ASKAP Pipeline processing and simulations

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ASKAP Computing Team Members

- Team members
  - Marsfield: Tim Cornwell, Ben Humphreys, Juan Carlos Guzman, Malte Marquarding, Tony Maher, Euan Troup, Max Voronkov, Matthew Whiting, Xinyu Wu (from May)
  - Narrabri: Dave Brodrick
  - Parkes: Simon Hoyle
  - Dwingeloo: Ger van Diepen
  - Socorro: Urvashi Rau
- Mostly software engineers
  - Astronomers - Tim, Max, Matthew

Using ASKAP

- Synthesis image of Centaurus A
- Required 1200 hours observing on the Australia Telescope Compact Array

- ASKAP will take ~ 10 minutes

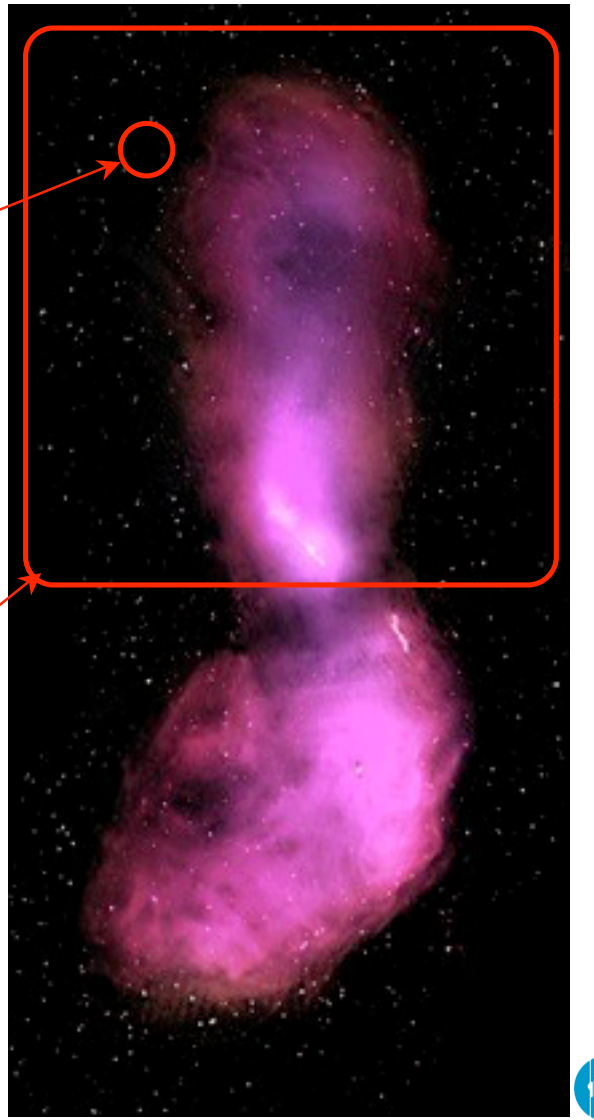

Image: Ilana Feain, Tim Cornwell

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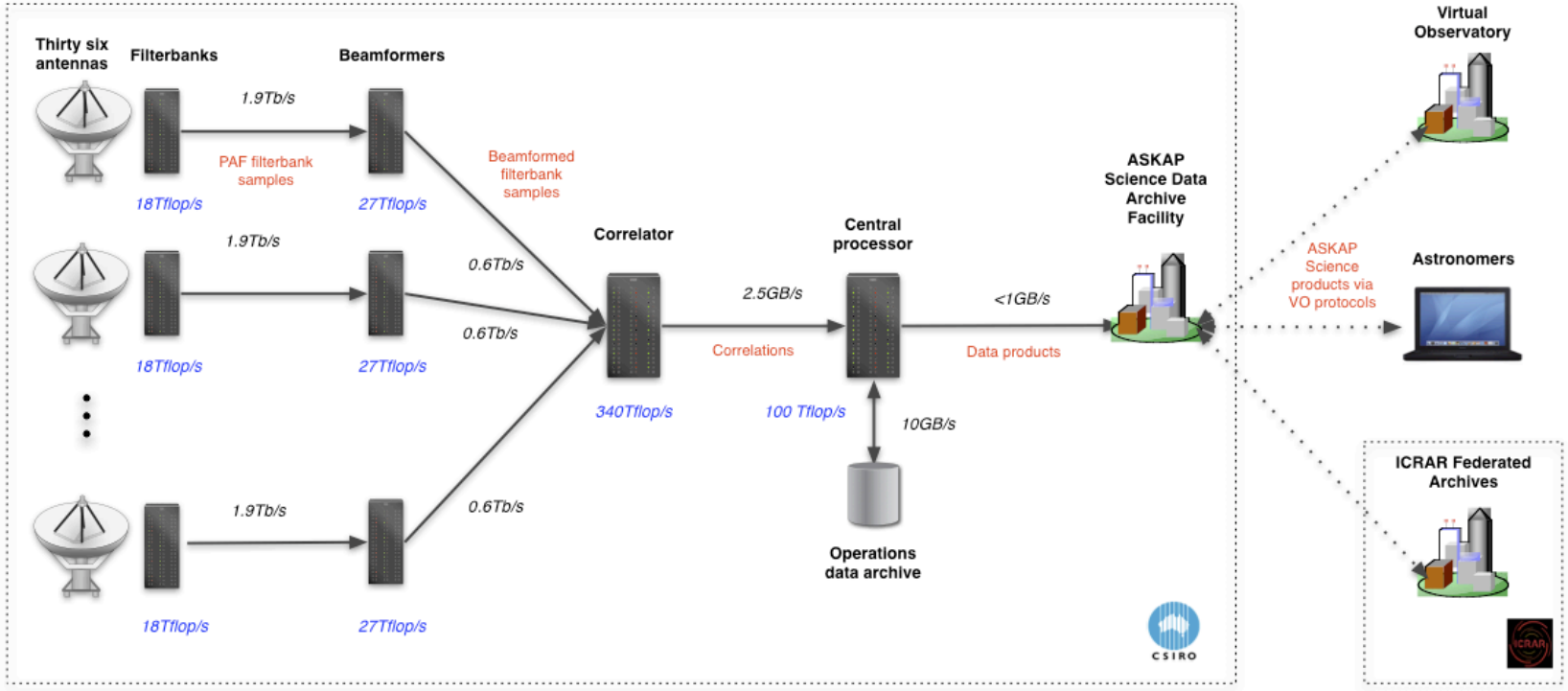
Data flow



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Response to Imaging Challenges

- Large size of data flow presents challenges for processing
- Control complexity of the data and manage computing load
- 3-axis mount partially in response to this
  - Removes need for beam rotation in software
- Maintain an accurate Global Sky Model
  - Used to subtract bright sources from continuum sky before processing
  - Derived during early operations for entire sky
  - Science imaging uses GSM as starting point - small differences only
- Post-gridding weighting schemes used
  - Gridding/degridding dominates computing load (90%)
- PSF good enough to not need full deconvolution of spectral-line and transient pipeline data
- Distributed processing necessitates custom-built pipeline software
  - Existing tools not parallelisable (CASA, miriad, …)

Spectral-line Pipeline overview

- Keep full 16384 channels
- Two polarisations only
- Global Sky Model subtracted prior to imaging
  - Use previously-made model and predict forward
  - GSM needs to be of sufficient S/N to not degrade sensitivity
- No deconvolution in imaging
  - Maybe for a few nearby galaxies, or Galactic objects, but single major cycle only
  - Array configuration means PSF is good enough
- Cataloguing done immediately
  - Measure as much as we can while we can
- Create image cutouts, moment maps and spectral plots
- Will have data quality evaluation built in to pipeline

