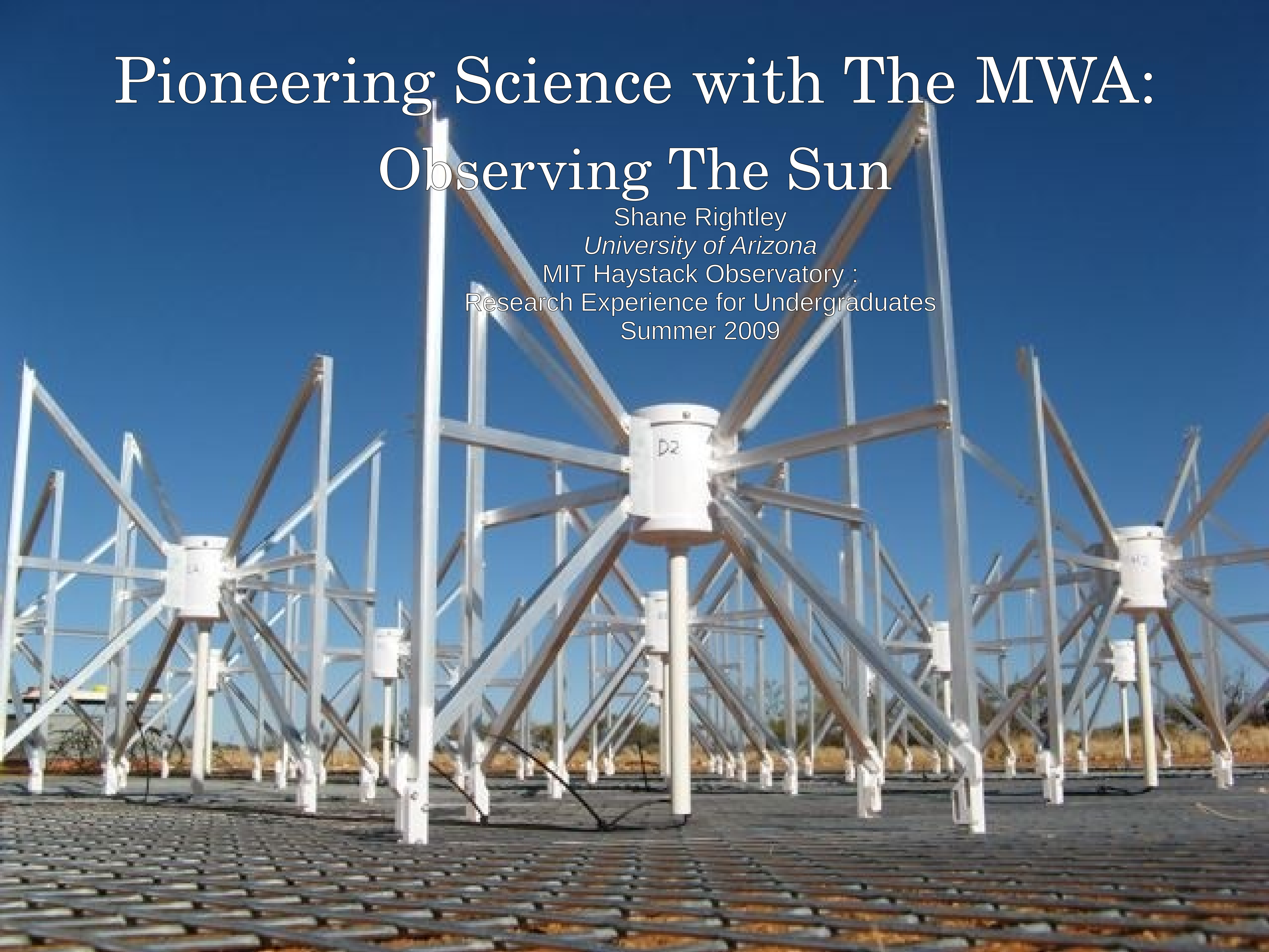
Pioneering Science with The MWA: Observing The Sun

