Reionization with the Murchison Widefield Array (MWA)

Judd D. Bowman
Arizona State University
MWA Project Scientist

MWA Team

Partner Institutions

Australia National University
Commonwealth Scientific Industrial Research Organization (CSIRO)
Curtin University of Technology
Harvard University / Smithsonian Center for Astrophysics
Massachusetts Institute of Technology / Haystack Observatory
Massachusetts Institute of Technology / Kavli Institute
Melbourne University
Raman Research Institute
Swinburne University of Technology
University of Sydney
University of Tasmania
University of Western Australia
Victoria University of Wellington

Commissioning Team

Martin Bell (Sydney)
Gianni Bernardi (SKASA)
Ramesh Bhat (Curtin)
Frank Briggs (ANU)
Avinash Deshpande (RRI)
Aaron Ewall-Wice (MIT)
Lu Feng (MIT)
Bryna Hazelton (UW)
Natasha Hurley-Walker (Curtin)
Danny Jacobs (ASU)
Nadia Kudryavtseva (Curtin)
Emil Lenc (Sydney)
Ben McKinley (ANU)
Daniel Mitchell (Univ. Melbourne)
Divya Oberoi (NCRA)
Steve Ord (Curtin)P
ietro Procopio (Univ. Melbourne)
Jennifer Riding (Univ. Melbourne)
Randall Wayth (Curtin)

And many more team members!


Timor Sea
Northern Territory
You are here
MWA is here
Queensland
Australia
Western Australia
Coral Sea
South Australia
New South Wales
Great Australian Bight
Australian Capital Territory
Victoria
Tasmania
Imagery ©2013 TerraMetrics, Map data ©2013 GBRMPA, Goog

N. Hurley-Walker (Curtin)

MWA Timeline

- 2006-2008: Project initiation, design, and development
- 2008-2011: Operation of 32T prototype system
- 2012 August: Science commissioning commenced
- 2012 December: Practical completion of telescope
- 2013 July 9: Operational launch (last week!)
- 2013-2015: Minimum planned operation

MWA System Parameters

Table 1. System Parameters for the MWA

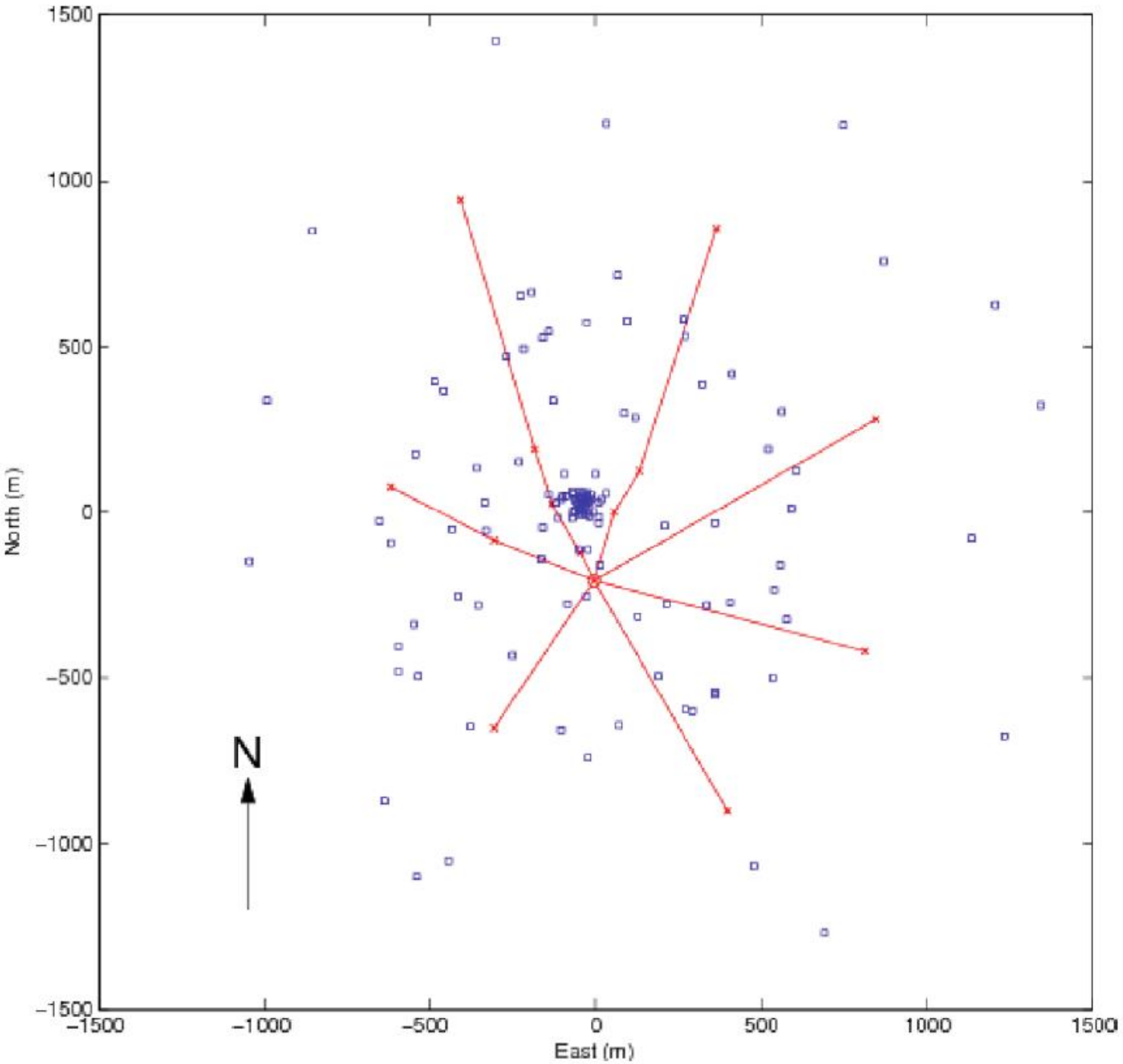
Parameter	Symbol	150 MHz	200 MHz
Number of tiles	N	128	128
Area of one tile at zenith (m^2)	$A_{\rm eff}$	21.5	19.8
Total collecting area (m^2)		2 752	2 534
Receiver temperature (K)	$T_{\rm rcv}$	50	25
Typical sky temperature[a] (K)	$T_{\rm sky}$	350	170
Field of view[b] ($\deg^2$)	$\Omega_{\rm P}$	610	375
Instantaneous bandwidth (MHz)	B	30.72	30.72
Spectral resolution (MHz)		0.04	0.04
Temporal resolution		0.5 s uncalibrated 8 s calibrated	0.5 s uncalibrated 8 s calibrated
Polarisation		Full Stokes	Full Stokes
Minimum baseline (m)		7.7	7.7
Maximum baseline (m)		2 864	2 864
Angular resolution (1.5-km array)		~3 arcmin	~2 arcmin
Angular resolution (3-km array)		~2 arcmin	~1 arcmin

[a] Nijboer, Pandey-Pommier, & de Bruyn (2009).
[b] Based on the FWHM of the primary beam. Imageable area is significantly larger.

- SEFD = ~20 kJy at 200 MHz at high Galactic latitude
- Bandpass is 80 to 300 MHz (corresponding to 15>z>4)

