

Intro to wide-field VLBI processing

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The radio interferometer measurement equation (RIME)

- The **Radio Interferometry Measurement Equation** (RIME) for antennas p and q ,

Visibilities as measured by baseline pq

Sky brightness distribution

Directional cosines (i.e. sky coordinates)

Direction-independent effects (DIEs) e.g., bandpass, complex gain errors

Direction-dependent effects (DDEs) e.g., primary beam, ionosphere

Phase term

$$V_{pq} = G_p \left(\iint_{lm} E_p B K_{pq} E_q^H dl dm \right) G_q^H$$

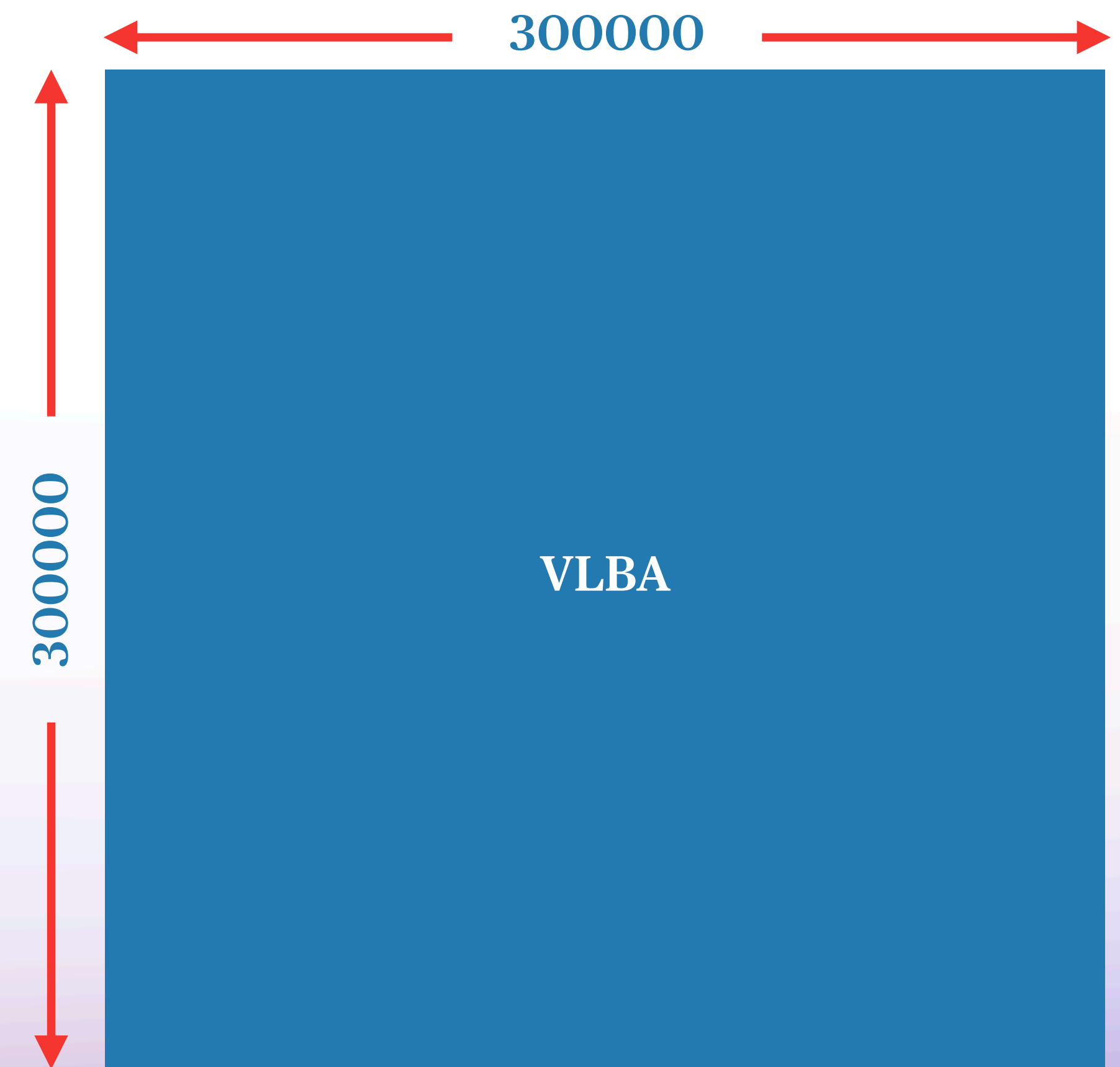
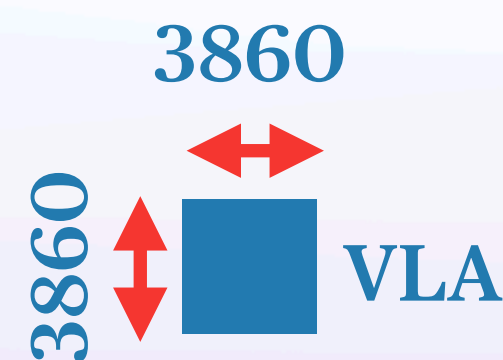
$$K_{pq} = (1/n) \exp \left\{ -2\pi i \left[u_{pq} l + v_{pq} m + w_{pq} (n-1) \right] \right\}$$

