Part 2:
spectral setup, receivers and correlator

German ARC: ALMA community days (March 2017)

Outline

Part 1: by Á. Sánchez-Monge

- Introduction to aperture synthesis
- Interferometers: spatial filters

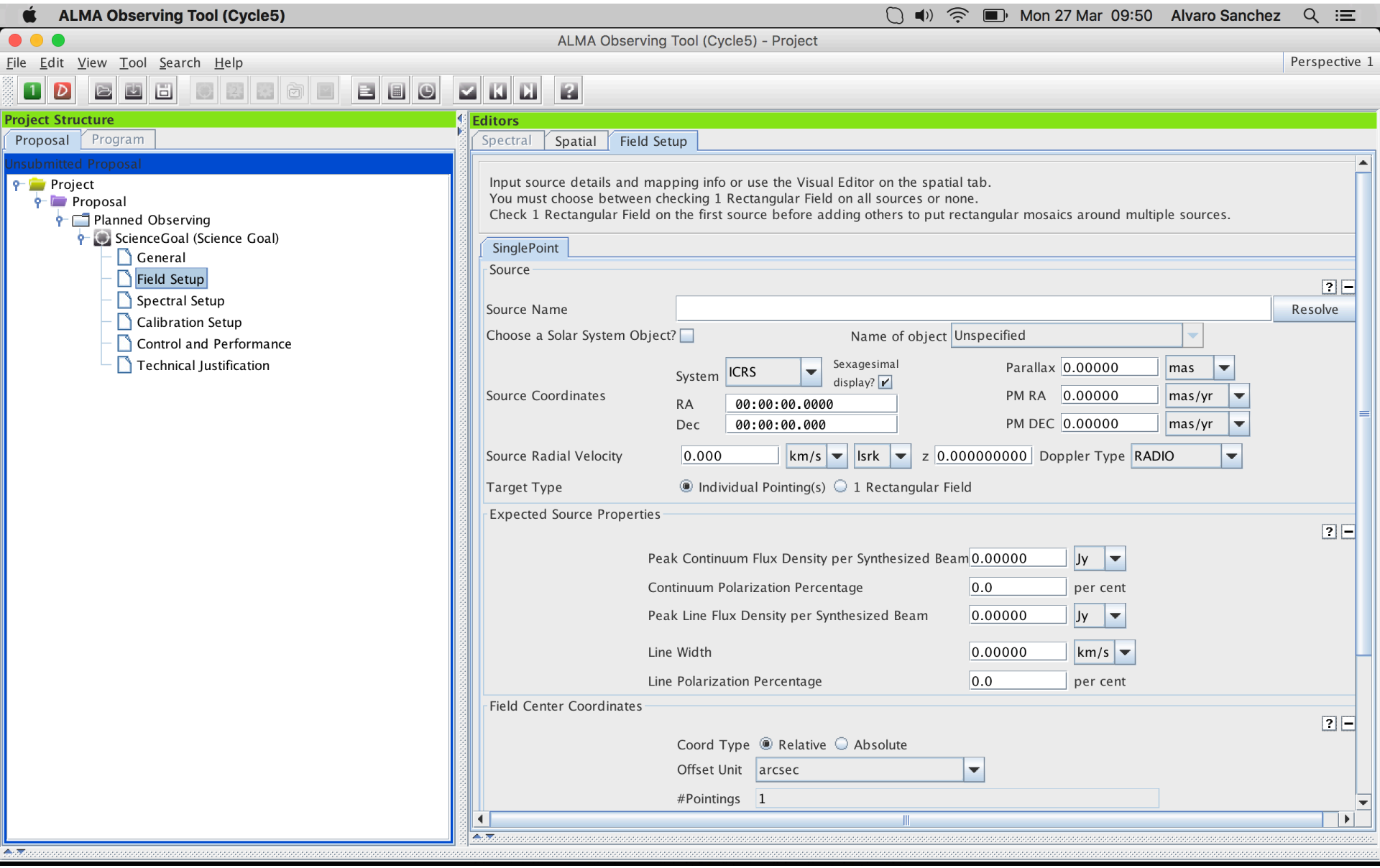
Part 2: by Á. Sánchez-Monge

- Interferometers: spectral setup
- An overview of receivers and correlator

Part 3: by Y. Pidopryhora

- The sensitivity of an interferometer

Spectral setup in the almaOT



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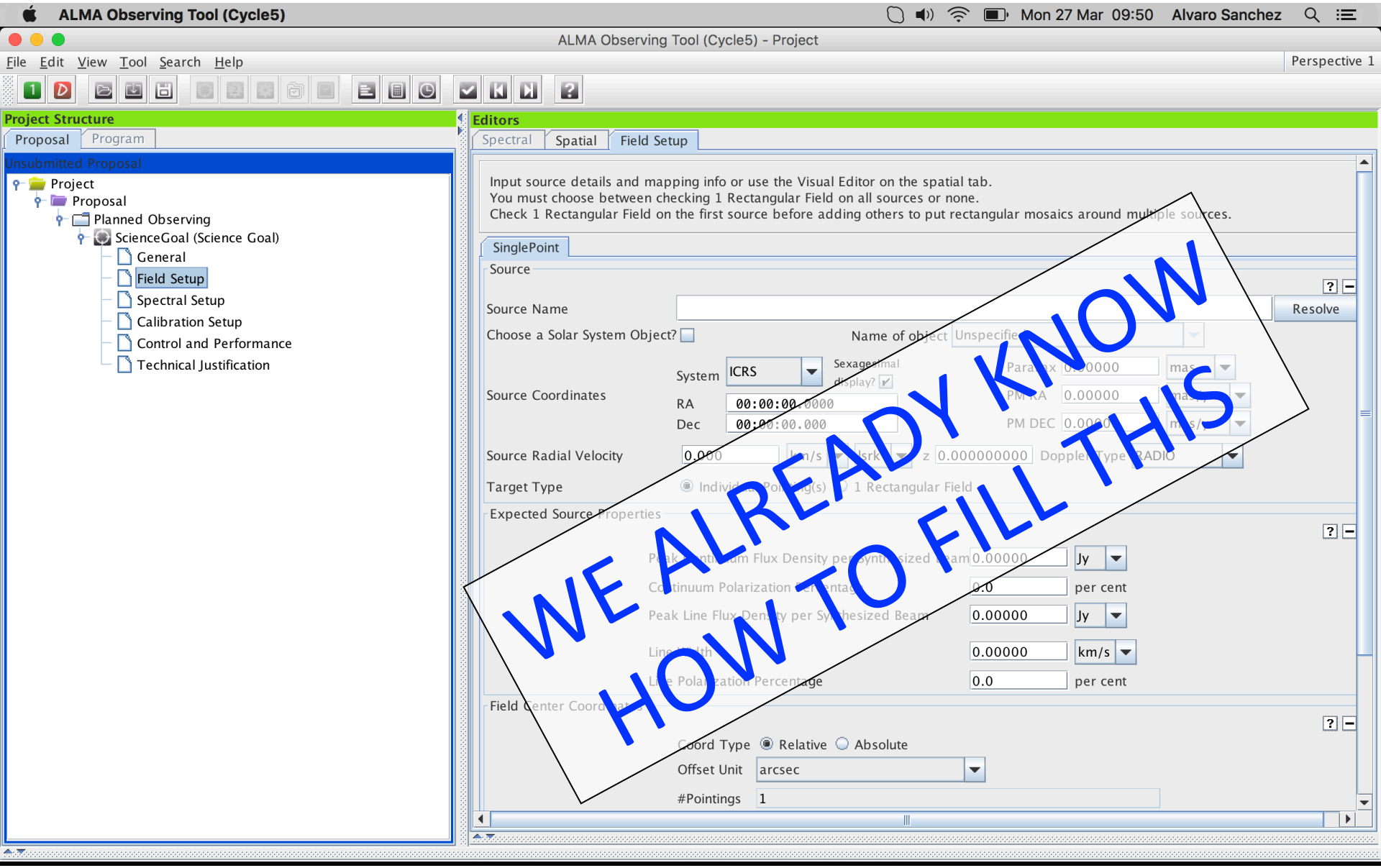

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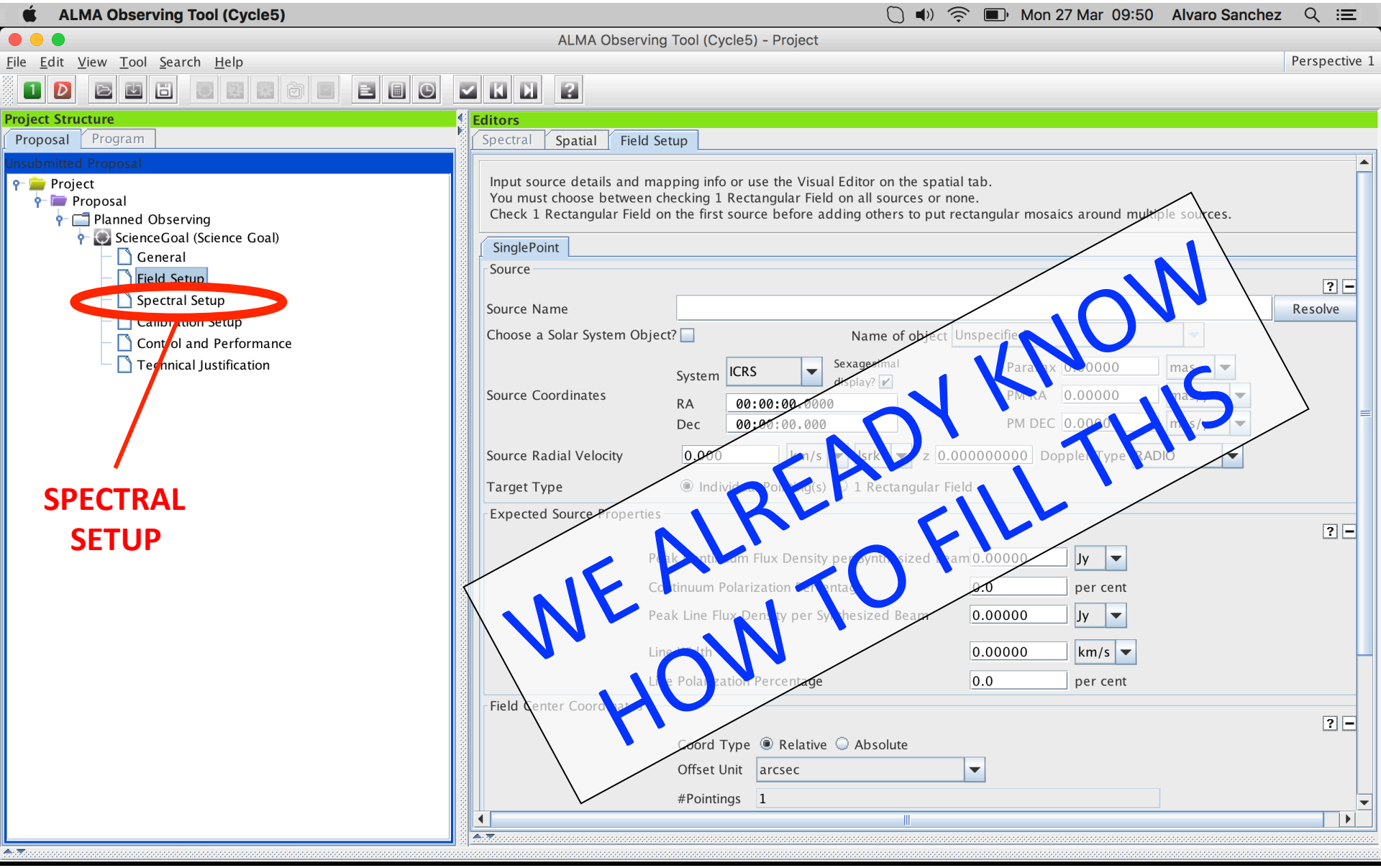

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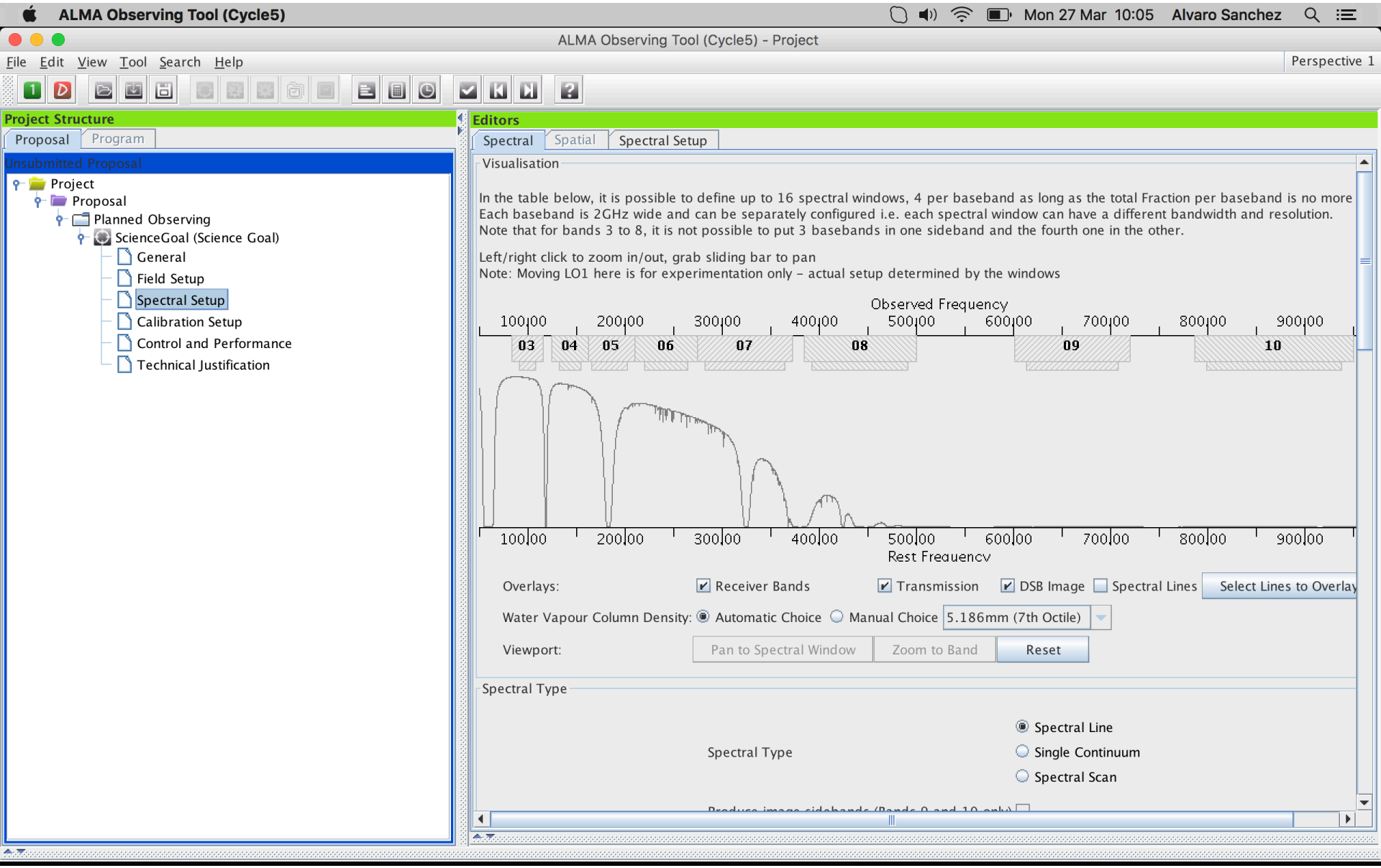

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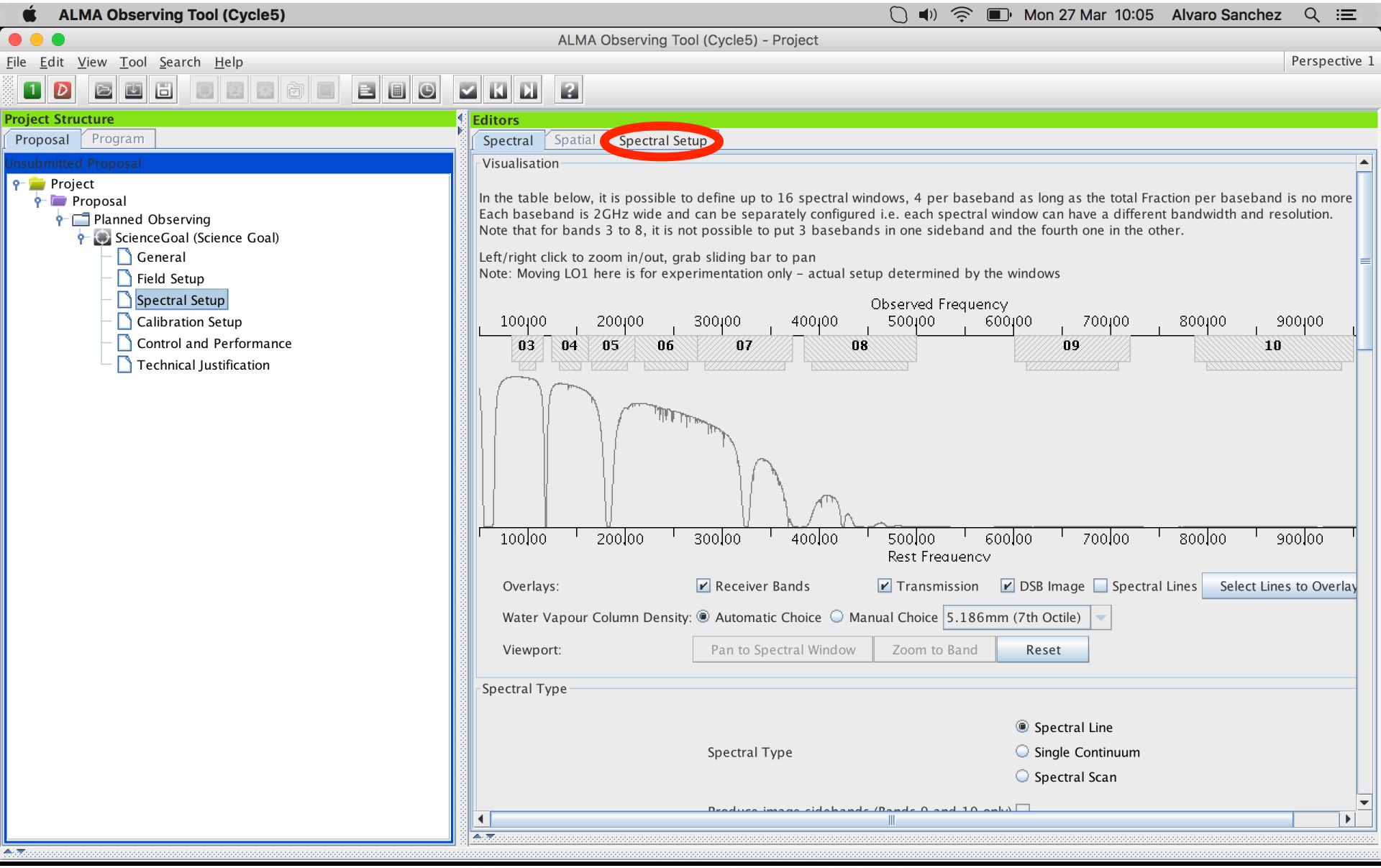