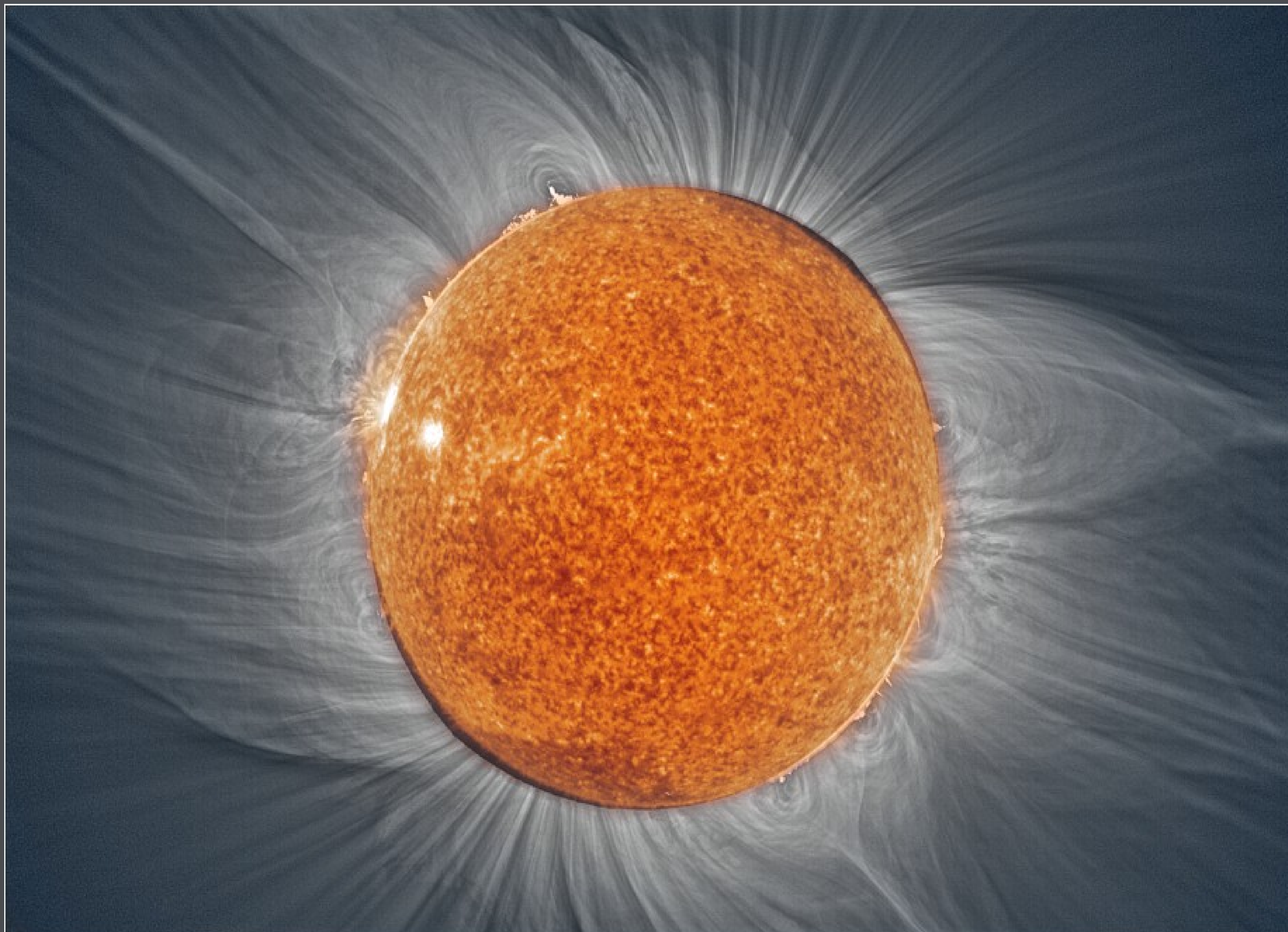
Shane Rightley
University of Arizona
MIT Haystack Observatory :
Research Experience for Undergraduates
Summer 2009



Overview

- The Sun
- The Observations
- Data Reduction
- Results
- Conclusions
- Future Work