Other Pipelines

- Continuum mode
  - Average visibility stream to 256 channels. Keep full Stokes
  - Able to do full imaging with deconvolution over full 30 sq.deg.
  - Always have a good continuum model of the sky
  - Automatic cataloguing
    - Keep continuum model up to date for calibration
    - Create science catalogues

- Transient mode
  - Correlator outputs every 5 seconds
  - Average visibilities to 32 channels
  - Remove sky model and look for new / varied sources
  - Raise alerts and maintain light-curves
  - Search on longer timescales as well

Source finding

- ASKAP pipelines will have automatic source extraction and cataloguing built in
- Capable of:
  - Forming science catalogues for continuum, emission line, absorption line and transient data products
  - Keep Global Sky Model up to date
  - Produce associated data products for each source: moment maps, integrated spectra plots, cutouts
- Integrate with imaging pipeline, to make use of data while in memory
  - Large data products, so want to minimise disk I/O
  - Utilise distributed processing to minimise memory usage per cpu

Duchamp Source Finder

- *Duchamp* is an open-source astronomical source finder optimised for spectral-line cubes
- Stand-alone program developed outside ASKAPsoft, but library used in ASKAP pipelines as 3rd-party package
- Basic algorithm is:
  - Define threshold (use cube statistics)
  - Search each 2D image or 1D spectrum, recording detected objects
  - Combine objects to form 3D structures
  - Measure parameters from combined sources
- Smoothing or wavelet reconstruction possible to enhance objects above the noise
- Range of graphical output to help understand detections

http://www.atnf.csiro.au/people/Matthew.Whiting/Duchamp

ASKAPsoft source detection

- Source detection currently built upon *Duchamp*
- Uses code as a library, and adds functionality on top
- Parallel-processing done in coarse-grained fashion:
  - Split up image in user-defined manner
  - Each chunk searched separately with Duchamp algorithms
  - Any sources at/near edge are handled by a master process
  - Reduces memory impact on any single cpu
- Other features not (yet) in stand-alone package
  - For 2D case, have Gaussian fitting capabilities
    - Decompose detected sources into Gaussian components
    - Functionality comes from casacore library
  - Variable detection threshold across image
  - Integration with multi-frequency synthesis output

- Form of ASKAP source detector(s) to be determined in consultation with science teams (ASKAP Working group 2)
  - Developing protocols to convert algorithms into pipeline code

ASKAP End-to-End Simulations

- Construct simulations of the full pipeline processing
  - Sky Model → Telescope Simulator → Imager → Analysis
- Necessary for testing pipeline software
  - How does imaging work with appropriate range of source properties?
  - How does imaging scale to appropriate sizes?
  - How does source extraction perform?
- Necessary for testing science questions
  - How does imaging pipeline treat various source types?
  - How does source extraction perform?
  - What survey strategies will be appropriate?

- Coordination of these activities across SSPs managed through an ASKAP Working Group
- ASKAP Computing responsible for running simulations with prototype pipelines and disseminating resulting data

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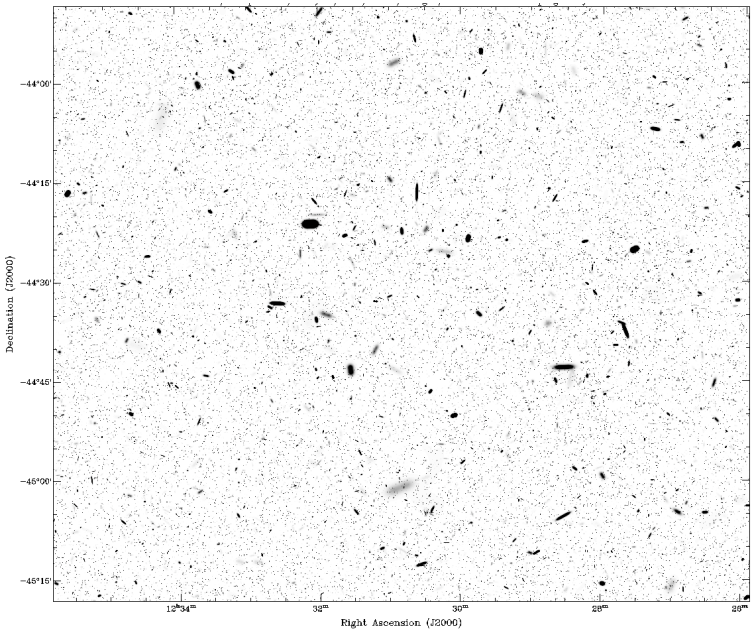
Sky Models

