Making images with ASKAP

Max Voronkov | ASKAP Software scientist

20 November 2012

Astronomy and Space Science
www.csiro.au

Australian Square Kilometre Array Pathfinder

- Radio interferometer with 36 identical 12m antennas used together
- Located in the radio-quiet zone in the Western Australian outback

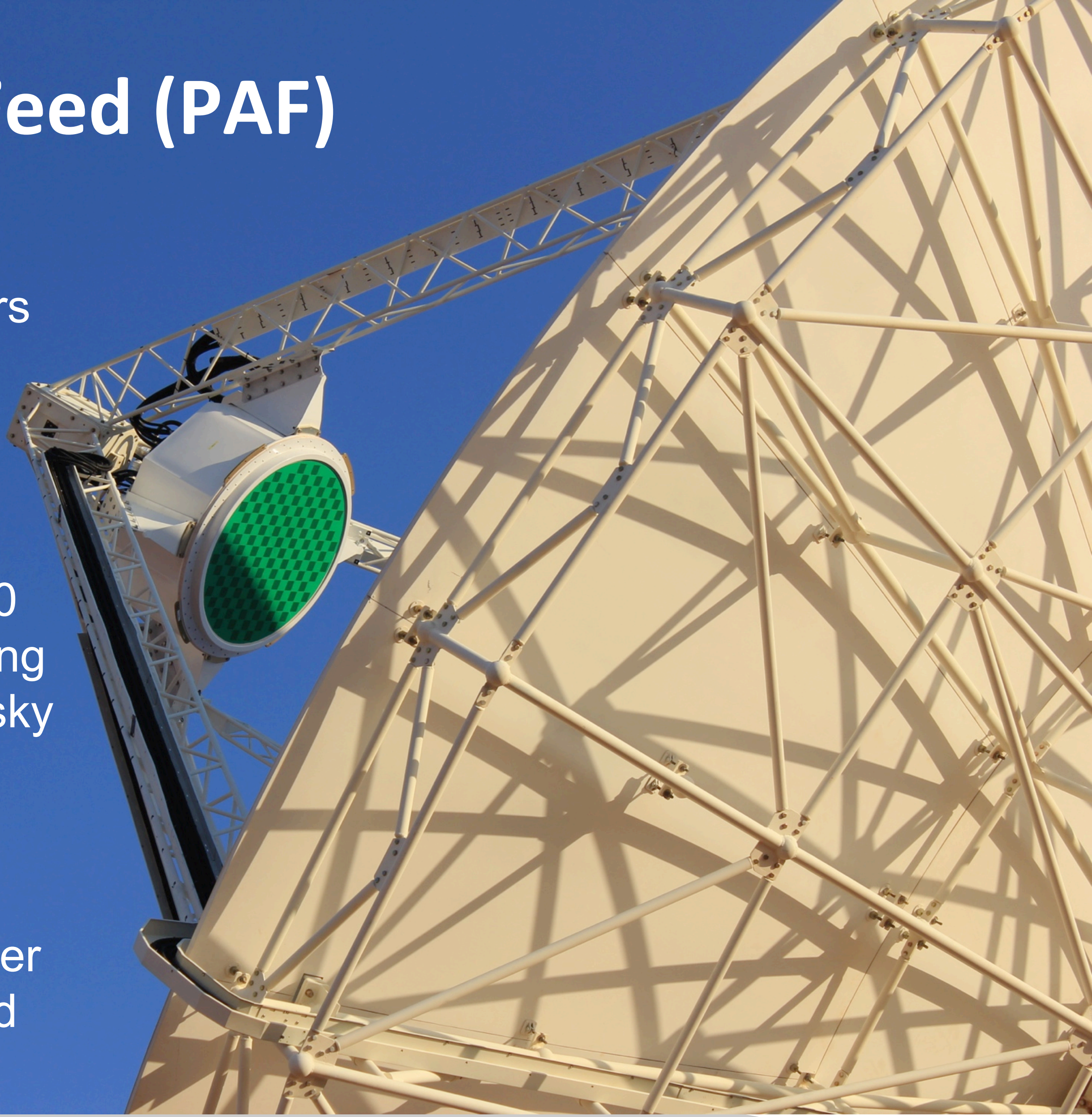
Key new features:

- Phased array feed
- Multiple synthetic beams on the sky
- 3-axis mount

↓

Wide field of view

Phased Array Feed (PAF)



