OT Tutorial: Novice group (more about the OT and ALMA)

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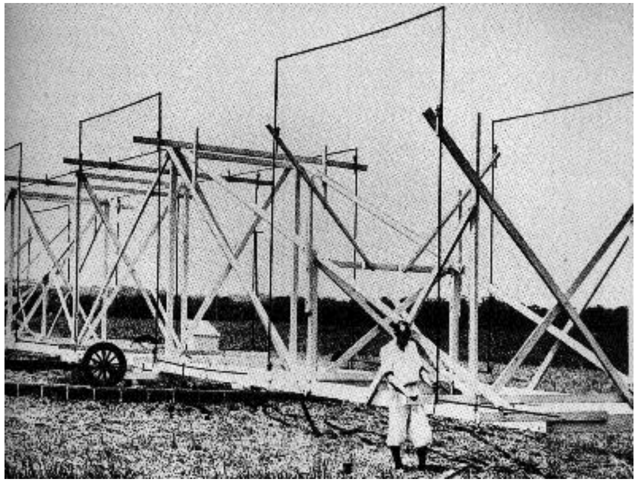
Flux density



- Standard unit is the Jansky (Jy)
- 1 Jy = 10^{-26} W m^{-2} Hz^{-1}
- Named after Karl Jansky
  - – Detected radio waves from the galaxy
- 1 Jy is a pretty bright radio source
- The brightest submillimetre galaxies are 10's of mJy
- Masers can be 1000's of Jy!

Synthesis map units

- The noise in a radio map has units of Jy per beam
  - This is the synthesised beam of the interferometer
- This is not a “true” map of surface brightness!
  - Each pixel tells you how much flux would be collected by your beam if pointed at that position
  - The peak pixel in a map of a point source is equal to the total flux of the source -> point-source sensitivity
  - Sensitivity is independent of angular resolution

$$\sigma = \frac{\rho T_{\mathrm{sys}}}{\eta_{\mathrm{c}} \sqrt{N(N-1)\,\Delta\nu\, t_{\mathrm{int}}}}$$

Brightness Sensitivity

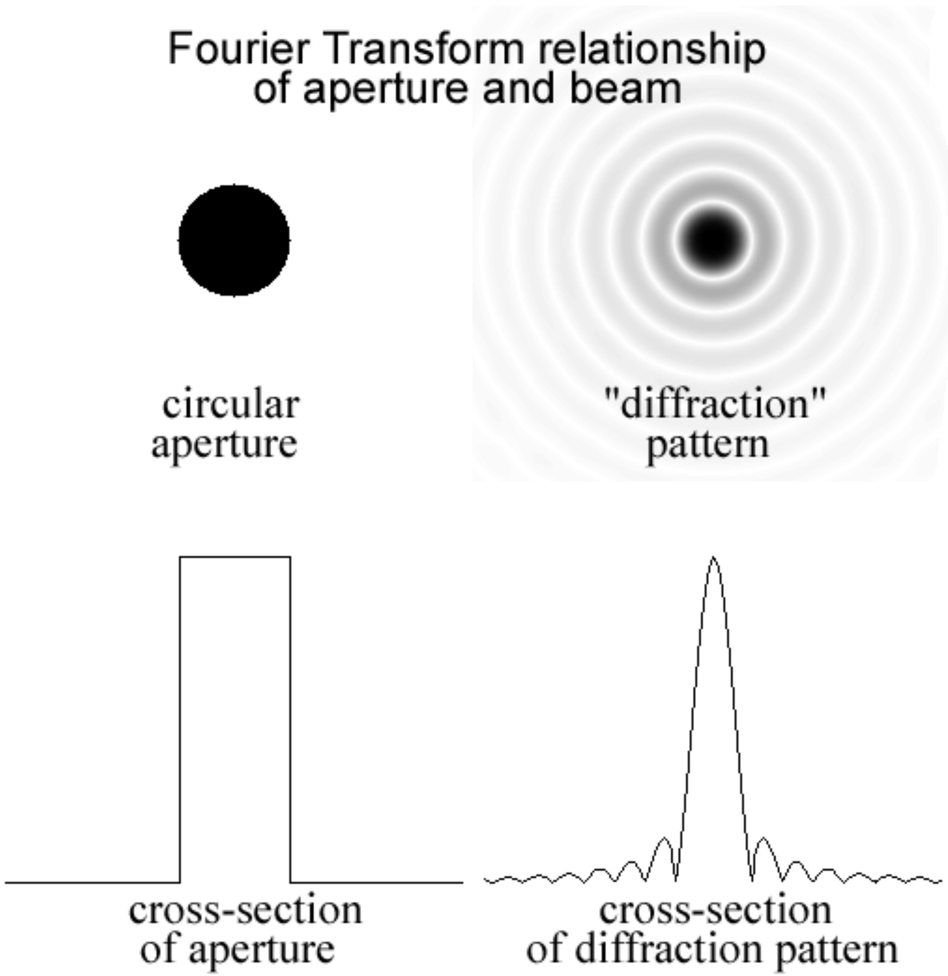
- A true surface brightness sensitivity needs to know the actual size of the beam
- Convert to temperature units using the Rayleigh Jeans approximation to the Planck formula
  - Thermal sources are characterised by a temperature
  - Sensitivity is not independent of the angular resolution (source size)

