Non-coplanar baselines effects

The non-coplanar effects of array causes problems with the Fourier transform, in fact, for a non-coplanar array with non-zero w terms the Fourier transform is not applicable. This means that except for East-West arrays an interferometer does not simply sample the Fourier transform of the sky brightness distribution. However, for practical purposes, whether or not the errors introduced by not correcting for the w term affects the image quality depends on the parameters of the instrument.

The w-term can be considered as an extra kernel multiplied with the Fourier transform, which introduces and additional phase term. Considering a correction factor as due to Fresnel diffraction one can determine for what baselines and observing frequencies the errors cannot be ignored and the a correction (w-projection) needs to be done. For $w < B/\lambda$, the phase term introduced by the Fresnel diffraction can be expressed as:

$$\frac{B\lambda}{D^2} = \left(\frac{r_{\mathrm{F}}}{D}\right)^2,$$

where B is the baseline length, λ the wavelength, r_F the Fresnel zone diameter, and D the diameter of the telescope. Perhaps a more useful quantity is the inverse, the Fresnel number:

$$N_{\mathrm{F}} = \frac{D^2}{B\lambda}.$$

Non-coplanar effects are important for $N_F < 1$.

Non-coplanar baselines effects

For the different ALMA bands there exists a maximum baseline length for which w-projection becomes important and needs to be taken into account when performing the deconvolution (clean). The table below lists the observing bands of ALMA (1-10), and corresponding frequency/wavelength. For each band are listed the primary beam Θ, the baseline length B_F for which $N_F < 1$, equivalent resolution θ, and the corresponding w_{MAX}.

ALMA Band	**ν**	**λ**	**Θ**	***B_F***	**θ**	***w_{MAX}***
	(GHz)	**(μm)**	**(“)**	**(km)**	**(‘’)**	**(Mλ)**
1	35	8571	177	17	0.1263	2.0
2	75	4000	83	36	0.0275	9.0
3	100	3000	62	48	0.0155	16.0
4	140	2143	44	67	0.0079	31.4
5	180	1667	34	86	0.0048	51.8
6	230	1304	27	110	0.0029	84.6
7	345	870	18	166	0.0013	190.4
8	450	667	14	216	0.0008	324.0
9	675	444	9	324	0.0003	729.0
10	850	353	7	408	0.0002	1156.0
D (m)	12					

Only for the lowest frequency bands does the Fresnel number come close to 1 for the most extended arrays (15 km). In practice, it appears that the w-projection will not have a large impact on the imaging capabilities.

However, in the CASA guides an alternative method to determine the w-projection effects is used, described by the equation

$$d_{max}[arcsec] = 120 \times \sqrt{\frac{\lambda[cm] \times \phi_E[°]}{b_{max}[km]}}$$

where d_{max} is the maximum diameter of the field that can be imaged, λ the wavelength, Φ_E the phase error, and b_{max} the longest baseline.

For a dynamic range of 1:500 a phase error of < 5 degrees is required which means that for the lower frequency bands in the more extended configuration w-projection needs to be taken into account when imaging the entire primary beam, Table 2.

ALMA Band			**b_{max} (km)**		**Θ (")**
		0.2	**8**	**16**	
1	d_{max}	555	88	62	177
2		379	60	42	83
3		329	52	37	62
4		278	44	31	44
5		245	39	27	34
6		217	34	24	27
7		177	28	20	18
8		155	24	17	14
9		126	20	14	9
10		113	18	13	7

The w-term can be corrected by either faceting or w-projection. Faceting is done by imaging a small enough field that it is not affected by the w-term, it can be done in either the image or the uv domain, the benefit of doing it in the uv domain is that it is not affected by emission that crosses the facet boundaries. However, the faceting techniques are CPU intensive and w-projection is approximately an order of magnitude faster than faceting, at the expense of using more memory. A combined faceting/w-projection technique can also be employed.

When setting up the w-projection in the clean task the number of w projection planes needs to be determined. According to the casa guides this is

$$n_w = b_{max}[k\lambda] \times \frac{d_{max}^2[arcmin]}{600}$$

where n_w is the number of projection planes, b_{max} the maximum baseline length, and d_{max} the image size, Table 3.