188 independent receivers

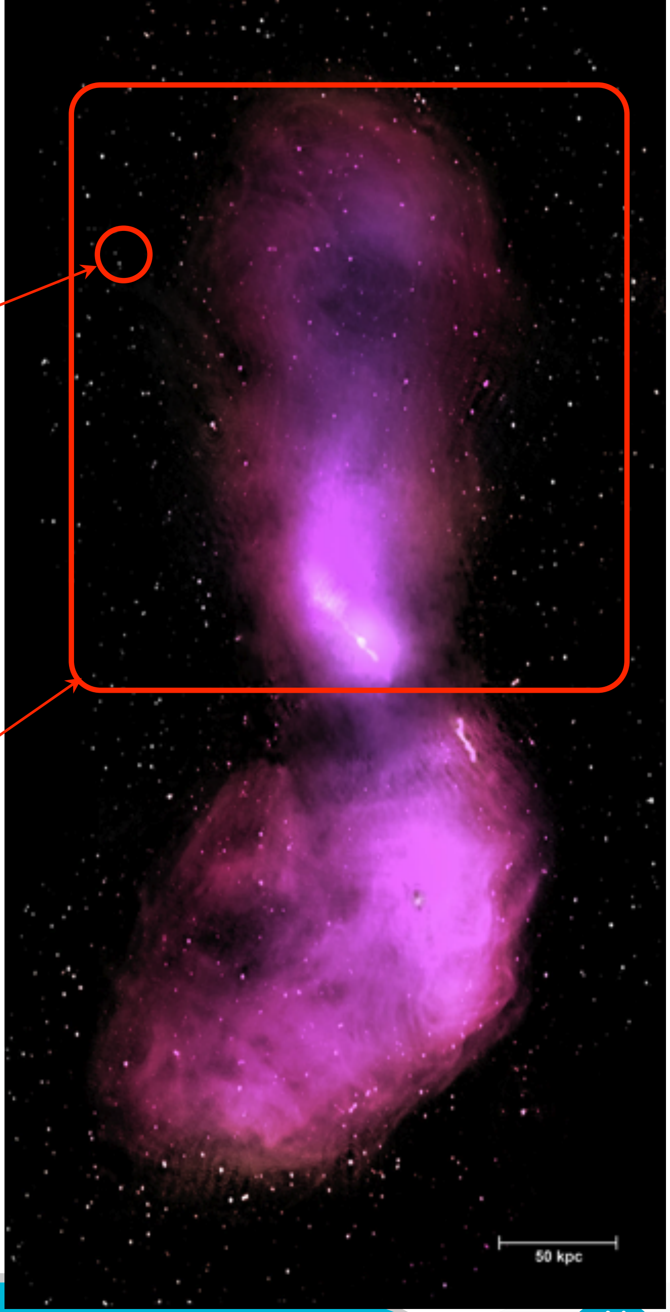
Beamformer computes 30 linear combinations making individual beams on the sky