The Sun

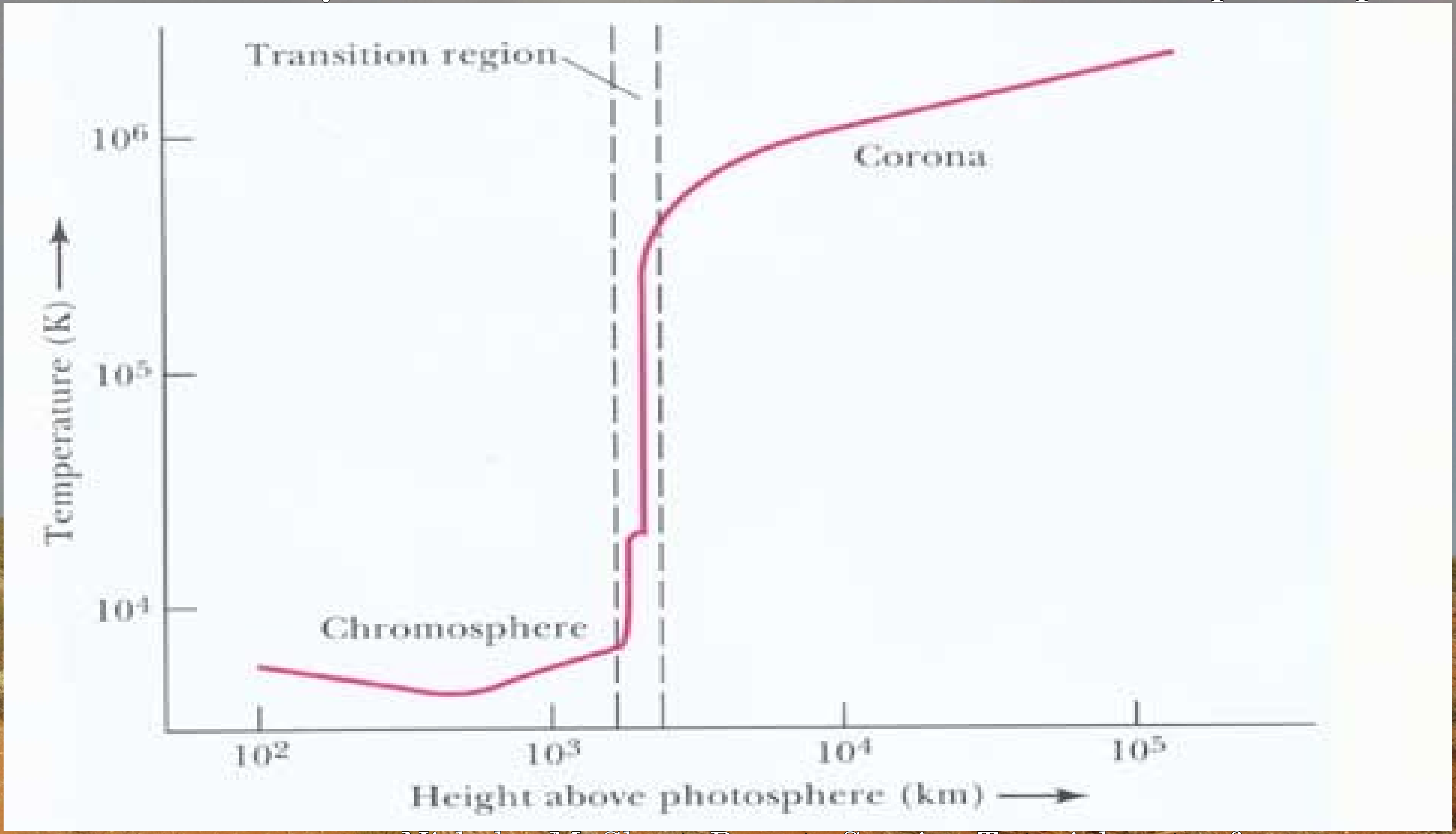


Total Solar Eclipse 2006

© 2006 Miloslav Druckmüller, Peter Aniol, ESA/NASA

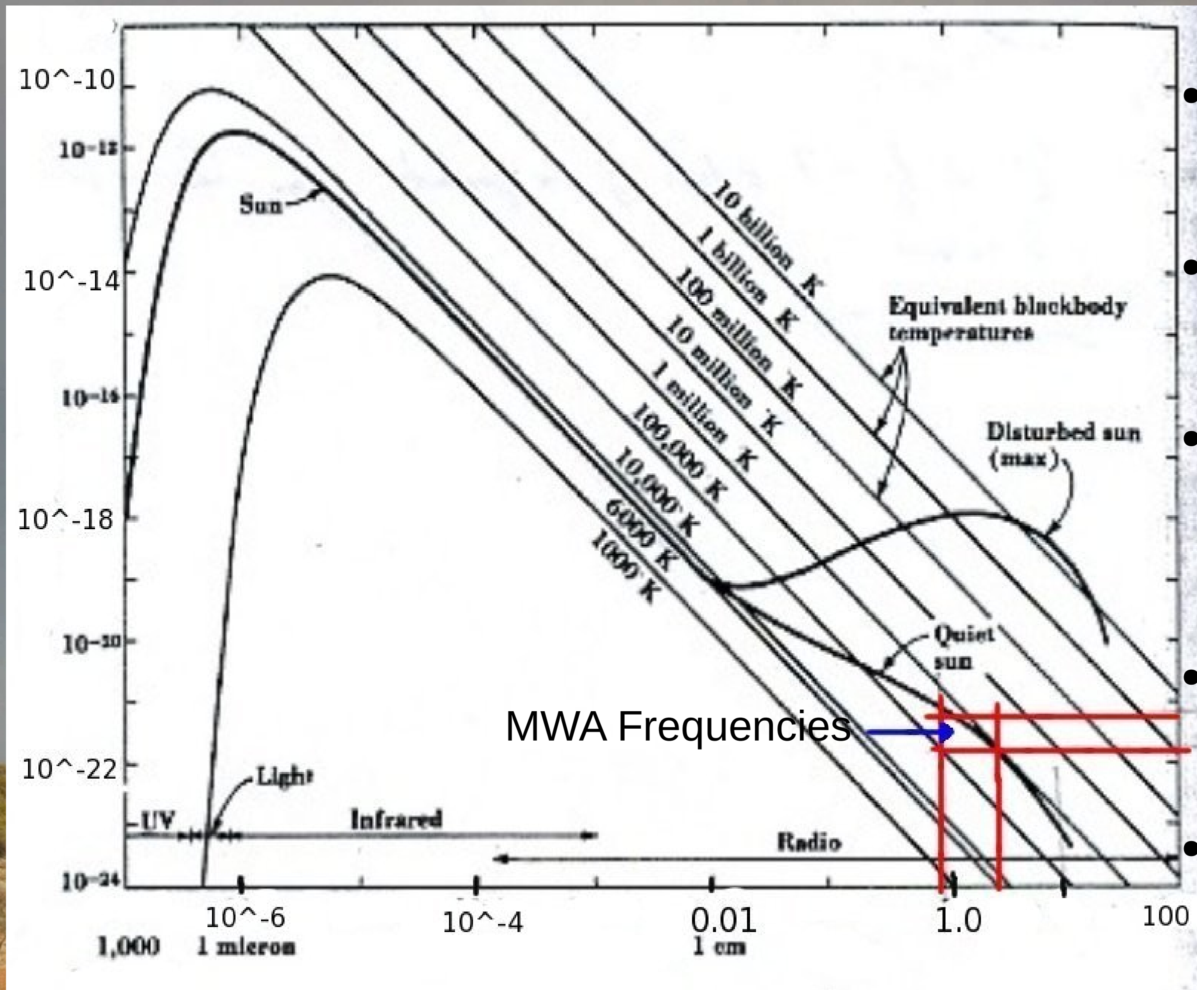
The Sun

- The corona is tenuous but hot
  - Density of the corona is ~10^-12 times that of the photosphere



Nicholas M. Short, Remote Sensing Tutorial rst.gsfc.nasa.gov

The Radio Sun



- Quiet sun emits like a blackbody
- Optical depth increases with wavelength
- At high freq. - chromosphere dominates observation
- At low freq – corona dominates observation
- Transition region leads to intermediate brightness temperatures

