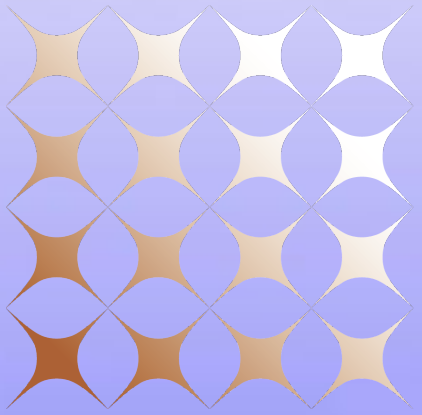
Commissioning and Calibrating the Murchison Widefield Array (MWA)

Natasha Hurley-Walker

International Centre for Radio Astronomy Research

Astounding Stories of Super-Science
Hobart, Tasmania
20th April 2012



MWA
MURCHISON
WIDEFIELD
ARRAY

Outline

- Project
- Instrument
- Science
- Location
- Data
- Calibration

MWA Collaboration

50-60 active participants over three countries

- MIT Haystack Observatory
- MIT Kavli Institute
- Harvard-Smithsonian Center for Astrophysics
- University of Melbourne
- Curtin University
- Australian National University
- ATNF
- University of Tasmania
- University of Western Australia
- University of Sydney
- Swinburne University
- Raman Research Institute
- Victoria University of Wellington

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The Murchison Widefield Array

Murchison Widefield Array

- 128 16-antenna tiles
- 80—300 MHz receiving band
- Primary beam FWHM ~ 45—20°
- Synthesised beam FWHM ~ 15—2'
- 1.28 MHz spectral resolution
- Baselines of 4—2000 m
- Measures two orthogonal polarizations
- Testbed for real-time correlation and imaging systems

Murchison Widefield Array

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- Primary beam FWHM ~ 45—20°
- Synthesised beam FWHM ~ 2—15'
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- Baselines of 4—2000 m
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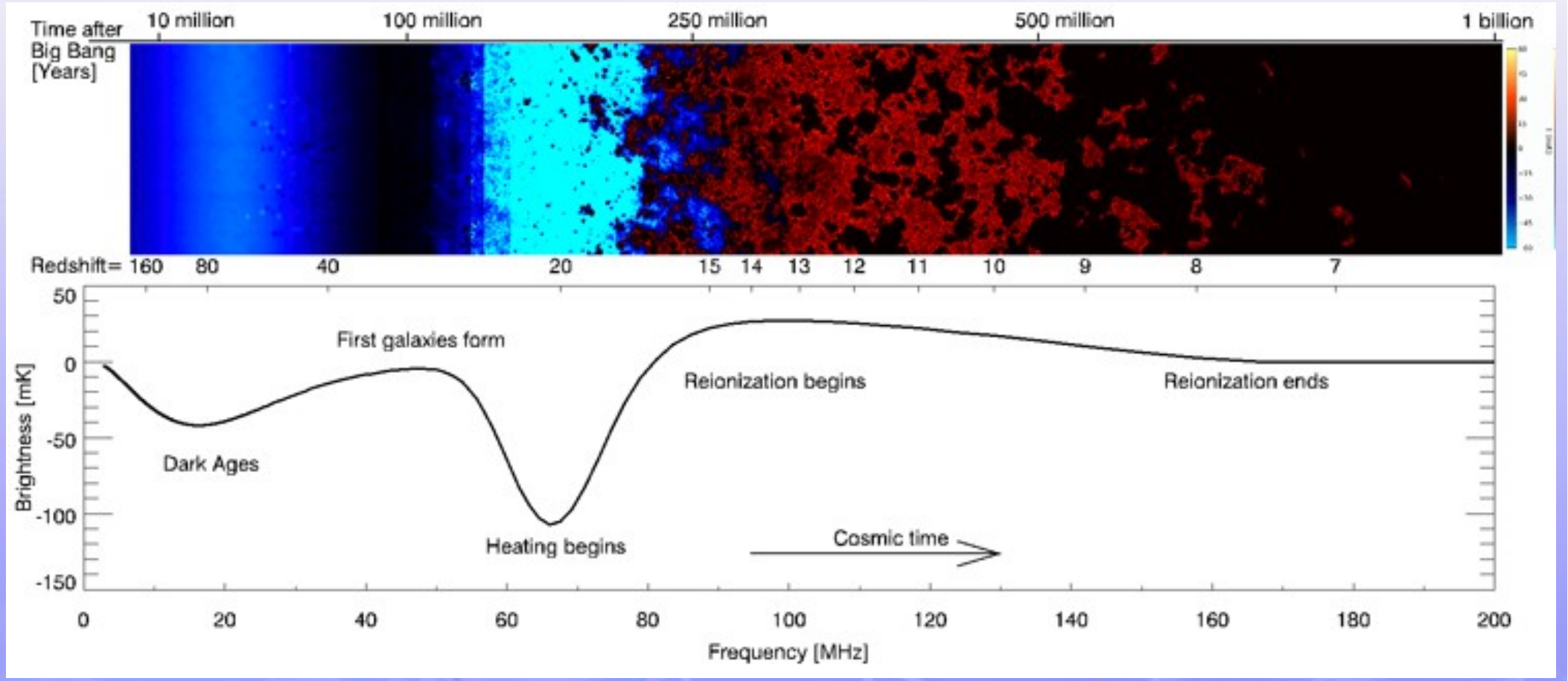
- Testbed for real-time correlation and imaging systems

32-element prototype active 2009-2011;
128-element full array now under construction

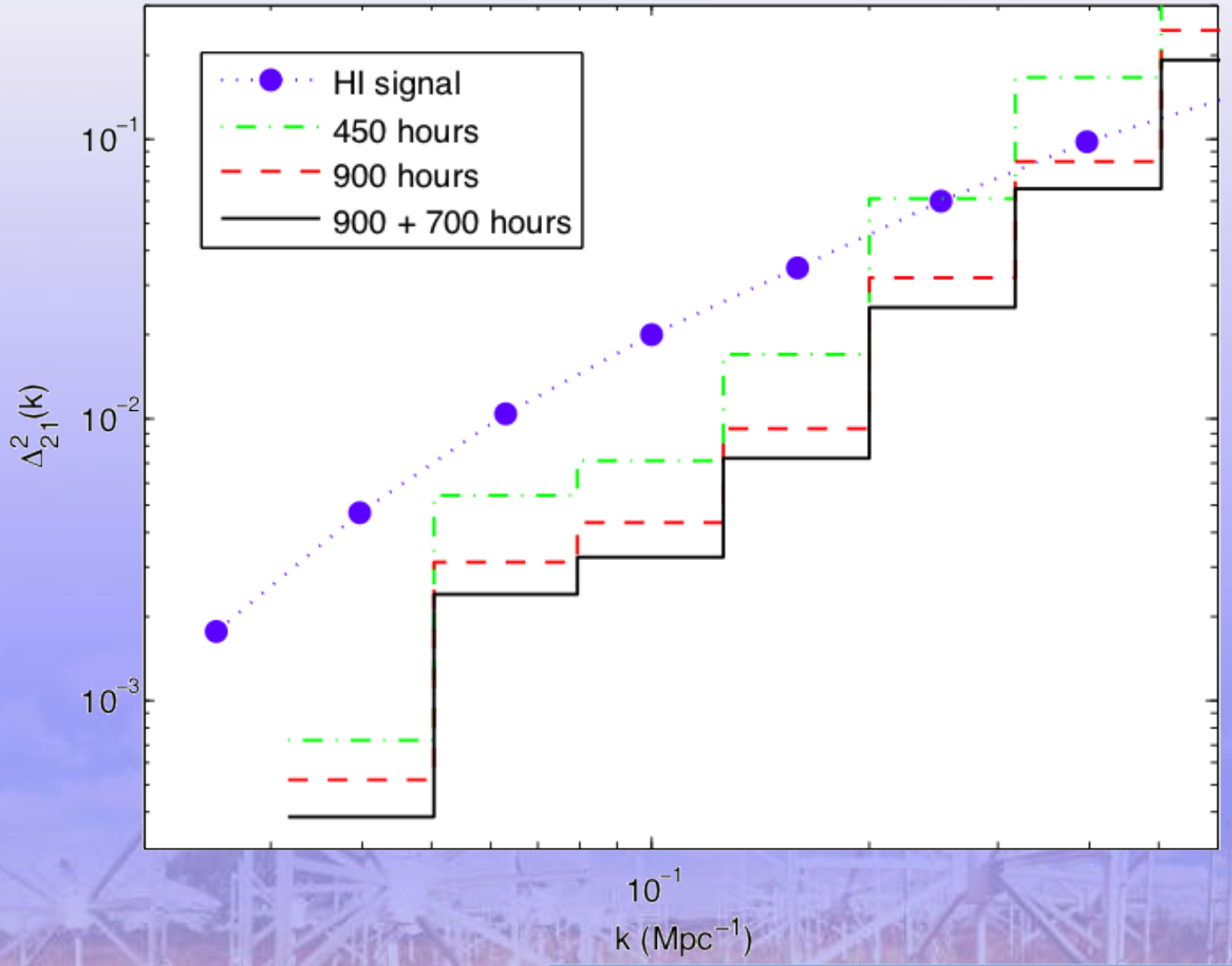
Science Goals

- Epoch of Reionisation
- Transient radio sources
- Solar, Heliospheric and Ionospheric Science
- Galactic and Extra-Galactic Science

Epoch of Reionisation

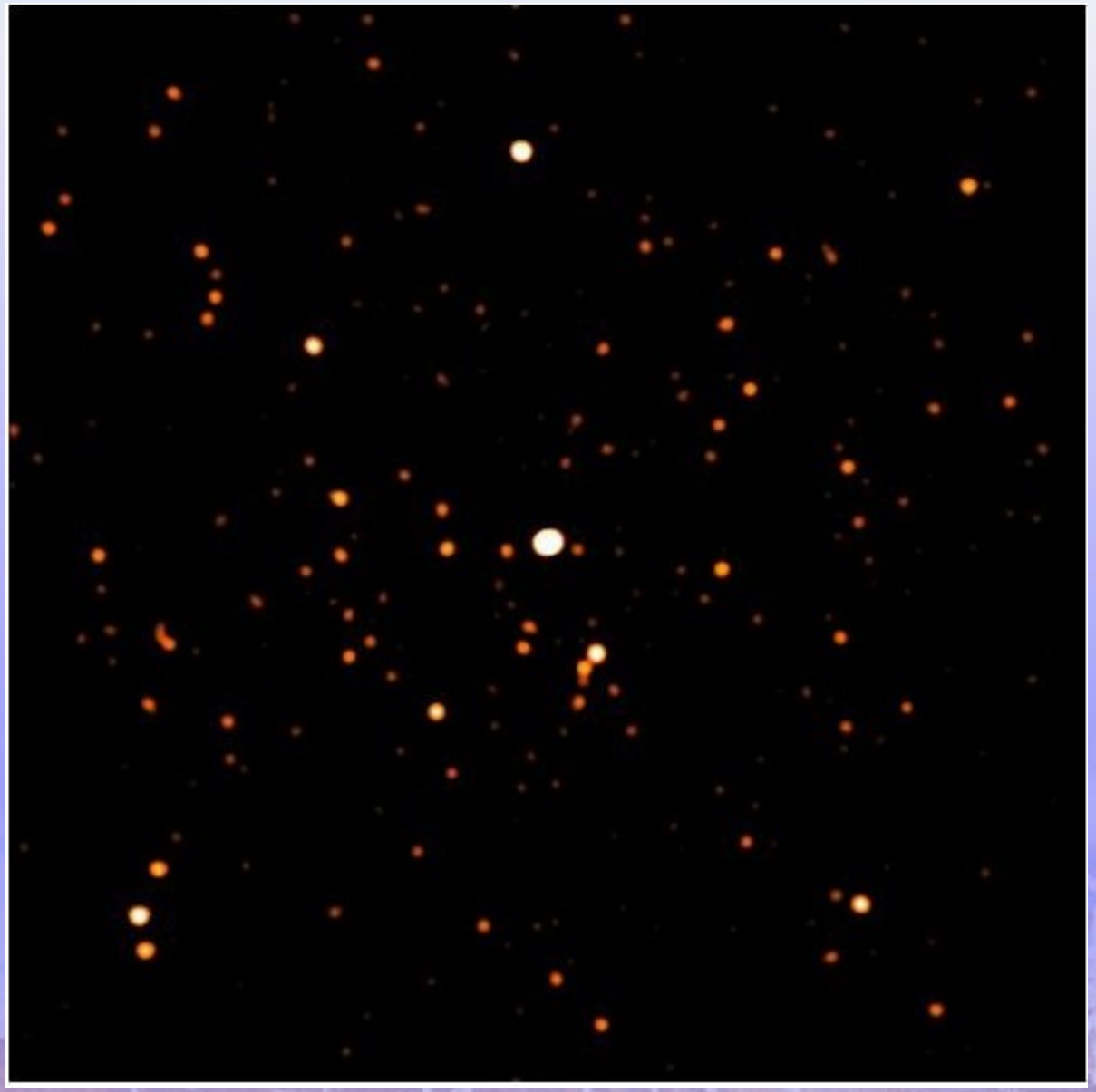


Epoch of Reionisation



ArXiv: 1204.3111 Bearsley et al

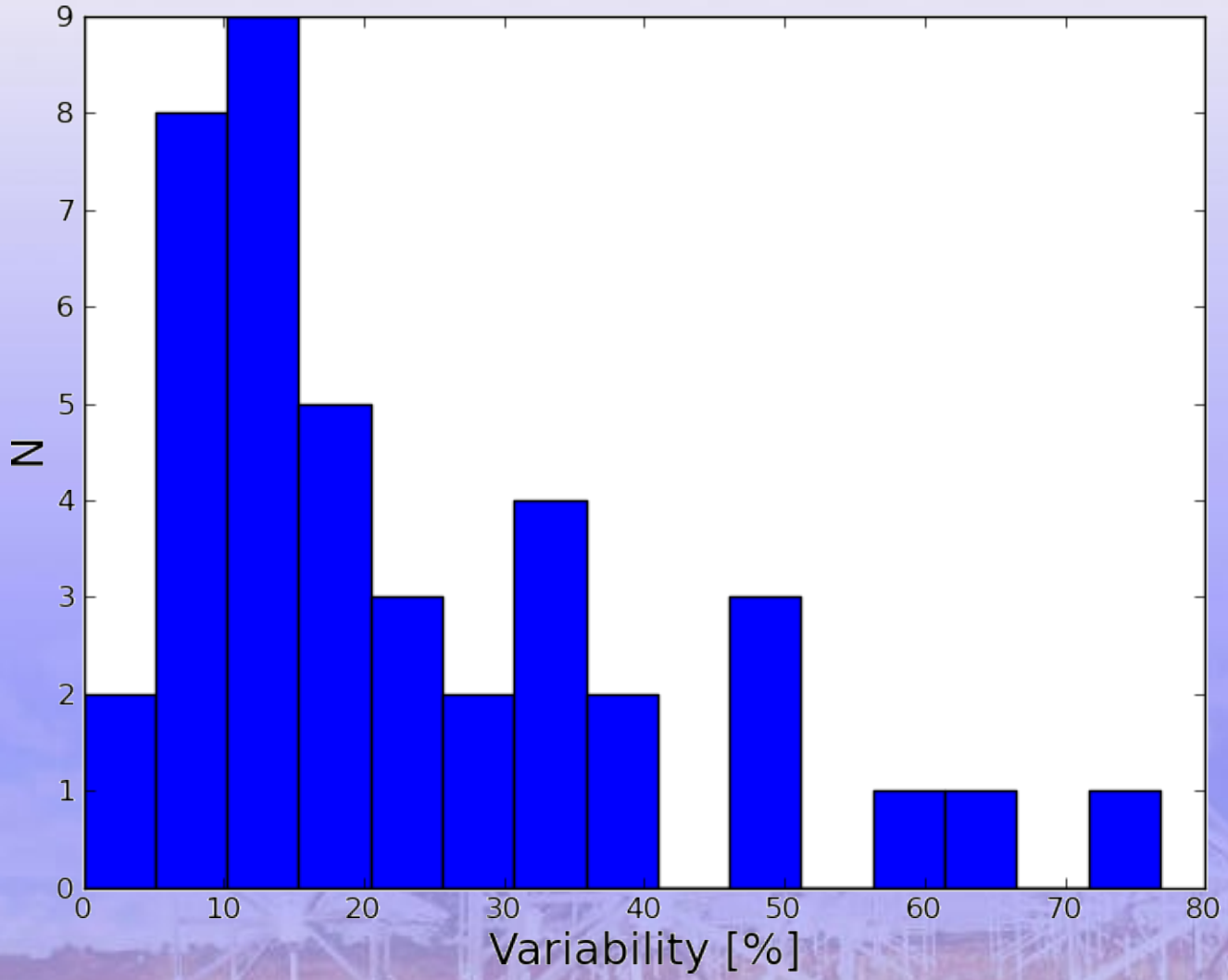
Transient radio sources



- Compare snapshot images for bright events:
  - GRBs
  - X-ray binaries
  - Pulsars
  - RRATS
  - etc...!

