Gridding and preconditioning in ASKAPsoft

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ASKAP Computing
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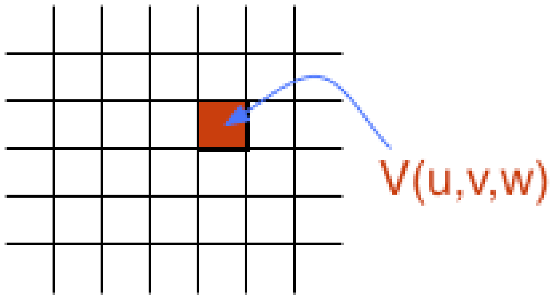
Convolutional gridding: basics



- Measurements don't lie on a regular grid

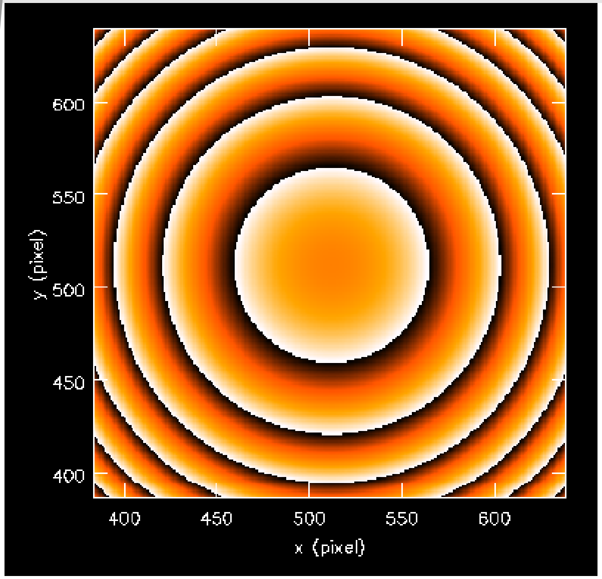
  need gridding to be able to use FFT
- Convolve with some function
- Sample the result of this convolution at regular grid points

$$V_g(u_0,v_0)=\sum_u\sum_v V(u,v)C(u-u_0,v-v_0)$$

Size of the convolution kernel $C(\Delta u,\Delta v)$ affects the performance

- Kernel $C(\Delta u,\Delta v)$ is calculated at a finer grid (oversampling)
- Appropriate oversampling plane is chosen on the basis of u and v
- Grid correction: divide the image by FT of the kernel
- One of the simplest kernels - prolate spheroidal function
  - Optimal aliasing reduction, very compact (7x7 pixels in ASKAPsoft)
  - Oversampling factor is hard coded to be 128 in ASKAPsoft

Convolutional gridding: AProject and WProject



- Convolution done during gridding comes out as a multiplication at the image domain
- Normally we do grid correction to remove this effect (i.e divide by FT of the kernel)
- However, one can apply image plane multiplicative effects by choosing a CF appropriately (and not grid-correcting for it)

Phase screen in the image plane defined by the w-term $\exp\left(2\pi i w\left(1-\sqrt{1-l^2-m^2}\right)\right)$