ALMA Band			**Baseline (km)**		**Θ (")**
		0.2	**8**	**16**	
1	n_w	0.34	13.51	27.01	**177**
2		0.16	6.30	12.61	**83**
3		0.12	4.73	9.45	**62**
4		0.08	3.38	6.75	**44**
5		0.07	2.63	5.25	**34**
6		0.05	2.06	4.11	**27**
7		0.03	1.37	2.74	**18**
8		0.03	1.05	2.10	**14**

ALMA Band			Baseline (km)		Θ (“)
		0.2	8	16	
9		0.02	0.70	1.40	9
10		0.01	0.56	1.11	7

Wide-field imaging / Mosaicing
A problem in wide field (wide band) imaging is that of the primary beam correction. The primary beam cannot be assumed to be rotationally symmetric and needs to be determined for the different positions across the field. Also, with the large bandwidth of the ALMA the primary beam is frequency dependent. This can be corrected by including a second kernel in the Fourier transform, similar to that of the w-projection but in this case for the general case, and is called A-projection. The A-projection is currently implemented in CASA.

To perform the A-projection requires the primary beam of the antenna to be known. Currently the ALMA antennas are described by a scaled version of the VLA antennas. A library of ALMA antennas primary beams is planned. Dirk Petry is currently working on this and a report of his work is expected by the middle of 2012. Currently the ALMA beams are not connected to the imaging algorithms in CASA, a first test version of this is expected in April 2012. Once completed there will be three different primary responses to choose from:

1) the Airy disk primary beam which has been used for ALMA until now
2) simulated primary beams for the Vertex and AEM antennas
3) primary beams from ray tracing (a simplified but still useful simulation) for all ALMA antenna types including the 7m.

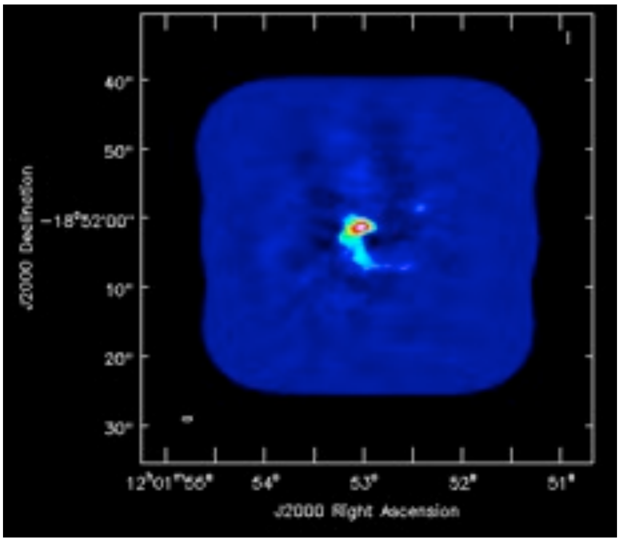
* The w-projection implementation in CASA is done by Bhatnagar (NRAO)

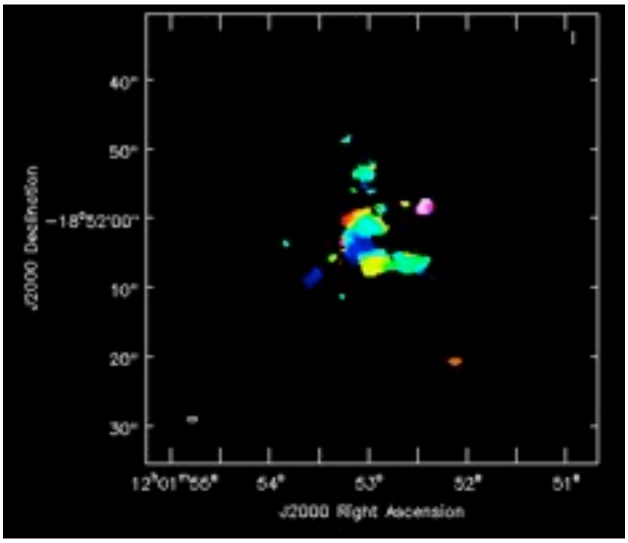
* An alternative implementation of the w-projection algorithm is being developed by Vorenkov, the implementation is more cpu efficient but requires much more memory and is probably only useful for very specific situations.