$$n = \sqrt{1 - l^2 - m^2}$$

Imaging the entire primary beam - challenges

1. Image sizes

- Assuming ~0.5 degree field-of-view (25m telescopes at 1.4 GHz) w/ 3x PSF sampling
 - *Very Large Array (VLA)* A-configuration (1.4" resolution) - $\sim 1.4 \times 10^7$ pixels
 - *Very Long Baseline Array (VLBA)* - (~6 mas resolution) - $\sim 1 \times 10^{11}$ pixels



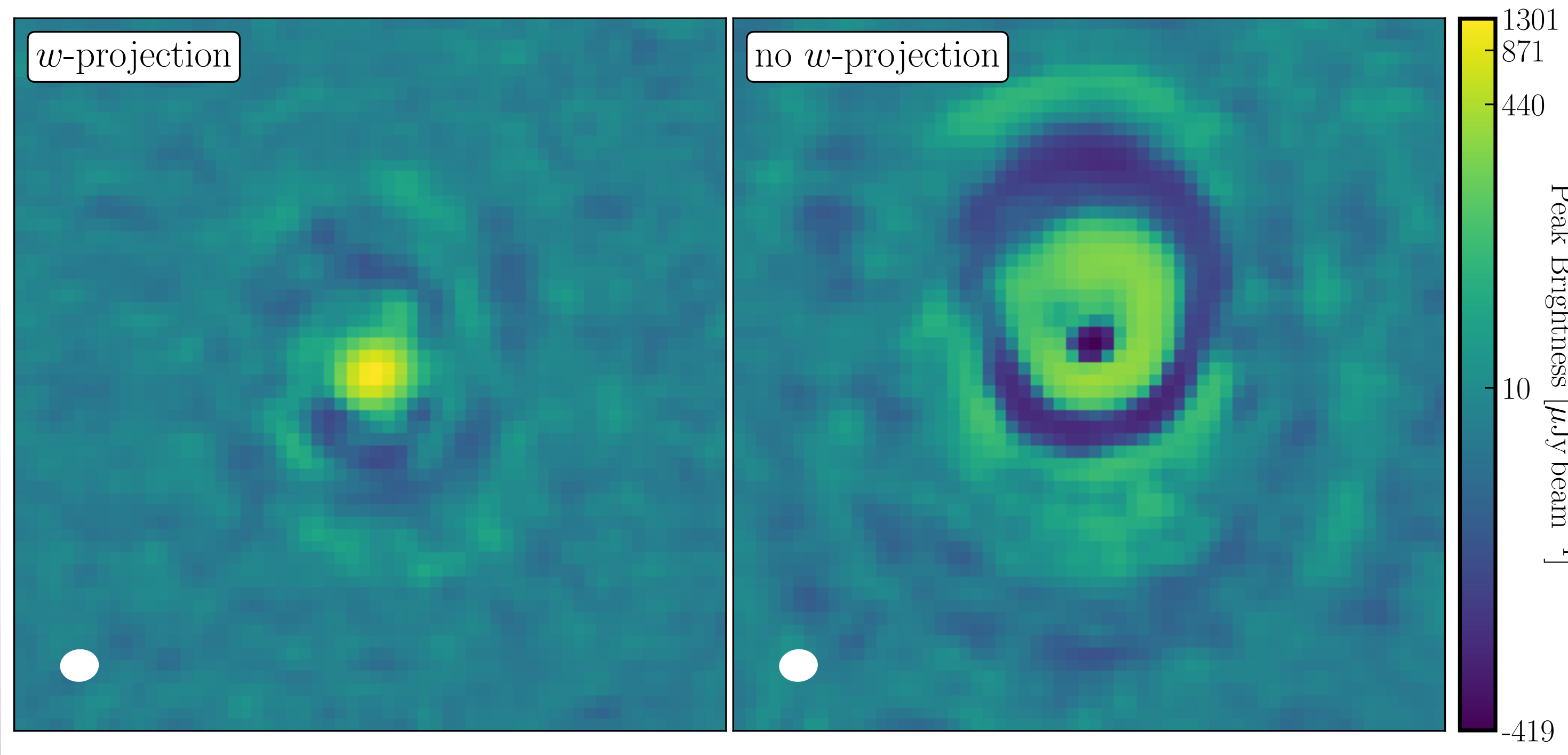
Imaging the entire primary beam - challenges

