

# Frequently Asked Questions



Francesco Costagliola (thanks to E. Liuzzo e A. Mignano)



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# Goals:

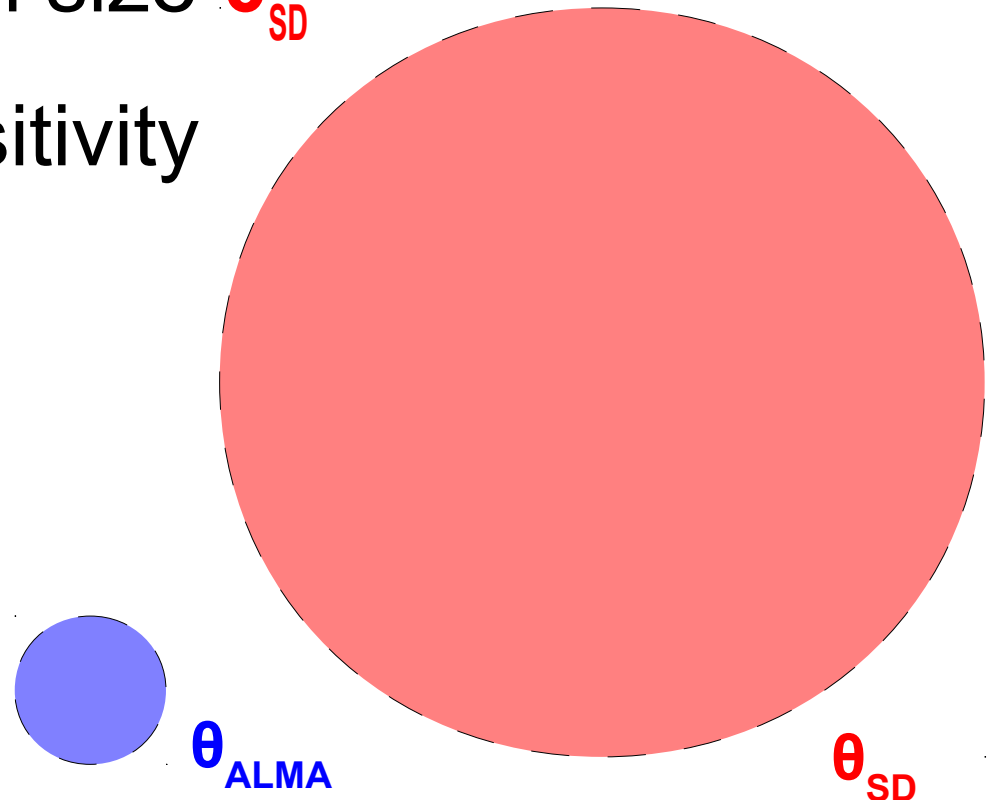
- Derive observation parameters from previous observations or theoretical estimates
- Choose the right setup for your science goal

# Topics:

- Continuum and line peak sensitivity
- Spectral resolution
- Spatial filtering and maximum recoverable size
- Dynamic range

# Peak flux estimation

- You find unresolved single dish observations in the literature, with a main beam brightness temperature  $T_{SD}$  and beam size  $\theta_{SD}$
- What is the required sensitivity for ALMA observations at  $\theta_{ALMA}$  resolution ?

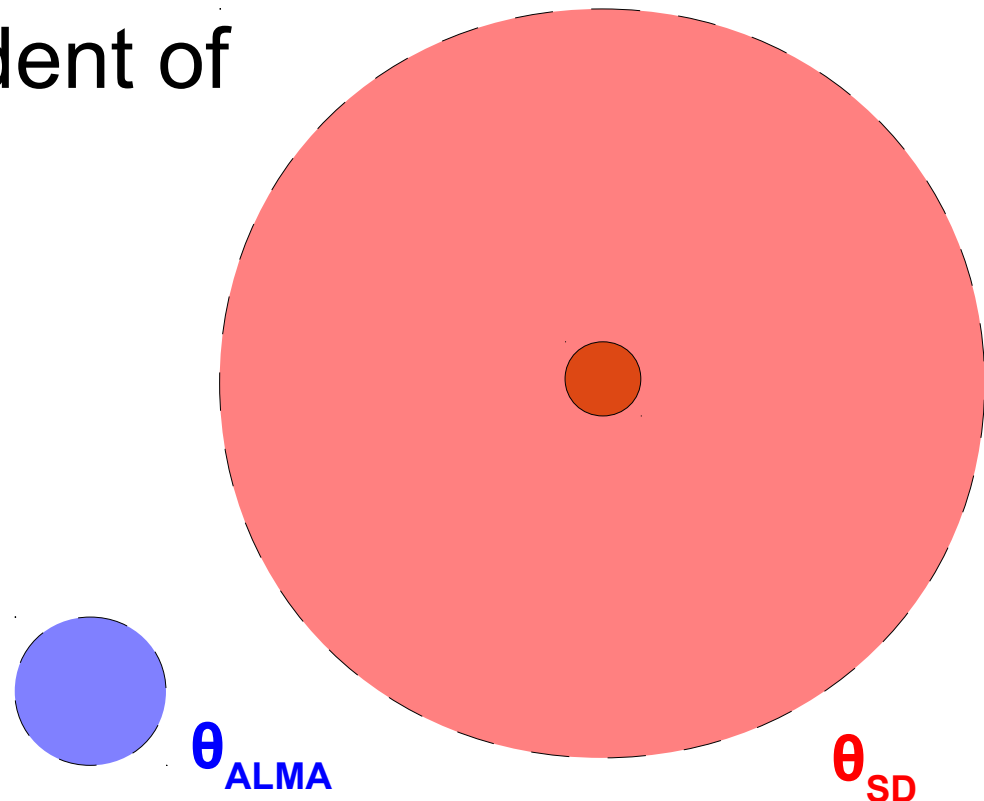


# Peak flux estimation

- The source is smaller than the ALMA beam (point source)
- Flux in Jy/beam independent of the beam

- $F_{SD} = 2 k T_{SD} \Omega_{SD} / \lambda^2$

- $F_{ALMA} = F_{SD}$



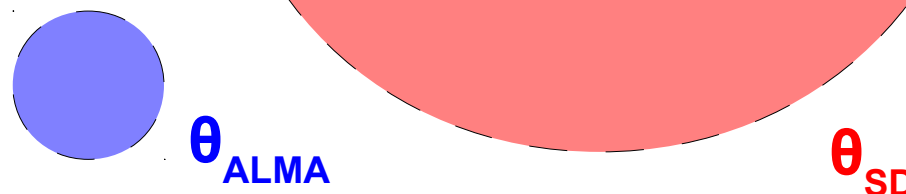
# Peak flux estimation

- The source is smaller than the ALMA beam (point source)
- Flux in Jy/beam independent of the beam

- $F_{SD} = 2 k T_{SD} \Omega_{SD} / \lambda^2$

A tip: use the time calculator to easily convert K to Jy

- $F_{ALMA} = F_{SD}$



# Peak flux estimation

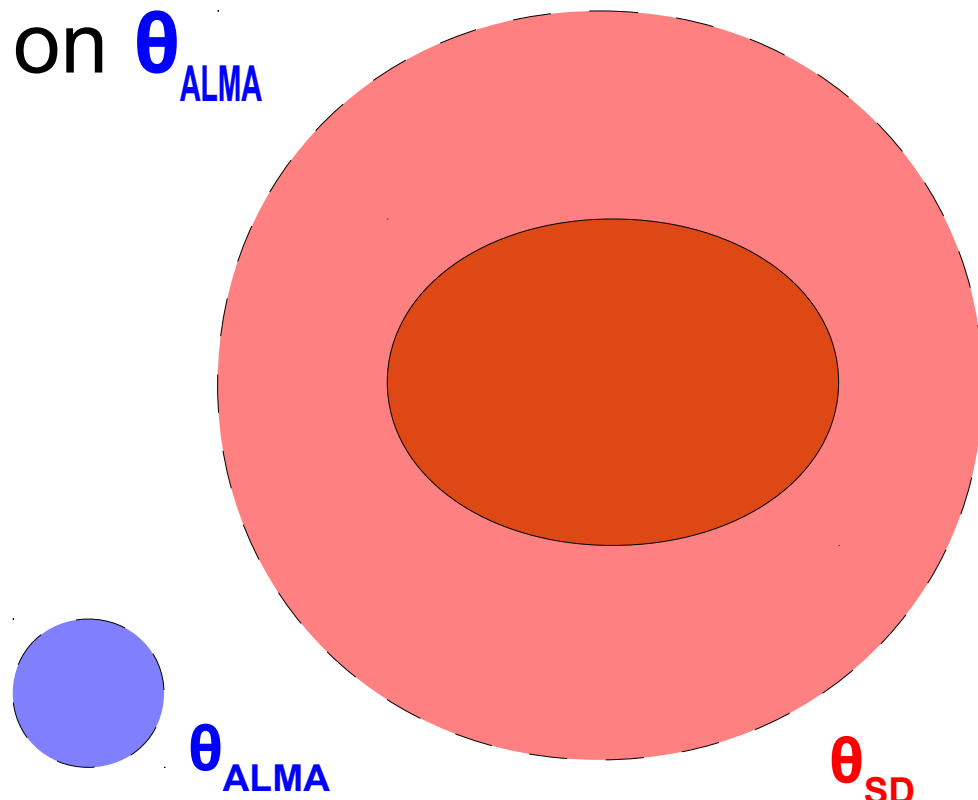
- The source is larger than the ALMA beam, with size  $\theta_s$  and a uniform brightness temperature  $T_s$
- Flux in Jy/beam depends on  $\theta_{ALMA}$

- $F_{SD} = 2 k T_{SD} \Omega_{SD} / \lambda^2$

- $F_{ALMA} = F_{SD} (\theta_{ALMA} / \theta_s)^2$

or

$$F_{ALMA} = 2 k T_s \Omega_{ALMA} / \lambda^2$$



# In the time calculator:

- A source is observed with a single dish with  $\theta_{SD} = 10''$  and has  $T_{SD} = 1$  K at 300 GHz
- Which is the sensitivity required for ALMA observations at  $\theta_{ALMA} = 1''$  resolution ?

