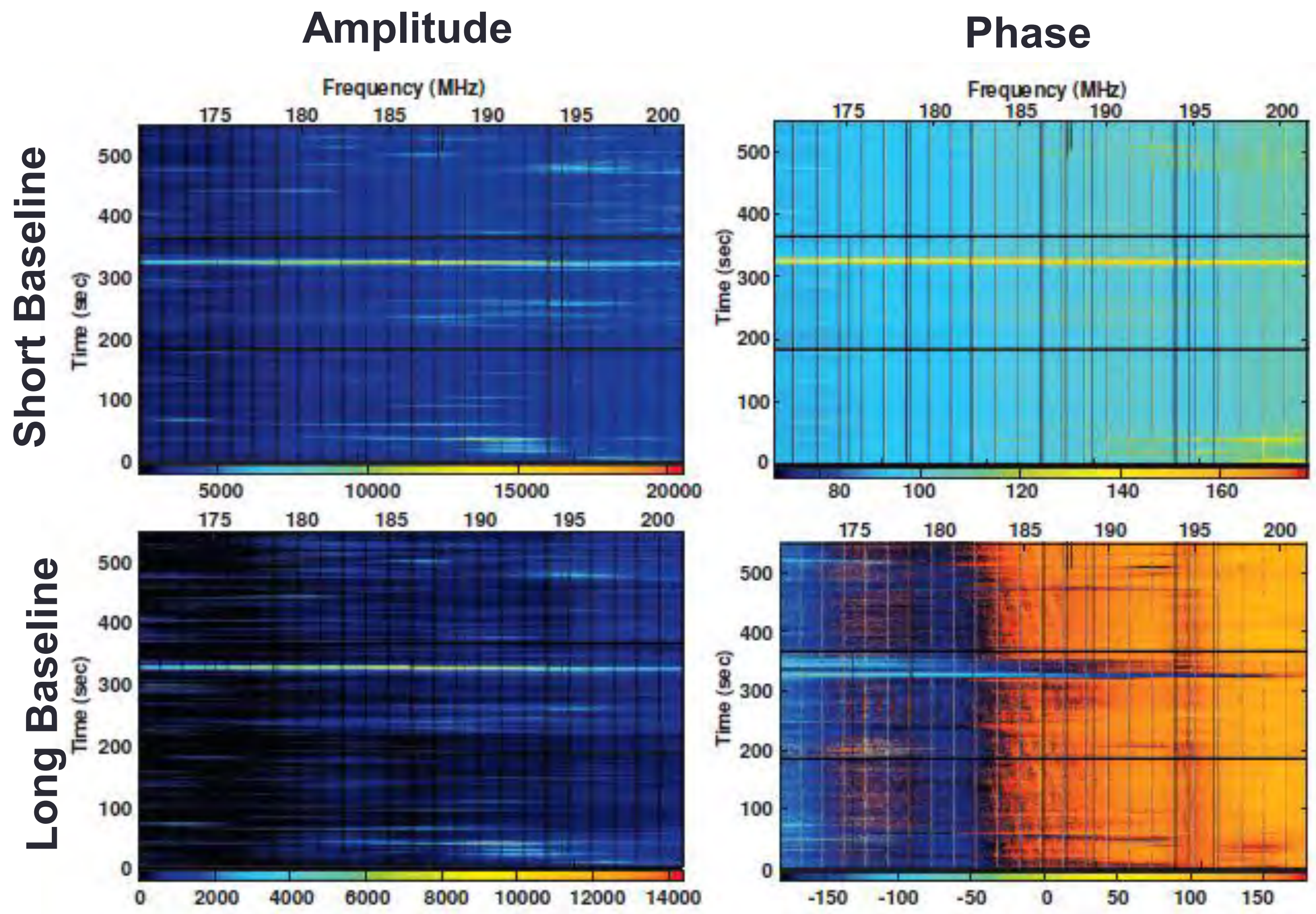
32T – The MWA Prototype

- 32 tiles (elements)
- Randomized Reuleaux triangle configuration
- Max baseline ~300m

- Engineering Prototype
  - Verify and optimize hardware performance
  - End-to-end integration
  - Field operation experience
  - Early science
- Operated: Nov. 08 - Sep. 11



Fine scale emission structure



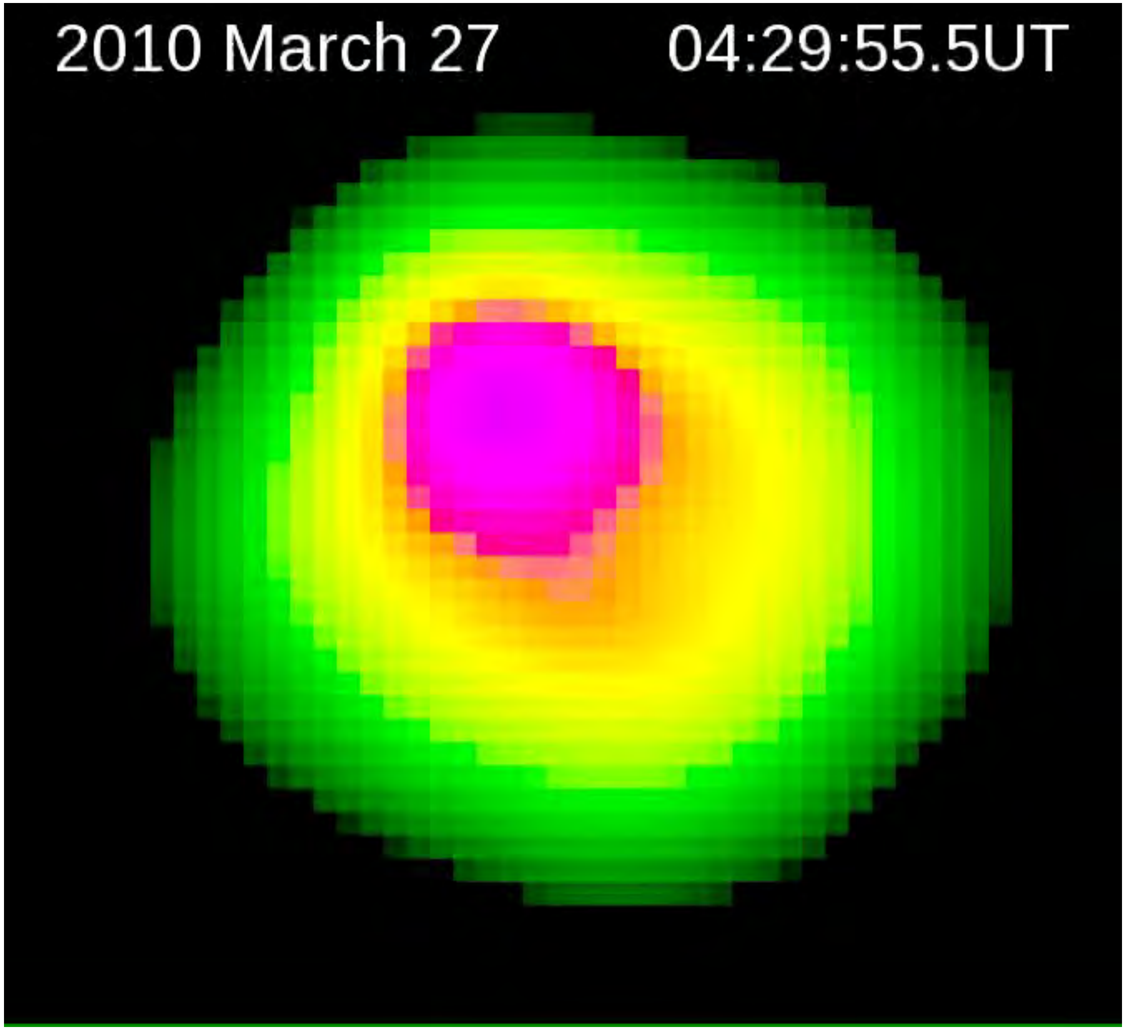
See numerous non-thermal emission features not seen by other instrumentation

