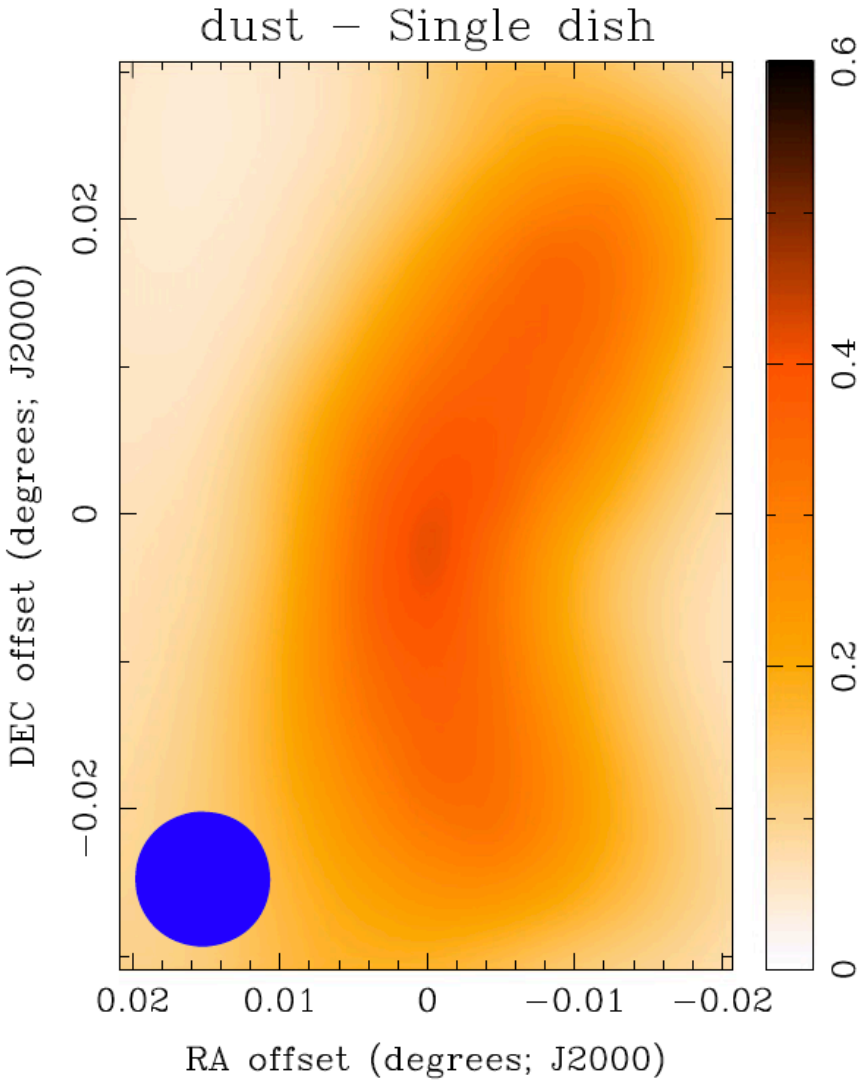
Combining Single Dish and Interferometer Data

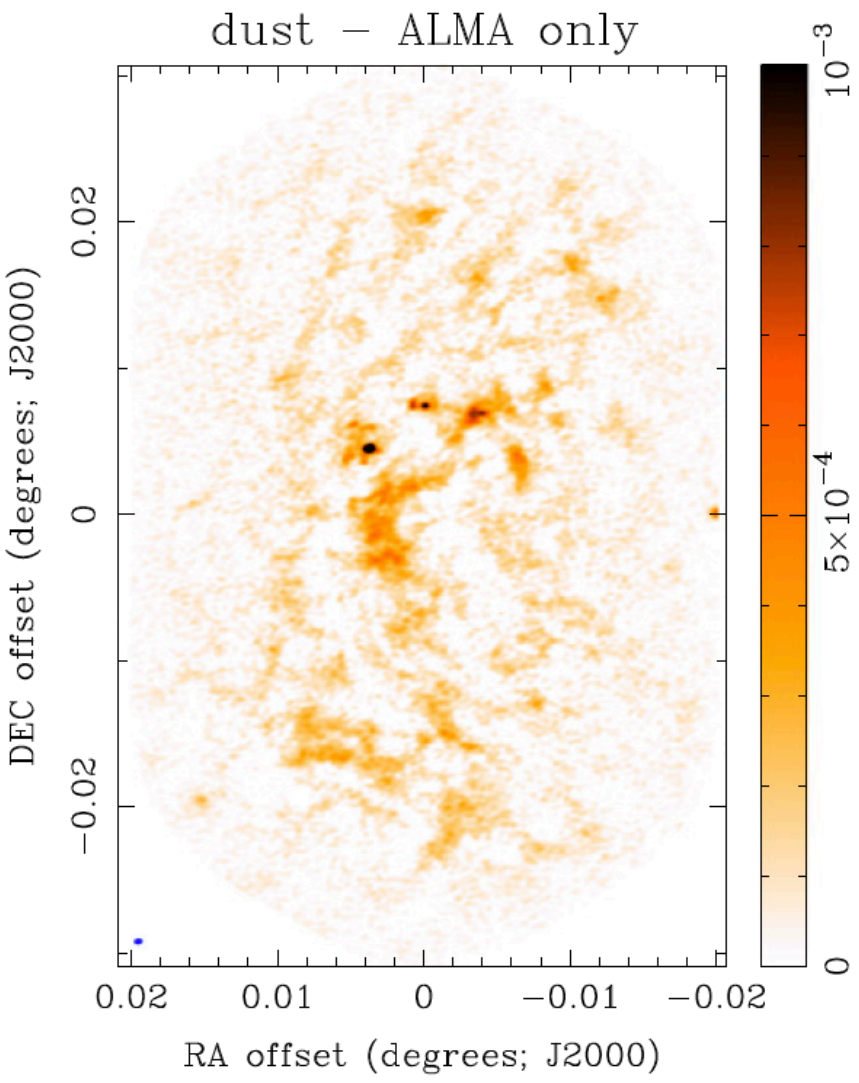
Natalie Butterfield

Talk Outline

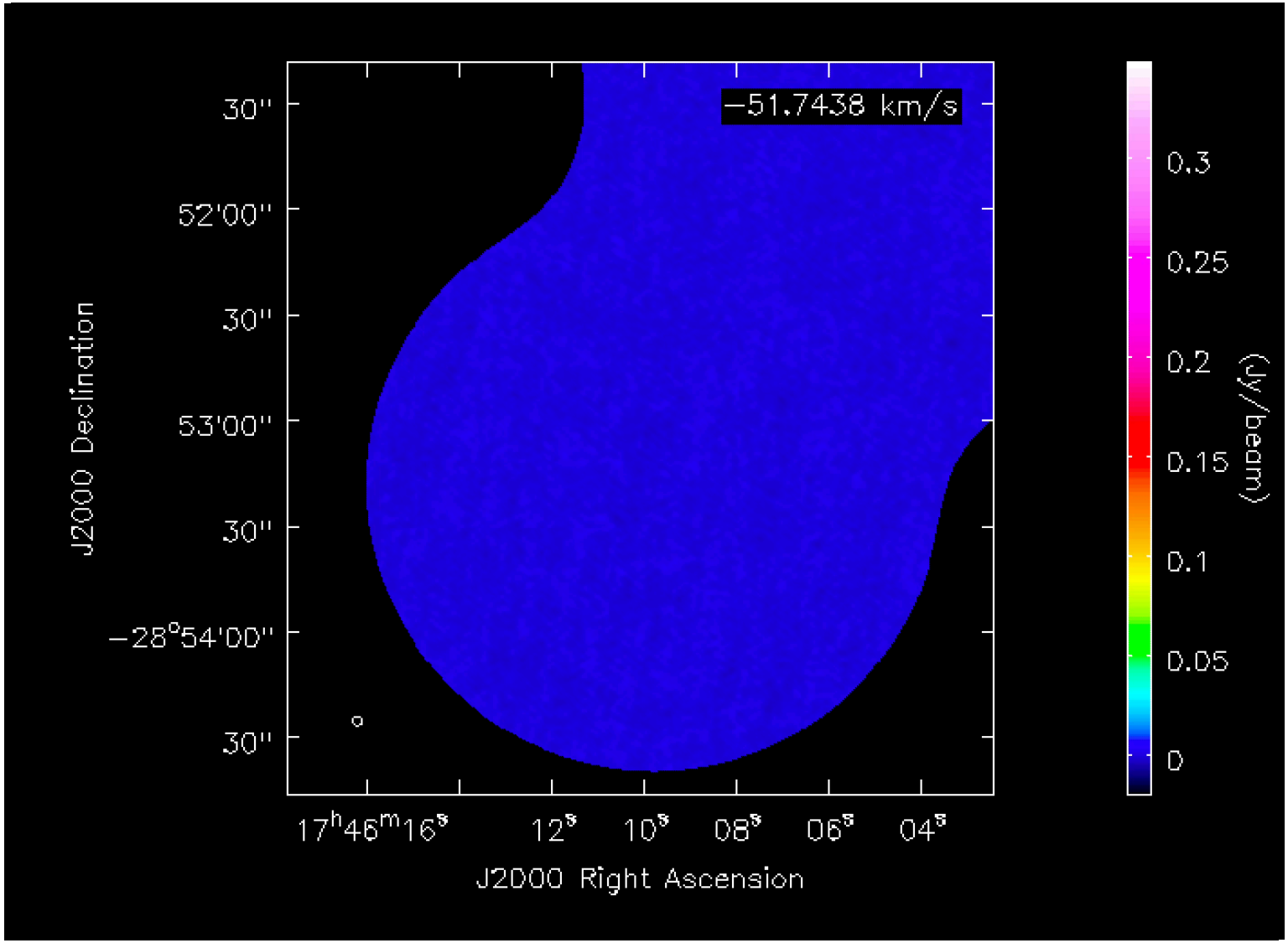
- Imaging SD vs Interferometer Data
    - discuss: resolution, size scales, etc
- Imaging artifacts in interferometer data
    - Negative bowls, Data cube example
- Science behind negative bowls
- Measuring visibilities
    - Example of what SD+VLA data means in UV plane
- Real-life example in science
    - Rathborne 2015 example; measurements
- How to do feathering
    - Casa task: feathering example
- Baselines for VLA and ALMA: which arrays to use with GBT data
- Summary slide