Point source:

$$\begin{aligned} \bullet F_{ALMA} &= F_{SD} = 2 \text{ k } T_{SD} \Omega_{SD} / \lambda^2 \\ &= 7.36 \text{ Jy/beam} \end{aligned}$$

Extended uniform source

$$\begin{aligned} \bullet F_{ALMA} &= F_{SD} (\theta_{ALMA} / \theta_S)^2 \\ &= 0.0736 \text{ Jy/beam} \end{aligned}$$

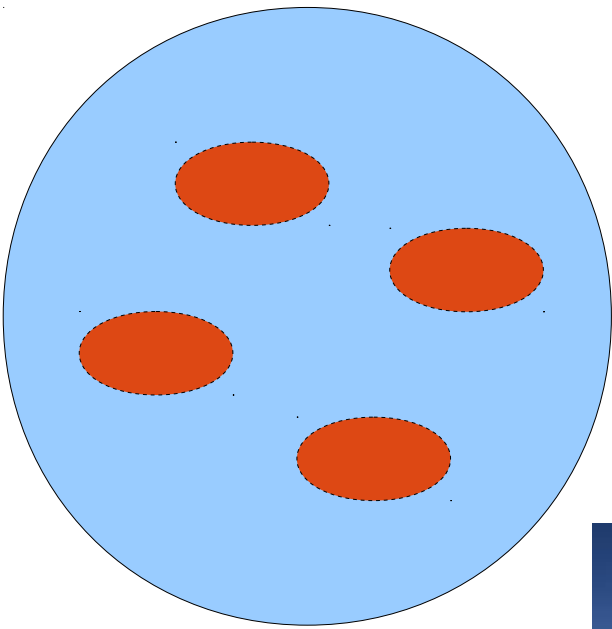
**A factor 10,000 in exposure time !!**



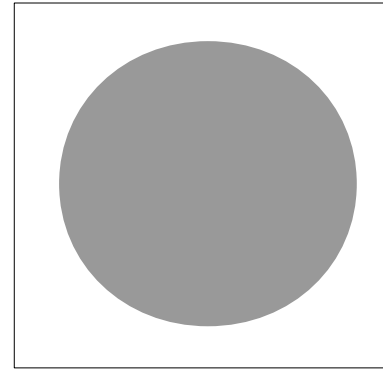
# Peak flux estimation

- Assumptions on the morphology of the emission have a great impact on integration time!
- For point sources  $F_{ALMA} = F_{SD}$
- For extended sources  $F_{ALMA} \propto (\theta_{ALMA})^2$
- Choose your resolution wisely!

