A reproducible workflow for multi-frequency radio continuum spectral mapping

Chandra Murugeshan[1] **and Jordan Collier**[2]

[1] Australian SKA Regional Centre (AusSRC), University of Western Australia; [2] Australian SKA Regional Centre (AusSRC), Curtin University

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Astronomical Data Analysis Software and Systems

1 Why spectral index matters

- The radio spectral index (α) describes how brightness (S) changes with frequency (ν).
- Spectral-index maps measure this pixel by pixel and help distinguish emission mechanisms.
- Flat, steep or steepening spectra provide clues to particle ageing, feedback, mergers and galaxy evolution.

$$S_\nu \propto \nu^\alpha$$

Reliable spectral mapping requires images to be matched in angular resolution and aligned on a common sky grid.

2 Pre-processing heterogeneous input images

Images from multiple sub-bands or telescopes can have different synthesised beams, image sizes, pixel scales, coordinate frames and observing frequencies. The workflow pre-processes images to common resolution, grid etc.

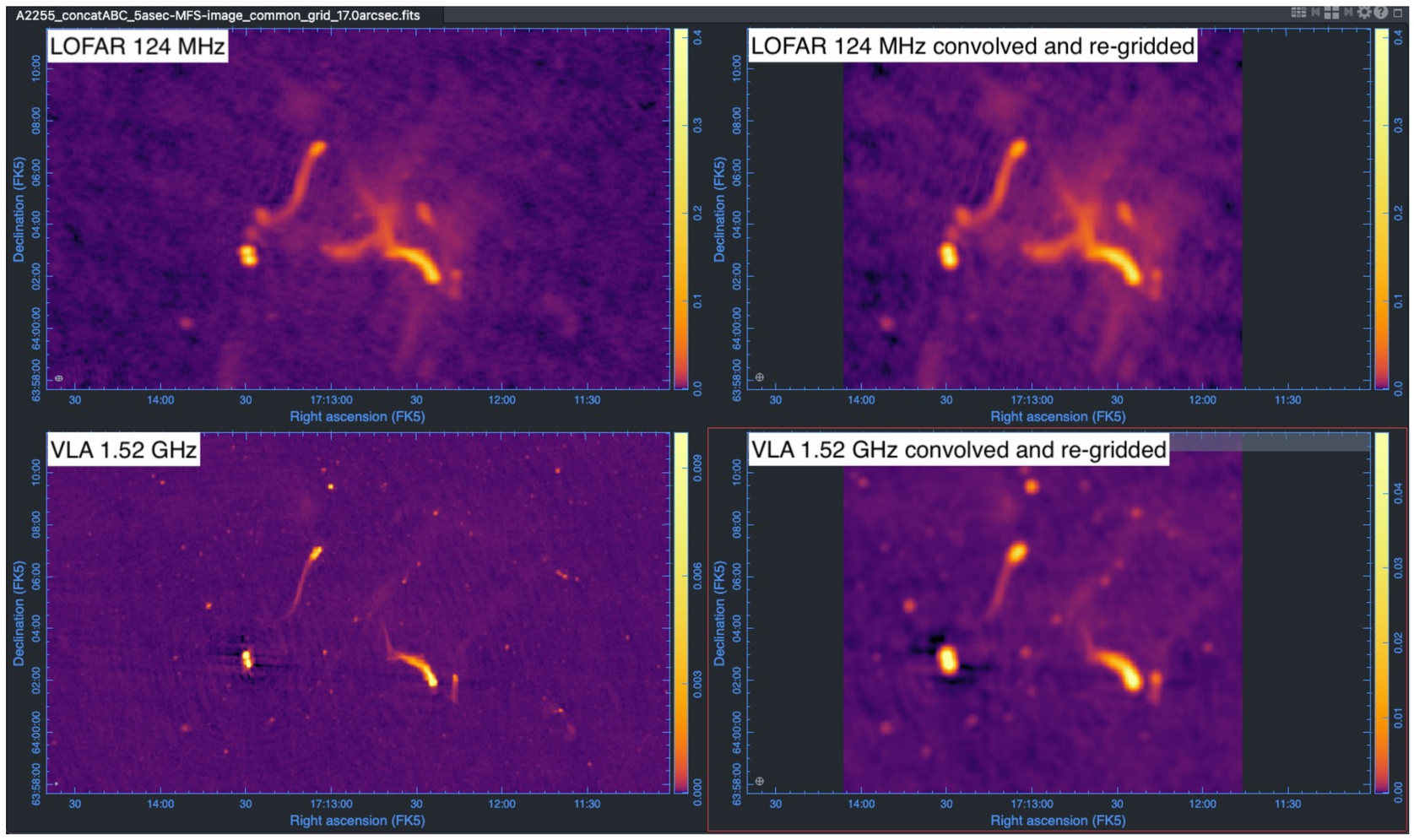


Figure 1. LOFAR 124 MHz and VLA 1.52 GHz images before and after convolution to a common beam and re-gridding to a common WCS.

Pre-processing Workflow

1. Read input FITS images + metadata
2. Read beam + frequency
3. Determine common elliptical beam
4. Convolve to common beam
5. Re-grid to common WCS
6. Construct matched frequency cube
7. Write frequency and beam information table

Sanity Checks: Warns if frequency gaps are large • Warns if input beam sizes differ significantly • Designed to scale to large images

Consistent pixel-by-pixel comparison and flux measurements

3 Spectral modelling from the matched cube

Use the matched image cube to fit spectral models per pixel and return spectral maps, uncertainty and fit-quality maps.