Imaging SD vs Interferometer Data

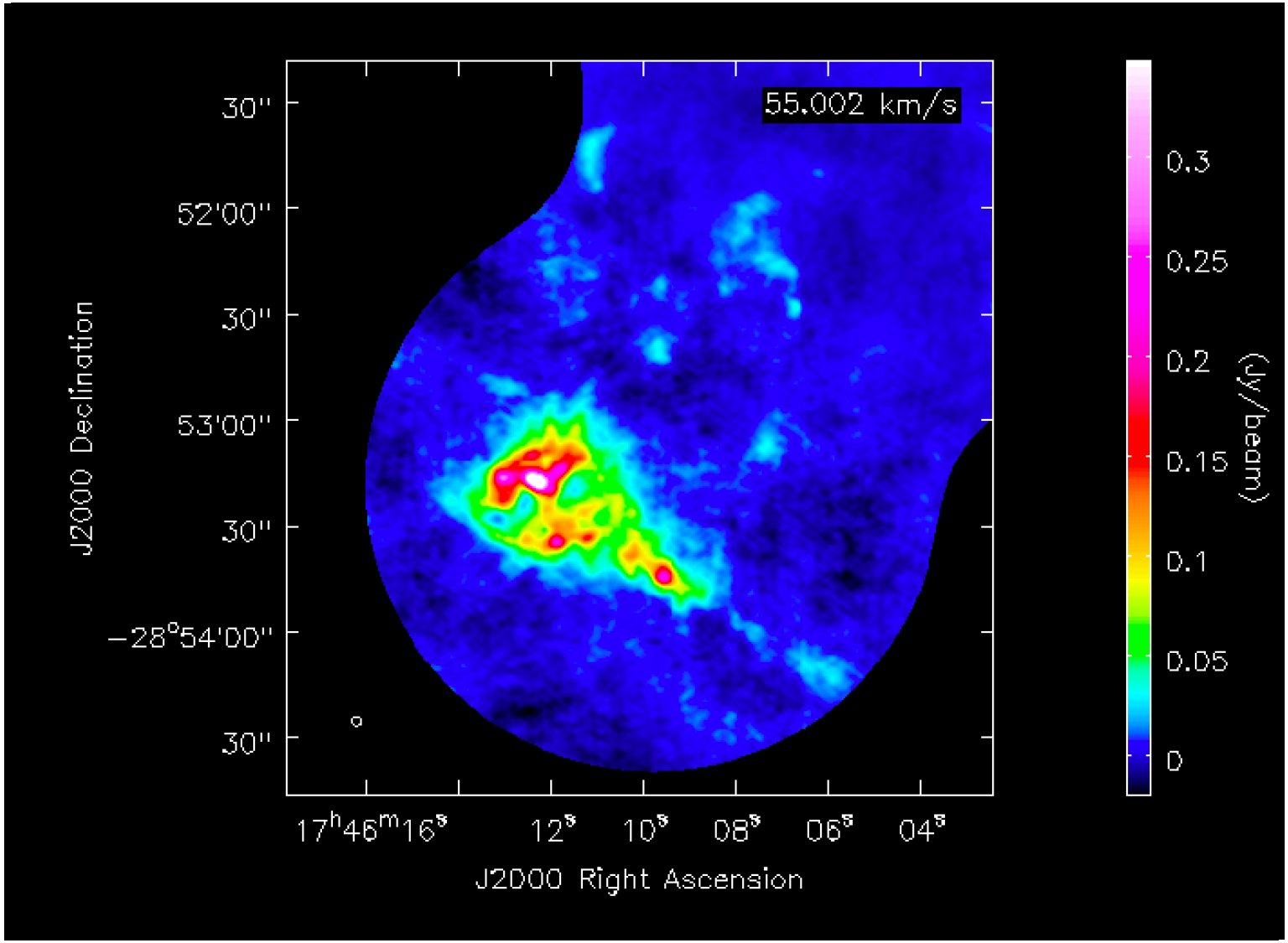




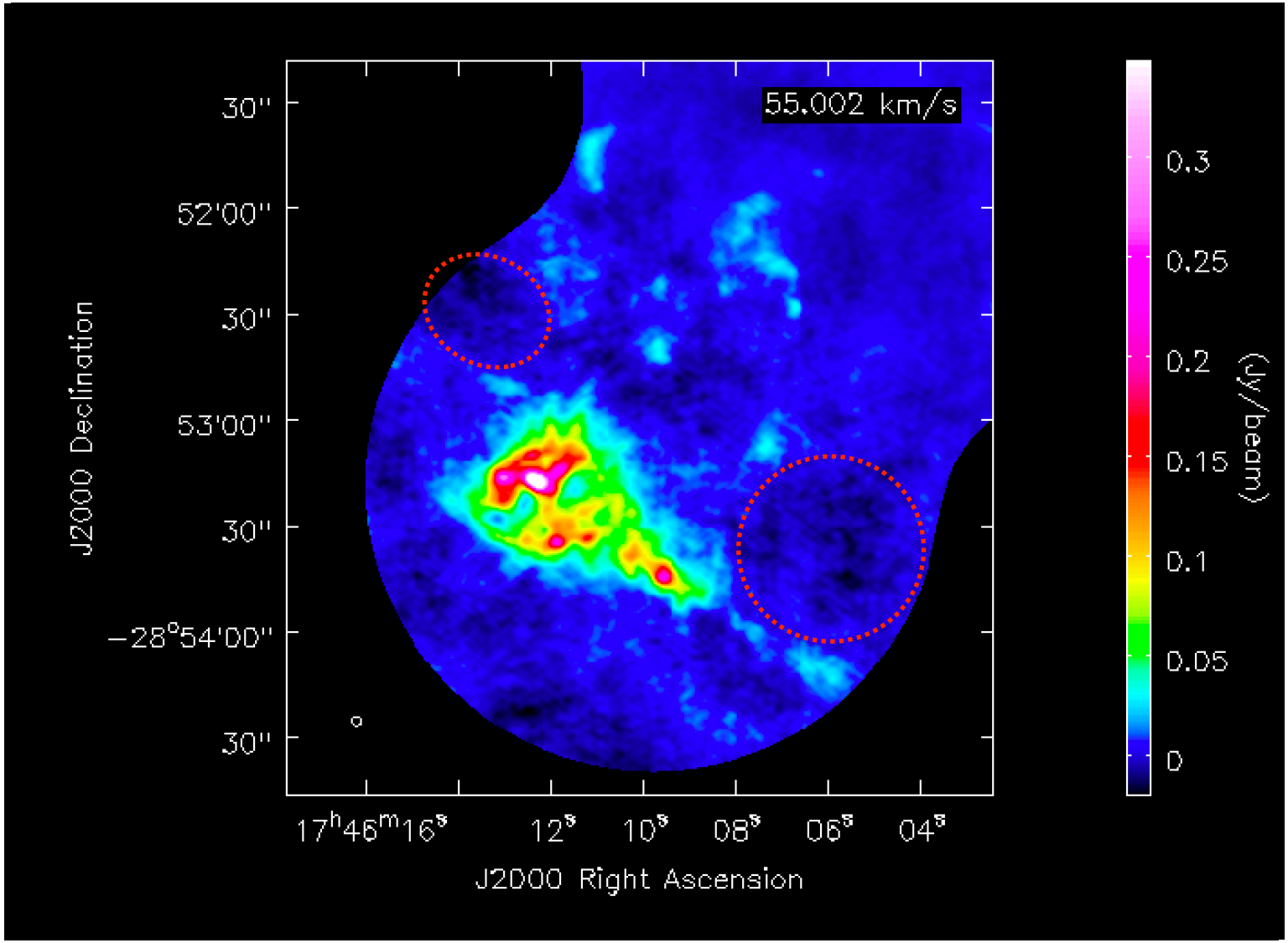
Imaging Artifacts in Interferometer Data