$$\sigma_{\mathrm{SB}} = \frac{\sigma_{\mathrm{PS}}\,\lambda^2}{2k\,\Omega}\,\mathrm{K}$$

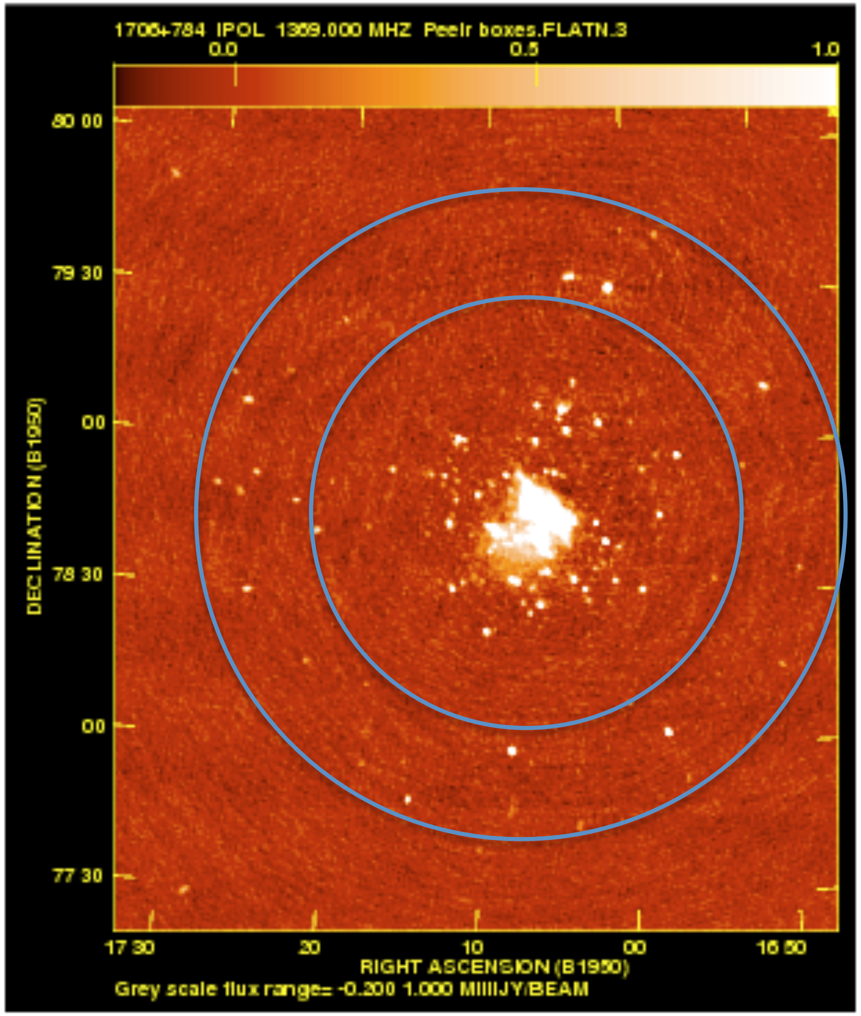
(Ω is the solid beam angle of interest)