Tingay et al. 2013

MWA - an imaging array: array layout



Core: ~50 tiles distributed uniformly within a 100 meter radius core

- High surface brightness sensitivity on ~1 degree scales

Mid-array: additional ~60 tiles distributed out to 750 meters

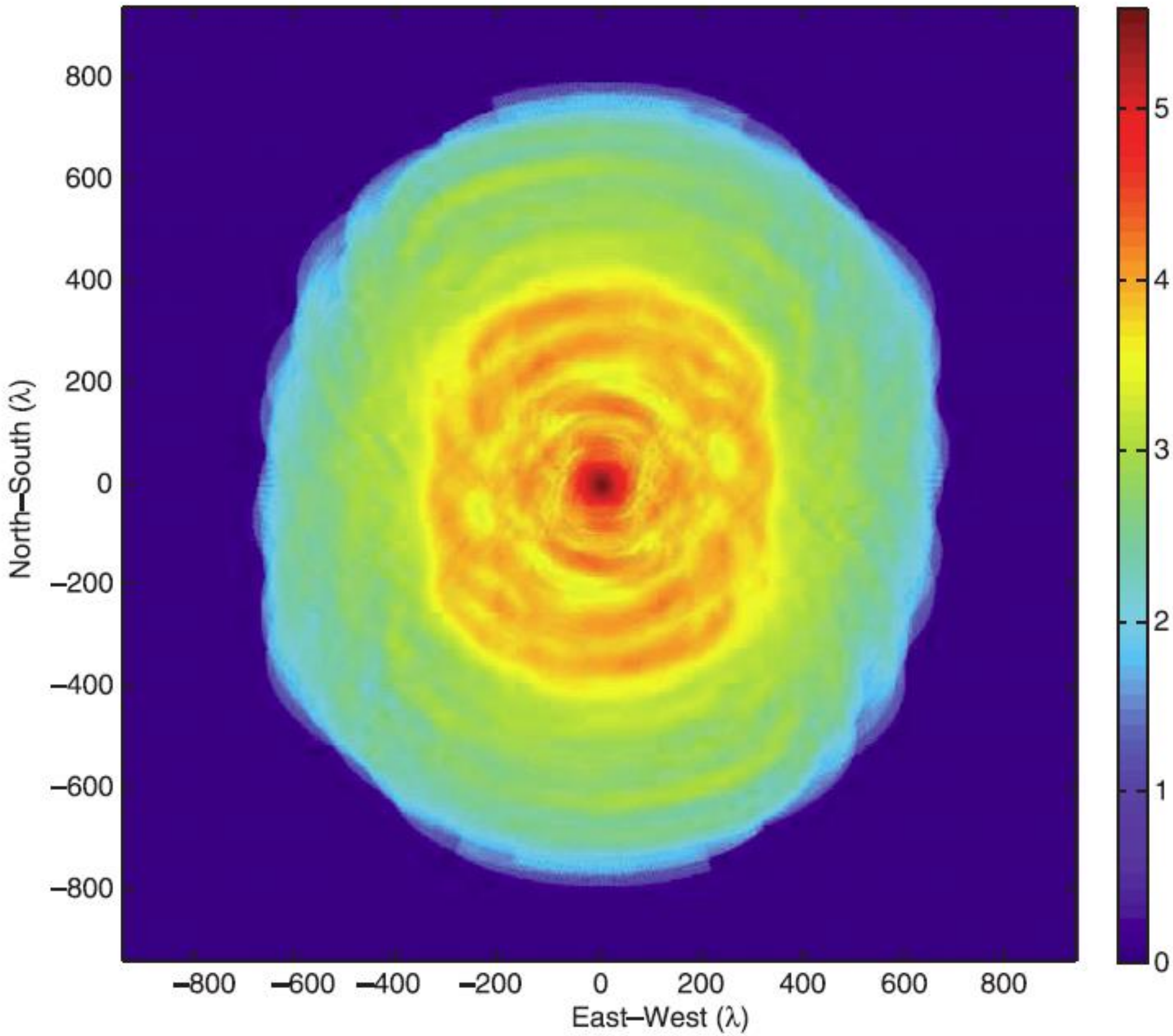
- Excellent PSF

Outliers: 16 tiles at a radius of ~1.5 km

- ~1 arcmin resolution

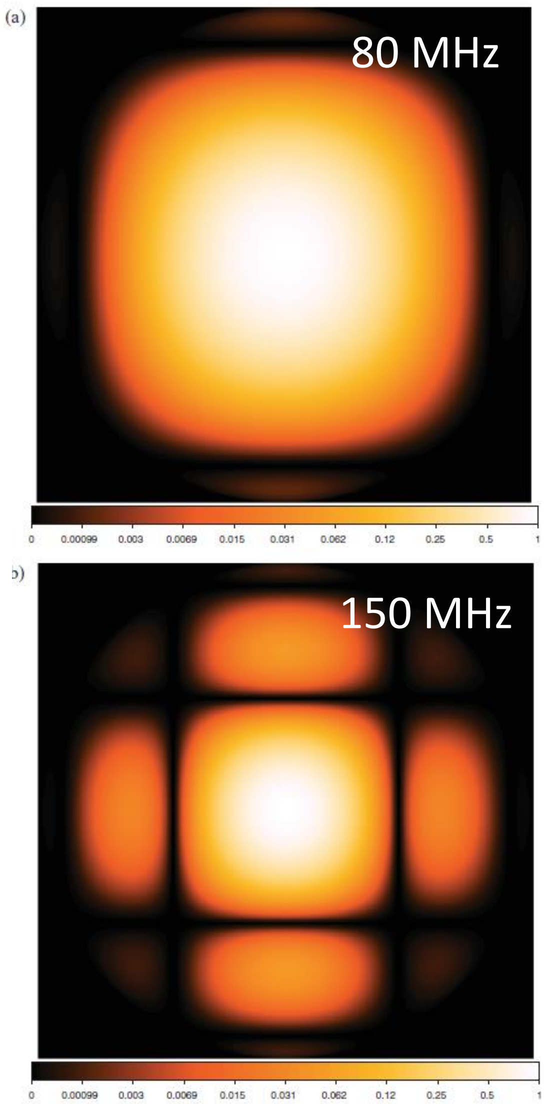
Tingay et al. 2013

MWA - an imaging array: UV coverage

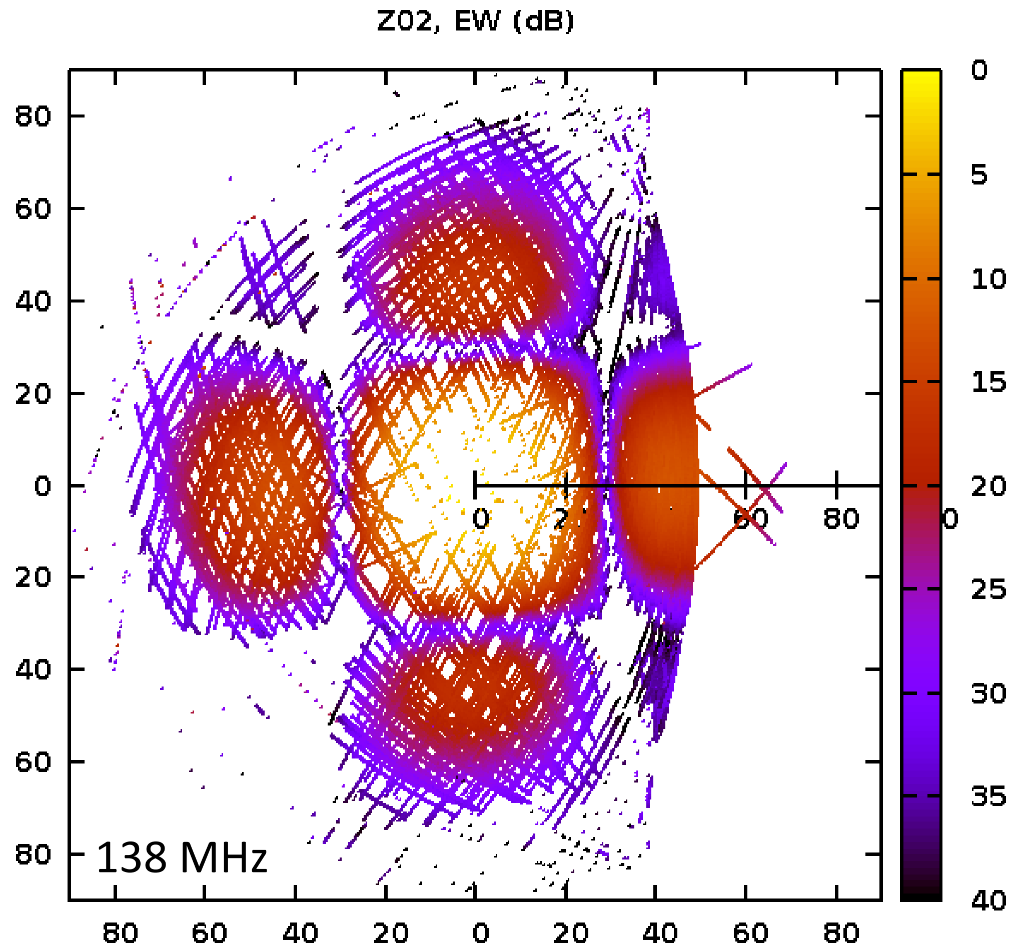


Beardsley et al. 2013

Beam pattern (FOV)



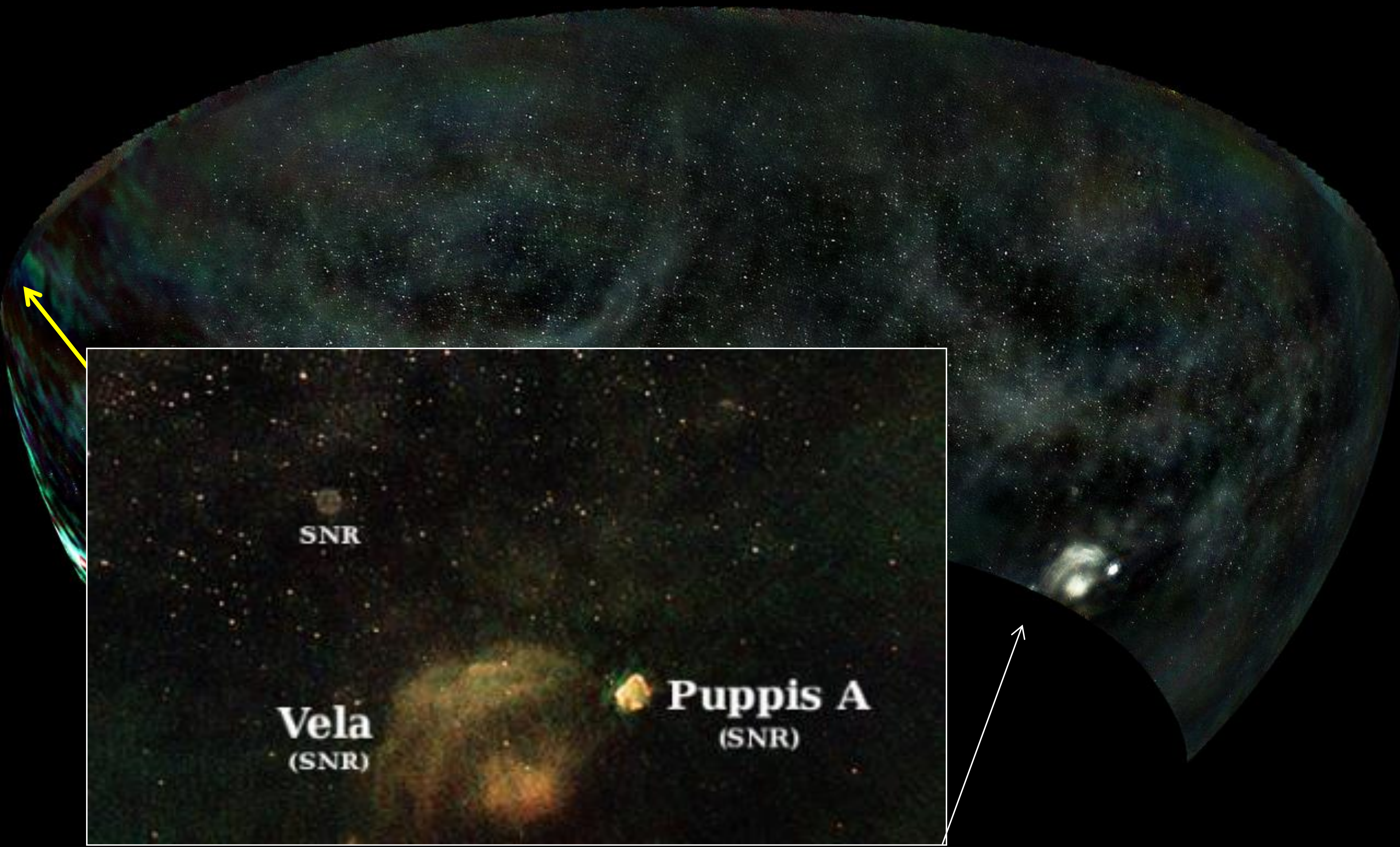
Tingay et al. 2013



Abraham Neben (MIT)
Daniel Mitchell (Melbourne)

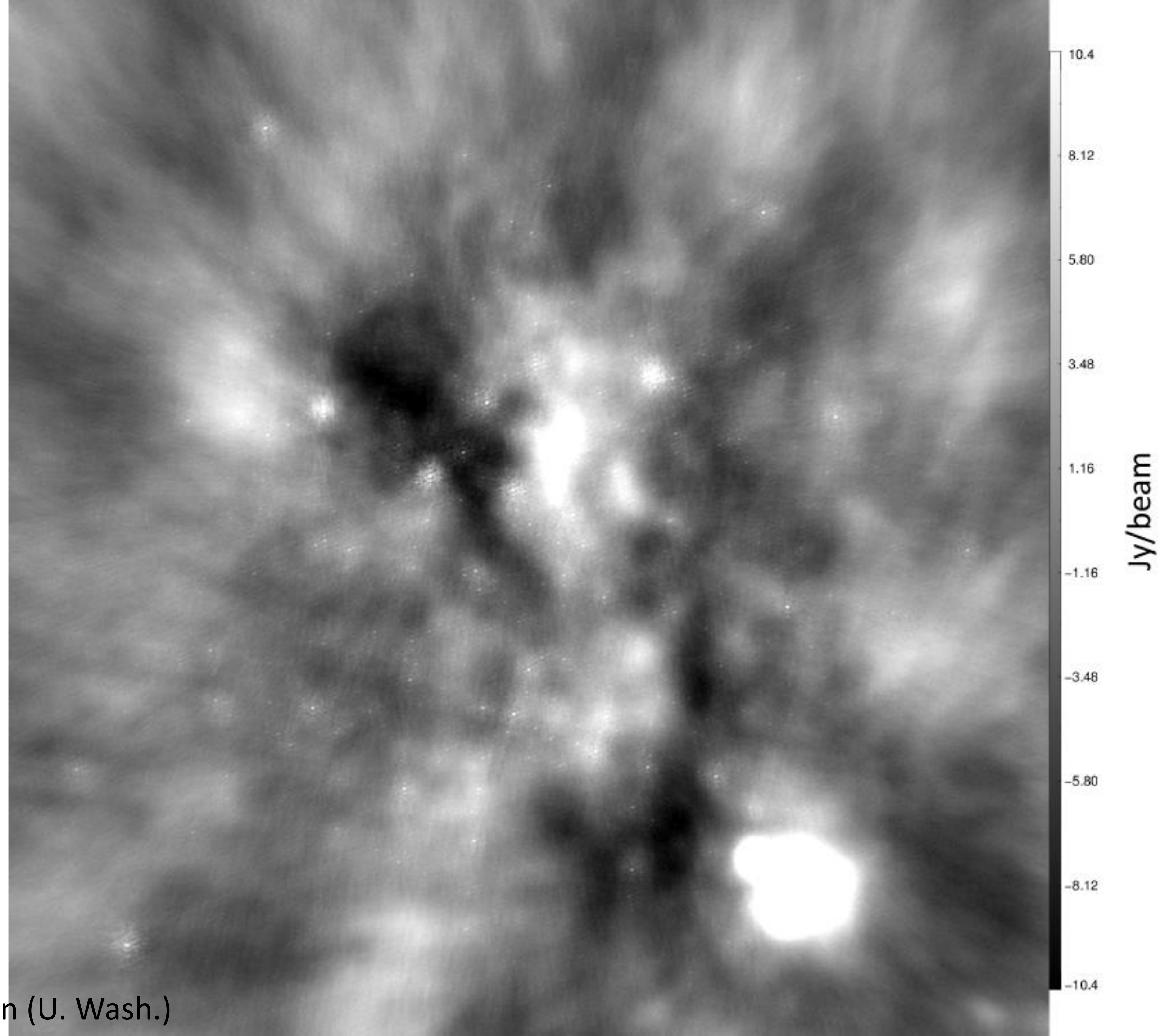
Early examples of imaging and source detection