Imaging Artifacts in Interferometer Data

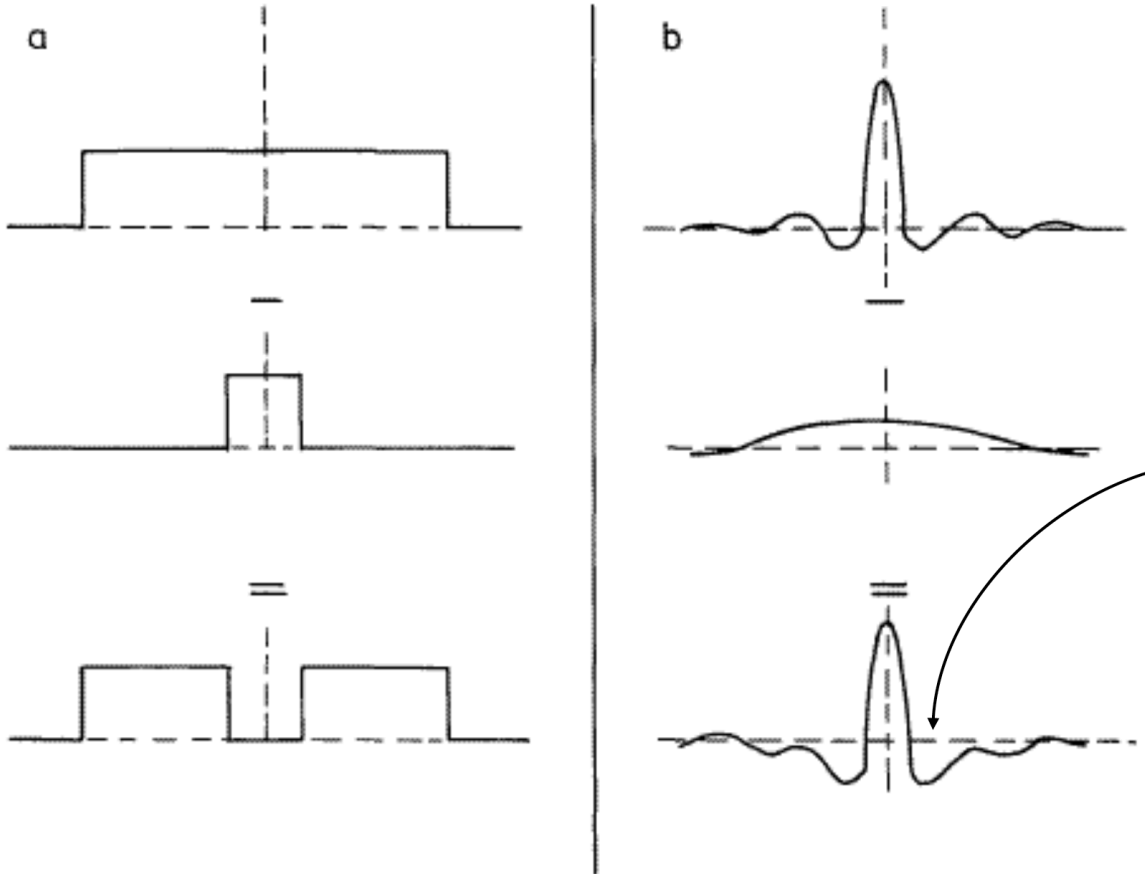


Imaging Artifacts in Interferometer Data



Science behind ‘Negative Bowls’

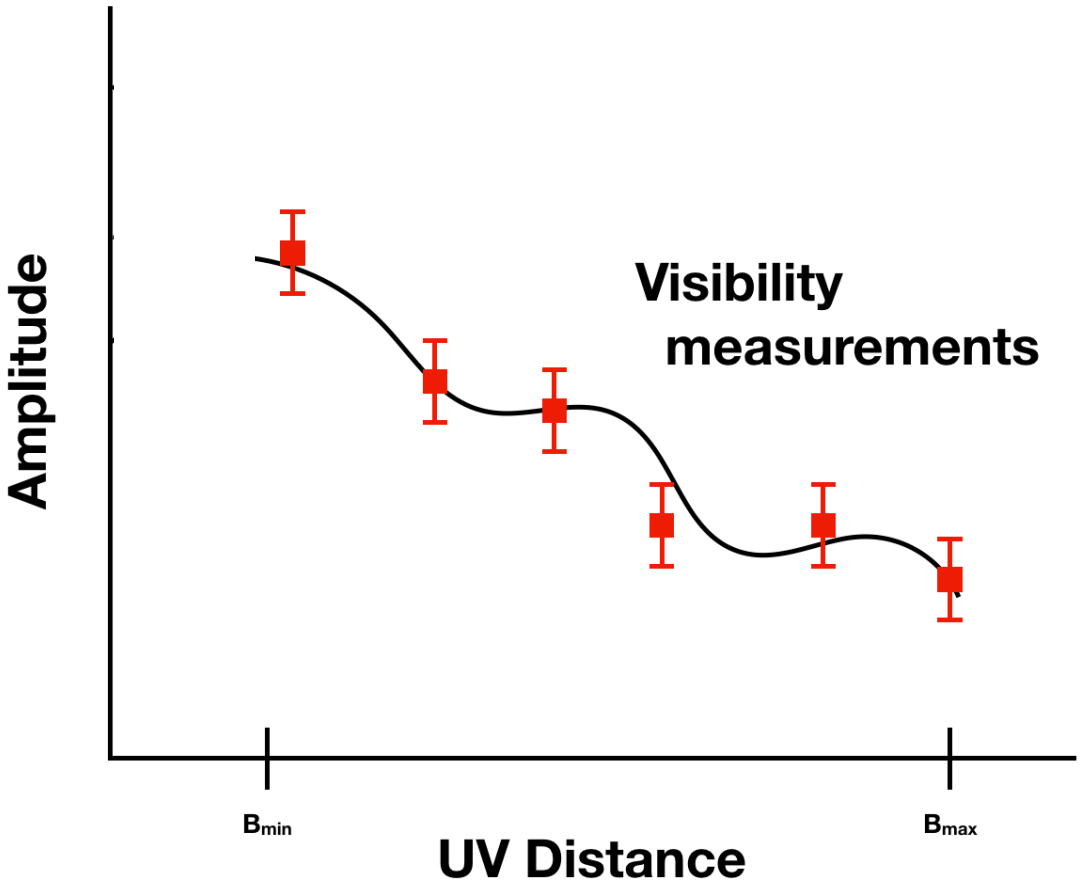
- UV plane
- PSF

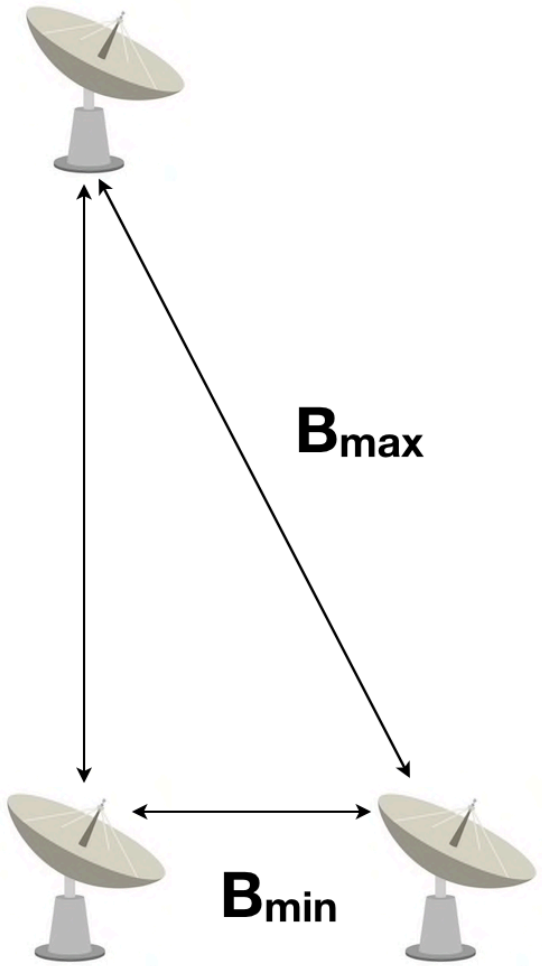


- Braun & Walterbos (1985)
- Negative ‘bowl’