Field of View

- The Field of View of the array is that of one antenna
- The OT refers to it in various ways
  - Main Beamsize
  - Antenna Beamsize
- The beam is the Fourier transform of the aperture
  - Main central lobe with response reducing towards edges
  - Further out are concentric sidelobes
- ALMA central lobe (primary beam) width is 1.2 λ/D
  - D is the antenna width



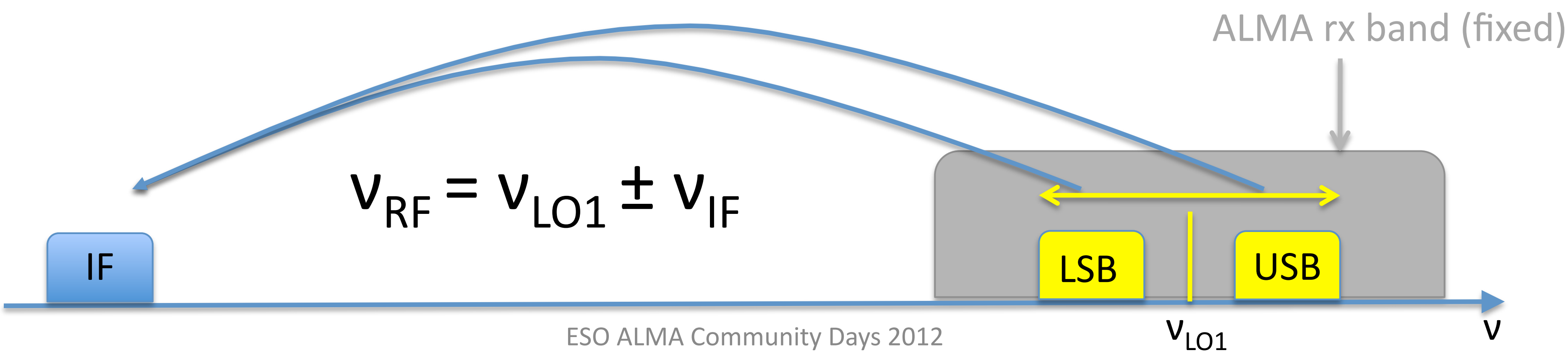
Theory



VLA 1st sidelobe

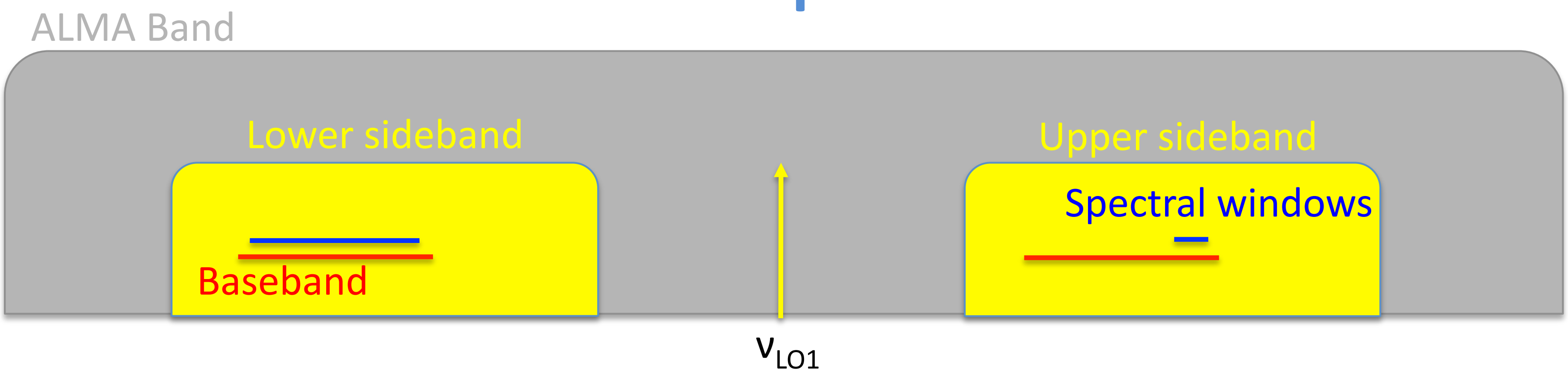
Sidebands

- Most radio astronomy receivers have 2 sidebands
  - Caused by mixing the sky signal with a local oscillator
- Sidebands are mapped to a lower frequency band
  - IF range sets width and separation of sidebands
  - Differs for different bands!
- Varying LO1 causes the sidebands to move
  - Very flexible – "heterodyne" system!