Oberoi et al, 2011

High dynamic range imaging

- 193.3 MHz
- 0.88 MHz
- 1 s/frame
- 30 s

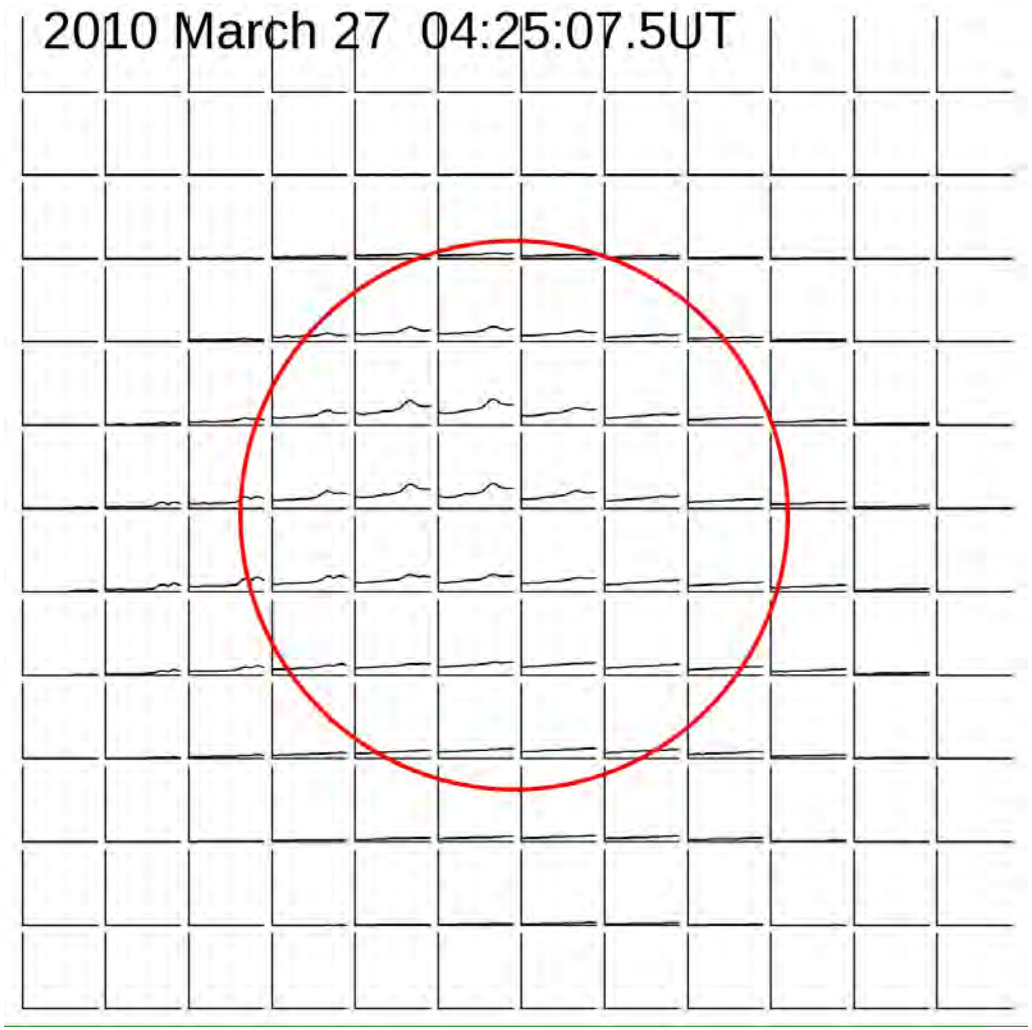
- Imaging Dynamic Range ~2,500
- Order of magnitude improvement over the earlier state-of-the-art (Nançay Radio-heliograph, France)



Oberoi et al, 2011

Spectoscopic imaging

- Spatially localized spectra
- Squares - 300”x300”
- 170-201 MHz
- 24 pt. spectra, separated by 1.28 MHz
- 10 s