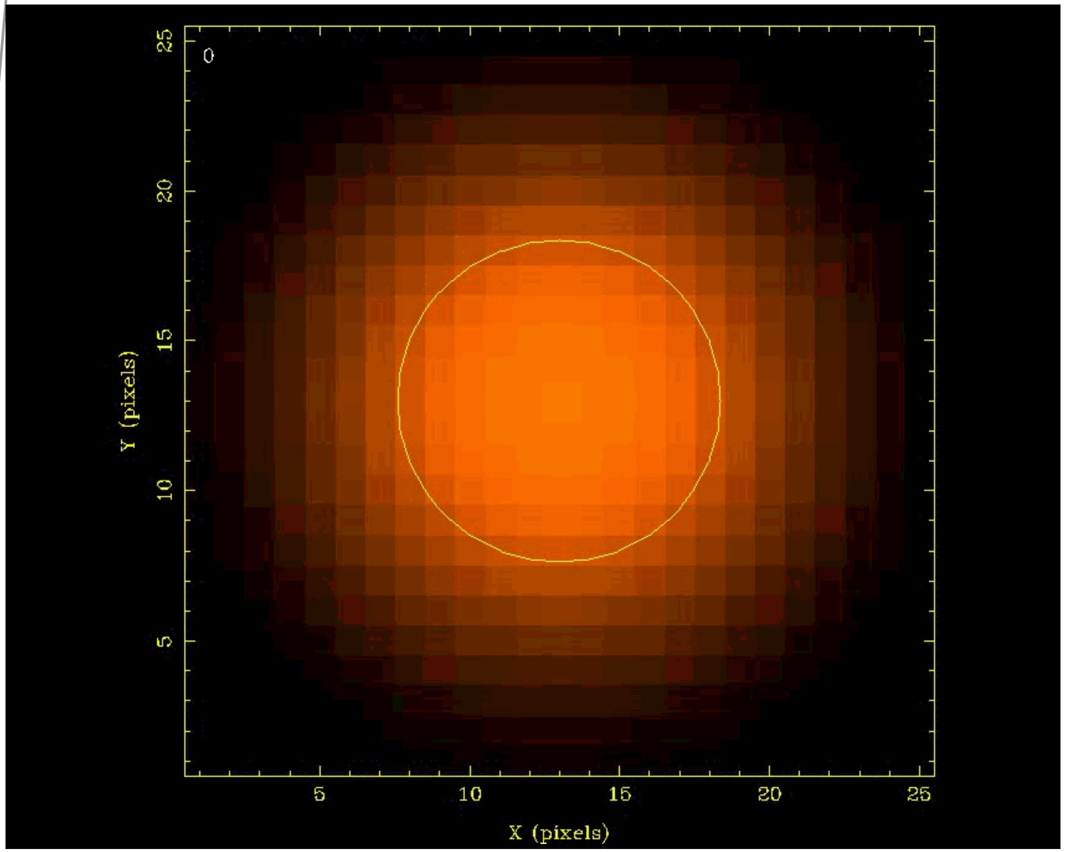
primary beam (mosaicing) and w-term can both be taken into account via special choice of convolution functions

FT of this gives CF of the w-projection algorithm

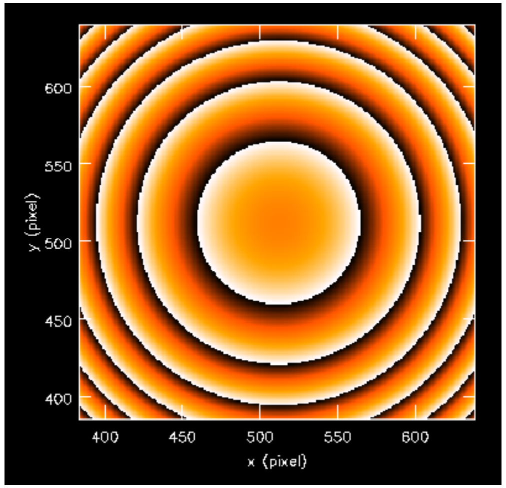
This term of the mosaicing equation can be calculated via CF. This is A-projection algorithm