- Telescope simulator needs a “true” sky to observe
- Provide with image of sky model
- Current simulations start with SKADS Simulated Skies
  - S3-SEX (Willman et al 2008) and S3-SAX (Obreschkow et al 2009)
- Convert catalogues into images by pixelising each component
  - Both point sources and extended (not diffuse) sources
  - S3-SAX has double-horned analytic spectral profiles
- Precess to desired location on sky

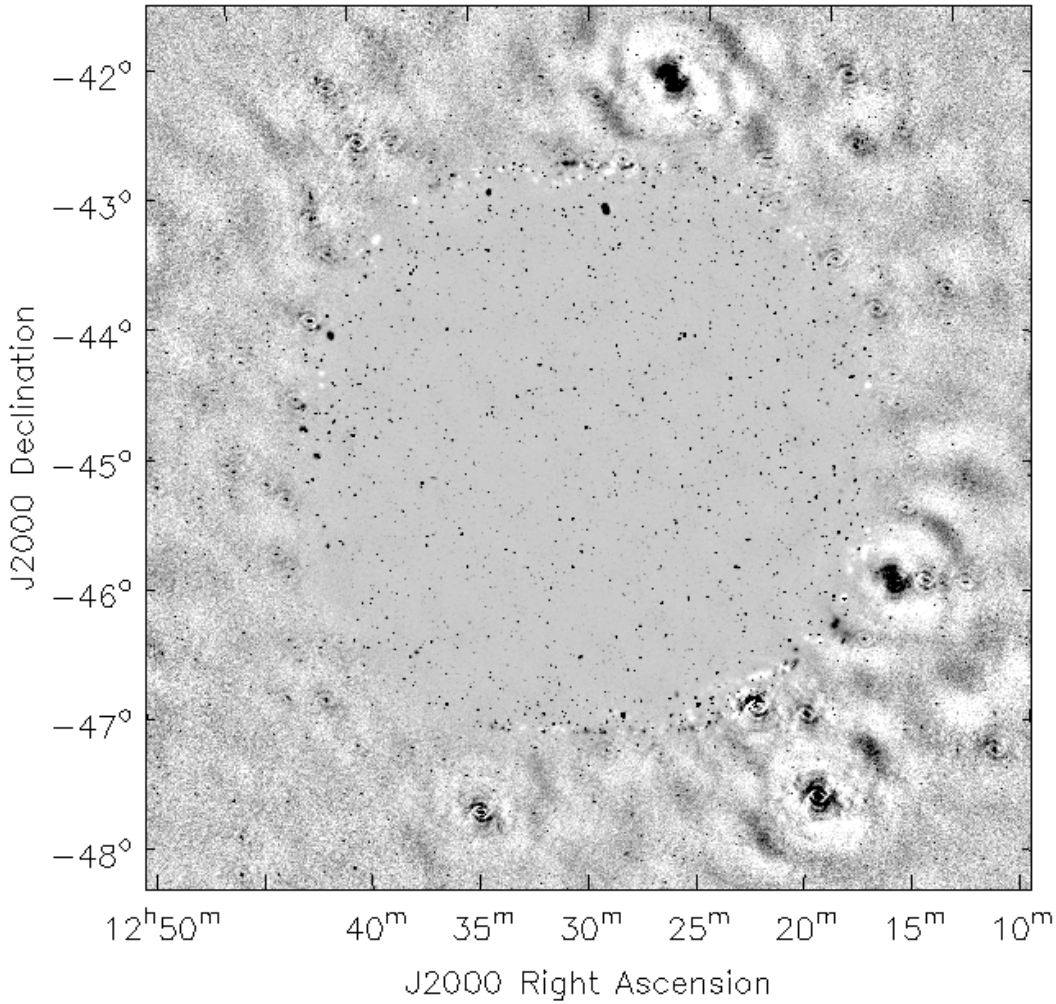


Telescope simulator & imager

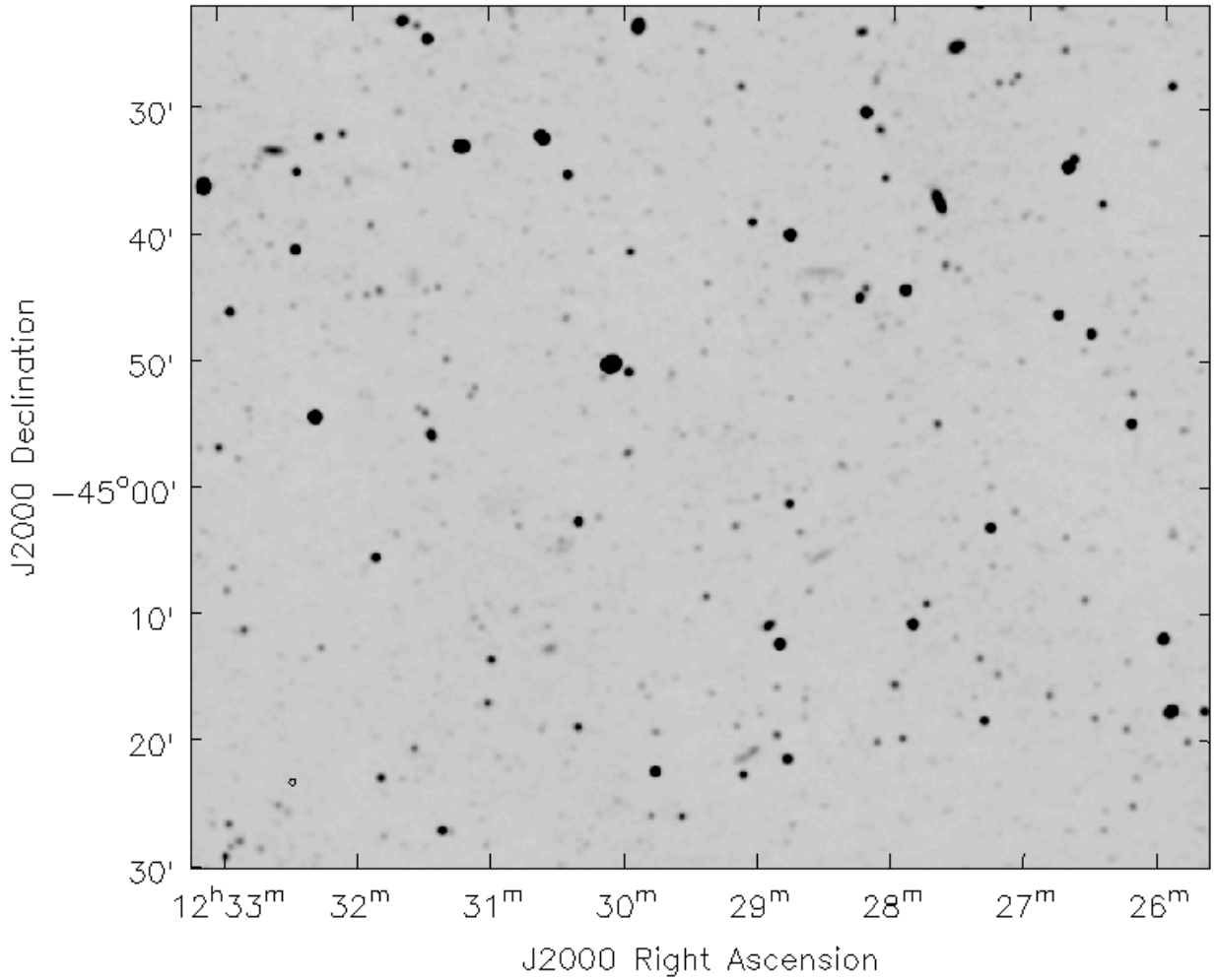
- "Observe" the sky model to produce visibilities
- Required inputs:
  - Sky model
  - Array configuration and synthetic beam distribution
  - Correlator configuration (frequencies, polarisations)
  - Integration time etc
  - Gridding parameters