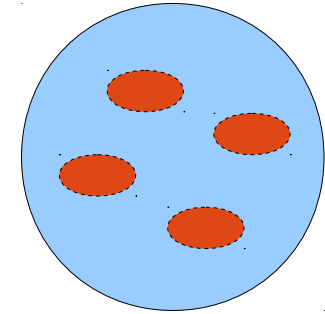
# Spatial filtering of large scales



v



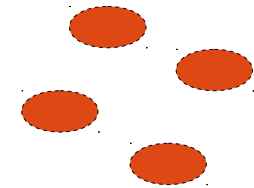
u



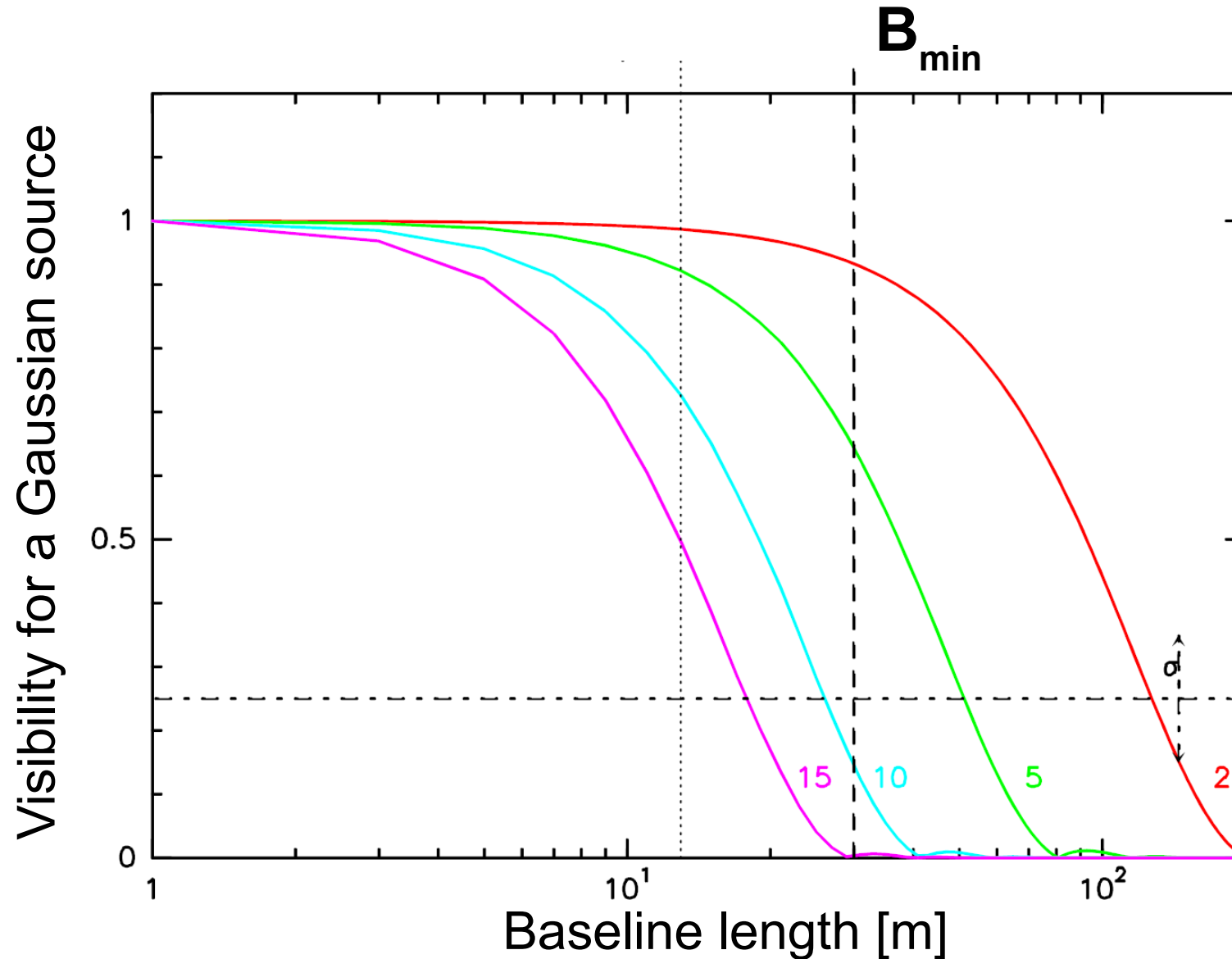
v



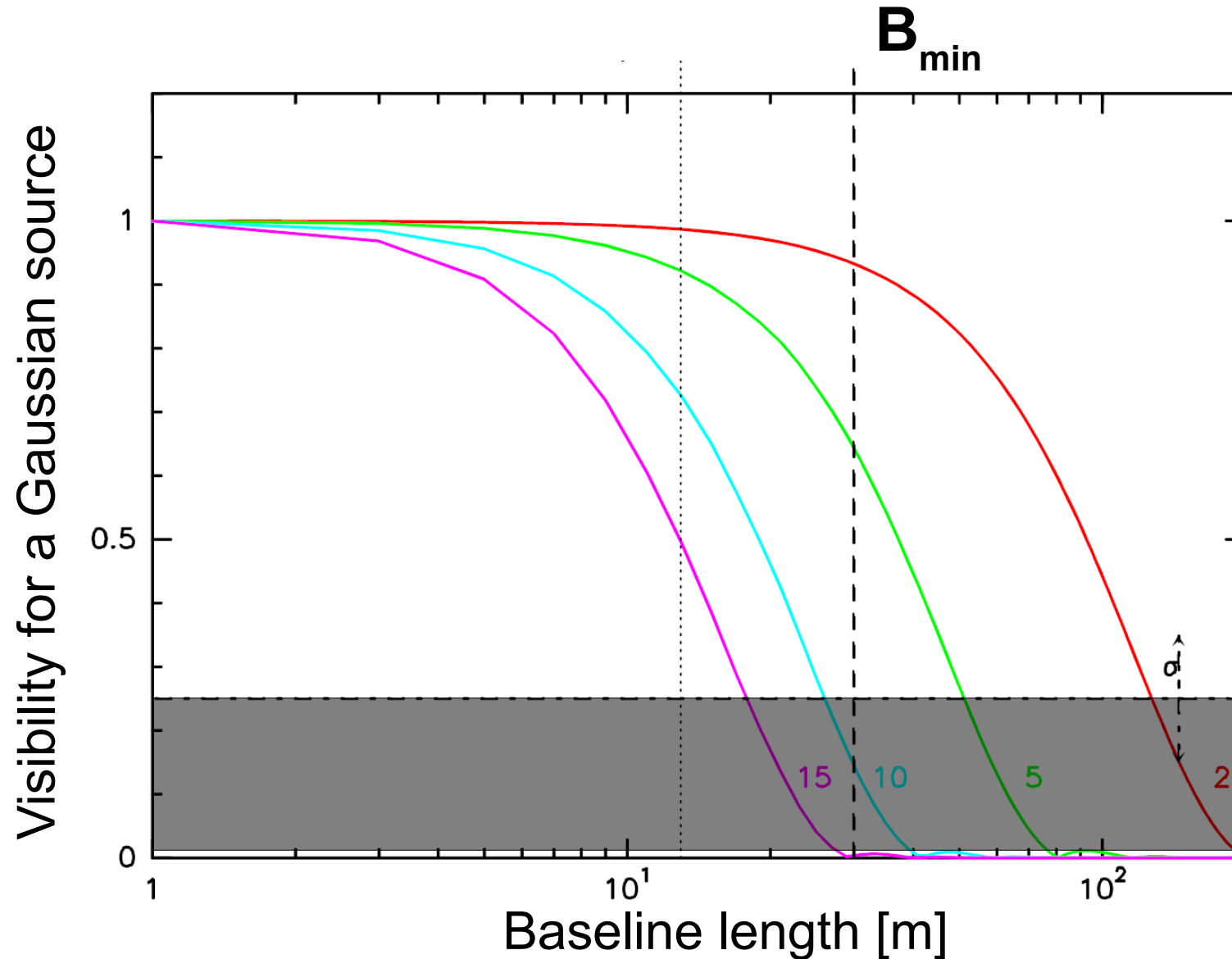
u



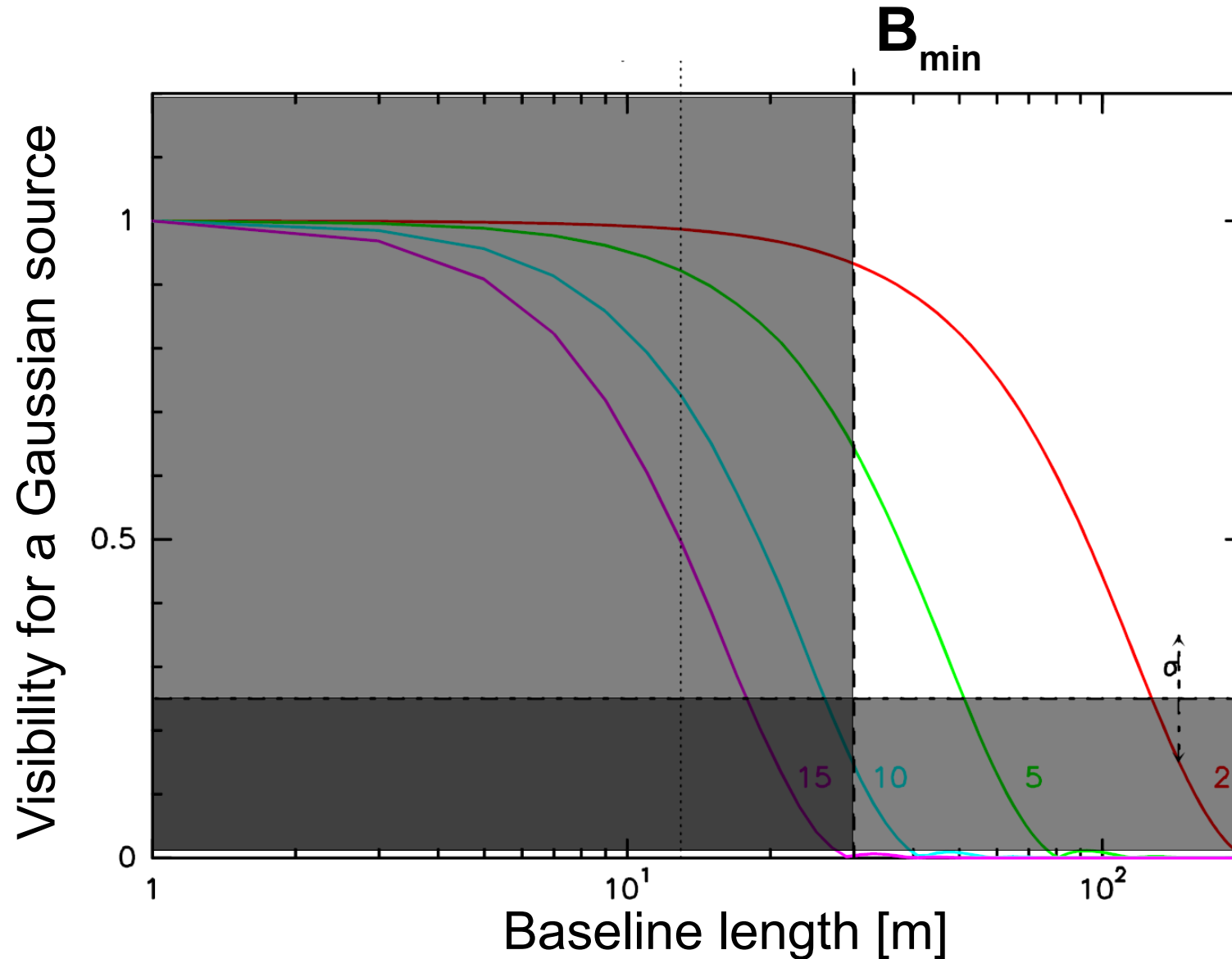
# Maximum Recoverable Scale



# Maximum Recoverable Scale

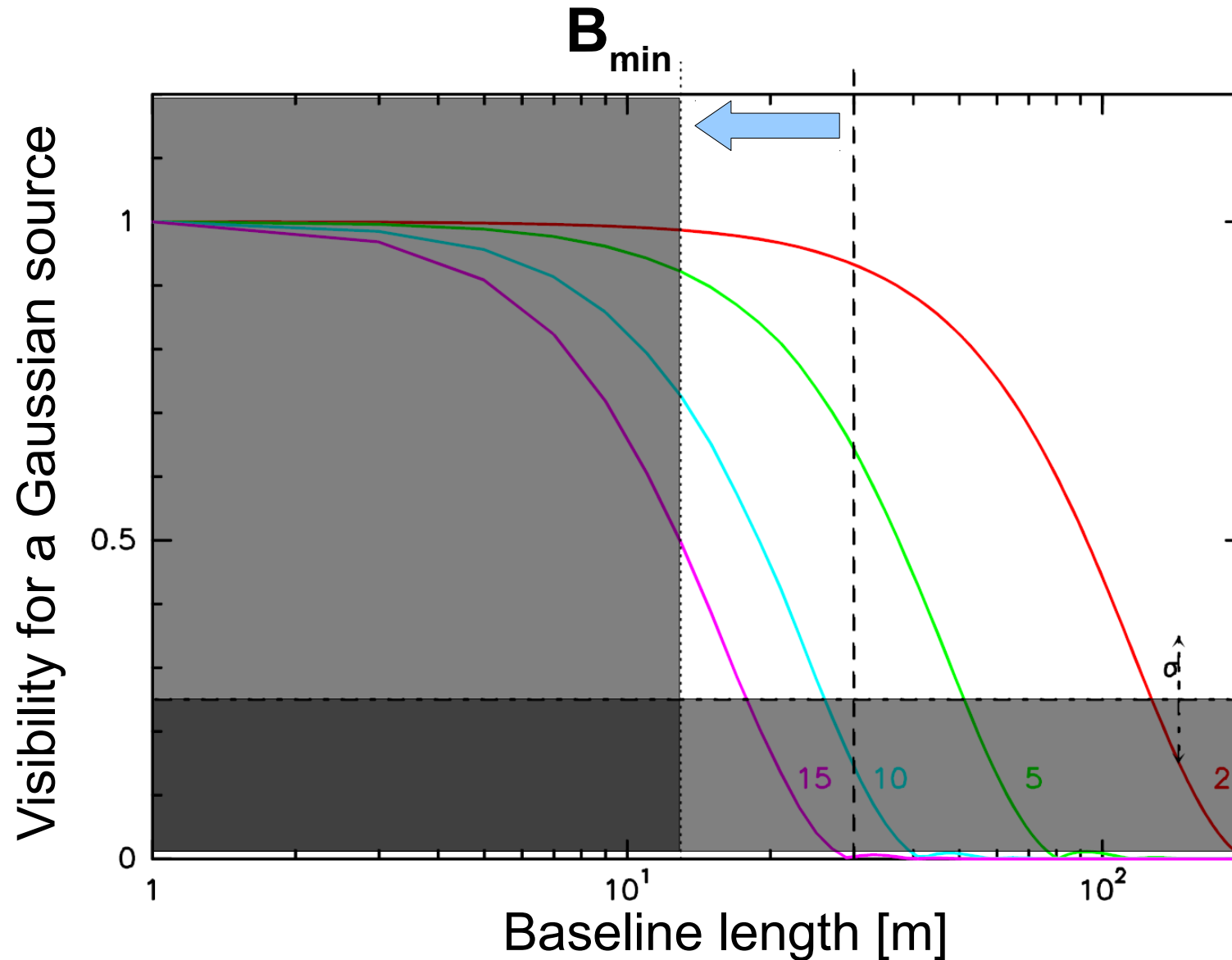


# Maximum Recoverable Scale

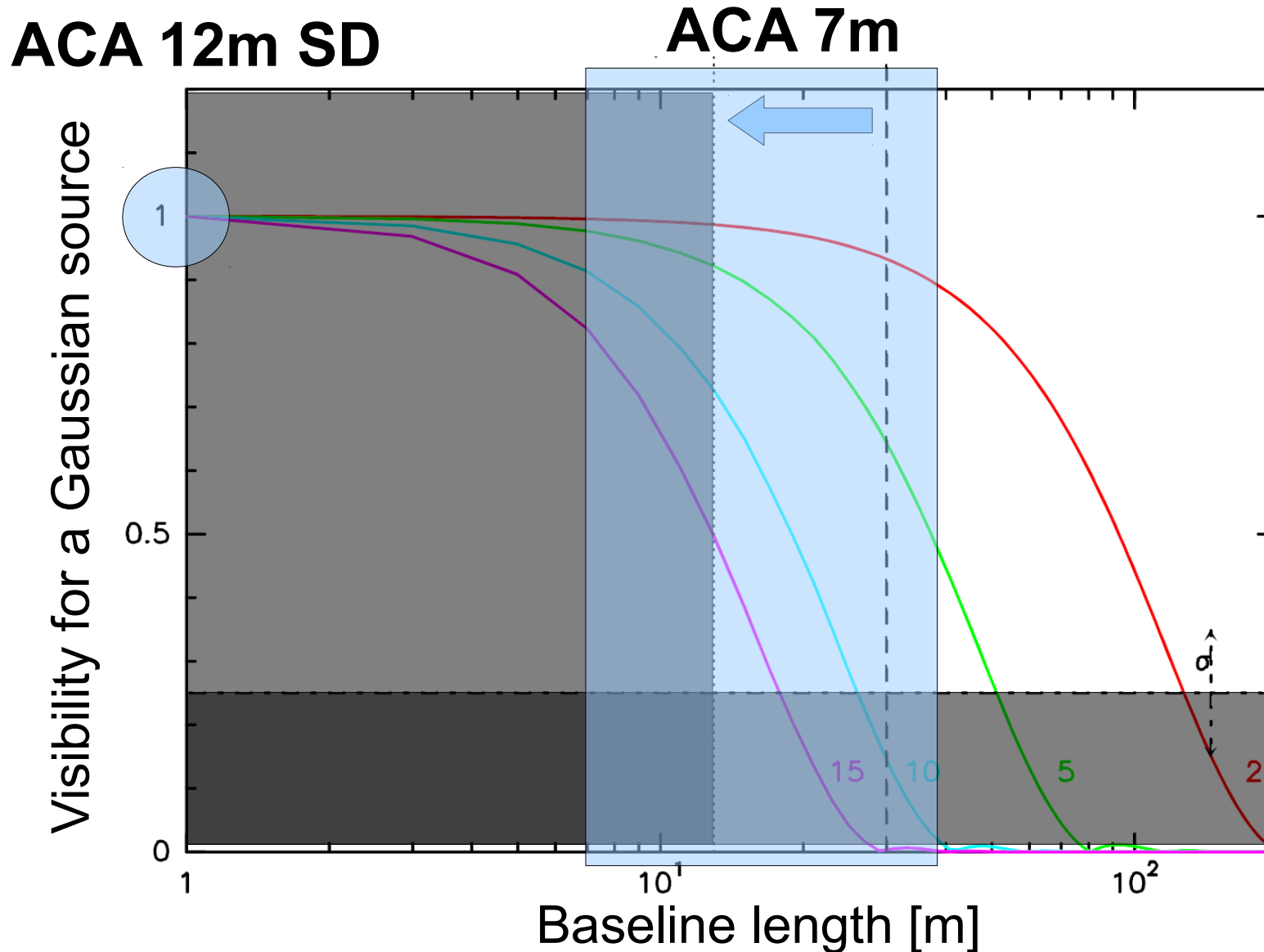




# Maximum Recoverable Scale



# Maximum Recoverable Scale



# Maximum Recoverable Scale

In ALMA Technical Handbook : <https://almascience.nrao.edu/documents-and-tools>

	Band	3	4	6	7	8	9	10
	Frequency (GHz)	100	150	230	345	460	650	870
Configuration								
7-m	$\theta_{res}$ (arcsec)	15.0	10.0	6.5	4.3	3.3	2.3	1.7
	$\theta_{MRS}$ (arcsec)	42.8	28.6	18.6	12.4	9.3	6.6	4.9
C36-1	$\theta_{res}$ (arcsec)	3.4	2.3	1.5	1.0	0.7	0.5	0.4
	$\theta_{MRS}$ (arcsec)	25.3	16.9	11.0	7.3	5.5	3.9	2.9
C36-2	$\theta_{res}$ (arcsec)	1.8	1.2	0.8	0.5	0.4	0.3	0.2
	$\theta_{MRS}$ (arcsec)	25.2	16.8	11.0	7.3	5.5	3.9	2.9
C36-3	$\theta_{res}$ (arcsec)	1.2	0.8	0.5	0.4	0.3	0.2	0.1