Single night zenith drift scan



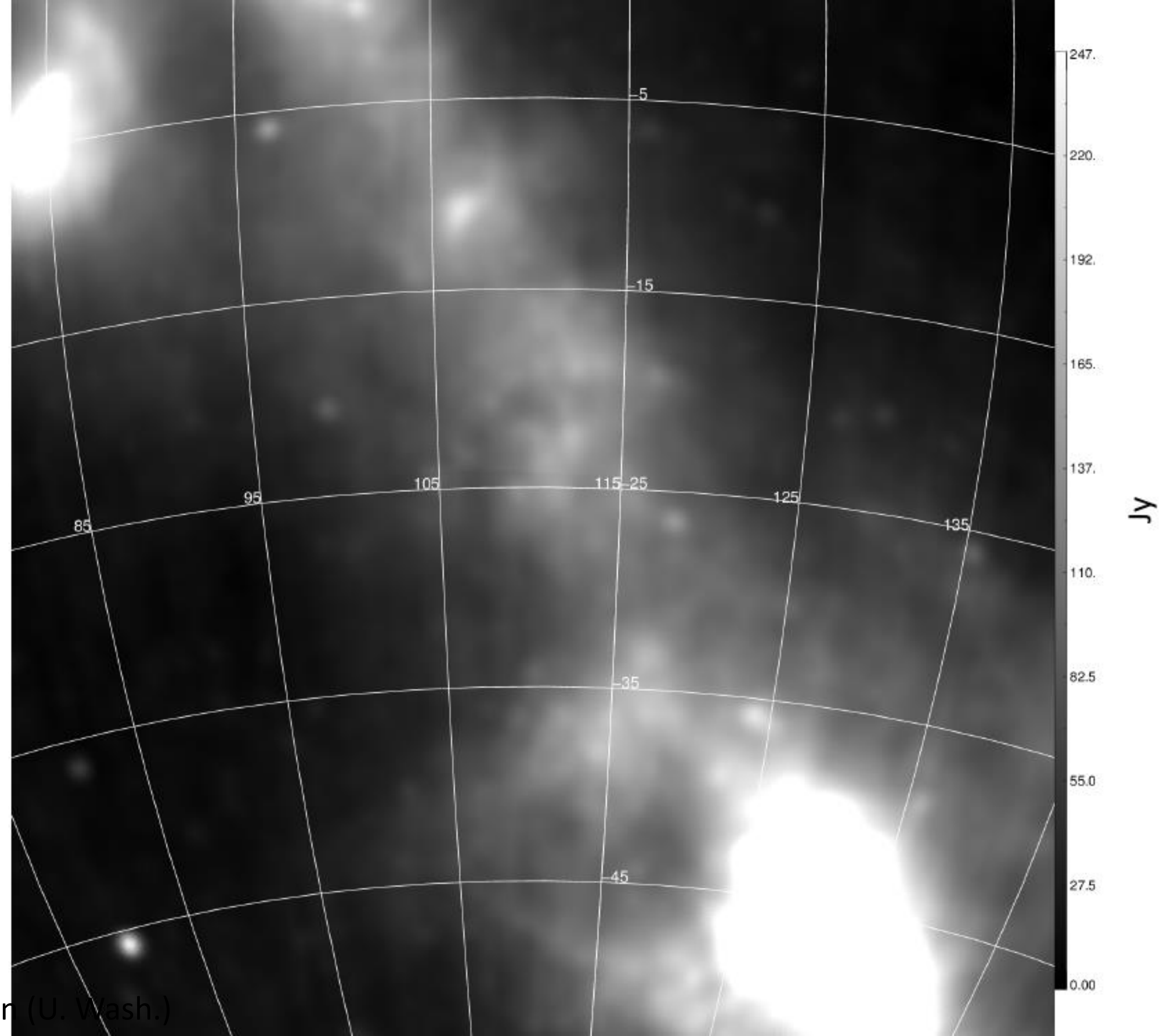
Andre Offringa (ANU) and the MWA commissioning team

Dirty XX image



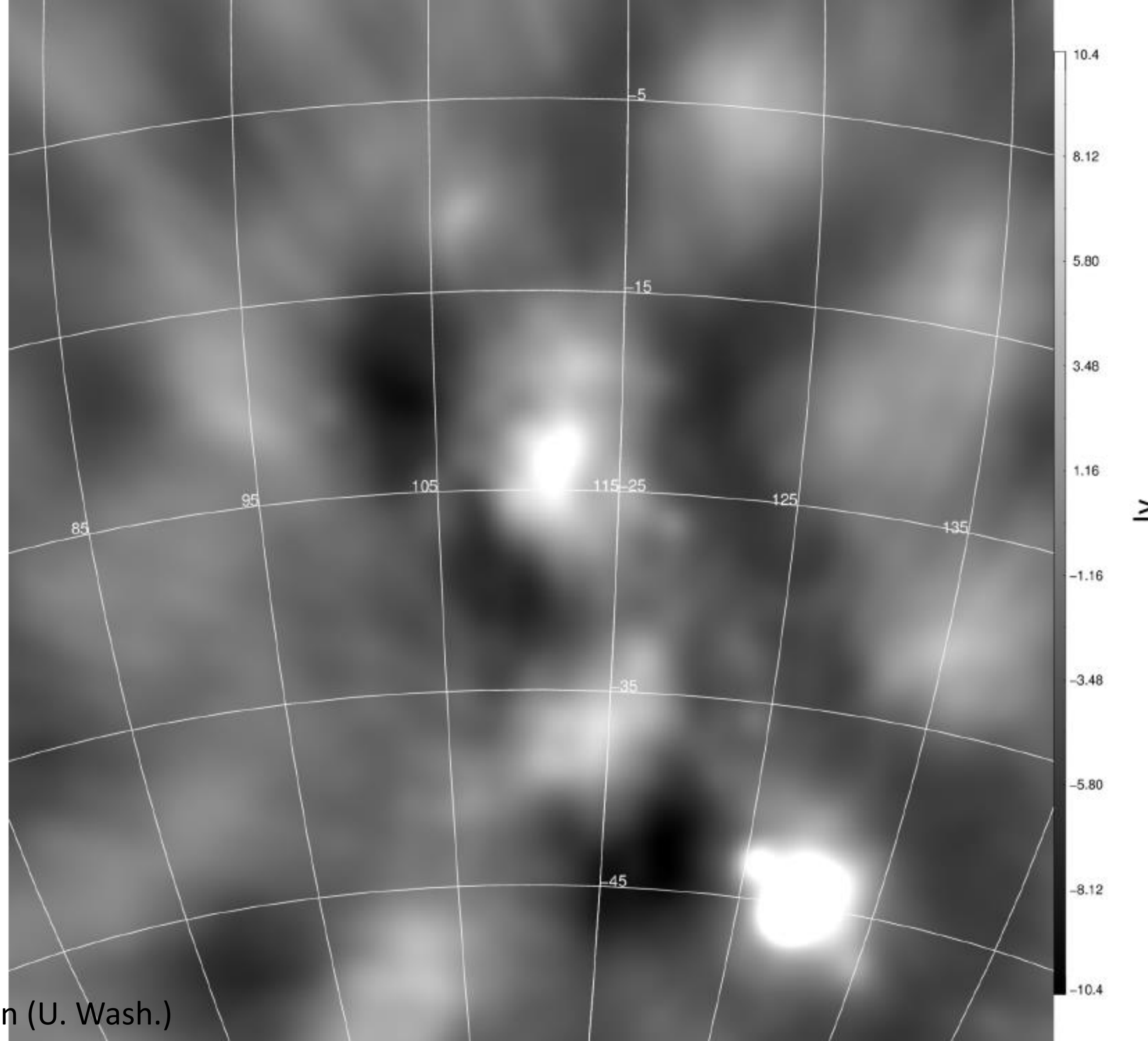
Ian Sullivan (U. Wash.)

Input diffuse model
Stokes I

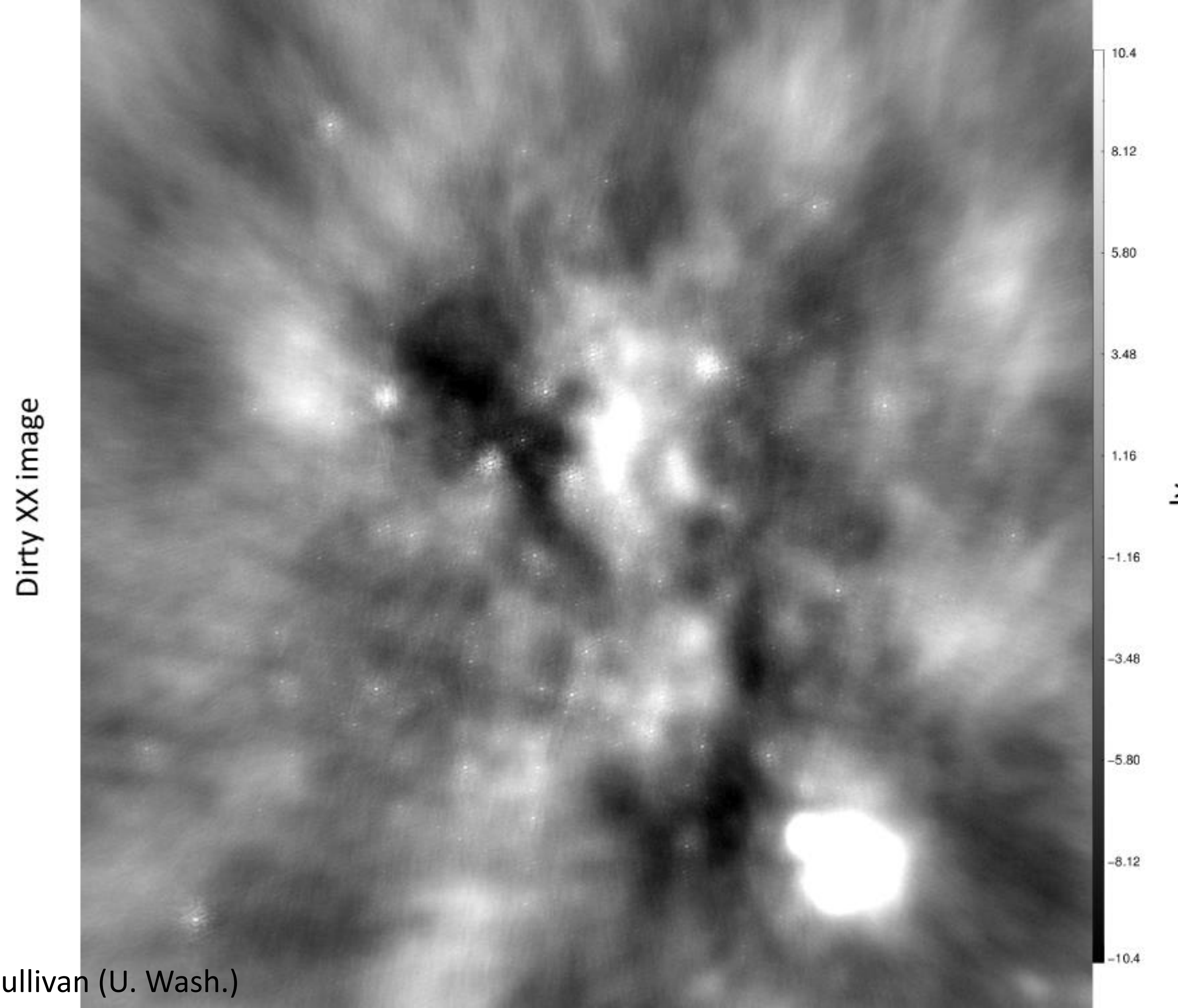


Ian Sullivan (U. Wash.)

Diffuse model with XX HMF applied

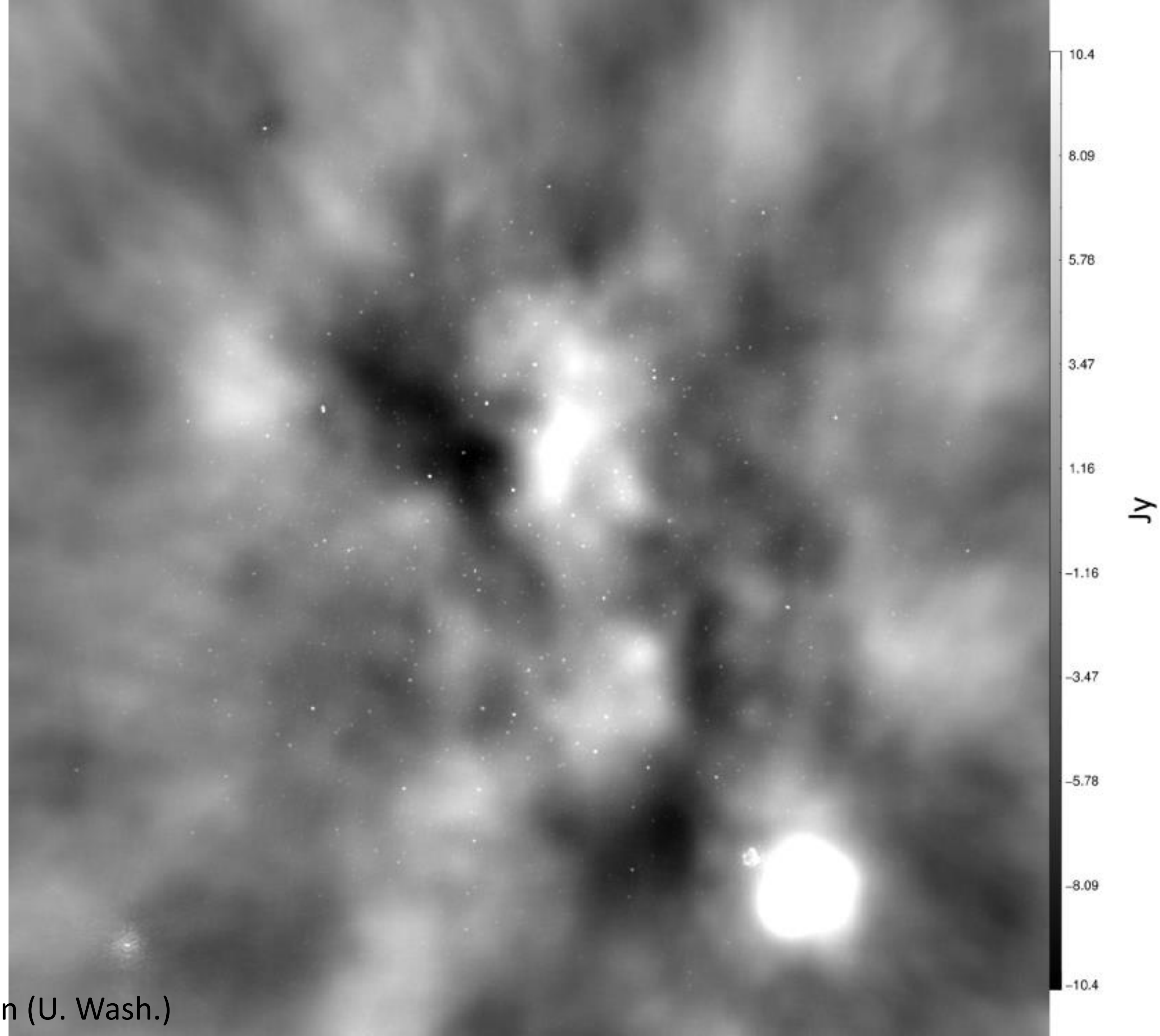


Ian Sullivan (U. Wash.)