- Imager then reads visibilities to create image
- Parallel processing via master-worker arrangement under MPI
- Highly scalable if no cleaning required
  - Have not been cleaning spectral-line cubes, so able to run at high efficiency on 256 cores at NCI National Facility
  - Do not have distributed MS clean working yet, so cleaning (e.g. Continuum data) is not as efficient in cpu use

Continuum simulation



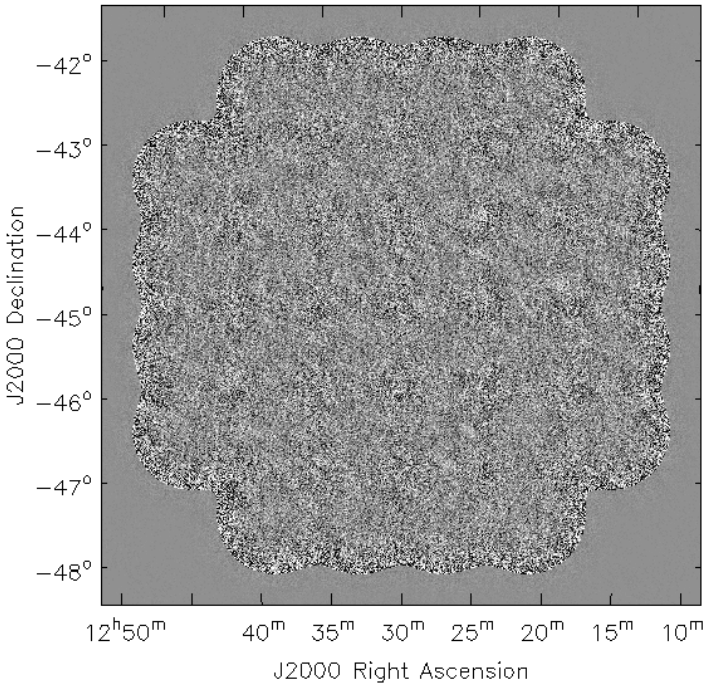
Continuum simulation (zoom)