1 Set user parameters
- Input cube + masking strategy
- Thresholds + minimum frequencies
- Spectral model

2 Generate RMS maps

PyBDSF per channel → RMS cube

3 Apply spatial/spectral mask
- RMS-based S/N per channel
- or user-defined flux threshold

4 Fit spectral model per pixel

Power law / broken power law + many other models

5 Output science products
- Spectral-index / uncertainty maps
- Goodness-of-fit + diagnostics

- **Supports uncertainty-aware fitting**
- **Returns uncertainty maps and diagnostics**
- **Enables pixel-by-pixel spectral analysis**

4 Example science outputs

Spectral-index map (left) and uncertainty map (right)

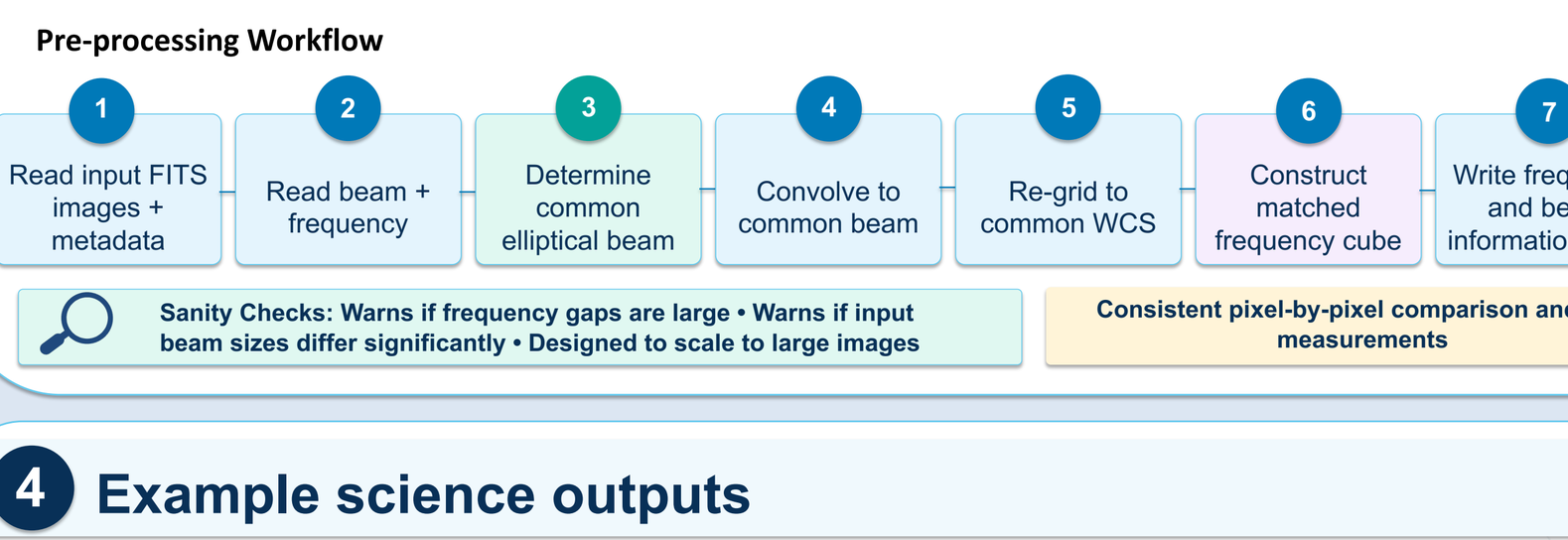


Figure 2. Spectral index α and associated uncertainty maps.

Goodness-of-fit map (reduced χ^2)

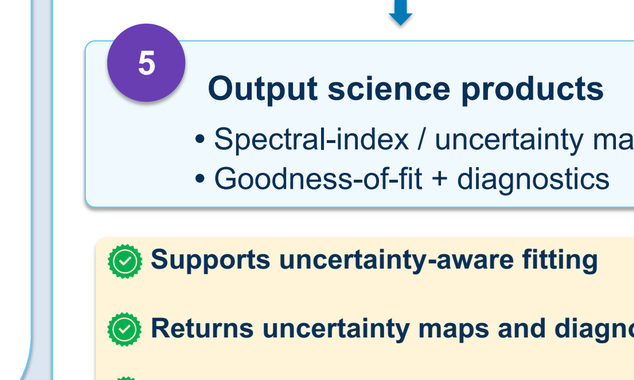


Figure 3. Reduced χ^2 from pixel-wise fitting.

Example broken-power-law fit

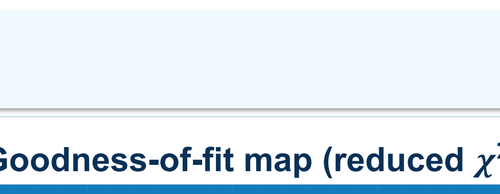


Figure 4. Example fit using the flux from the multi-frequency images

Reproducible, flexible, science-ready spectral mapping

Notebook-based processing • Beam matching and WCS alignment • Frequency-aware cubes • Spectral models and diagnostic maps