$$I = \frac{\sum_k A_k I_k}{\sum_k A_k^2}$$

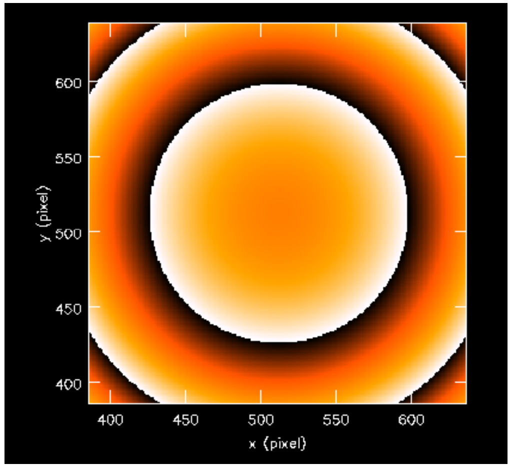
WProject gridder: convolution functions



Phase screen for a large w-term

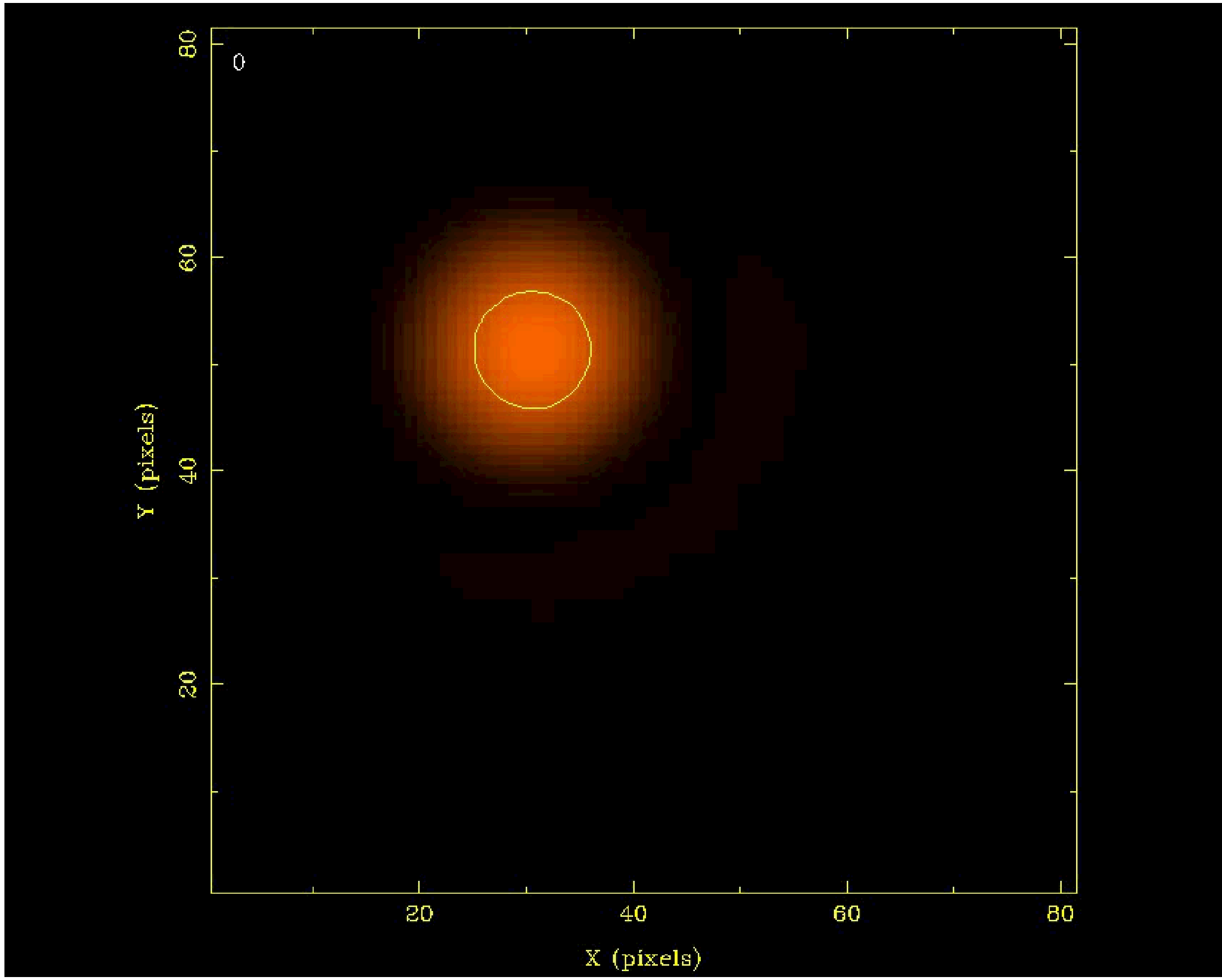


Phase screen for a small w-term

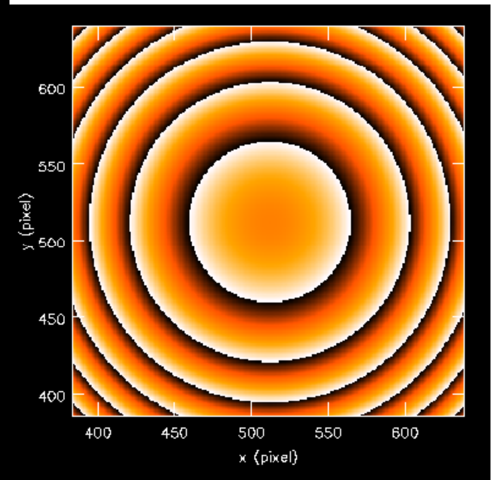


- Single offset beam
- Frame = w-plane
- CF is FT of $\exp\left(2\pi i w\left(1-\sqrt{1-l^2-m^2}\right)\right)$
  - Size depends on the w-term!