Integrated snapshots of Pictor A: Dr Nadia Kudryavtseva, ICRAR

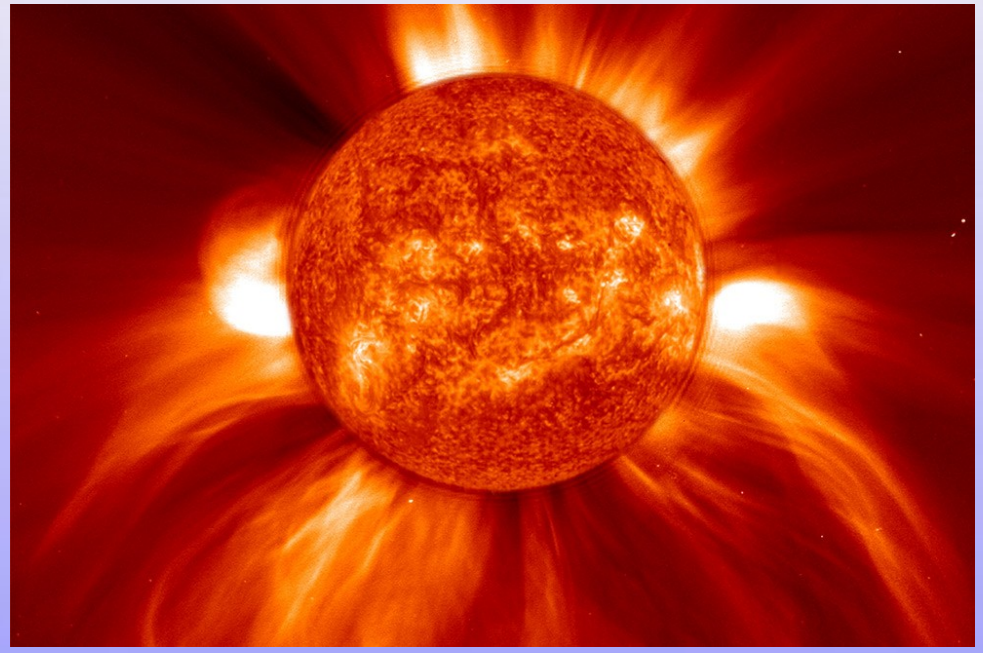
Transient radio sources



- Compare snapshot images for bright events:
  - GRBs
  - X-ray binaries
  - Pulsars
  - RRATS
  - etc...!
- No events → upper limit on variability

Integrated snapshots of Pictorus A: Dr Nadia Kudryavtseva, ICRAR

Solar Science



- Huge S/N even at subsecond intervals
- High resolution compared to disc of sun
- Wide-spectrum observations: 30MHz instantaneous bandwidth
- Monitor for flare events

Solar Science

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- Wide-spectrum observations: 30MHz instantaneous bandwidth
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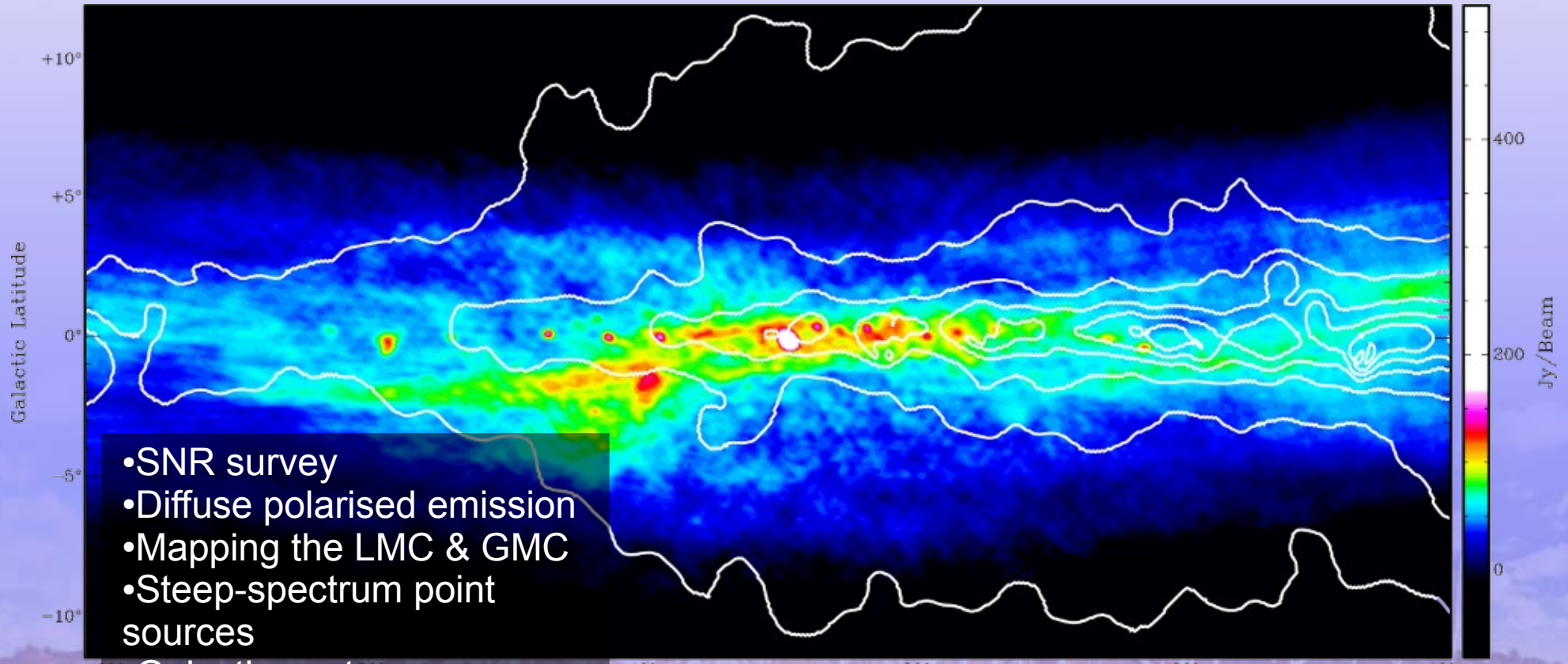
Dr Divya Oberoi, NCRA, Pune, India

Galactic and Extragalactic Science

- … everything else!



- SNR survey
- Diffuse polarised emission
- Mapping the LMC & GMC
- Steep-spectrum point sources
- Galactic centre
- Clusters and relics
- ...
-


Great Sandy Desert
Northern Territory
Hamersley Range
Gibson Desert
MWA
ASKAP
Australia
Western Australia
Geraldton WA, Australia
Great Victoria Desert
Lake Raeside
South Australia
Perth WA, Australia
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Cnes/Spot Image
© 2012 Whereis® Sensis Pty Ltd
US Dept of State Geographer
715 km
Google earth
26°52'27.28" S 122°16'43.12" E elev 545 m
Eye alt 2507.96 km


N
MWA
ASKAP
Lake Austin
Lake Noondi
Geraldton WA, Australia
142 km
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
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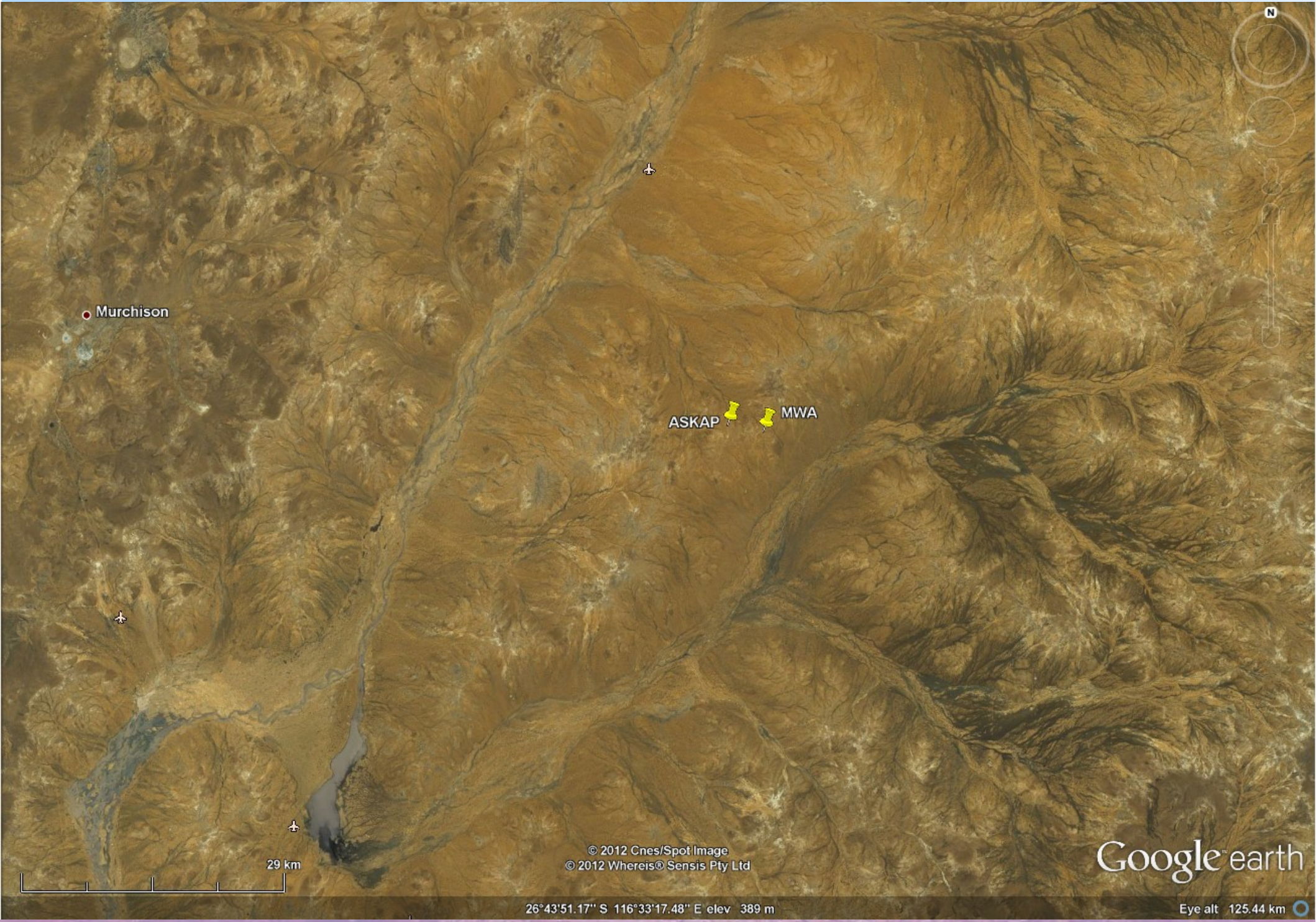
Google earth
27°05'37.43" S 116°08'22.72" E elev 294 m
Eye alt 581.03 km


