MWA status overview

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Outline

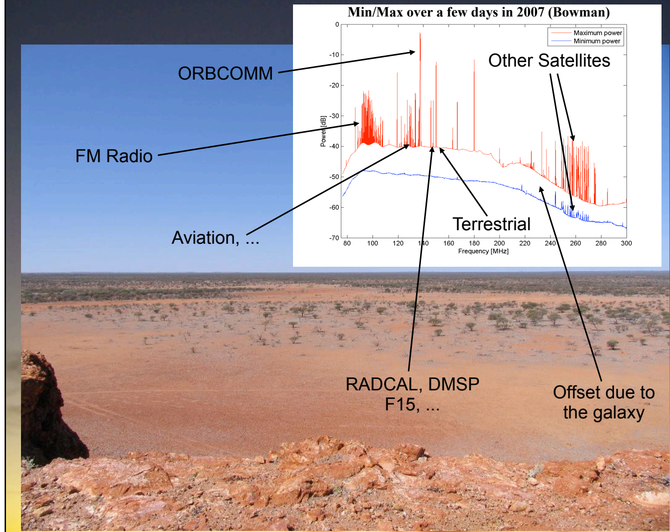
- MWA overview
- Calibration and imaging challenges
- Calibration and imaging approach

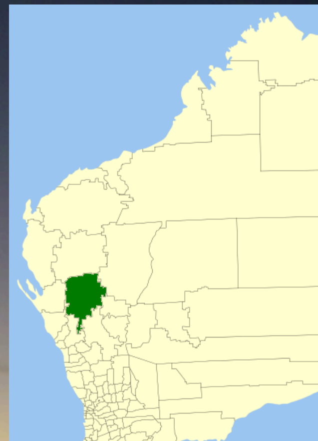
The MWA Consortium

- MIT-Haystack
- MIT campus (MKI)
- Smithsonian Inst.
- Harvard U.
- U. Melbourne
- Curtin U. of Tech.
- U. WA
- U. Tasmania
- U. Sydney
- ANU
- Raman Research Inst.
- CSIRO

Also contributions from individuals/groups
at U. Wisc, U. Wash, CalTech

MRO Radio Quiet Zone, Western Australia



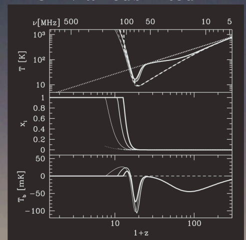


Shire of Murchison
Pop: ~110 in 41,173 km^2

MWA Goals

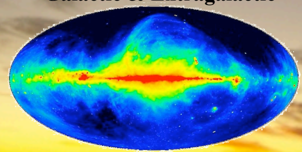
Demonstrate real/time calibration and imaging; SKA precursor facility

EoR via redshifted HI



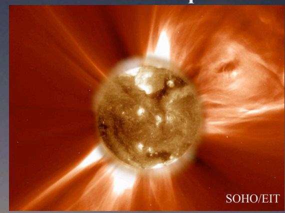
Pritchard & Loeb 2008

Galactic & Extragalactic

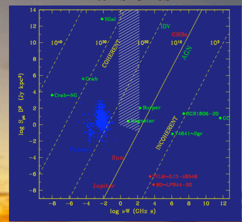


Testori et al. (2001, 2004) / Wooleben et al. (2005)