3-axis mount gives a better stability of the system and simplifies imaging

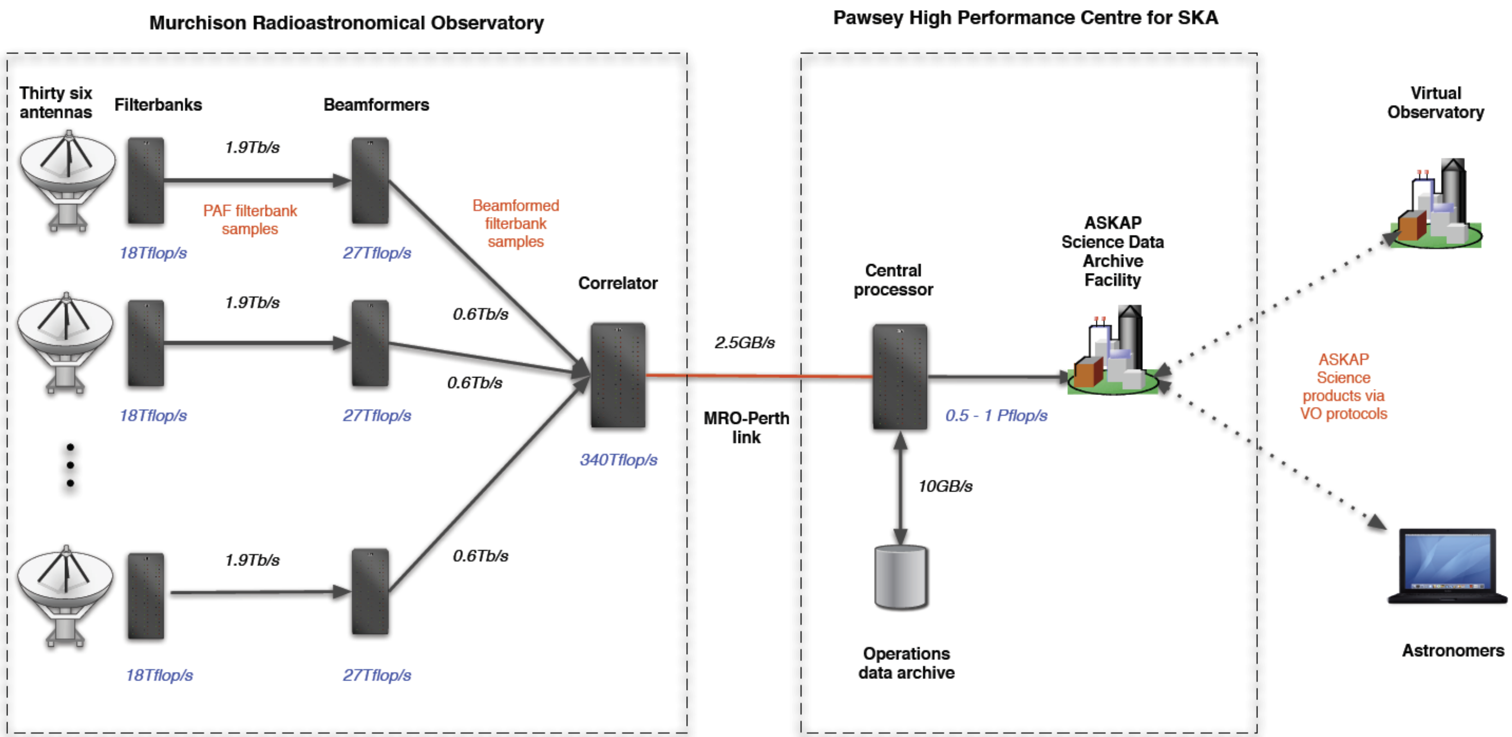
ASKAP: Wide Field of View

- Required 1200 hours observing with the Australia Telescope Compact Array

- ASKAP will take about 10 minutes



ASKAP data flow



- Wide field of view implies large volume of data
  - Approximately 200 TB of visibility data per day
  - Need for automatic processing and analysis, 20 TB/day of science products to be stored permanently

Science requires good image quality

- Need to minimise artefacts (most of the science is usually in weak sources)