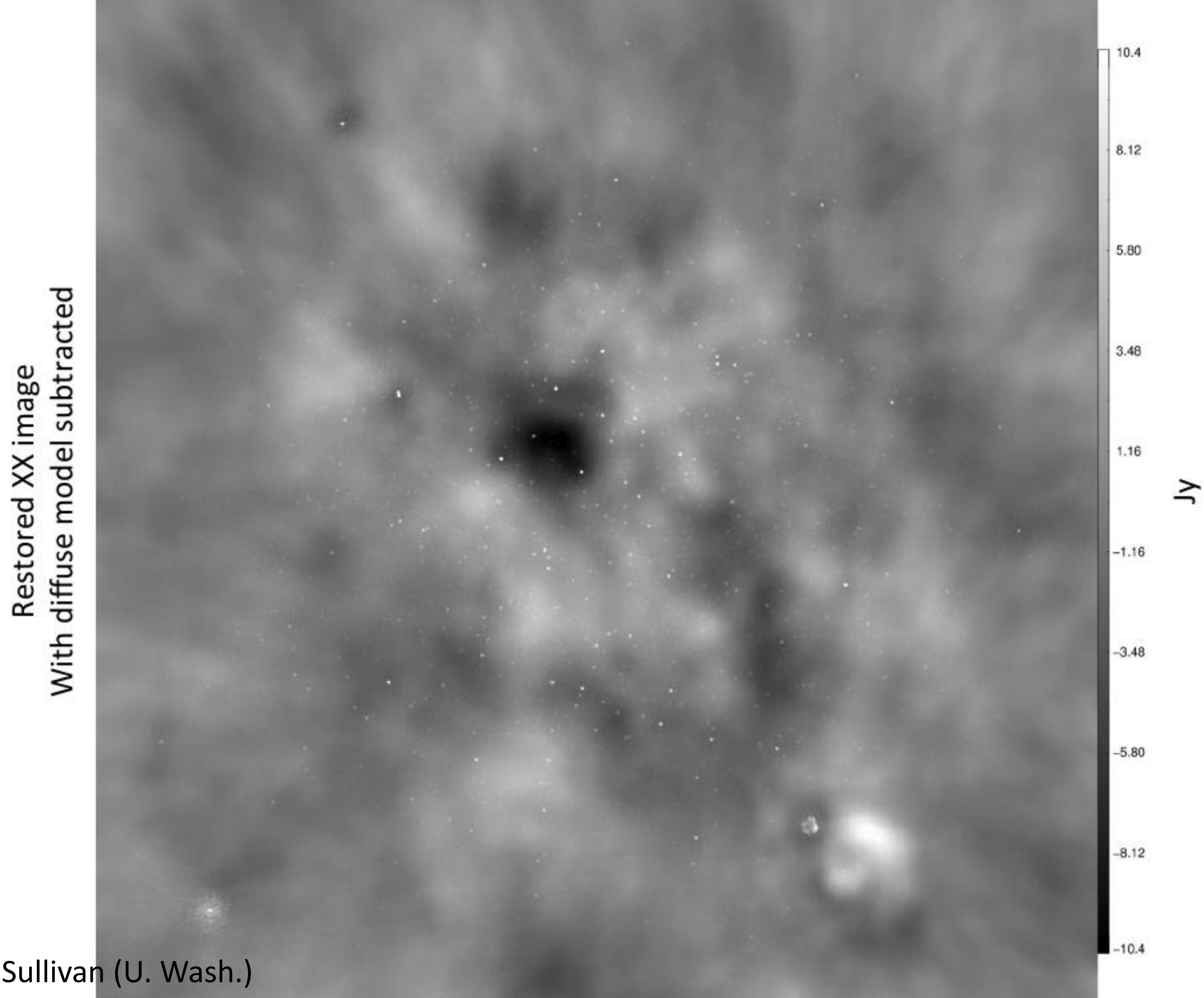


Ian Sullivan (U. Wash.)

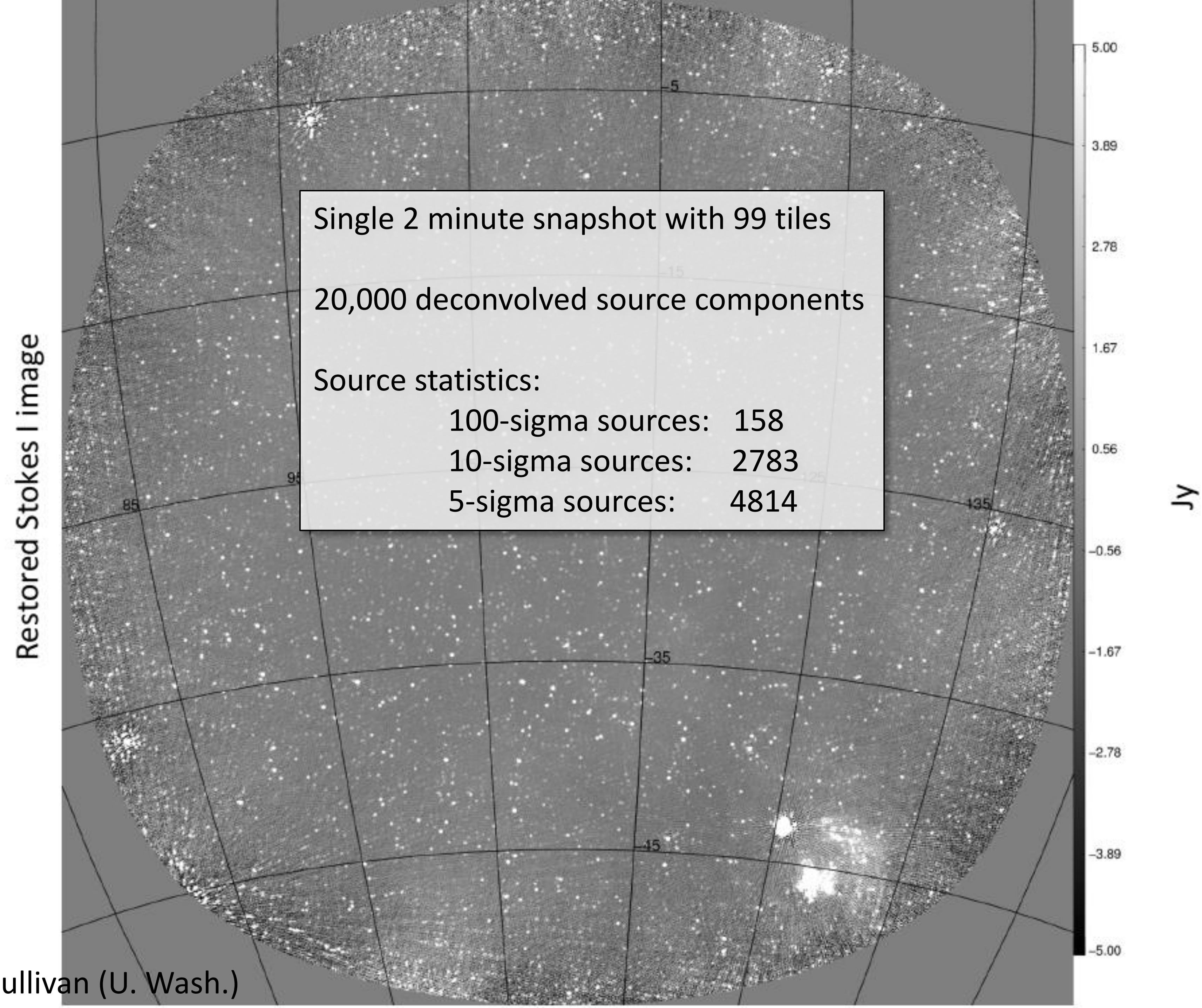
Restored XX image
No subtraction of diffuse model



Ian Sullivan (U. Wash.)



Ian Sullivan (U. Wash.)



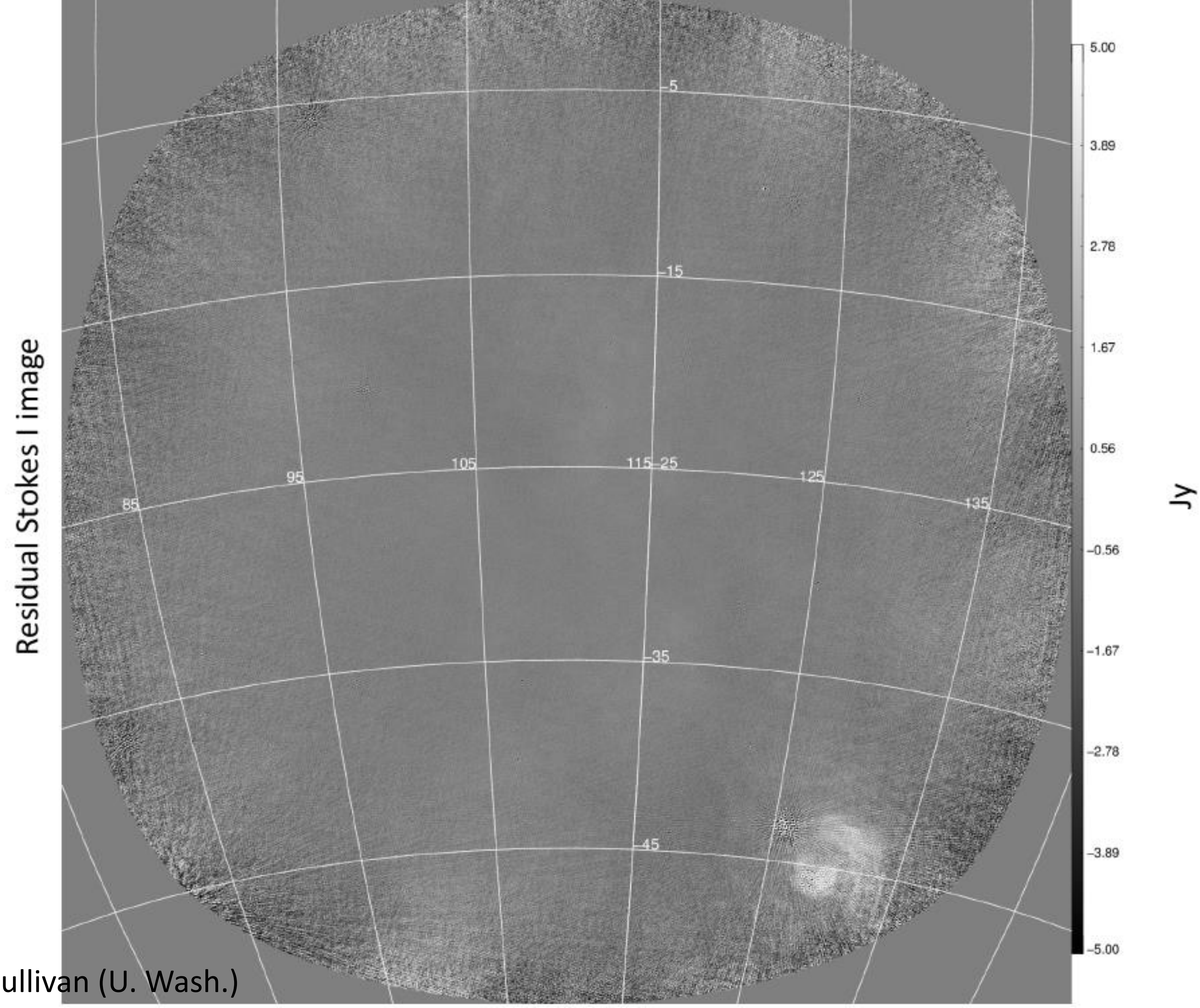
Single 2 minute snapshot with 99 tiles

20,000 deconvolved source components

Source statistics:

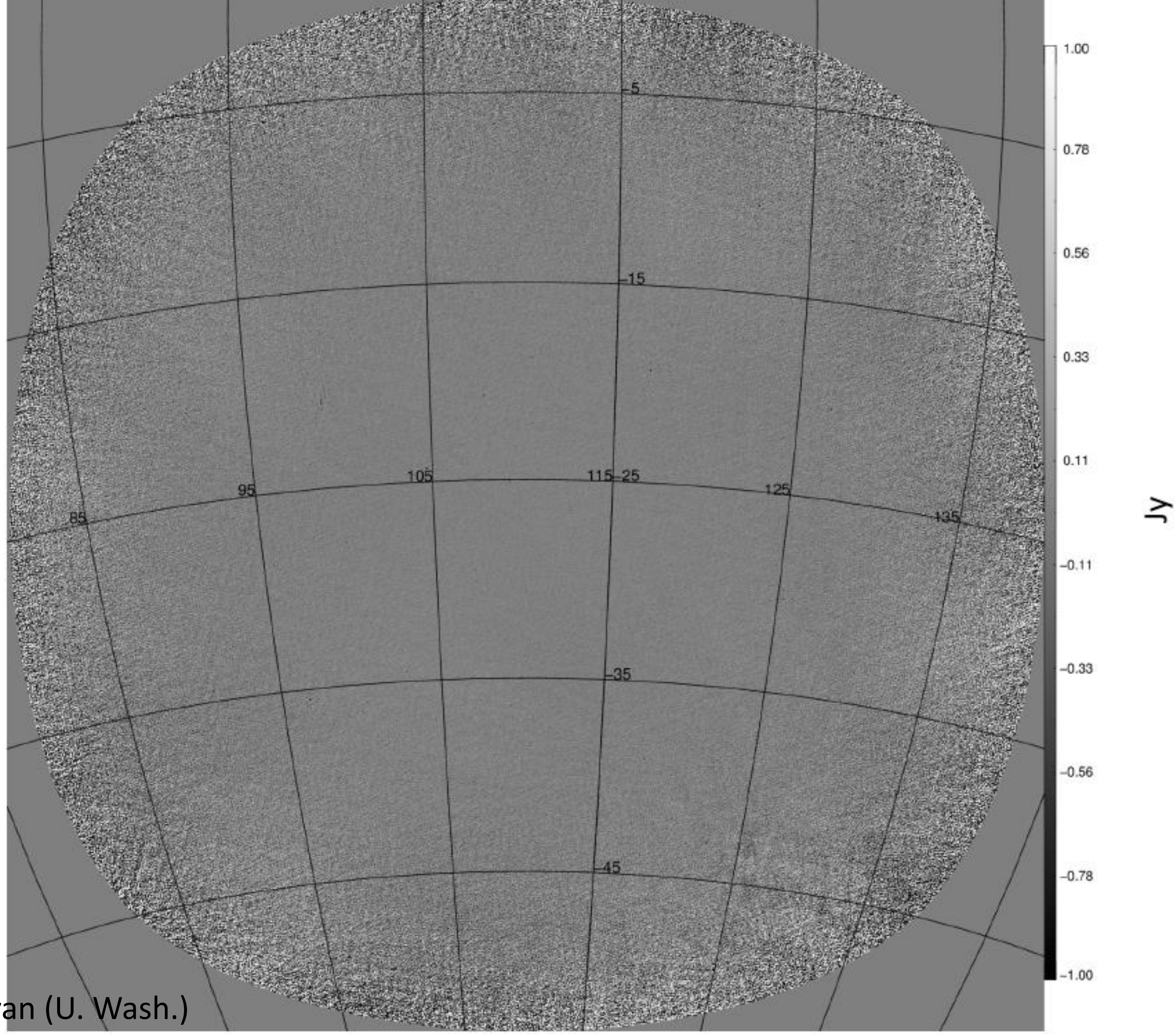
100-sigma sources: 158
10-sigma sources: 2783
5-sigma sources: 4814

Ian Sullivan (U. Wash.)



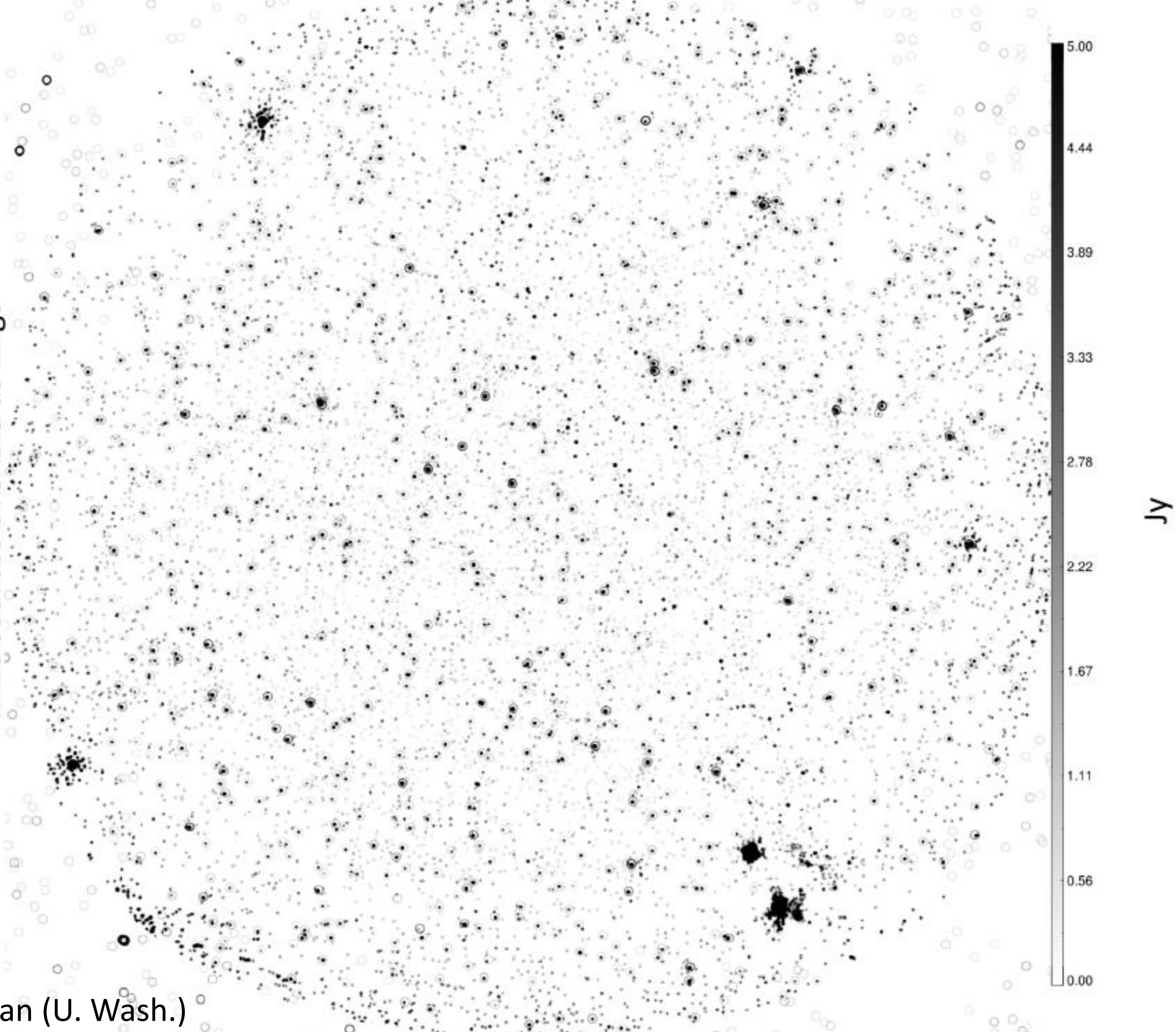
Ian Sullivan (U. Wash.)

Residual Stokes Q image



Ian Sullivan (U. Wash.)

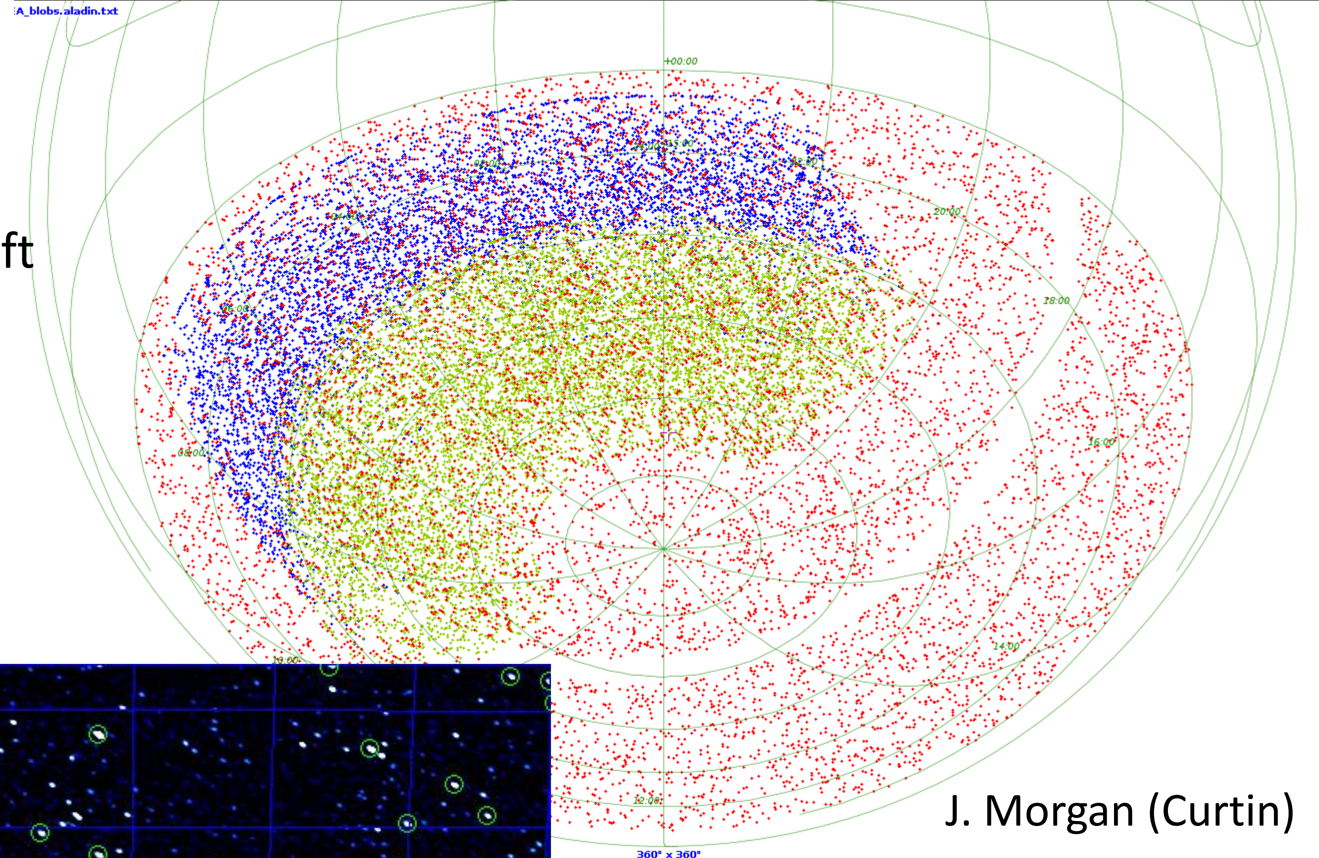
Stokes I sources
MRC sources overlaid as rings



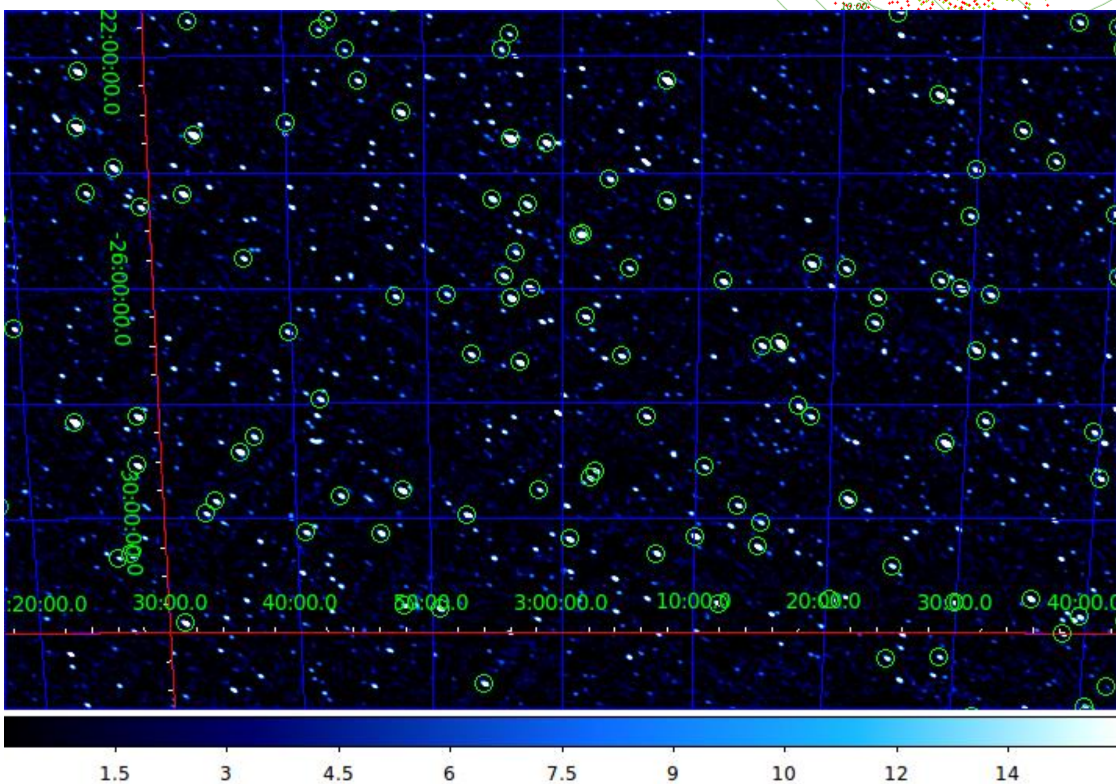
Ian Sullivan (U. Wash.)