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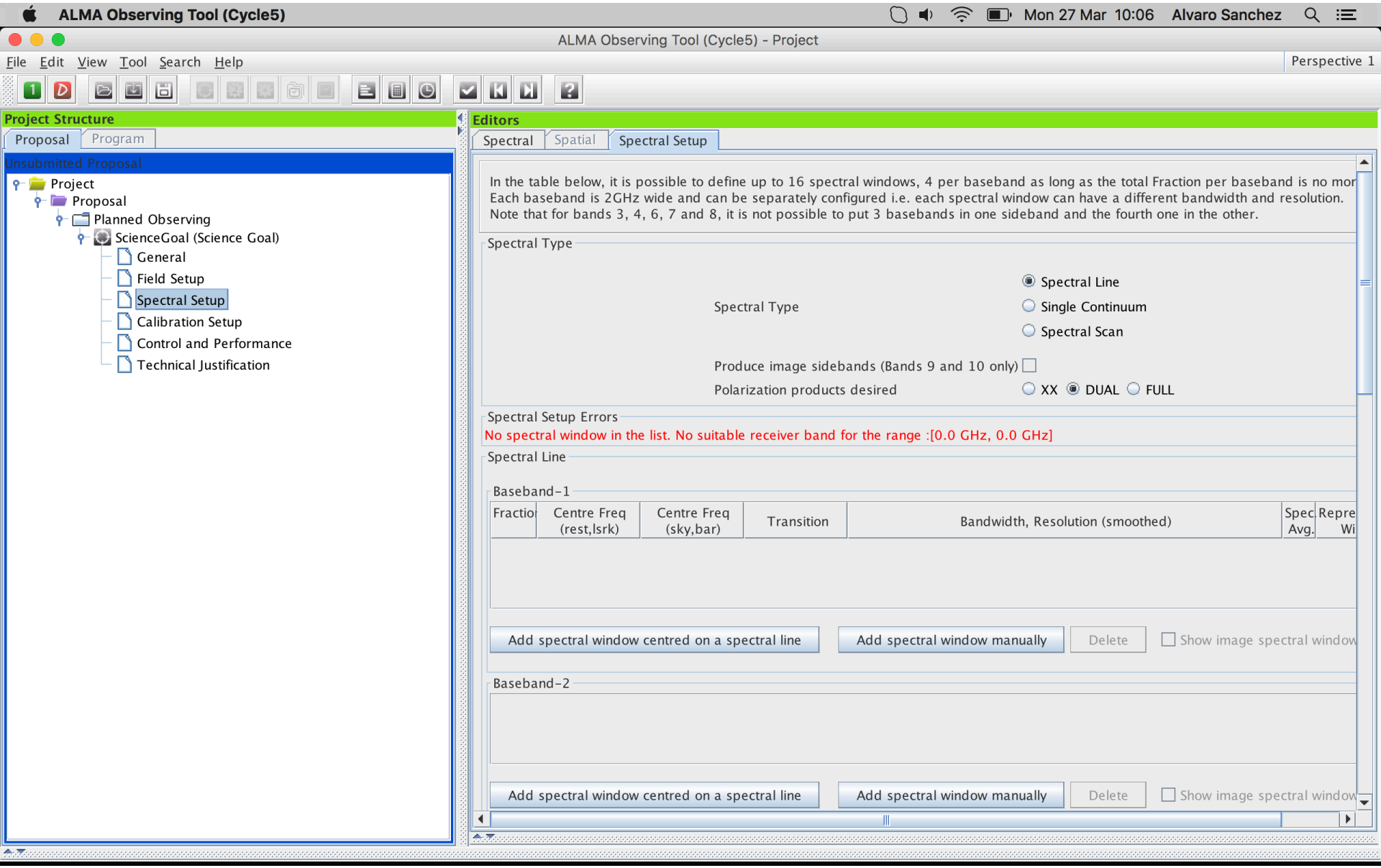

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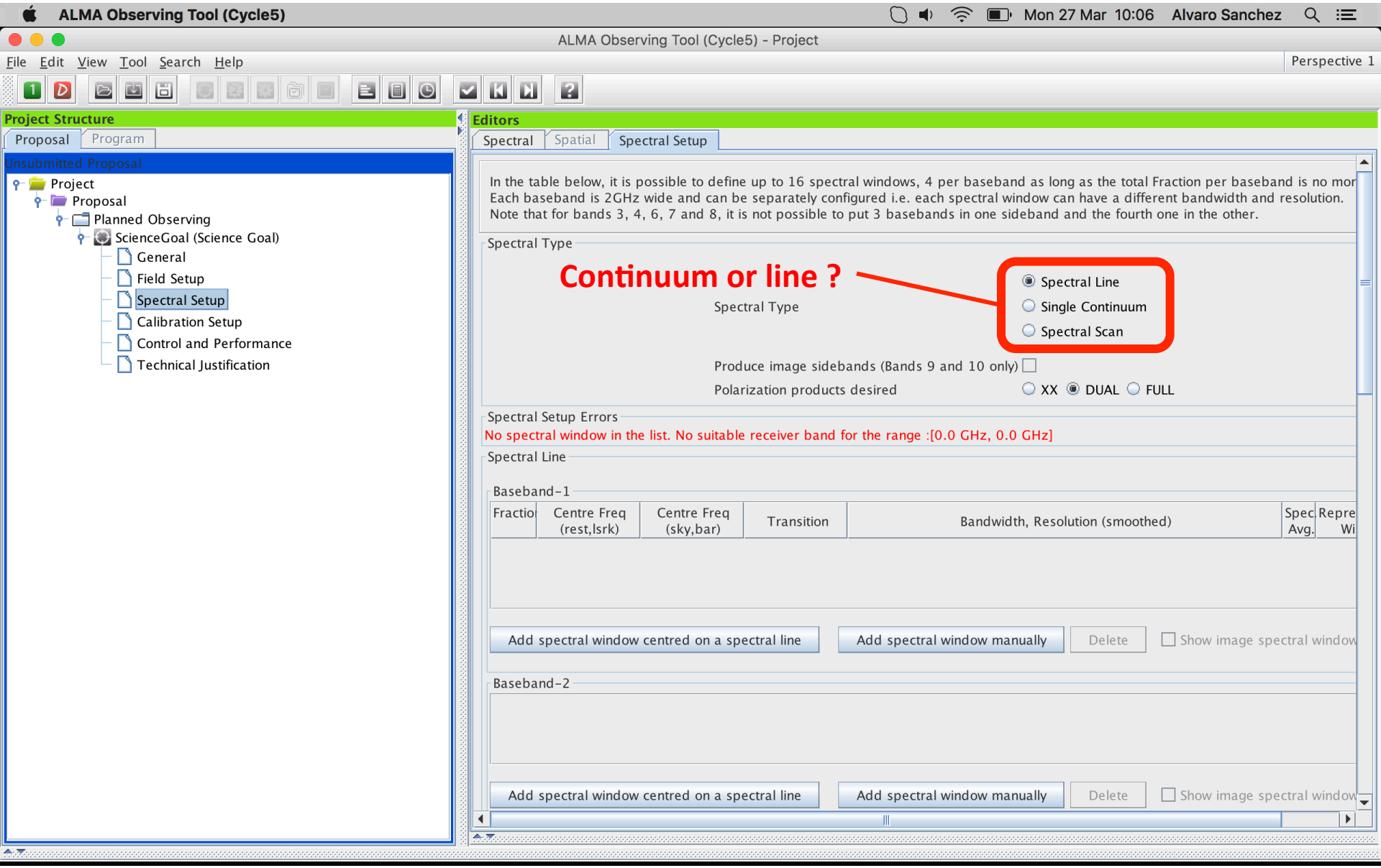

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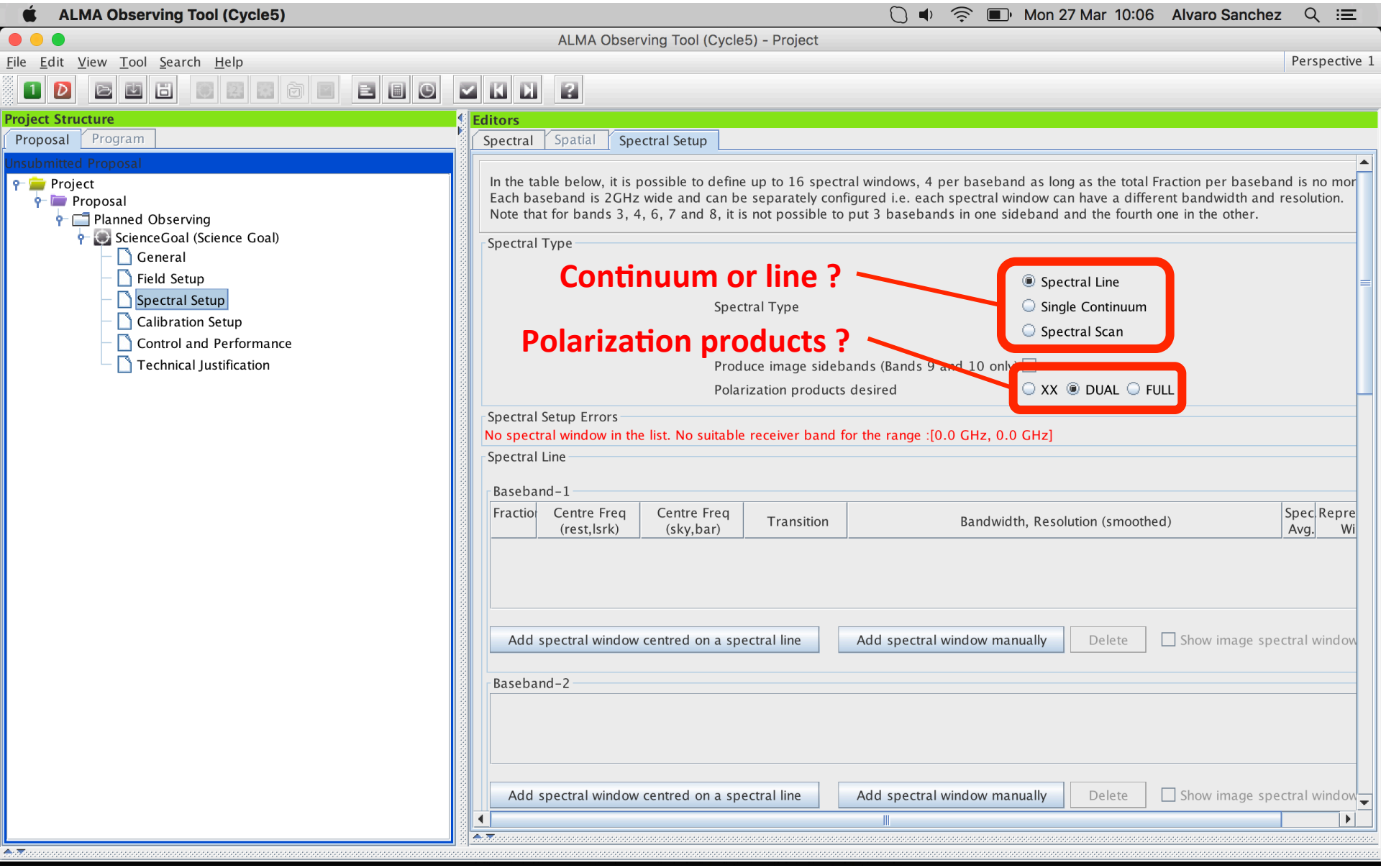

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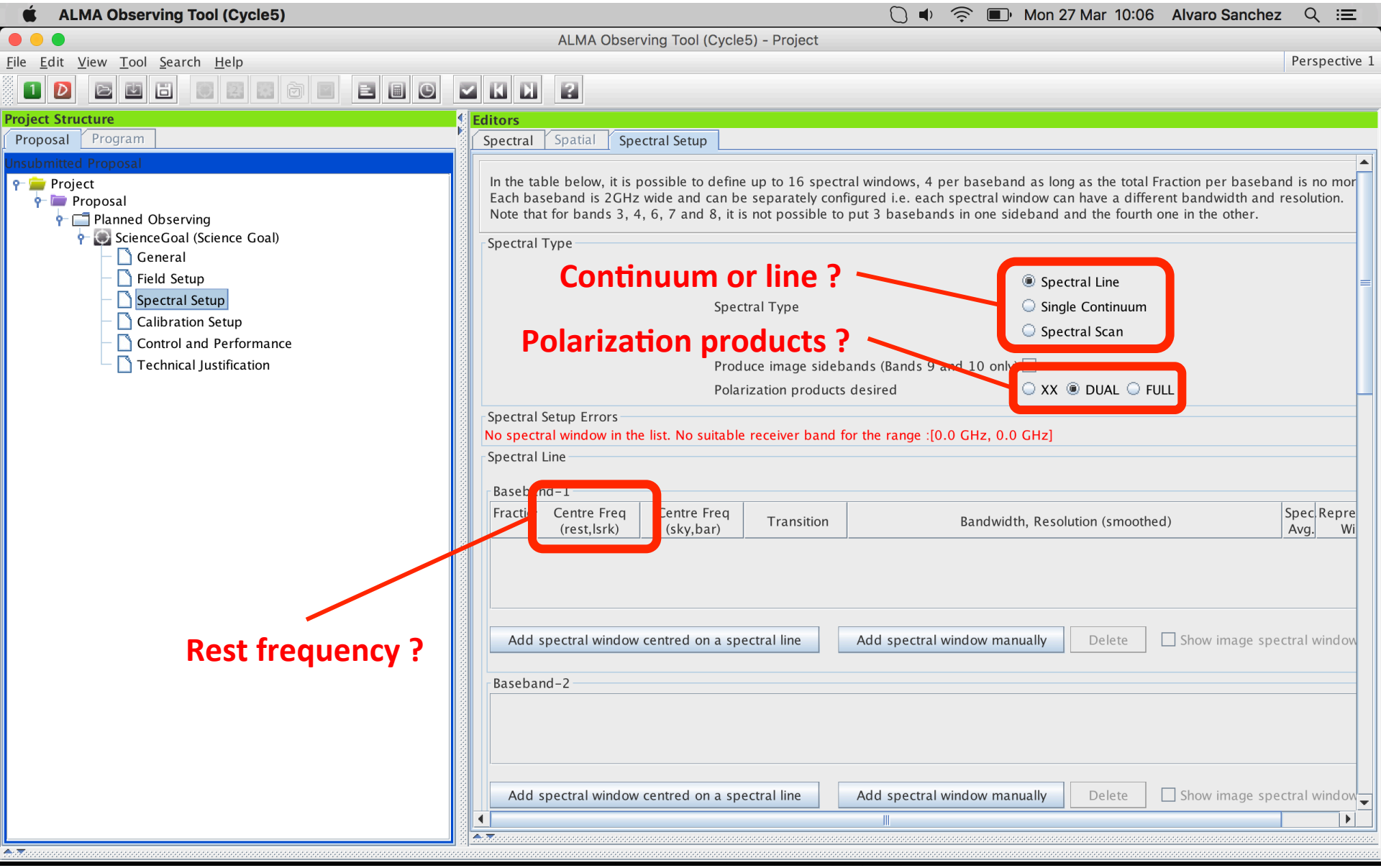

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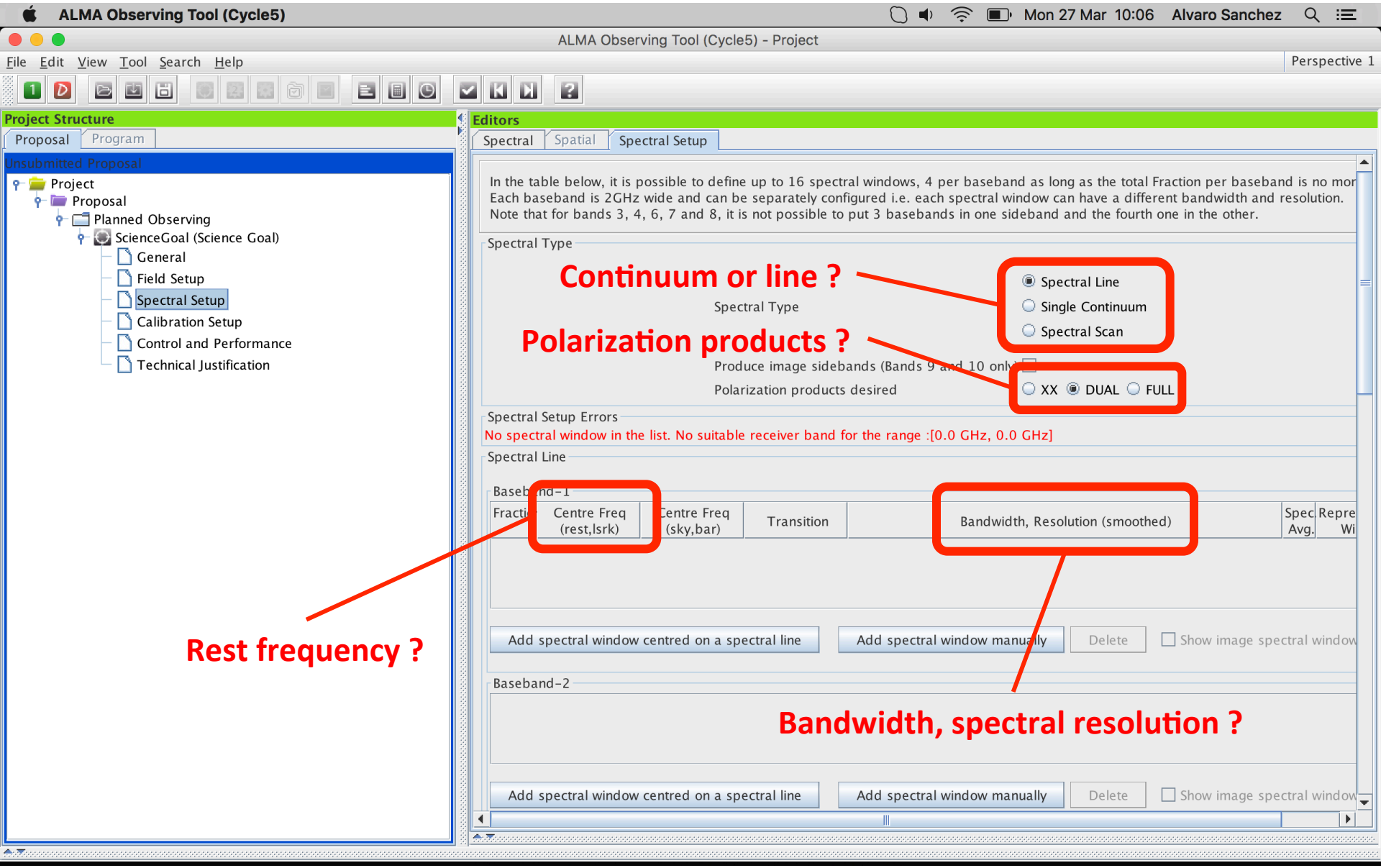

What do we need to know?