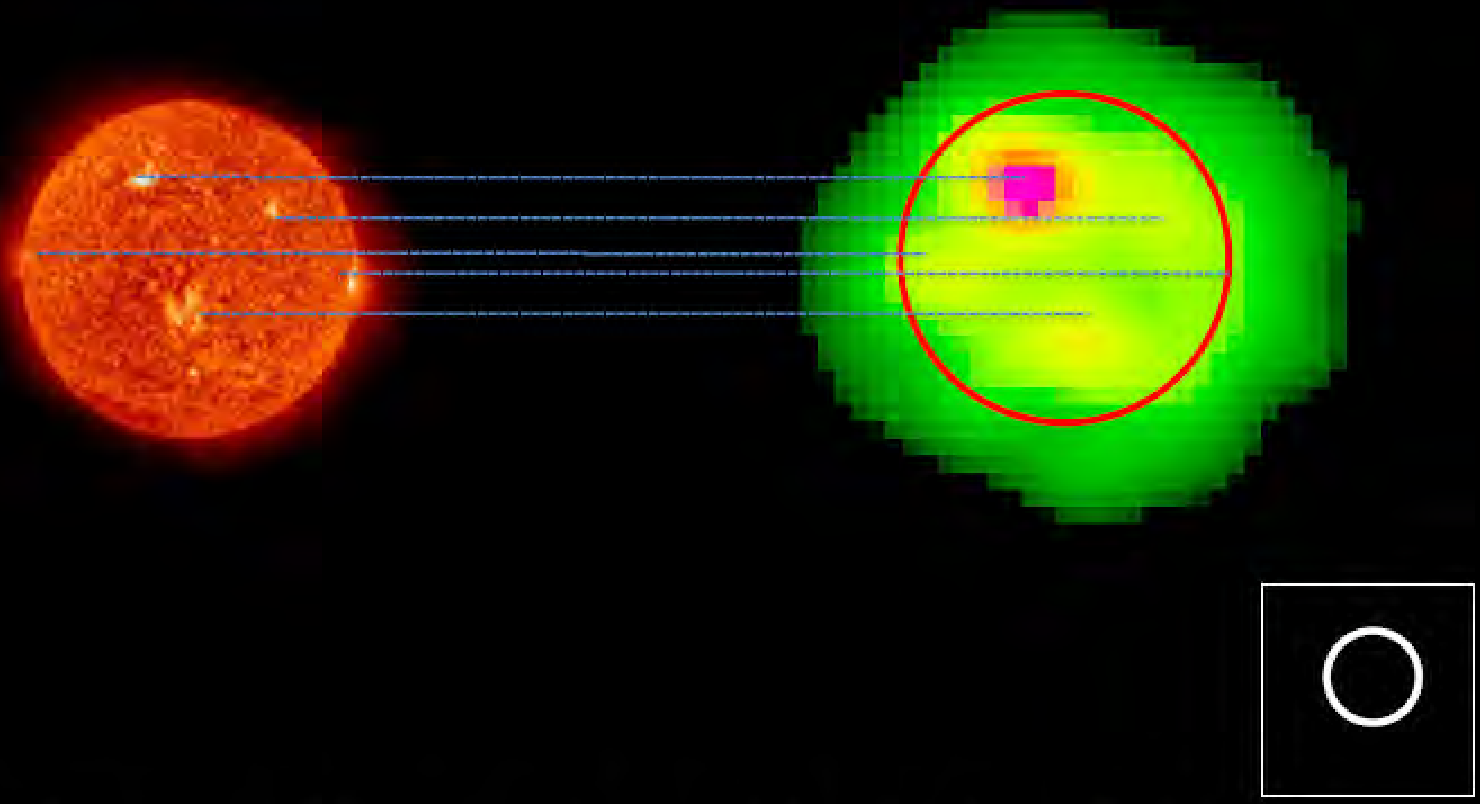


Oberoi et al, 2011

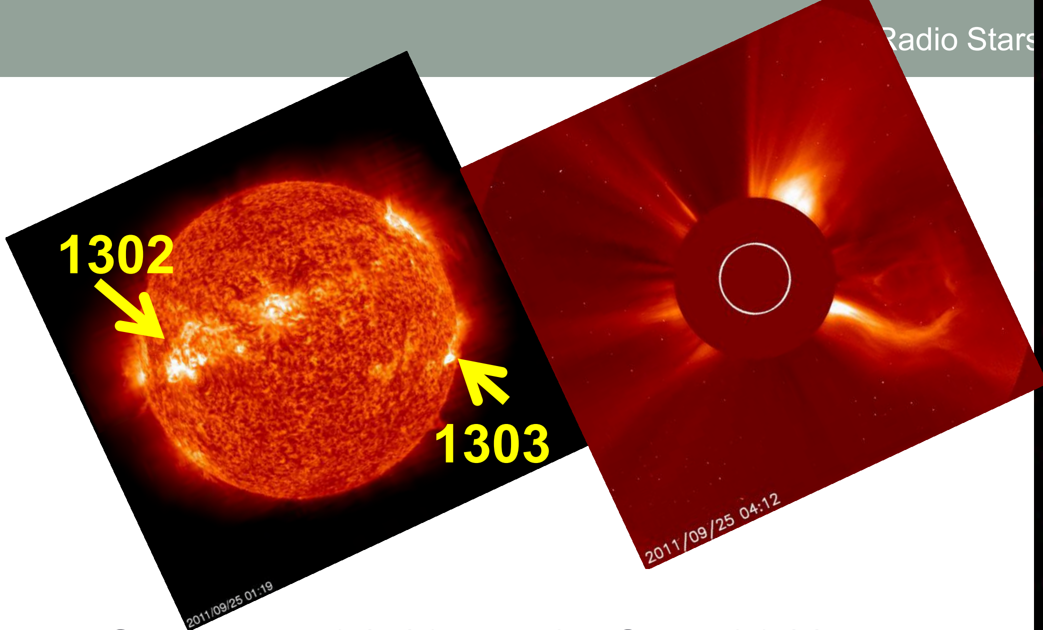
Solar Images from 2010 March 27

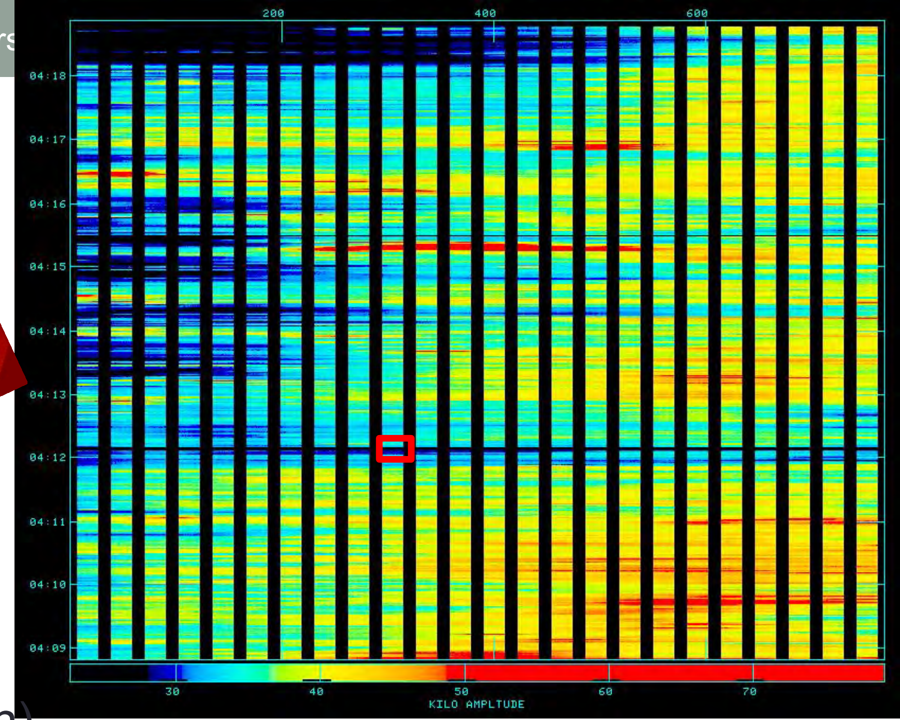
SOHO 304 Å image (01:19 UT)

32T image @193 MHz (04:26:38 UT) (“Super-resolved”: 500″x 500″ restoring beam)



Super-resolution reveals possible underlying features corresponding to all of the brightest EUV regions.