Slide Credit: Brian mason

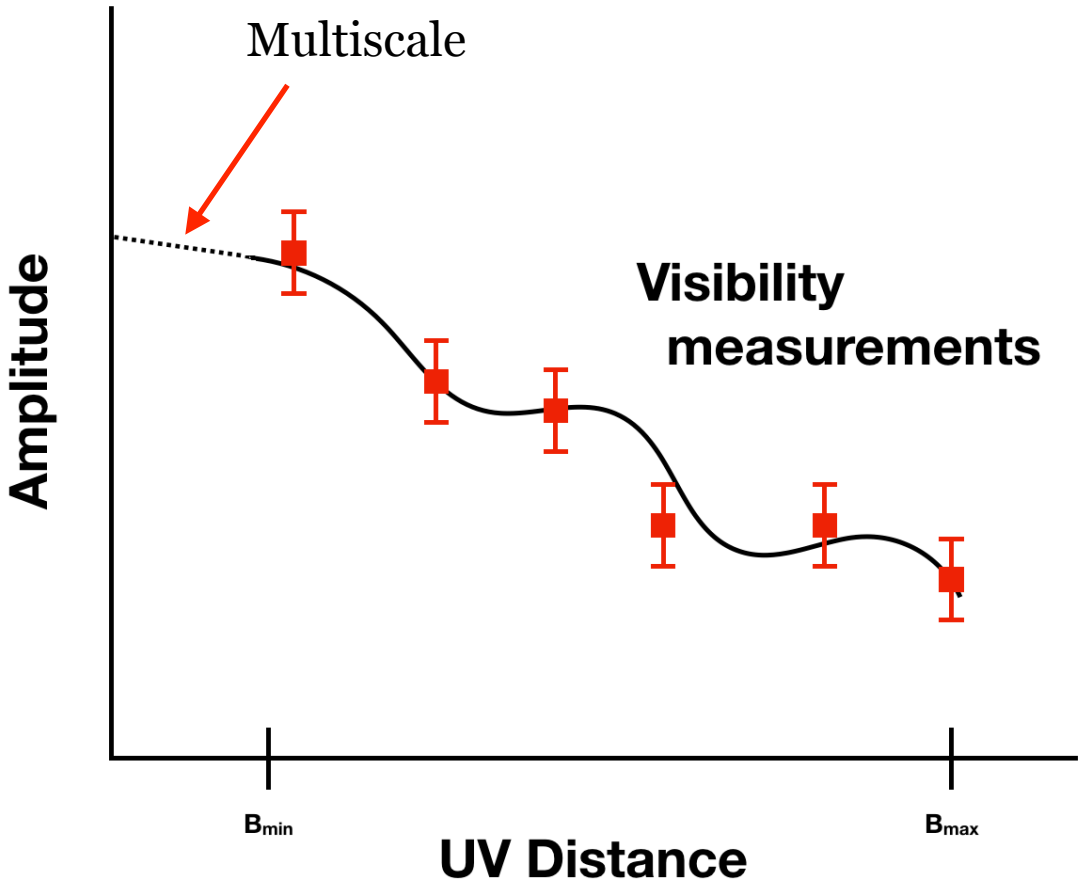
Measuring Visibilities

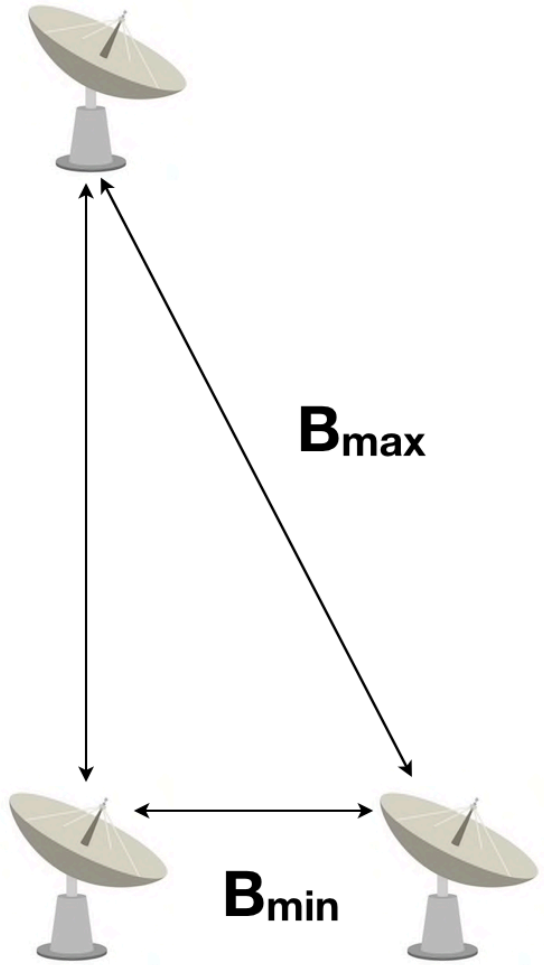




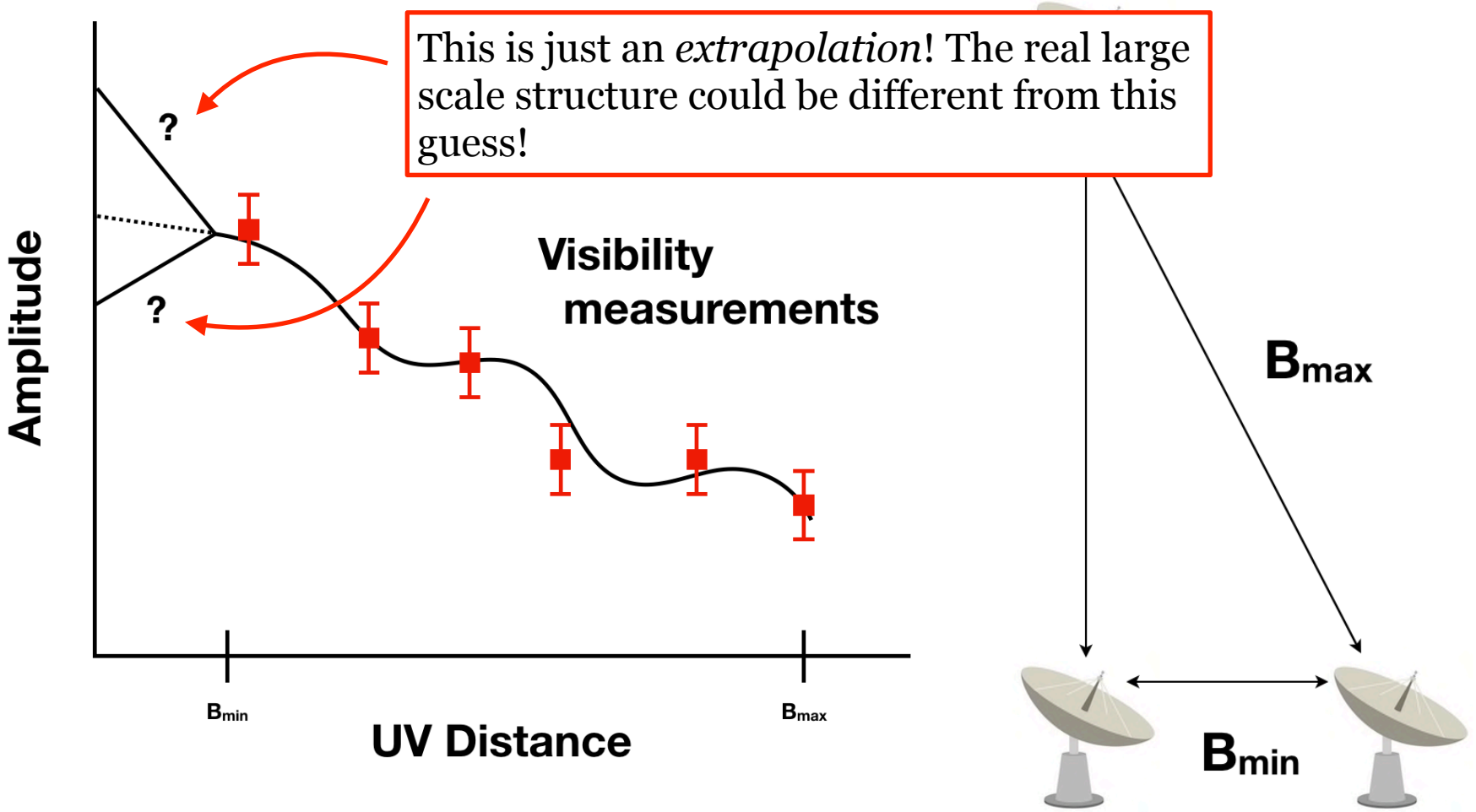
Measuring Visibilities

Multiscale: CASA clean parameter; recover some large scale structure.





Measuring Visibilities



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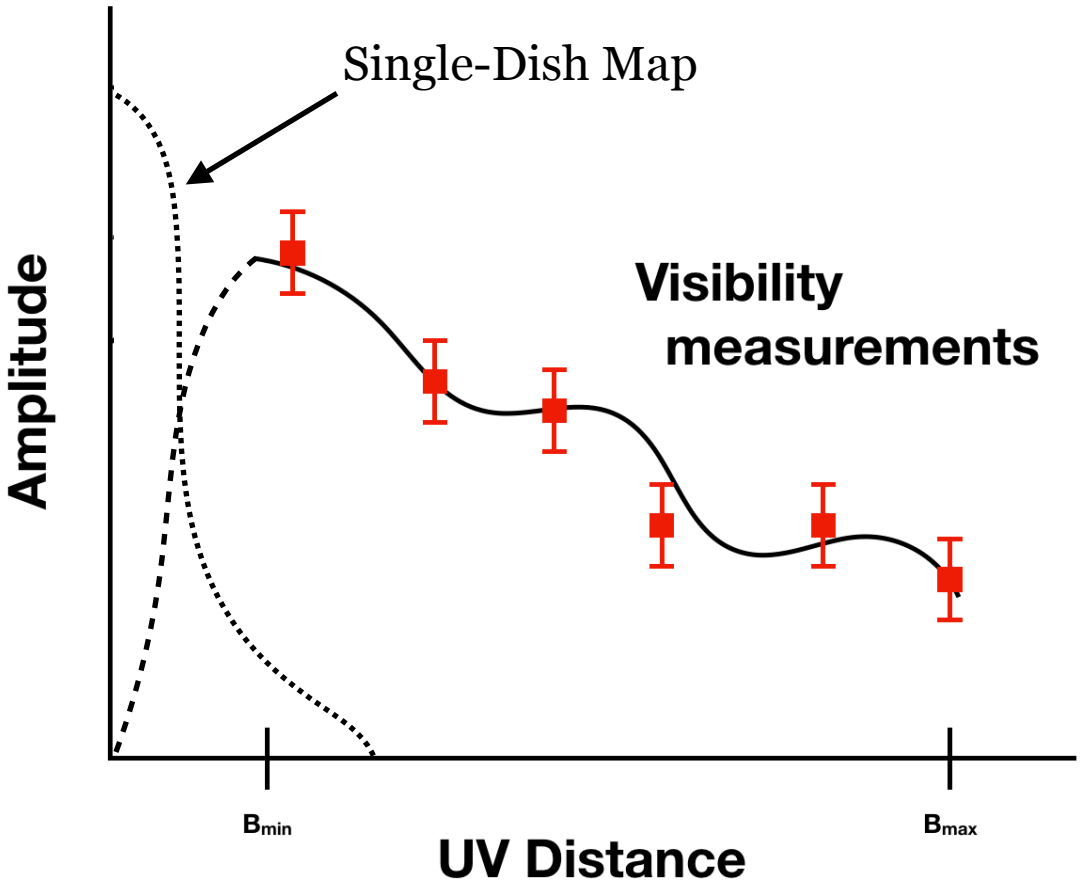