- continuum or line (both?)
- frequency of the lines to observe
- velocity / redshift of the source
- bandwidth / velocity coverage
- spectral resolution
- polarization products
- …

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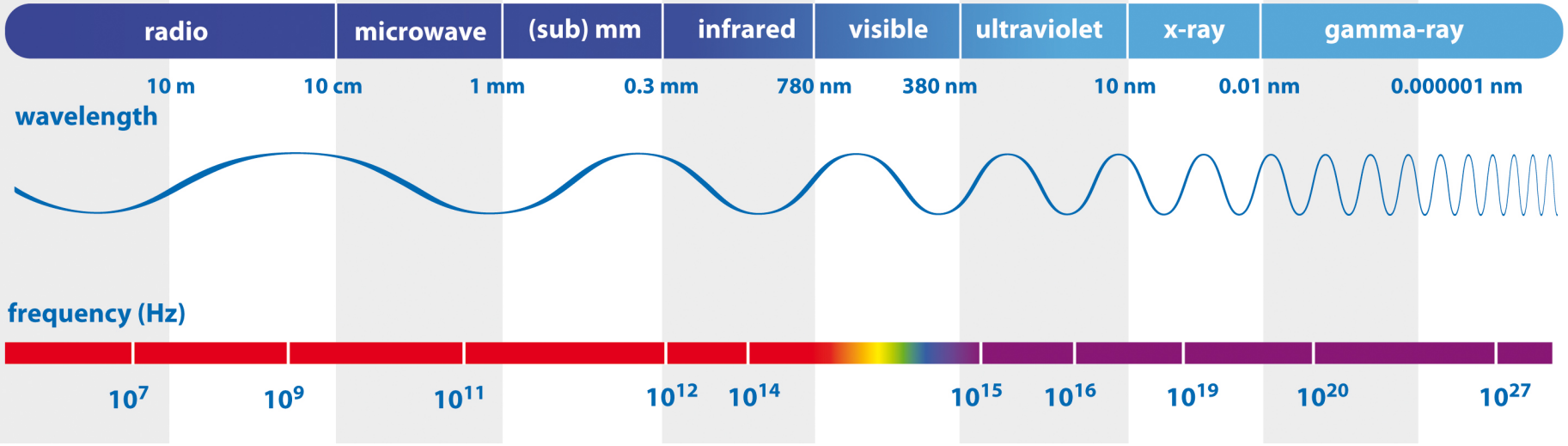
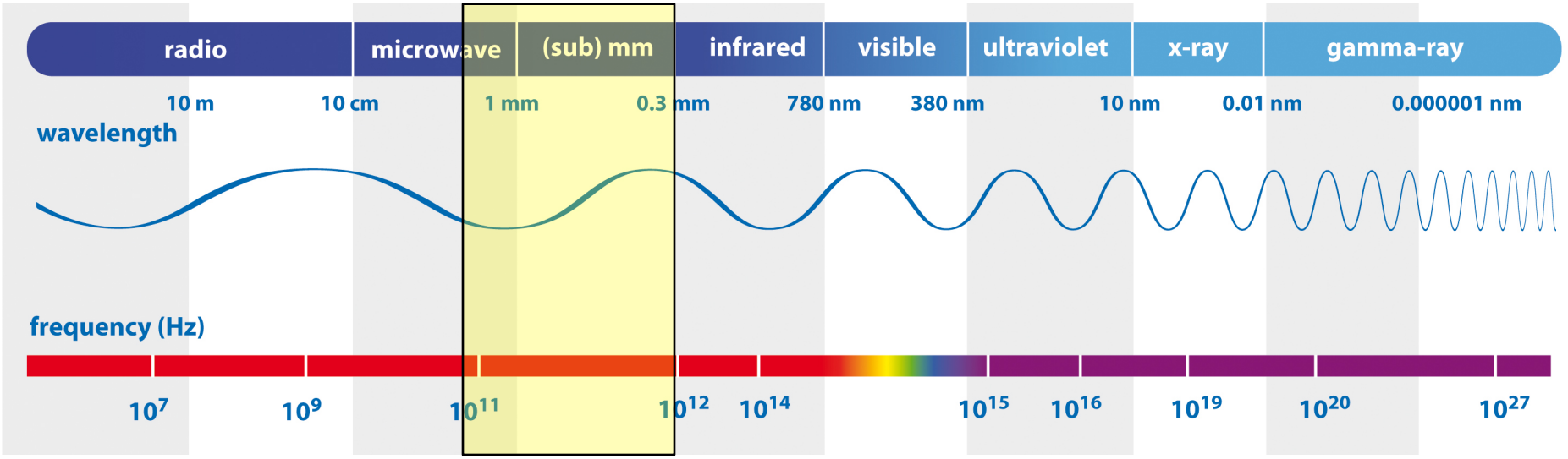
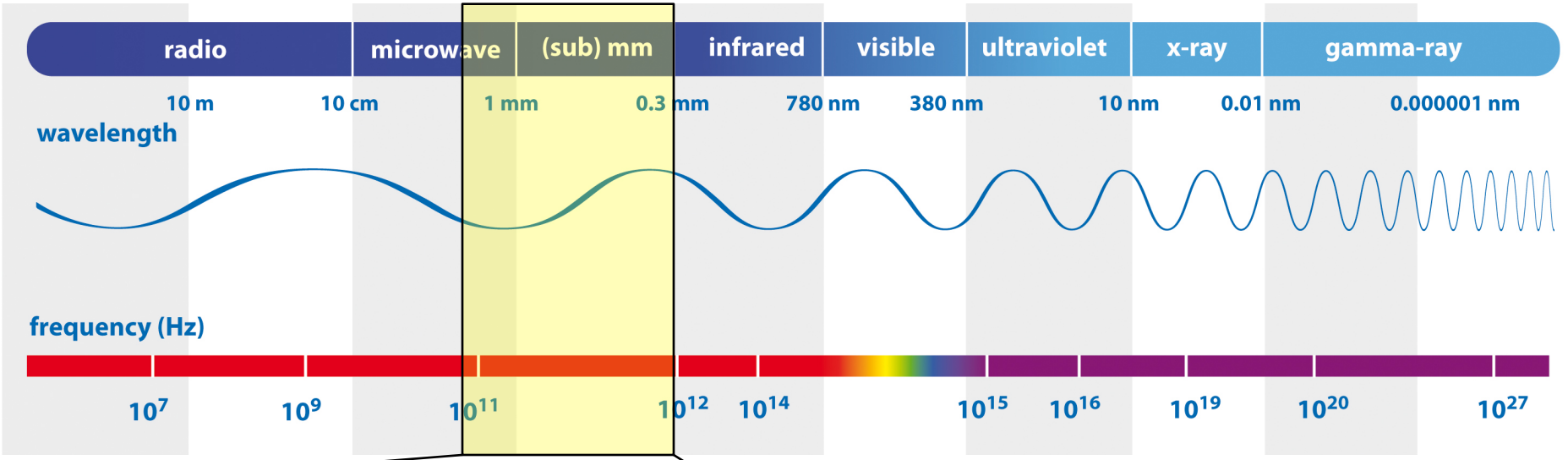
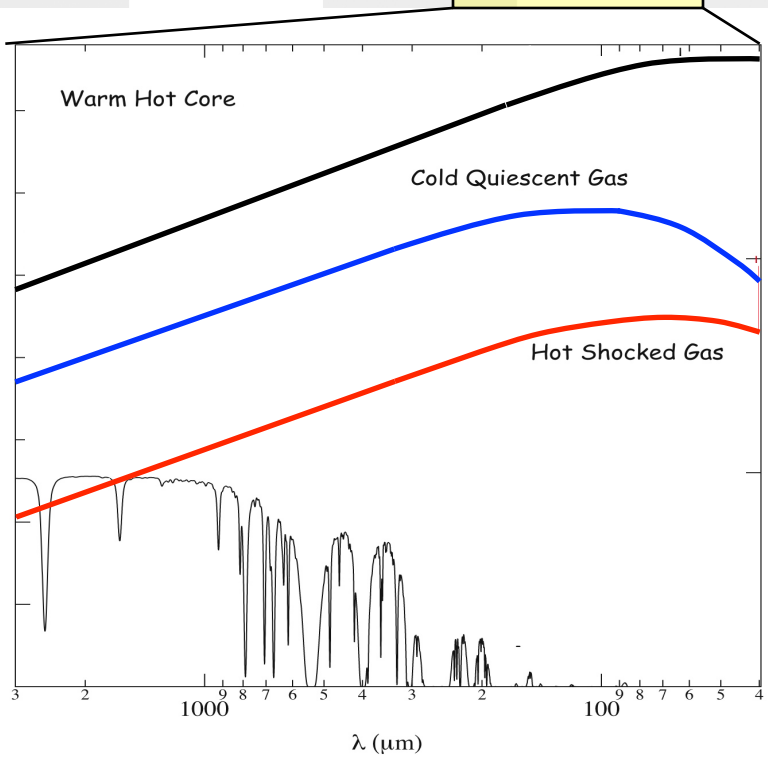

radio
microwave
(sub) mm
infrared
visible
ultraviolet
x-ray
gamma-ray
10 m
10 cm
1 mm
0.3 mm
780 nm
380 nm
10 nm
0.01 nm
0.000001 nm
wavelength
frequency (Hz)
10^7
10^9
10^11
10^12
10^14
10^15
10^16
10^19
10^20
10^27



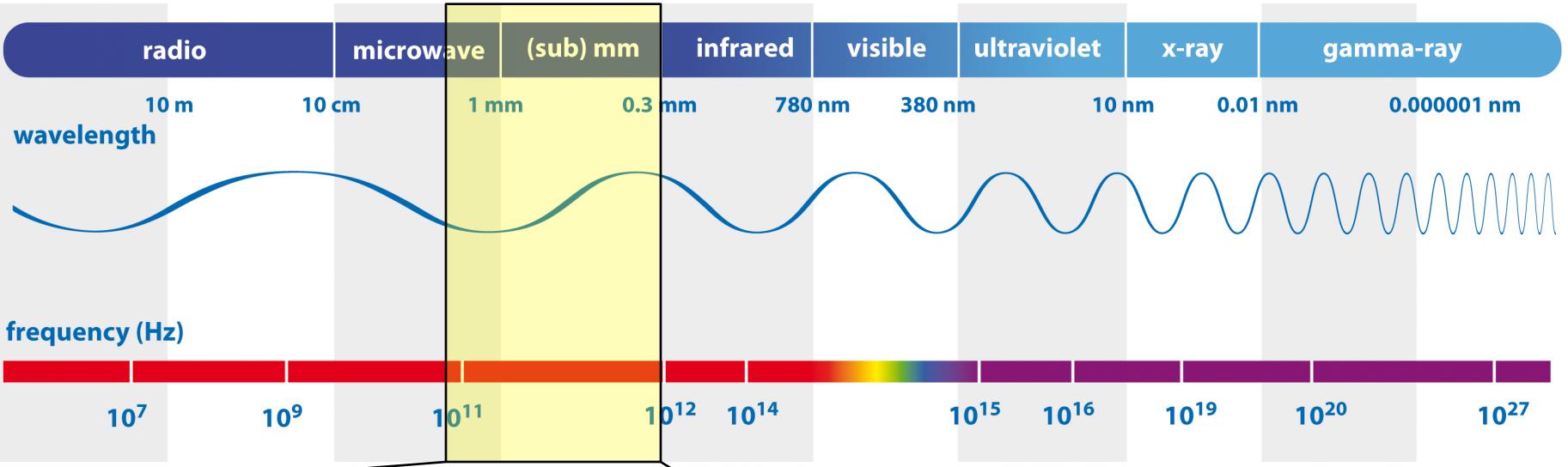
ALMA observable range

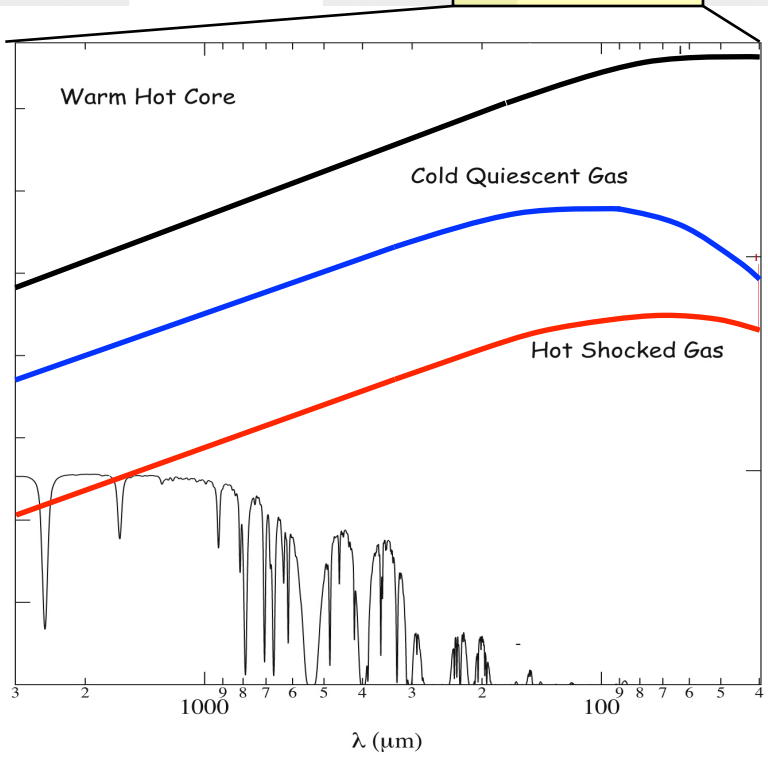
"**Cold Universe**"

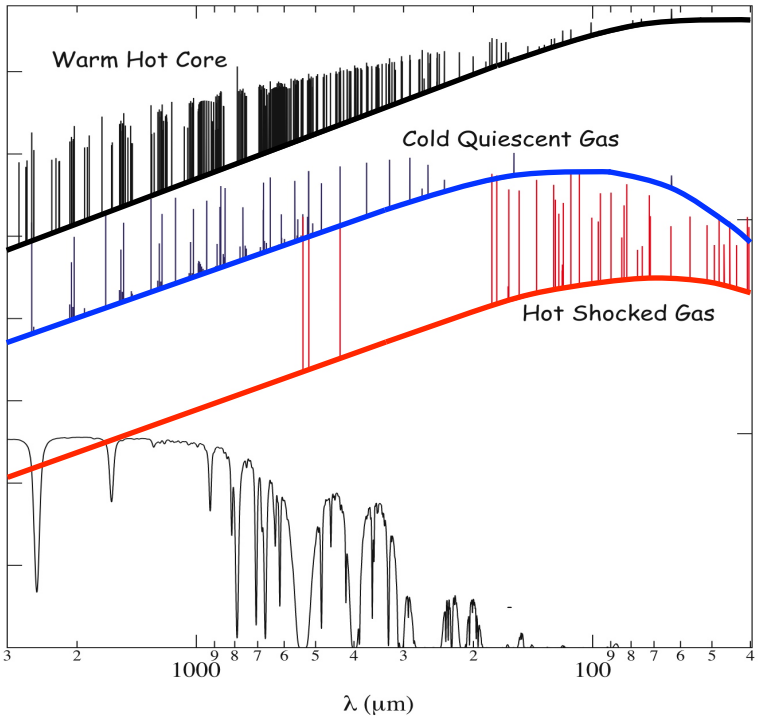




continuum emission



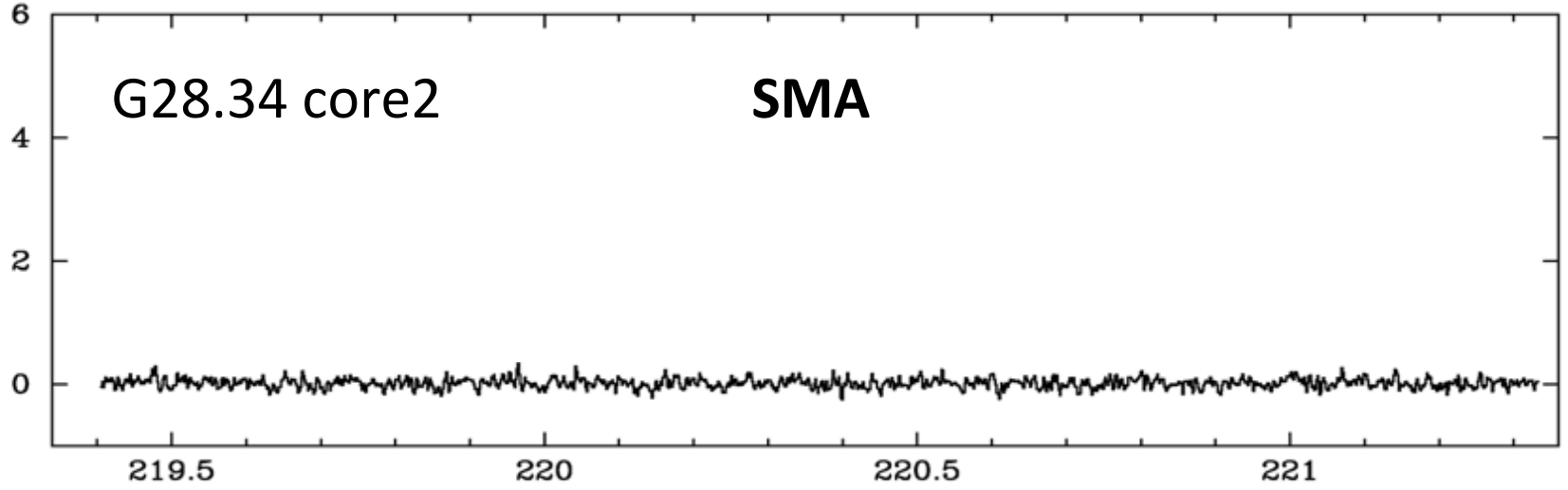




continuum emission

line emission

Can we detect spectral lines?