- Good model of the instrument and the measurement process
- Good sky model

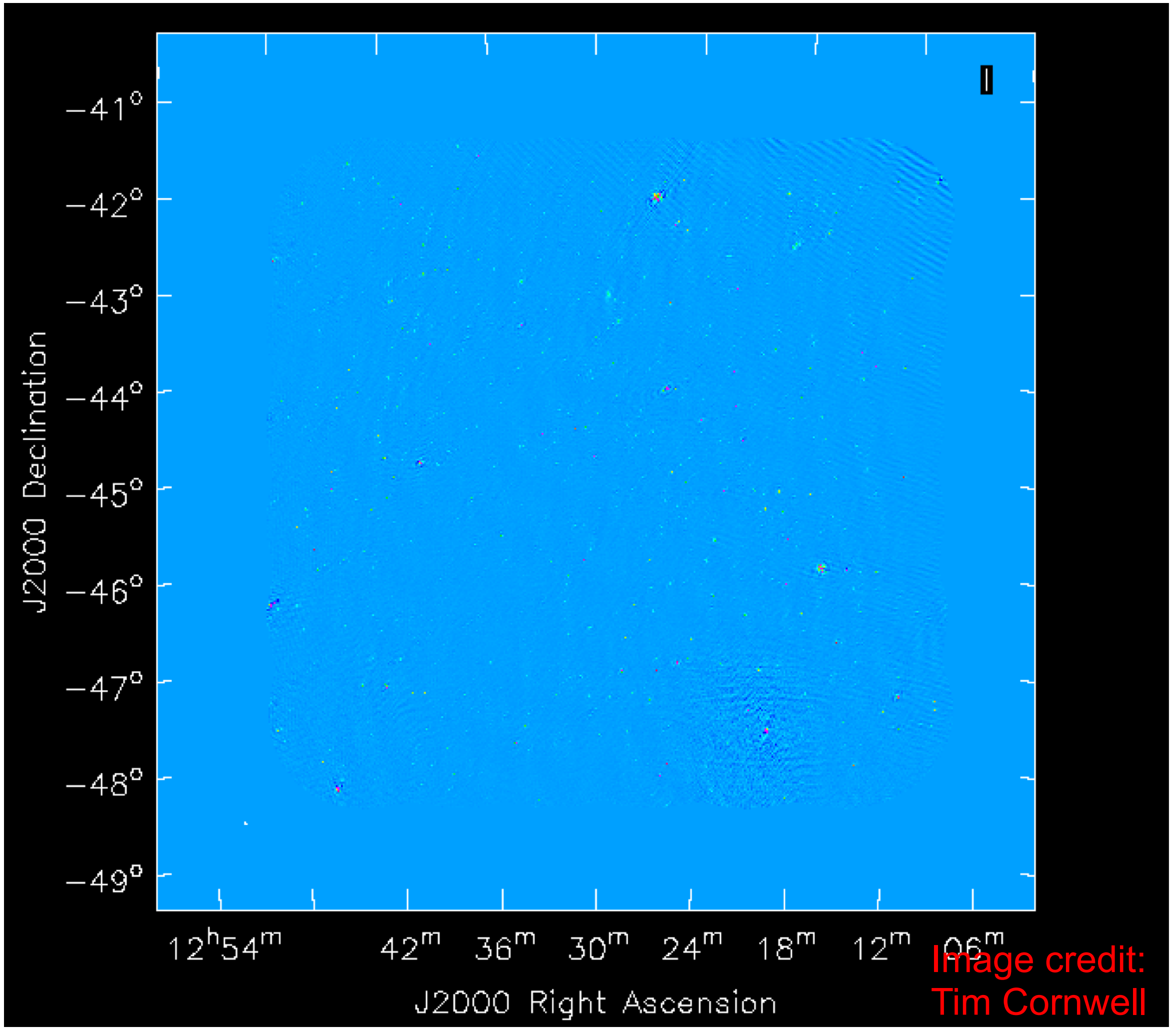
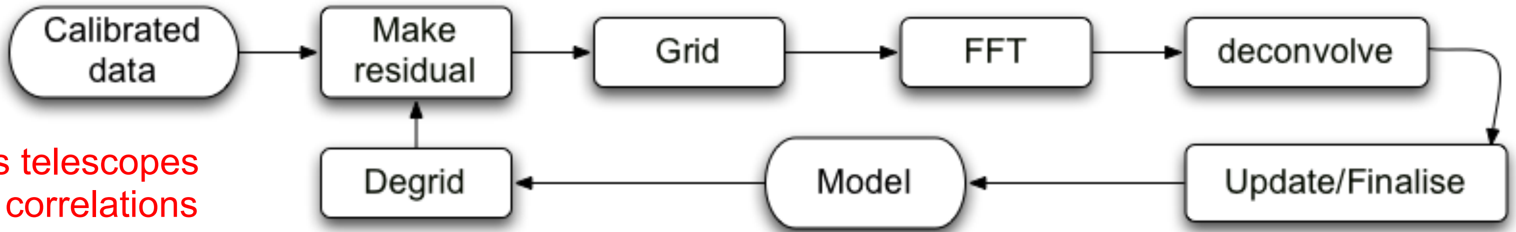


Image credit: Tim Cornwell

Simulated BETA image (using only first 6 antennas)

Indirect imaging of the sky



Synthesis telescopes measure correlations between received voltages for each pair of antennas

To the first order (narrow FOV), the measurement equation is a 2D Fourier Transform

Three different types of images are required

Continuum image

- Very accurate image
- Need multiple iterations
- Hard to parallelize

Spectral line cube

- 16416 independent images
- Each at slightly different frequency
- Embarrassingly parallel task
- One iteration may be sufficient