- Signal processing (e.g. amplification, digitization) does not work well at radio (high!) frequencies
- Astronomical signals must be down-converted to lower frequencies
- This is done by combining the receiver output with the signal from a local oscillator

Basebands and spectral windows



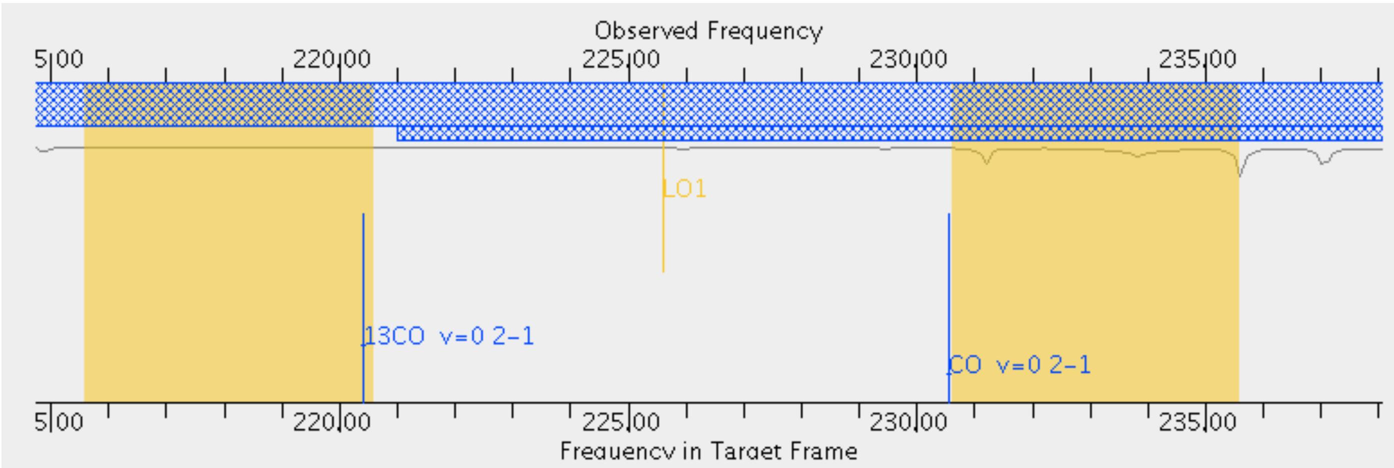
- 4 basebands sample the sideband signals
  - Each is 2-GHz wide and has two polarizations (X and Y)
- Spectral windows sample the baseband signals
  - Spectral windows are what you define in the OT
- OT calculates sideband and basebands automatically based on defined spws

ALMA receivers

- ALMA has three kinds of receiver
  - Single Sideband (SSB – bands 1 and 2)
  - Sideband Separating (2SB – bands 3 to 8)
  - Double Sideband (DSB – bands 9 and 10)
- No SSB receivers at Cycle 1