Zhang et al (2008)

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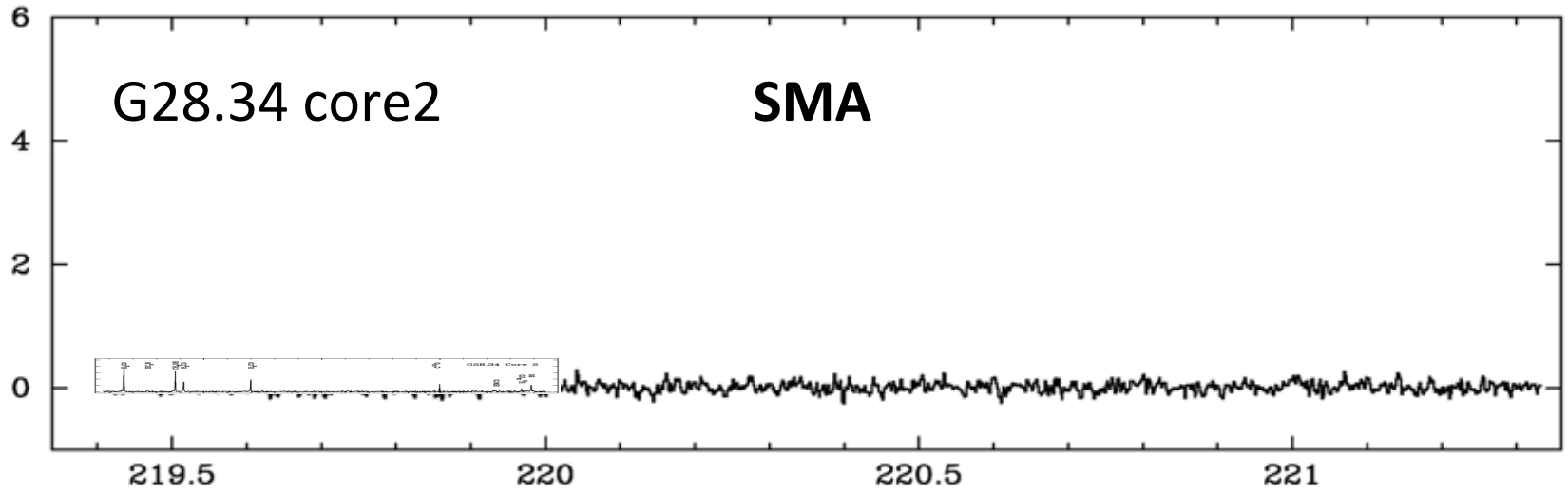

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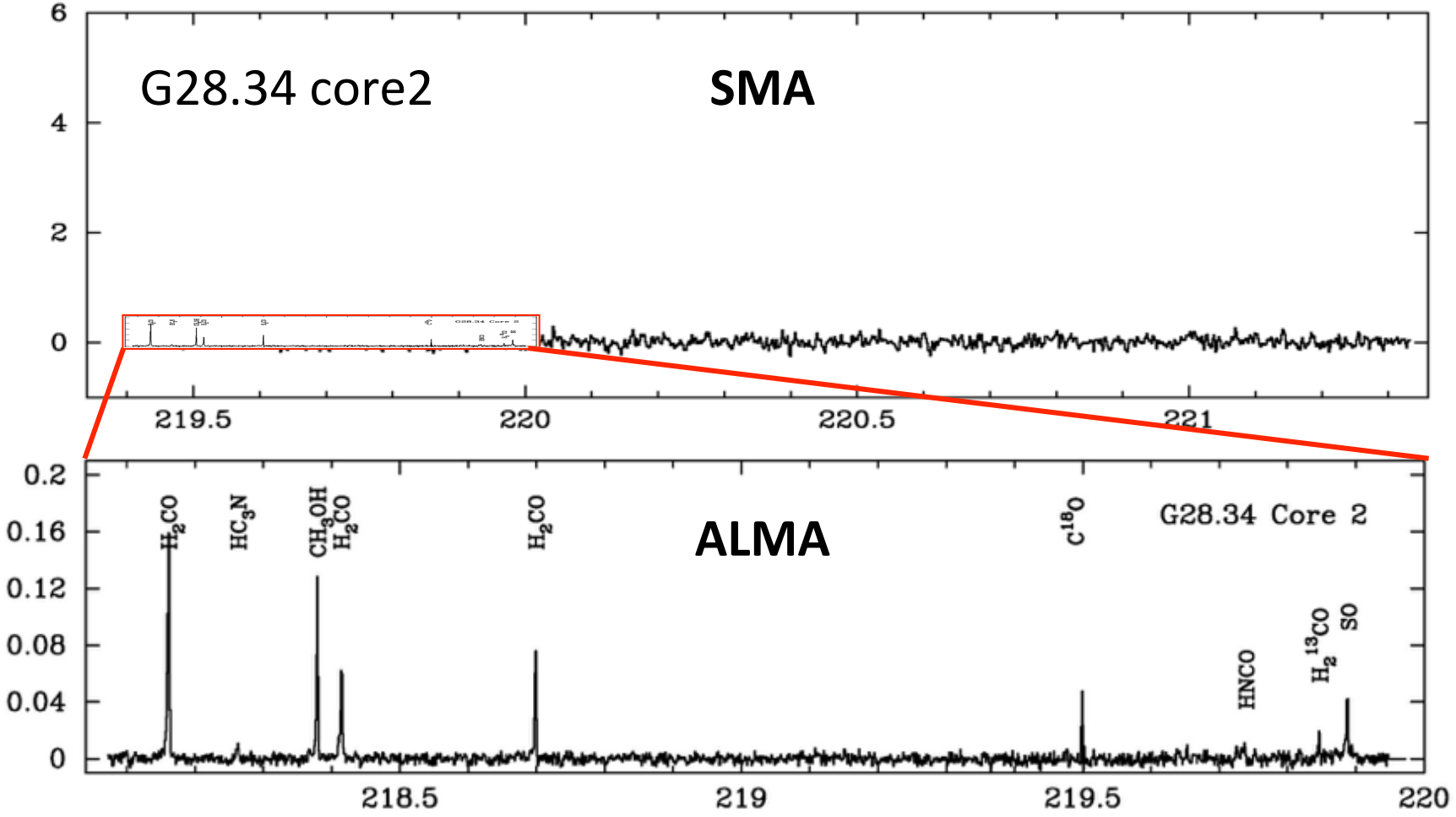
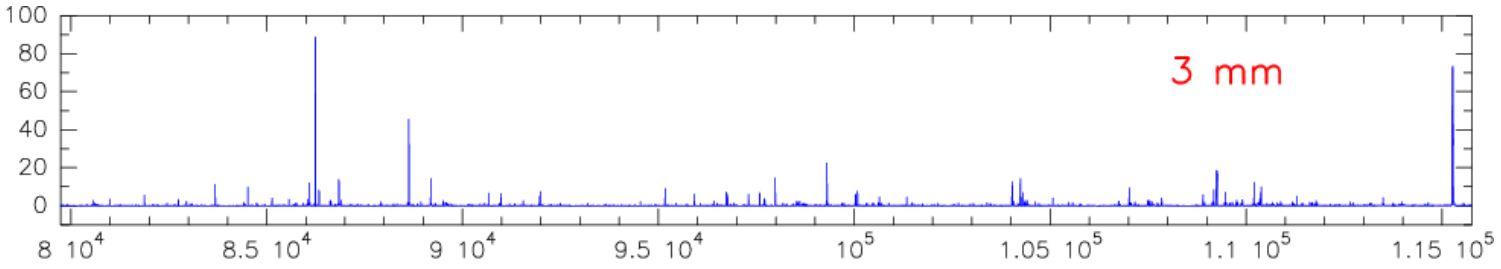


Can we detect spectral lines?

When sensitivity can be a problem
... entering the ALMA era



Tercero et al (2010)

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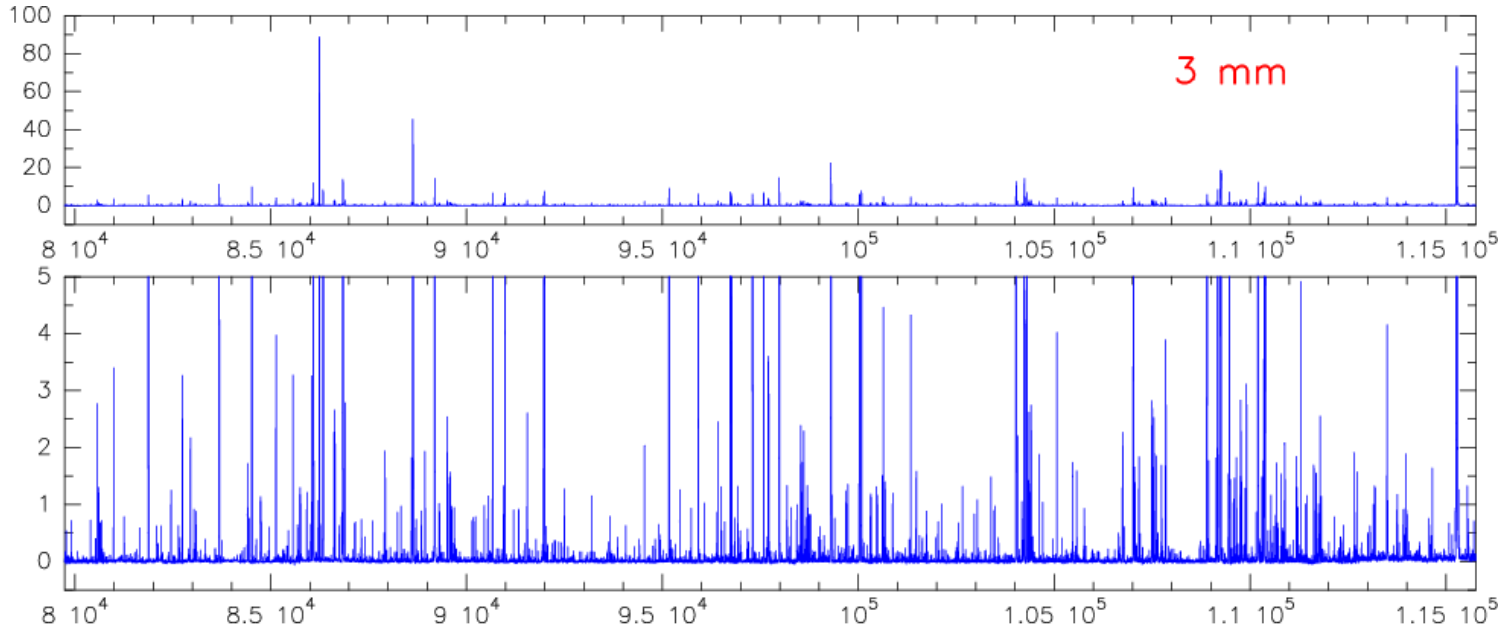

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When sensitivity can be a problem
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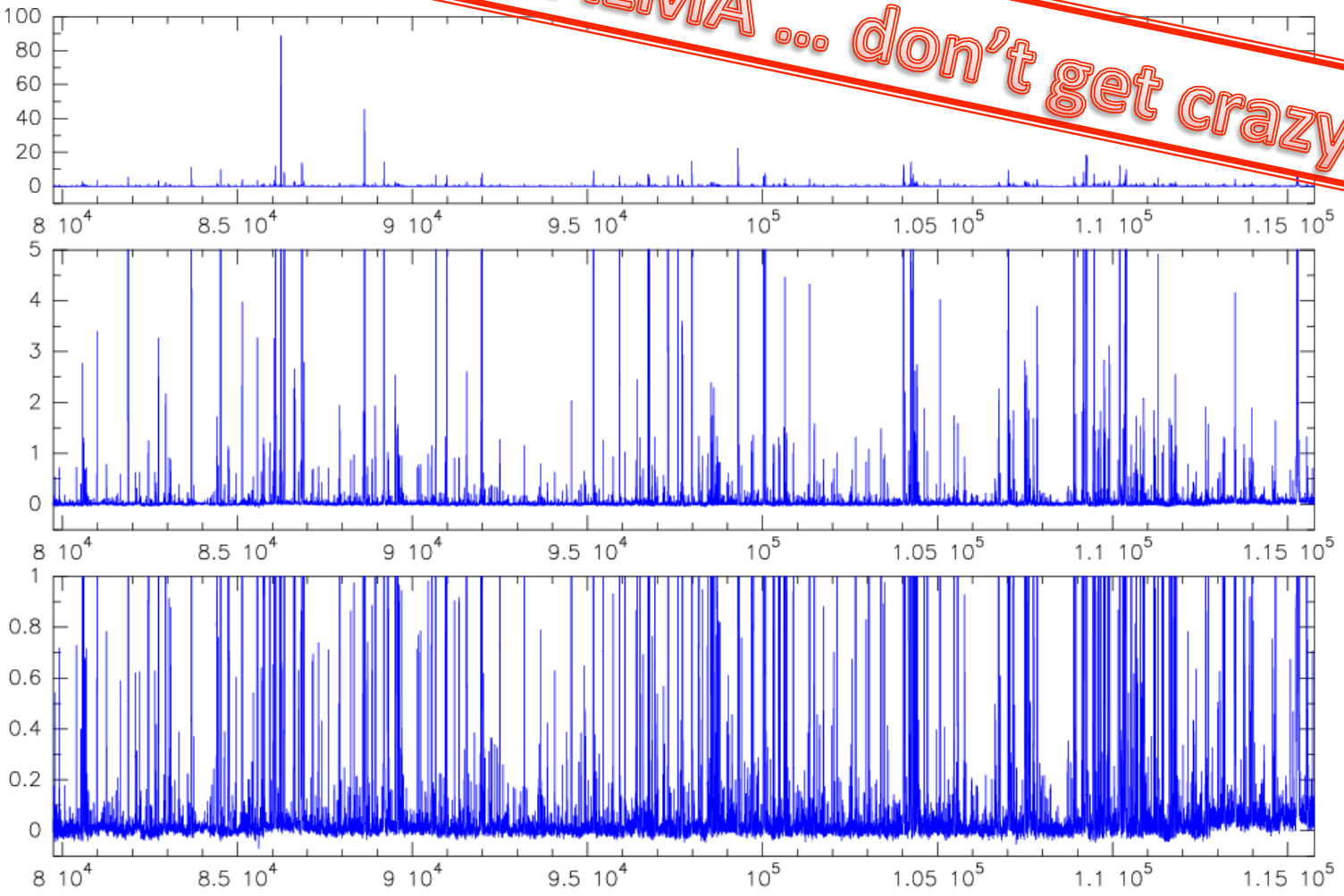
With ALMA ... don't get crazy!