Solar & Heleospherical



Transients

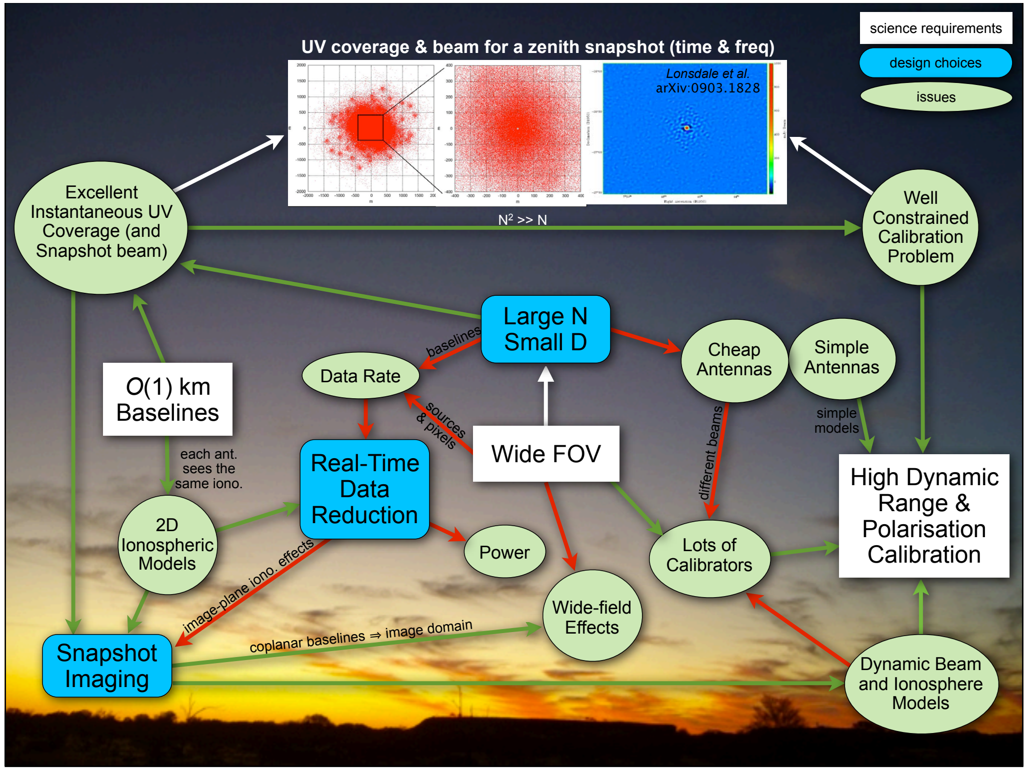


Chatterjee & Murphy (adapted from Cordes et al. 2003)

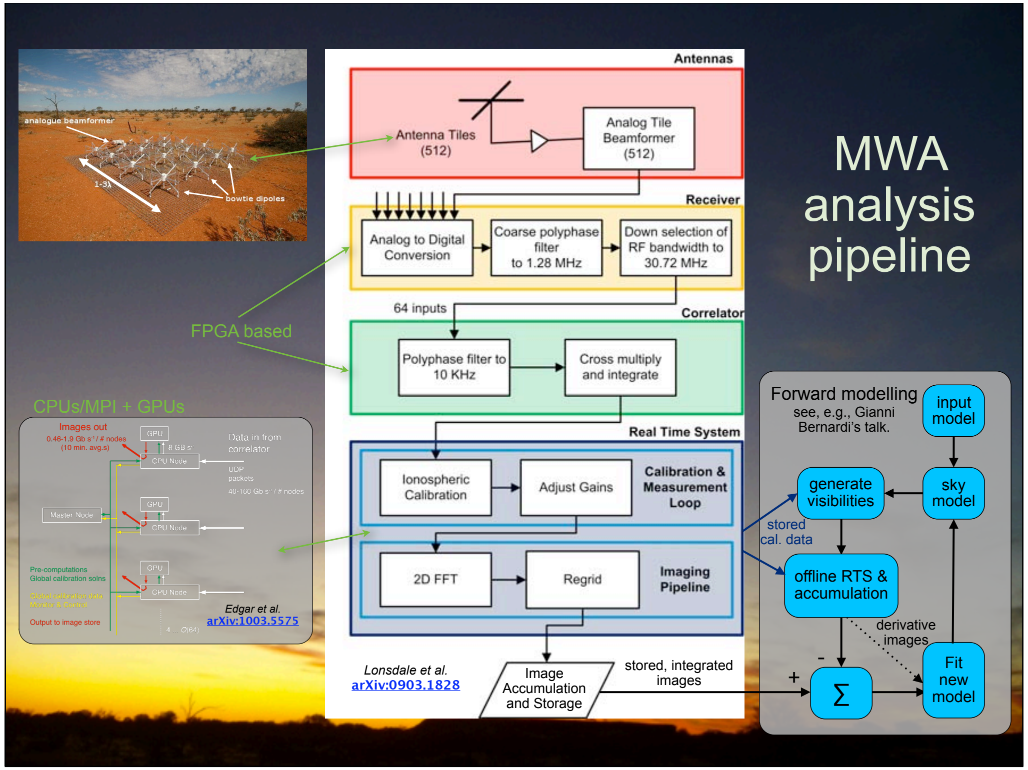
MWA Specifications

- Lots of antennas (512 "cheap" tiles: "fix in software")
- Good snapshot beam (>10^5 concentrated baselines)
- High-dynamic-range imaging
- Fully-polarised description