N
Murchison
ASKAP
MWA
29 km
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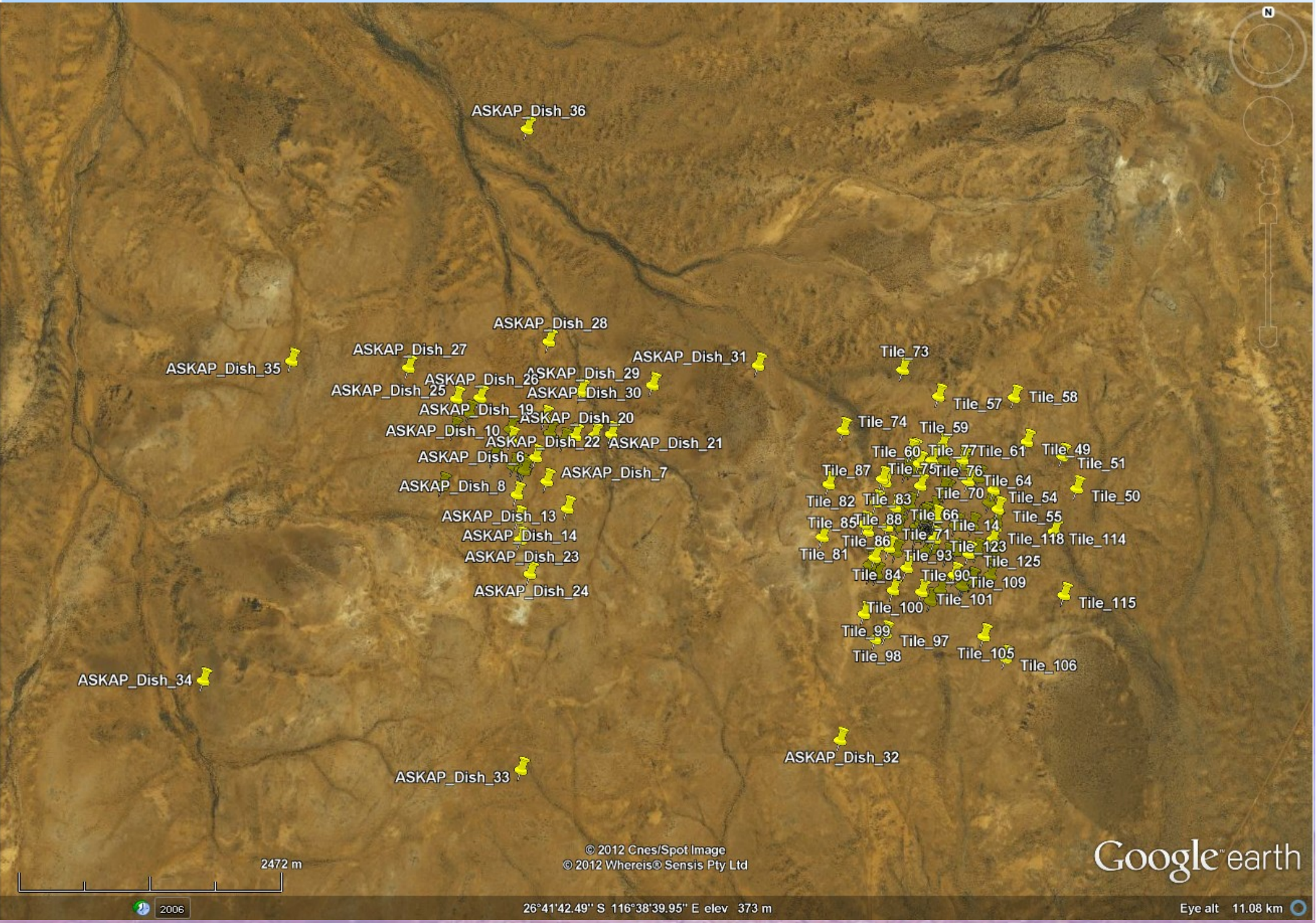
Google earth
26°43'51.17" S 116°33'17.48" E elev 389 m
Eye alt 125.44 km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Tile_125
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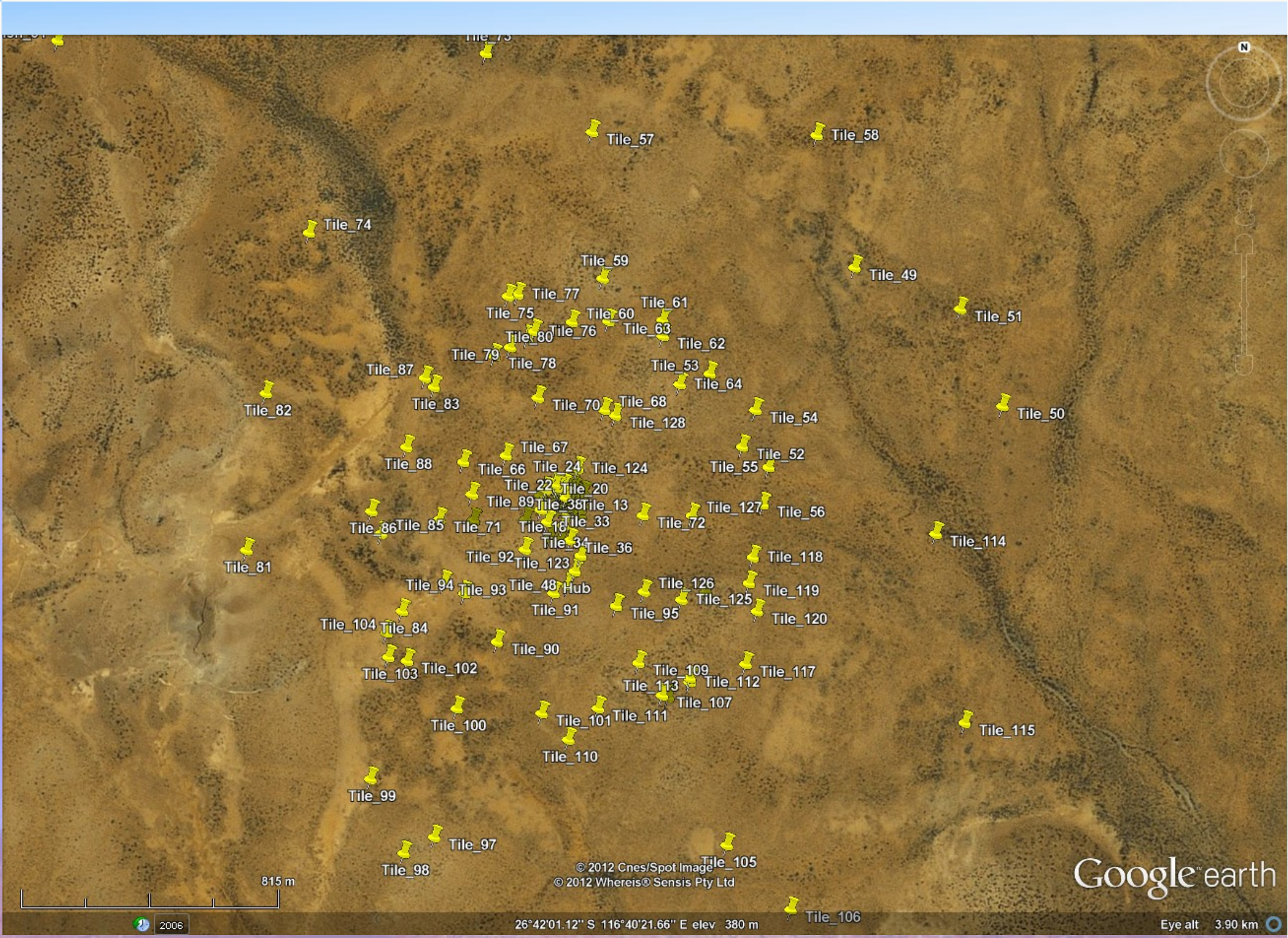
Tile_101
Tile_115
Tile_100
Tile_99
Tile_97
Tile_98
Tile_105
Tile_106
© 2012 Cnes/Spot Image
© 2012 Whereis® Sensis Pty Ltd
2472 m
Google earth
2006
26°41'42.49" S 116°38'39.95" E elev 373 m
Eye alt 11.08 km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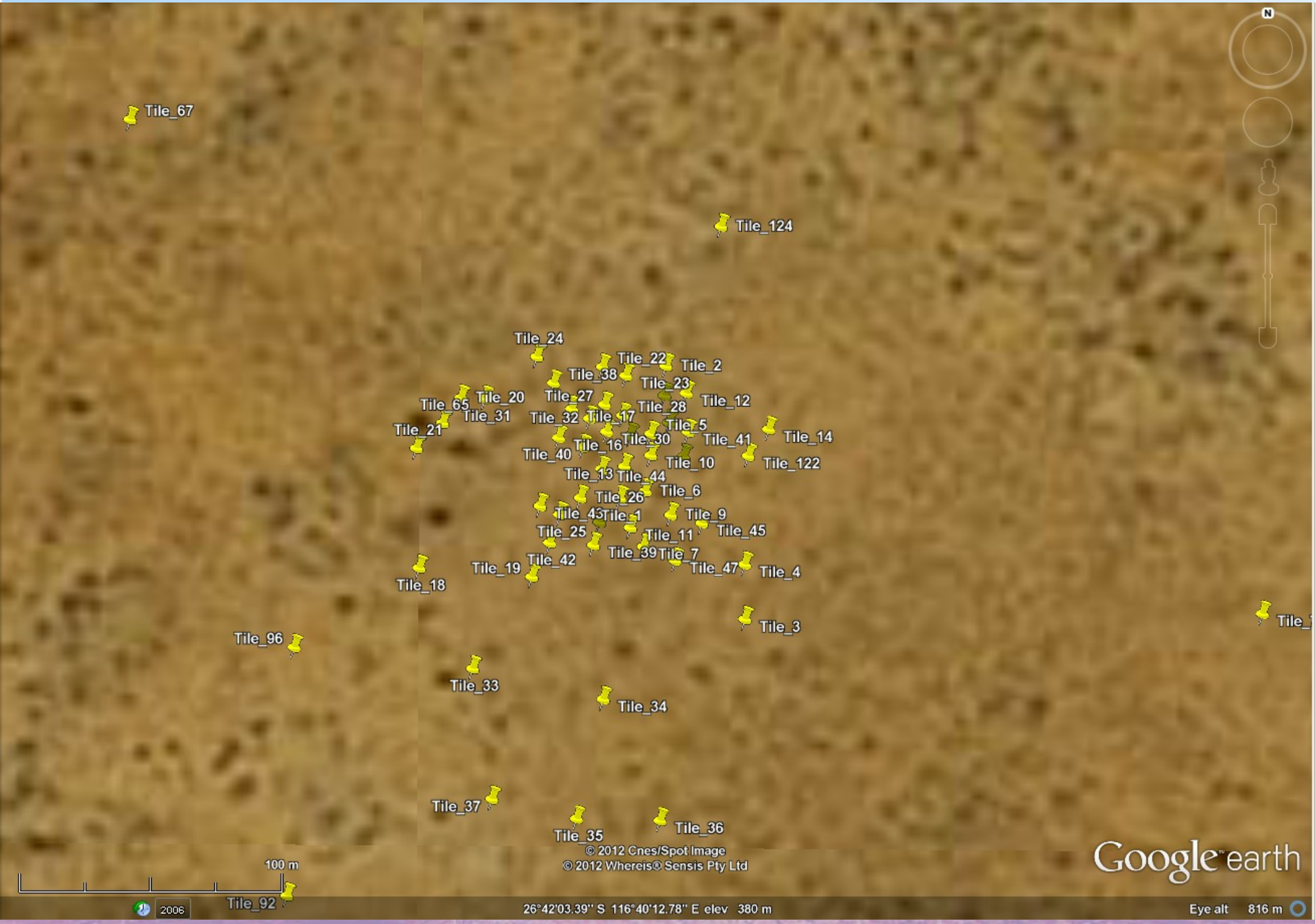
© 2012 Cnes/Spot Image
© 2012 Whereis® Sensis Pty Ltd
815 m
Google earth
2006
26°42'01.12" S 116°40'21.66" E elev 380 m
Eye alt 3.90 km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Tile_36
Tile_92
100 m
© 2012 Cnes/Spot Image
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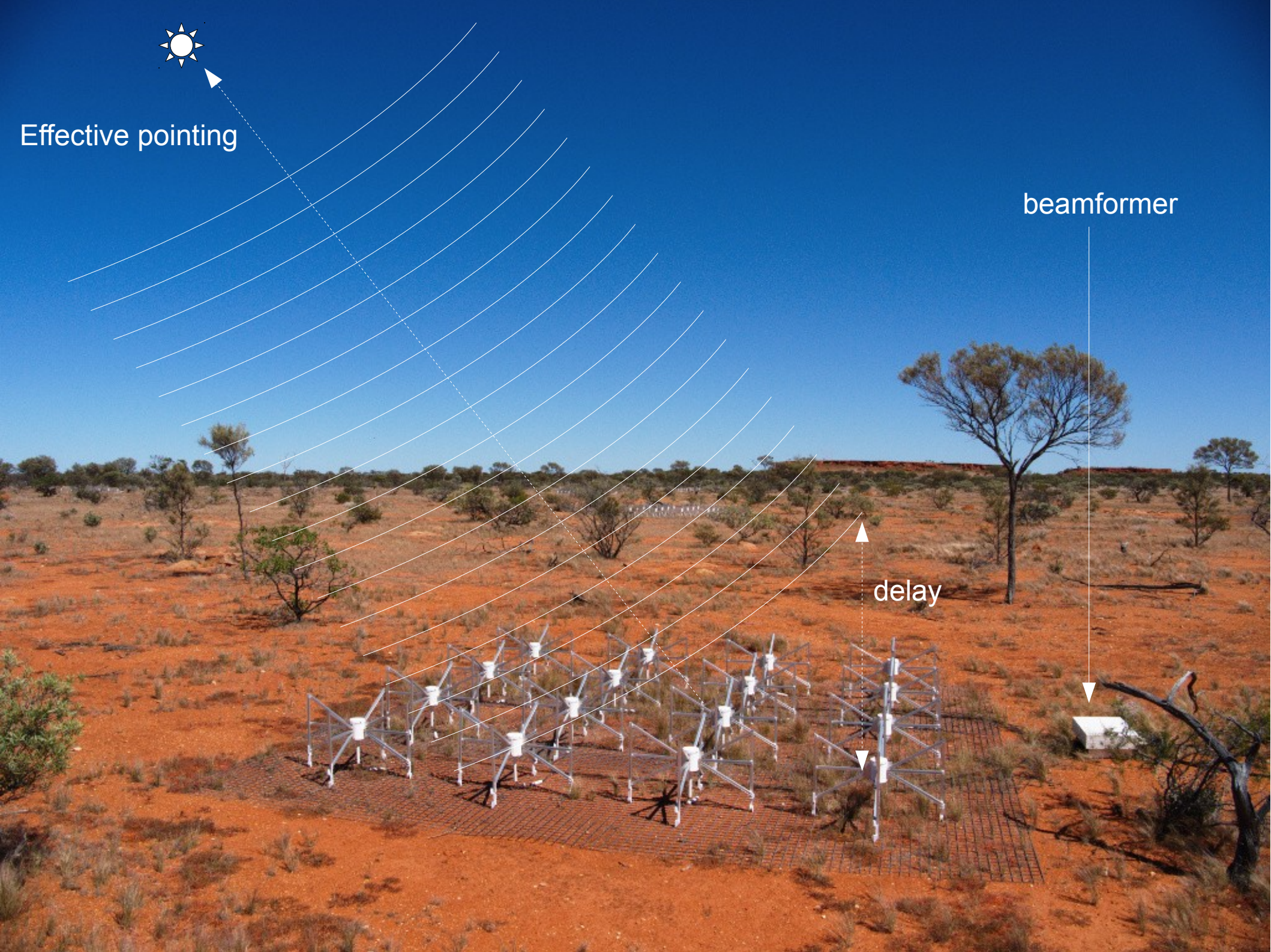
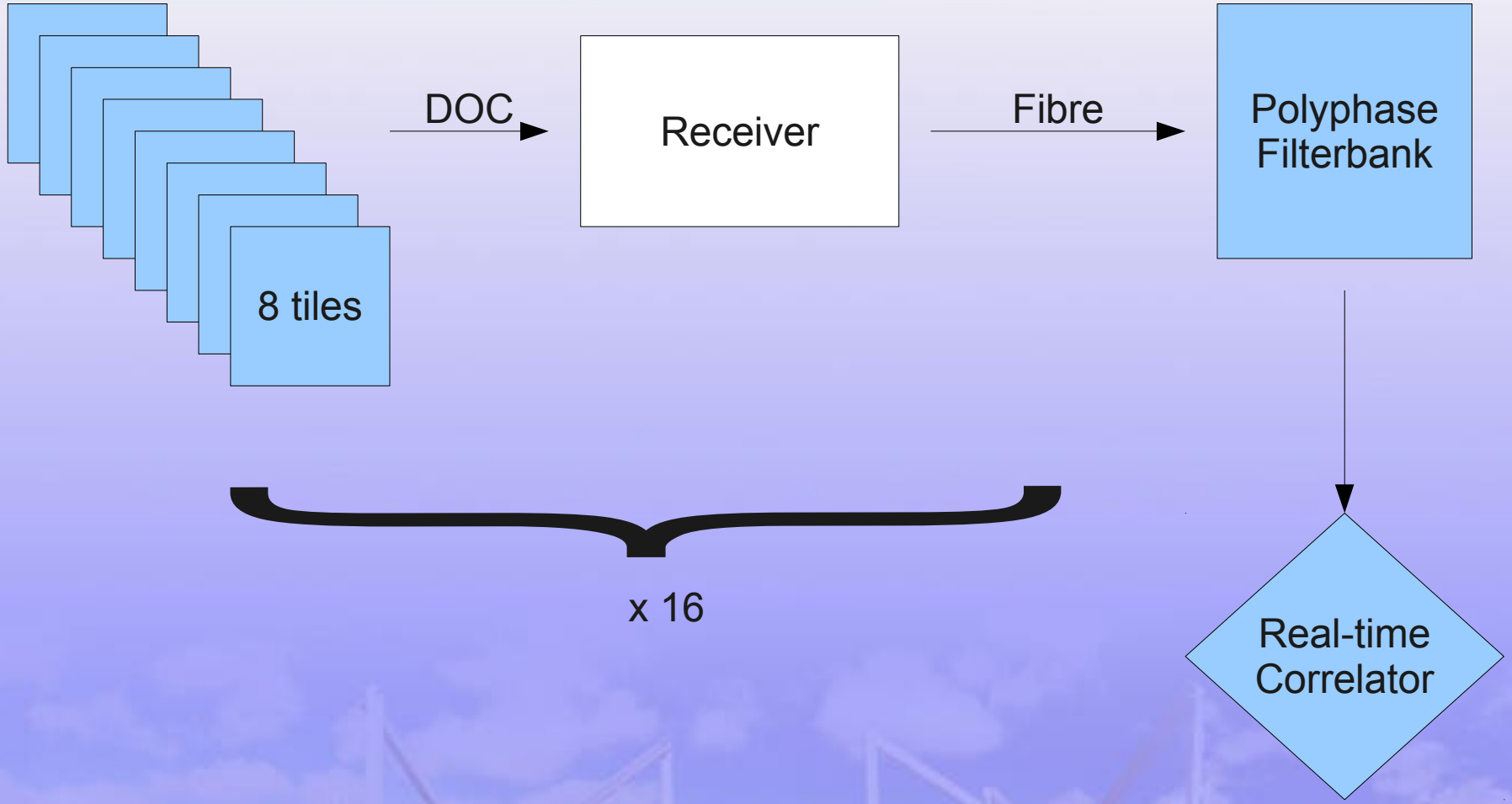
Google earth
2006
26°42'03.39" S 116°40'12.78" E elev 380 m
Eye alt 816 m