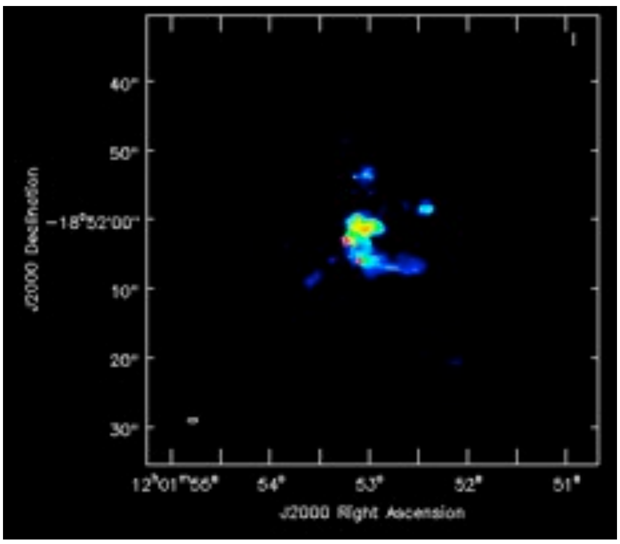
Practical example - Antennae Band 7
As part of the science verification data of ALMA is distributed the wide-field/mosaic example of the Antennae galaxies, consisting of CO(3-2) and continuum observations of the Northern and Southern core.

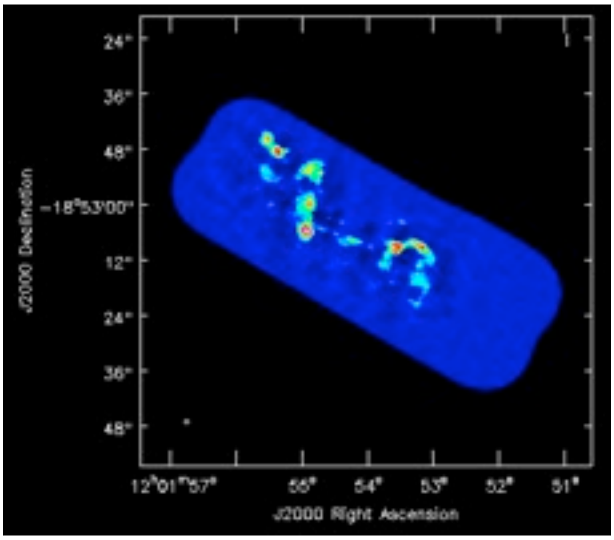
To test the effect of w-projection and A-projection a script for imaging the Antennae band 7 data was used. The script is run on the calibrated data with clean masks determined from interactively cleaning the data the first time. The clean task is run with w-projection turned on, with A-projection using the ALMA telescope (Airy disk) model, and with the VLA/ATCA?? as observatory to see the effects of using an inappropriate primary beam. The primary beam of the telescope can be changed in the observatory table (browsetable()) and changing the telescope_name from ALMA to i.e. VLA.

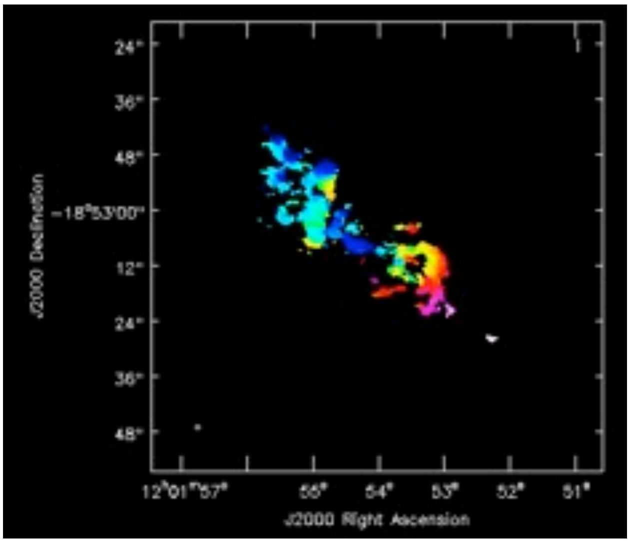
The clean masks are shown in Fig 1 and 2 for the North and South region.

