Frequently Asked Questions

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

Frequently Asked Questions

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

Goals:

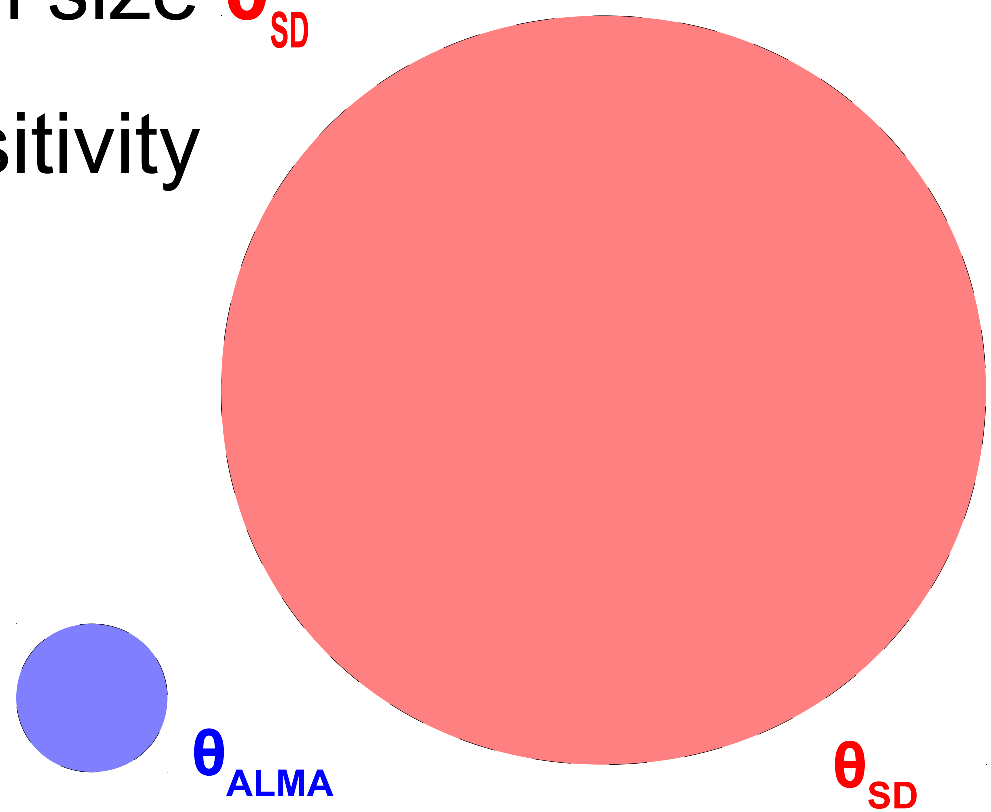
- Derive observation parameters from previous observations or theoretical estimates
- Choose the right setup for your science goal

Topics:

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

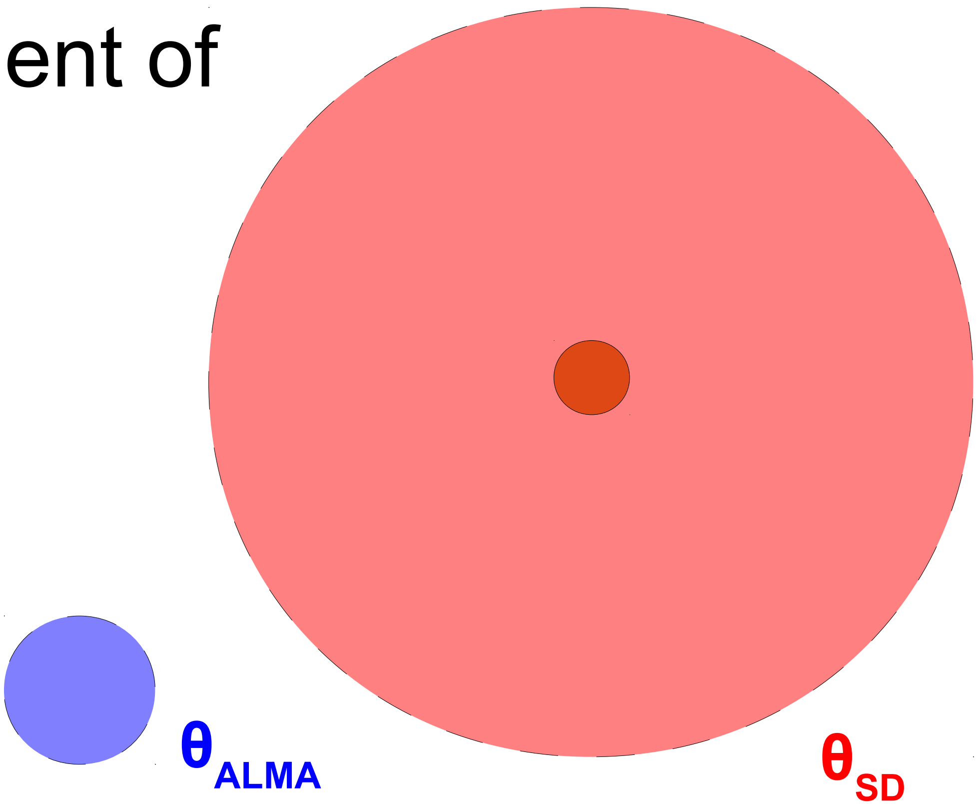
Peak flux estimation

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



Peak flux estimation

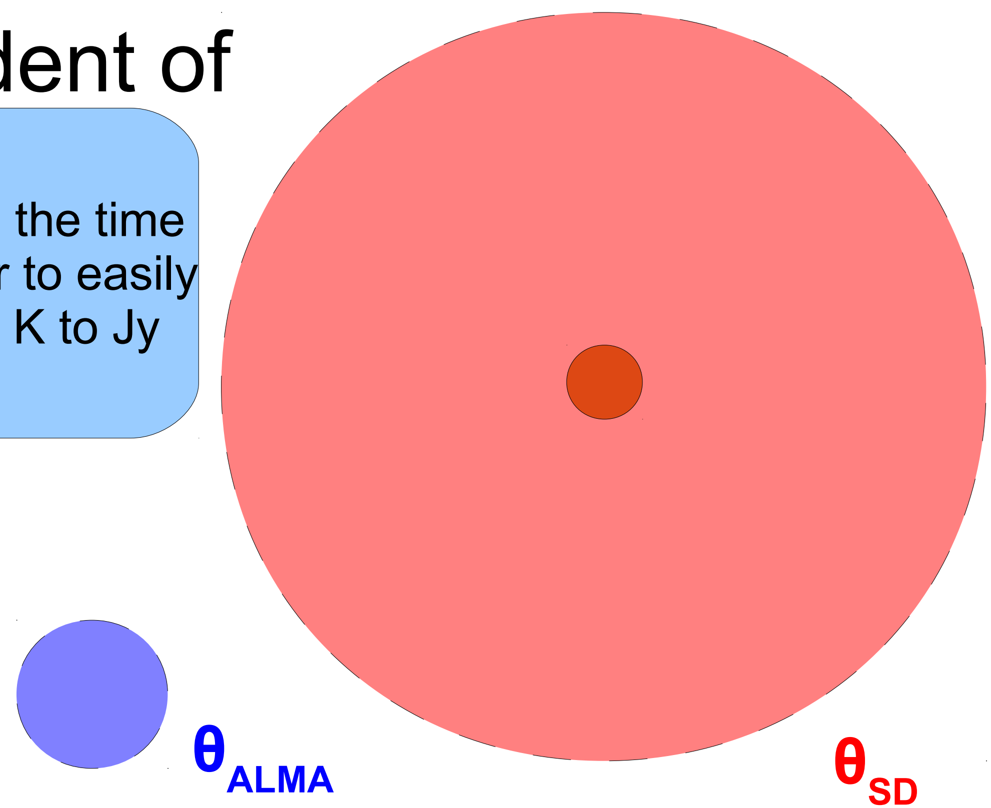
- The source is smaller than the ALMA beam (point source)
- Flux in Jy/beam independent of the beam
- $F_{SD} = 2\,k\,T_{SD}\,\Omega_{SD} / \lambda^2$
- $F_{ALMA} = F_{SD}$



Peak flux estimation

- The source is smaller than the ALMA beam (point source)
- Flux in Jy/beam independent of the beam
- $F_{SD} = 2\,k\,T_{SD}\,\Omega_{SD} / \lambda^2$
- $F_{ALMA} = F_{SD}$

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

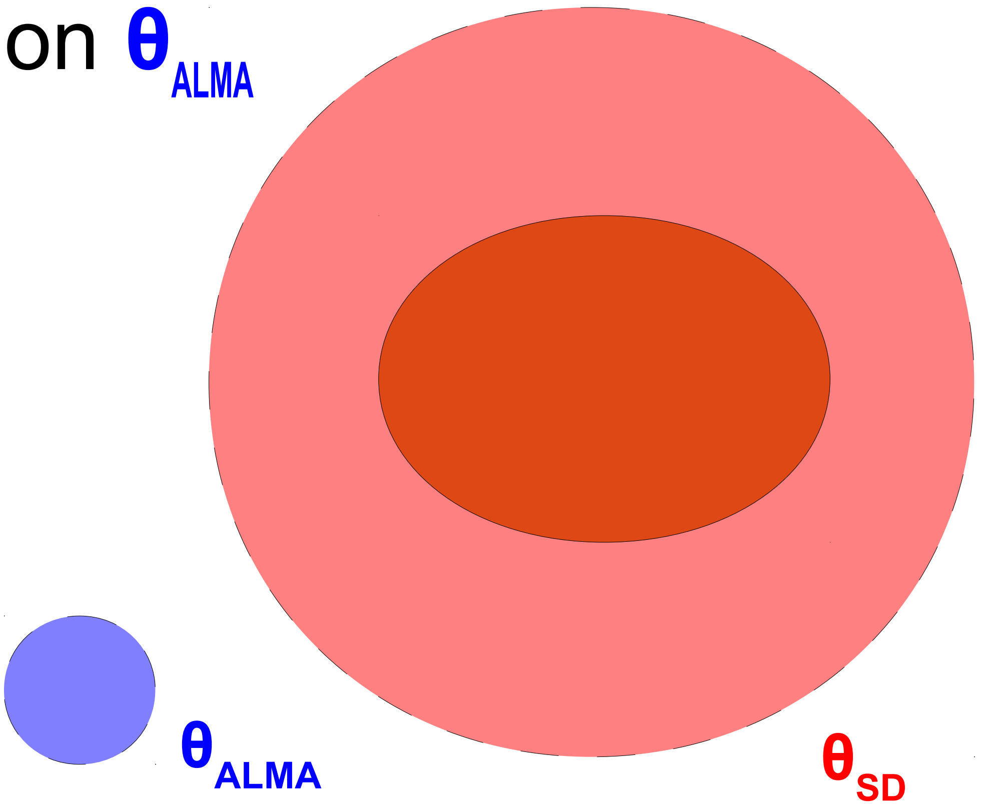


Peak flux estimation

- The source is larger than the ALMA beam, with size θ_s and a uniform brightness temperature T_s
- Flux in Jy/beam depends on θ_{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 θ_{SD}=10” and has T_{SD}= 1 K at 300 GHz
- Which is the sensitivity required for ALMA observations at θ_{ALMA}=1” resolution ?