	$\theta_{MRS}$ (arcsec)	25.2	16.8	10.9	7.3	5.5	3.9	2.9
C36-4	$\theta_{res}$ (arcsec)	0.7	0.5	0.3	0.2	0.15	0.1	0.08
	$\theta_{MRS}$ (arcsec)	9.6	6.4	4.2	2.8	2.1	1.5	1.1
C36-5	$\theta_{res}$ (arcsec)	0.5	0.3	0.2	0.14	0.1	0.07	0.06
	$\theta_{MRS}$ (arcsec)	7.8	5.2	3.4	2.2	1.7	1.2	0.9
C36-6	$\theta_{res}$ (arcsec)	0.3	0.2	0.1	0.08	0.06	0.04	0.03
	$\theta_{MRS}$ (arcsec)	4.8	3.2	2.1	1.4	1.0	0.7	0.5
C36-7	$\theta_{res}$ (arcsec)	0.1	0.08	0.05	0.034	-	-	-
	$\theta_{MRS}$ (arcsec)	1.5	1.0	0.65	0.43	-	-	-
C36-8	$\theta_{res}$ (arcsec)	0.075	0.05	0.03	-	-	-	-
	$\theta_{MRS}$ (arcsec)	1.1	0.7	0.5	-	-	-	-

$$MRS ["] = 37200 / (B_{min} [m] \nu [GHz])$$

# Maximum recoverable scale

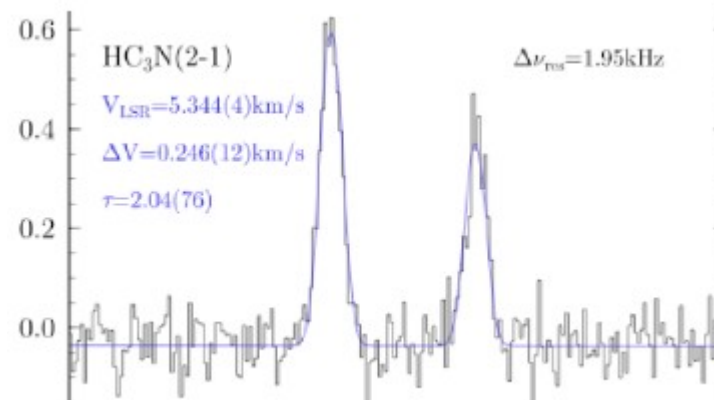
- Spatial filtering due to missing short-spacings of the antennas
- Large scales are filtered out: missing flux!
- $MRS ["] = 37200 / (B_{min}[m] \nu[\text{GHz}])$
- The **ACA** can be used to fill in short spacings  
(The OT automatically warns you if needed)
- Choose your resolution carefully, huge implications for observing time requested!