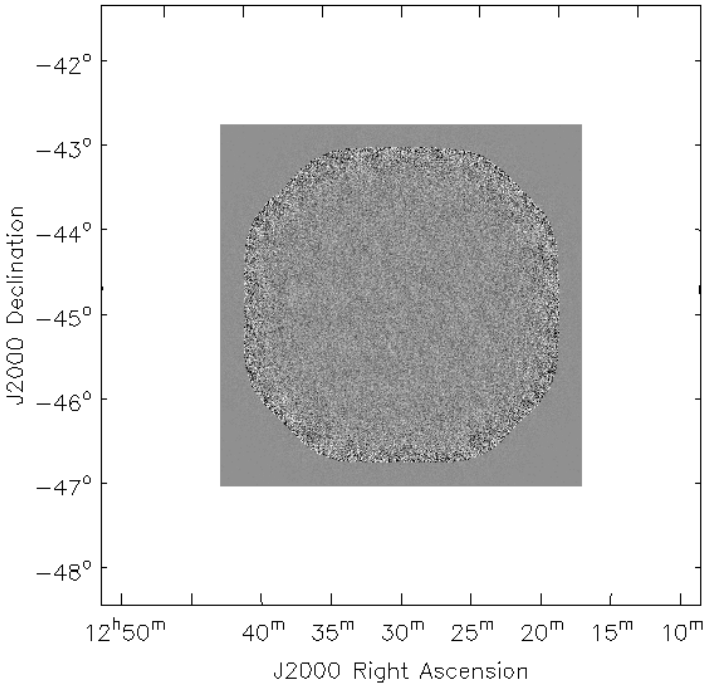


Spectral-line simulation

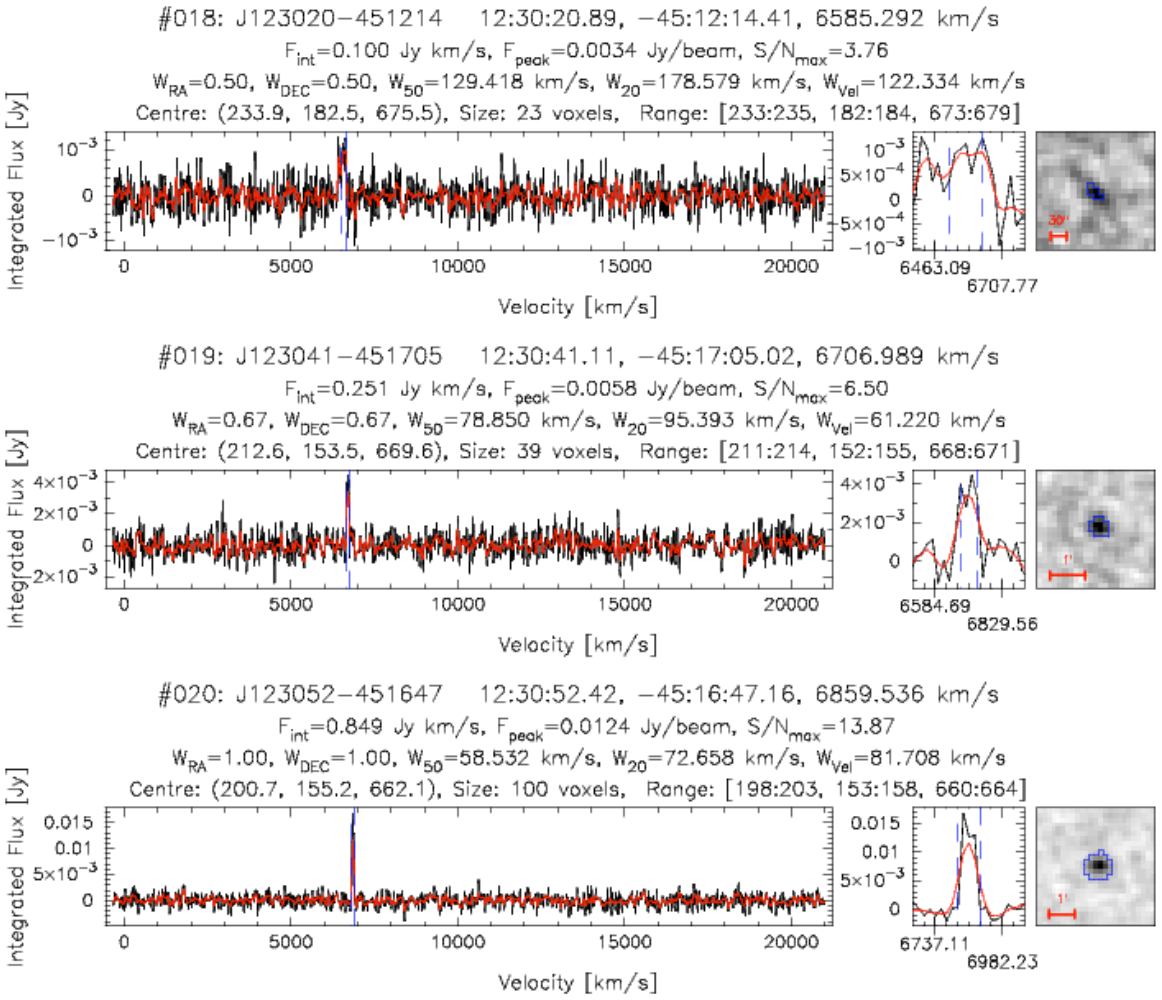
- Use S3-SAX as input model
- 2km core of the ASKAP configuration
  - 30 antennas only, giving natural resolution of 30”
- Coarser channels than planned for ASKAP
  - 92.5 kHz: binned 5x
  - Increase redshift coverage in simulation while keeping number of channels manageable
- Simulate an 8-hour observation, with 5-sec integrations
  - Large amount of data: 5.5 TB of measurement sets
- Simulating done per channel
- PAF simulated with 32 synthetic beams
  - Initial simulation: spaced at 1° separation
  - Not critically sampled, so noise variations seen
  - 2nd simulation had 0.5° separation - noise more uniform