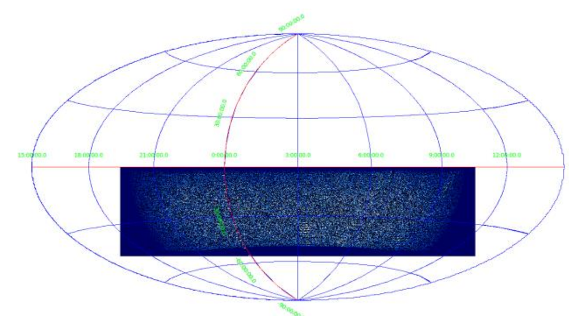
Sources

- Zenith and -45 Dec drift
- Commissioning using only 25% of array ("gamma array")
- 30,000+ sources
- MRC source overlays



J. Morgan (Curtin)





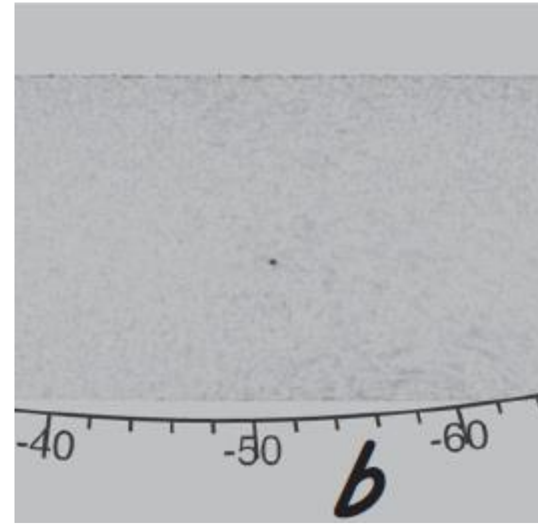
R. Wayth (Curtin)

Polarized Sources

- **Estimate ~1 polarized source/deg^2**
  - Extrapolated from higher frequencies, previous surveys
  - Many will be faint ~mJy
  - 6 sources detected during commissioning:

Source name	Type	Polarised Flux (mJy beam^{-1} RMSF^{-1})	RM (rad m^{-2})	RM (literature) (rad m^{-2})
PMN J0351−2744	AGN Hot spot	303	+32.1	+34.7 [a]
PSR J0437−4715	Pulsar	239	+0.0	+0.0 [b]
PSR J0628−285	Pulsar	180	+45.6	+46.5 [b]
PMN J0636−2041	AGN Hot spot	921	+49.1	+47.1 [a]
PSR J0742−2822	Pulsar	235	+149.3	+149.95 [b]
PSR J0835−4510	Pulsar	642	+35.6	+31.38 [b]

- **RM resolution = 0.3 rad/m^2** for synthesis across full MWA band, better with centroiding
- **RM maximum** = **1300 rad/m^2** for 40 kHz spectral resolution
- **Instrumental polarization leakage** better than <1%, and only ~0.1% near calibrators



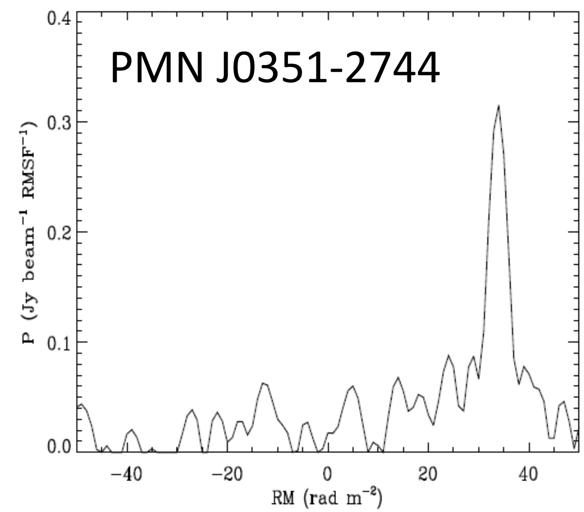
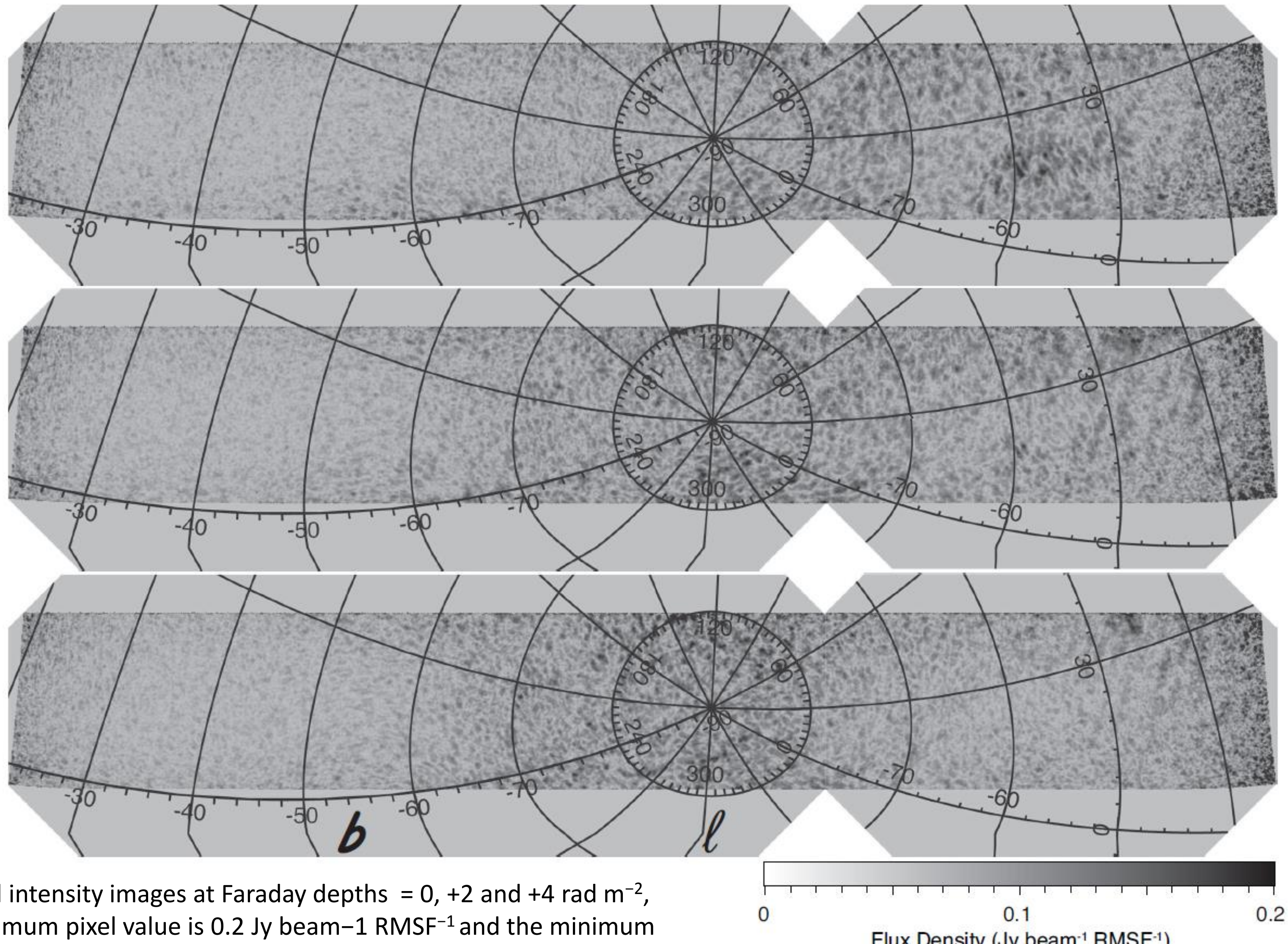


FIG. 7.— The Faraday depth spectrum of PMN J0351-2744 at 188 MHz. The spectrum peaks at RM = $+33.85 \pm 0.07$ rad m^{-2}

Emil Lenc (Sydney) / Bernardi et al. 2013

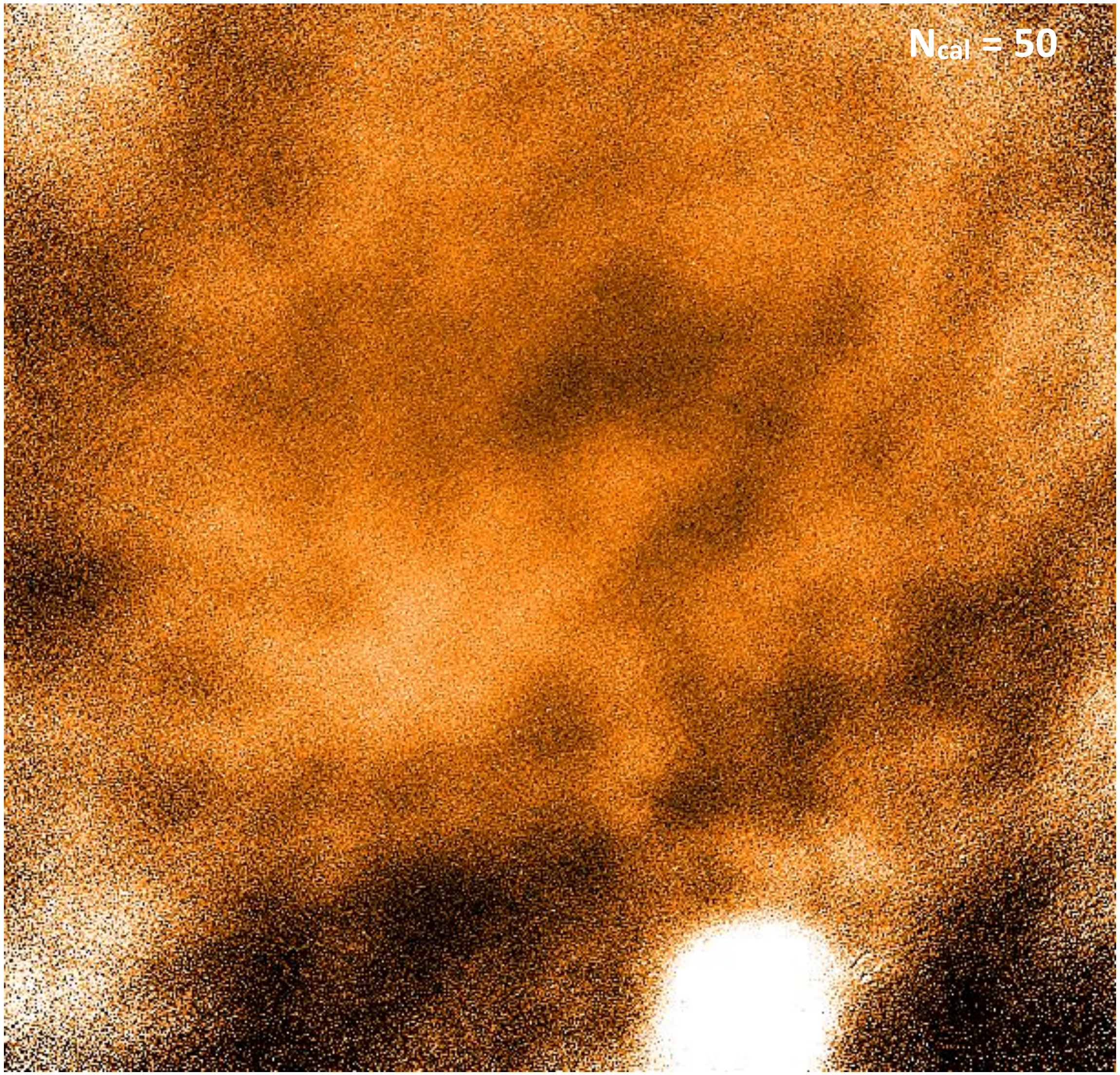
Polarized Diffuse Emission



Polarized intensity images at Faraday depths = 0, +2 and +4 rad m^{-2}, The maximum pixel value is 0.2 Jy beam−1 $RMSF^{-1}$ and the minimum pixel value is zero. The conversion factor is 1 Jy beam−1 $RMSF^{-1}$ = 44.4 K $RMSF^{-1}$. **15 arcmin resolution. 2400 sq. degrees. P = 13 K**

Bernardi et al. 2013

Joint widefield imaging and calibration in real-time (RTS)



Full peeling of MRC sources with J-matrix fits

N_a = 99 tiles
Subtract 500 sources
Calibrate on N_{cal} sources

~$N_{pol}N_a(N_a-1)/2$ vis
~$N_{pol}N_a$ unknowns

Want N_{cal} < ~$N_a/2$ so able to solving independently for ~50 calibrators in this observation