Point source:

- $F_{ALMA} = F_{SD} = 2\,k\,T_{SD}\,\Omega_{SD} / \lambda^2$
  = 7.36 Jy/beam

Extended uniform source

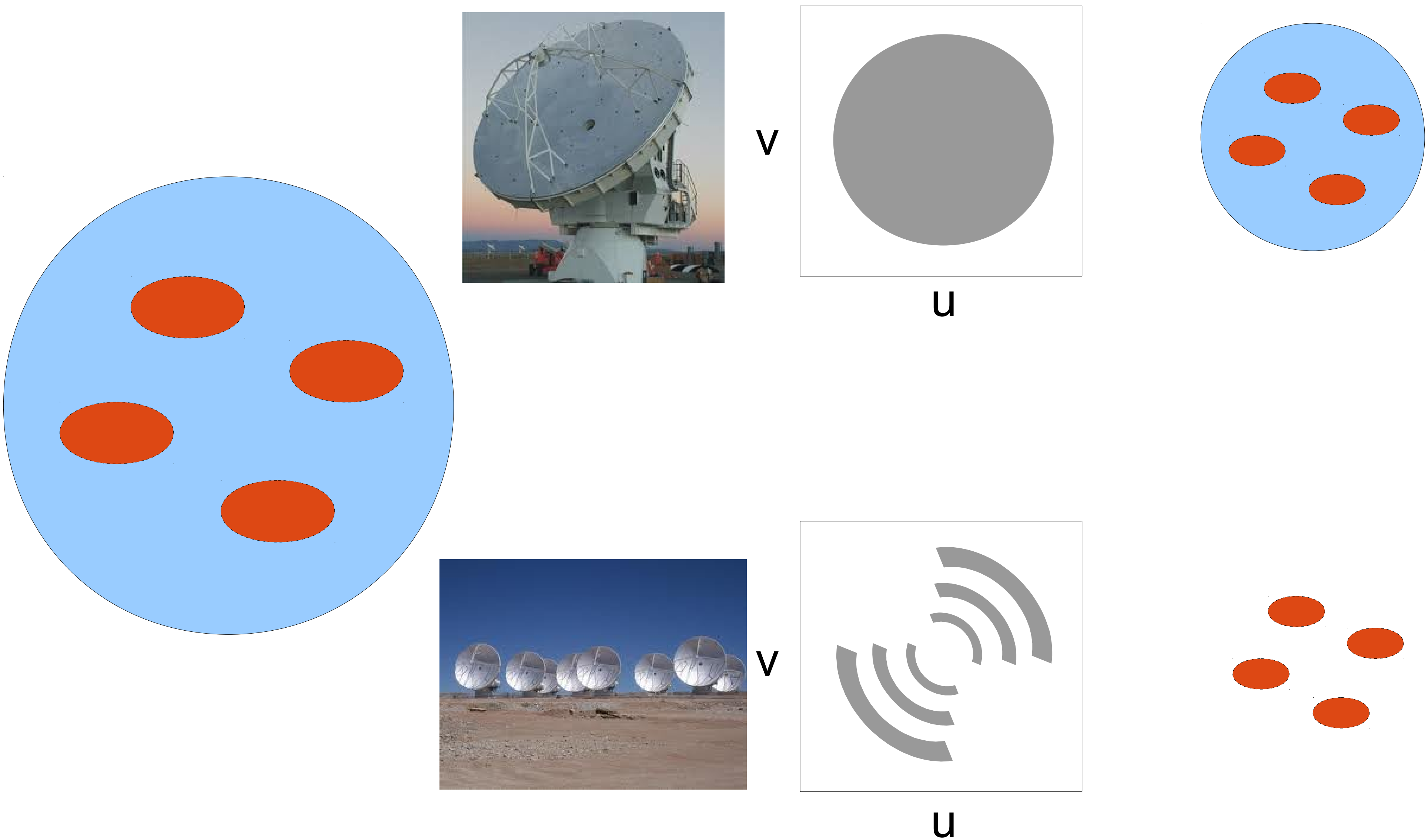
- $F_{ALMA} = F_{SD}\,(\theta_{ALMA}/\theta_S)^2$
  = 0.0736 Jy/beam

A factor 10,000 in exposure time !!