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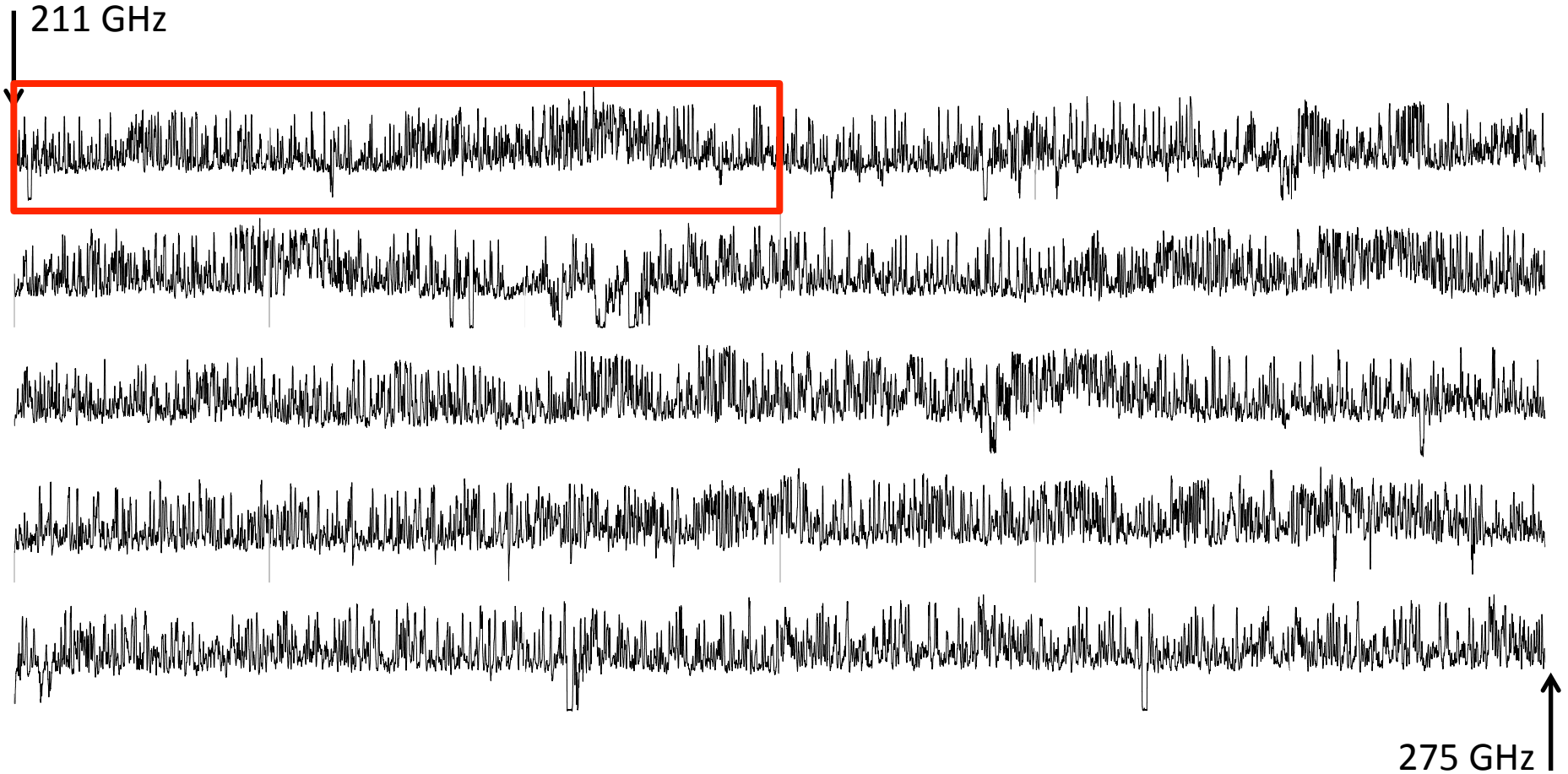
Can we detect spectral lines?

Spectrum (211-275 GHz) towards 1 single pixel



Sánchez-Monge et al (2017)

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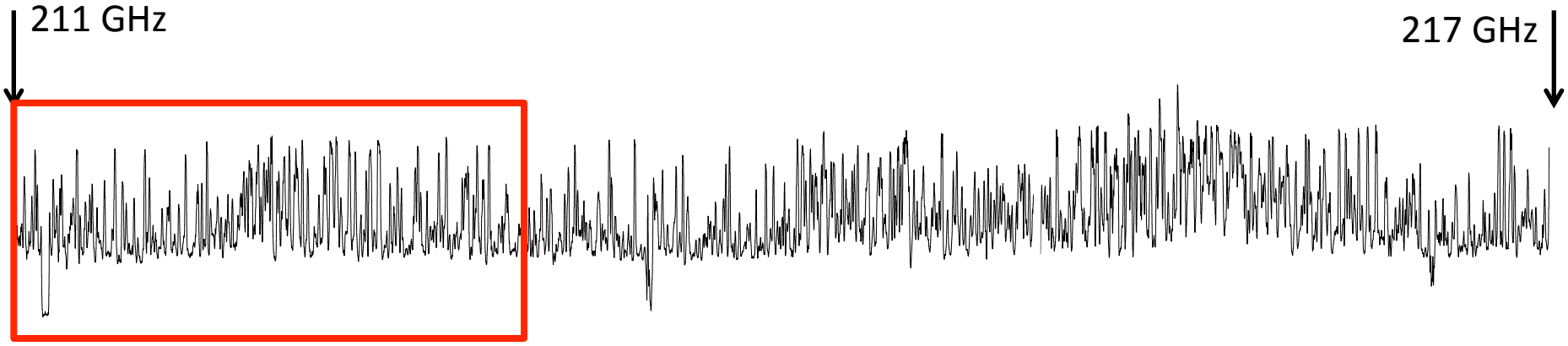

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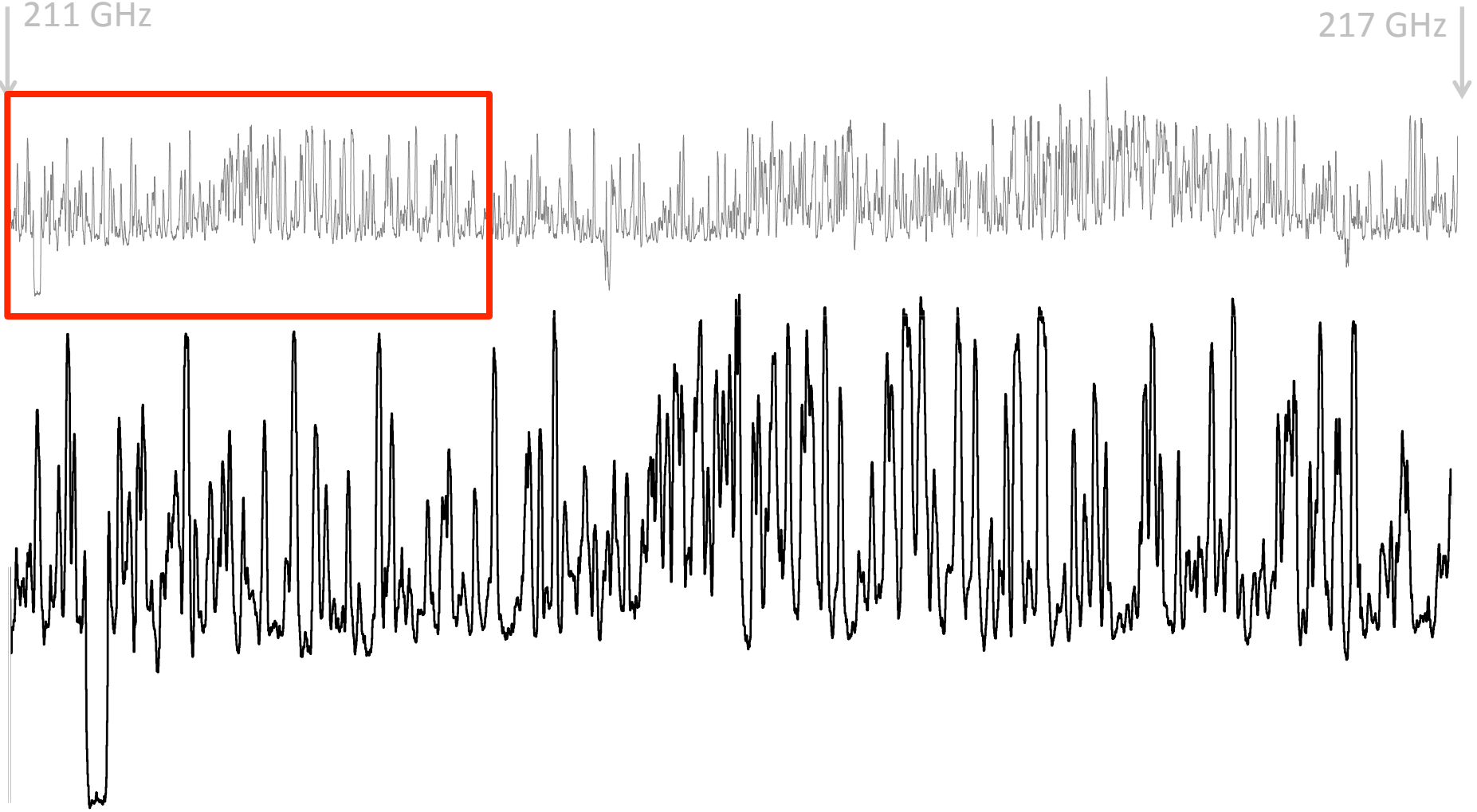

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Can we detect spectral lines?

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What do you want to observe?

continuum emission

line emission

both (continuum and line)

What do you want to observe?

continuum emission

- which frequency/wavelength (band)
- intensity of the source (rms) [see next Section]
- spatial distribution (beam, LAS) [see previous Section]

line emission

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What do you want to observe?

continuum emission

- which frequency/wavelength (band)
- intensity of the source (rms) [see next Section]
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line emission

- which line (frequency, band)
- intensity of the source (rms) [see next Section]
- spatial distribution (beam, LAS) [see previous Section]
- line shape (bandwidth, spectral resolution)

both (continuum and line)

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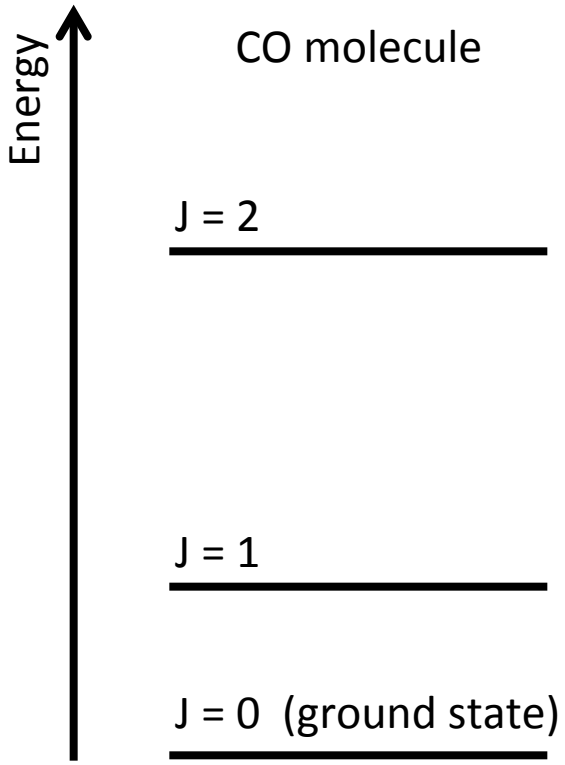
Basic concepts of spectral line observations

Rest frequency

Basic concepts of spectral line observations

Rest frequency

spectral line: transition between two different energy levels of a molecule, atom or ion



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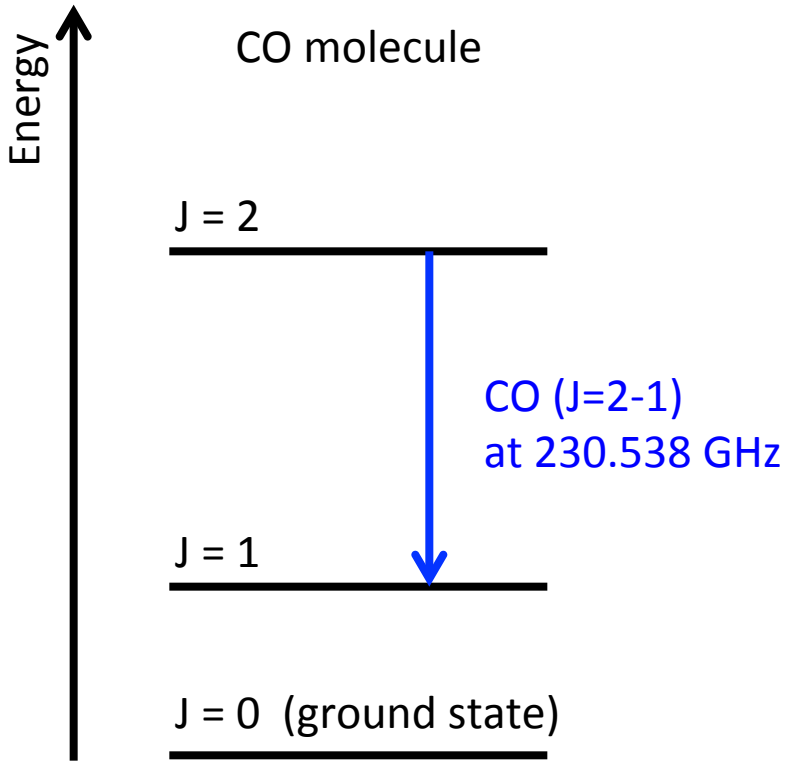

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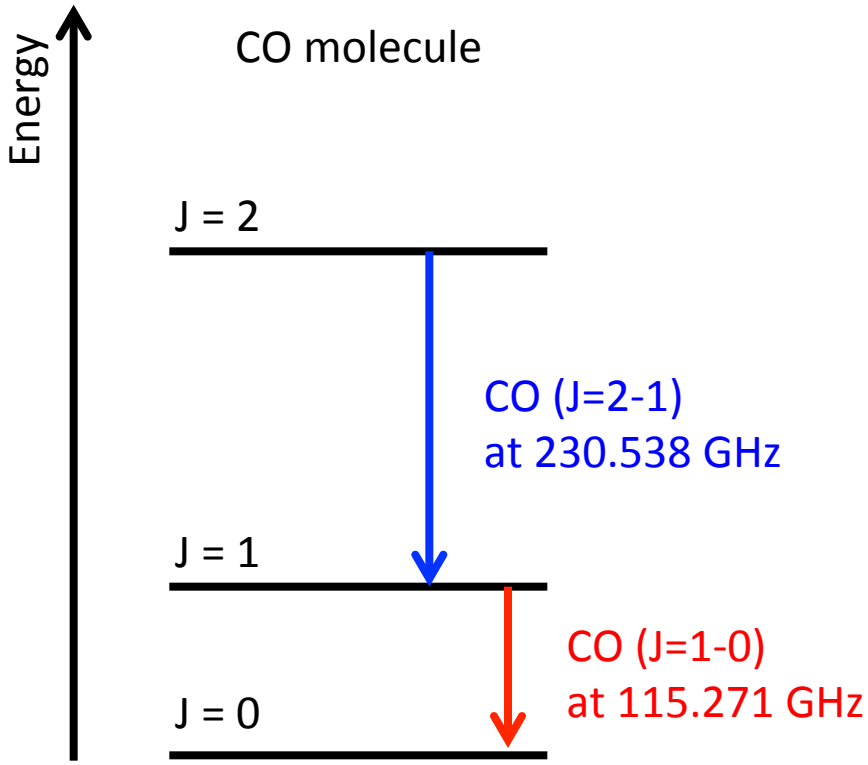

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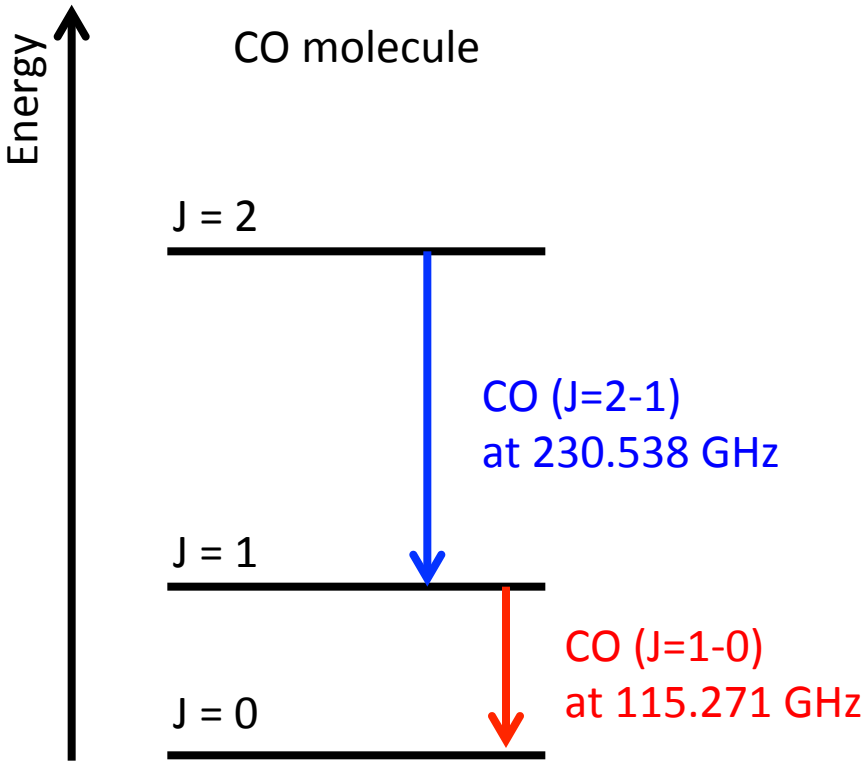

Rest frequencies can be found in molecular databases:

CDMS
www.astro.uni-koeln.de/cdms

JPL
spec.jpl.nasa.gov

Splatalogue
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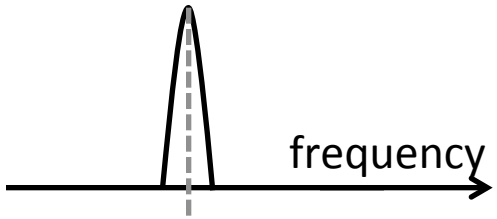

source
with v = 0

230.538 GHz
Band 6

Basic concepts of spectral line observations

Velocity (Vlsr) / redshift (z)