The Radio Sun

S. F. SMERD

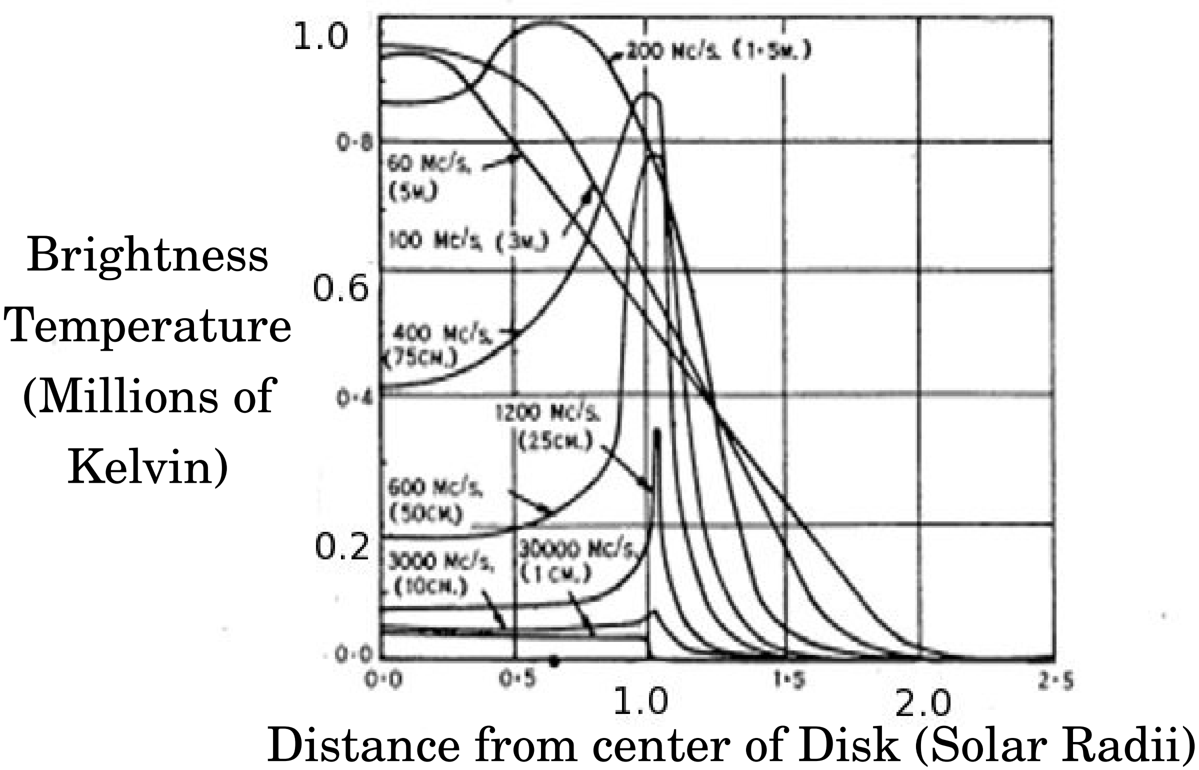
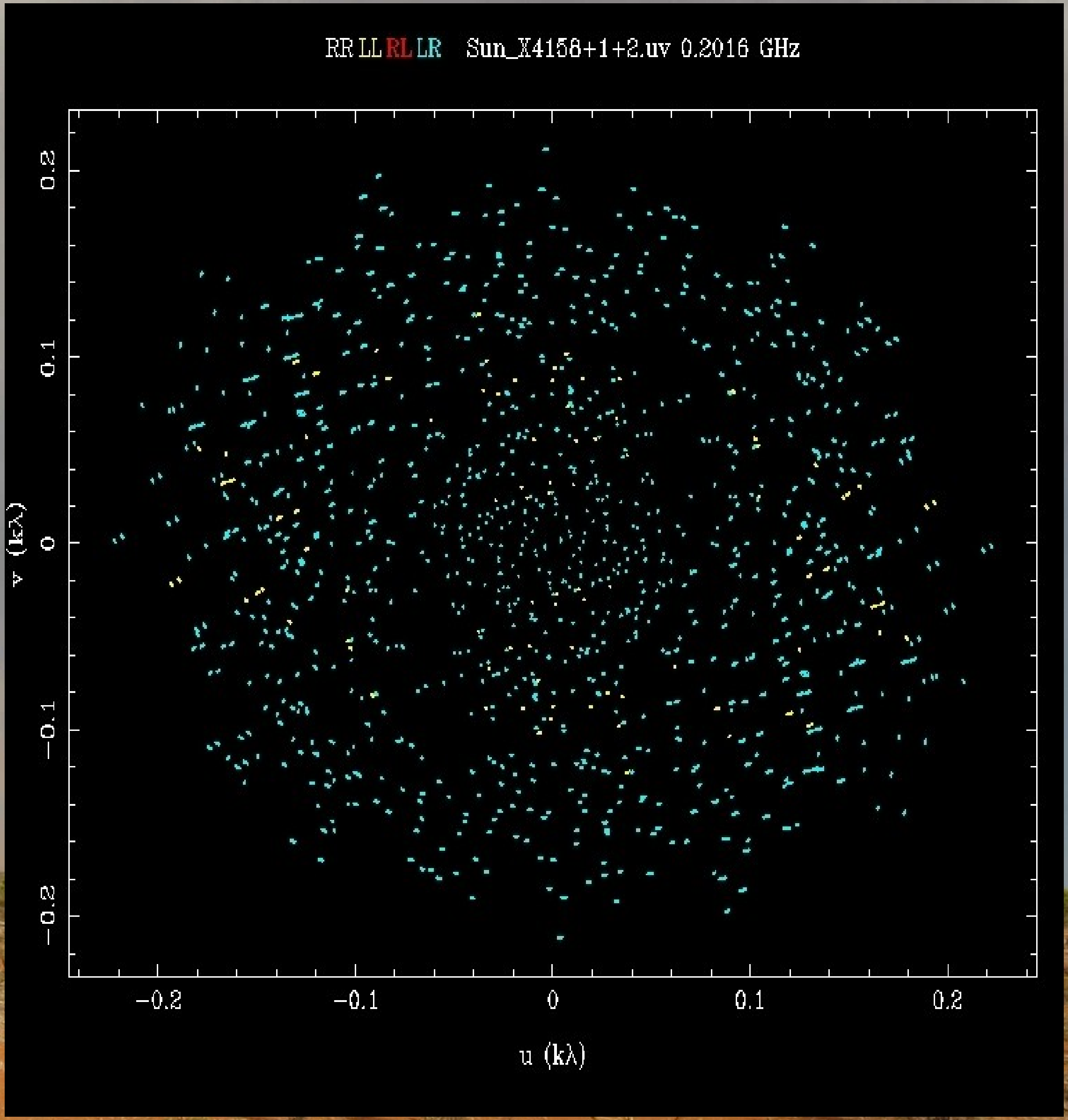


Fig. 4.—The variation of the effective temperature with distance from the centre of the disk at different radio frequencies. The values used for the chromospheric and coronal temperatures are 3×10^4 and 10^6 °K. respectively.