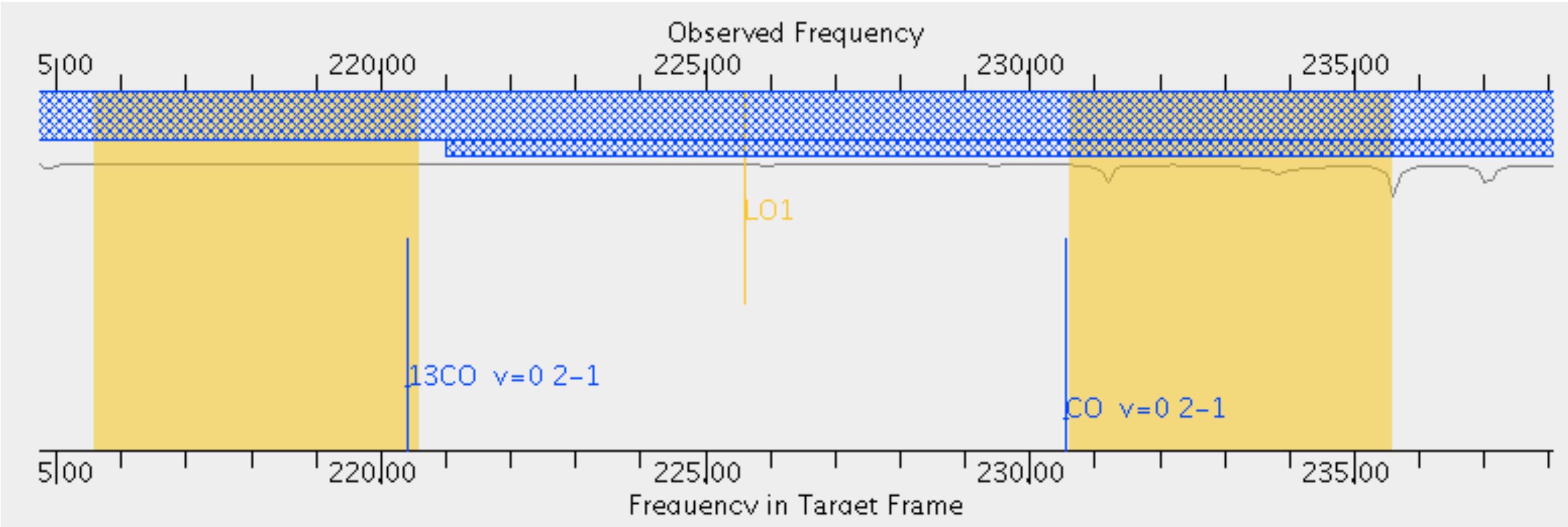
2SB receivers (B3-8)

- Sidebands are separated in the receiver
- Sidebands are **generally**
  - 4 GHz wide and separated by 8 GHz
- Band 6 is the odd one out
  - 5 GHz wide and separated by 10 GHz
  - Allows simultaneous detection of CO and 13CO (just!)



How wide is an IF?

- The IF range for e.g. band 6 is 5-10 GHz
  - This range is not a "hard" limit
  - Sidebands are thus not drawn completely accurately