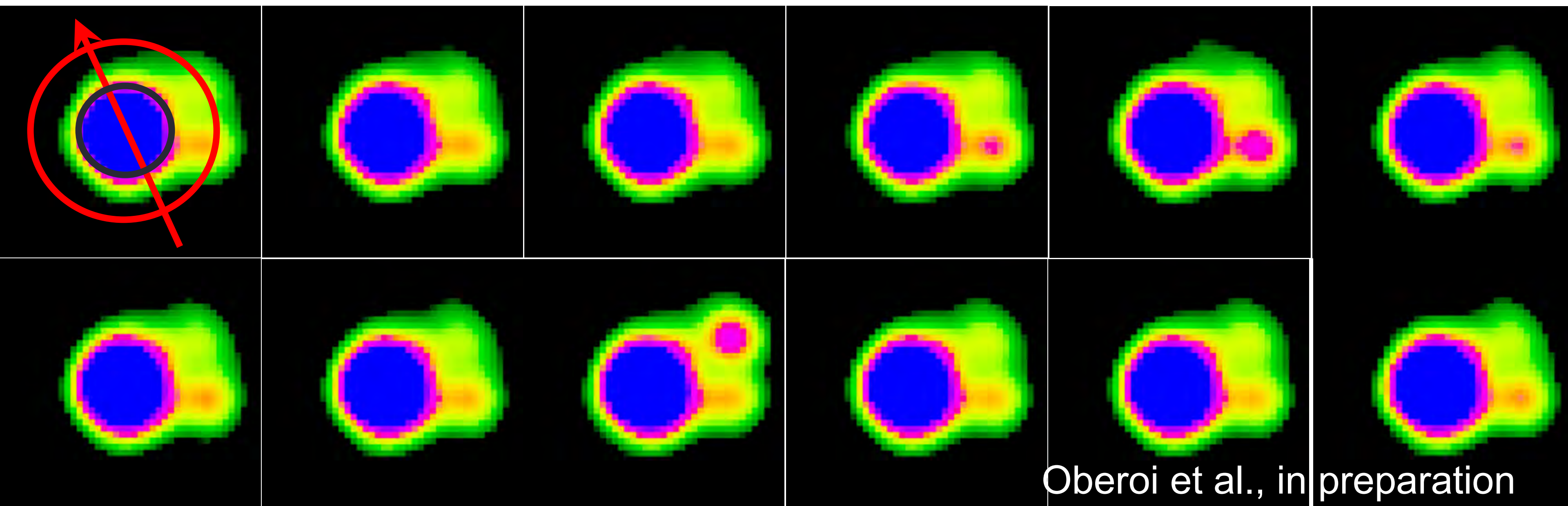




HINODE XRT 01:19 UT, 25 Sep. 2011

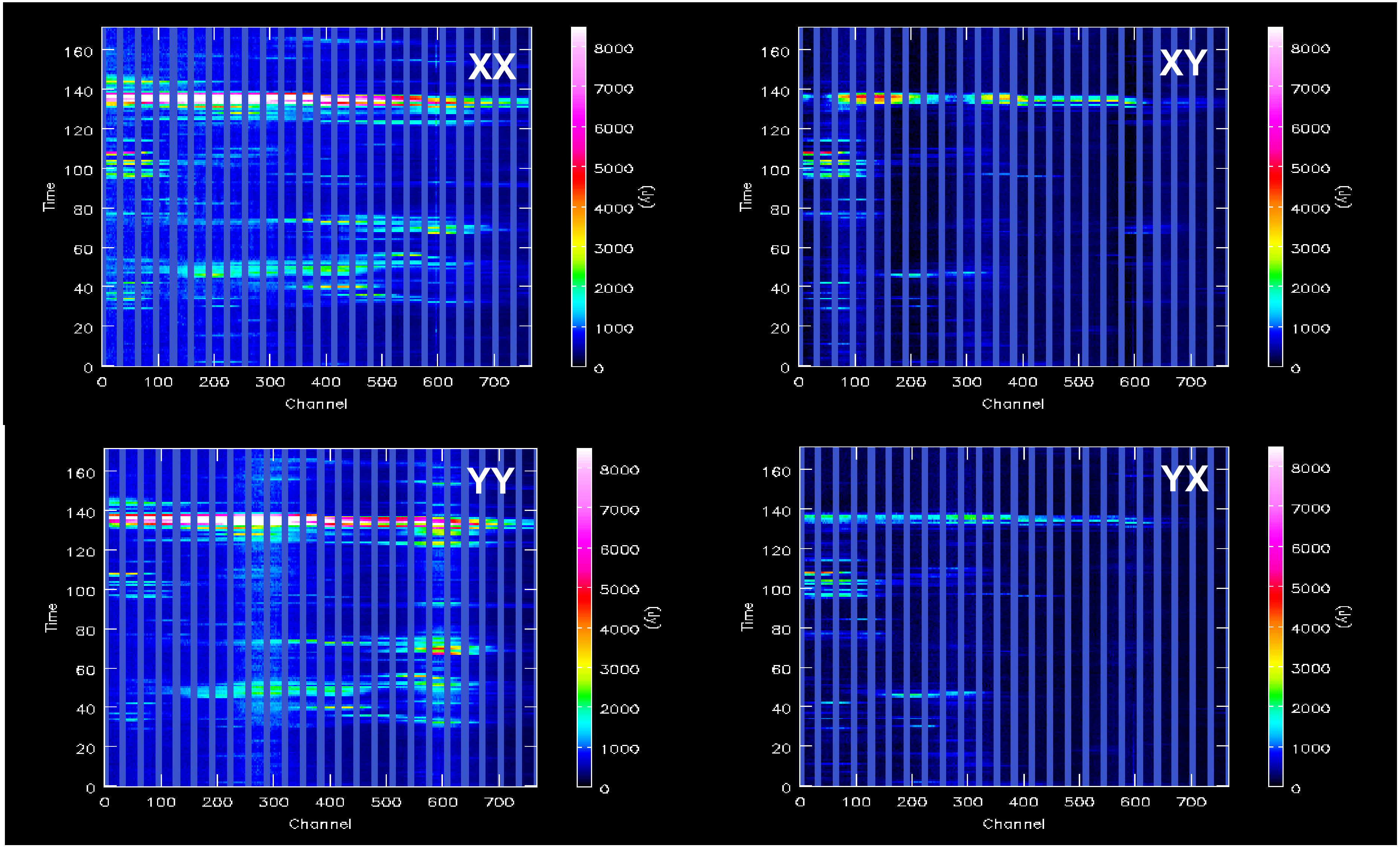
SOHO/LASCO C2 at 04:12 UT (19 s integration)