2. Non-coplanarity or the w term

Ideal radio interferometer measurement equation

$$V(u, v) = \iint_{lm} B(l, m) \exp \left\{ -2\pi i \left[ul + vm + w(n-1) \right] \right\} \frac{dl dm}{n}$$
$$*n = \sqrt{1 - l^2 - m^2}$$

e-MERLIN - source 7.5' from pointing centre



- The pesky extra term of:

$$\frac{1}{n} \exp [w(n-1)]$$

stops us having a true 2D-FT

- Solving requires calculating and implementing convolutional product. Relatively more computationally expensive

Imaging the entire primary beam - challenges

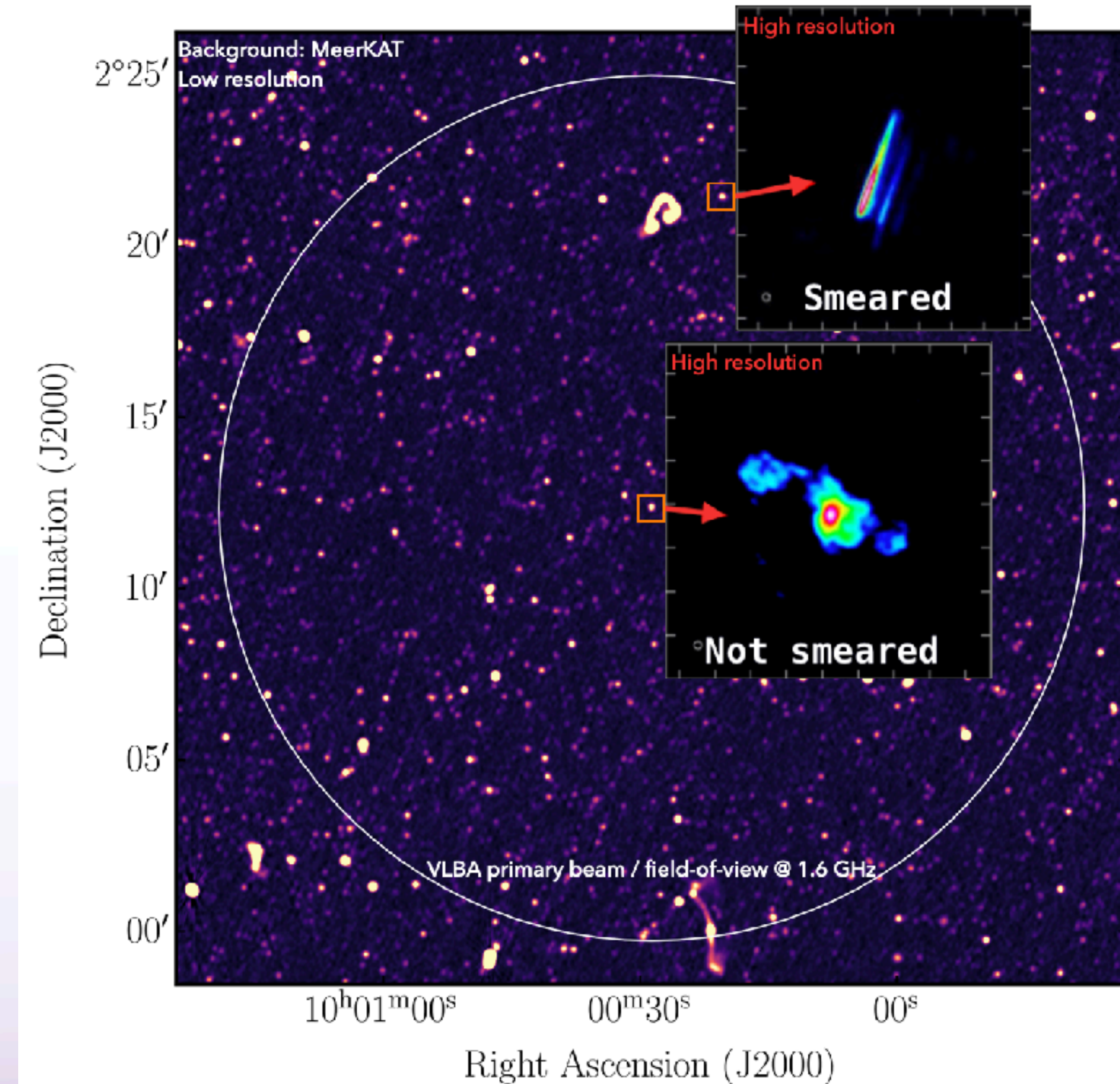
3. Smearing

RIME

$$*n = \sqrt{1 - l^2 - m^2}$$

$$V_{pq} = \iint_{l,m} B(l, m) \exp \left\{ -2\pi i \left(u_{pq}l + v_{pq}m + w_{pq}(n - 1) \right) \right\} \frac{dldm}{n}$$

- Caused by averaging of the data in time and frequency (loss of coherence)