Daniel Mitchell (Melbourne)

Upcoming Observations

photo: John Goldsmith

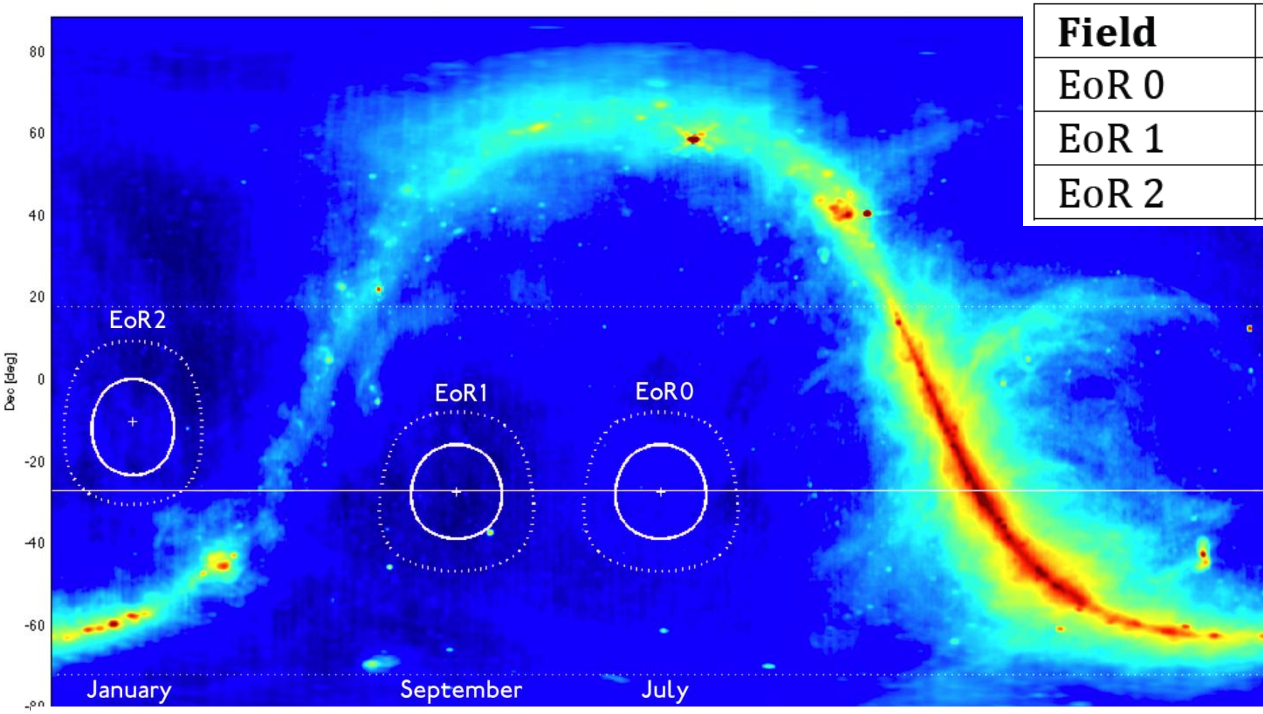
750 hours of observations planned in 2013B (started this month):

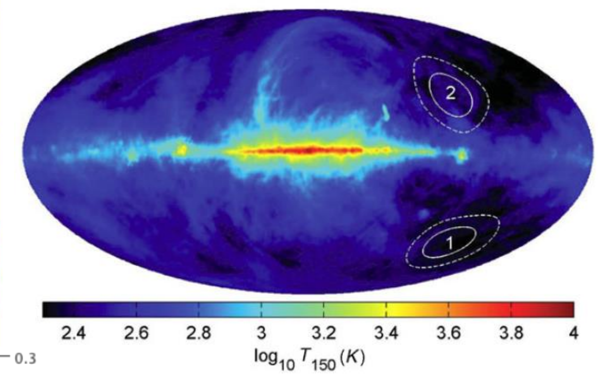
- ~400 hours for redshifted 21 cm, concentrating on $6<z<9$
- ~150 hours for all-sky survey
- Plus additional science and instrument development time

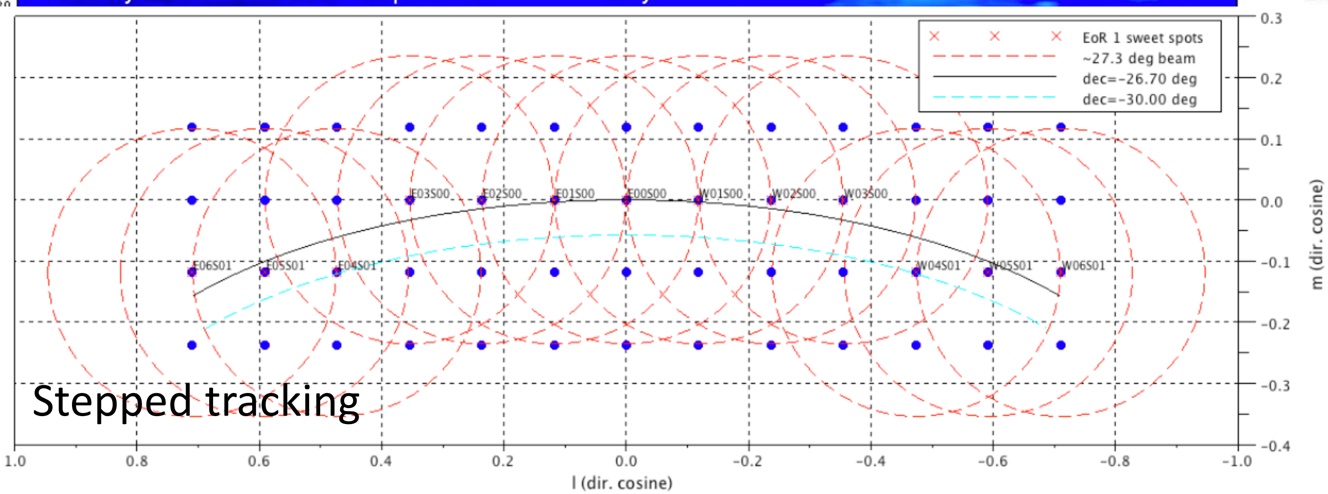
Expect roughly equivalent observing time in 2014A

MWA EoR Observations

Field	Coords
EoR 0	RA=00.00hr, Dec=-30.00deg
EoR 1	RA=04.00hr, Dec=-27deg
EoR 2	RA=11.33hr, Dec=-10deg

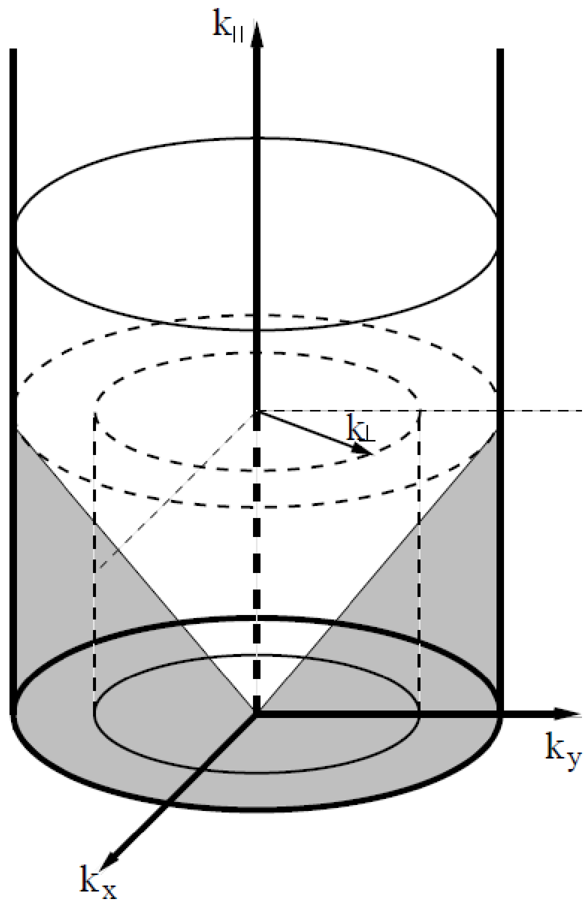


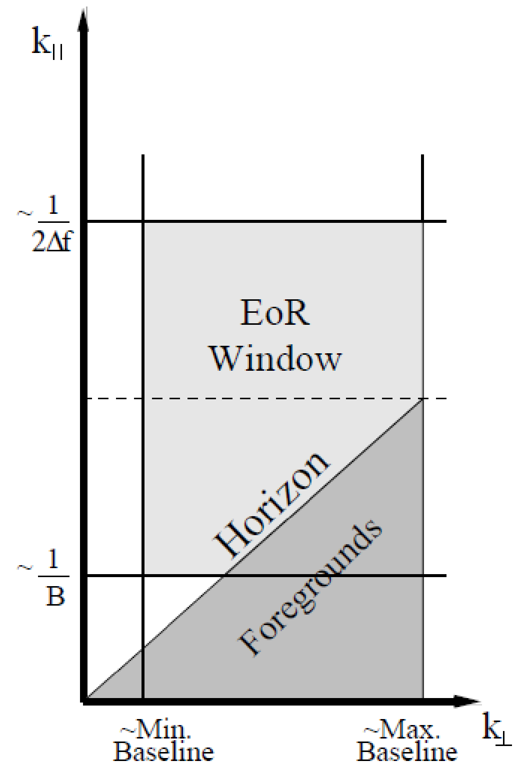




Daniel Jacobs (ASU)

Observational properties of the 21 cm signal in Fourier domain



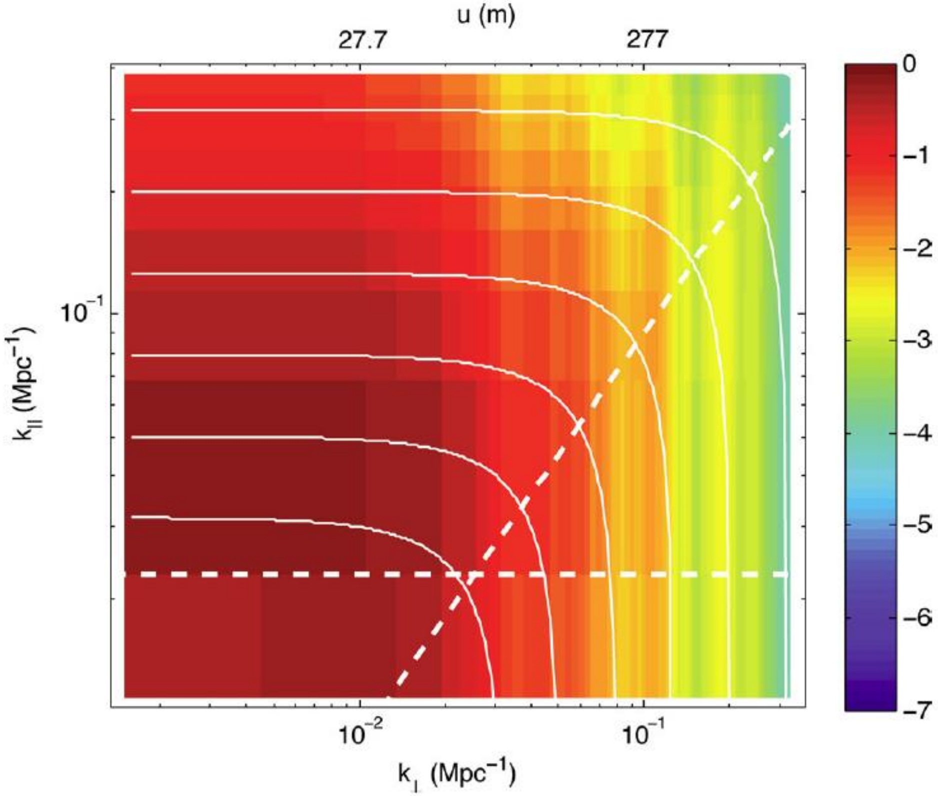


- There is an EoR window where the signal should dominate
- Can use understanding to identify errors below the imaging limit