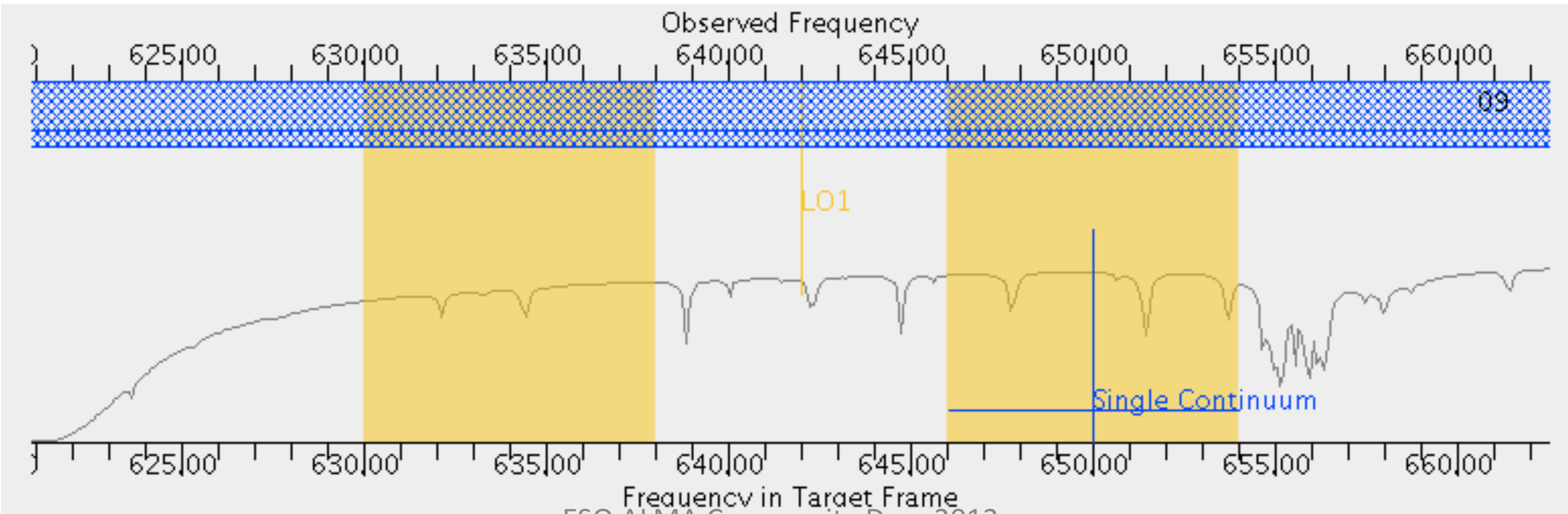


Band 6 IF range

- The band 6 IF range was supposed to be 4-10 GHz
  - Required for doing CO and 13CO easily
- Now 5-10 GHz
  - 4-6 GHz range was much noisier than expected
- 5-6 GHz only to be used if absolutely necessary
  - OT does not warn about this!
  - Increased noise here is not taken into account!

DSB receivers (B9-10)

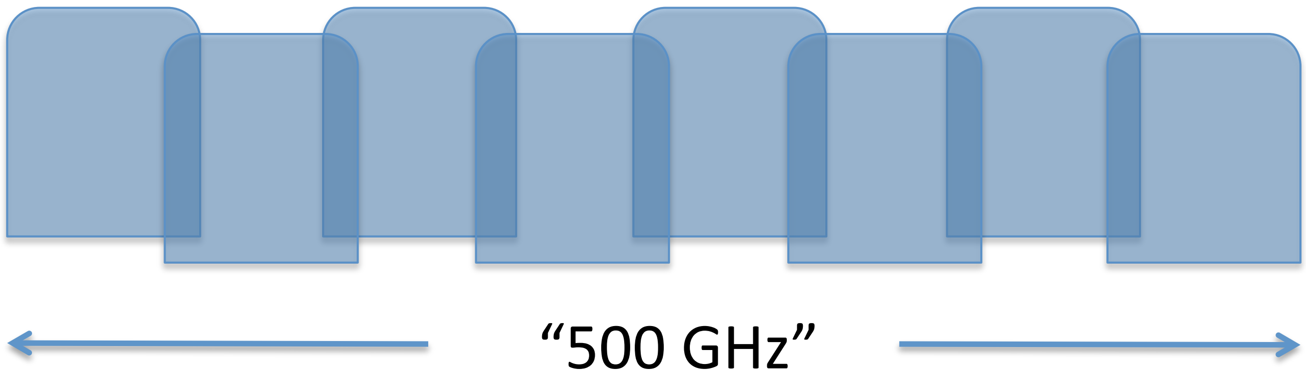
- Sidebands are separated in the correlator
- Two methods:
  - Suppression: one of the sidebands is thrown away
  - Separation: both sidebands are retained (**not for ES**)
- Sidebands are 8 GHz wide and separated by 8 GHz



Correlator Modes

- TDM (time division mode)
  - Pseudo-continuum/broad spectral lines
  - SPW always 2-GHz wide with 64-256 channels
- FDM (frequency division mode)
  - High-resolution spectral line
  - SPW can be 58.6-1875 MHz wide with up to 8192 channels
- FDM uses the Tunable Filter Banks
  - Each filter is 62.5-MHz wide
  - Multiple filters stitched together to form larger windows