Imaging the entire primary beam - challenges

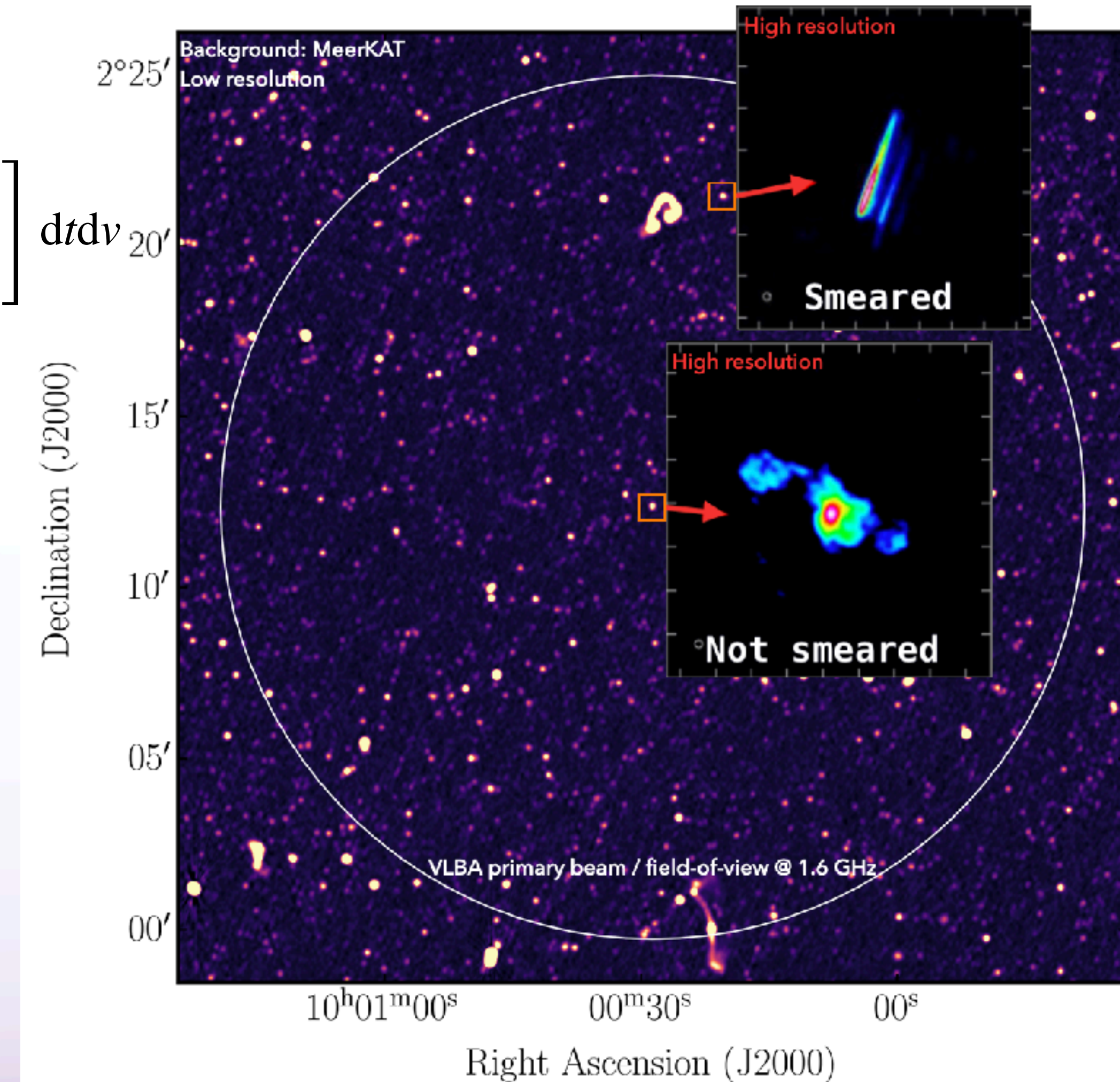
3. Smearing

‘Post-correlation’ RIME

$$*n = \sqrt{1 - l^2 - m^2}$$

$$\langle v_{pq} \rangle = \frac{1}{\Delta t \Delta \nu} \iint_{t_0, \nu_0}^{t_1, \nu_1} \left[\iint_{l, m} B(l, m) \exp \left\{ -2\pi i \left(u_{pq} l + v_{pq} m + w_{pq} (n - 1) \right) \right\} \frac{dl dm}{n} \right] dt d\nu$$