Transient image

- Very coarse image
- Made every 5 seconds

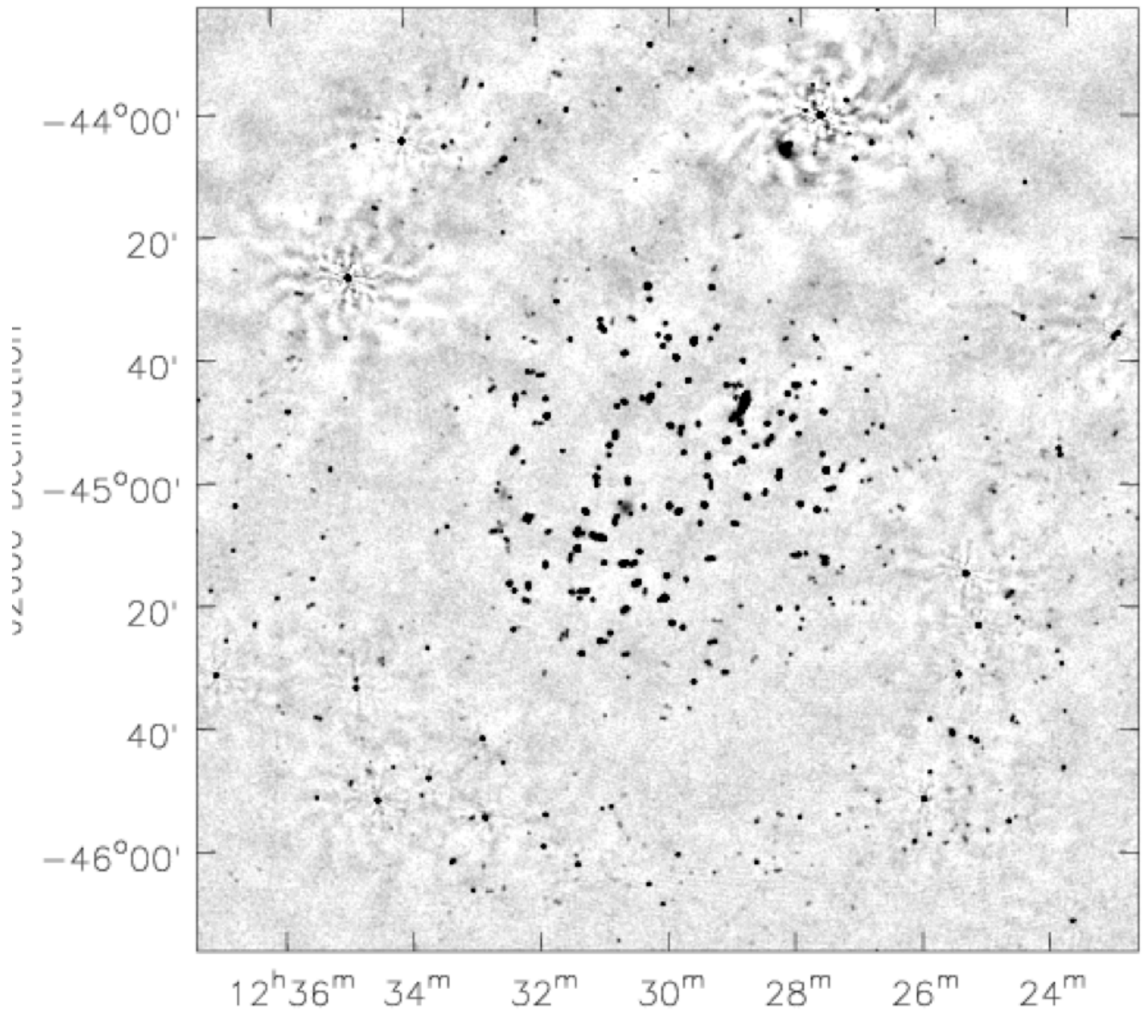
We need to make images in near real time, ideally all three types in parallel

Wide field imaging: beam pattern

Beam pattern attenuates the sky

If it is constant, we can correct for it both during (A-projection) and after the imaging

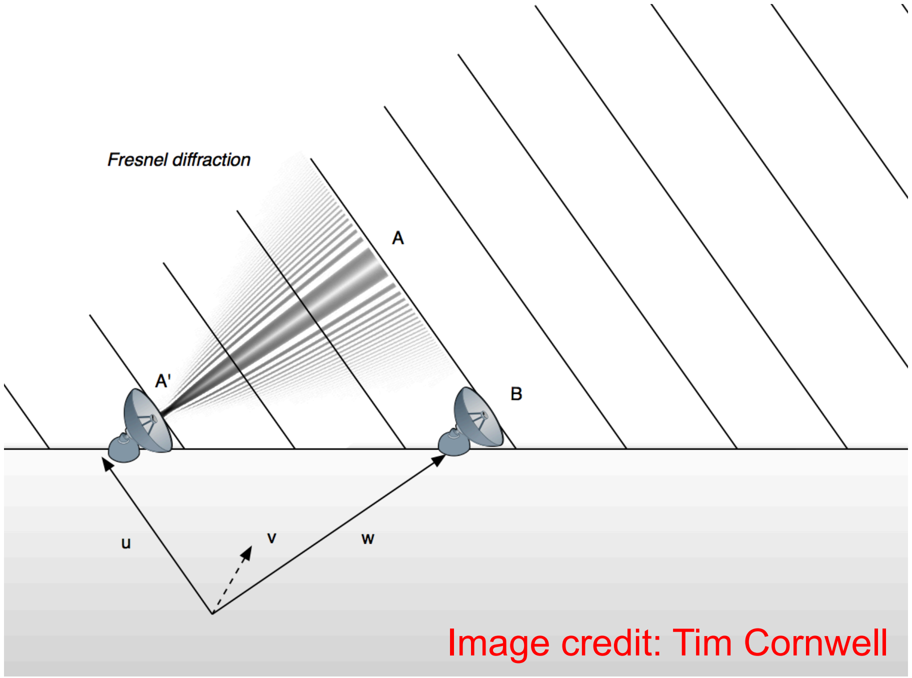
Ignoring variations (e.g. rotation) causes artefacts. 3-axis mount helps!