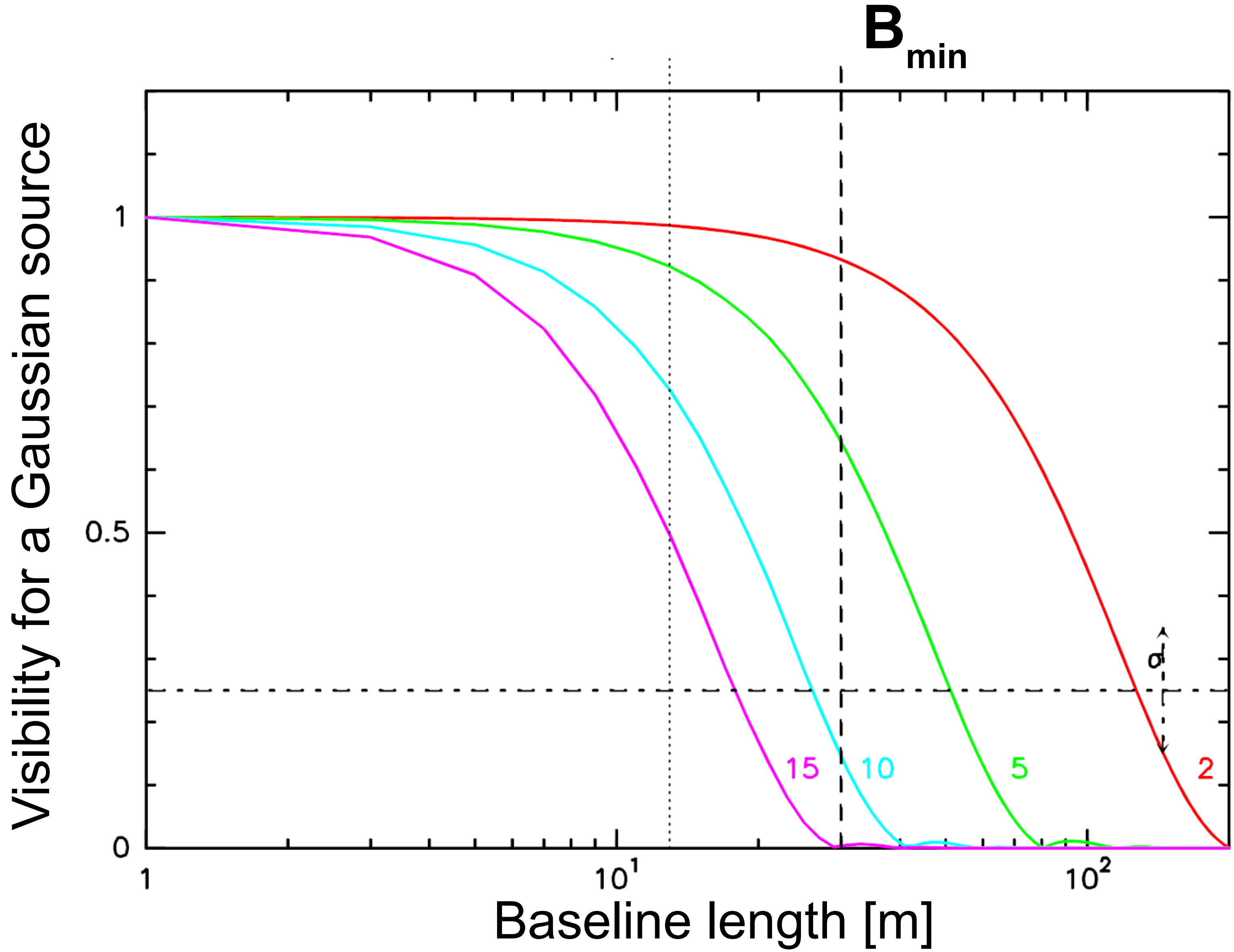
Peak flux estimation

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

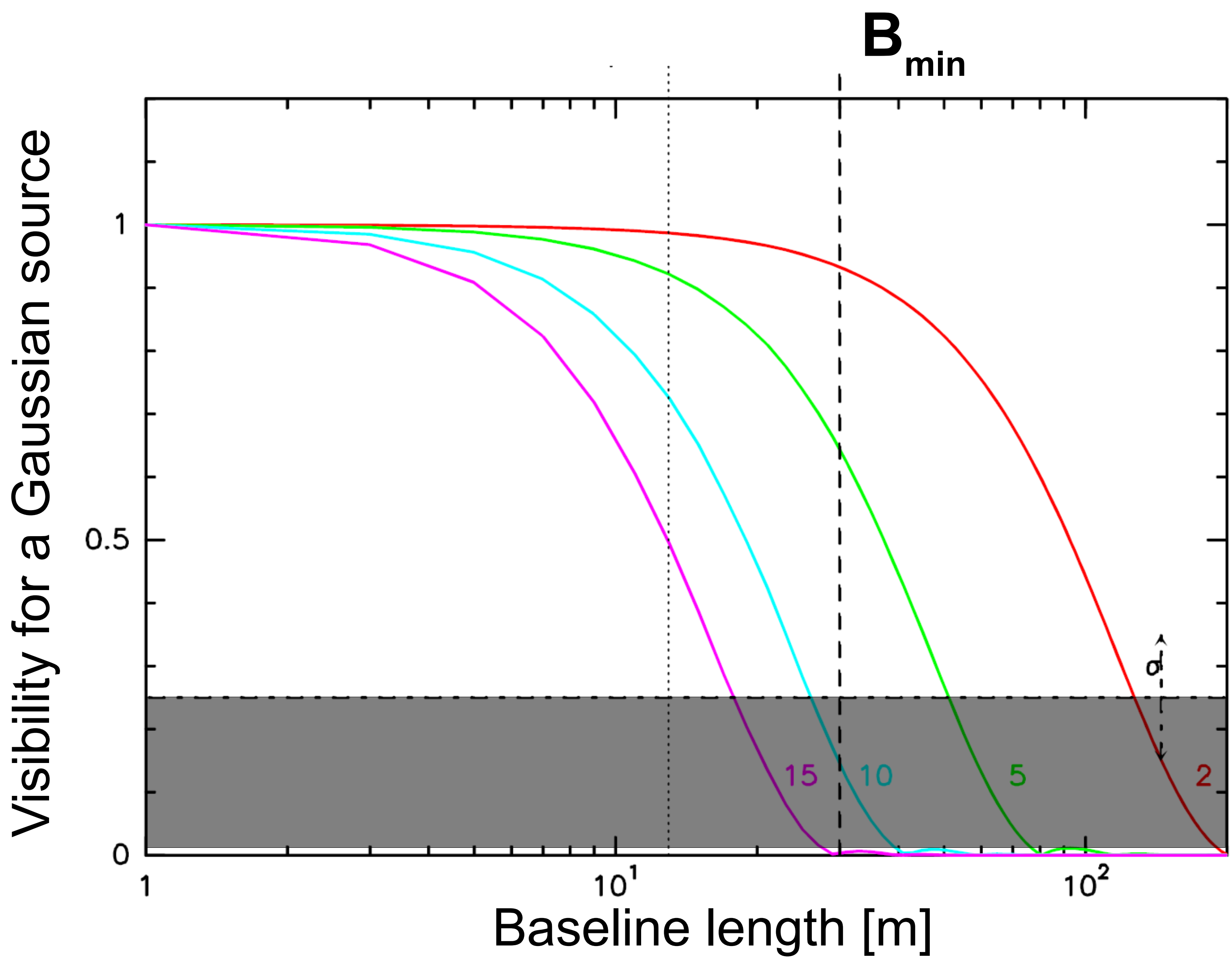
Spatial filtering of large scales



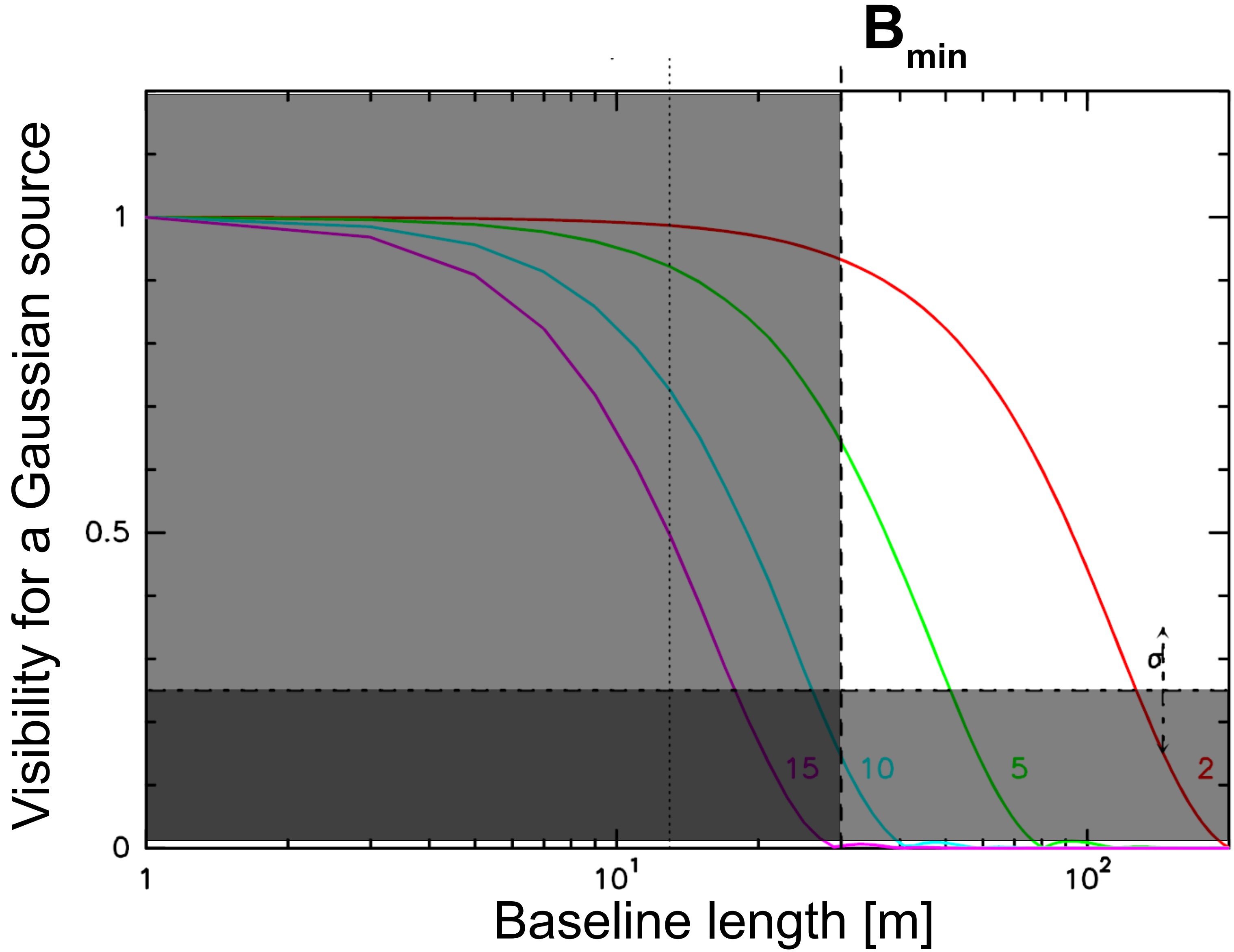
Maximum Recoverable Scale



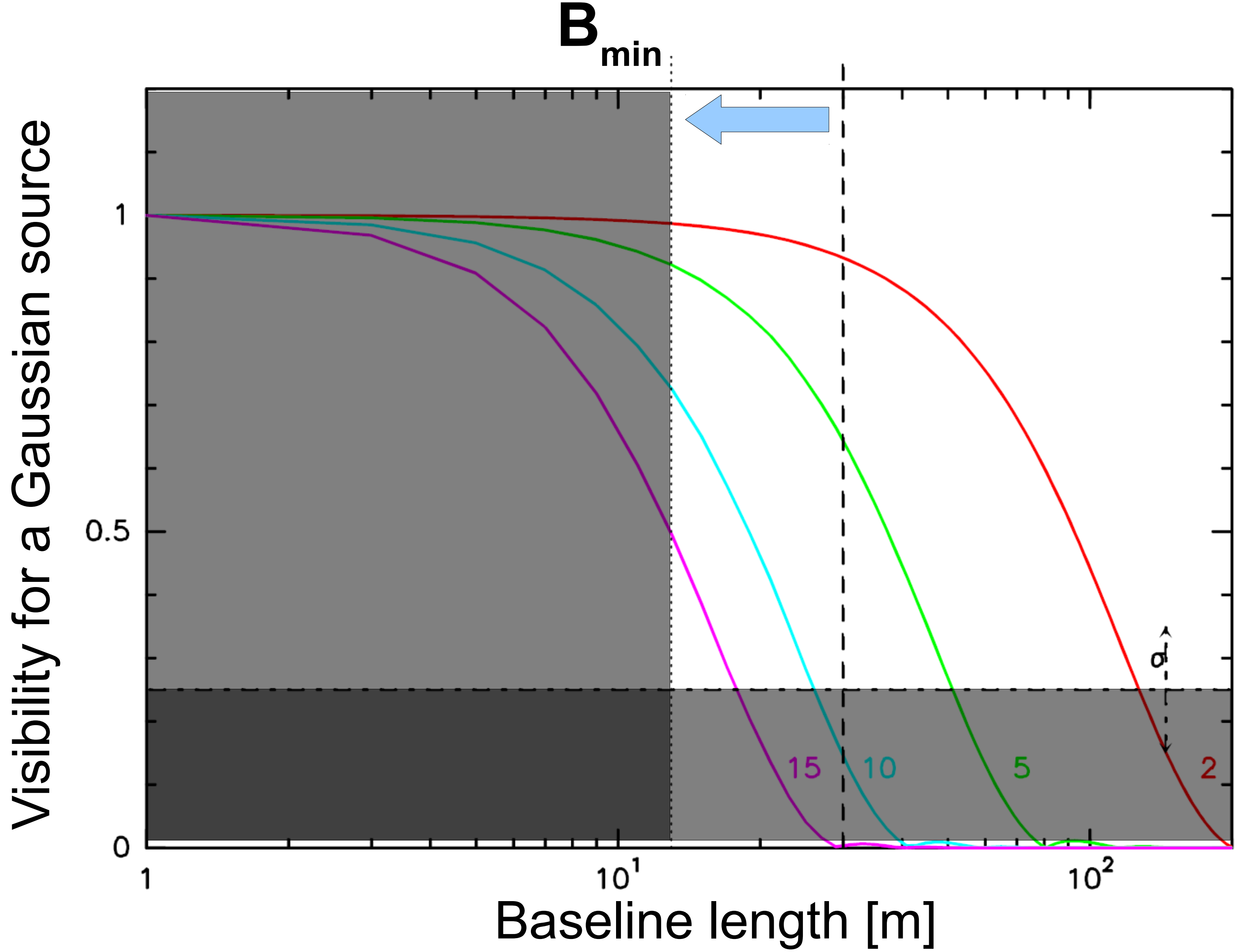
Maximum Recoverable Scale



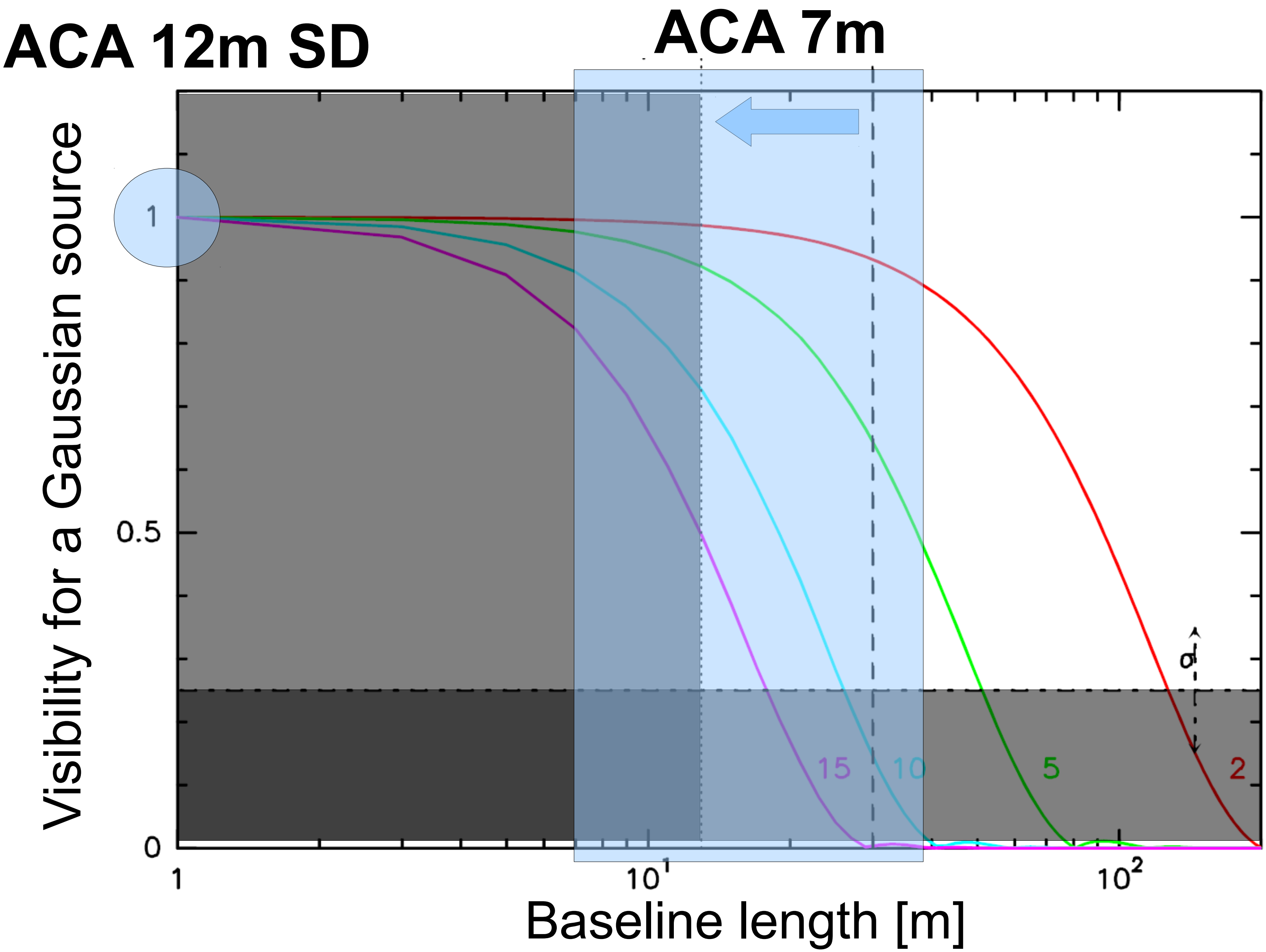
Maximum Recoverable Scale



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

$$\text{MRS} [''] = 37200/(B_{min}[m]\ \upsilon[GHz])$$

Maximum recoverable scale

- Spatial filtering due to missing short-spacings of the antennas
- Large scales are filtered out: missing flux!
- MRS [''] = 37200/(Bmin[m] υ[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!