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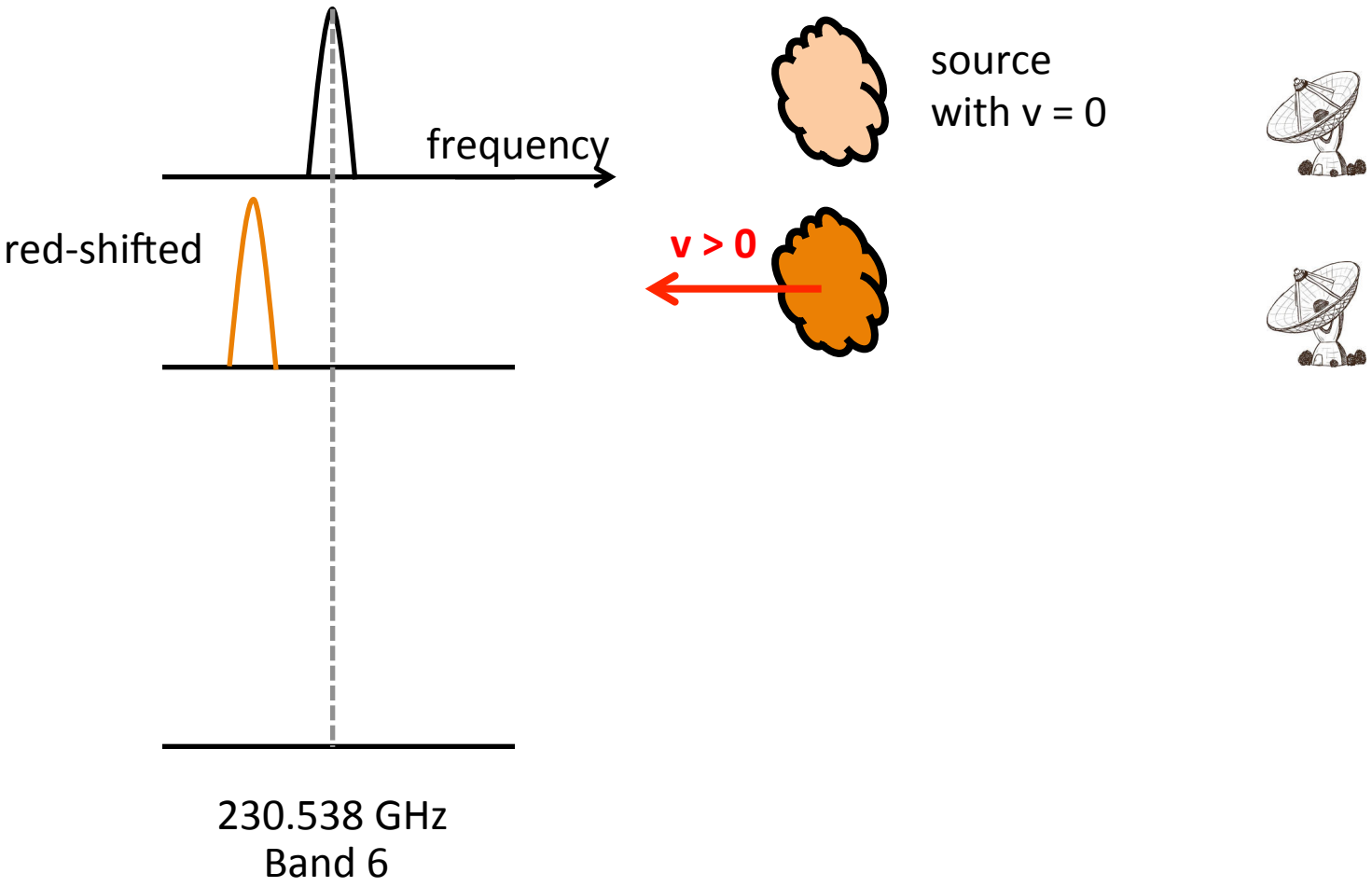

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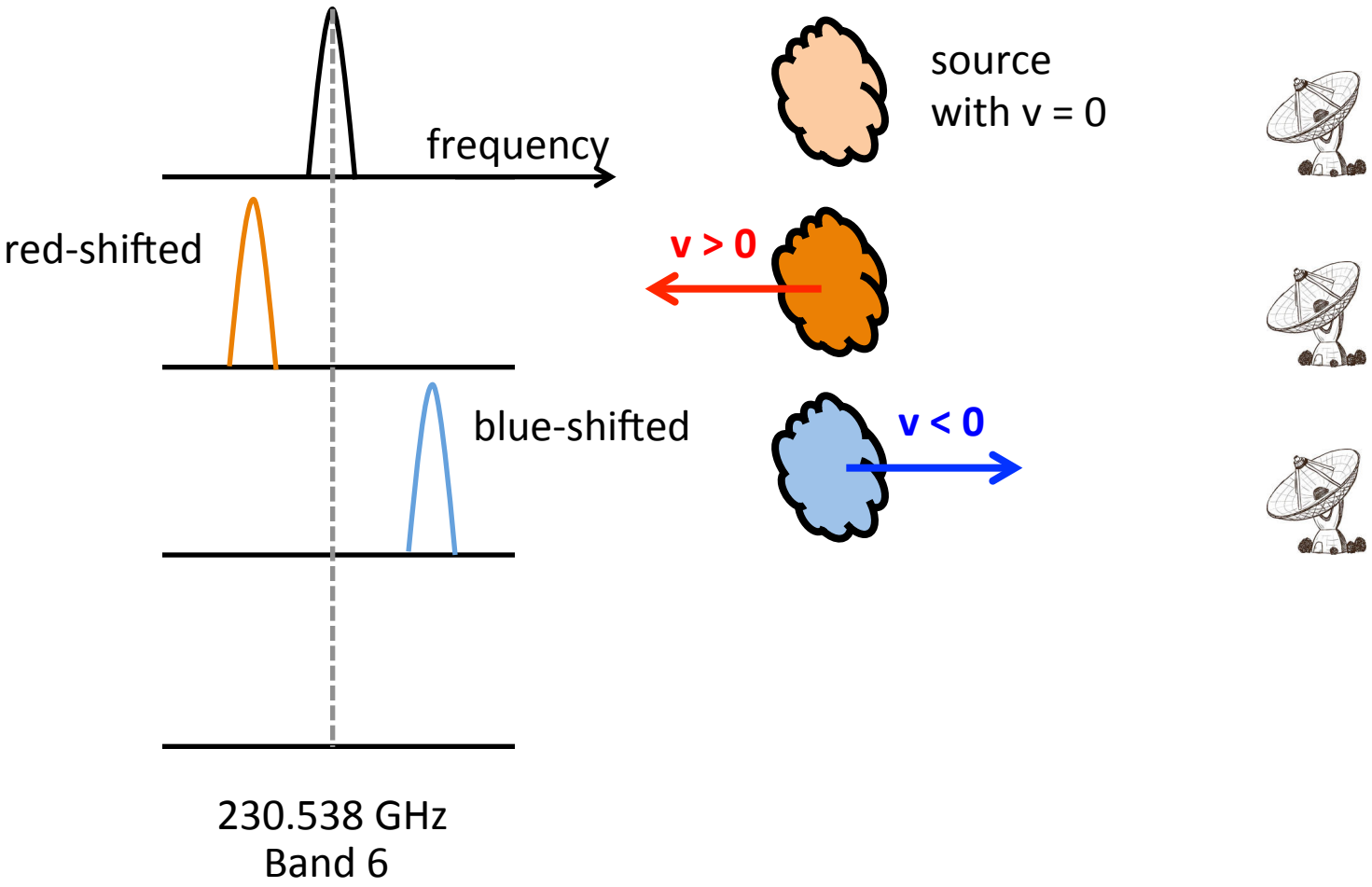

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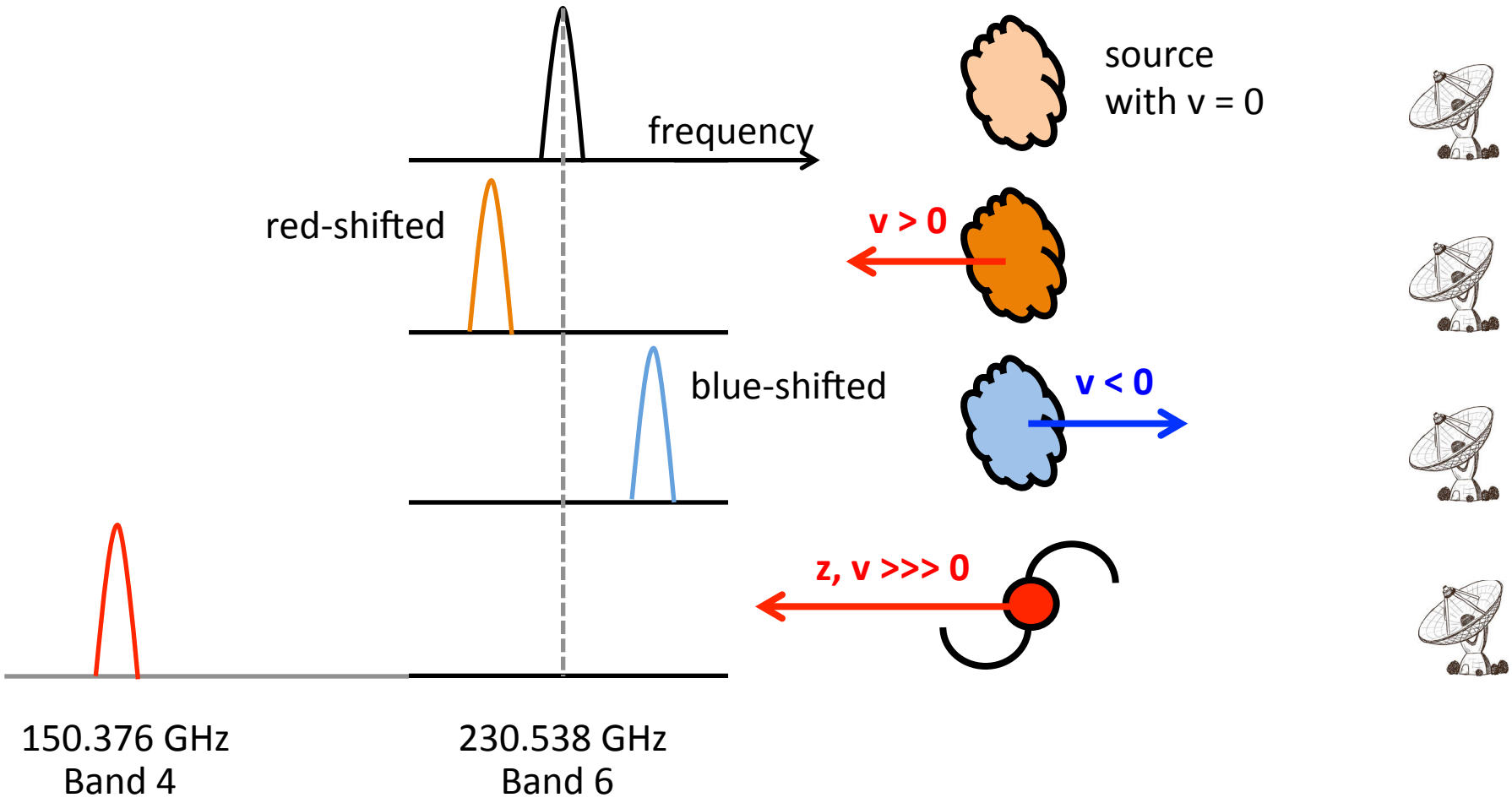

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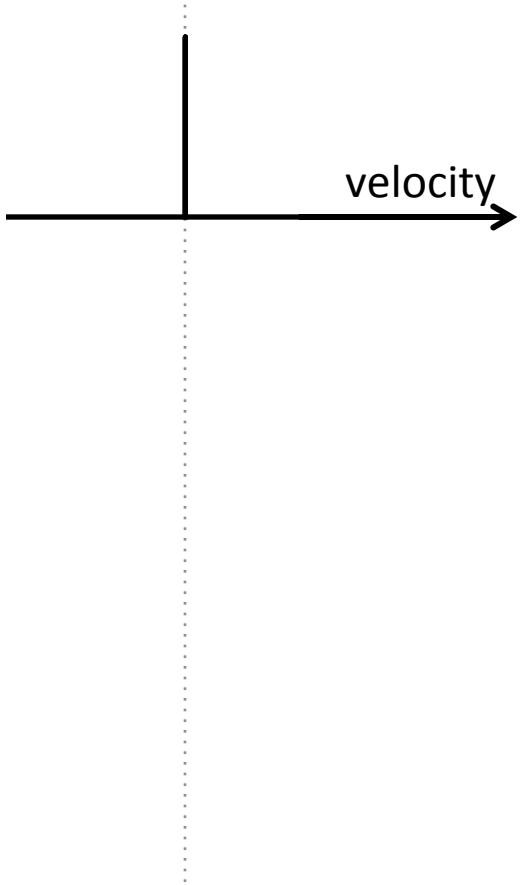

each spectral line has an exact frequency

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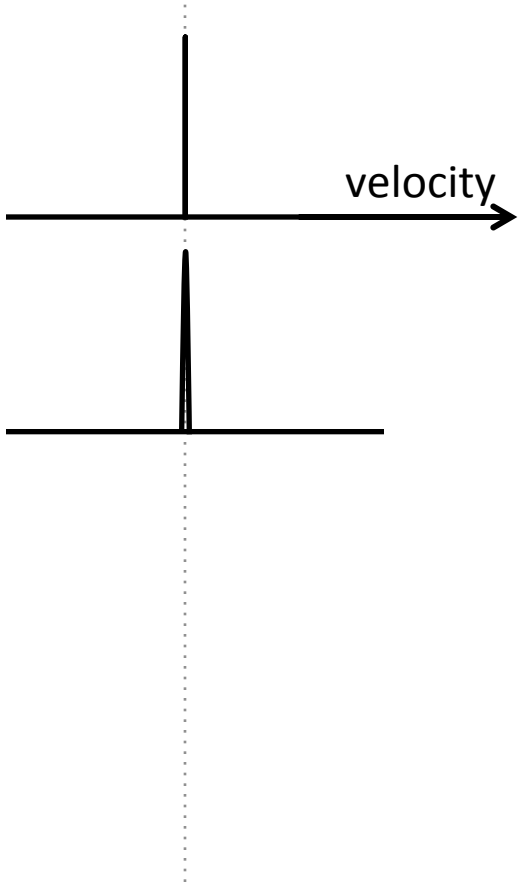

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natural broadening

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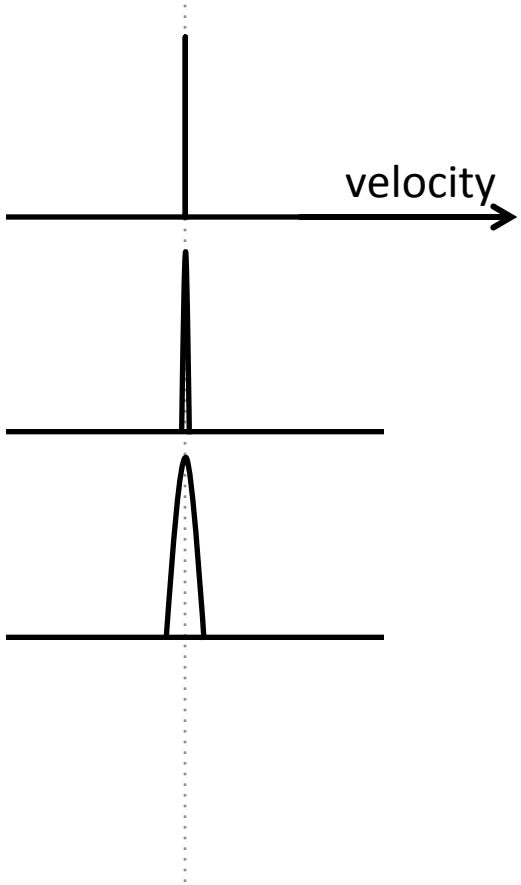

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natural broadening

thermal, microturbulent, pressure broadening

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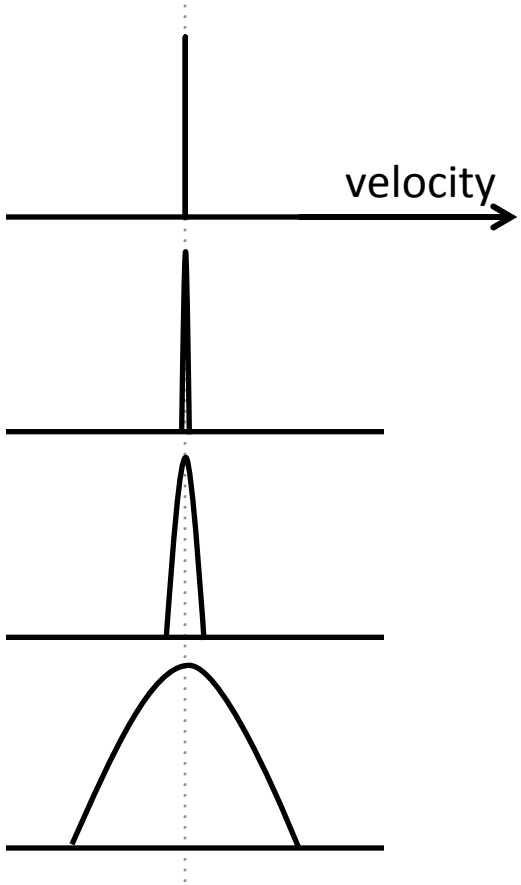

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large-scale motions broadening

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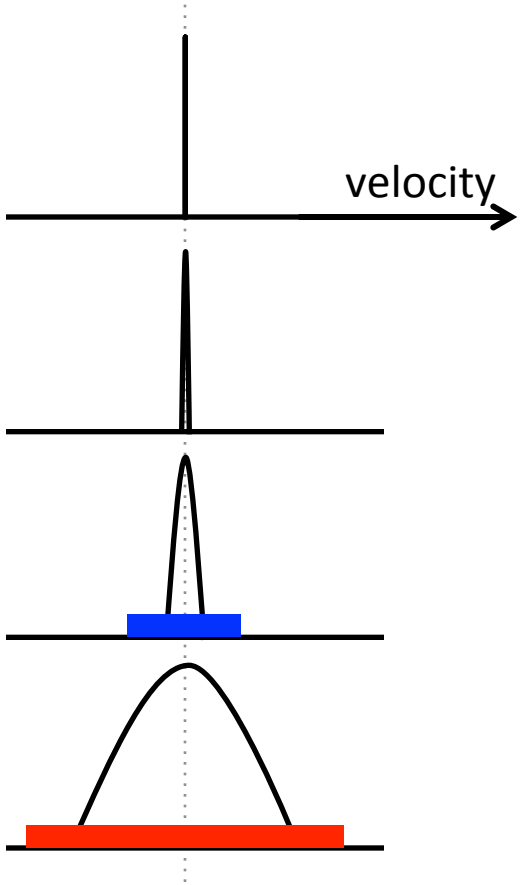

Depending on the linewidth of the line, you will cover a **narrower**/**broader** frequency (velocity) range