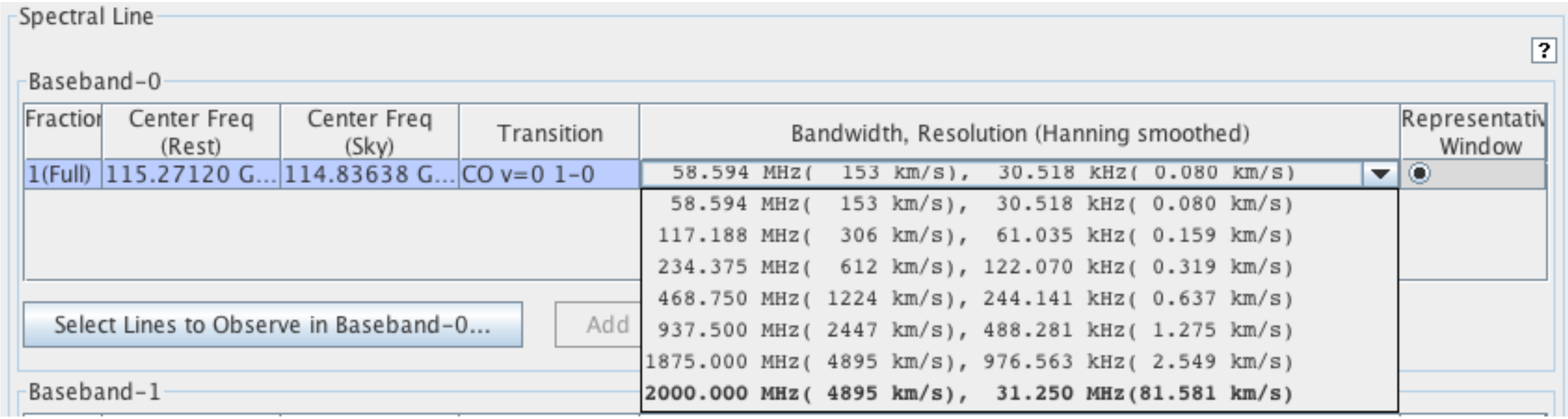
Tunable Filter Banks



Overlap causes effective bandwidth to be reduce by 15/16
i.e. 500 GHz-wide mode is actually 469-GHz wide

Available correlator modes

- 14 modes are available for Cycle 0
  - 2 TDM
  - 12 FDM
- Choose one for each spectral window



Bold text indicates TDM mode

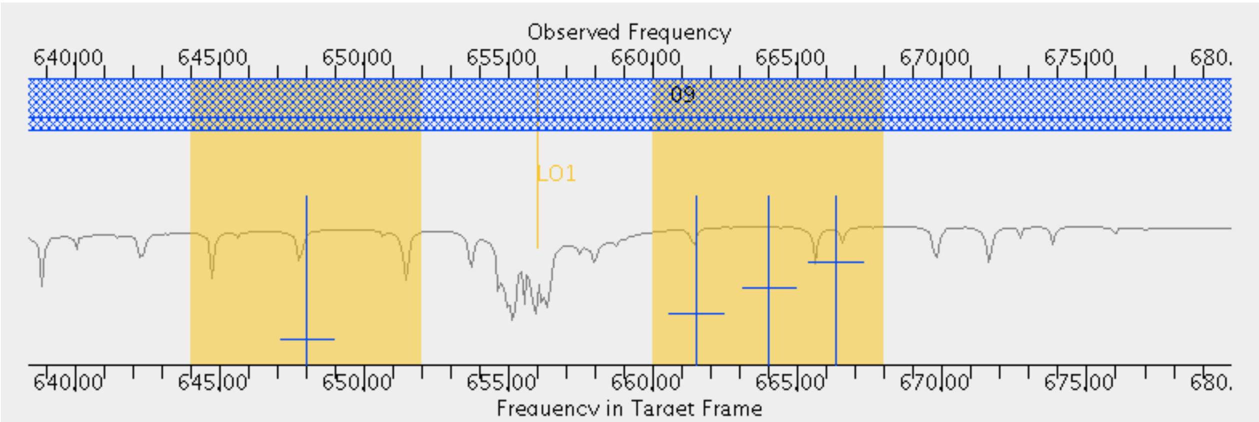
Hanning smoothing

- All ALMA spectral are by default Hanning smoothed
  - $0.25\, S(\nu-1) + 0.5\, S(\nu) + 0.25\, S(\nu+1)$
  - Reduces sidelobes around spectral lines
  - Broadens spectral features
- Spectral resolution is twice the channel width
  - An unresolved spectral line will have this width
  - Spectral window tables display spectral resolution assuming Hanning smoothing