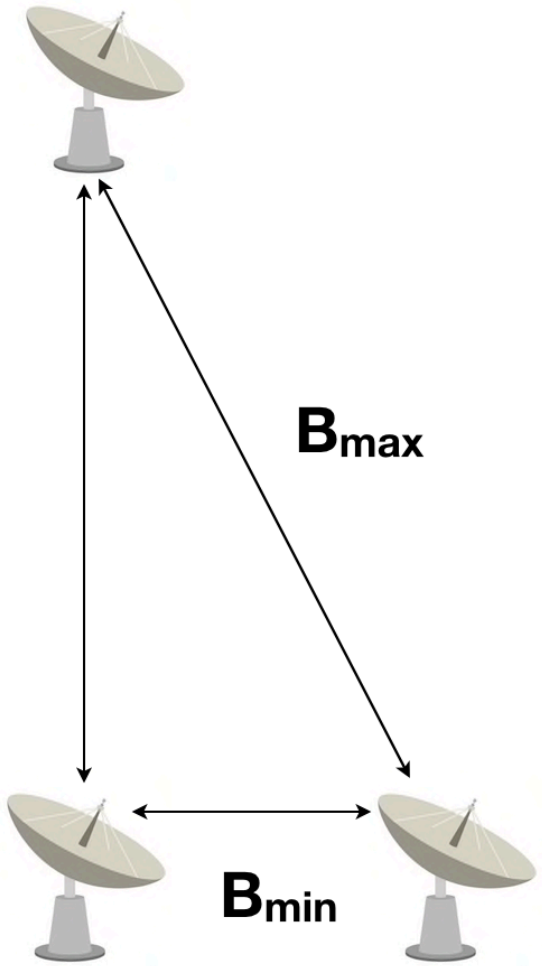

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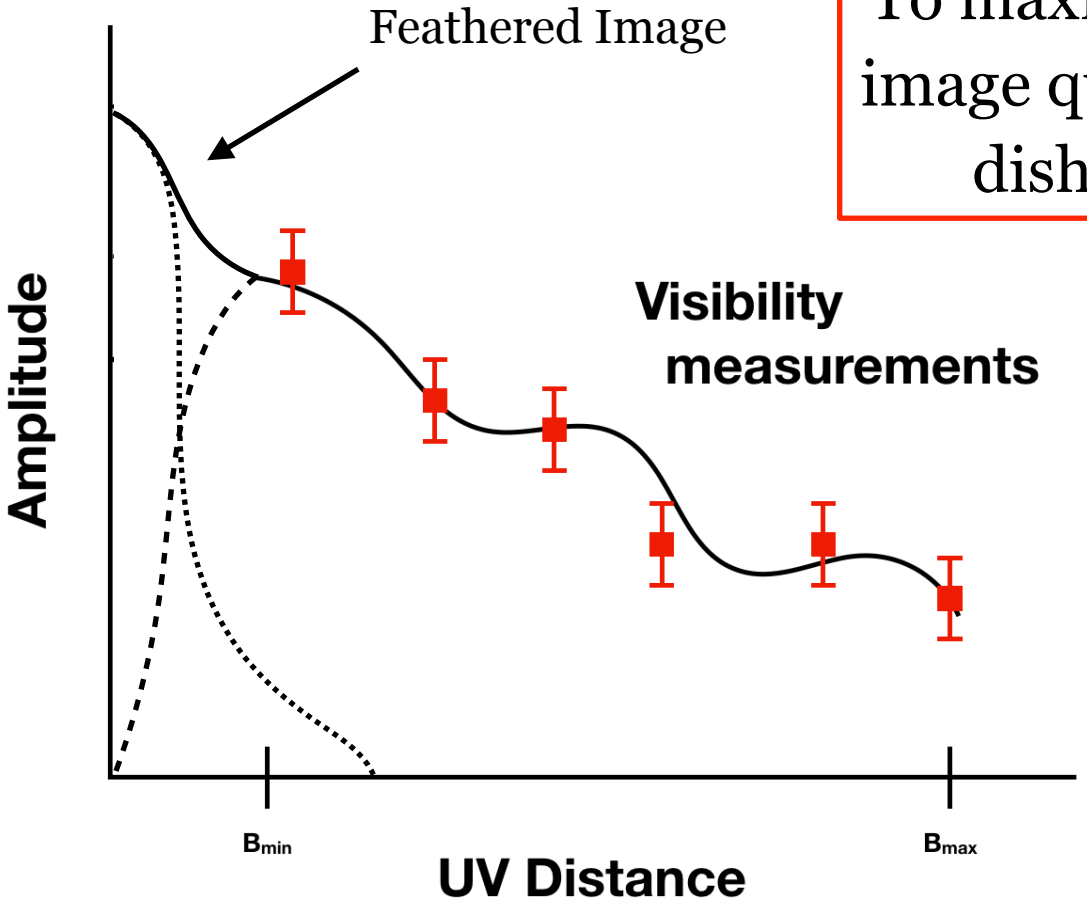
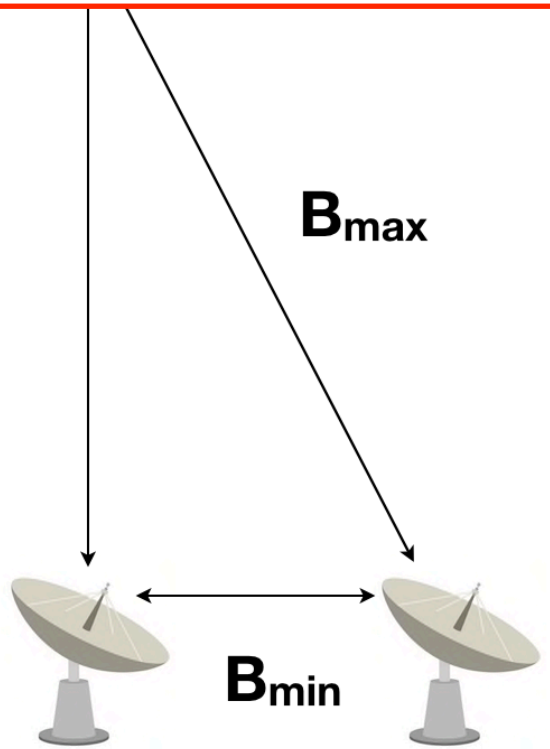
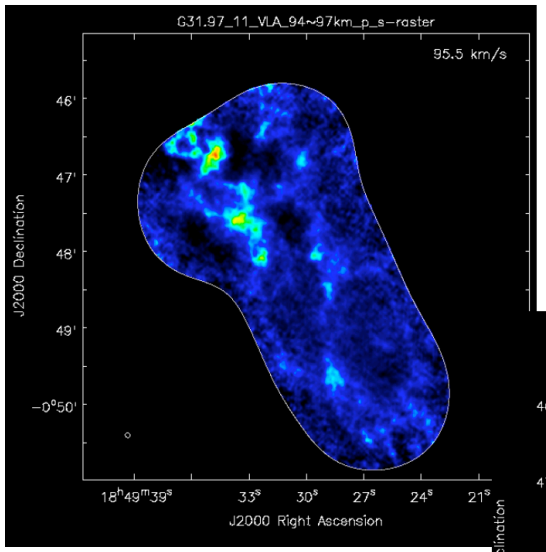


To maximize flux recovery and image quality you want a single dish size of D>1.5x B_{min}



Example of Feathering

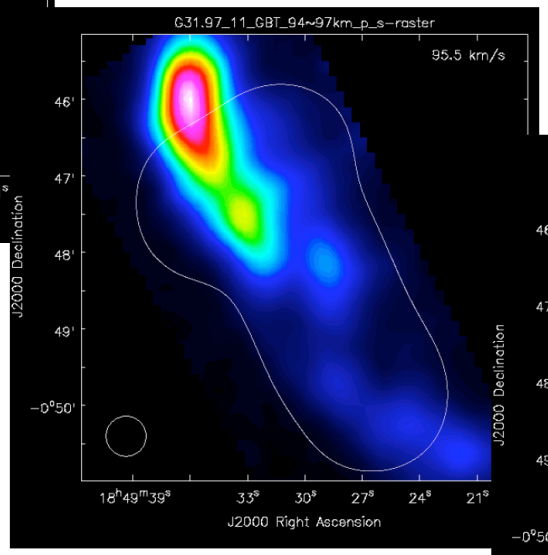
EVLA NH_3 (multi-scale CLEANed)



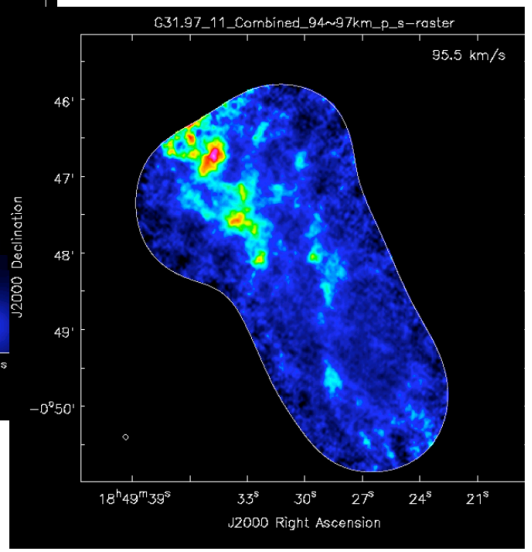
DiRienzo et al. (2015)