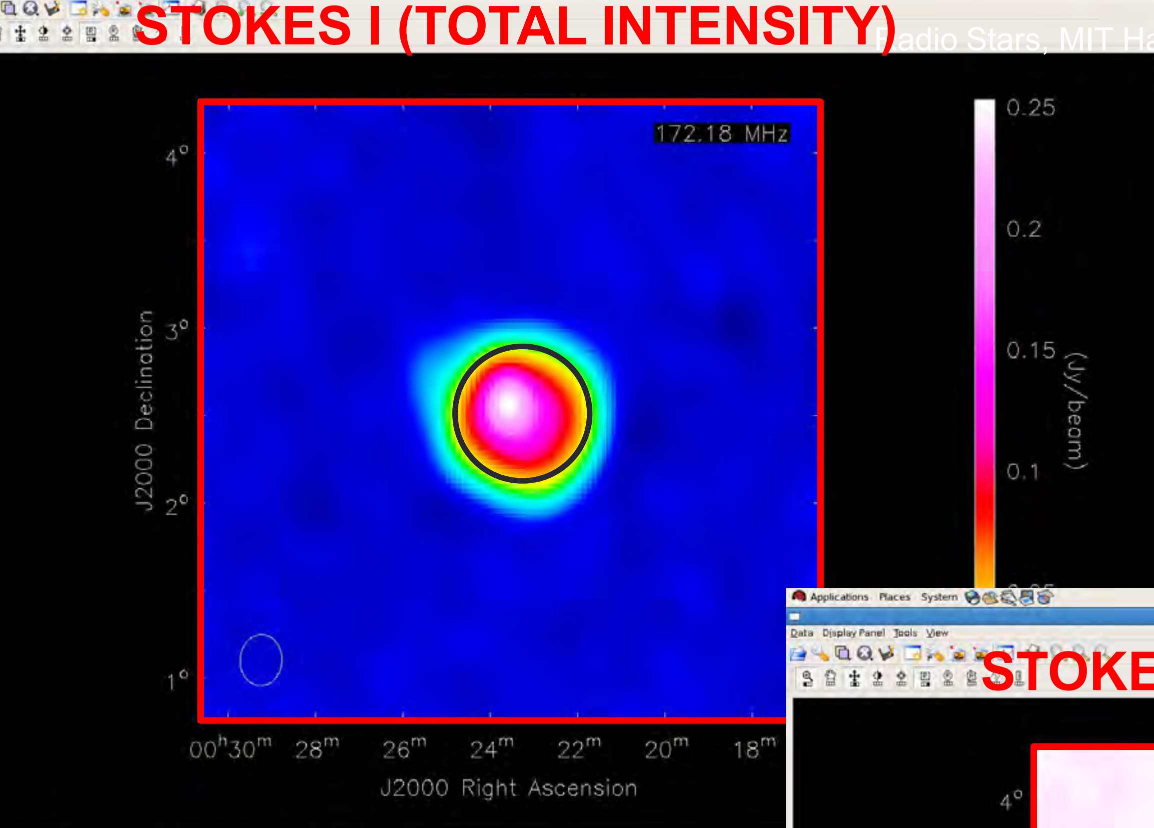
32T 152.3 MHz, 1s, 80 kHz, θ_0=13.3', log scale, DR ~1100, images are 1 s apart