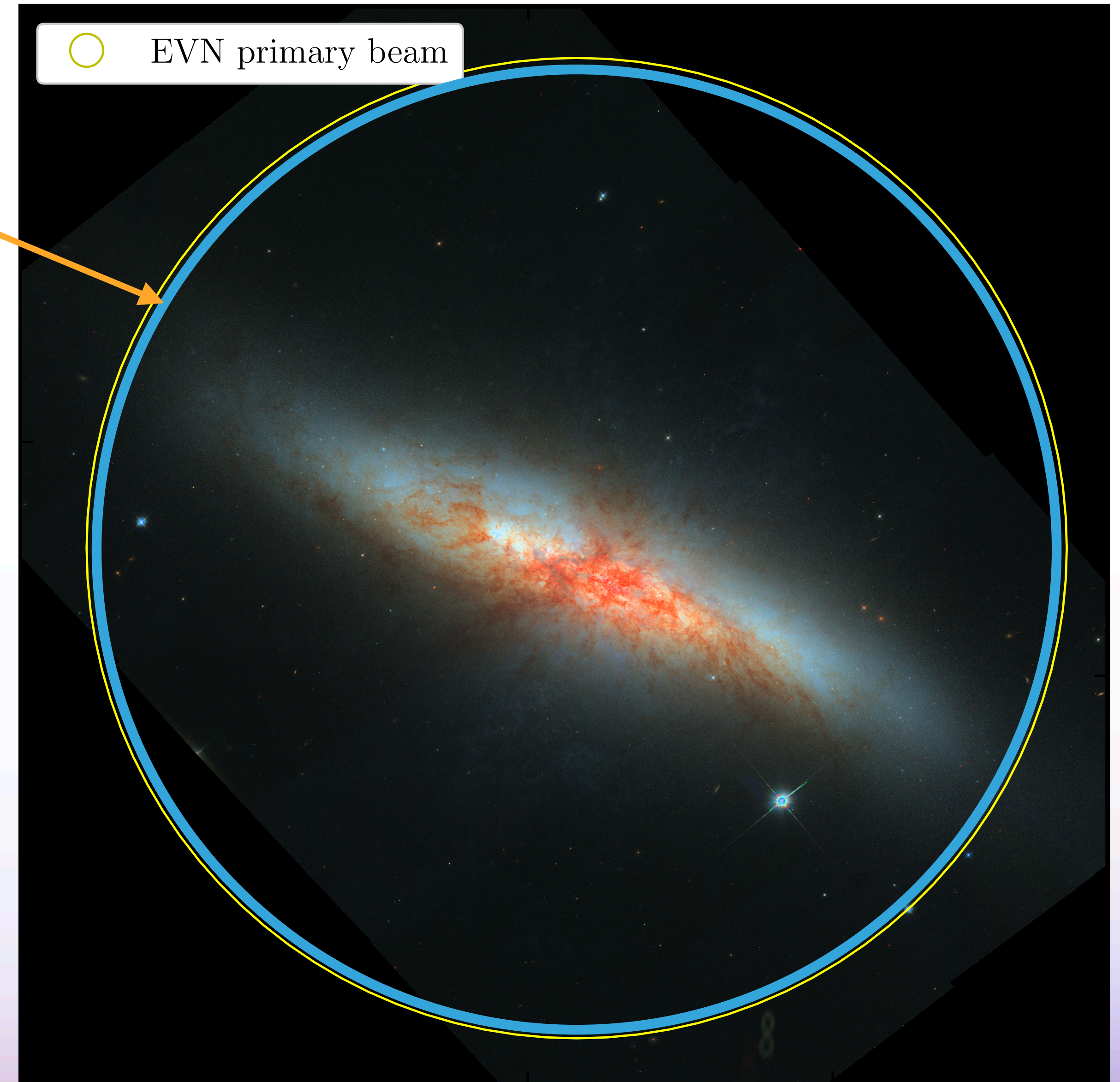
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Standard wide-field correlation

- Correlate at high temporal & frequency resolution to restrain smearing
- *Result* - one huge data set which is 99.99999% noise
- This huge single data set is often TBs* in size
- Often have to shift to different positions which is inaccurate using standard software.