To maximize flux recovery and image quality you want a single dish size of $D>1.5x\ B_{min}$

GBT NH_3

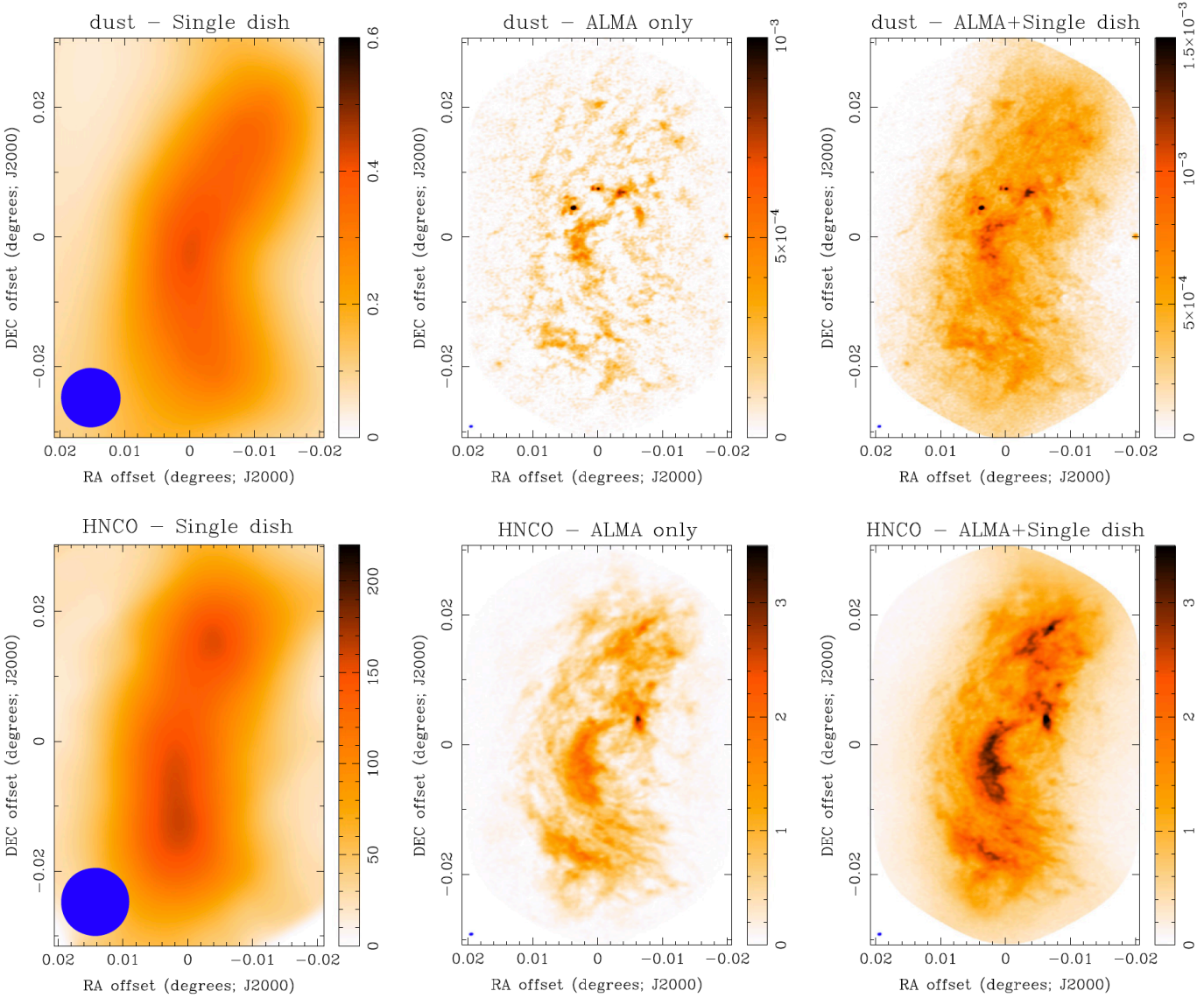


Feathered



Slide Credit: Brian mason

Rathborne et al. (2014) Example



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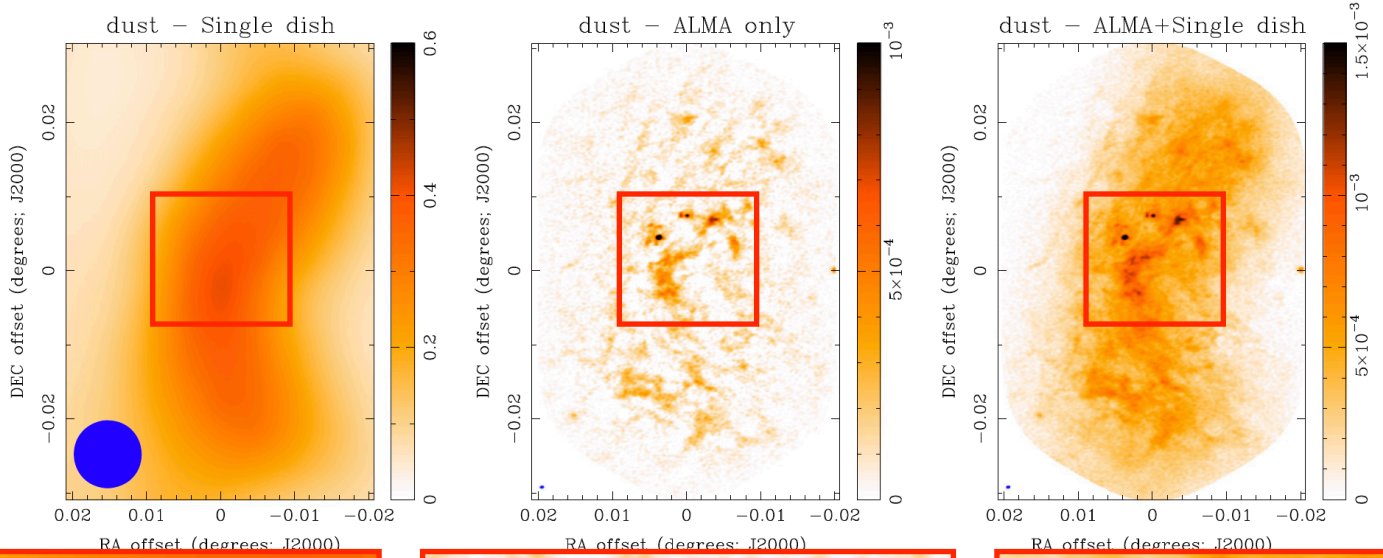
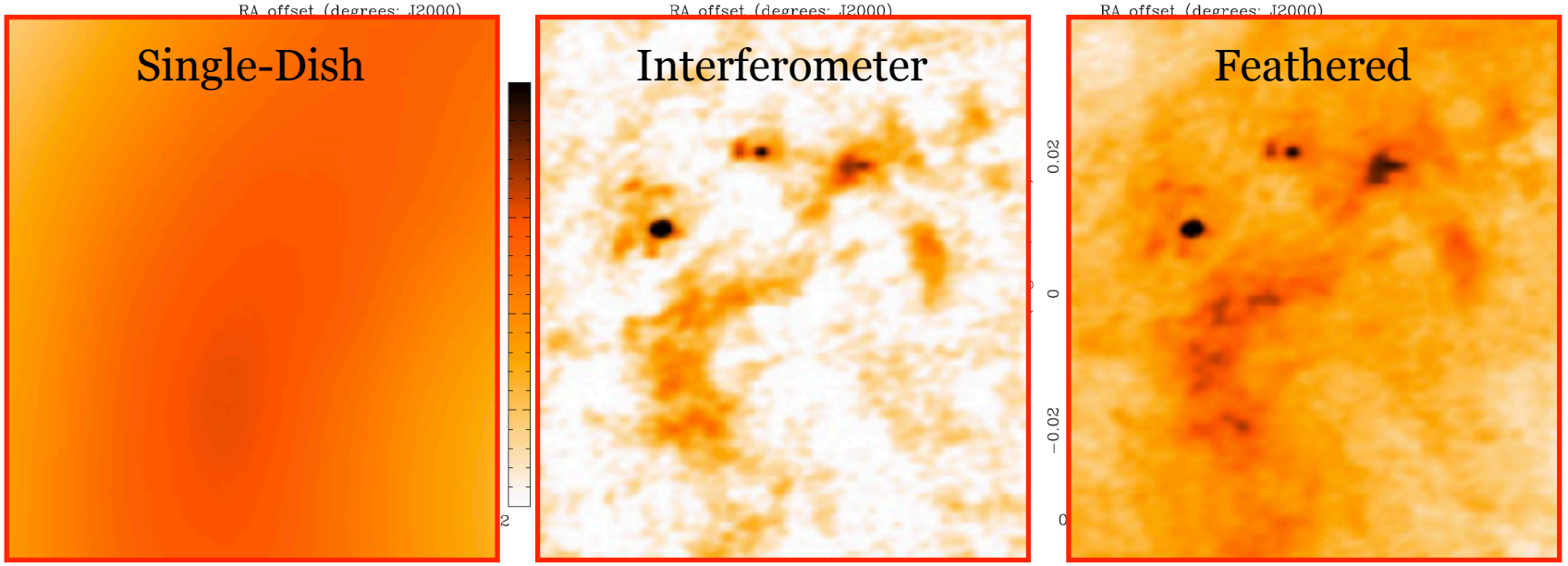
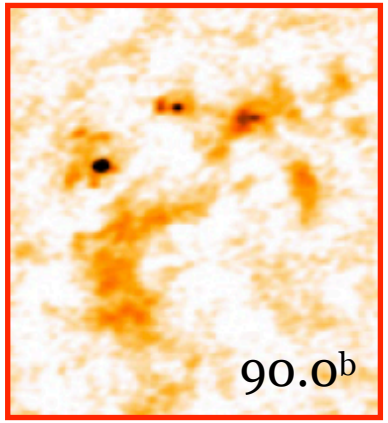
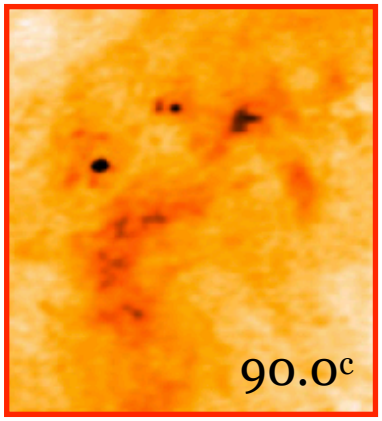




Valid Flux Measurements

Missing flux from large scale structures can effect measurements!