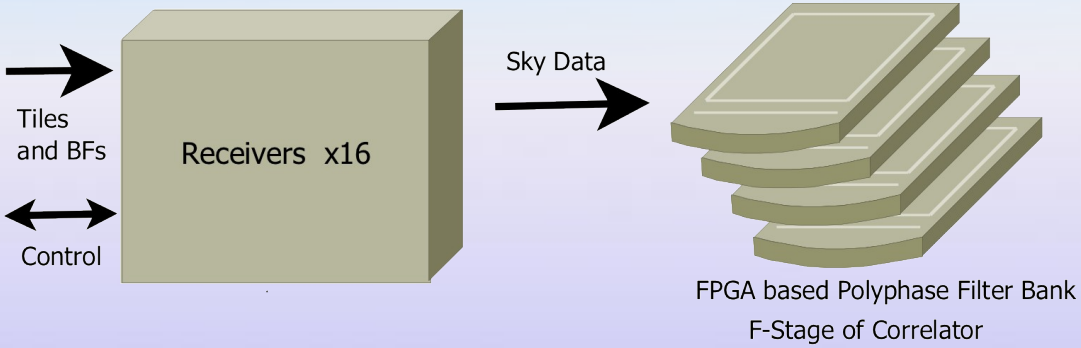

Effective pointing
beamformer
delay

Data Flow


8 tiles
DOC
Receiver
Fibre
Polyphase Filterbank
x 16
Real-time Correlator

Dave Pallot, ICRAR

Data flow



Data flow

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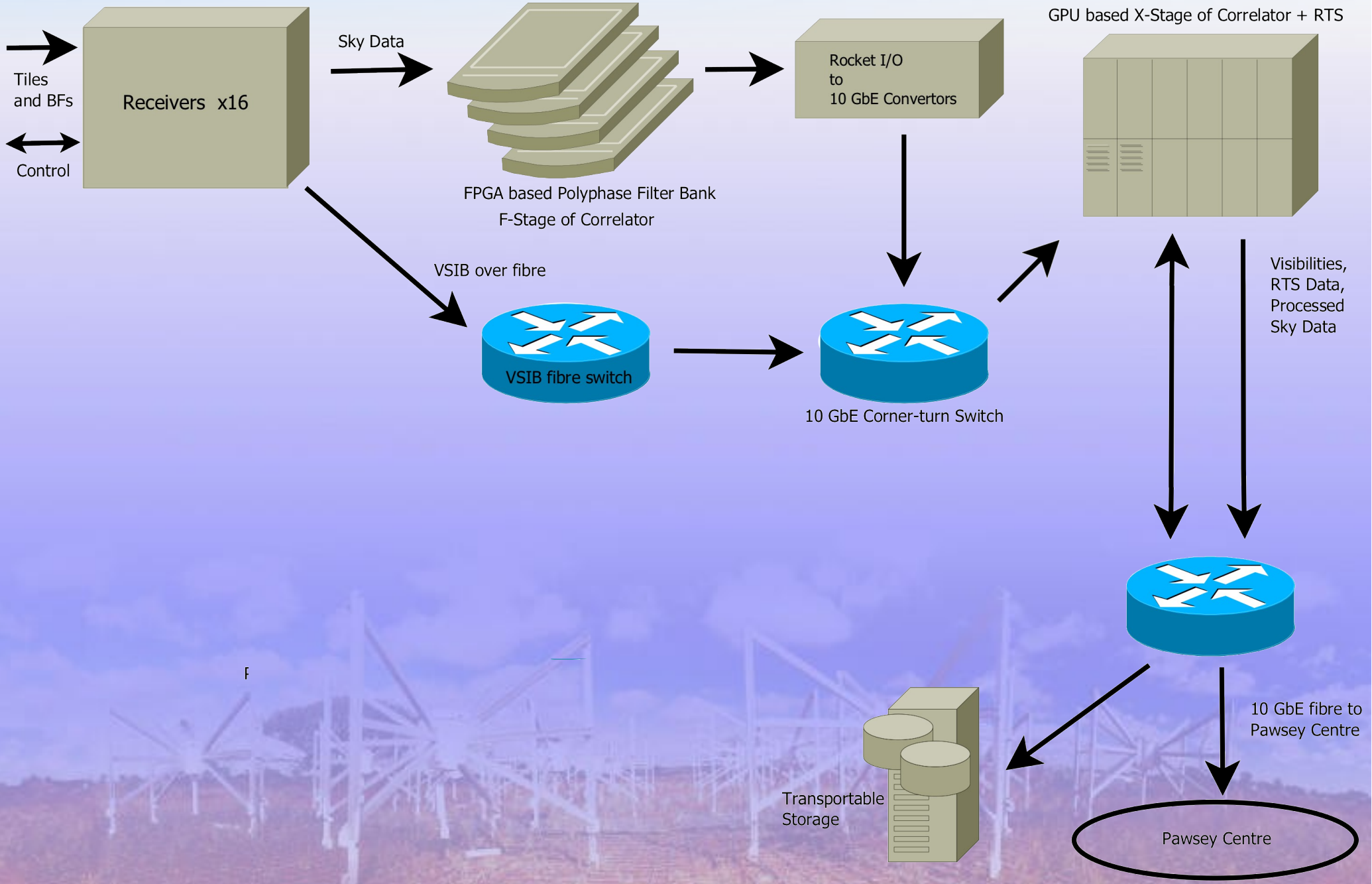

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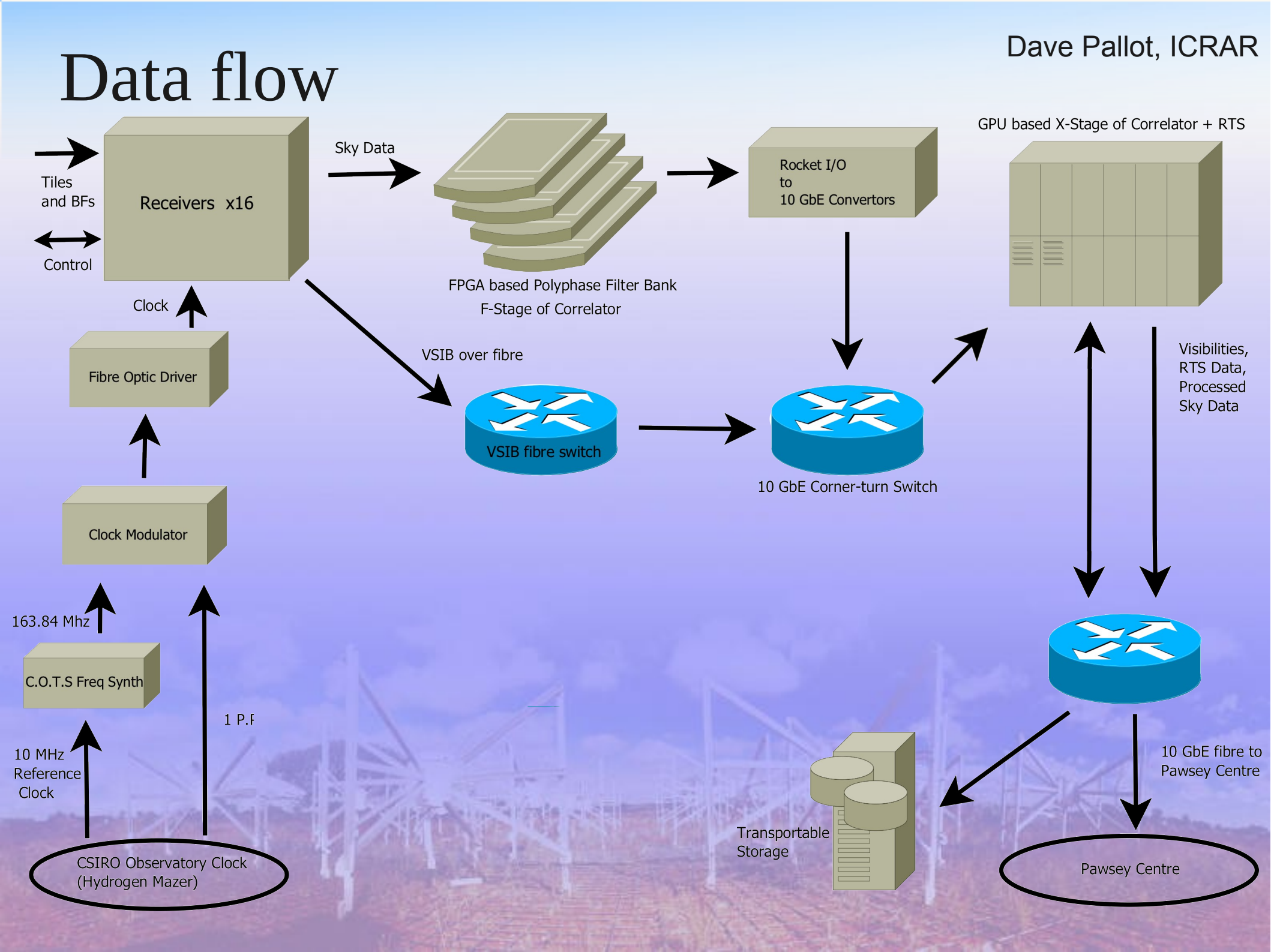

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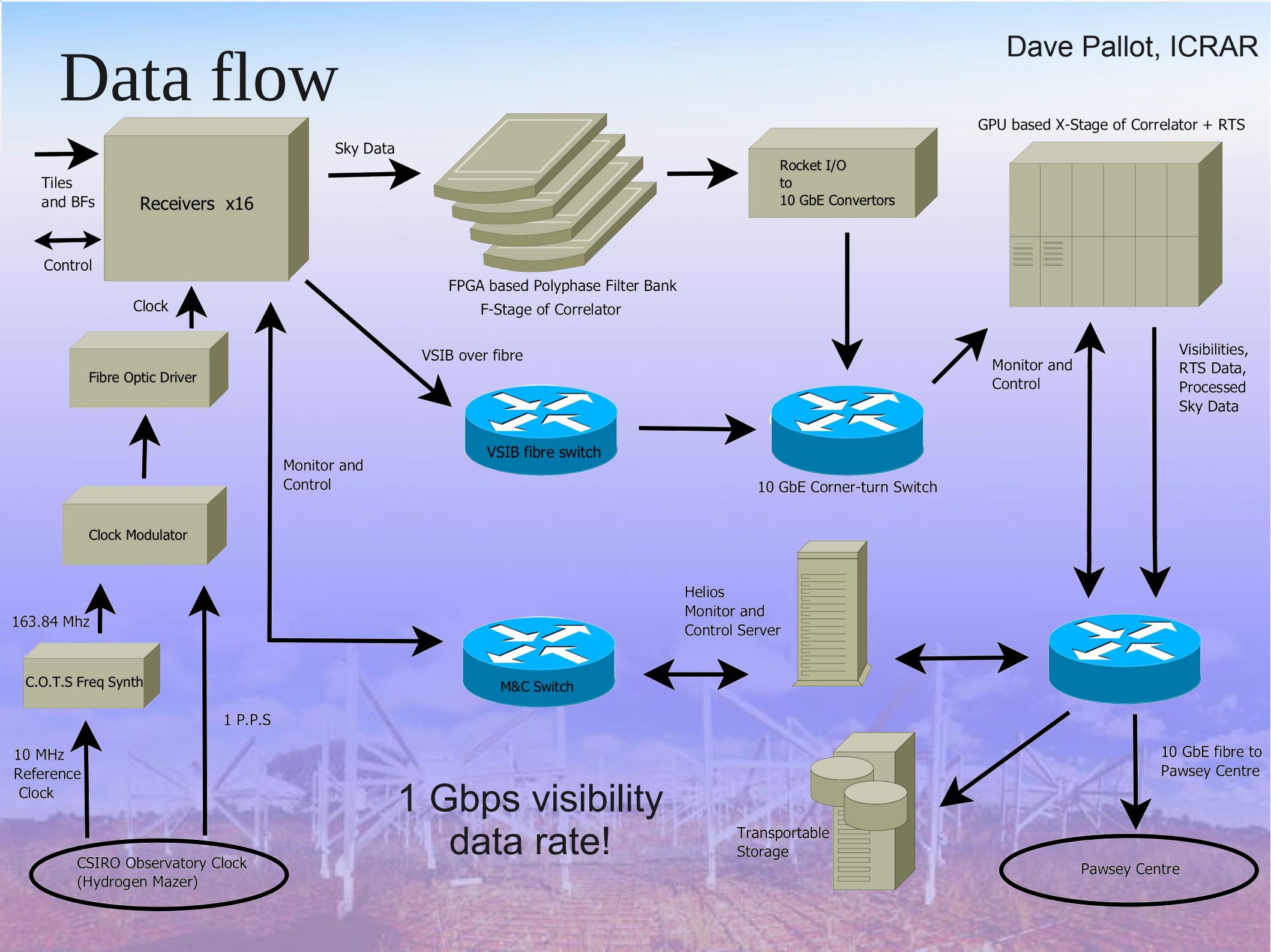
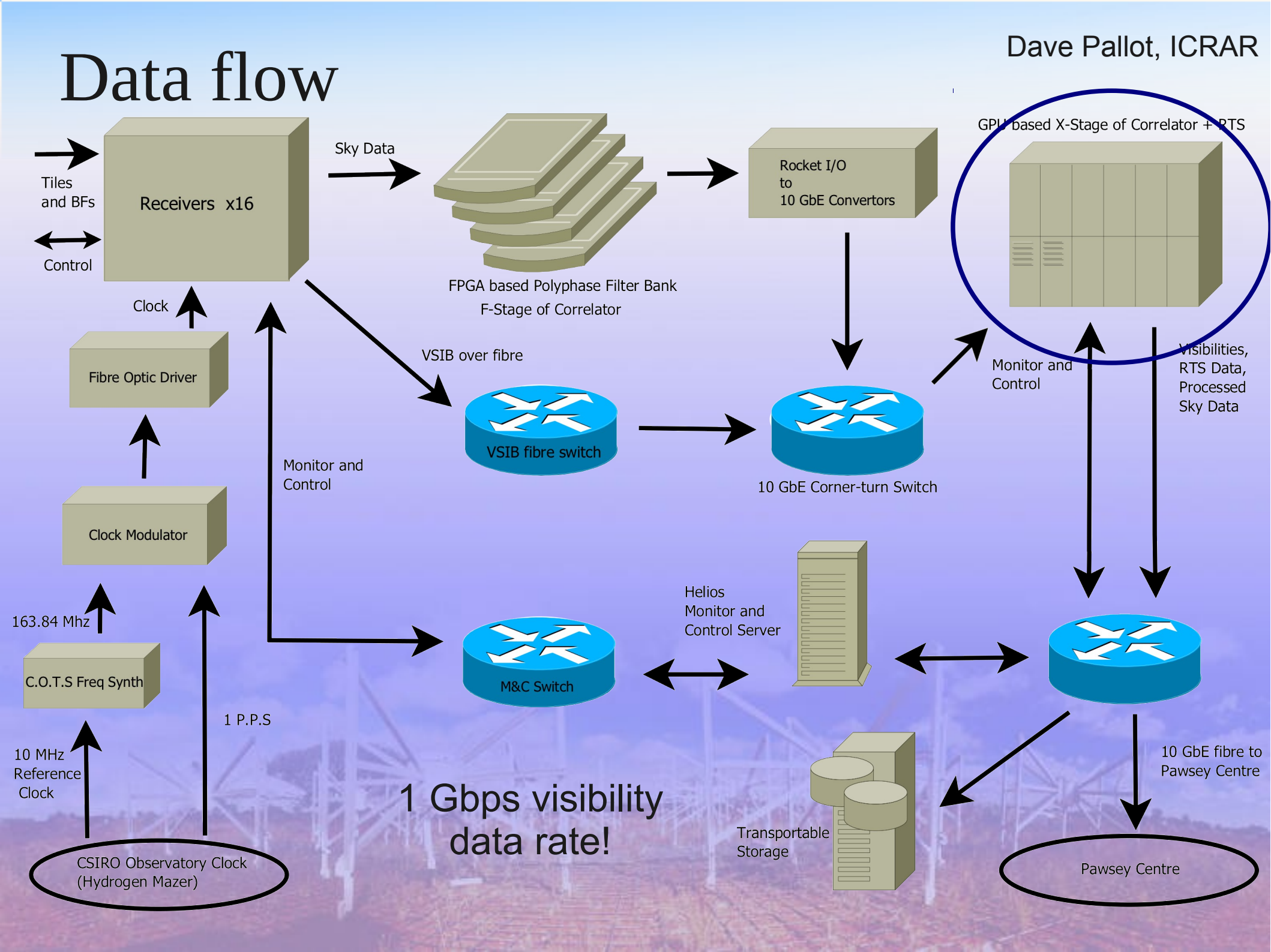
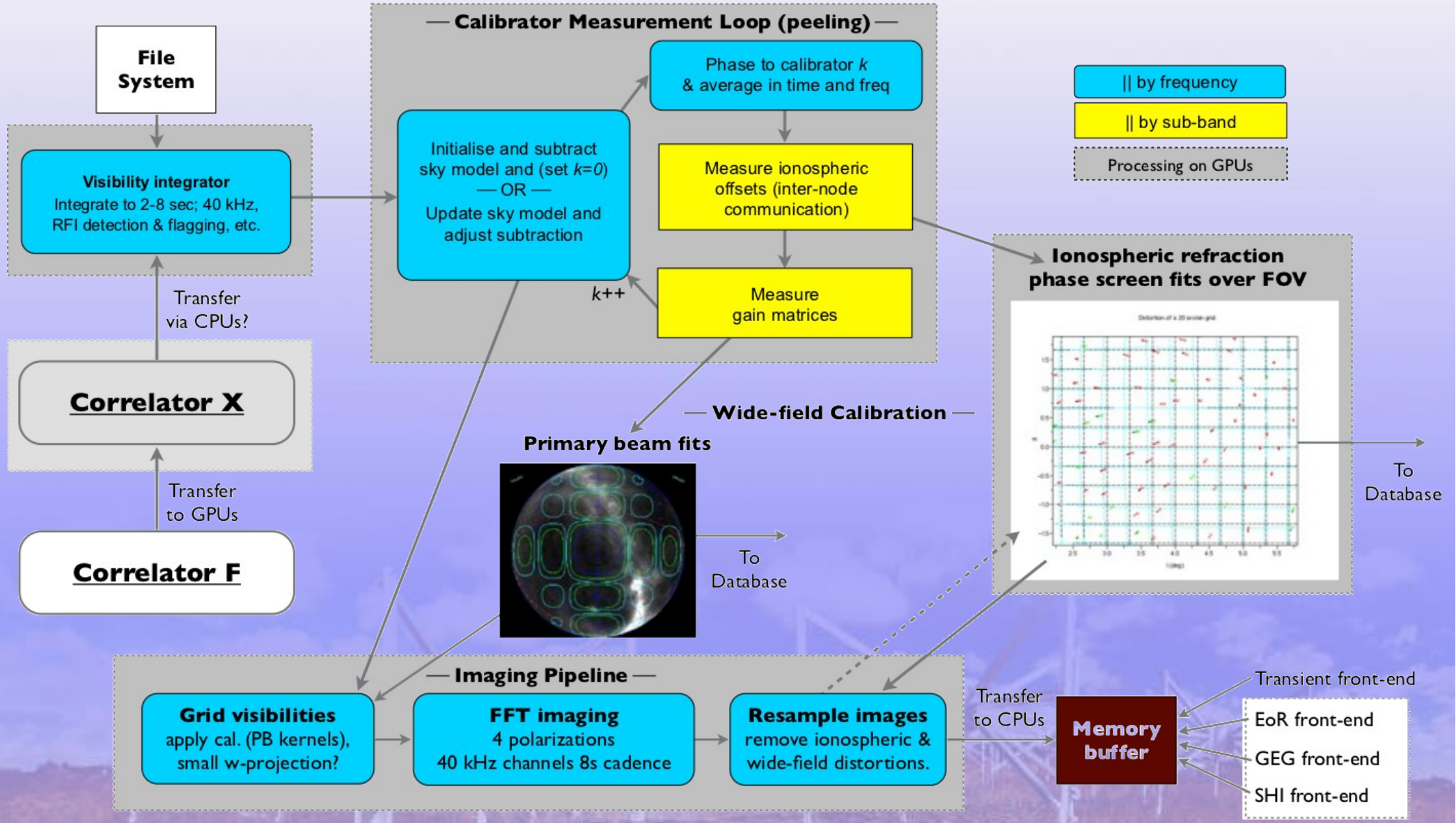