Field-of-view due to smearing

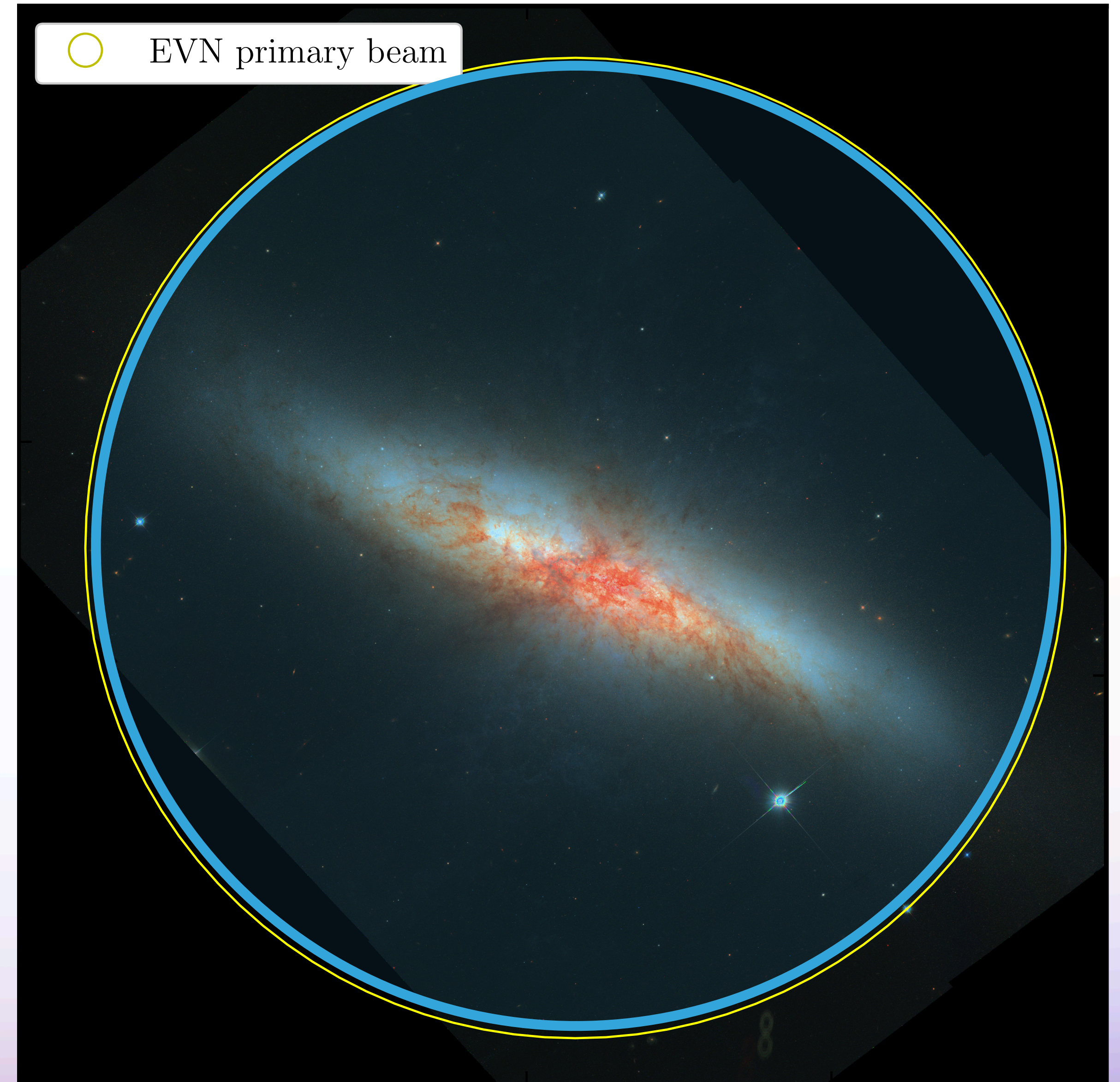


Multiple phase-centre correlation

1. Split data into time chunks
2. Correlate each chunk at very high time & frequency resolution to prevent smearing
3. Copies & phase shift to multiple locations in primary beam
4. Average in time & frequency

Result - you receive lots of small (in FoV and size) *data sets at different positions* across the primary beam so it's easily parallelisable!

- Choice of phase centres is up to the user and could cover entire primary beam, or just some known sources of interest e.g. VLA positions etc.