The Astrophysical Journal, 805:72 (25pp), 2015 May 20

Table 3
Continuum Regions

	Area	Cont.	Measured Flux (mJy)[a] 24.1	25.4	27.5	36.4	90.0[b]	90.0[c]	Spectral Index (24–90 GHz)		log N_{Lyc}
	(sq″)	Level	(GHz)	(GHz)	(GHz)	(GHz)	(GHz)	(GHz)	Uncorrected[b]	Corrected[c]	(phot s^{-1})
C1	35.7	10σ	4.6 ± 0.1	4.6 ± 0.2	4.2 ± 0.2	2.6 ± 0.1	3.1 ± 0.1	6.6 ± 0.3	−0.29 ± 0.01	0.27 ± 0.03	46.5
C2	279.1	6σ	18.8 ± 0.1	18.7 ± 0.1	15.6 ± 0.1	8.2 ± 0.2	10.5 ± 0.1	27.3 ± 0.3	−0.43 ± 0.01	0.28 ± 0.03	47.2
C3	27.6	10σ	2.3 ± 0.1	2.4 ± 0.1	2.1 ± 0.1	2.6 ± 0.2	5.9 ± 0.1	11.3 ± 0.6	0.68 ± 0.01	1.17 ± 0.05	45.9
C4	14.8	6σ	1.0 ± 0.1	0.9 ± 0.1	0.9 ± 0.1	0.5 ± 0.1	1.9 ± 0.1	4.2 ± 0.5	0.52 ± 0.09	1.1 ± 0.1	45.9
C5	16.1	10σ	6.3 ± 0.1	5.6 ± 0.2	4.0 ± 0.1	NA	1.0 ± 0.2	1.9 ± 0.4	−1.31 ± 0.03	−0.86 ± 0.05	…
C6	81.6	6σ	4.5 ± 0.1	4.2 ± 0.1	5.5 ± 0.1	6.1 ± 0.1	11.8 ± 0.1	26.6 ± 0.5	0.74 ± 0.07	1.34 ± 0.09	46.5
C7	161.9	6σ	10.7 ± 0.1	8.4 ± 0.2	10.1 ± 0.2	5.9 ± 0.2	8.3 ± 0.1	28.4 ± 0.4	−0.1 ± 0.15	0.8 ± 0.18	46.9
C8	164.2	6σ	8.4 ± 0.1	5.7 ± 0.1	6.3 ± 0.1	2.8 ± 0.1	6.4 ± 0.1	32.3 ± 0.5	−0.1 ± 0.17	1.1 ± 0.14	46.8
C9	521.8	6σ	43.4 ± 0.1	34.1 ± 0.2	37.7 ± 0.2	35.8 ± 0.2	24.4 ± 0.3	80.9 ± 0.3	−0.3 ± 0.25	0.6 ± 0.3	47.5
C10	7.7	10σ	1.6 ± 0.1	1.6 ± 0.2	NA	NA	0.6 ± 0.1	1.0 ± 0.1	−0.73 ± 0.03	−0.35 ± 0.01	…

[a] "NA" indicates this region was outside or near the edge of the field of view.
[b] Values from 3 mm ALMA-only image of Rathborne et al. (2014b).
[c] Values from single-dish-corrected ALMA image of Rathborne et al. (2014b).

Mills et al. (2015)

How to Feather Images

CASA task: feather

- Parameters:
  - ‘lowres’ - Low-resolution image
  - ‘highres’ - High-resolution image
  - ‘imagename’ - output feathered image
- Assumptions:
  - Overlapping spatial frequencies
  - Well-defined primary beams
- Requirements:
  - Low resolution, single dish (SD) image
  - High-resolution, interferometric (IF) image
  - Primary beam of the high-resolution image (PB)

How to Feather Images

CASA task: feather

See Hoffmann & Kepley (2018) for more details (GBT memo #300)

- Parameters:
  - ‘lowres’ - Low-resolution image
  - ‘highres’ - High-resolution image
  - ‘imagename’ - output feathered image
- Assumptions:
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Baselines for ALMA and VLA

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 7 Array configurations

Config	Lmax		Band 3	Band 4	Band 5	Band 6	Band 7	Band 8	Band 9	Band 10
	Lmin		100 GHz	150 GHz	183 GHz	230 GHz	345 GHz	460 GHz	650 GHz	870 GHz
7-m Array	45 m	AR	12.5″	8.4″	6.8″	5.4″	3.6″	2.7″	1.9″	1.4″
	9 m	MRS	66.7″	44.5″	36.1″	29.0″	19.3″	14.5″	10.3″	7.7″
C43-1	161 m	AR	3.4″	2.3″	1.8″	1.5″	1.0″	0.74″	0.52″	0.39″
	15 m	MRS	28.5″	19.0″	15.4″	12.4″	8.3″	6.2″	4.4″	3.3″
C43-2	314 m	AR	2.3″	1.5″	1.2″	1.0″	0.67″	0.50″	0.35″	0.26″
	15 m	MRS	22.6″	15.0″	12.2″	9.8″	6.5″	4.9″	3.5″	2.6″
C43-3	500 m	AR	1.4″	0.94″	0.77″	0.62″	0.41″	0.31″	0.22″	0.16″
	15 m	MRS	16.2″	10.8″	8.7″	7.0″	4.7″	3.5″	2.5″	1.9″
C43-4	784 m	AR	0.92″	0.61″	0.50″	0.40″	0.27″	0.20″	0.14″	0.11″
	15 m	MRS	11.2″	7.5″	6.1″	4.9″	3.3″	2.4″	1.7″	1.3″
C43-5	1.4 km	AR	0.54″	0.36″	0.30″	0.24″	0.16″	0.12″	0.084″	0.063″
	15 m	MRS	6.7″	4.5″	3.6″	2.9″	1.9″	1.5″	1.0″	0.77″
C43-6	2.5 km	AR	0.31″	0.20″	0.16″	0.13″	0.089″	0.067″	0.047″	0.035″
	15 m	MRS	4.1″	2.7″	2.2″	1.8″	1.2″	0.89″	0.63″	0.47″
C43-7	3.6 km	AR	0.21″	0.14″	0.11″	0.092″	0.061″	0.046″	0.033″	0.024″
	64 m	MRS	2.6″	1.7″	1.4″	1.1″	0.75″	0.56″	0.40″	0.30″
C43-8	8.5 km	AR	0.096″	0.064″	0.052″	0.042″	0.028″	N/A	N/A	N/A
	110 m	MRS	1.4″	0.95″	0.77″	0.62″	0.41″			
C43-9	13.9 km	AR	0.057″	0.038″	0.031″	0.025″	0.017″	N/A	N/A	N/A
	368 m	MRS	0.81″	0.54″	0.44″	0.35″	0.24″			
C43-10	16.2 km	AR	0.042″	0.028″	0.023″	0.018″	0.012″	N/A	N/A	N/A
	244 m	MRS	0.50″	0.33″	0.27″	0.22″	0.14″			

ALMA 11 arrays

4 arrays **VLA**

GBO = 100 m
Arecibo = 300 m

Table 3.1.1: Configuration Properties

Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
B_{min} (km[1])	0.68	0.21	0.035[5]	0.035
Band	**Synthesized Beamwidth θ_{HPBW}**(arcsec)[1,2,3]			
74 MHz (4)	24	80	260	850
350 MHz (P)	5.6	18.5	60	200
1.5 GHz (L)	1.3	4.3	14	46
3.0 GHz (S)	0.65	2.1	7.0	23
6.0 GHz (C)	0.33	1.0	3.5	12
10 GHz (X)	0.20	0.60	2.1	7.2
15 GHz (Ku)	0.13	0.42	1.4	4.6
22 GHz (K)	0.089	0.28	0.95	3.1
33 GHz (Ka)	0.059	0.19	0.63	2.1
45 GHz (Q)	0.043	0.14	0.47	1.5
Band	**Largest Angular Scale θ_{LAS}**(arcsec)[1,4]			
74 MHz (4)	800	2200	20000	20000
350 MHz (P)	155	515	4150	4150
1.5 GHz (L)	36	120	970	970
3.0 GHz (S)	18	58	490	490
6.0 GHz (C)	8.9	29	240	240
10 GHz (X)	5.3	17	145	145
15 GHz (Ku)	3.6	12	97	97
22 GHz (K)	2.4	7.9	66	66
33 GHz (Ka)	1.6	5.3	44	44
45 GHz (Q)	1.2	3.9	32	32