Oberoi et al., in preparation

Signatures of polarised emission

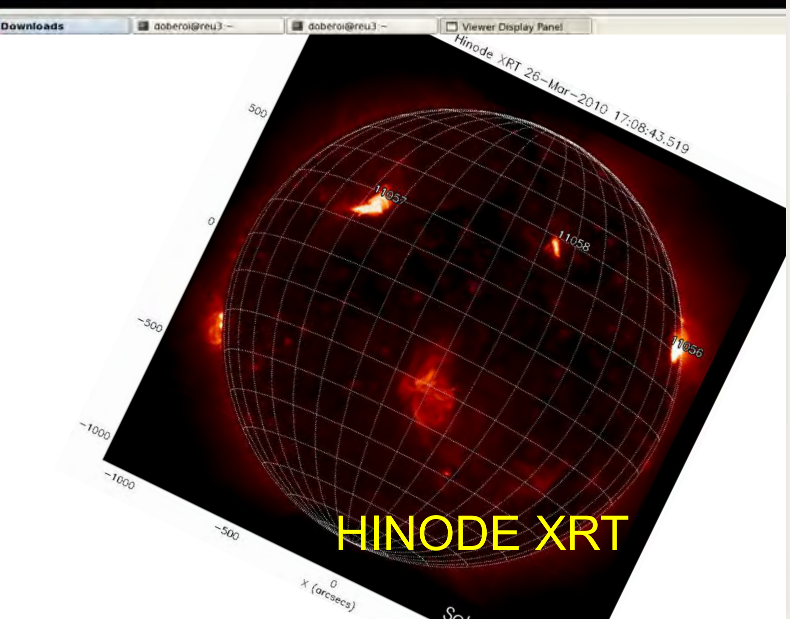


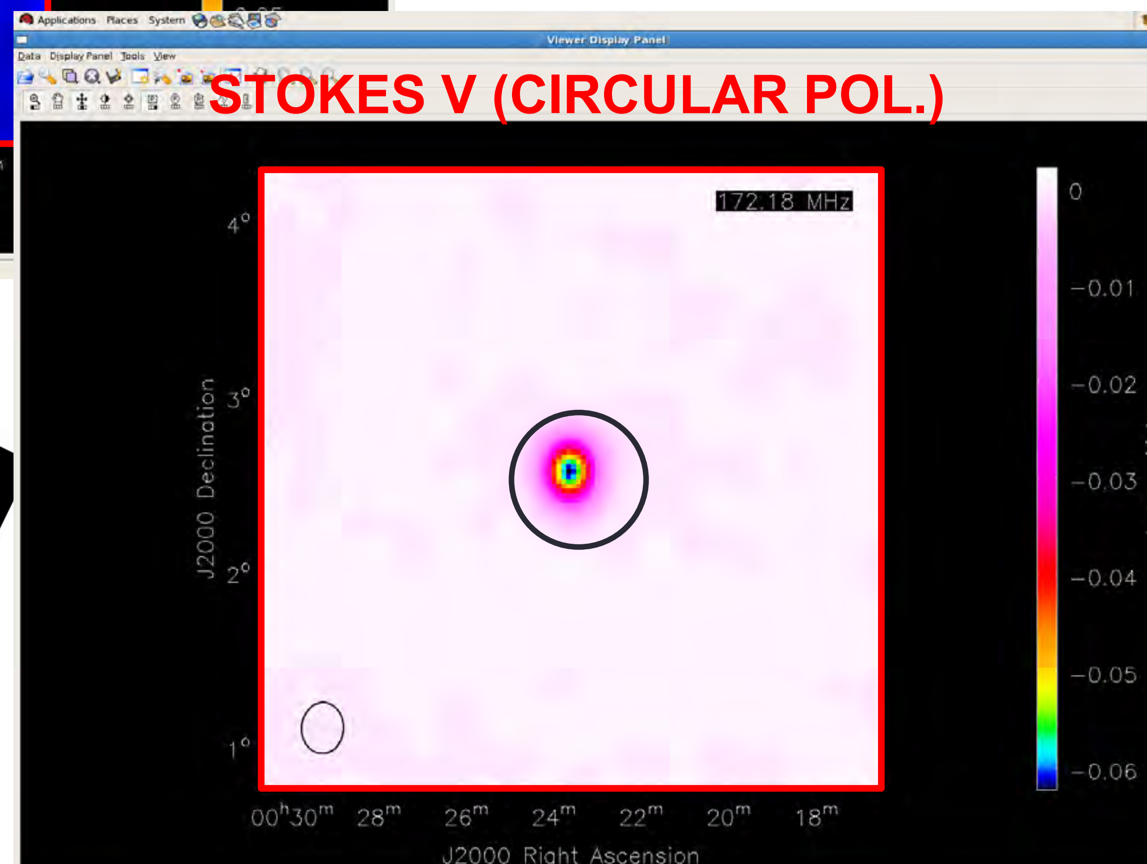


Each image corresponds to 1 s and 40 kHz integration

Frames 1.28 MHz apart, span ~170-200 MHz for the same time slice

Oberoi et al., in preparation



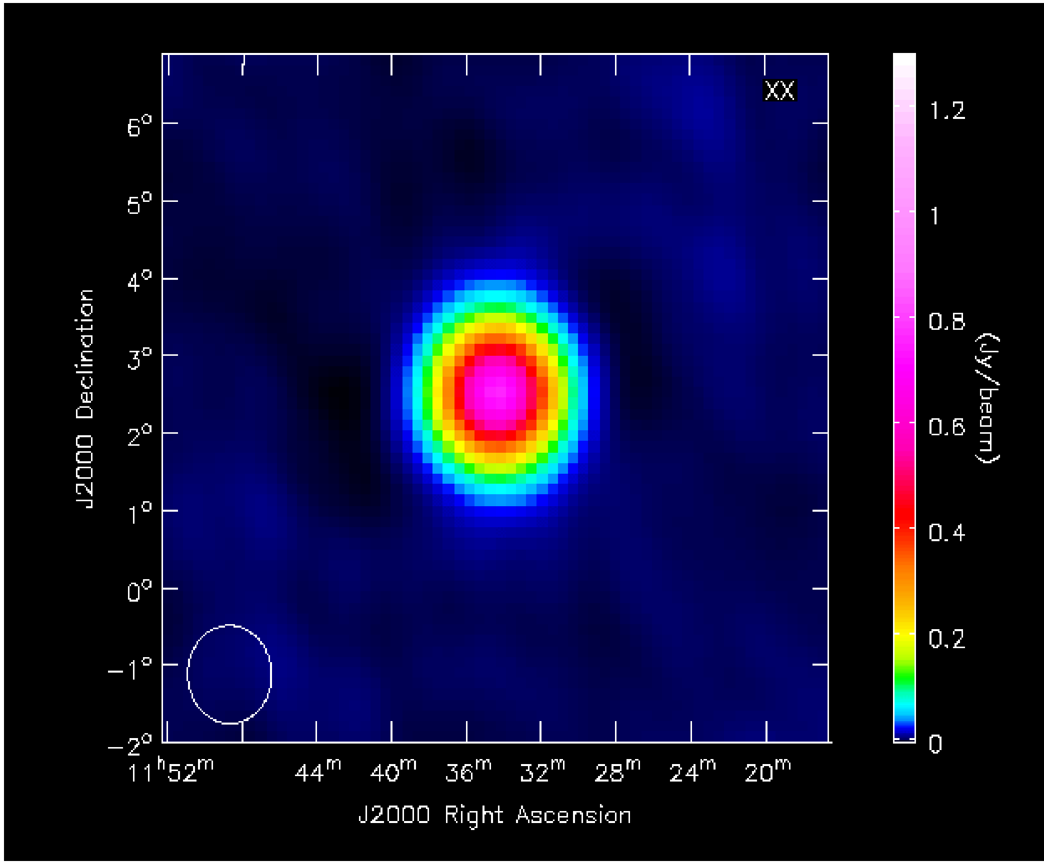


Detection of Stokes V

- 27 Mar 2010, 04:28:10 UT
- Data from the 32 element MWA prototype
- Preliminary relative calibration in arbitrary units
- Imaging dynamic range
  - XX Pol: ~1000
  - Stokes I: ~500
  - Stokes V: ~300
- Uncorrected for instrumental pol. Note instrumental pol. will vary smoothly in frequency
- Maximum Stokes V observed ~25%
- Preliminary results from an imaging pipeline being implemented in CASA

Alpha array - Commissioning data

- Max baseline ~50λ
- 16 Sep, 2012 06:56:50 to 06:57:31
- 149.64 MHz
- Each Frame 1s, 10 kHz Dynamic range ~350
  - ~50 clean components
  - All of them in 2 adjacent pixels (PSF ~5x5 pixels)
- ~40 s



Conclusions

- MWA has already demonstrated high fidelity, high dynamic range, spectroscopic imaging capability (+ polarimetric imaging)
- MWA construction is now nearing completing
- Initial commissioning activities proceeding as planned
- Science commissioning for the 128T array will commence next year
- Focus on calibration, analysis pipeline and science results
- Exciting times ahead… stay tuned