  } e.g., EoR foregrounds & CME backgrounds
- Wide frequency range (31 MHz from 80–300 MHz)
- Wide, steerable FOV (10-50 degrees)
- A few arc-minute resolution (1.5 km: 2.5'-8.5')
- Max BL ~ km (isoplanatic patch size): ~ 2D ionosphere

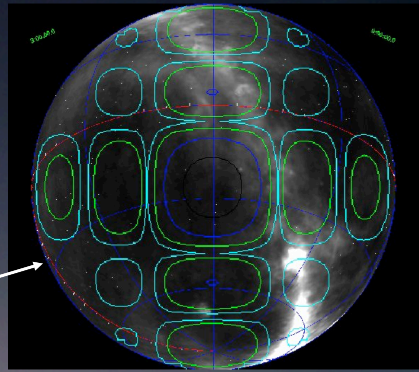


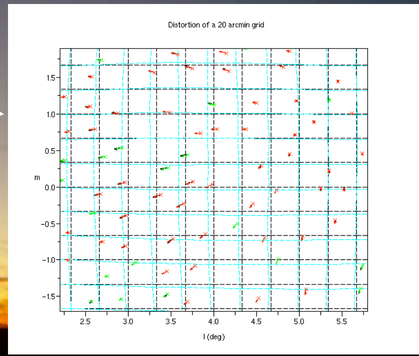
UV coverage & beam for a zenith snapshot (time & freq)
Lonsdale et al.
arXiv:0903.1828
science requirements
design choices
issues
Excellent Instantaneous UV Coverage (and Snapshot beam)
N² >> N
Well Constrained Calibration Problem
Large N Small D
baselines
Data Rate
Cheap Antennas
Simple Antennas
O(1) km Baselines
sources & pixels
Wide FOV
simple models
different beams
High Dynamic Range & Polarisation Calibration
each ant. sees the same iono.
Real-Time Data Reduction
2D Ionospheric Models
Power
Lots of Calibrators
image-plane iono. effects
Wide-field Effects
coplanar baselines ⇒ image domain
Snapshot Imaging
Dynamic Beam and Ionosphere Models


MWA analysis pipeline
analogue beamformer
bowtie dipoles
FPGA based
CPUs/MPI + GPUs
Images out
Data in from correlator
GPU
CPU Node
Master Node
Pre-computations
Global calibration solns
Output to image store
Edgar et al.
arXiv:1003.5575
Antennas
Antenna Tiles (512)
Analog Tile Beamformer (512)
Receiver
Analog to Digital Conversion
Coarse polyphase filter to 1.28 MHz
Down selection of RF bandwidth to 30.72 MHz
64 inputs
Correlator
Polyphase filter to 10 KHz
Cross multiply and integrate
Real Time System
Ionospheric Calibration
Adjust Gains
Calibration & Measurement Loop
2D FFT
Regrid
Imaging Pipeline
Lonsdale et al.
arXiv:0903.1828
Image Accumulation and Storage
stored, integrated images
Forward modelling
see, e.g., Gianni Bernardi's talk.
input model
generate visibilities
sky model
stored cal. data
offline RTS & accumulation
derivative images
+
-
∑
Fit new model

Calibration

- Solve for the location of, and gain towards, many known point sources.
- Use the gain measurements (Jones matrices) to constrain a primary beam model for each antenna tile.
- Use the position offsets to constrain a 2D ionospheric phase screen.
- Use the ~ λ^2 dependency of the ionosphere to isolate the models.





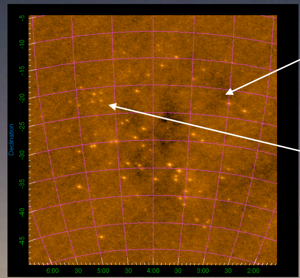
Imaging

Produce re-gridded, weighted snapshot images

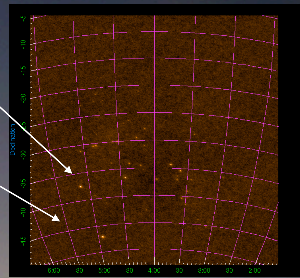
- 10^5 BLs, 10^3 freqs, 4 pol. products per 0.5 sec: $O(10)$ GB/s
    - too much data to store: **real-time processing.**
- 8 second cadence to correct $O(1)$ min ionospheric changes.
- **Incorporate primary beam models into the gridding.**
- **Deal with the ionosphere in the image plane.**
- **Deal with w-terms in the image plane (at the same time).**
- **Integrate processed images over 5 – 10 min.**
    - Formal self-calibration not possible, but storing all cal. info.
    - forward modeling, matched filtering, ...
- **Need and have excellent instantaneous uv coverage.**