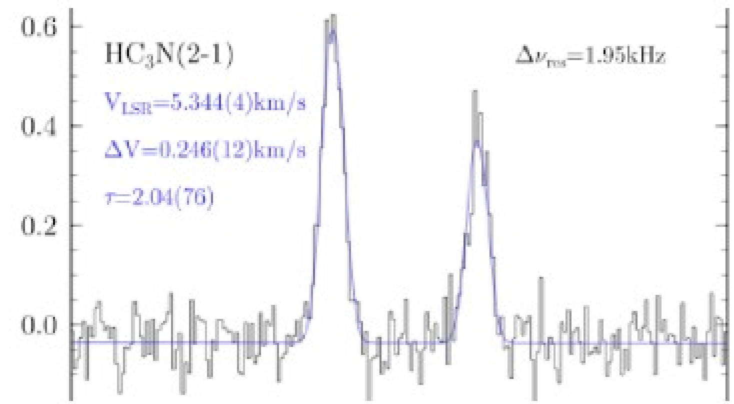
Spectral line sensitivity

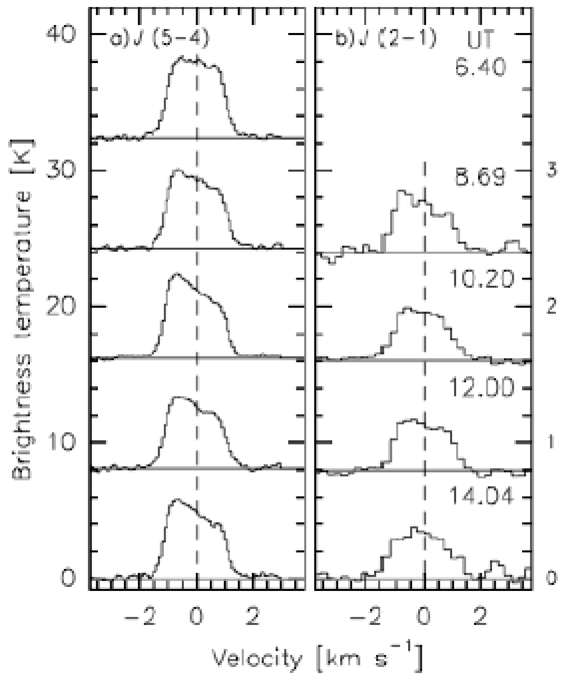
- Gaussian profile
  - SN on the peak

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

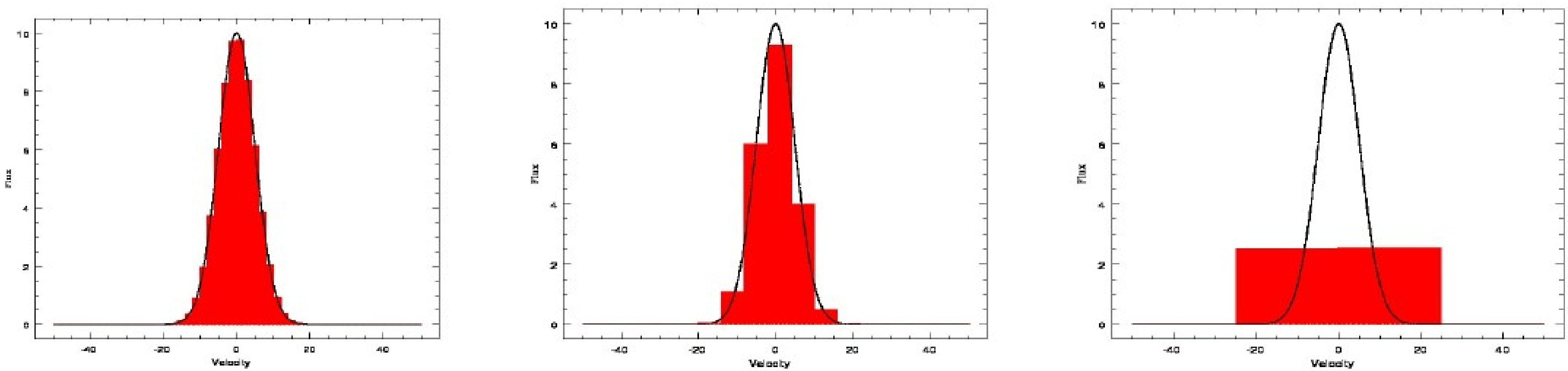
- Undefined profile
  - SN on the area

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





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 x spectral resolution

- $\Delta\upsilon$ [Hz] =υ [Hz] Δv [m/s] / c [m/s]

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

Spectral resolution

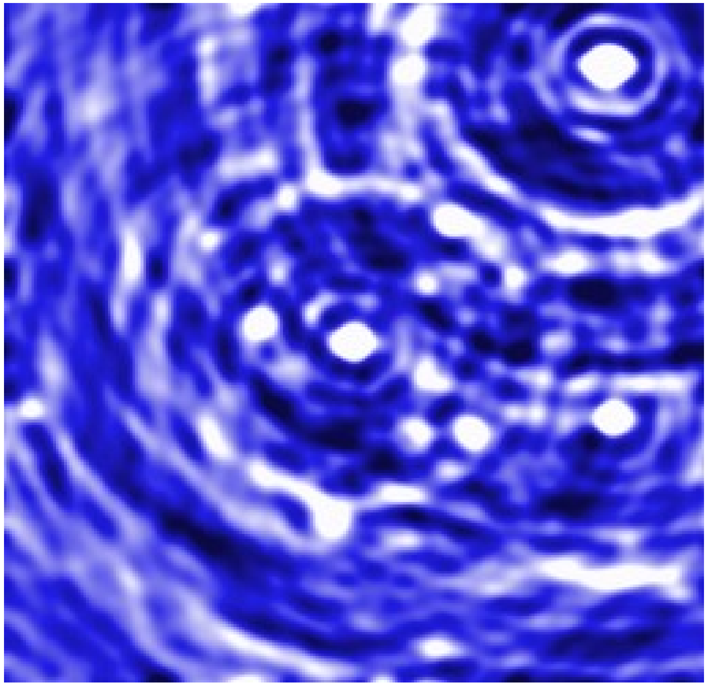
- Sample your line: at least 6 channels / line FWHM
- Sensitivity depends on spectral resolution

  rms(Jy) $\propto$ $1/\Delta v^{1/2}$

- Choose the right resolution for your Science Goal!