Acknowledgements

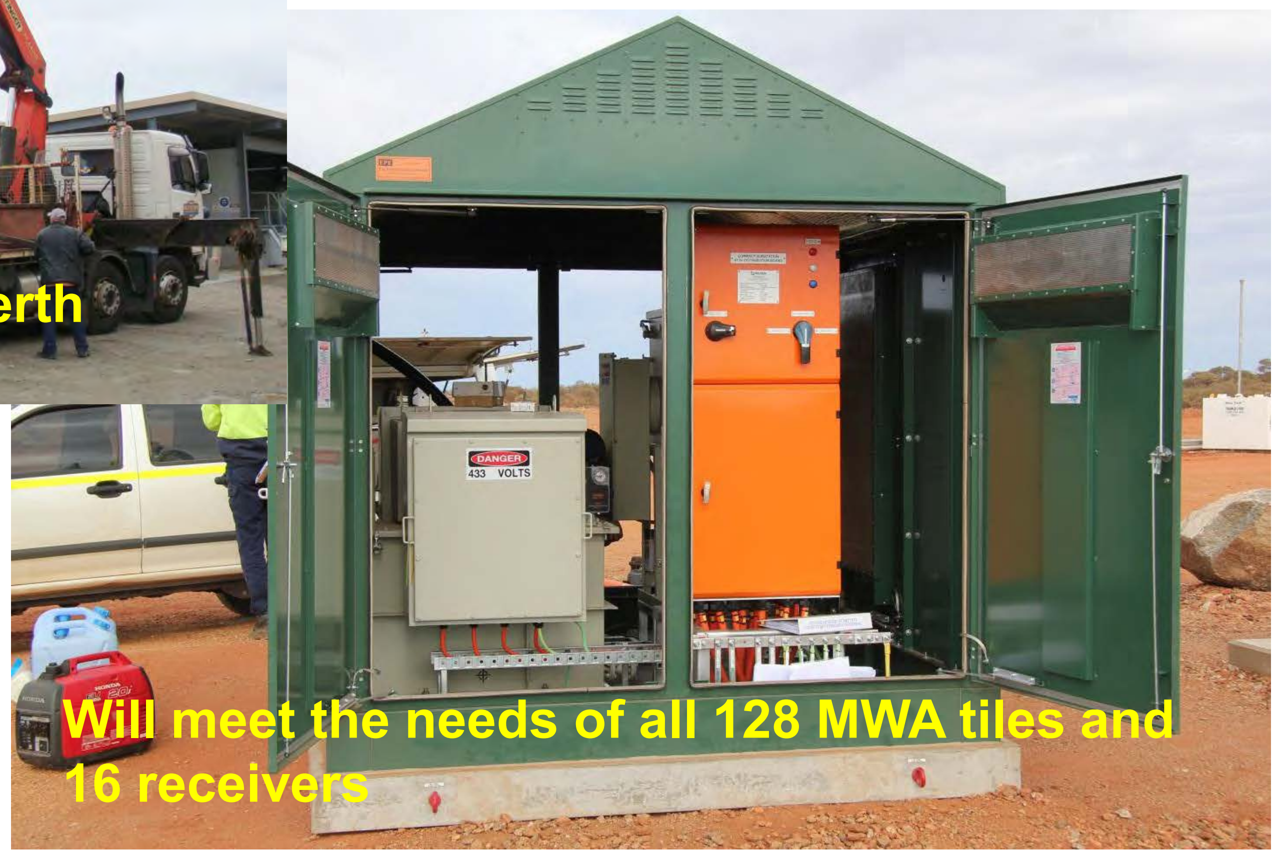
Photographs – Contributors to the MWA Facebook page and Kirsten Gottschalk (ICRAR)

The CSIRO building

Will house much of the MWA signal processing including the correlator and the Real Time System.