Data flow

Dave Pallot, ICRAR



Calibration: Real-Time System



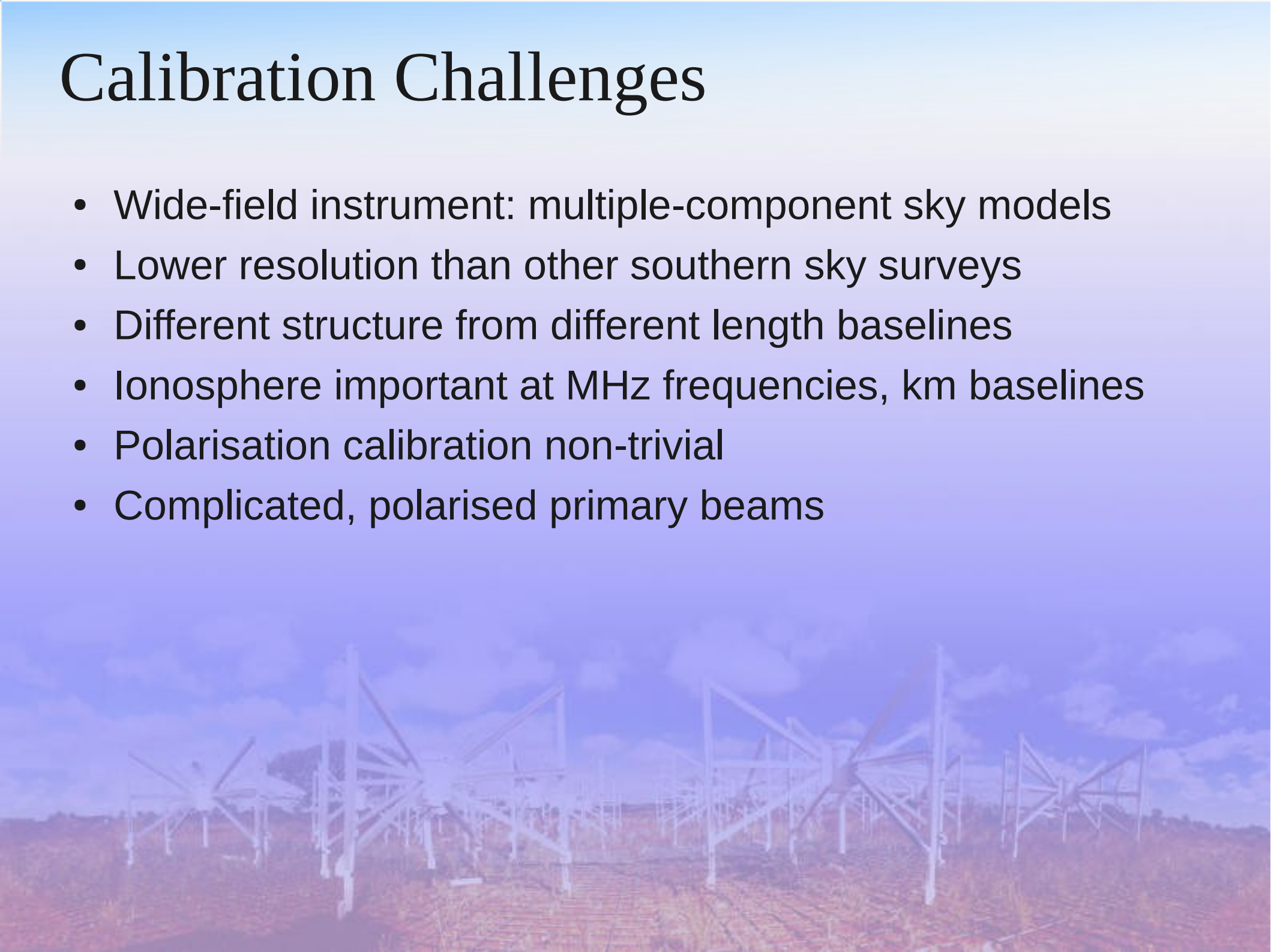
Dr Dan Mitchell, CAASTRO, Melbourne University

Intermediate Calibration: CASA

- Full capabilities of RTS requires high sensitivity: 100+ elements
- CASA is workable with the 32-element prototype: “only” ~24,000 visibilities per second
- Can use standard CASA tasks:
  - Setjy / input sky model
  - Bandpass
  - Clean
- Plus various bolt-on modules:
  - Flagging
  - Primary beam correction

Calibration Challenges

- Wide-field instrument: multiple-component sky models
- Lower resolution than other southern sky surveys
- Different structure from different length baselines
- Ionosphere important at MHz frequencies, km baselines
- Polarisation calibration non-trivial
- Complicated, polarised primary beams



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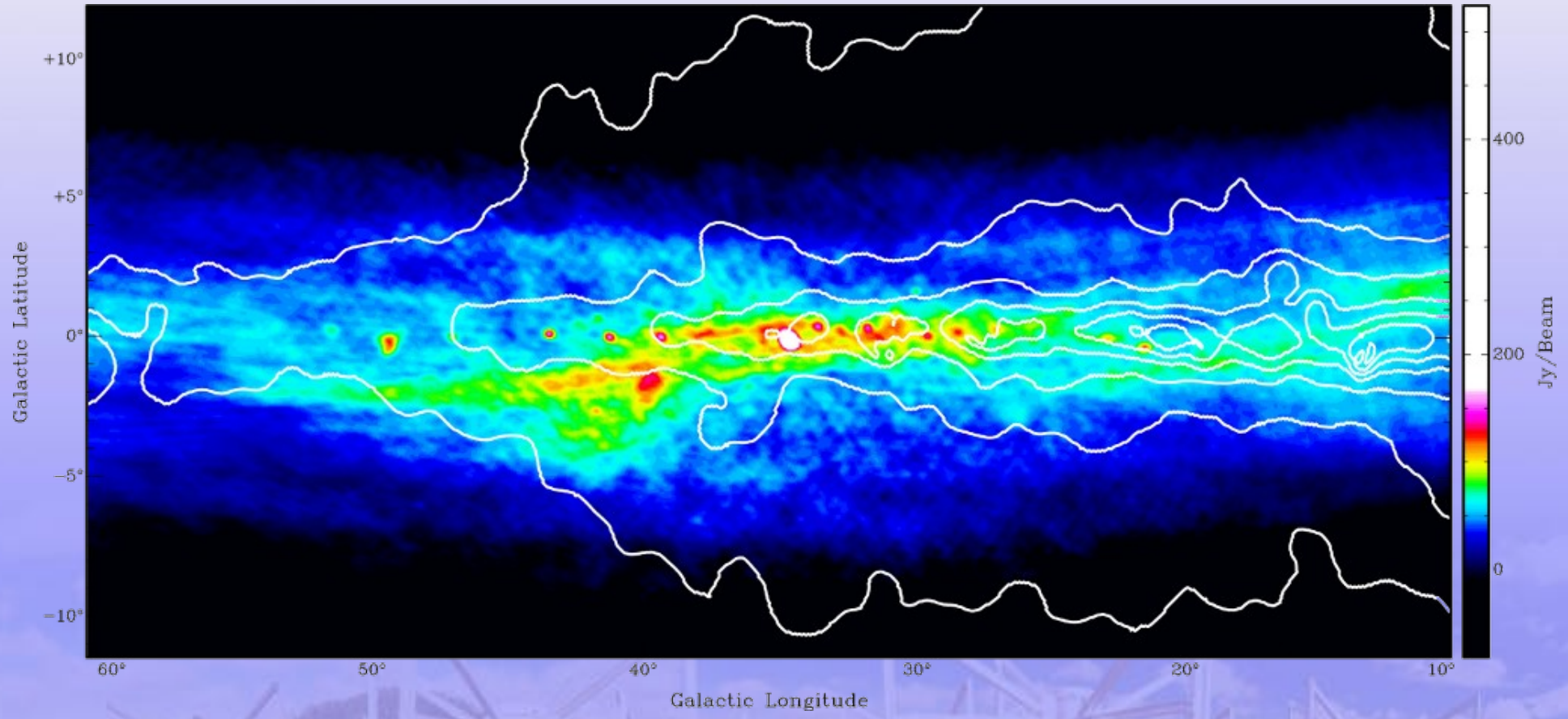
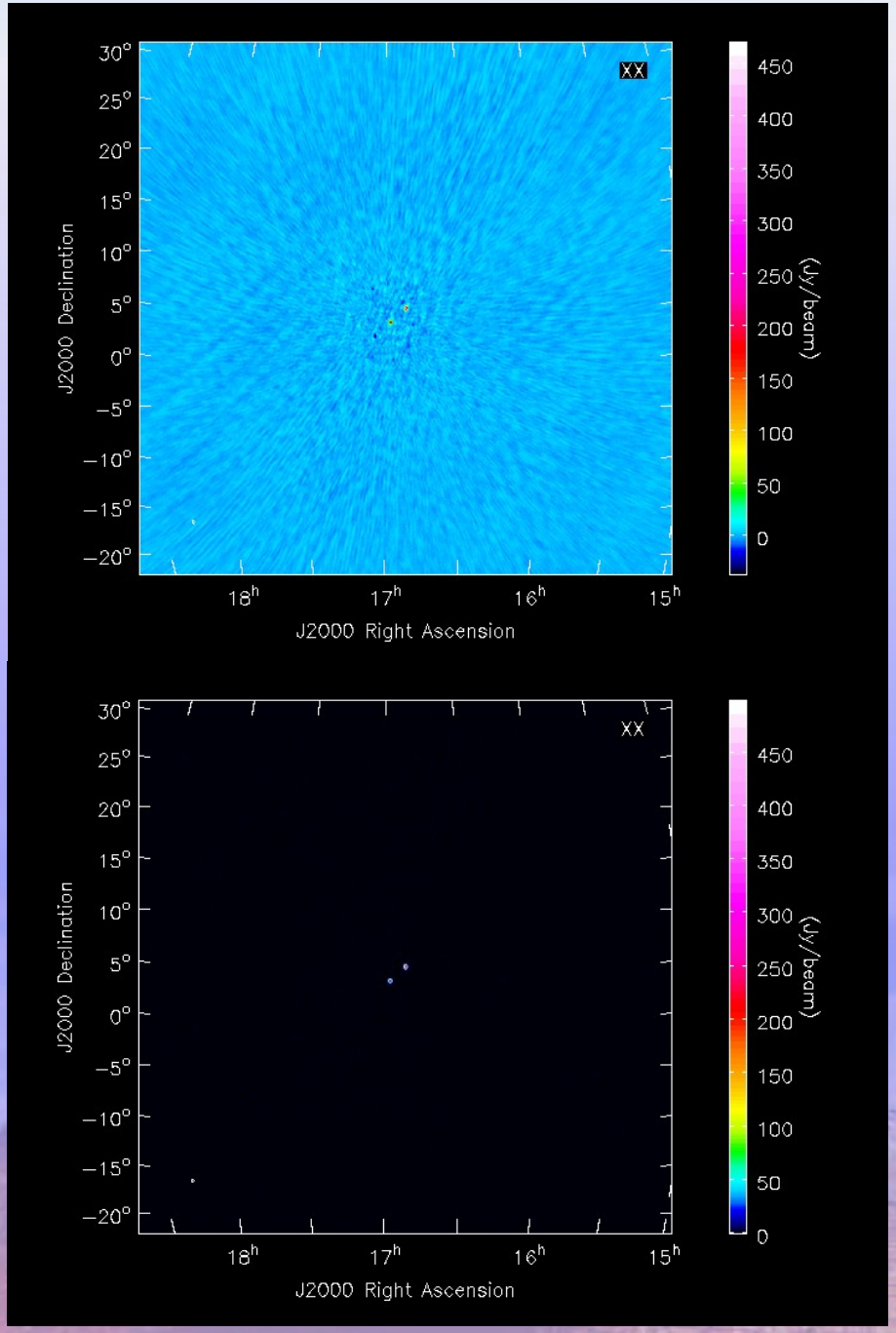
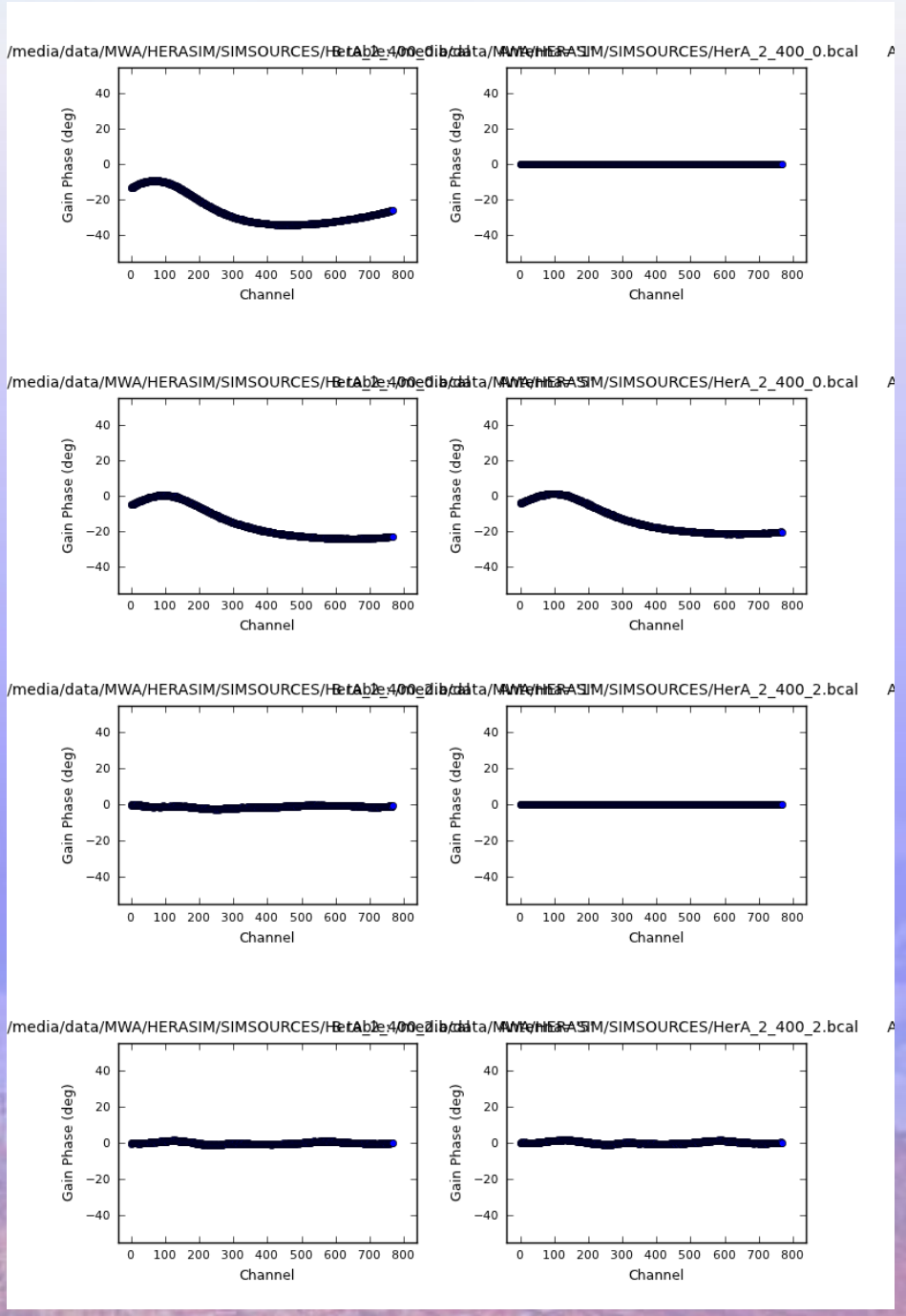
A wide-field instrument...