Baselines for ALMA and VLA

Table A-1: Angular Resolutions (AR) and Max … y configurations

Config	Lmax / Lmin		Band 3 100 GHz	Band 4 150 GHz	…	…	…	…	…	…
7-m Array	45 m	AR	12.5″	8.4″						1.4″
	9 m	MRS	66.7″	44.5″						7.7″
C43-1	161 m	AR	3.4″	2.3″						.39″
	15 m	MRS	28.5″	19.0″						3.3″
C43-2	314 m	AR	2.3″	1.5″						.26″
	15 m	MRS	22.6″	15.0″						2.6″
C43-3	500 m	AR	1.4″	0.94″						.16″
	15 m	MRS	16.2″	10.8″						1.9″
C43-4	784 m	AR	0.92″	0.61″						.11″
	15 m	MRS	11.2″	7.5″						1.3″
C43-5	1.4 km	AR	0.54″	0.36″						063″
	15 m	MRS	6.7″	4.5″						.77″
C43-6	2.5 km	AR	0.31″	0.20″						035″
	15 m	MRS	4.1″	2.7″						.47″
C43-7	3.6 km	AR	0.21″	0.14″						024″
	64 m	MRS	2.6″	1.7″						.30″
C43-8	8.5 km	AR	0.096″	0.064″						N/A
	110 m	MRS	1.4″	0.95″						
C43-9	13.9 km	AR	0.057″	0.038″						N/A
	368 m	MRS	0.81″	0.54″						
C43-10	16.2 km	AR	0.042″	0.028″						N/A
	244 m	MRS	0.50″	0.33″	0.27″	0.22″	0.14″			

Config	Lmax / Lmin		Band 3 100 GHz
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	9 m	MRS	66.7″
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	15 m	MRS	28.5″
C43-2	314 m	AR	2.3″
	15 m	MRS	22.6″
C43-3	500 m	AR	1.4″
	15 m	MRS	16.2″
C43-4	784 m	AR	0.92″
	15 m	MRS	11.2″
C43-5	1.4 km	AR	0.54″
	15 m	MRS	6.7″
C43-6	2.5 km	AR	0.31″
	15 m	MRS	4.1″
C43-7	3.6 km	AR	0.21″
	64 m	MRS	2.6″

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1.5 GHz (L)	1.3	4.3	14	46
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6.0 GHz (C)	0.33	1.0	3.5	12
10 GHz (X)	0.20	0.60	2.1	7.2
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22 GHz (K)	0.089	0.28	0.95	3.1
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1.5 GHz (L)	36	120	970	970
3.0 GHz (S)	18	58	490	490
6.0 GHz (C)	8.9	29	240	240
10 GHz (X)	5.3	17	145	145
15 GHz (Ku)	3.6	12	97	97
22 GHz (K)	2.4	7.9	66	66
33 GHz (Ka)	1.6	5.3	44	44
45 GHz (Q)	1.2	3.9	32	32

Baselines for ALMA and VLA

Table A-1: Angular Resolutions (AR) and Maximum Recoverable Scales (MRS) for the Cycle 7 Array configurations

Config	Lmax		Band 3	Band 4					
	Lmin		100 GHz	150 GHz					
7-m Array	45 m	AR	12.5″	8.4					
	9 m	MRS	66.7″	44.5					
C43-1	161 m	AR	3.4″	2.3					
	15 m	MRS	28.5″	19.0					
C43-2	314 m	AR	2.3″	1.5					
	15 m	MRS	22.6″	15.0″	12.2″	9.8″	6.5″	4.9″	3.5″	2.6″
C43-3	500 m	AR	1.4″	0.94″	0.77″	0.62″	0.41″	0.31″	0.22″	0.16″
	15 m	MRS	16.2″	10.8″	8.7″	7.0″	4.7″	3.5″	2.5″	1.9″
C43-4	784 m	AR	0.92″	0.61″	0.50″	0.40″	0.27″	0.20″	0.14″	0.11″
	15 m	MRS	11.2″	7.5″	6.1″	4.9″	3.3″	2.4″	1.7″	1.3″
C43-5	1.4 km	AR	0.54″	0.36″	0.30″	0.24″	0.16″	0.12″	0.084″	0.063″
	15 m	MRS	6.7″	4.5″	3.6″	2.9″	1.9″	1.5″	1.0″	0.77″
C43-6	2.5 km	AR	0.31″	0.20″	0.16″	0.13″	0.089″	0.067″	0.047″	0.035″
	15 m	MRS	4.1″	2.7″	2.2″	1.8″	1.2″	0.89″	0.63″	0.47″
C43-7	3.6 km	AR	0.21″	0.14″	0.11″	0.092″	0.061″	0.046″	0.033″	0.024″
	64 m	MRS	2.6″	1.7″	1.4″	1.1″	0.75″	0.56″	0.40″	0.30″
C43-8	8.5 km	AR	0.096″	0.064″	0.052″	0.042″	0.028″	N/A	N/A	N/A
	110 m	MRS	1.4″	0.95″	0.77″	0.62″	0.41″			
C43-9	13.9 km	AR	0.057″	0.038″	0.031″	0.025″	0.017″	N/A	N/A	N/A
	368 m	MRS	0.81″	0.54″	0.44″	0.35″	0.24″			
C43-10	16.2 km	AR	0.042″	0.028″	0.023″	0.018″	0.012″	N/A	N/A	N/A
	244 m	MRS	0.50″	0.33″	0.27″	0.22″	0.14″			

Table 3.1.1: Configuration Properties

Configuration	A	B	C	D
B_{max} (km[1])	36.4	11.1	3.4	1.03
B_{min} (km[1])	0.68	0.21	0.035[5]	0.035

4 arrays → VLA

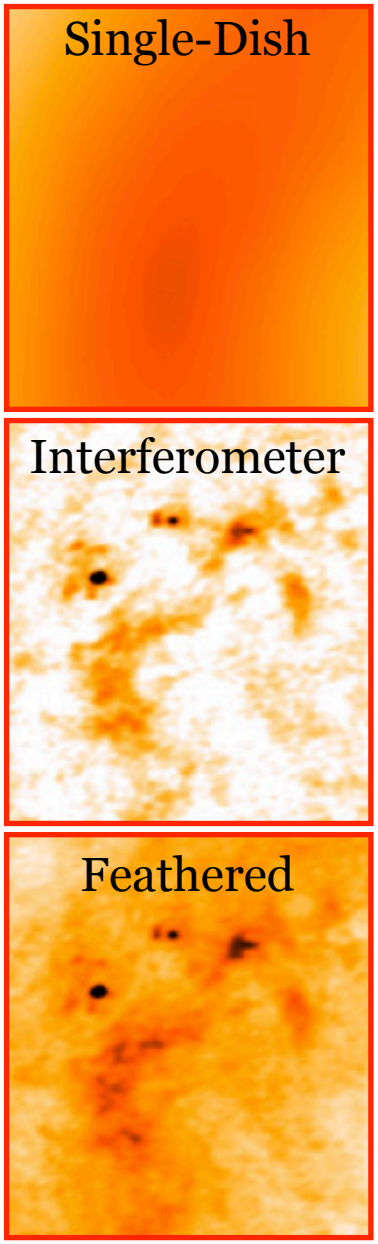
GBO = 100 m
Arecibo = 300 m

Table 3.1.1: Configuration Properties

Configuration	A	B	C	D
[1]			3.4	1.03
			0.035[5]	0.035
mwidth θ_{HPBW}(arcsec)[1,2,3]				
			260	850
			60	200
			14	46
			7.0	23
			3.5	12
10 GHz (X)	0.20	0.60	2.1	7.2
15 GHz (Ku)	0.13	0.42	1.4	4.6
22 GHz (K)	0.089	0.28	0.95	3.1
33 GHz (Ka)	0.059	0.19	0.63	2.1
45 GHz (Q)	0.043	0.14	0.47	1.5
Band	**Largest Angular Scale θ_{LAS}**(arcsec)[1,4]			
74 MHz (4)	800	2200	20000	20000
350 MHz (P)	155	515	4150	4150
1.5 GHz (L)	36	120	970	970
3.0 GHz (S)	18	58	490	490
6.0 GHz (C)	8.9	29	240	240
10 GHz (X)	5.3	17	145	145
15 GHz (Ku)	3.6	12	97	97
22 GHz (K)	2.4	7.9	66	66
33 GHz (Ka)	1.6	5.3	44	44
45 GHz (Q)	1.2	3.9	32	32

Summary

- Combination of SD+IF data is ‘feathering’
- To maximize flux recovery and image quality you want a single dish size of D>1.5x B_{min}
  - For the GBT: VLA arrays D & C; ALMA arrays C43-1 —C43-7
  - For Arecibo: VLA array D, C, & B
- CASA task: ‘Feather’
- Valid Flux Measurements
  - Need single-dish data to get valid flux measurements



Additional References

- Rathborne et al. (2014)
  - Example of combining ALMA and Mopra Data
- Hoffmann & Kepley (2018)
  - GBT memo #300: Correcting ALMA 12 m Array Data for missing short spacings using the GBT
  - CASA scripts
- CASA Guide: 'M100 Band3 Combine'
  - Steps on combining TP+7m+12m ALMA data
- DiRienzo et al. (2015)
  - Feathering VLA+GBT data
- Brian Mason slides on Mosaicking
- Braun & Walters (1985)
  - Science behind negative 'bowls'

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