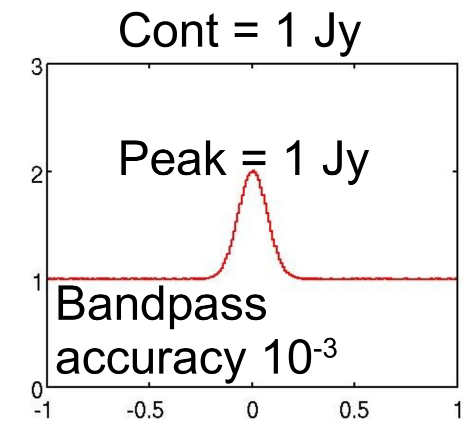
Imaging dynamic range

- 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!

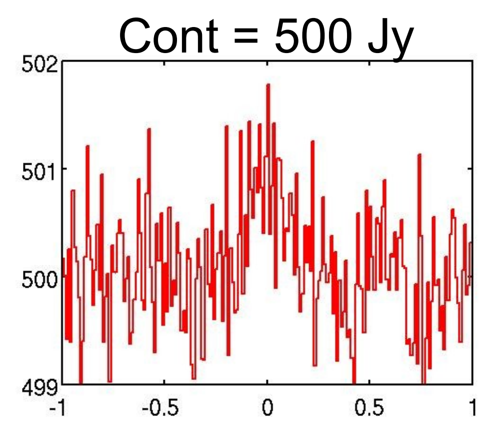


Spectral dynamic range

- Uncertainties in bandpass calibration limit the capability of detecting faint spectral features over a strong continuum

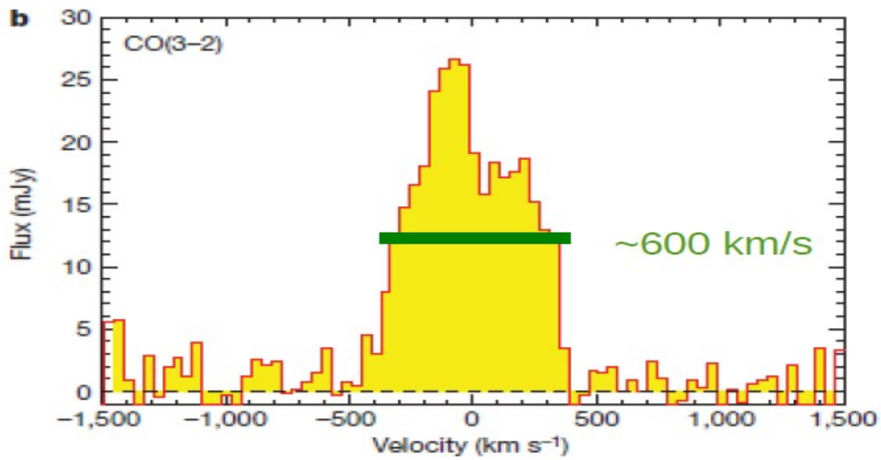


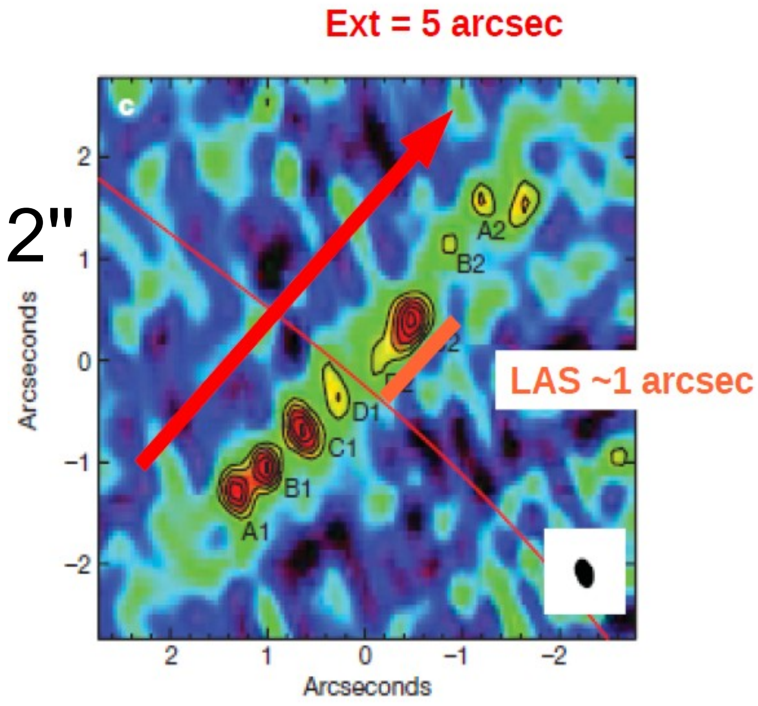
- SDR= Continuum Flux / Line RMS
- ALMA guarantees:
  - SDR $\leq$ 1000 for Bands < 9
  - SDR $\leq$ 500 for Bands 9 and 10
- Higher SDR must be justified!



An example:

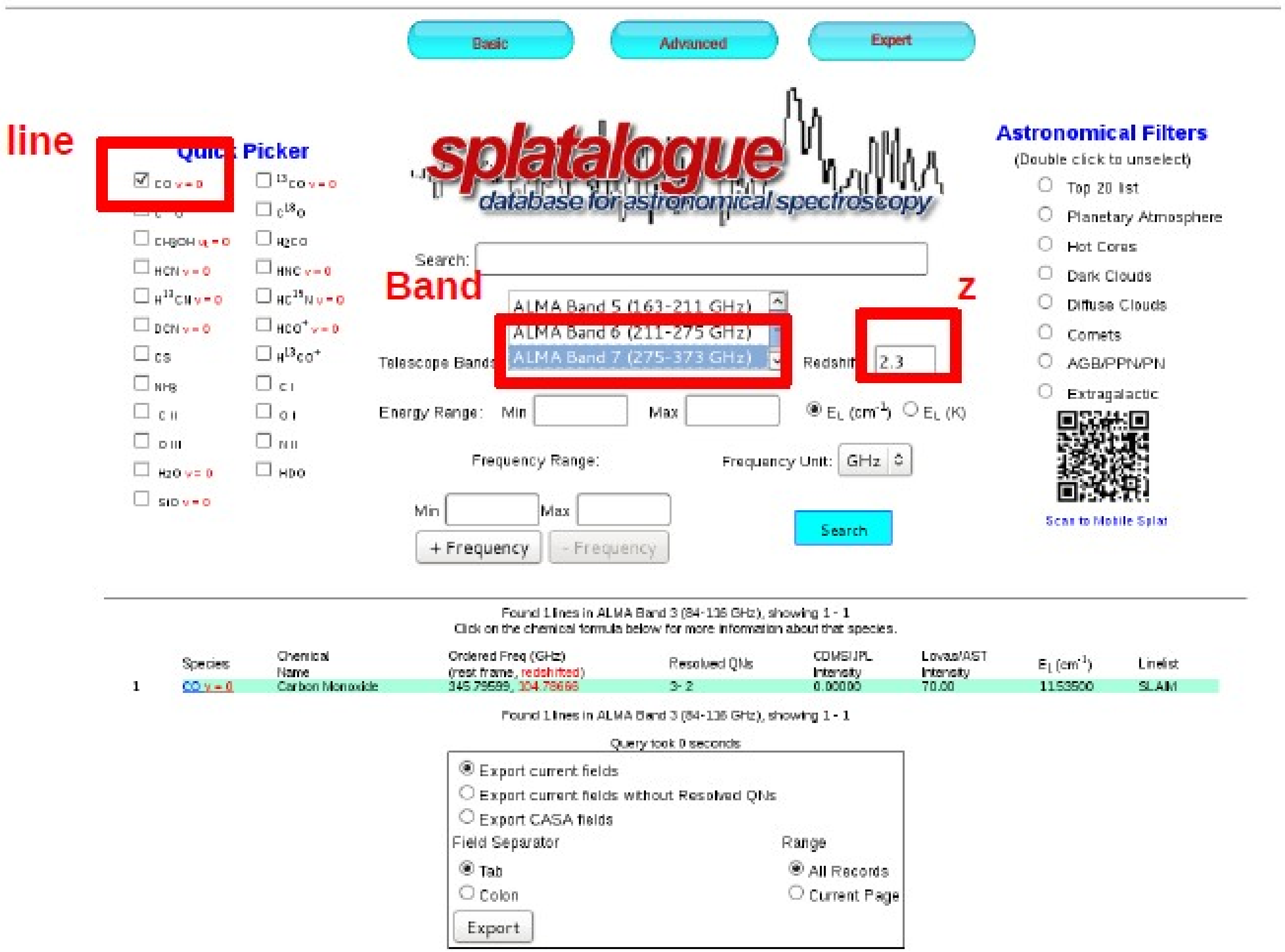
- We want:
  - Continuum and CO 9-8 in the Cosmic Eyelash (z=2.3) at θ_{ALMA}=0.2"
- We start from :
  - SMA 850μm continuum at θ_{SMA}=0.2"
  - PdBI CO (3-2) at θ_{PdBI}=1"