# Spectral line sensitivity

- Gaussian profile

- SN on the peak

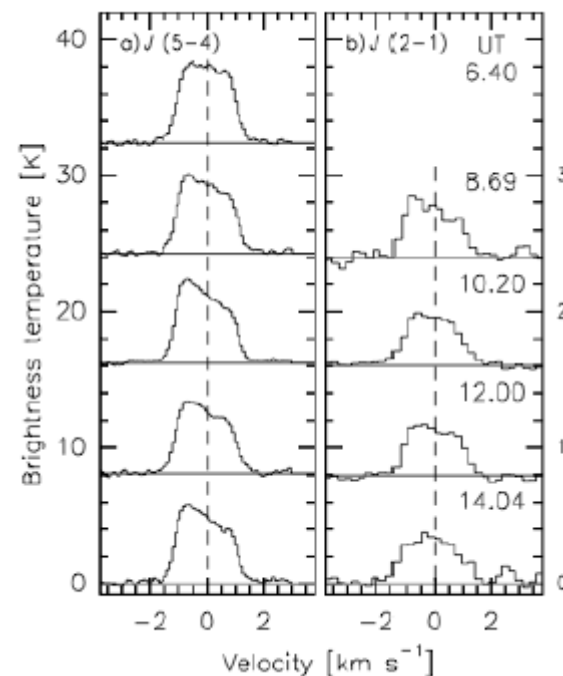
$$rms(Jy) = \frac{Area(Jy \cdot kms^{-1})}{FWHM(kms^{-1}) \cdot SN}$$



- Undefined profile

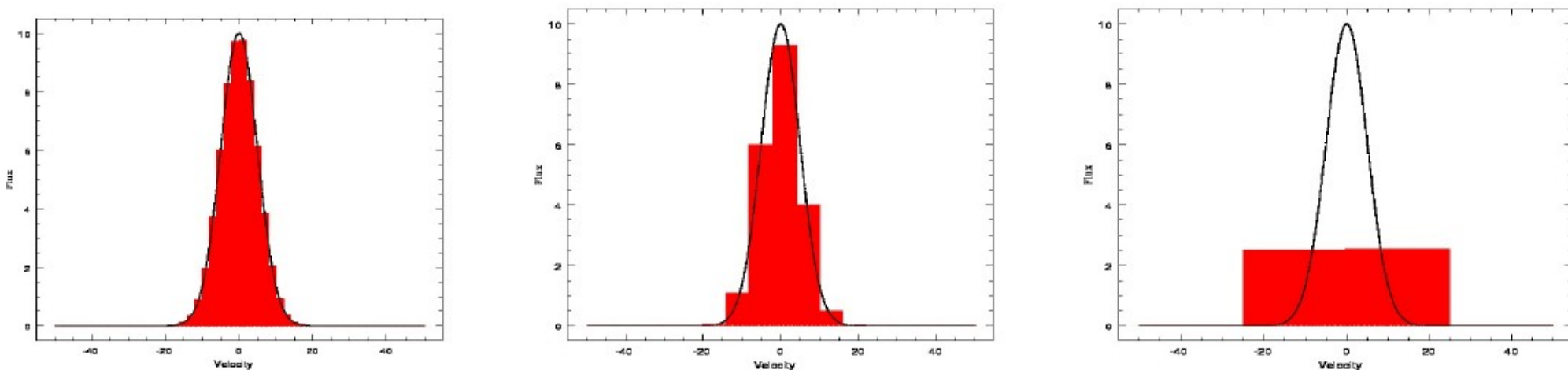
- SN on the area

$$rms(Jy) = \frac{Area(Jy \cdot kms^{-1})}{N_{chan}^{1/2} \cdot \Delta v(kms^{-1}) \cdot SN}$$





# Spectral resolution (line sampling)



- If channel width  $<$  FWHM peak flux independent of channel width
- Choose at least 3 resolution elements per FWHM
- Resolution depends on Science Goal, sensitivity

# Spectral resolution (sensitivity)

- Sensitivity depends on spectral resolution
- In OT spectral resolution > channel spacing !!
- Channel spacing  $\leq 2 \times$  spectral resolution
- $\Delta\nu$  [Hz] =  $v$  [Hz]  $\Delta v$  [m/s] /  $c$  [m/s]

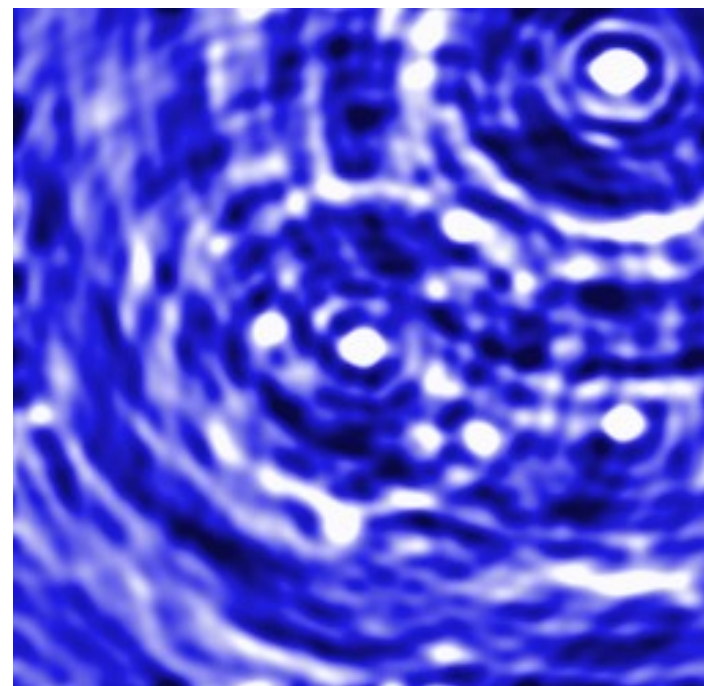
$$\Delta S \propto \frac{T_{sys}}{D^2 [n_p N(N-1) \Delta\nu \Delta t]^{1/2}} \text{ W m}^{-2} \text{ Hz}^{-1}$$

# Spectral resolution

- Sample your line: at least 6 channels / line FWHM
- Sensitivity depends on spectral resolution  
 $\text{rms(Jy)} \propto 1/\Delta\nu^{1/2}$
- Choose the right resolution for your Science Goal!

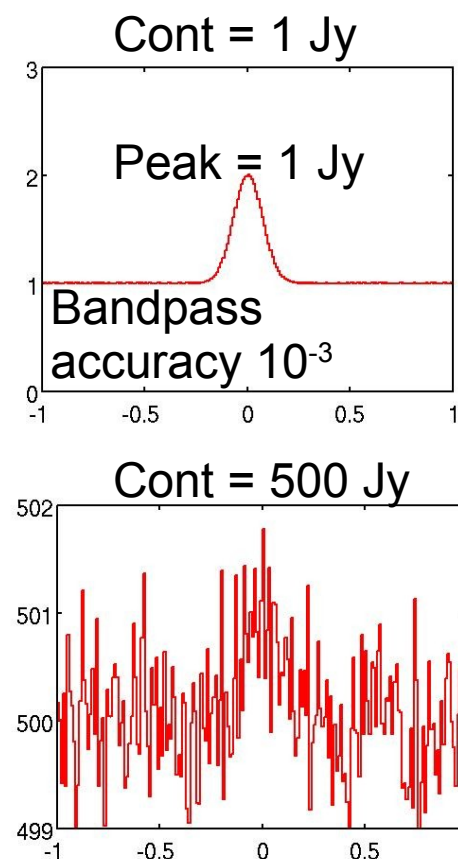
# Imaging dynamic range

- Bright sources in the field of view introduce strong sidelobes which affect the rms in the clean image
- **IDR= Max continuum flux / Continuum RMS**
- ALMA guarantees:
  - IDR  $\leq$  100 for Bands < 9
  - IDR  $\leq$  50 for Bands 9 and 10
- **Higher IDR must be justified!**



# Spectral dynamic range

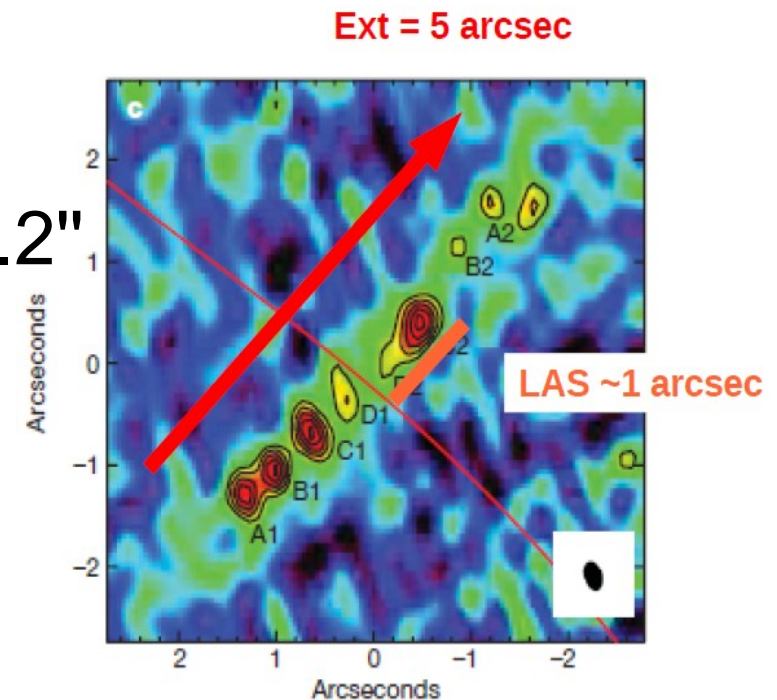
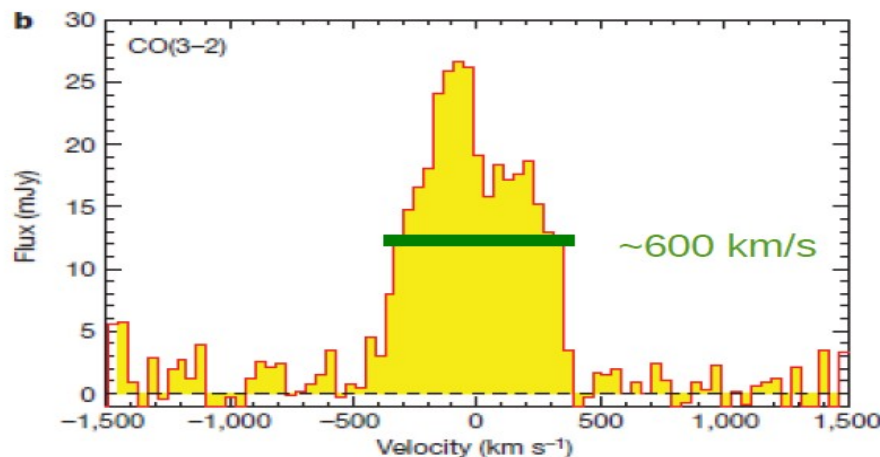
- Uncertainties in bandpass calibration limit the capability of detecting faint spectral features over a strong continuum
- **SDR = Continuum Flux / Line RMS**
- ALMA guarantees:
  - SDR  $\leq$  1000 for Bands < 9
  - SDR  $\leq$  500 for Bands 9 and 10
- **Higher SDR must be justified!**