AWProject gridder: convolution functions



Phase screen = phase gradient locally = offset in the uv domain

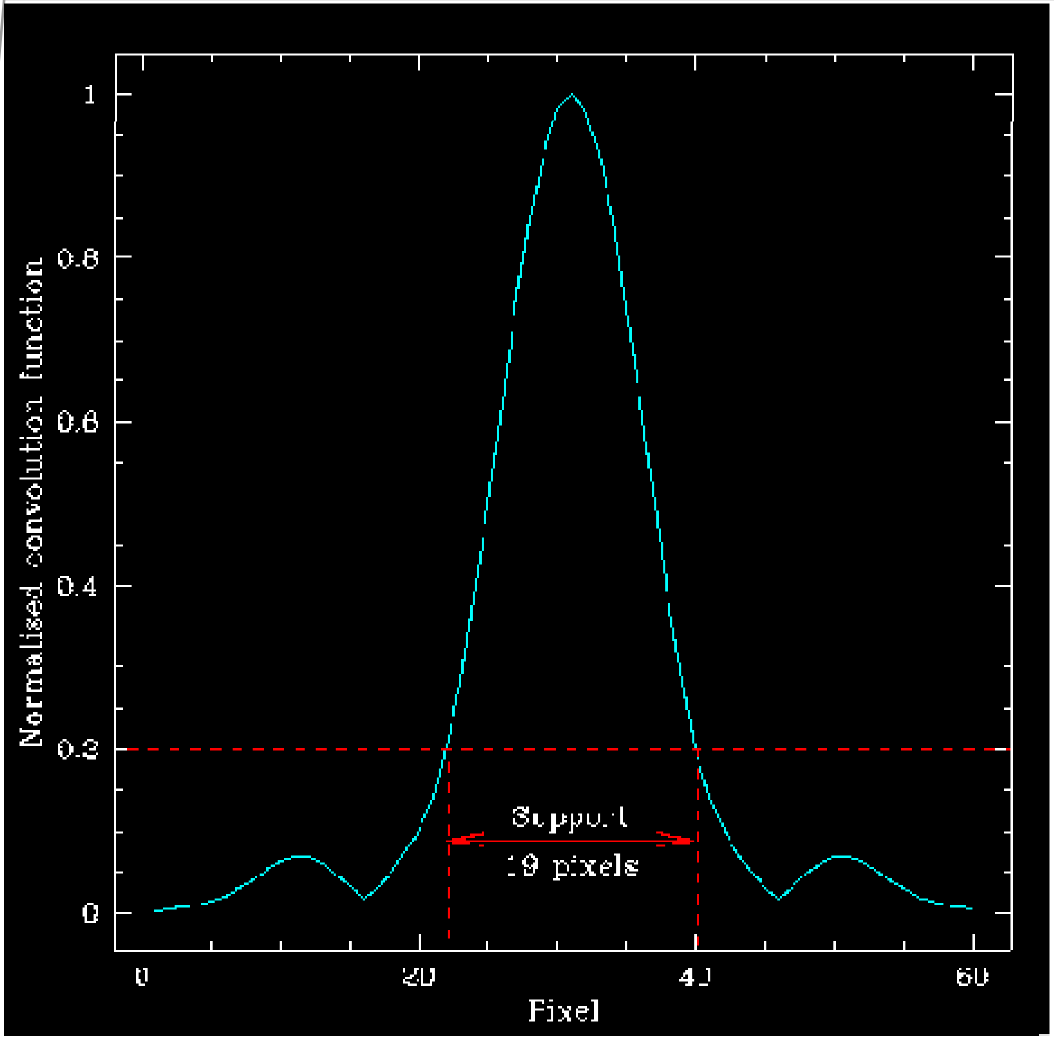


- Size depends on the w-term
- Offset depends on the w-term

•Simulated single offset beam

•Each frame = single w-plane

Support of convolution function (CF)