60 degrees

Multi-component sky models





Generating the Sky Model

- Existing catalogues
  - Molongolo: 843MHz, >1Jy, 1' resolution
  - Culgoora:
    - 80 MHz, >4 Jy, 1.85'
    - 160 MHz, >2 Jy, 3.70'
  - Parkes: 4.85GHz, >30mJy, 5'
- In development:
  - MWA
  - PAPER

- FT image and sample appropriate components
- What are 'appropriate'?
  - Resolution effects
  - source spectra
  - variability
- What are the effects of using the wrong model?

Calibration Challenges

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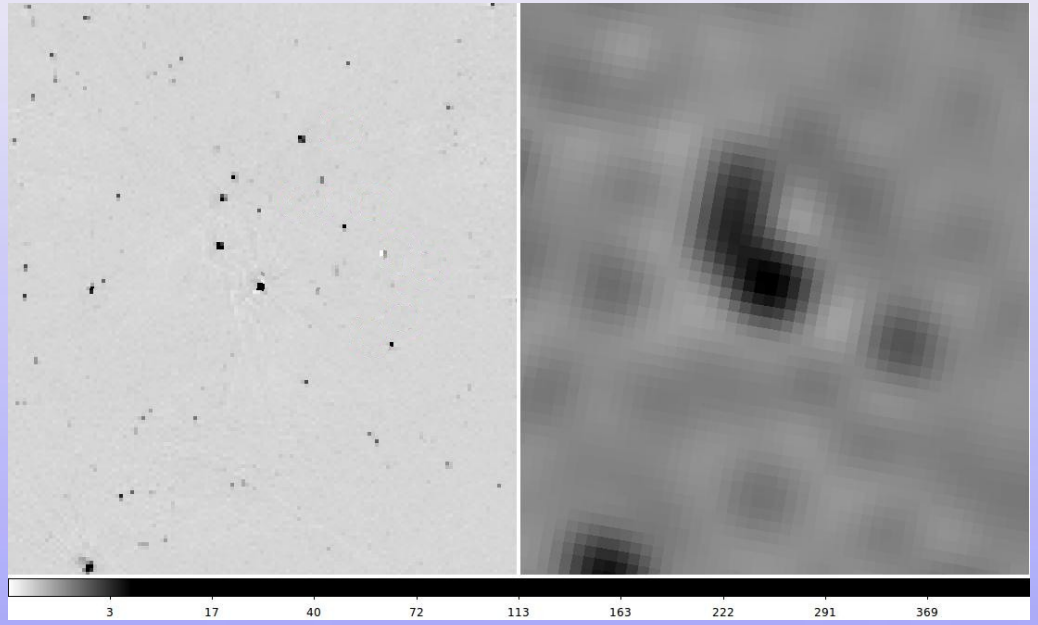

Molongolo MWA32T

- FT image and sample appropriate components
- What are 'appropriate'?
  - Resolution effects
  - source spectra
  - variability
- What are the effects of using the wrong model?

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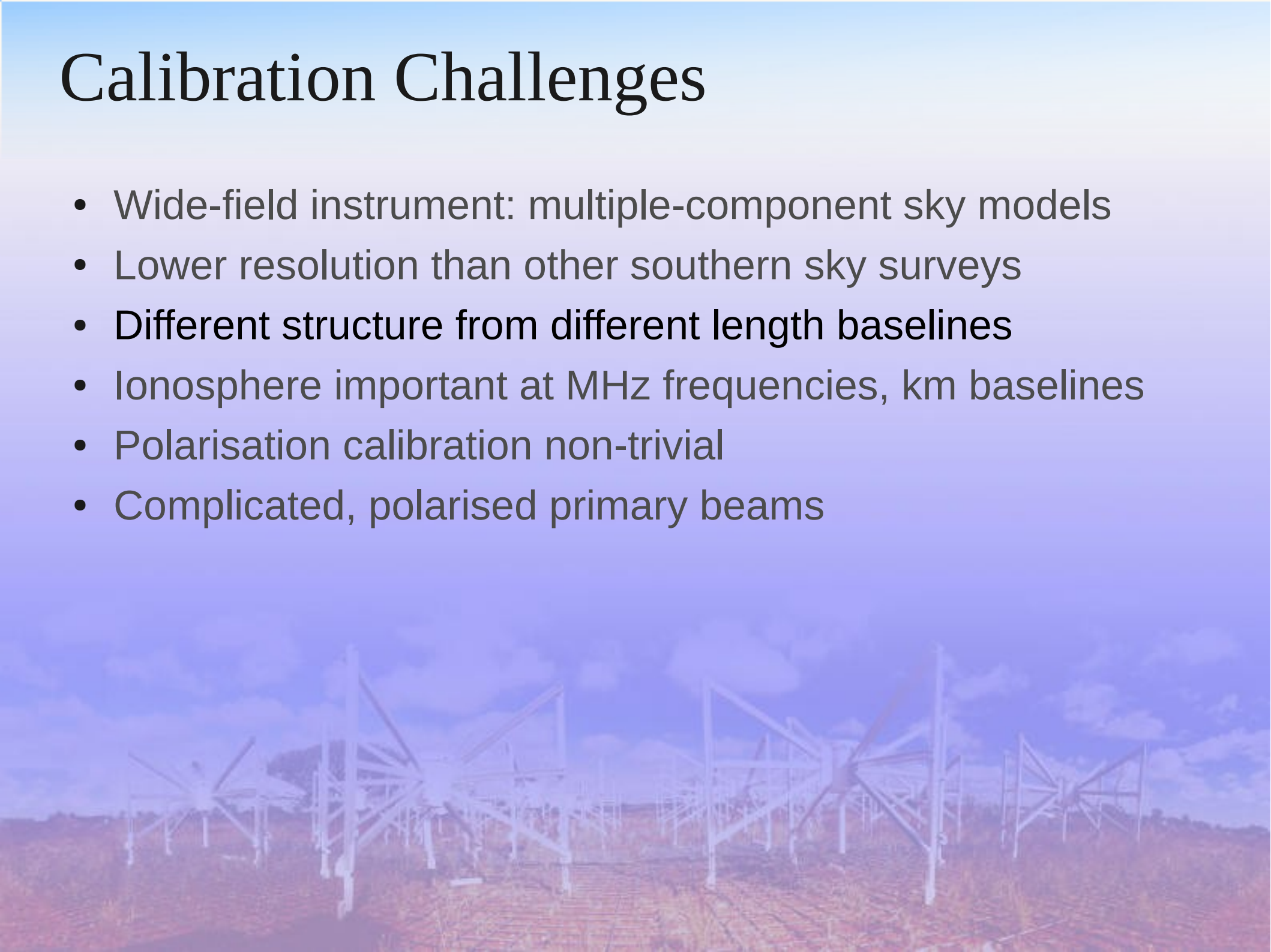
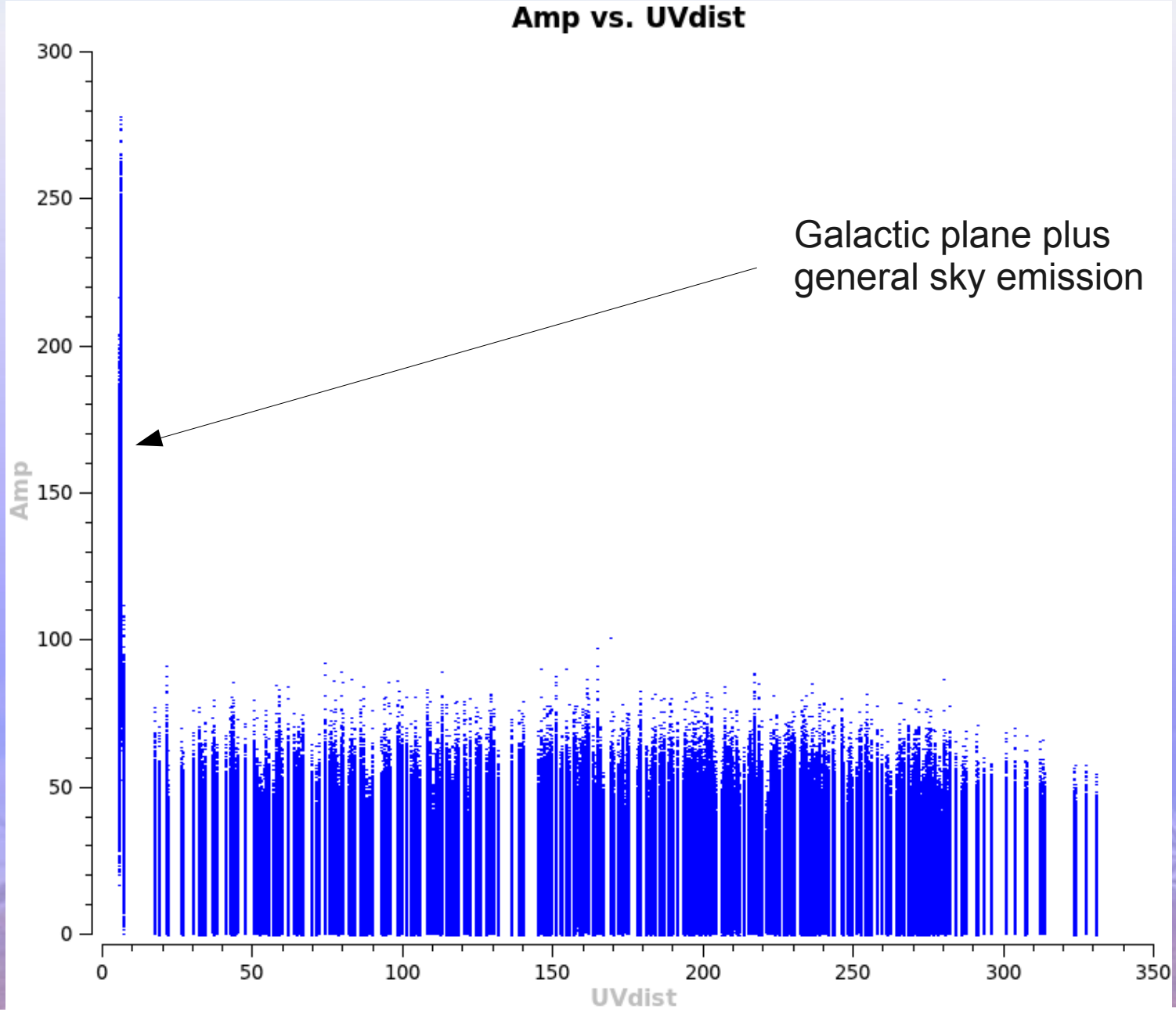