# An example:

- We want:
  - Continuum and CO 9-8 in the Cosmic Eyelash ( $z=2.3$ ) at  $\theta_{\text{ALMA}} = 0.2''$
- We start from :
  - SMA 850 $\mu\text{m}$  continuum at  $\theta_{\text{SMA}} = 0.2''$
  - PdBI CO (3-2) at  $\theta_{\text{PdBI}} = 1''$



# Look for the line at the right z

<http://www.cv.nrao.edu/php/splat/>

The screenshot shows the 'splatalogue' website interface. At the top, there are three tabs: 'Basic', 'Advanced', and 'Expert'. The main header features the 'splatalogue' logo and the tagline 'database for astronomical spectroscopy'. On the left, there is a 'Quick Picker' section with a list of chemical species and their vibrational states. The 'CO v=0-0' option is highlighted with a red box. In the center, there is a search bar and a dropdown menu for 'Telescope Bands'. The 'ALMA Band 7 (275-373 GHz)' option is highlighted with a red box. To the right of the dropdown, the 'Redshift' field is set to '2.3' and is also highlighted with a red box. Below the search bar, there are fields for 'Energy Range' and 'Frequency Range', and a 'Search' button. On the right side, there is an 'Astronomical Filters' section with a list of filters and a QR code. Below the search interface, there is a table of search results. The table has columns for 'Species', 'Chemical Name', 'Ordered Freq (GHz)', 'Resolved QNs', 'CDMS/JPL Intensity', 'Lova/AST Intensity', 'E<sub>l</sub> (cm<sup>-1</sup>)', and 'LineID'. The first row shows 'CO v=0-0' with a chemical name of 'Carbon Monoxide', an ordered frequency of 345.79695-304.79695 GHz, resolved QNs of 3-2, and other parameters. Below the table, there is an 'Export' section with radio buttons for 'Export current fields', 'Export current fields without Resolved QNs', and 'Export CASA fields'. There are also options for 'Field Separator' (Tab, Colon) and 'Range' (All Records, Current Page).

# Look for the line at the right z

<http://www.cv.nrao.edu/php/splat/>

The screenshot shows the SPLAT database interface. On the left, the 'line Picker' has 'CO v=0' checked. The 'Telescope Band' is set to 'ALMA Band 7 (275-373 GHz)'. The 'Redshift' is set to '2.3'. The search results table is highlighted with a red box and contains the following data:

Species	Chemical Name	Ordered Freq (GHz) (rest frame, redshifted)	Resolved QNs	CDMS/JPL Intensity	Lovas/AST Intensity	EL (cm <sup>-1</sup> )	Linelist
CO v=0	Carbon Monoxide	92.173970, 314.21587	8-7	0.00000		107.64200	SLAIM
CO v=0	Carbon Monoxide	193.61238, 314.21587	9-8	0.00000	17.5	138.39000	SLAIM
CO v=0	Carbon Monoxide	115.108544, 349.08850	10-9	0.00000		172.97800	SLAIM

Below the table, an 'Export' dialog box is open, showing options to export current fields, current fields without resolved QNs, or CASA fields. The 'Field Separator' is set to 'Tab' and 'Range' is set to 'All Records'.

z=2.3  
CO 9-8 in Band 7  
Redshifted frequency: 314.216 GHz

# Spectral setup

In the OT we select one baseband for CO 9-8 and three basebands for continuum

The screenshot displays the 'Spectral Setup' window in the ALMA software. The top section, 'Visualisation', contains explanatory text and a spectral plot. The plot shows 'Observed Frequency' on the top axis (ranging from 990,000 to 1,070,000 MHz) and 'Rest Frequency' on the bottom axis (ranging from 990,000 to 1,060,000 MHz). A blue shaded region represents the observed frequency range, and a yellow shaded region represents the rest frequency range. A vertical line at 313,000 MHz is labeled 'CO J=9-8 continuum'. Below the plot are controls for 'Overlays' (Receiver Bands, Transmission, Overlay Lines, DSB Image), 'Water Vapour Column Density' (Automatic Choice, Manual Choice), and 'Viewport' (Pan to Line, Zoom to Band, Reset).

The 'Spectral Type' section shows 'Spectral Line' selected. The 'Polarization products desired' section shows 'DUAL' selected.

The 'Spectral Setup Errors' section is empty. The 'Spectral Line' section shows a table with one entry for 'Baseband-1'.

Fraction	Center Freq (Rest)	Center Freq (Sky)	Transition	Bandwidth, Resolution (smoothed)	Spec. Avg.	Representative Window
1(Full)	1032.90000 GHz	313.00000 GHz	continuum	2000.000 MHz( 1796 km/s), 31.250 MHz(29.931 km/s)	1	

Buttons at the bottom include 'Select Lines to Observe in Baseband-1...', 'Add', and 'Delete'.

# Spectral setup

Editors

Spectral | Spatial | Spectral Setup

Polarization products desired  XX  DUAL  FULL

**TDM**

Spectral Setup Errors

Spectral Line

Baseband-1

Fraction	Center Freq (Rest)	Center Freq (Sky)	Transition	Bandwidth, Resolution (smoothed)	Spec. Avg.	Representative Window
1(Full)	1032.90000 GHz	313.00000 GHz	continuum	2000.000 MHz( 1796 km/s), 31.250 MHz(29.931 km/s)	1	<input type="radio"/>

Select Lines to Observe in Baseband-1... Add Delete

Baseband-2

1(Full)	1036.91239 GHz	314.21587 GHz	CO v=0 9-8	2000.000 MHz( 1789 km/s), 31.250 MHz(29.816 km/s)	1	<input checked="" type="radio"/>
---------	----------------	---------------	------------	---	---	----------------------------------

Select Lines to Observe in Baseband-2... Add Delete

**CO(9-8)**

Baseband-3

1(Full)	993.30000 GHz	301.00000 GHz	continuum	2000.000 MHz( 1867 km/s), 31.250 MHz(31.125 km/s)	1	<input type="radio"/>
---------	---------------	---------------	-----------	---	---	-----------------------

Select Lines to Observe in Baseband-3... Add Delete

Baseband-4

1(Full)	996.60000 GHz	302.00000 GHz	continuum	2000.000 MHz( 1861 km/s), 31.250 MHz(31.022 km/s)	1	<input type="radio"/>
---------	---------------	---------------	-----------	---	---	-----------------------

Select Lines to Observe in Baseband-4... Add Delete

# Spectral setup

The screenshot shows the 'Spectral Setup' window in the ALMA software. It features a table with four basebands. The second baseband is highlighted with a red box and contains the line 'CO v=0 9-8'. Annotations include blue callouts for 'Line name' and 'Channel width 30 km/s' pointing to the line name and bandwidth columns, and another blue callout for 'Line redshifted frequency' pointing to the center frequency column. Red text labels 'TDM' and 'CO(9-8)' are also present.