Cycle-1 spectral window constraints

- Only one spw per baseband
- 2SB receivers (bands 3-8)
  - All basebands in one sideband or 2 in USB and 2 in LSB
  - A 3/1 split is **not** possible
- DSB receivers
  - Each baseband can be placed in either sideband

DSB



Single Continuum

- Only define a single frequency
  - This is usually not observed! (Bands 3, 6 and 7)
- Each spw has an effective bandwidth of 1.875 GHz
  - Due to anti-aliasing filter (data includes 2 GHz)

Representative frequency

- OT uses this for a number of things
  - Sets opacity for time estimate calculation
  - Array characteristics (resolution, field of view, etc.)
- Must choose one spw – most interesting one?
  - Exact choice only matters when opacity is variable near spectral line
  - Defaults to spw centre, but can be moved within the spw
- It is defined in the **rest frame** of the source
  - Velocities used to shift to the observed frame for each source

Science Goal Constraints

- Field Setup: up to 15 sources allowed
  - All must be within 15 degrees of each other
  - Rectangular definition (mosaic) only available when one source has been defined
  - Can't mix mosaics and "multiple pointings"
- Spectral Setup: only one is allowed which means…
  - One set of simultaneously detectable lines
    - However, these can move within a band due to source velocity
- Control Parameters: only one is allowed
  - Angular resolution, largest angular scale, ACA

You will often need to define multiple Science Goals

Source velocities

- OT shifts each spw to the observed frequency
  - All shifted setups must give a valid tuning
  - All must end up in the same band
- Only 5 velocities are allowed per Science Goal
  - OT checks if velocities can use the same tuning
  - Number of tunings reported on Time Estimate dialogue
- SG will not validate if >5 tunings or >1 band

Bugs we already know about

- Known Issues page:
  - Available via the Science Portal
    - http://almascience.eso.org
  - Or directly from
    - http://almasw.hq.eso.org/almasw/bin/view/OBSPREP/Cycle1KnownIssues

Spectral Line Example

- What do we require to write an ALMA spectral line proposal?
  - Some measure of line brightness (e.g. peak flux)
    - In Jy or in K (surface brightness)
    - If have Integrated flux and FWHM: peak = I / FWHM
  - Some measure of line width (e.g. FWHM)
  - Some measure of line **angular** extent (e.g. measured from a map)
  - Desired angular resolution of ALMA map (synthesized beam)

Spectral Line Example - Jy

- Width of line sets ALMA correlator mode
  - Usually want at least a couple of spectral resolution elements across the line (depends on science)
- Want at least a 5-sigma detection of peak flux in this spectral resolution element
  - Line may be bright enough to investigate wings
- For mapping, calculate number of ALMA beams across source
  - Divide by this factor
- Must achieve 5-sigma in Flux/# channels/# beams

Spectral Line Example - K

- Line fluxes can also be measured in Kelvins
  - Can be very useful as **can** give a true surface brightness
  - Beware of single dish fluxes!
- True surface brightness
  - Can use this directly in the OT (must give sensitivity in K and angular resolution)
- Single dish fluxes (JCMT, APEX, etc.)
  - Can report fluxes of unresolved sources in K (NOT A SURFACE BRIGHTNESS!!)
  - Need to convert to Jy using telescope-dependent factors

Spectral Line Example - OT

- For multiple lines, calculate using weakest line
- Ensure that line fits within spectral window
  - OT tries to warn you about this
- Very bright lines make weak lines difficult to detect
  - OT asks for brightest line for spectral dynamic range reasons
- Bandpass calibration more important for spectral lines
  - Only a Phase-2 consideration
  - Particularly important for broad, weak lines on strong continua