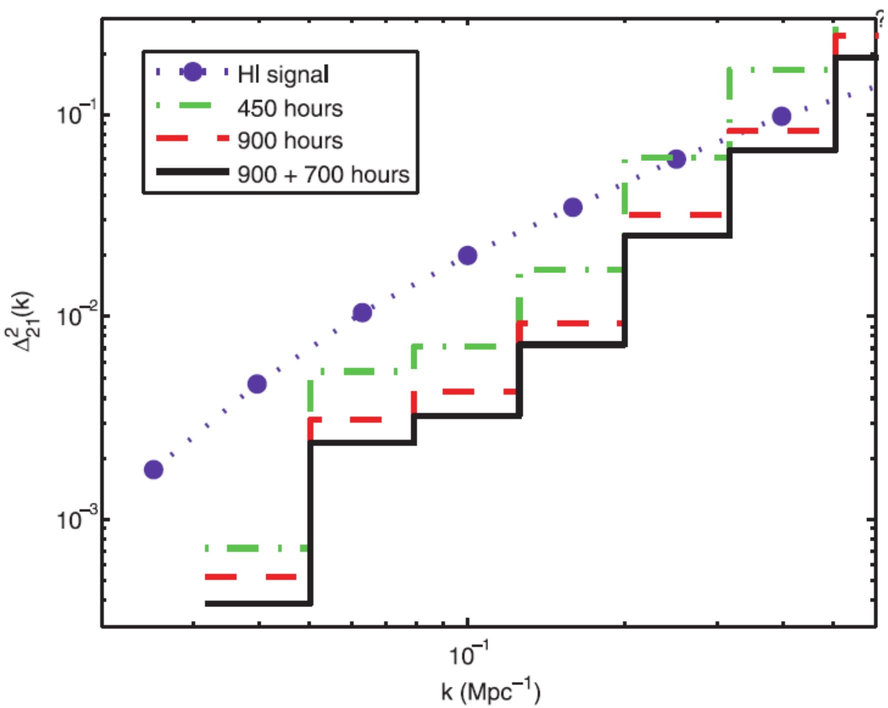
Datta et al. (2010)
Liu & Tegmark (2011)
Morales et al. (2012)
Vendatham et al. (2012)
Trott et al. (2012)
Parsons et al. (2012)
Hazelton et al. (2013)
Thyagarajan et al. (submitted)

MWA 21 cm sensitivity (theoretical)

Signal-to-noise per bin in 2D k-space



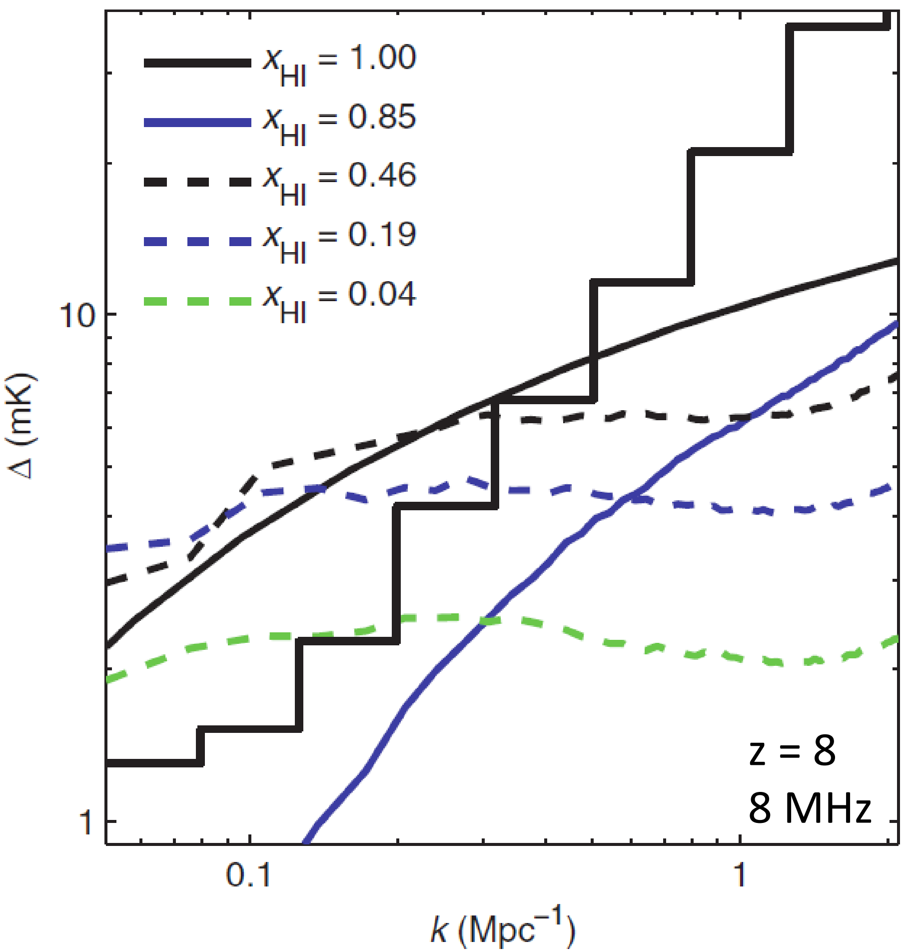
Uncertainty limits in 1D power spectrum



SNR < 1 / pixel (but 10^8 pixels)
Total power spectrum SNR = 14

Beardsley et al. 2013

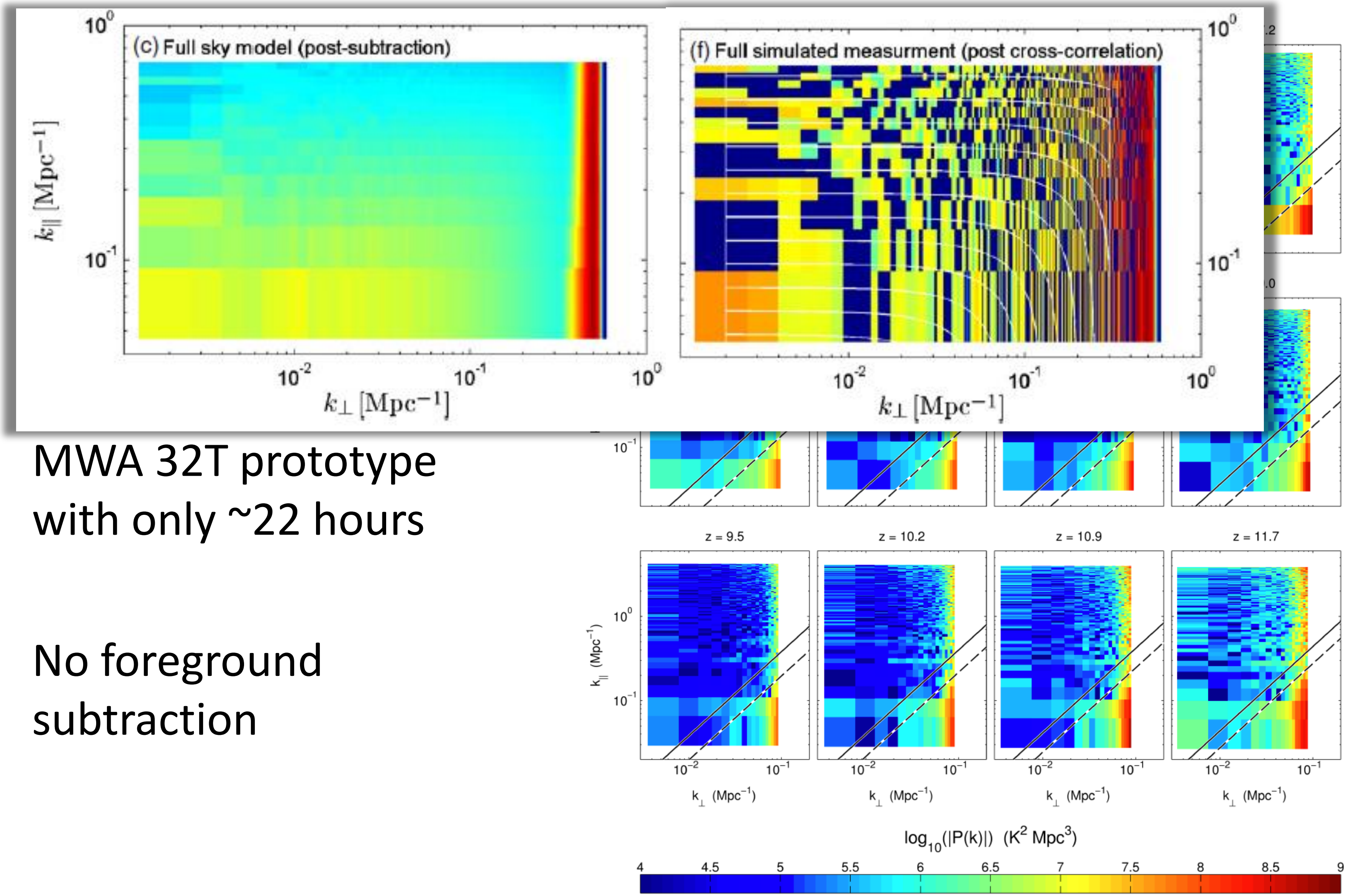
MWA 21 cm sensitivity vs. reionization



Bowman, et al. (2013)

Simulated 21 cm signal from Lidz et al. (2008)

MWA proof-of-concept results (1)

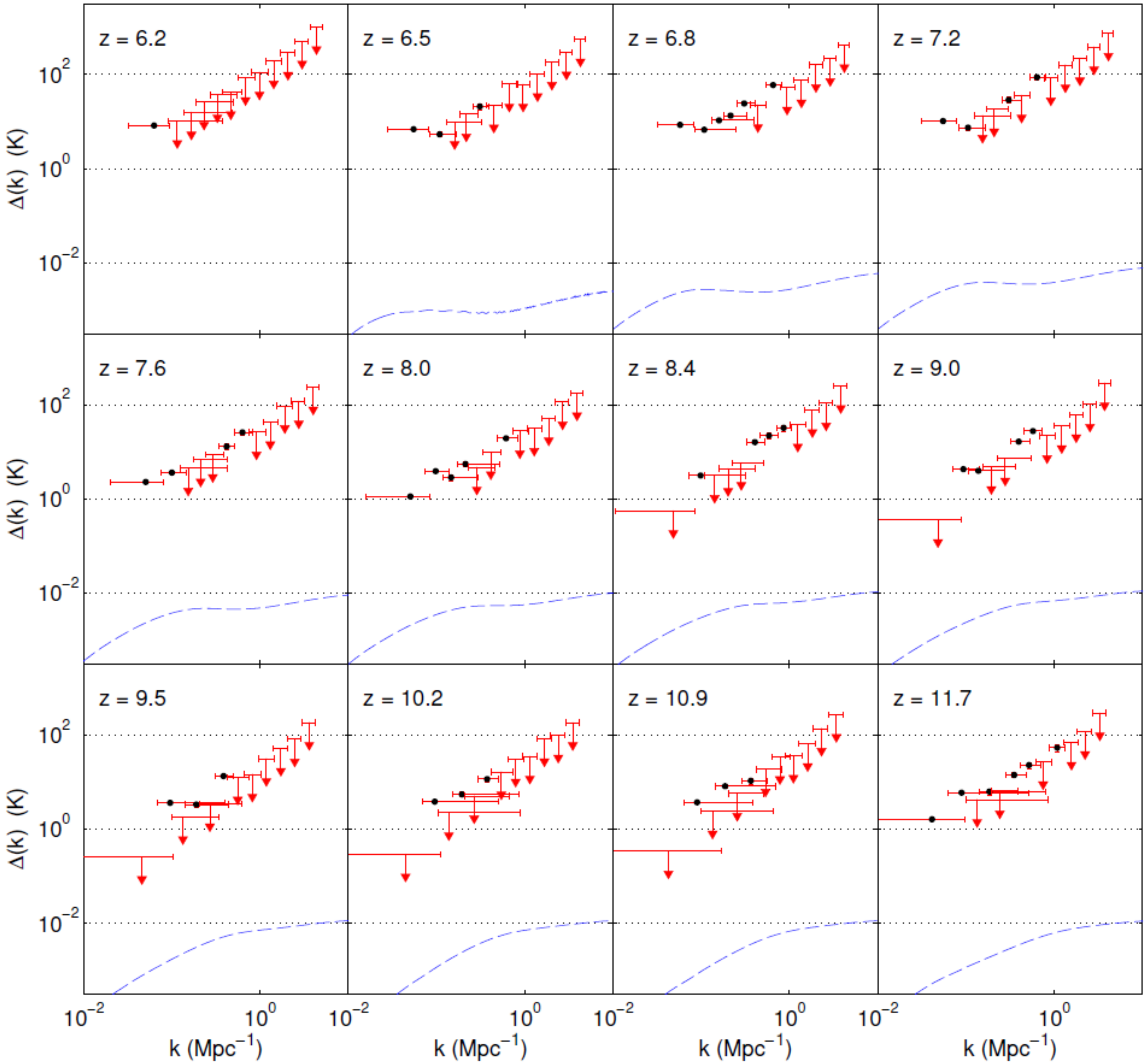


- MWA 32T prototype with only ~22 hours
- No foreground subtraction

Dillon, Liu et al. (submitted)

MWA proof-of-concept results (2)

- Power spectrum upper limits
- MWA 32T prototype with only ~22 hours



Dillon, Liu et al. (submitted)

Summary

- MWA is operational and performing well (and improving), encouraging for delivering first EoR results over the next couple years.
- Science capabilities enable full Stokes, high survey efficiency, surface brightness sensitivity, sampling of many timescales, high-dynamic range imaging from 1 arcmin to 15 degrees
- More information:
  - System overview (Tingay et al. 2013)
  - Science drivers (Bowman et al. 2013)
  - http://mwatelescope.org
- 21 cm data to be released to community 18 months after completion of observing season (including reduced data products). Archived at MIT and Melbourne Uni.
- Accepting open access observation proposals in Sept/Oct. 2013.