Polarization products desired  XX  DUAL  FULL

Spectral Setup Errors

Spectral Line

Baseband-1	Fraction	Center Freq (Rest)	Center Freq (Sky)	Bandwidth, Res	Representative Window
1(Full)	1032.90000 GHz	313.00000 GHz	continuum	2000.000 MHz( 1796 km/s), 31.250 MHz(29.816 km/s)	

Select Lines to Observe in Baseband-1... Add Delete

Baseband-2	Fraction	Center Freq (Rest)	Center Freq (Sky)	Bandwidth, Res	Representative Window
1(Full)	1036.91239 GHz	314.21587 GHz	CO v=0 9-8	2000.000 MHz( 1789 km/s), 31.250 MHz(29.816 km/s)	1

Select Lines to Observe in Baseband-2... Add Delete

Baseband-3	Fraction	Center Freq (Rest)	Center Freq (Sky)	Bandwidth, Res	Representative Window
1(Full)	993.30000 GHz	314.21587 GHz	continuum	2000.000 MHz( 1867 km/s), 31.250 MHz(31.125 km/s)	1

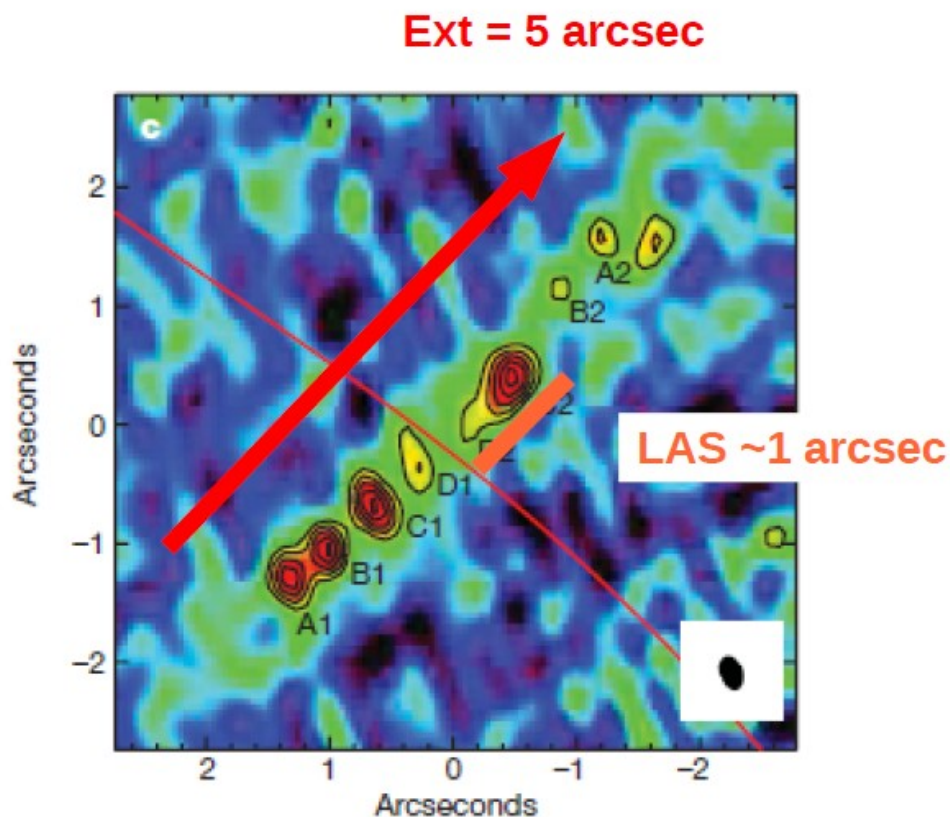
Select Lines to Observe in Baseband-3... Add Delete

Baseband-4	Fraction	Center Freq (Rest)	Center Freq (Sky)	Bandwidth, Res	Representative Window
1(Full)	996.60000 GHz	302.00000 GHz	continuum	2000.000 MHz( 1861 km/s), 31.250 MHz(31.022 km/s)	1

Select Lines to Observe in Baseband-4... Add Delete



# Morphology



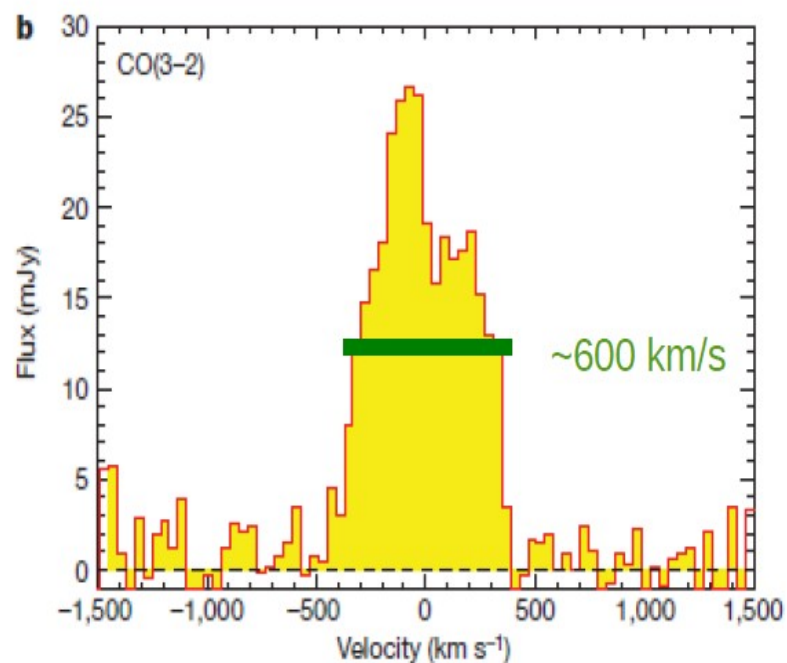
- From SMA continuum:
  - 5 components
  - Total extent 5"
    - FOV = 18" **no mosaic**  
**you can see it in the OT**
  - Maximum angular scale 1"
    - MRS = 2.8" **no ACA**



	Band	3	4	6	7	8	9	10
	Frequency (GHz)	100	150	230	345	460	650	870
Configuration								
7-m	$\theta_{res}$ (arcsec)	15.0	10.0	6.5	4.3	3.3	2.3	1.7
	$\theta_{MRS}$ (arcsec)	42.8	28.6	18.6	12.4	9.3	6.6	4.9
C36-1	$\theta_{res}$ (arcsec)	3.4	2.3	1.5	1.0	0.7	0.5	0.4
	$\theta_{MRS}$ (arcsec)	25.3	16.9	11.0	7.3	5.5	3.9	2.9
C36-2	$\theta_{res}$ (arcsec)	1.8	1.2	0.8	0.5	0.4	0.3	0.2
	$\theta_{MRS}$ (arcsec)	25.2	16.8	11.0	7.3	5.5	3.9	2.9
C36-3	$\theta_{res}$ (arcsec)	1.2	0.8	0.5	0.4	0.3	0.2	0.1
	$\theta_{MRS}$ (arcsec)	25.2	16.8	10.9	7.3	5.5	3.9	2.9
C36-4	$\theta_{res}$ (arcsec)	0.7	0.5	0.3	0.2	0.15	0.1	0.08
	$\theta_{MRS}$ (arcsec)	9.6	6.4	4.2	2.8	2.1	1.5	1.1
C36-5	$\theta_{res}$ (arcsec)	0.5	0.3	0.2	0.14	0.1	0.07	0.06
	$\theta_{MRS}$ (arcsec)	7.8	5.2	3.4	2.2	1.7	1.2	0.9
C36-6	$\theta_{res}$ (arcsec)	0.3	0.2	0.1	0.08	0.06	0.04	0.03
	$\theta_{MRS}$ (arcsec)	4.8	3.2	2.1	1.4	1.0	0.7	0.5
C36-7	$\theta_{res}$ (arcsec)	0.1	0.08	0.05	0.034	-	-	-
	$\theta_{MRS}$ (arcsec)	1.5	1.0	0.65	0.43	-	-	-
C36-8	$\theta_{res}$ (arcsec)	0.075	0.05	0.03	-	-	-	-
	$\theta_{MRS}$ (arcsec)	1.1	0.7	0.5	-	-	-	-

In ALMA Technical Handbook : <https://almascience.nrao.edu/documents-and-tools>

# Spectral information



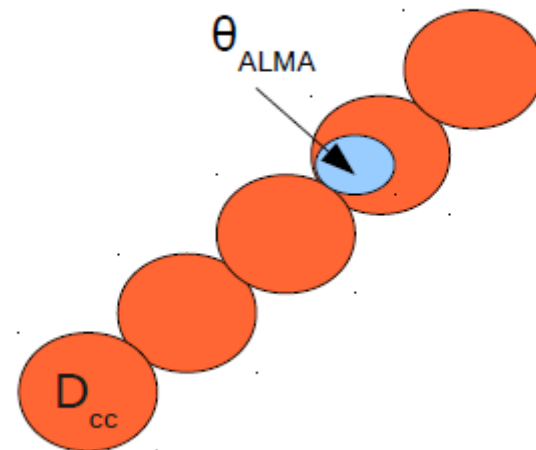
- FWHM = 600 km/s
    - We need  $\Delta v \leq 100$  km/s
    - Channel spacing 30 km/s **OK!**
  - $F_{[\text{CO}(3-2)]} = 13.8$  Jy km/s
  - $F_{\text{peak}}[\text{CO}(3-2)] = F_{[\text{CO}(3-2)]} / \text{FWHM} = 23$  mJy
- in one beam of 1"