Effects of the beam rotation; image credit: Tim Cornwell

Wide field imaging: w-term

A number of algorithms exist: faceting, w-stacking, w-projection, snap-shot imaging, hybrid



$$V_{AB} = \int I(l,m) e^{-2\pi j(ul+vm)} dl dm$$

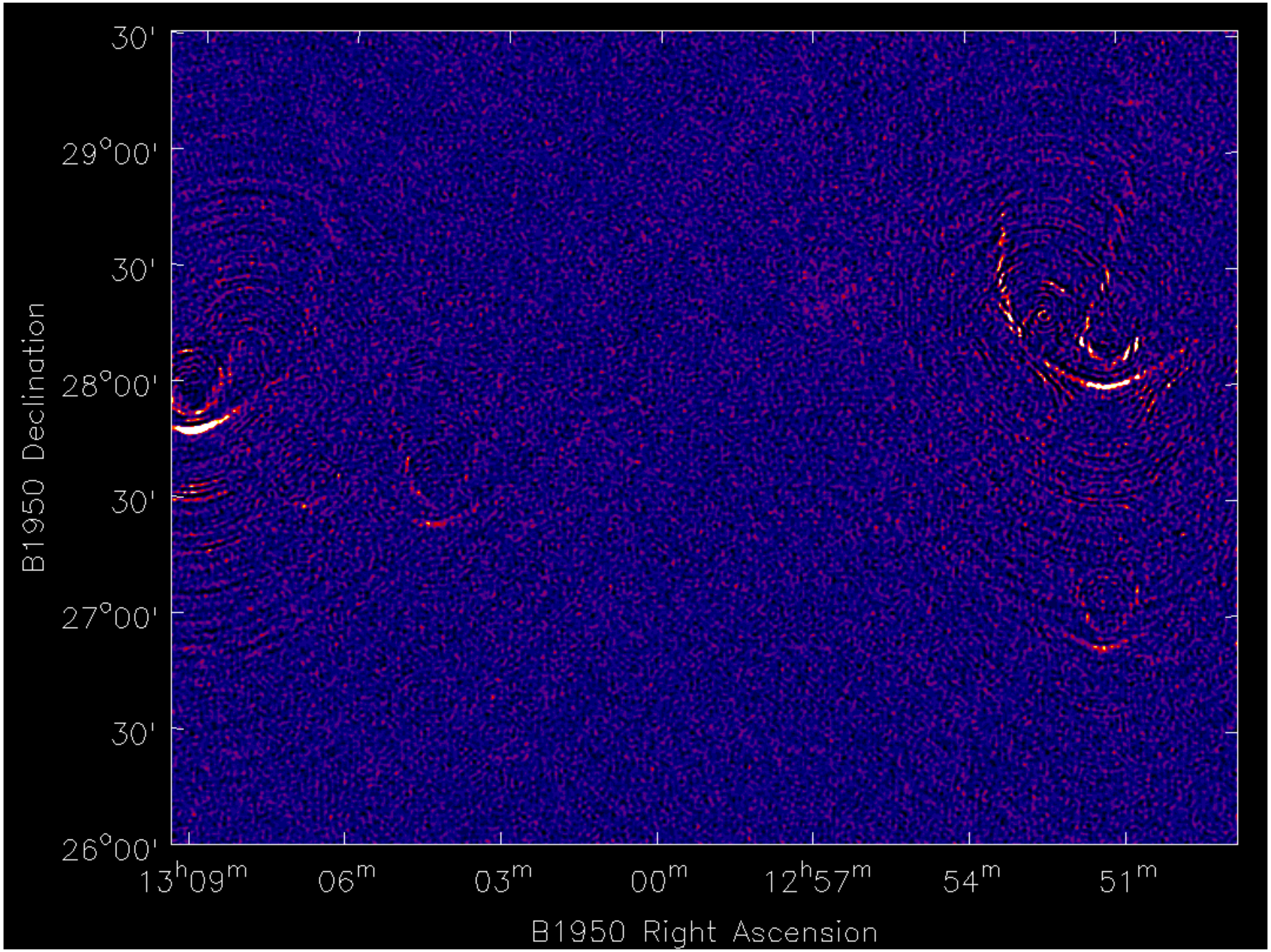
$$V_{A'B} = \int I(l,m) e^{-2\pi j\left(ul+vm+w\sqrt{1-l^2-m^2}\right)} \frac{dl dm}{\sqrt{1-l^2-m^2}}$$