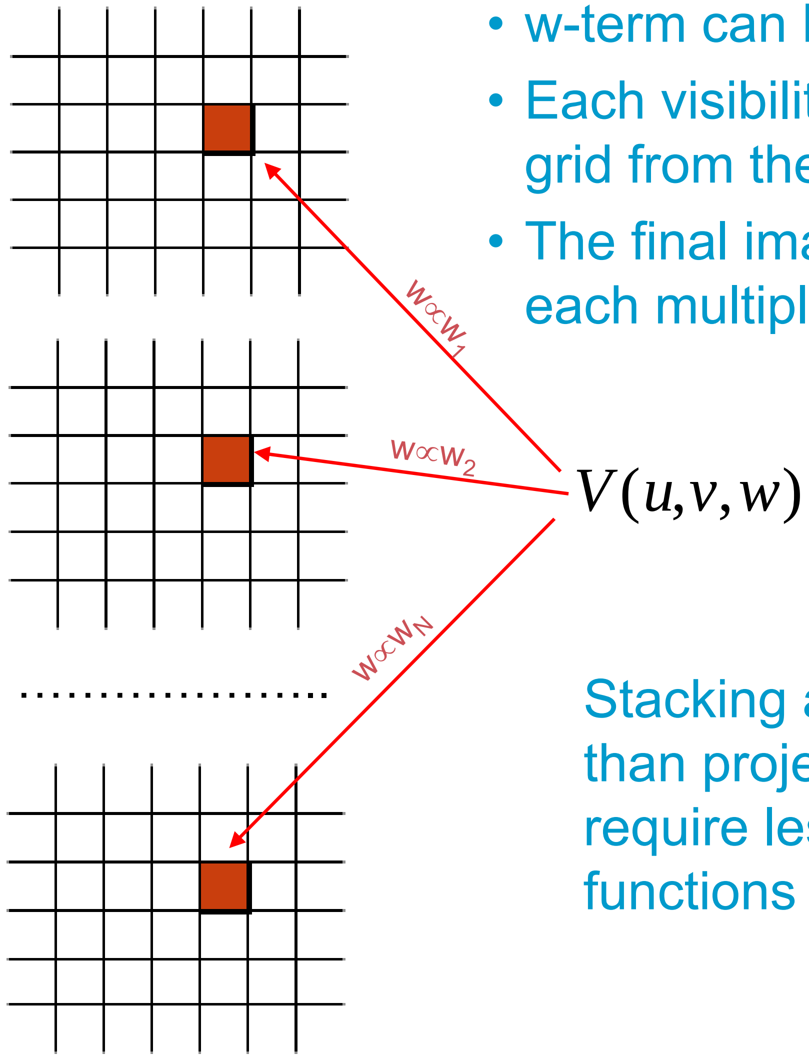
Example of the convolution function for a large w-term (single oversampling plane)

- CFs are generated in a maxsupport x maxsupport buffer
- Support is searched using a given threshold (cutoff parameter)
- We throw an exception if found support exceeds the ratio image size / oversample
- Then we extract oversample^2 slices, support x support each (oversample is a stride factor in slicing of the CF)

WStack and AProjectWStack gridders

- w-term can be accounted for in the image domain
- Each visibility is gridded into the most appropriate grid from the stack according to its w-term
- The final image is a sum across FTs of all grids, each multiplied by the image plane w-term

$$\exp\left(2\pi i w\left(1-\sqrt{1-l^2-m^2}\right)\right)$$



Stack of grids

Stacking algorithms need more memory than projection algorithms, but usually require less computations (convolution functions have smaller support)