- Brightness Profiles
  - Hot corona more apparent at lower frequencies
  - Edge of Sun has longest path through the corona-largest brightness temps.
  - Refraction and Scattering
    - Effects go as lambda squared
    - Lower wavelengths-brightened horns move inward

The MWA 32T

- Prototype for the MWA array
- 32 tiles
- Observes at 80-300 MHz
- 1.28 MHz bandwidth
- ~300 m max baseline



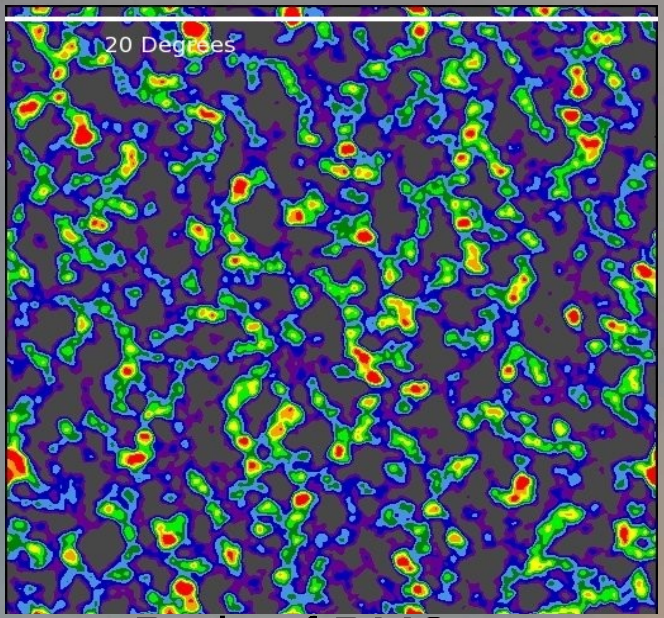
UV coverage for MWA 32T

Data Reduction

- Observations from 18-19 Nov 2008
  - 85, 114, 143, 202 and 231 MHz
- The Plan: Going from voltages measured at each of the tiles to a calibrated brightness temperature map of the Sun
  - Flag known bad data
  - Verify data quality
  - Imaging
    - Self-calibrate - iteratively refine instrumental gains
    - CLEAN - deconvolve the PSF from the image
  - Flux calibration
    - The measured flux of Centaurus A is matched to the actual flux then solutions are translated to the solar data