# Sensitivity calculation (CO, Case 1)

- For CO 9-8 we assume:
  - Distributed in  $N=5$  components of  $D_{cc}=0.8'' < \theta_{ALMA}=0.2''$
  - $F_{[CO(9-8)]}=F_{[CO(3-2)]}/2.5$
  - $FWHM_{[CO(9-8)]}=FWHM_{[CO(3-2)]}$
  - $F_{peak}[CO(9-8)]=F_{peak}[CO(3-2)]/2.5=9.2 \text{ mJy}$
  - We want a  $SN=20$

$$rms=(F_{peak}[CO(9-8)]/N) \times R_N / SN = 0.006 \text{ mJy}$$

$$\text{where } R_N=(\theta_{ALMA}/D_{cc})^2$$

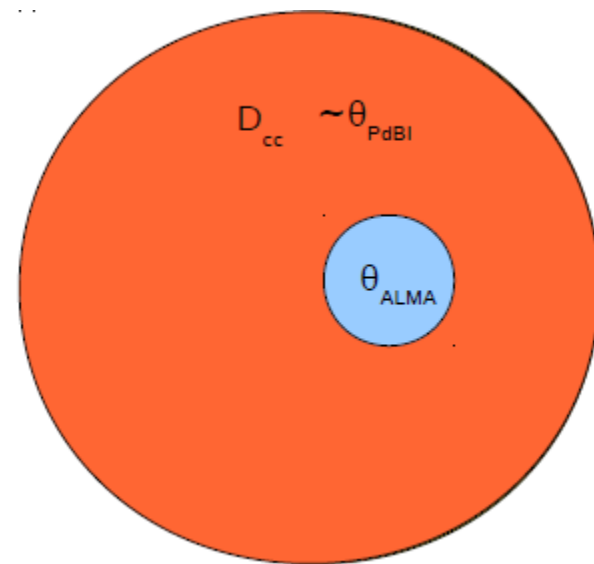


# Sensitivity calculation (CO, Case 2)

- For CO 9-8 we assume:
  - The source is unresolved for PdBI but resolved by ALMA with size  $D_{cc} = \theta_{PdBI}$
  - $F_{peak}[CO(9-8)] = 9.2 \text{ mJy}$
  - We want a SN=20

$$\text{rms} = F_{peak}[CO(9-8)] \times R_1 / \text{SN} = 0.02 \text{ mJy}$$

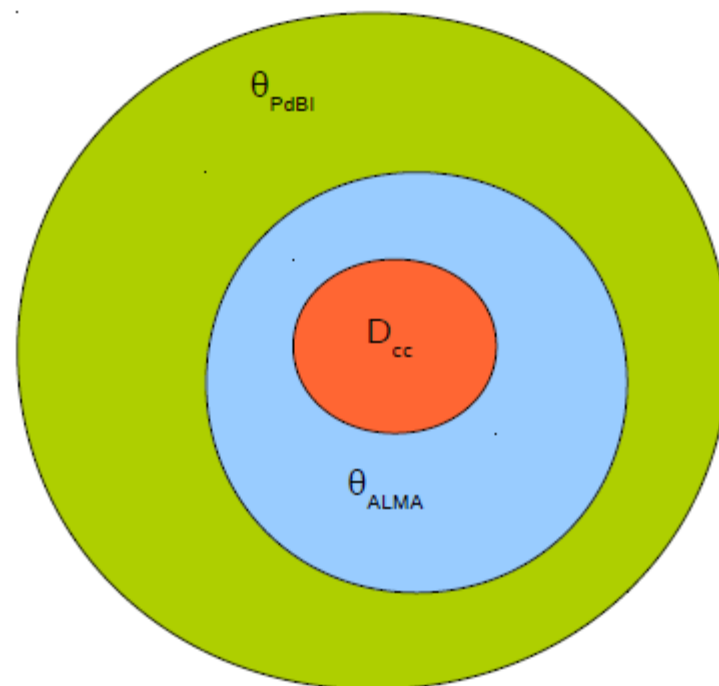
$$\text{where } R_1 = (\theta_{ALMA} / D_{PdBI})^2$$



# Sensitivity calculation (CO, Case 3)

- For CO 9-8 we assume:
  - The source will be unresolved in the ALMA beam
  - $F_{\text{peak}}[\text{CO}(9-8)] = 9.2 \text{ mJy}$
  - We want a SN=20

$$\text{rms} = F_{\text{peak}}[\text{CO}(9-8)] / \text{SN} = 0.46 \text{ mJy}$$



# What does the time estimator say?

Common Parameters

Dec: -01:00:00.000

Polarization: Dual

Observing Frequency: 315.0 GHz

Bandwidth per Polarization: 100.0 km/s

Water Vapour Column Density: 0.913mm (3rd Octile)

tau/Tsky: tau0=0.139, Tsky=34.977

Tsys: 148.413 K

Individual Parameters

	12m Array	7m Array	Total Power Array
Number of Antennas	36	10	2
Resolution	0.2 arcsec	6.543559075524949	19.63067722657485
Sensitivity (rms)	6.0 uJy	0.00000 uJy	0.00000 uJy
(equivalent to)	0.00185 K	0.00000 K	0.00000 K
Integration Time	53.53292 d	Infinity d	Infinity d

Case 1 , 53 Days !

12m Array

Number of Antennas: 36

Resolution: 0.2 arcsec

Sensitivity (rms): 20.0 uJy

(equivalent to): 0.00616 K

Integration Time: 4.81796 d

Case 2 , 4 Days !

12m Array

Number of Antennas: 36

Resolution: 0.2 arcsec

Sensitivity (rms): 500.0 uJy

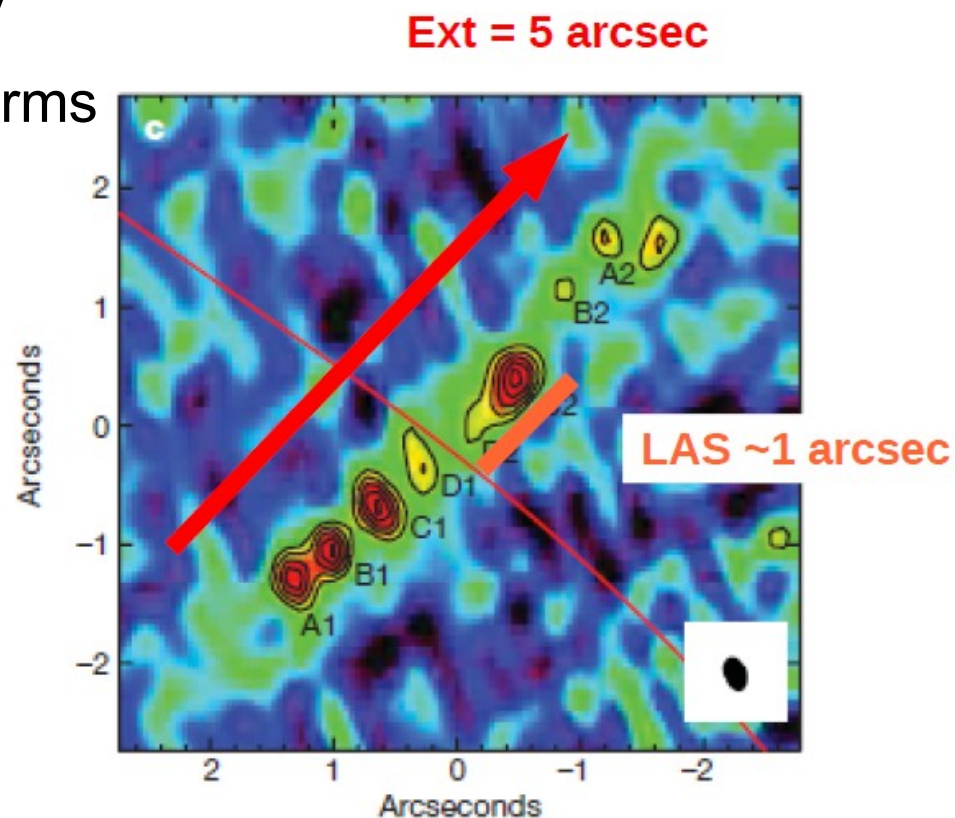
(equivalent to): 0.15403 K

Integration Time: 11.10059 min

Case 3 , 11 minutes

# Sensitivity calculation (Continuum)

- For the continuum
  - The faintest source has  $F_c = 1$  mJy
  - For a SN of 6 we need 0.17 mJy rms
  - For Case 3 we have 11 minutes on source
  - The bandwidth to calculate the SN is the aggregated bandwidth of the 3 continuum subbands  
 $BW = 3 \times 2 \text{ GHz} = 6 \text{ GHz}$





# What does the time estimator say?

**Common Parameters**

Dec	-01:00:00.000		
Polarization	Dual		
Observing Frequency	315.0	GHz	
Bandwidth per Polarization	6.0	GHz	
Water Vapour Column Density	<input checked="" type="radio"/> Automatic Choice <input type="radio"/> Manual Choice		
tau/Tsky	tau0=0.139, Tsky=34.977		
Tsys	148.413 K		

**Individual Parameters**

	12m Array		7m Array		Total Power Array
Number of Antennas	36		10		2
Resolution	0.2	arcsec	6.543559075524949		19.63067722657485
Sensitivity (rms)	66.16666	uJy	0.00000	uJy	0.00000
(equivalent to)	0.02038	K	0.00000	K	0.00000
Integration Time	11.0	min	Infinity	d	Infinity

Integration Time Unit Option: Automatic

Sensitivity Unit Option: Automatic

Calculate Integration Time      Calculate Sensitivity

After 11 minutes on source we get an rms of 0.07 mJy = SNR of 14 !

# Dynamic range

- Imaging

IDR=Max continuum / Continuum rms

$$= 6 \text{ mJy} / 0.07 \text{ mJy} = 85 < 100 \text{ OK}$$

- Spectral

SDR= Max continuum / line RMS

$$= 6 \text{ mJy} / 0.5 \text{ mJy} = 12 < 1000 \text{ OK}$$

# Good luck !