Spectral-line simulations



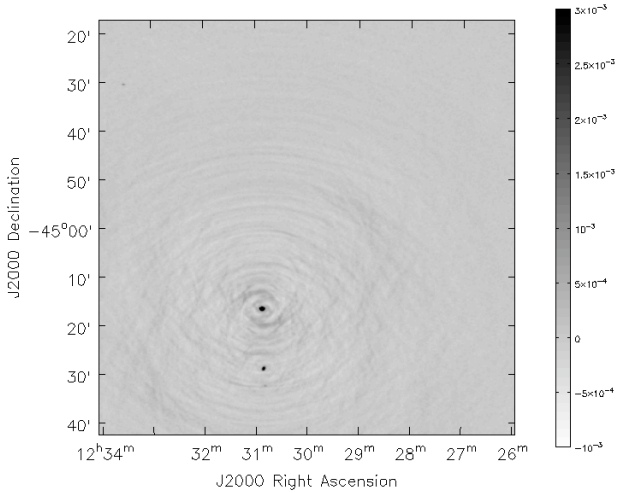


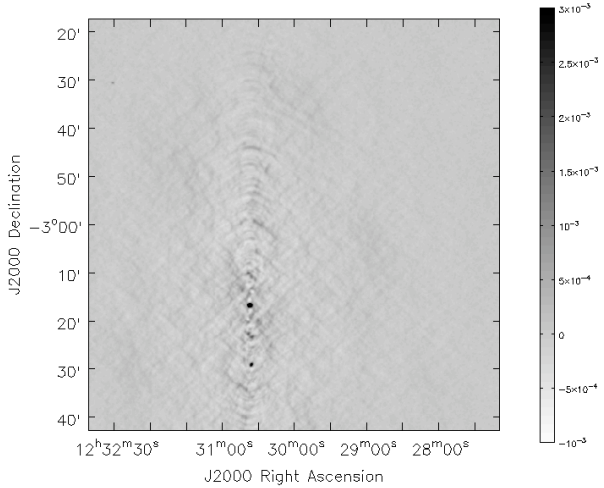
Example sources



Source-finding Test Cubes

- Provide small cubes with noise reduced by ~30x
- Many more sources for testing source finders
- Show PSF structure for the brightest sources (cube is not cleaned)
- Use two declinations: δ =-45° and δ=-3°
- Central part of field only, so sensitivity very uniform





Future simulations

- Want to simulate different ASKAP capabilities
  - Polarisation: S3-SEX + RM mask + %pol mask [end May]
  - Transients: coarsely sampled with known variable sources inserted [end May]
  - Galactic HI: simple spectral-line observation initially [July]
  - Diffuse continuum
- Additional extragalactic HI?
  - Alternative simulation inputs?
  - Larger, resolved galaxies?
  - Need to make appropriate use of limited resources
- Welcome input via ASKAP working group 1
  - Next meeting will be early June

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