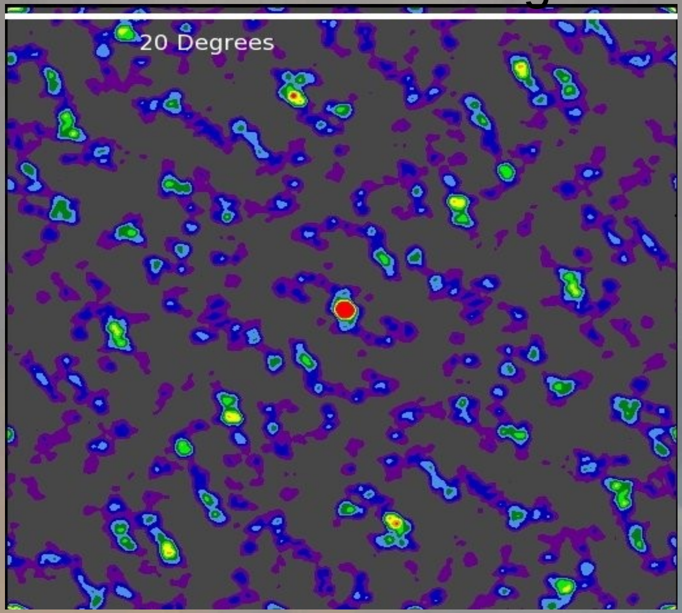
Data Reduction

Before Calibration



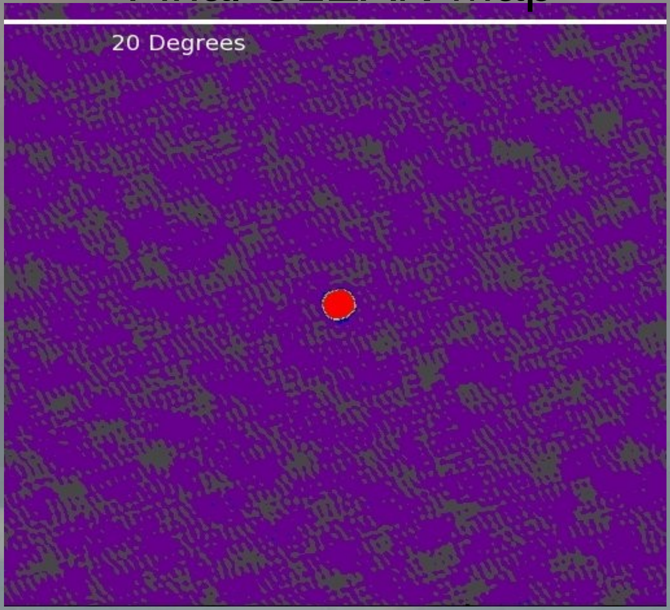
Ratio of RMS to maximum ~ 22%

Before CLEANing



Ratio of RMS to maximum ~11%

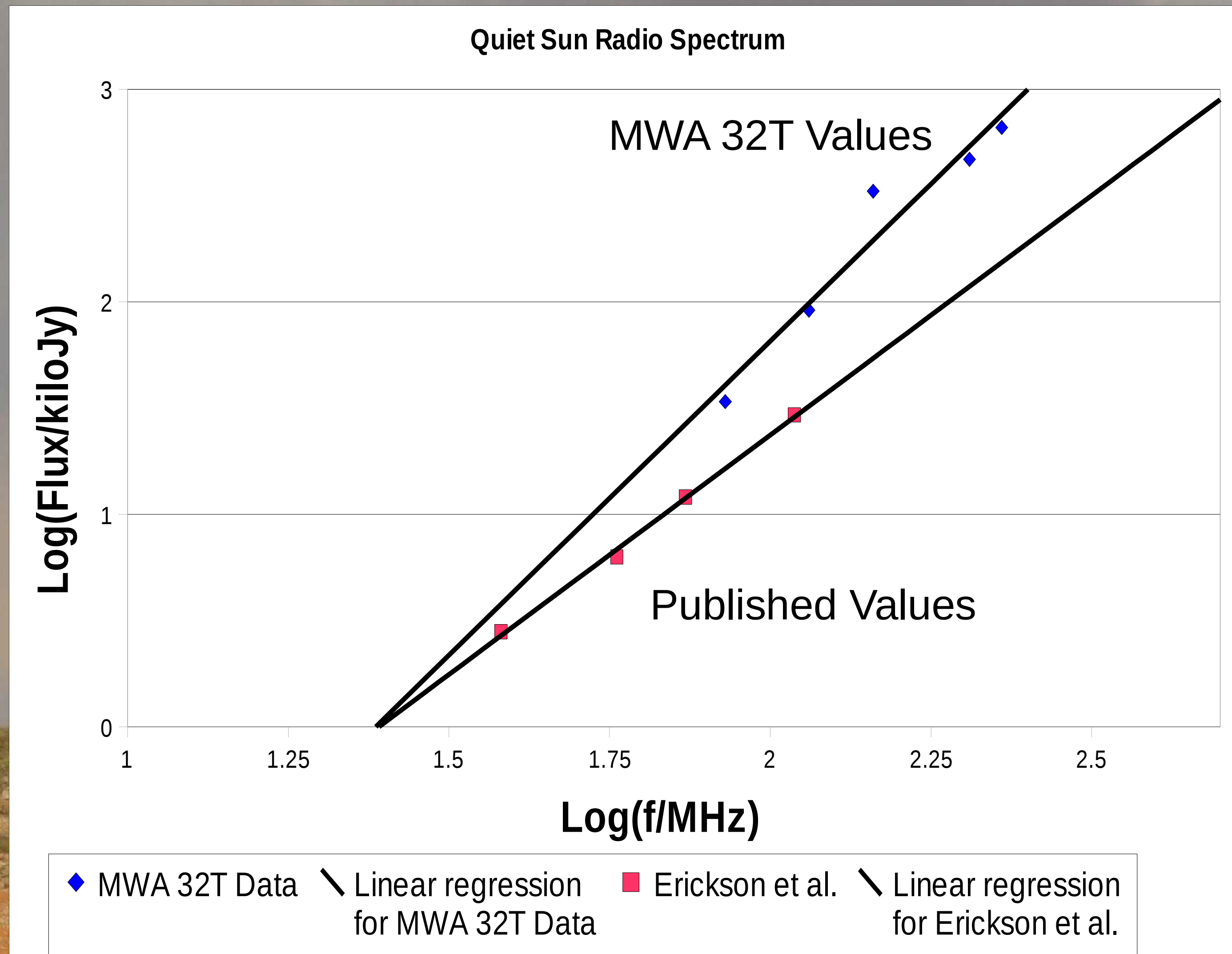
Final CLEAN Map



Ratio of RMS to maximum ~0.05%

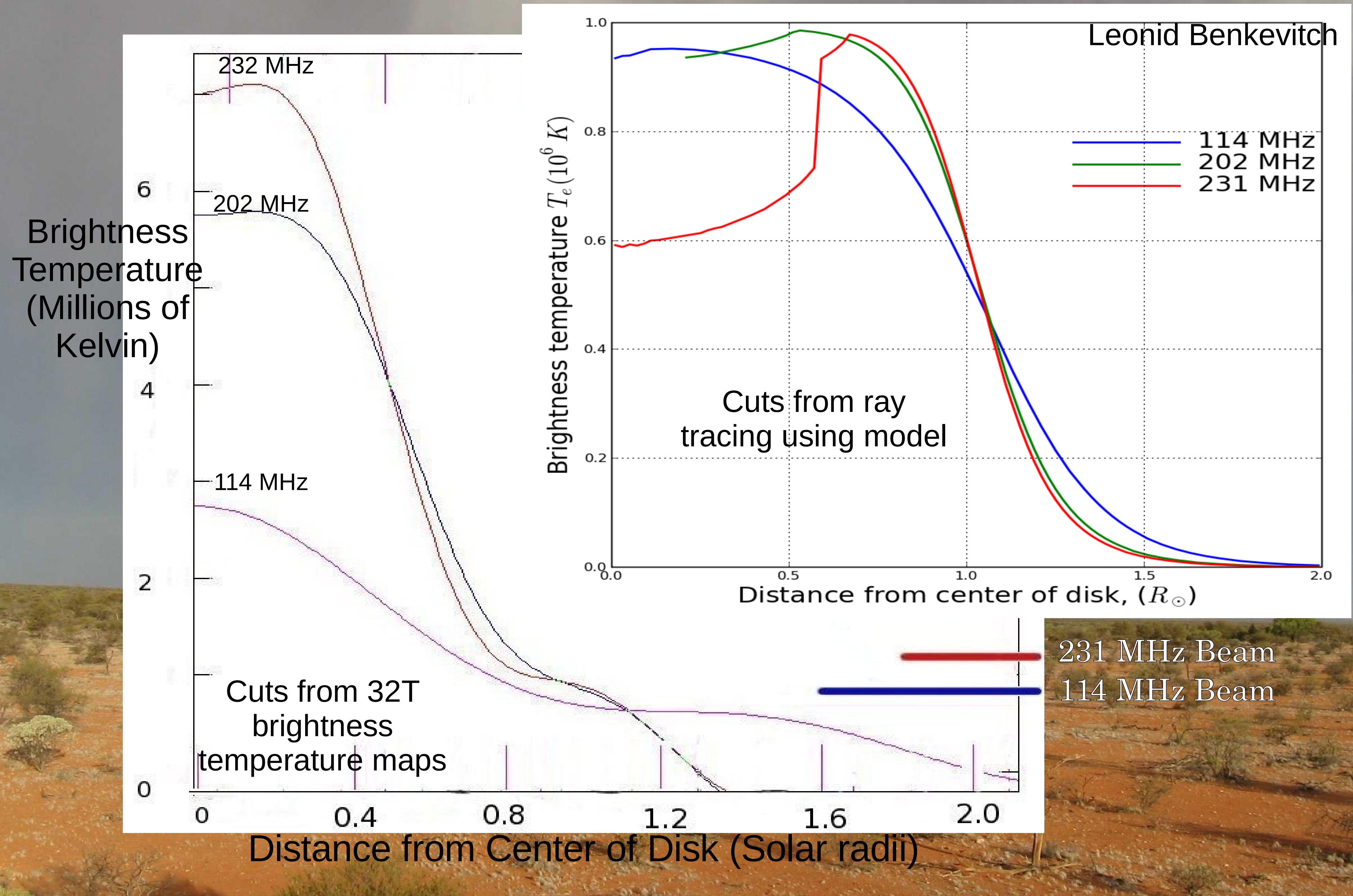
Results

- Measured fluxes between 30 and 670 thousand Janskys
- Our spectral index is 3, published values are 2.2<α<2.5, theory predicts α<2
- Sources of error
  - No correction for tile beamshape
  - Cen A is a complex source on several spatial scales



Erickson, Gergely, Kundu and Mahoney, 1977

Results



Leonid Benkevitch
Brightness temperature $T_e(10^6 K)$
1.0
0.8
0.6
0.4
0.2
0.0
0.0
0.5
1.0
1.5
2.0
Distance from center of disk, $(R_\odot)$
114 MHz
202 MHz
231 MHz
Cuts from ray tracing using model
232 MHz
202 MHz
114 MHz
Brightness Temperature (Millions of Kelvin)
6
4
2
0
0
0.4
0.8
1.2
1.6
2.0
Cuts from 32T brightness temperature maps
231 MHz Beam
114 MHz Beam
Distance from Center of Disk (Solar radii)

Conclusions

- The 32T data appear to be of good quality
  - Found similar trends to what we expected
- First Brightness temperature maps from the 32T
- Still lots to learn about the sun
  - The sun has yet to be studied at low frequencies with high fidelity imaging enabled by the new generation of instruments

The Future

- Tile beam corrections
  - Calculate and then compensate for gain vs. az,el differences
- Ray tracing analysis to look at possible values of electron temperatures and densities
- Additional Observations
  - Regular observations with 32T as the sun emerges from its deep minimum
- Full MWA (Further future)
  - Higher fidelity, higher resolution

Acknowledgments

- Divya Oberoi
- Leonid Benkevitch
- Lynn Matthews
- Vincent Fish and Phil Erickson
- K.T. Paul, Madeleine Needles and Haystack at large
- Greg McGlynn and the other REU's
- Rivier College
- The NSF

Data Reduction

- Need to determine if final images contain actual structure
  - Best fit models to images to see how well they correspond at several frequencies
    - One oblate disk, one oblate ring and 3 point sources
      - Rings larger at lower frequencies
      - Point sources approximately coordinate at all frequencies
    - RMS residuals bottomed out with >5 source models

Interferometry

- Attempts to recreate a single image by combining the signals from separate antennas to make an 'interference pattern'
- One pair of antennas picks out a particular angular scale on the scale oriented parallel to the line between the antennas
  - If things are too far apart or two close together the array won't see them
- Each pair of antennas make one 'baseline'
  - An infinite number of baselines in a circle would re-create the image of an antenna the size of the circle by filling in all the space