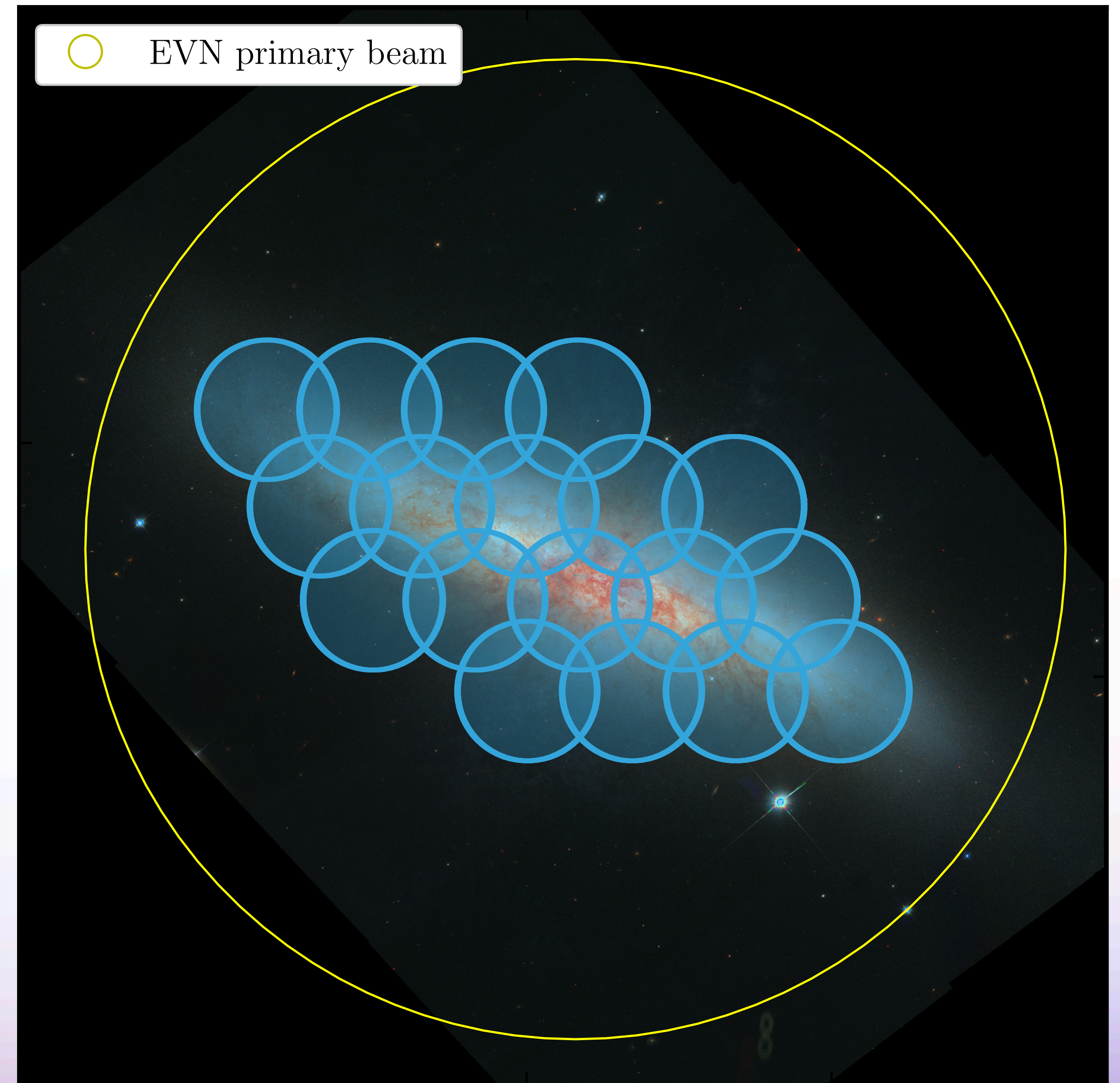
MORGAN ET AL., (2011); DELLER ET AL., (2011); KEIMPEMA ET AL., (2015)

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Steps to wide-field correlation

1. Calculate wide-field parameters and enter into control file:

- **Internal wide field correlation:**

- `fft_size_correlation` — number of frequency points/channels per subband. This must be a power of 2.
- `sub_integr_time` — sub integration time in microseconds.
- And the **averaging of the phase shifted data** by:
 - `number_channels` - number of frequency points/channels per subband.
 - `integr_time` - integration time.

2. Edit the vix file to include phase centre positions

3. Correlate and post process each output data set

4. Calibrate and have more than one source!