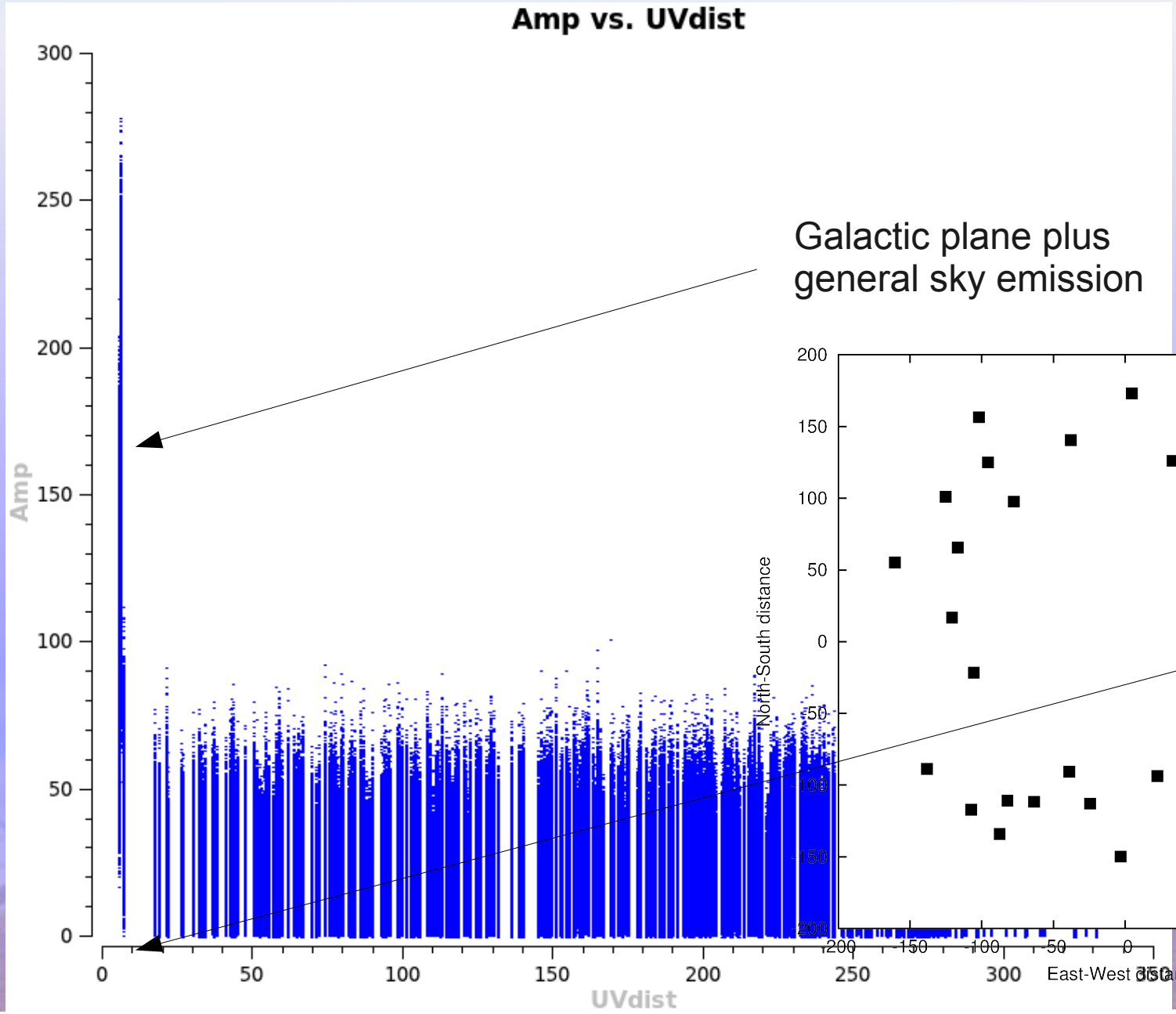
Sky structure: baseline response



Short baselines = Large angular scales

Long baselines = Small angular scales

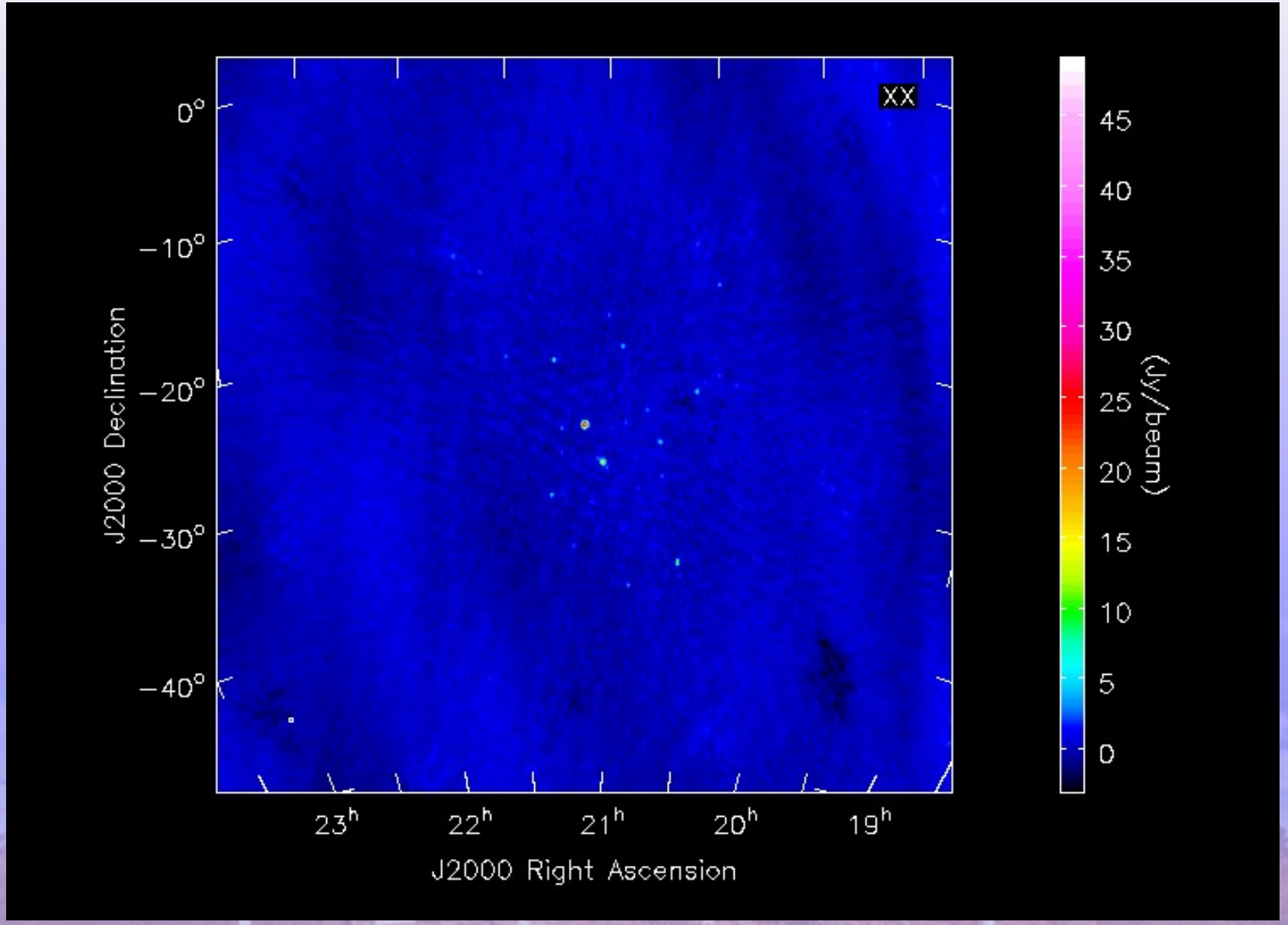
Sky structure: baseline response



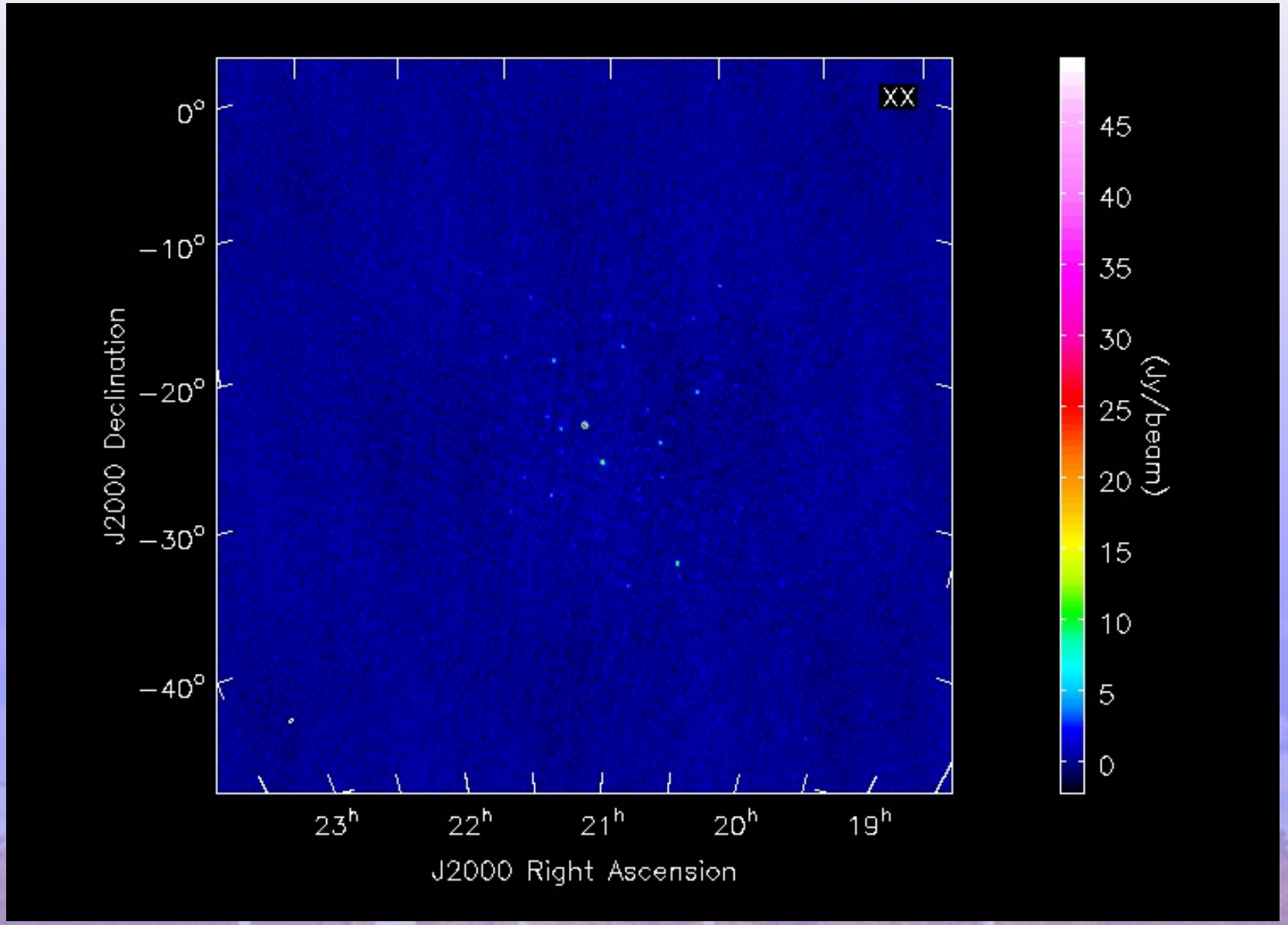
Short baselines = Large angular scales

Long baselines = Small angular scales

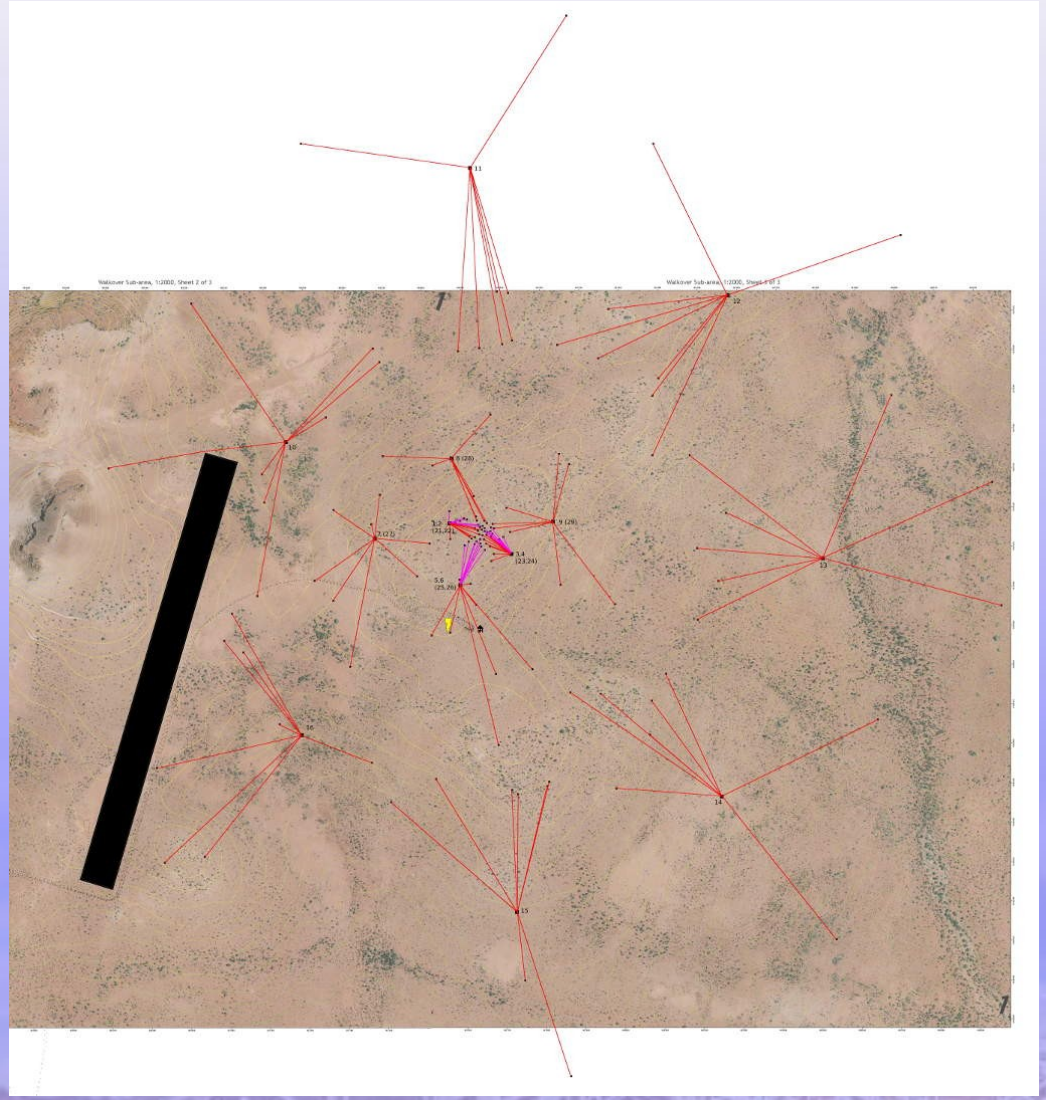
Sky structure: all baselines



Sky structure: short baselines tapered



Choosing our baselines for 128T



- Receivers commissioned in groups of four
- → Four different MWAs commissioned over the coming months
- Differing *uv*-coverage: a challenge, and an opportunity