For a coplanar array w=au+bv, the effect of the w-term can be accounted for by image reprojection – snap-shot imaging

Unaccounted w-term

Coplanar array

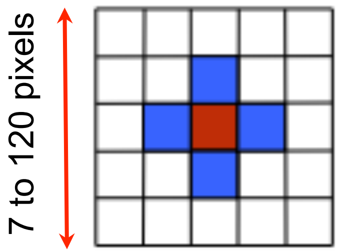
Time- and position-dependent shift



Gridding takes about 70% of processing time

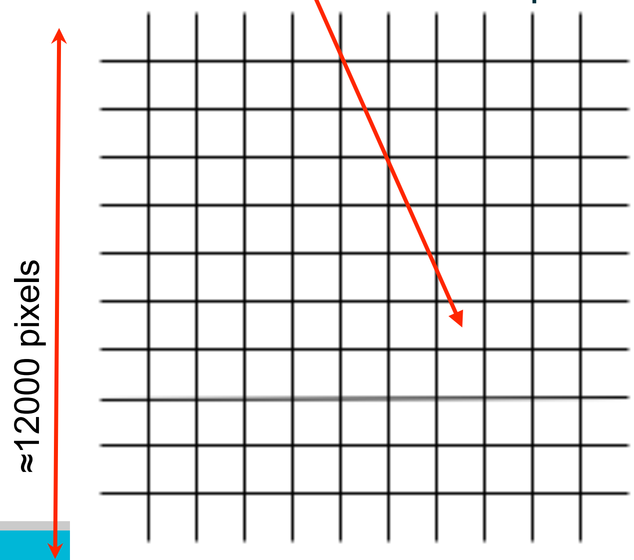
For each measured sample V:

Scale the whole convolution function (a 2D array) by V and put it on the grid



The choice of convolution function depends on the sample.

The place on the grid depends on the sample



There could be multiple grids. The choice of the grid depends on the sample.

- Complex multiplies & adds
- Low arithmetic efficiency
  - only 8 flops per 32 bytes of memory access

- Neither grids, nor the stack of convolution functions are likely to fit the cache
- Access pattern is semi-random
  - Getting data on and off the chip is the problem, rather than the computation