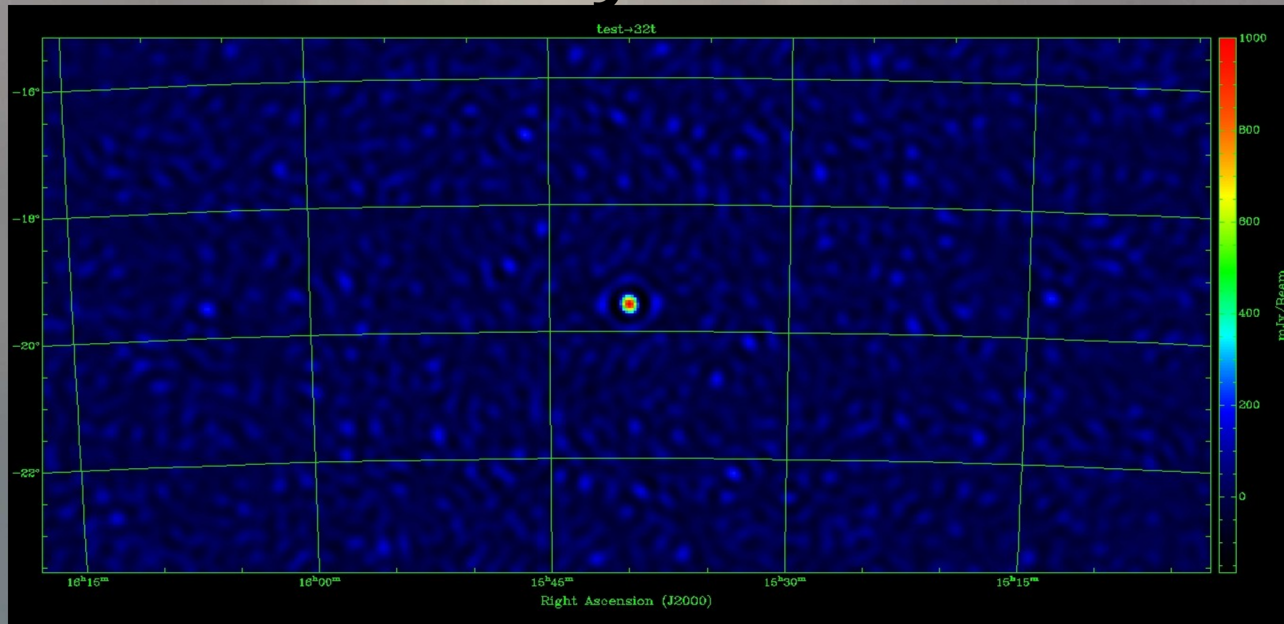
Data Reduction

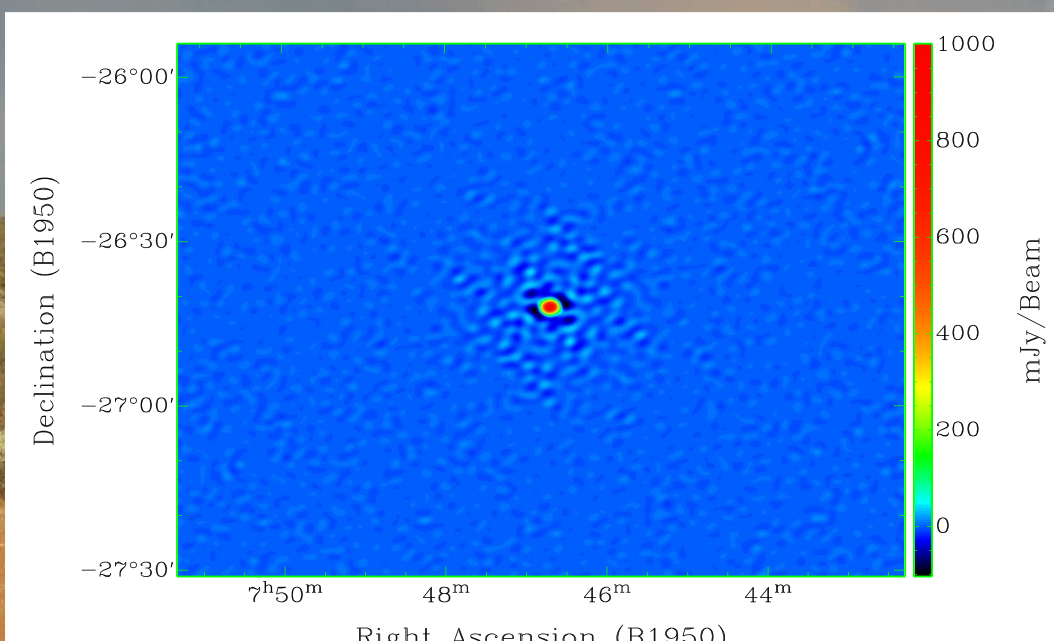
- Self calibrate and CLEAN
  - Signals still dominated by individual antenna responses
  - self-calibration uses the 496 baselines to solve for the 32 antenna gains
    - Least-squares to fit gains to a model for the expected image
  - Calibrated visibilities are still smeared out by the shape of the array's response pattern (beam)
    - CLEAN: Center a PSF on each of the brightest points and subtract them.
    - Add them all back in as spots and not PSF's
    - It's not perfect
      - Can pick up noise; solutions are not unique
  - CLEANed map is then given as self-calibration model
    - Iterative process

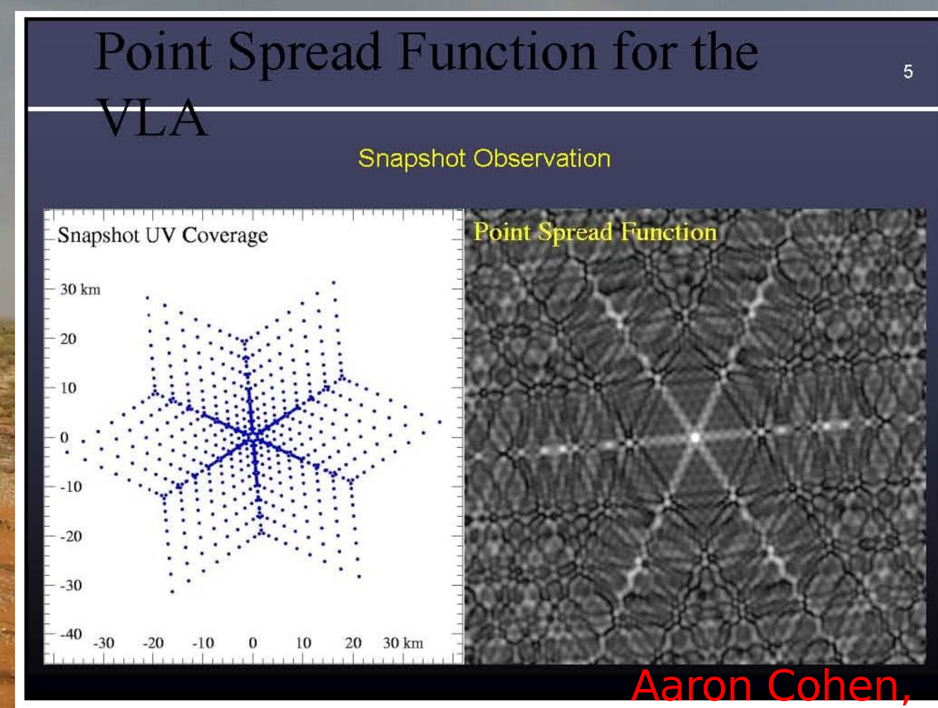
Data Reduction

- Still can't relate voltages from antennas to actual brightness of the sky
  - Need to tell the data how the voltage each baseline receives relates to the incoming flux
    - Flux calibration:
      - Image something with known brightness
      - Scale that image to match the expected brightness
      - Translate solutions from that image to the image of the sun

Why MWA?







Aaron Cohen, NRL