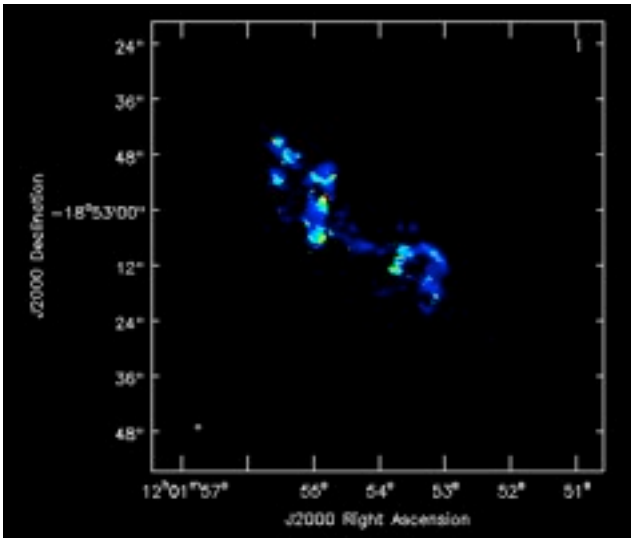

40"
50"
−18°52'00"
10"
20"
30"
12h01m55s
54s
53s
52s
51s
J2000 Right Ascension
J2000 Declination


40"
50"
−18°52'00"
10"
20"
30"
12h01m55s
54s
53s
52s
51s
J2000 Right Ascension
J2000 Declination


40"
50"
−18°52'00"
10"
20"
30"
12h01m55s
54s
53s
52s
51s
J2000 Right Ascension
J2000 Declination


J2000 Declination
J2000 Right Ascension
24"
36"
48"
−18°53'00"
12"
24"
36"
48"
12h01m57s
56s
54s
53s
52s
51s


J2000 Declination
J2000 Right Ascension
24"
36"
48"
−18°53'00"
12"
24"
36"
48"
12h01m57s
56s
54s
53s
52s
51s


J2000 Declination
J2000 Right Ascension
24"
36"
48"
−18°53'00"
12"
24"
36"
48"
12h01m57s
56s
54s
53s
52s
51s

ACA - heterogeneous baselines
Single dish - feathering

Special considerations:
describe in some detail...
imagermode='mosaic'
imsize=500,cell='0.13arcsec'
pbcor
minpb

gridmode='none'
gridmode='widefield'
gridmode='aprojection'

5.2.13 Primary beams in imaging
http://casa.nrao.edu/docs/UserMan/UserMansu250.html#x287-2840005.2.13

browsetable()
observatory - telescope_name ALMA -> VLA

Conclusions:
The new and upgraded instruments (i.e. ALMA and the e-VLA) require new software and algorithms to maximize their imaging capabilities. Direction dependent effects, such as primary beam needs to be taken into account and the high resolution often requires wide field and or mosaicing. Furthermore, the large bandwidth of the instruments means that both the spectral response of the instrument and sources needs to be determined.

Several methods for wide-field, wide-band and mosaicing are available in CASA. Currently not all the methods are implemented fully and notable the primary beams of the ALMA antennas are not yet available in the imaging algorithms and the A-projection can therefore not be properly tested. The implementation of the ALMA primary beams are expected in 2012 with a report by Dirk Petry during the middle of the year.

The w-term introduced by the sky and array curvature introduces a phase term that limits the dynamic range of the image. This only affects the lower frequency bands in the more extended configuration as the field of view decreases with higher frequencies. The w-term can be corrected by faceting in either the image or uv plane, by w-projection, or a combination of the two. The w-projection is an order magnitude faster than the faceting algorithms but requires more memory.

Results of comparison w/wo w-proj, A-proj, and ATCA PB