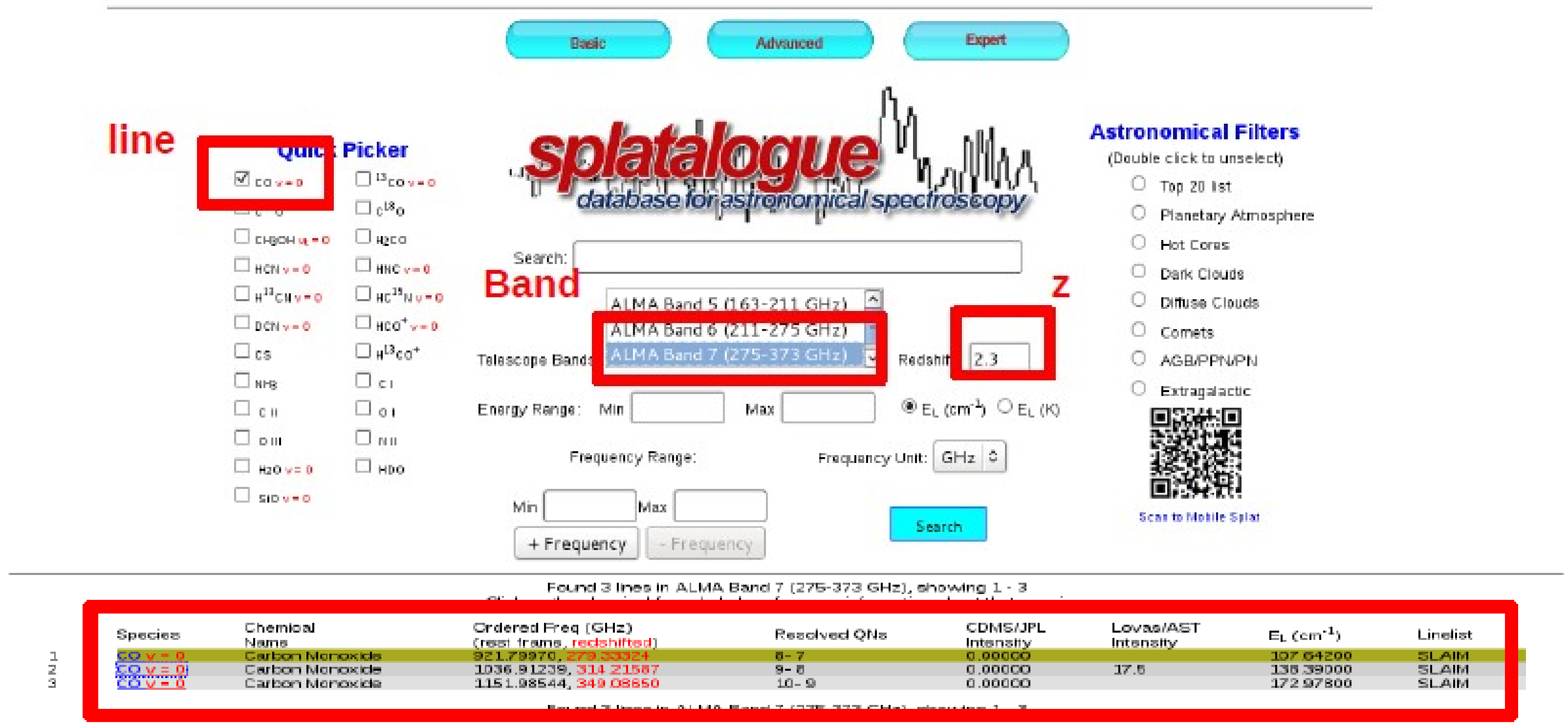
Look for the line at the right z

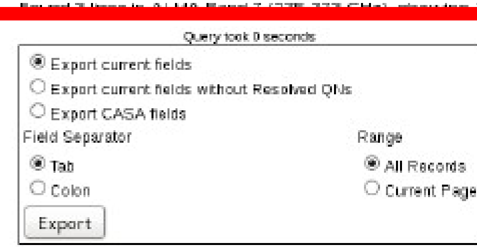
http://www.cv.nrao.edu/php/splat/



Look for the line at the right z

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

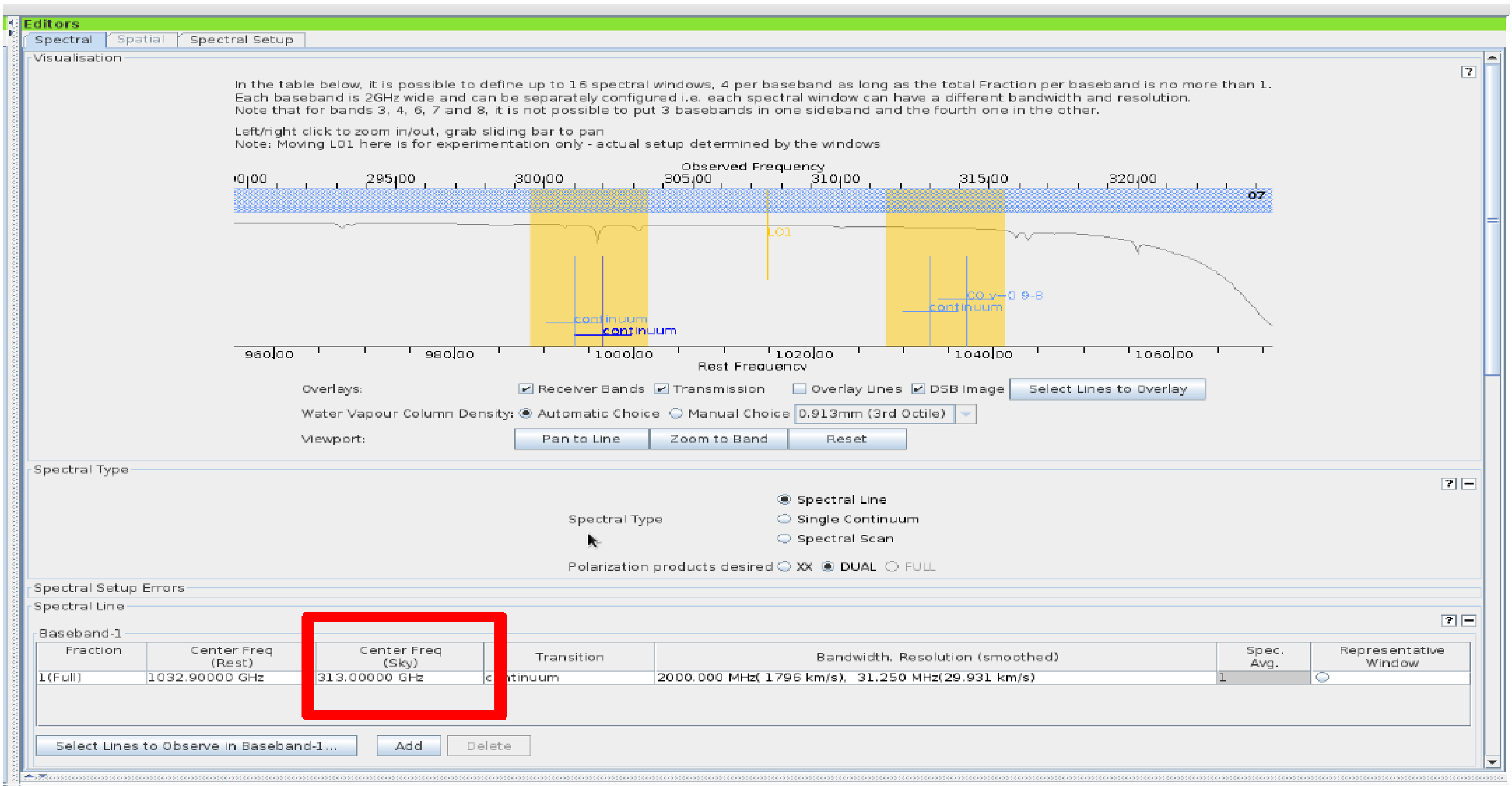




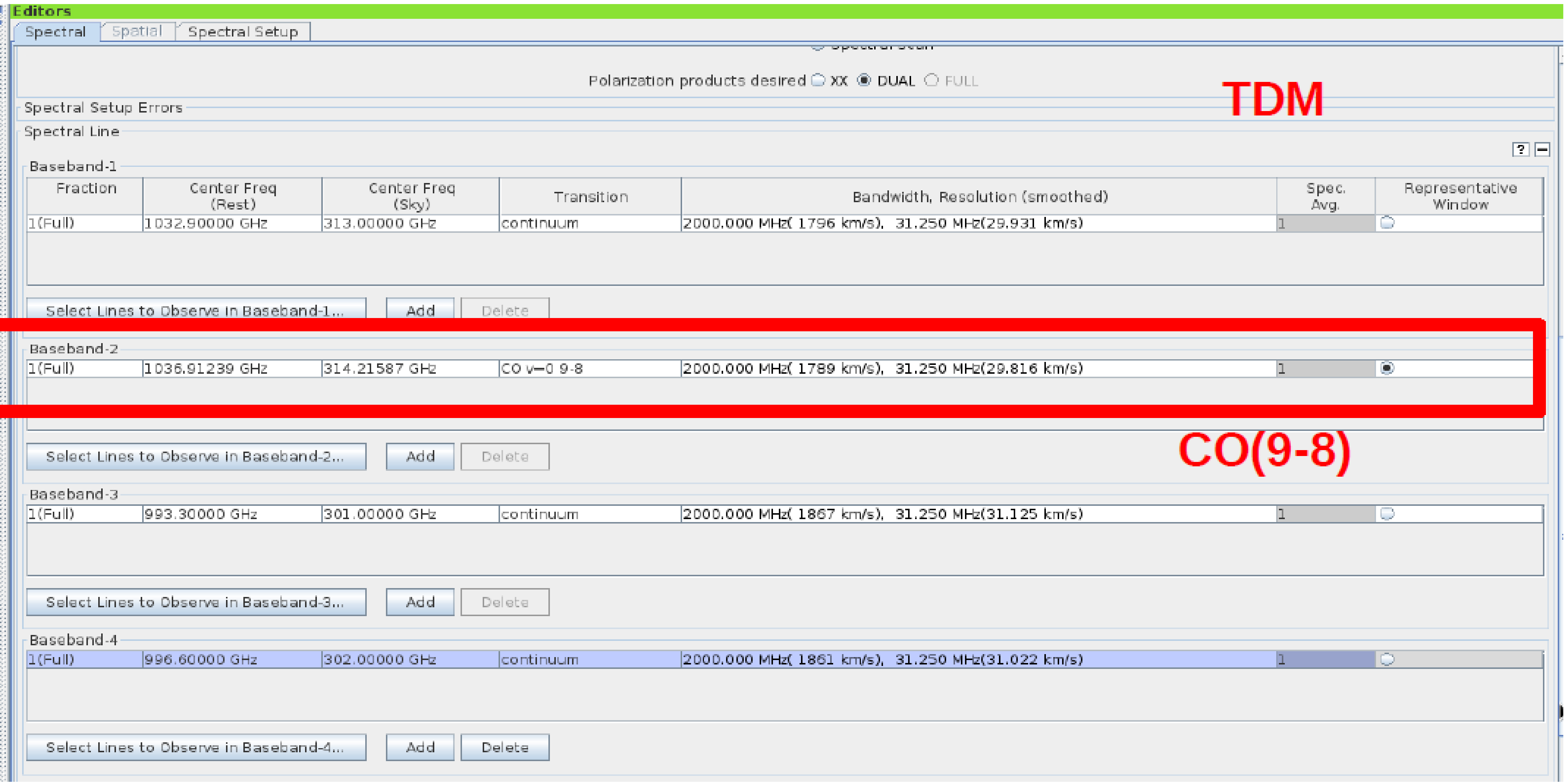
z=2.3
CO 9-8 in Band 7
Redshifted frequency: 314.216 GHz