Calibration Challenges

- Wide-field instrument: multiple-component sky models
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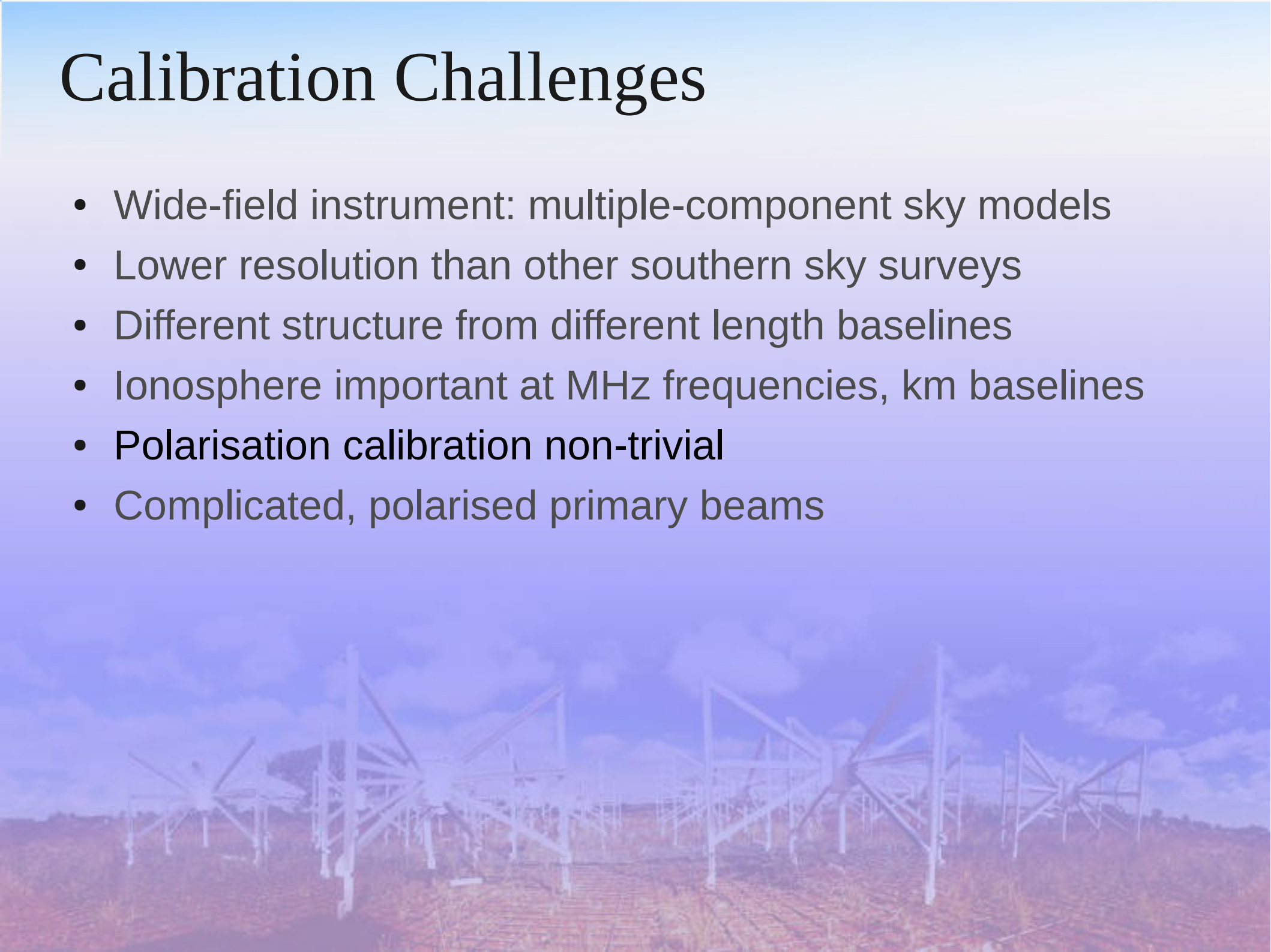
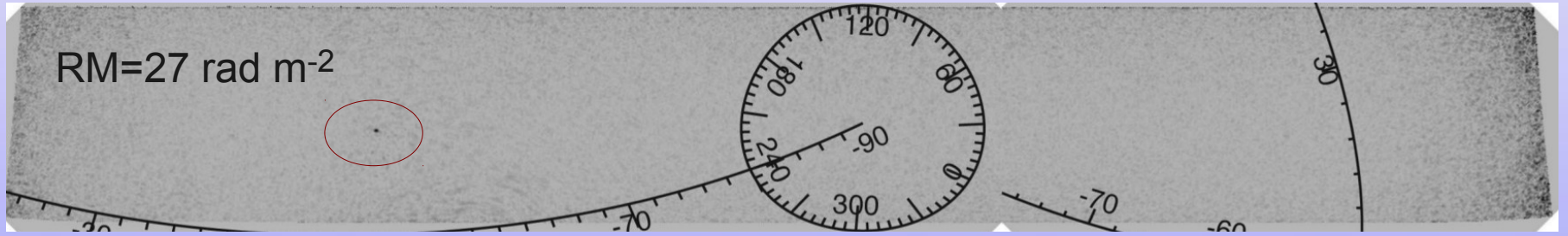
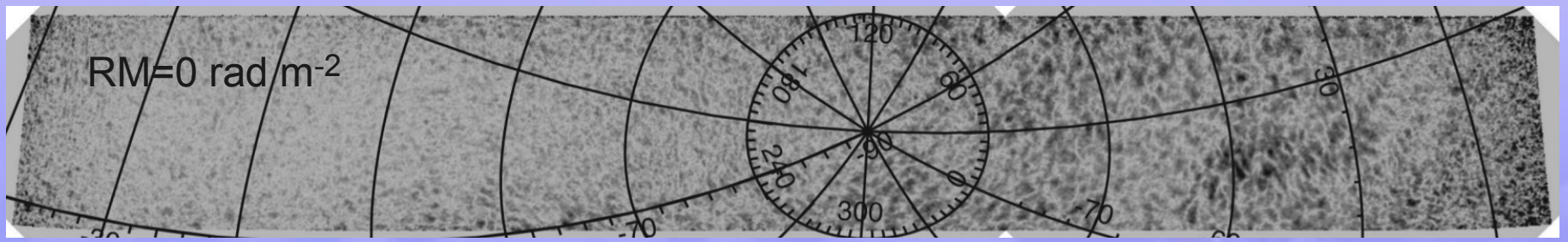


Polarisation calibration

- Instrumental polarisation ('XX', 'YY') easy to recover as tiles are all aligned North-South
- Recovering 'true' polarisation requires a polarised source



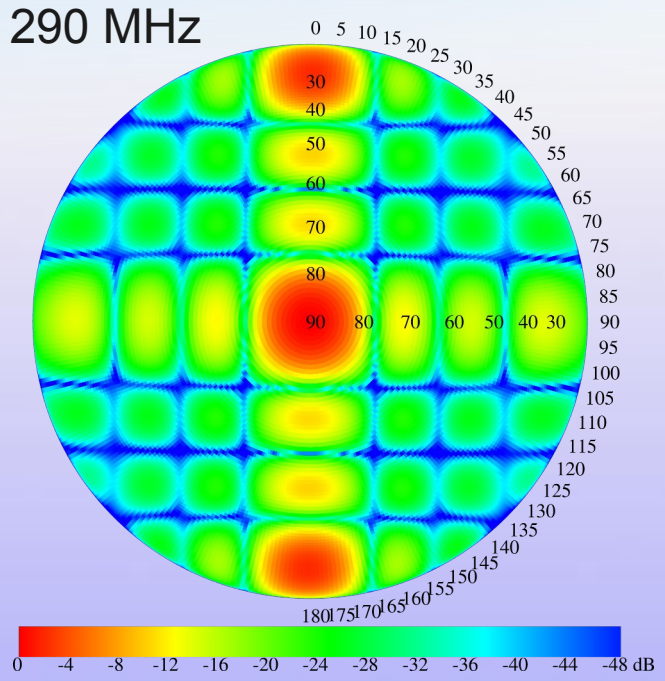


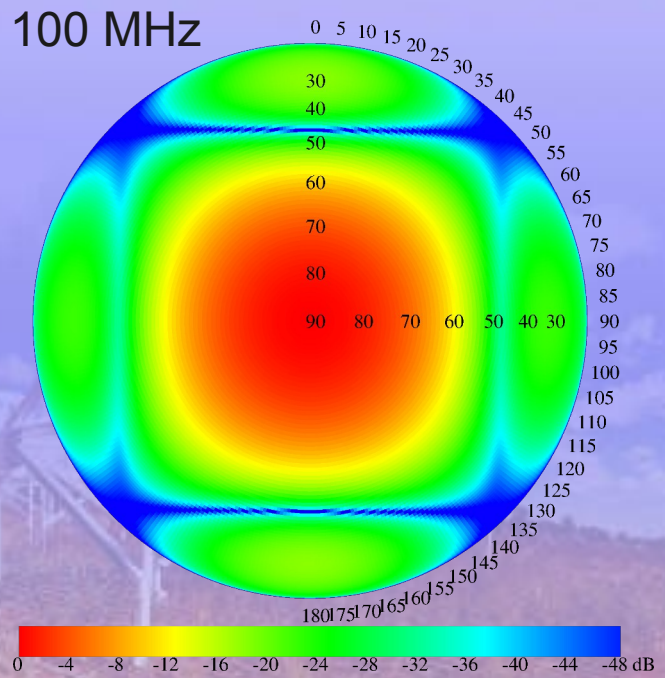
Dr Gianni Bernardi, CfA, Harvard

- Complex Galactic polarisation revealed
- Team currently investigating the possibility of using a highly off-axis unpolarised source for calibration

Primary Beams

- Not like a dish primary beam!
- One for each instrumental polarisation
- More complex at higher frequencies
- Difficult to model:
  - Real hardware with cables and struts
  - Differing dielectric ground plane
  - Mutual coupling between dipoles
  - Cross coupling across tiles
  - Short-dipole approximation wrong at low elevation (large zenith angles)
- Inspired us to try a new way of measuring them...





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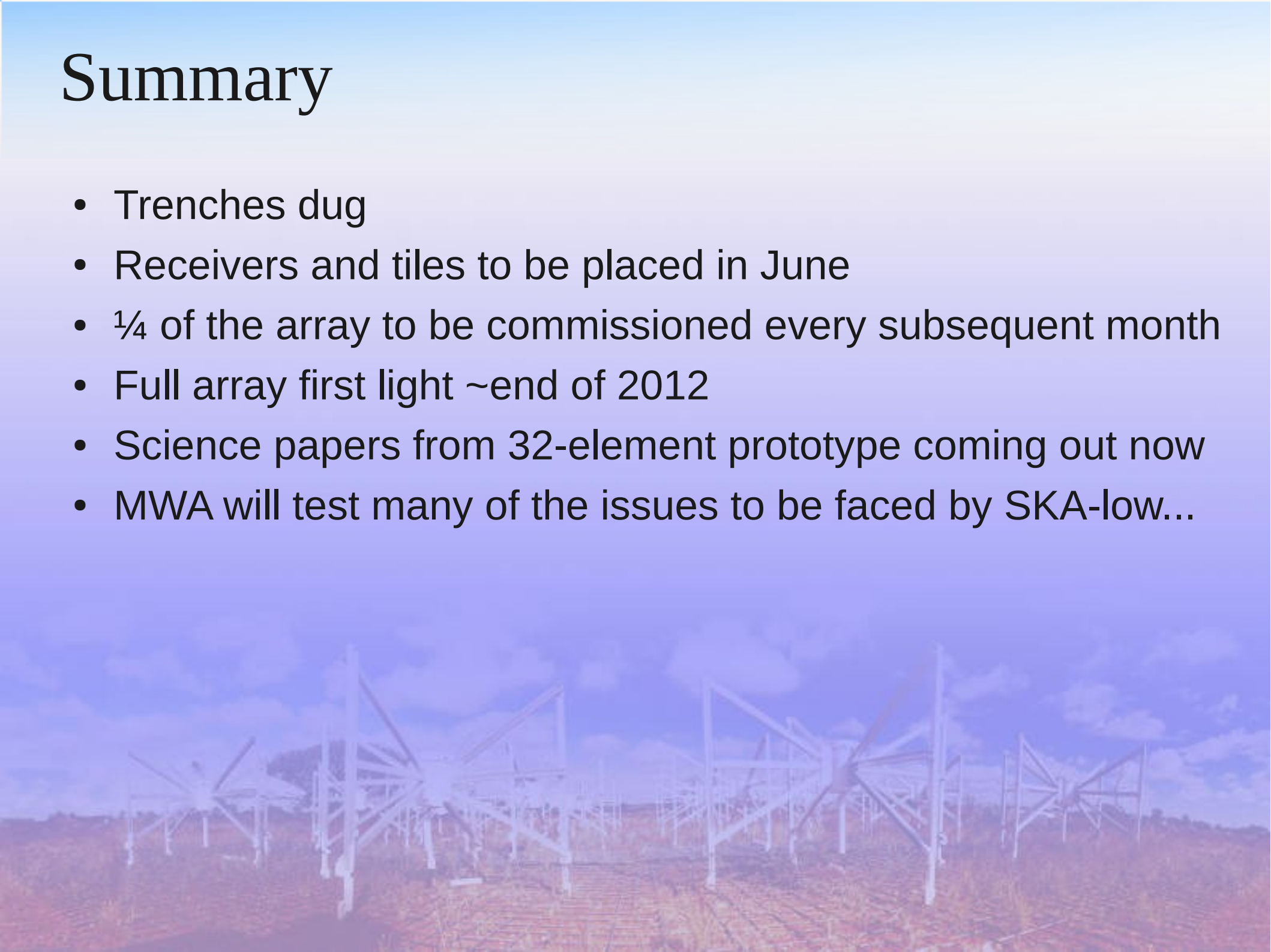
- Receivers and tiles to be placed in June
- ¼ of the array to be commissioned every subsequent month
- Full array first light ~end of 2012
- Science papers from 32-element prototype coming out now
- MWA will test many of the issues to be faced by SKA-low...



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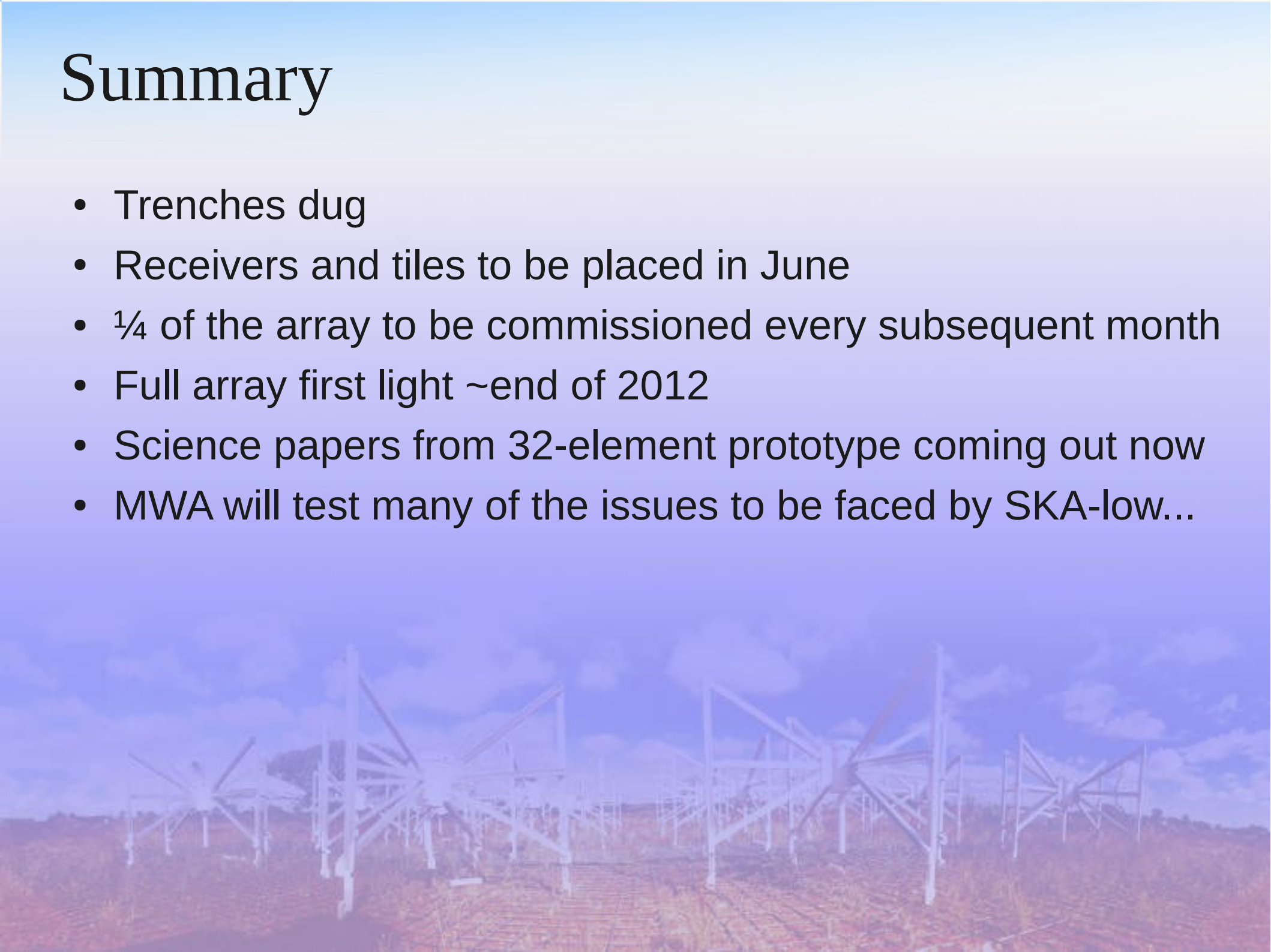

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Dr MWAnhattan