Warped Snapshot Simulation

Co-pol (instrument pp)



Cross-pol (instrument pq)



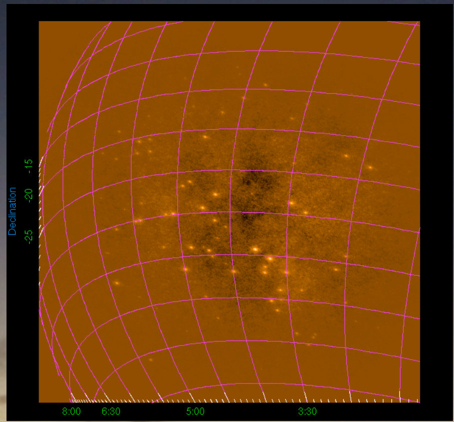
Significant changes in (l',m')

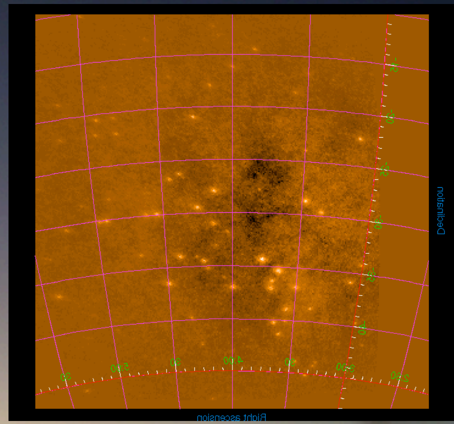
Significant changes in polarized gain

MAPS simulation: HA (img center) = -3.5 hrs to +3.5 hrs

- 2 of 4 FFT snapshot images per freq per cadence
- All input unpolarized (diffuse & point sources)
- All polarization comes from the instrument

Regridded Snapshots (-3.5 hrs to +3.5 hrs)





- The "true" grid is determined for each snapshot: wide-field grid and ionospheric refraction.
- Each pixel is weighted for optimal averaging: sky.gain^2/sig^2 (weighting is done during gridding).

- Each weighted snapshot is re-gridded to a static coordinate system (position & polarisation).
- Images are accumulated.

Calibration & Imaging Challenges

- **Strong sources in primary beam sidelobes**: peeling in real time system.
- **Wide field calibration**: phase track $O(200)$ & fit Jones matrices for $O(50)$ sources.
- **Wide field imaging**: snapshot imaging & coplanar baselines = image warp. Small w-projection?
- **Wide field deconvolution**: forward modelling.
- **Mosaicing in full polarization**: gridding kernels & weighted snapshots.
- **Mosaicing with different primary beams**: gridding kernels & forward modelling.
- **LDV pipeline processing**: Real-Time System (5 GBytes / sec).
- **LDV data formats (standardisation, common tools)**: MPI, CUDA, SLALIB, FITS, HEALPIX.
- **LDV processing power limitations and shortcuts**: 40 KW ✘, 8 sec ✘, short baselines = 2D iono. models ✔, coplanar baselines & snapshot imaging = image plan wide-field corrections ✔.
- **Sky models**: all-sky surveys.
- **Solvability (cal)**: Direct: 512×32 = 16,384 PB params; 130,816 baselines.
- **Solvability (cal)**: Via peeling loop: 512×50 = 25,600; 130,816 baselines. 32 params; 50 samples.
- **Time and frequency dependence**: real-time monitoring of instr. & iono. + storage.
- **Full pol imaging**: Produce weighted instr. pol. images with pixel-by-pixel Stokes conversion.
- **On-the-fly mapping**: Real-Time System. $O(10)$ TFLOPs / 8 seconds.
- **Long baselines / large fields of view**: 0.5 s, 40 kHz & 1 km = all sky. Store, calibrate and grid visibilities with 2, 4 or 8 second averaging, depending on the baseline length.
- **How much of the data to correlate**: 8192 dipoles → 512 antenna tiles → 1024 input correlator.