Spectral setup

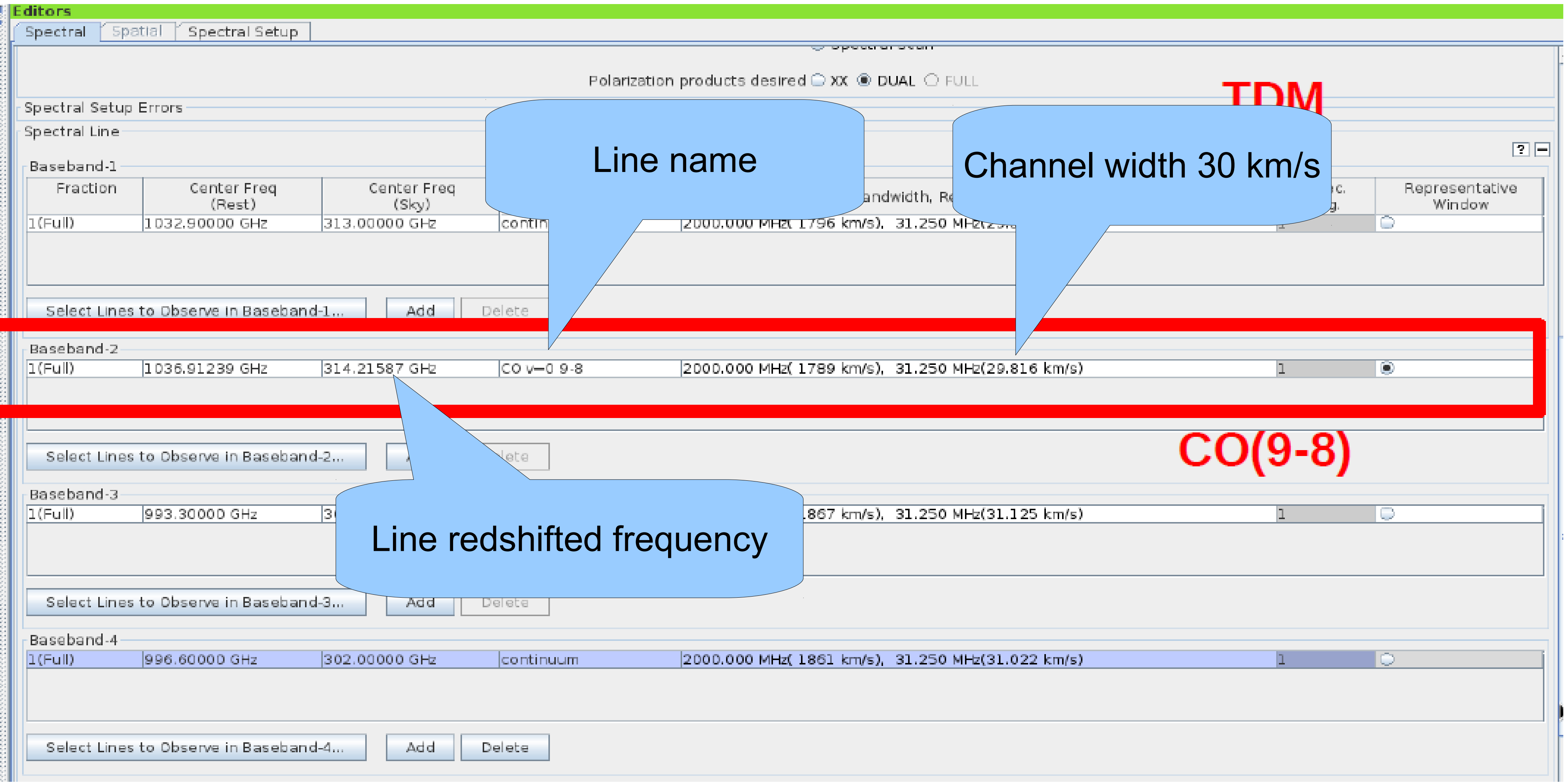
In the OT we select one baseband for CO 9-8 and three basebands for continuum



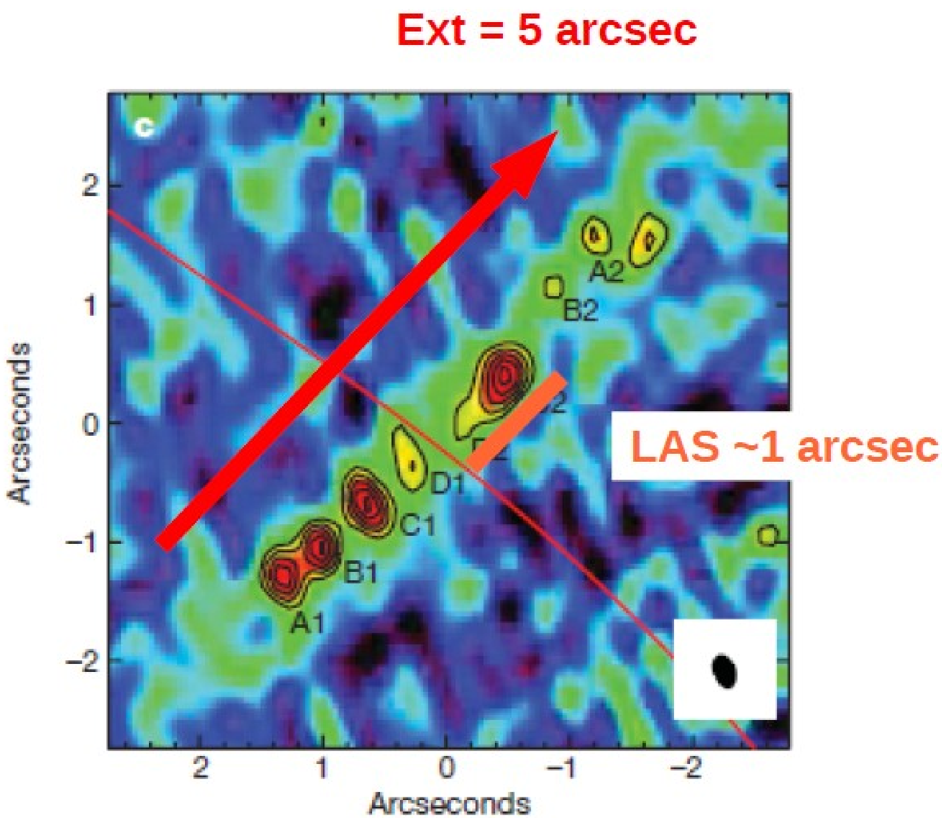
Spectral setup



Spectral setup



Morphology

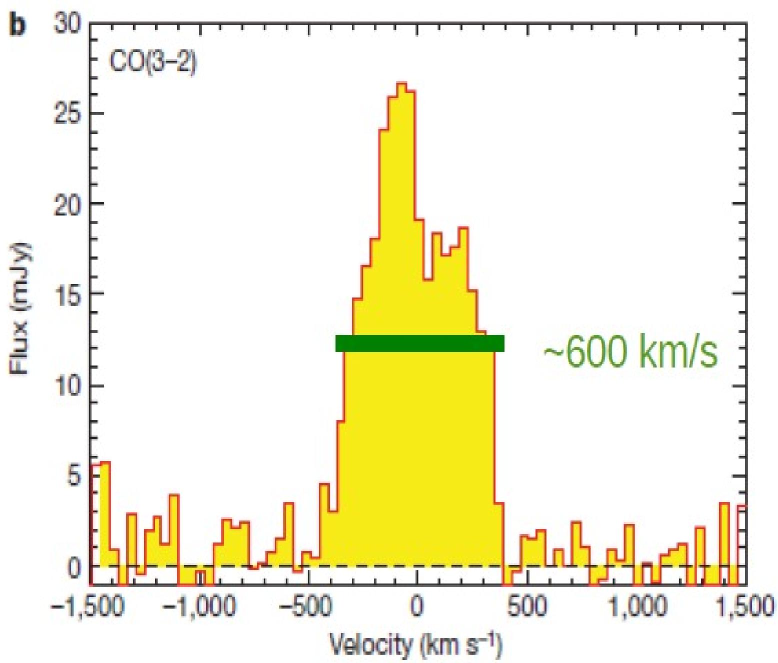


- From SMA continuum:
  - 5 components
  - Total extent 5"
    - FOV = 18" no mosaic you can see it in the OT
  - Maximum angular scale 1"
    - MRS = 2.8" no ACA

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

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

Spectral information



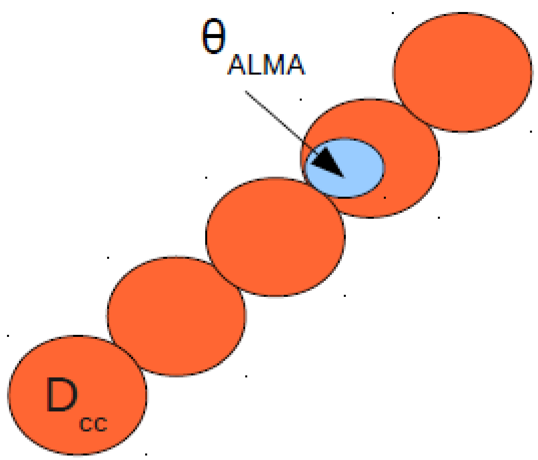
- FWHM = 600 km/s
  - We need $\Delta v \leq 100$ km/s
  - Channel spacing 30 km/s OK!
- $F_{[CO(3\text{-}2)]}$=13.8 Jy km/s
- $F_{peak}[CO(3\text{-}2)]=F_{[CO(3\text{-}2)]}/FWHM$=23 mJy in one beam of 1"