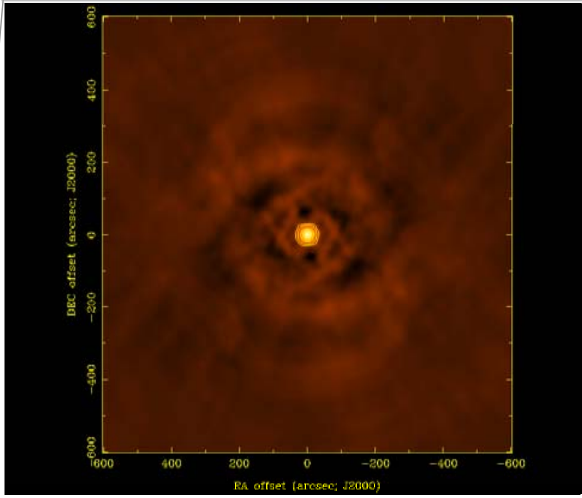
Preconditioning = weighting

- Traditional weighting schemes require two gridding passes
  - First pass to form visibility weight
  - Second pass to grid the product of visibilities and appropriate weights
- In ASKAPsoft we apply linear filters to images
  - One iteration over visibility data is sufficient
  - We use term ‘preconditioning’ because this filtering serves to regularise a system of normal equations which is solved at the minor cycle
  - Another interpretation is to improve PSF to make deconvolution easier
- Two main preconditioning options have been implemented:
  - Gaussian tapering
  - Wiener filter (somewhat related to Robust weighting)

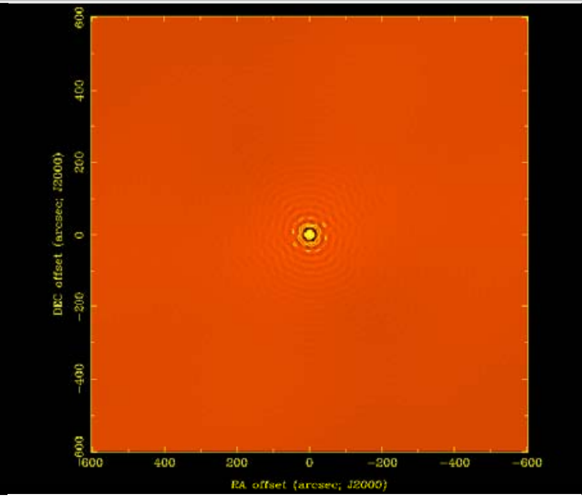
$$W_f = \frac{FT(psf)^*}{FT(psf)FT(psf)^* + N_p}$$ (in the uv-domain)

Noise power can be defined via robustness: $N_p = 10^{4R}$

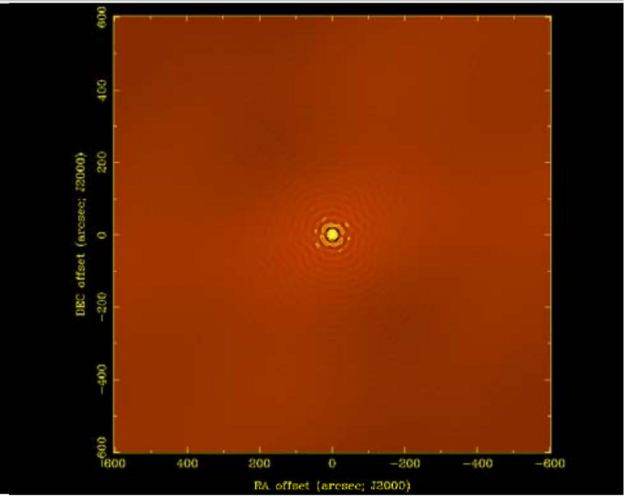
Wiener filter, tapering: PSFs



No taper, no filter



No taper, filter with R=-1



10'' taper, filter with R=-1

Emil Lenc developed a nice tool to visualize ASKAP PSF for different sets of parameters (note, images are not final; still work in progress):

http://www.atnf.csiro.au/people/Emil.Lenc/ASKAP/psf/sim/view.html

http://www.atnf.csiro.au/people/Emil.Lenc/ASKAP/psf/dingo/view.html

$$W_f = \frac{FT(psf)^*}{FT(psf)FT(psf)^* + N_p} \qquad N_p = 10^{4R}$$

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Summary

- ASKAPsoft has a number of gridder options implemented
- Variable and offset CF support makes the imaging much faster!
  - Offset support is really needed for mosaicing gridders only
  - Support search procedure is parameterized by cutoff. Lower cutoff means larger support, slower execution but higher accuracy.
- ASKAPsoft can handle the w-term via either the projection or stacking
  - Stacking is usually faster, but requires more memory
  - Both algorithms allow parallelization on w-term
  - Memory bandwidth considerations may favour the stacking algorithm (each grid is independent during gridding)
- Traditional weighting schemes (e.g. Robust or uniform weighting) require two iterations over visibility data
  - ASKAPsoft uses preconditioning (filtering) instead
  - A combination of Wiener filter and tapering gives nice results

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Thank you