The Transformer Hut

Being Loaded up in Perth



Will meet the needs of all 128 MWA tiles and 16 receivers

In the Trenches

When it was all dug up

An Aerial View

Setting up a tile

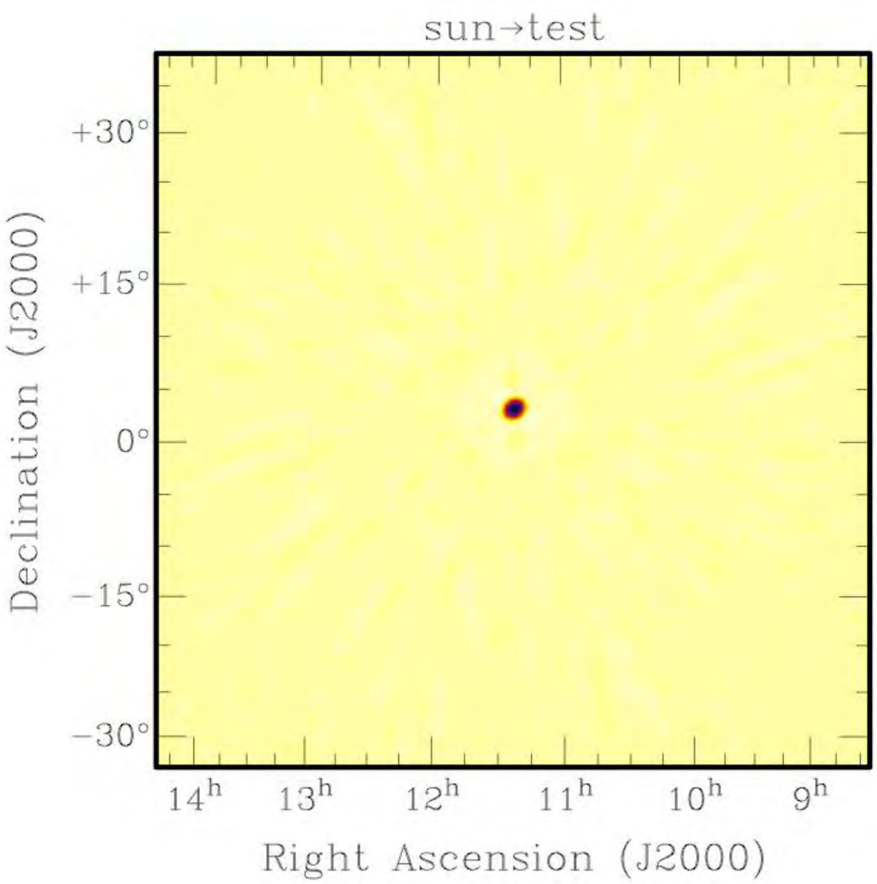
From the very first dipole …

to the last box of dipoles

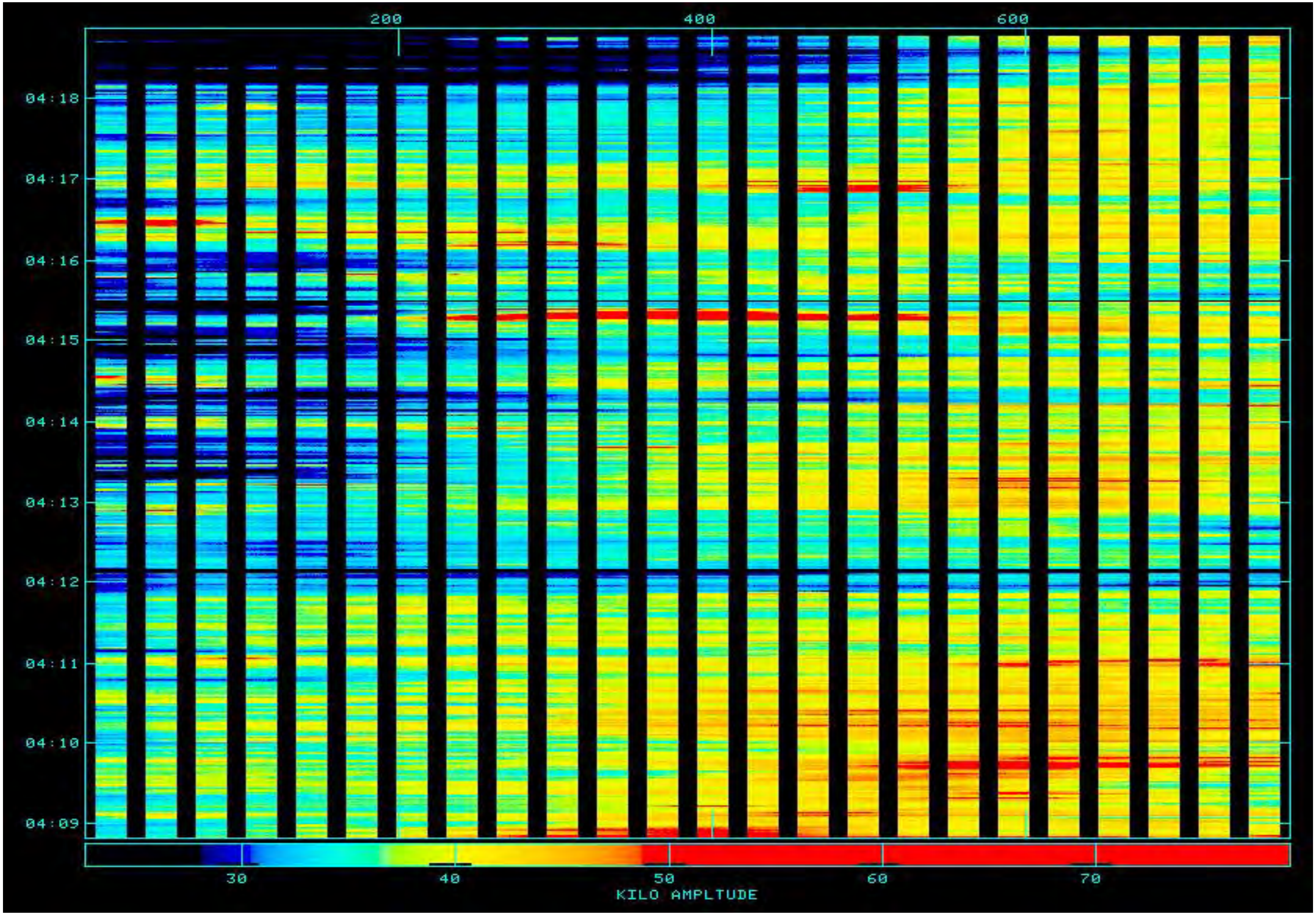
The Tile and Beamformer Deployment Crew

The First Receiver in the Field

First Image - Sun

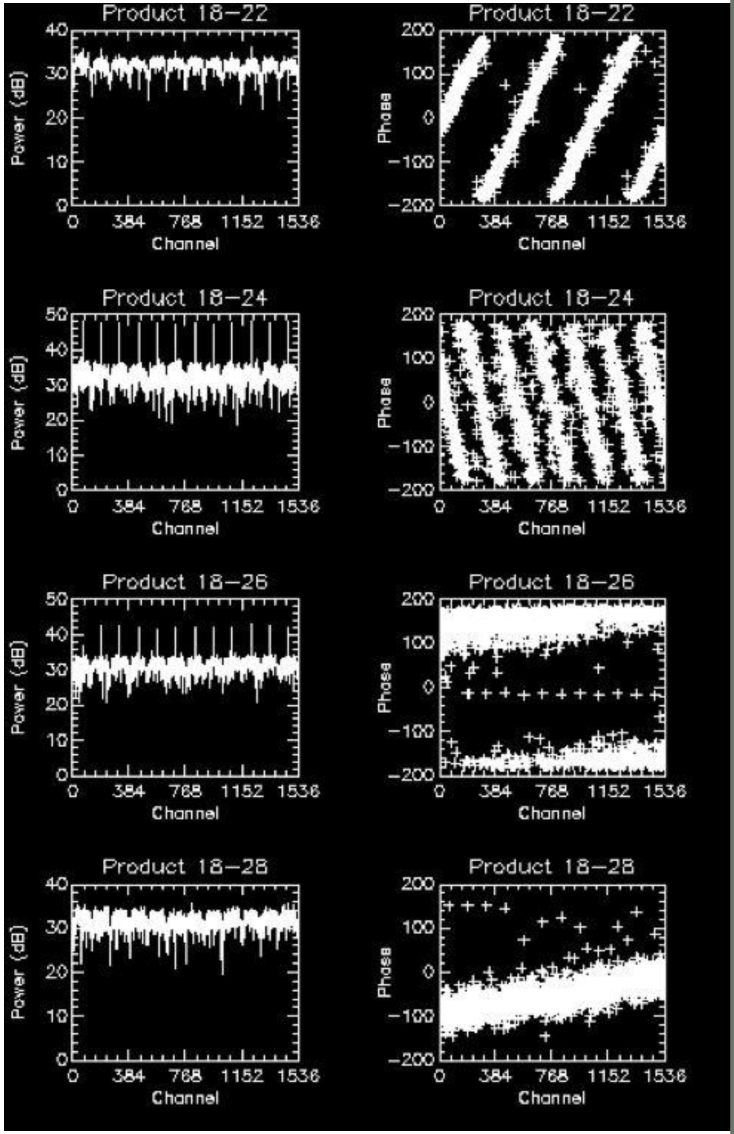


- Sep 11, 2012
- ν_0 = 142 MHz; $\Delta\nu$ = 30.72 MHz; Δt = 10 s



25 Sep, 2011, 140.2-170.9 MHz, ~4:09-4:19 UT, auto-correlation, Amp, XX

The First Light



Fringes on CasA
August 04, 2012
Receiver 2

Not everything worked fine in the first go, though