Basic concepts of spectral line observations

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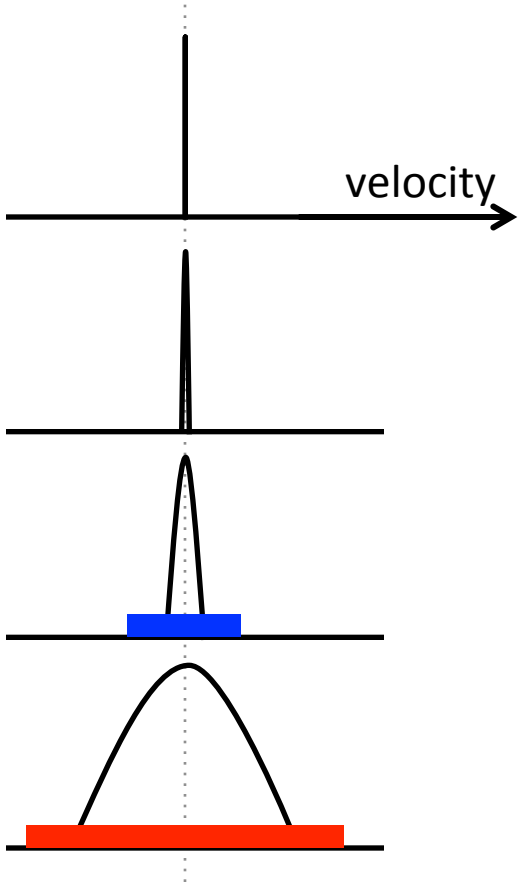


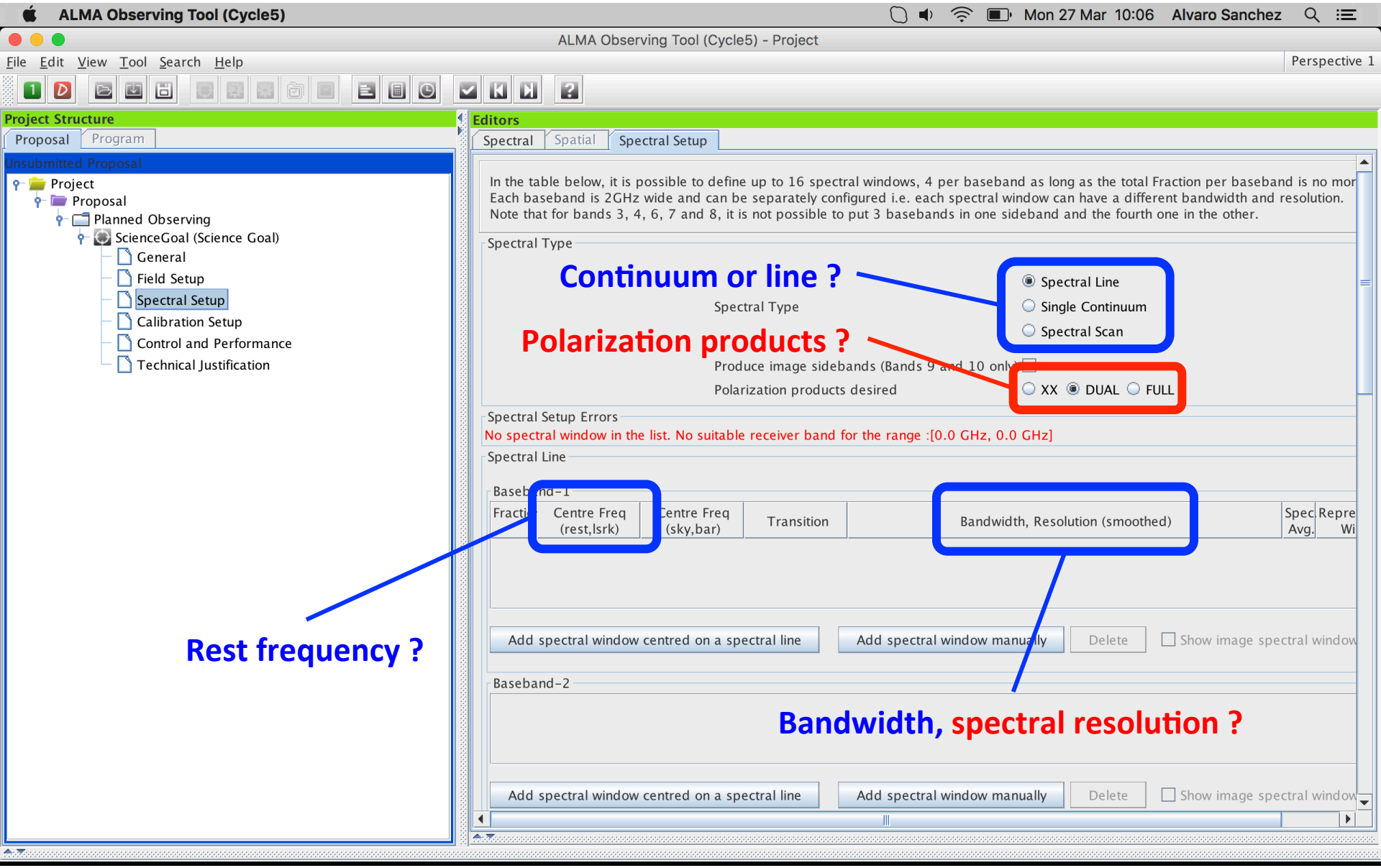
velocity linewidth (km/s)

frequency linewidth (Hz)

$$\Delta V = -\Delta\nu \frac{c}{\nu_0}$$

Depending on the linewidth of the line, you will cover a narrower/broader **frequency** (***velocity***) range

Spectral setup in the almaOT



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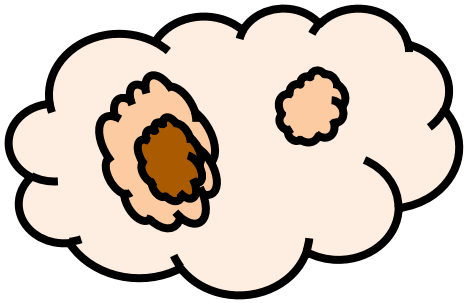
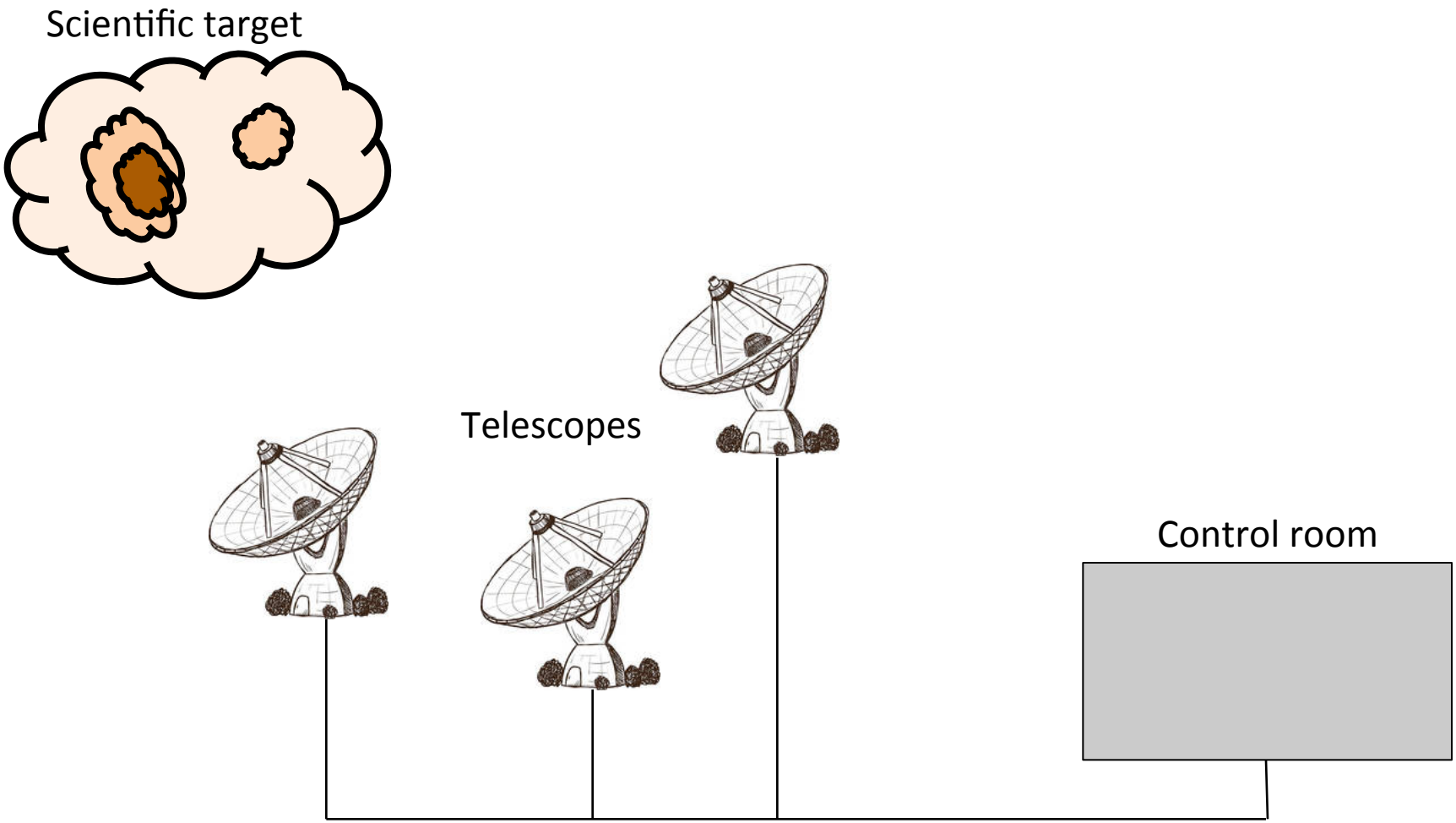
Spectral observations in a radio-interferometer

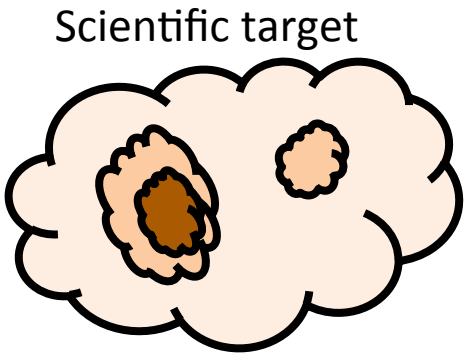
- frequency bands
- receivers
- correlator

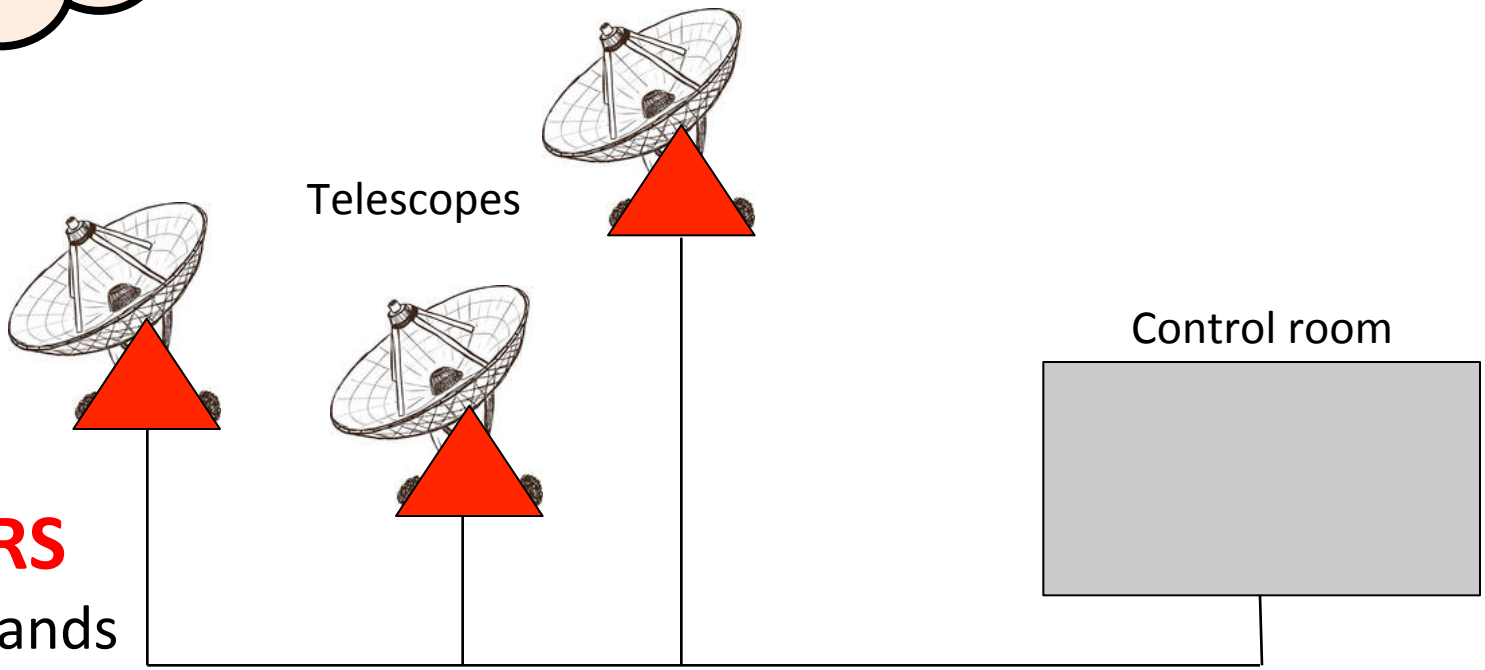
Scientific target



Telescopes

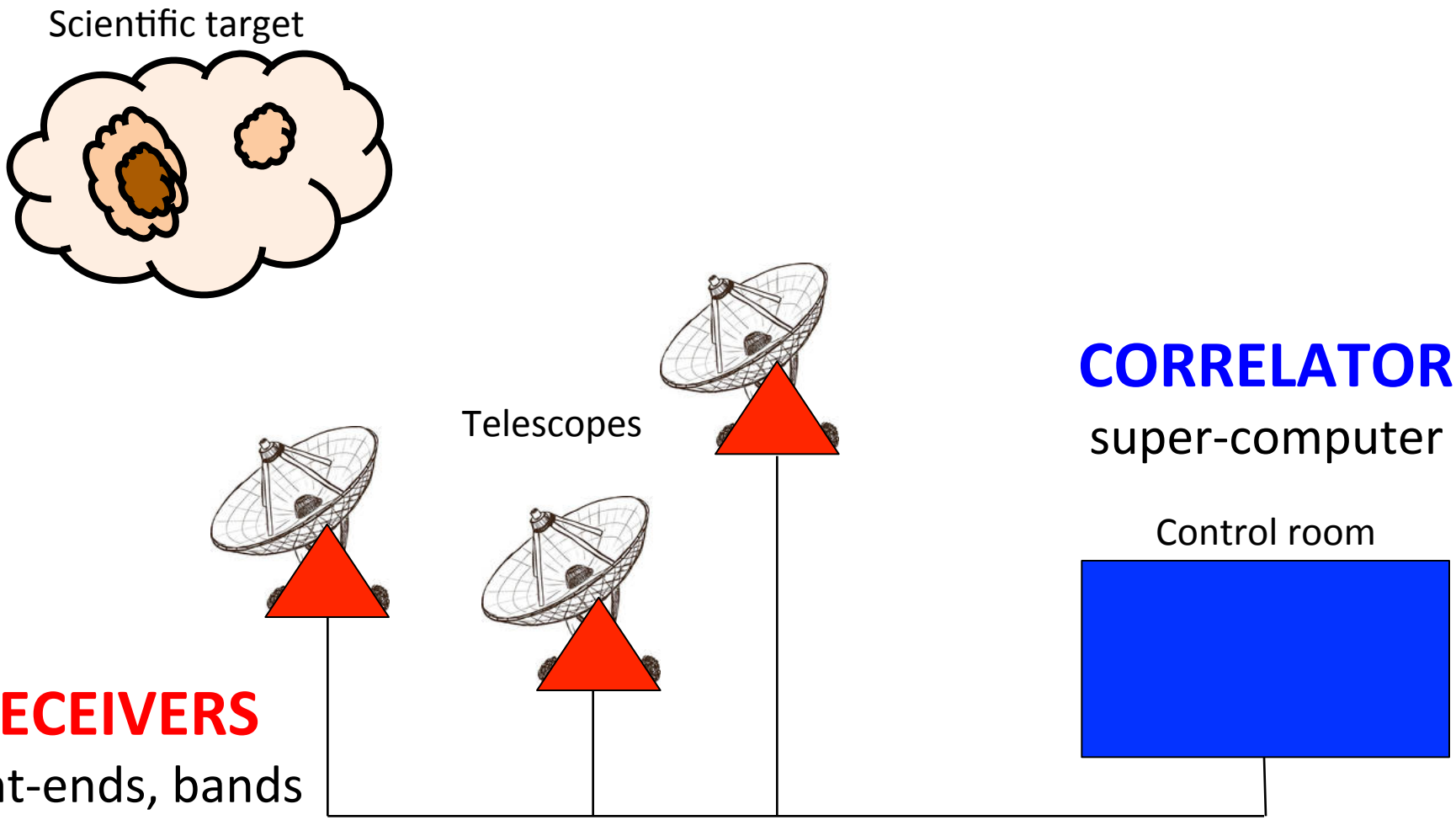

Scientific target
Telescopes
Control room



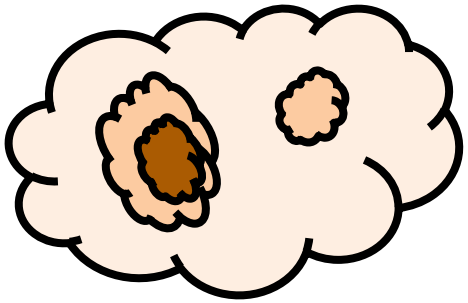


RECEIVERS

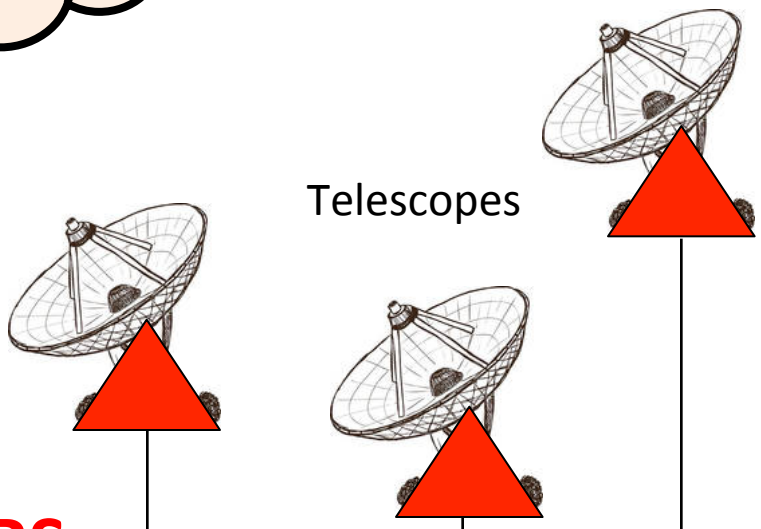
front-ends, bands


Scientific target
Telescopes
CORRELATOR
super-computer
Control room
RECEIVERS
front-ends, bands

Scientific target



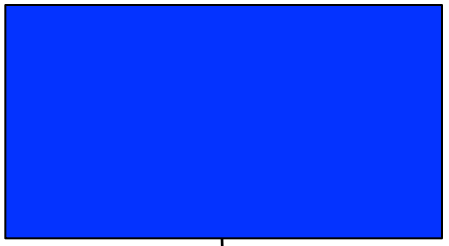
Telescopes



CORRELATOR

super-computer

Control room



RECEIVERS

front-ends, bands

WHAT frequencies do/can we observe?