Sensitivity calculation (CO, Case 1)

- For CO 9-8 we assume:
  - Distributed in N=5 components of D_{cc}=0.8"<θ_{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 mJy
  - We want a SN=20

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

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

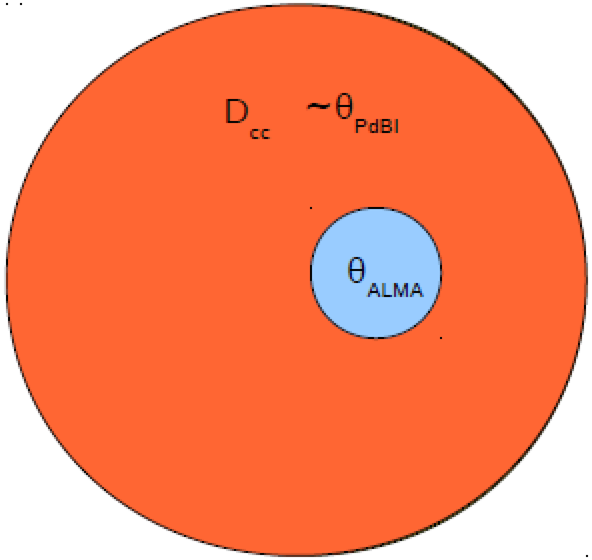


Sensitivity calculation (CO, Case 2)

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

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

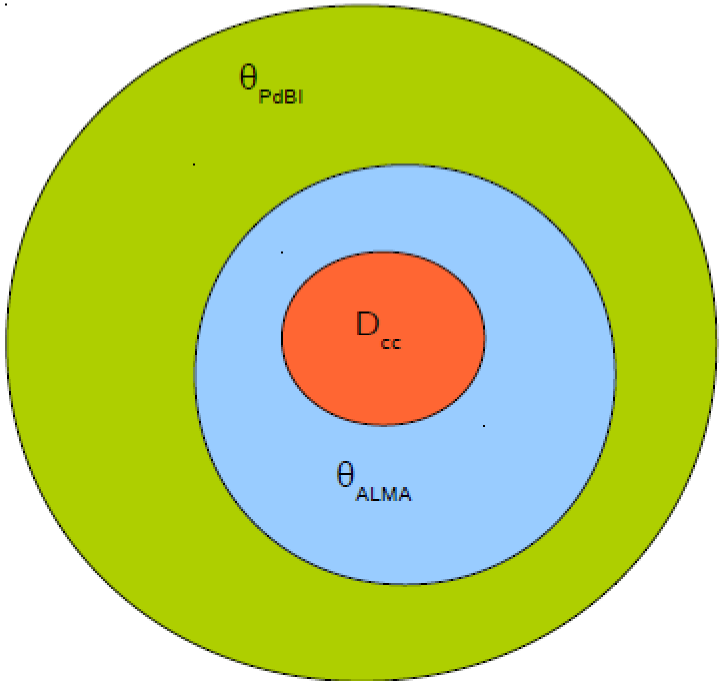
where $R_1 = (\theta_{ALMA}/D_{PdBI})^2$



Sensitivity calculation (CO, Case 3)

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

rms=F_{peak}[CO(9-8)]/ SN=0.46 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	◉ Automatic Choice ○ Manual Choice 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

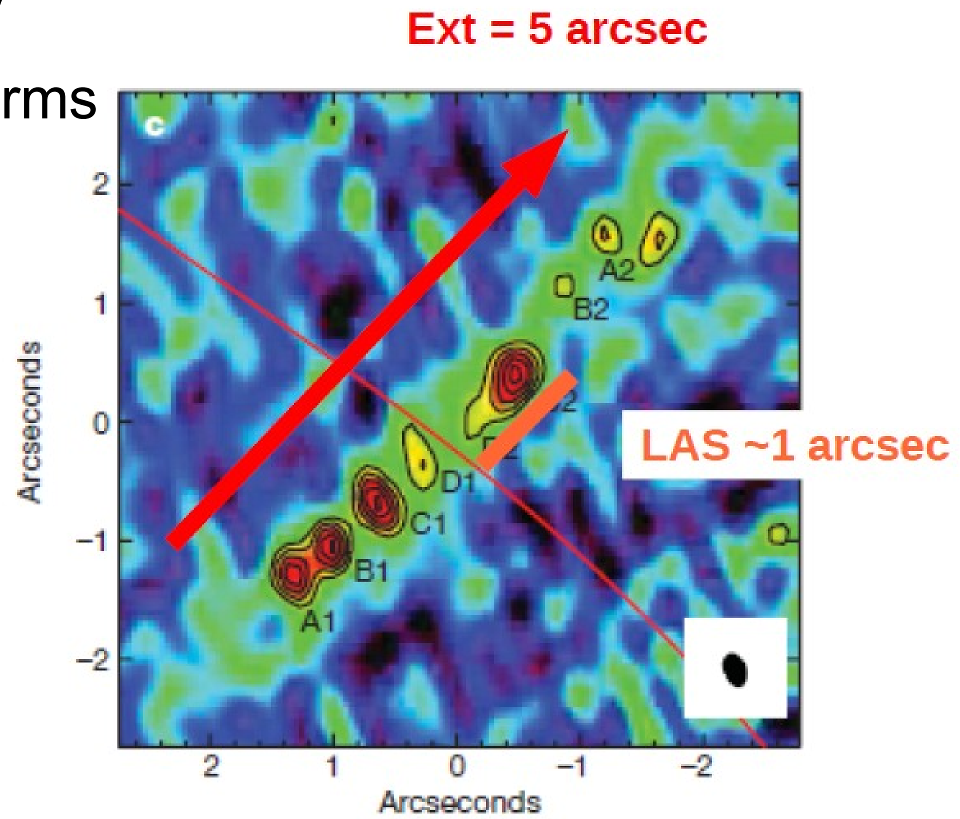
Case 2 , 4 Days !

	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

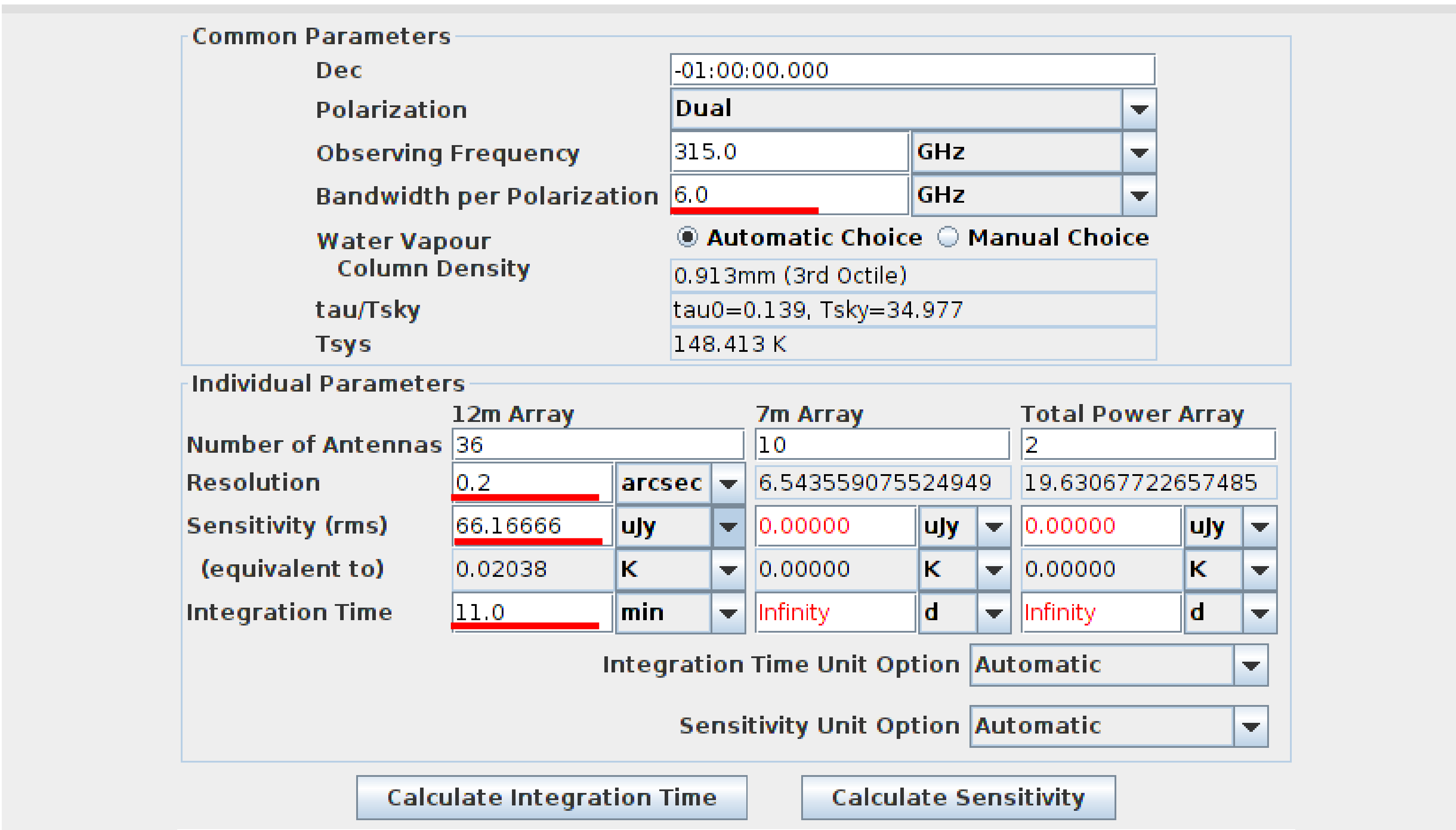
Case 3 , 11 minutes

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=3x2 GHz = 6 GHz



What does the time estimator say?



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 mJy / 0.07 mJy = 85 < 100 OK

- Spectral

  SDR= Max continuum / line RMS

  = 6 mJy / 0.5 mJy = 12 < 1000 OK

Good luck !