Low flops utilization

Efficiency issues

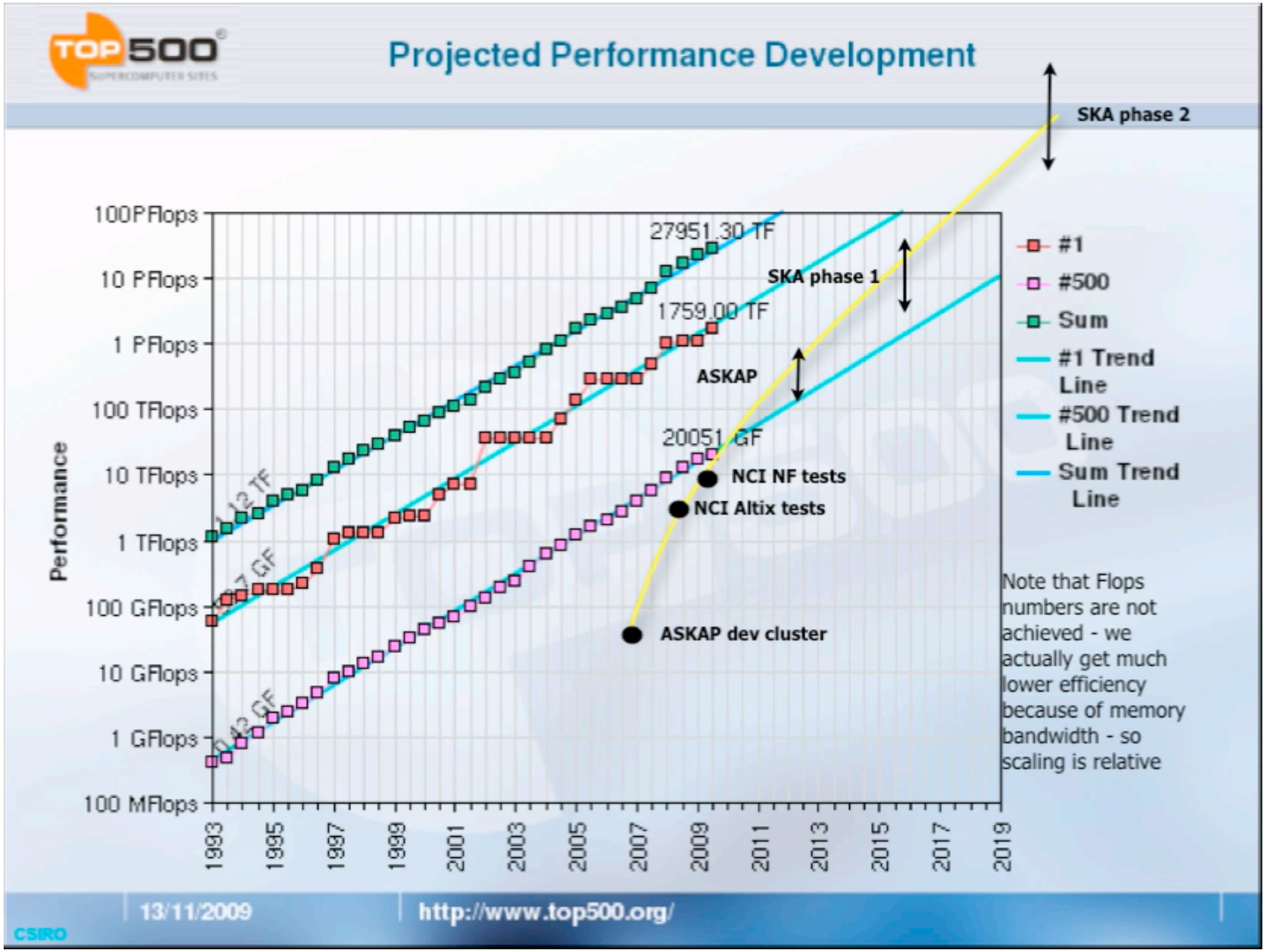
- The computation efficiency for the imaging problem is low
  - Low arithmetic efficiency/memory bandwidth
  - Small amount of available memory per core (sometimes we could only use a single core for the whole node)
- A new approach (distributed image to a greater degree) may be required for the SKA
  - Currently distribute in the way to minimise inter-rank communication
  - Some experience distributing the sky model represented by many images
  - Once had a great hope for shared memory parallelism, but dealing with the lack of thread safety in third party libraries is a challenge
- Different algorithms allow different tradeoffs between memory and the amount of computations
  - Our method of choice at the moment is a hybrid snap-shot imaging + AW-projection algorithm

Tim Cornwell's Mount Exaflop

ASKAP is 1% of SKA

Scaling to SKA is a challenge

Especially given the current struggle to contain memory use



CSIRO

Summary and future work

- Making images with ASKAP has a number of challenges
  - Memory size and low flops utilisation; algorithm efficiency
  - Accuracy of the measurement equation (taking into account more subtle effects requires more computation and often breaks some optimisations)
    - Beam pattern and w-term are certainly required to be modelled, the need for other week effects may come later as we gain more experience with the instrument
  - Automated reduction without human intervention
    - Need to find the best set of parameters
- Scaling to SKA is even more challenging
- The current work is largely focused on BETA (first 6 antennas)
  - Independent vs. joint processing of individual beams?
  - More parallelism, e.g. parallel deconvolution?
  - Better understanding of the instrument

We acknowledge the Wajarri Yamatji people as the traditional owners of the Observatory site

Thank you

Astronomy and Space Science
Max Voronkov
ASKAP Software Scientist

t +61 2 9372 4427
e maxim.voronkov@csiro.au
w www.narrabri.atnf.csiro.au/people/vor010