HOW do/can we observe those frequencies?

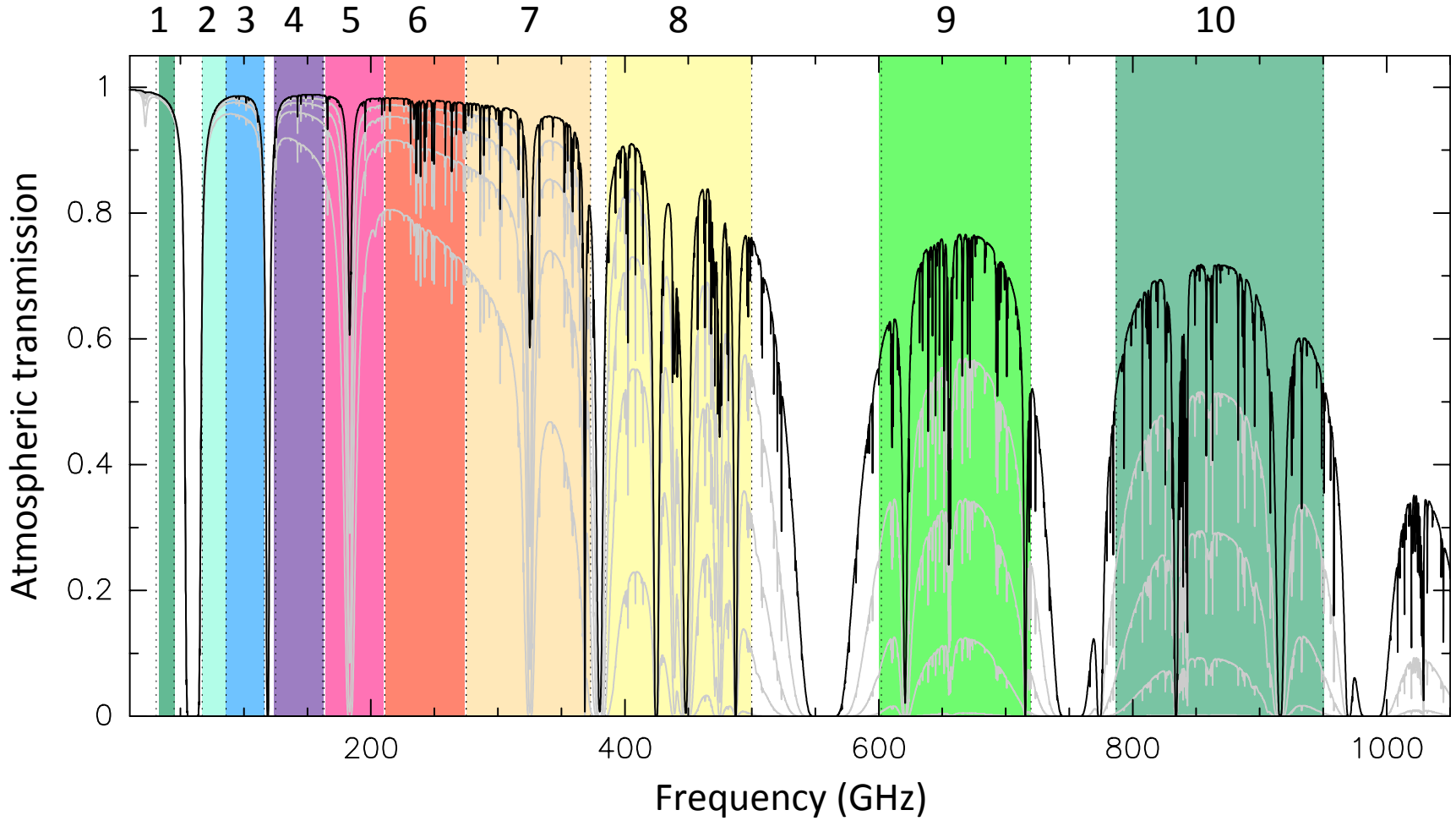
What do we need to know?

- continuum or line (both?)
- frequency of the lines to observe
- velocity /redshift of the source
- bandwidth / velocity coverage
- spectral resolution
- polarization products

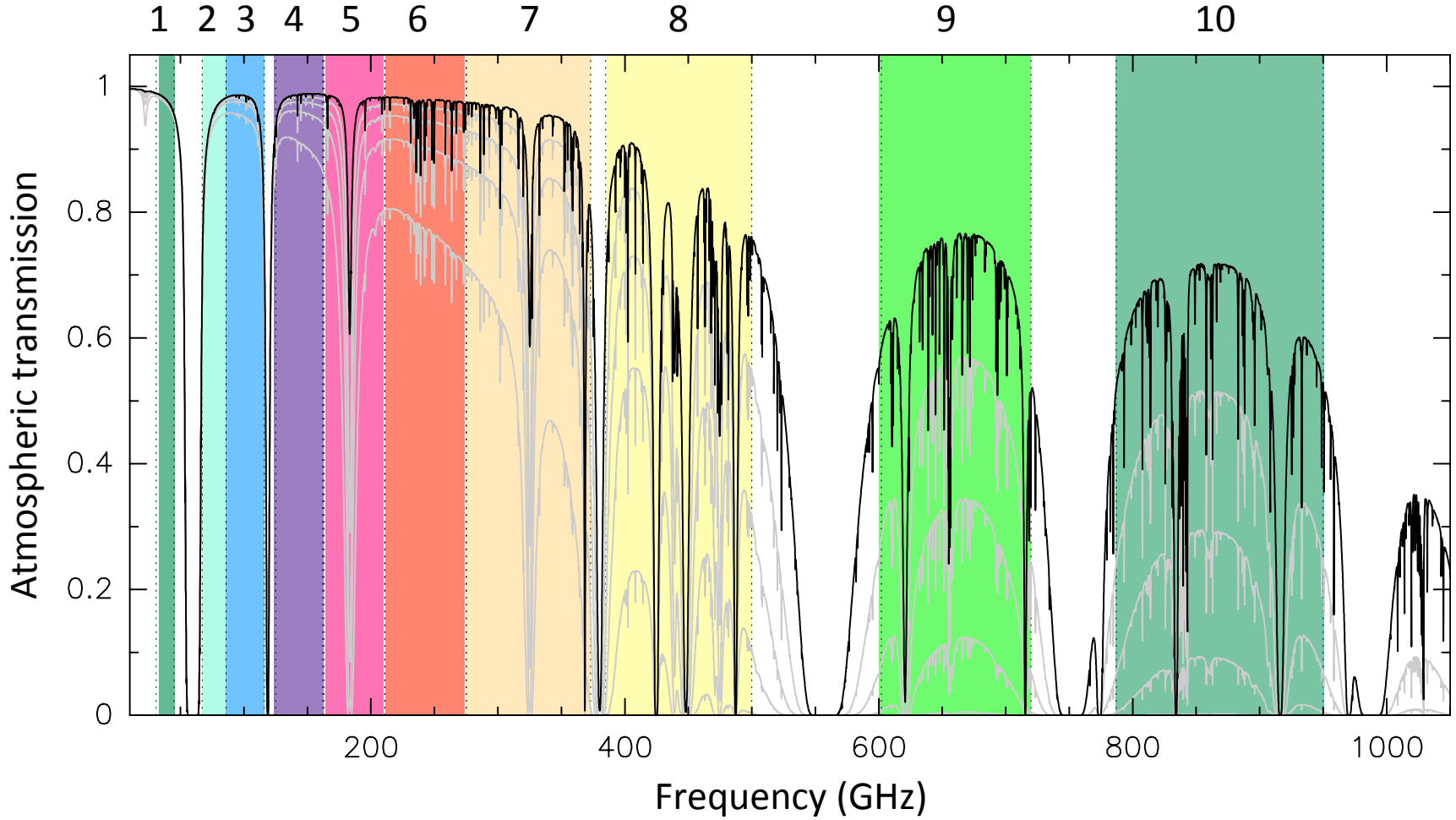
Spectral observations in a radio-interferometer

- **frequency bands**
- receivers
- correlator

ALMA frequency bands



ALMA frequency bands



Band 3: 84 – 116 GHz

Band 4: 125 – 163 GHz

Band 5: 159 – 211 GHz

Band 6: 211 – 275 GHz

Band 7/8: 275 – 373 GHz / 385 – 500 GHz

Band 9/10: 602 – 720 GHz / 787 – 950 GHz

What do we need to know?

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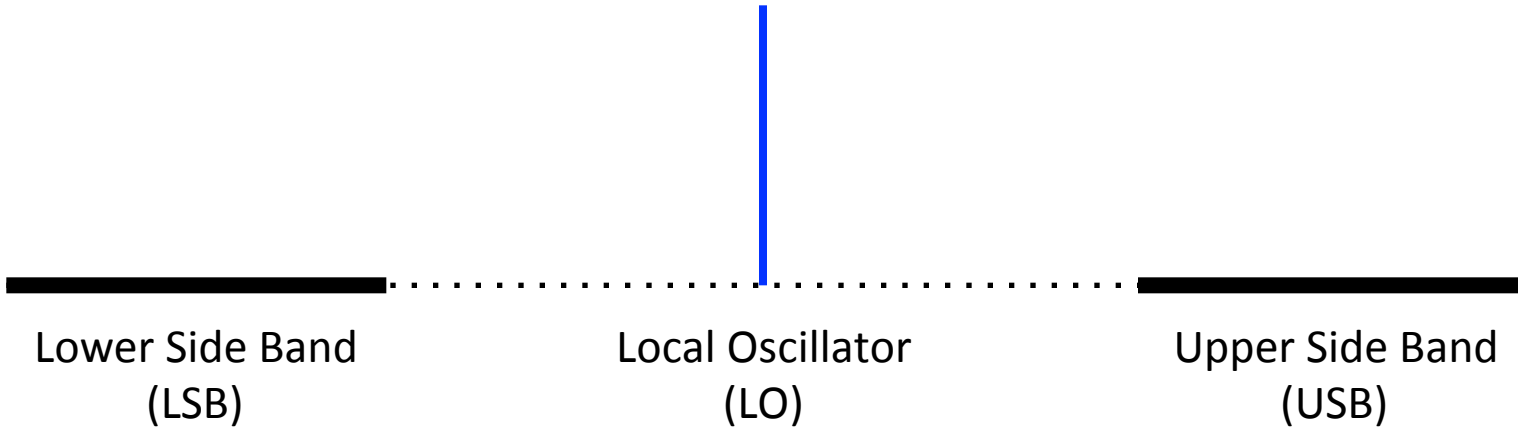
Spectral observations in a radio-interferometer

- frequency bands
- **receivers**
- correlator

ALMA receivers

Heterodyne receivers
are sensitive to Lower Side Band (LSB) and Upper Side Band (USB)



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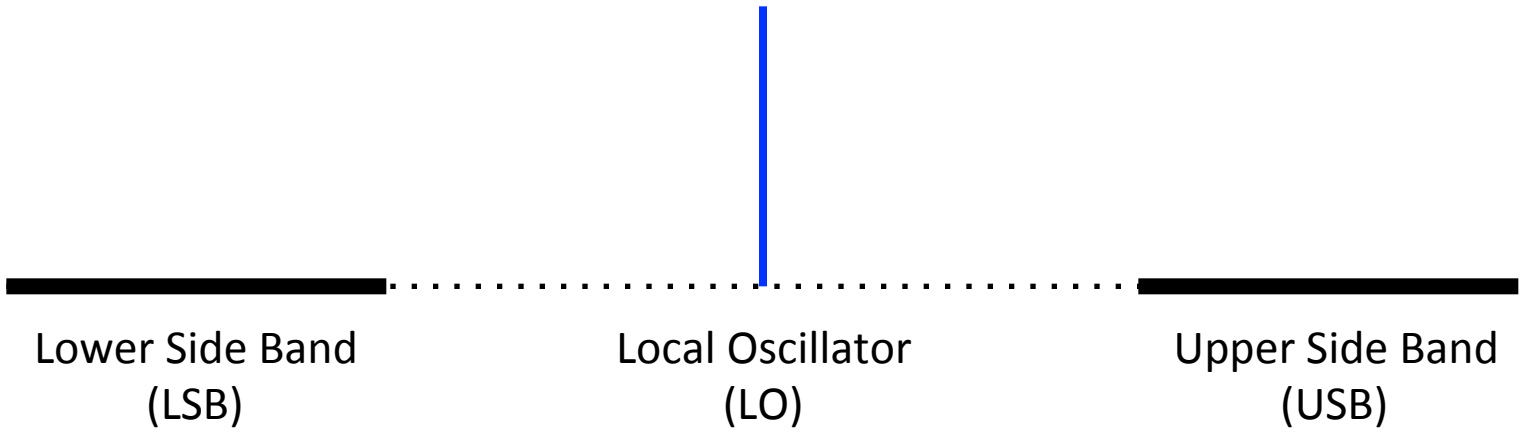
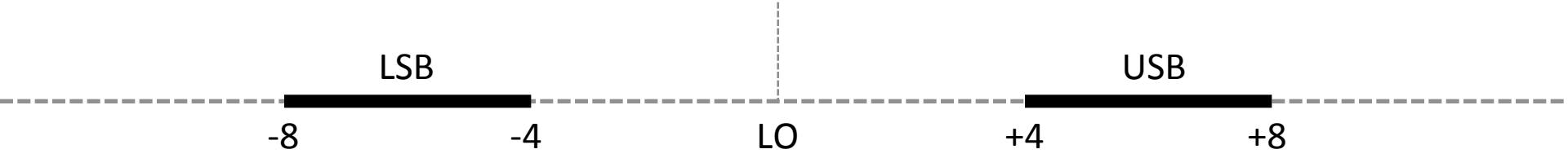


Heterodyne receivers can be:

SSB (single) outputs LSB **or** USB
DSB (double) outputs the sum LSB+USB (separated in correlator)
2SB (two) outputs LSB **and** USB (separately)

ALMA receivers

ALMA B3 / B4 / B5 / B7 / B8 2SB receivers 4-8 GHz



ALMA receivers

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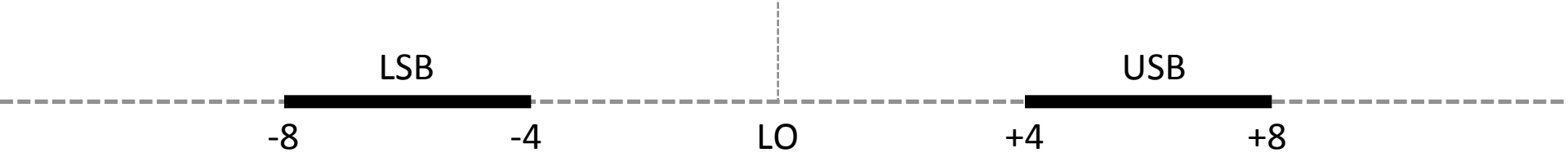
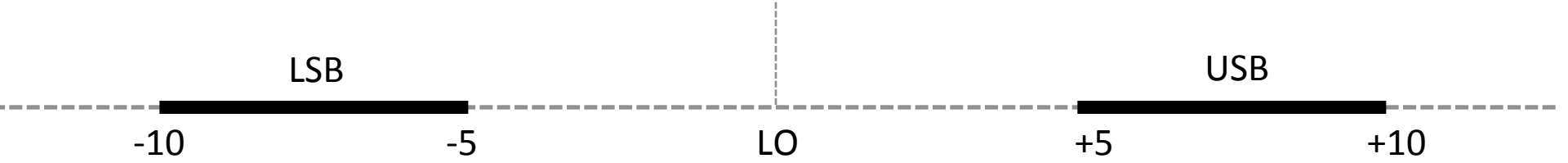


ALMA B6 2SB receivers 5-10 GHz



ALMA receivers

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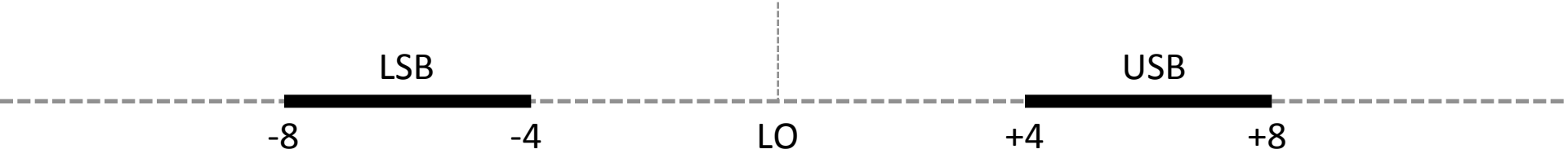

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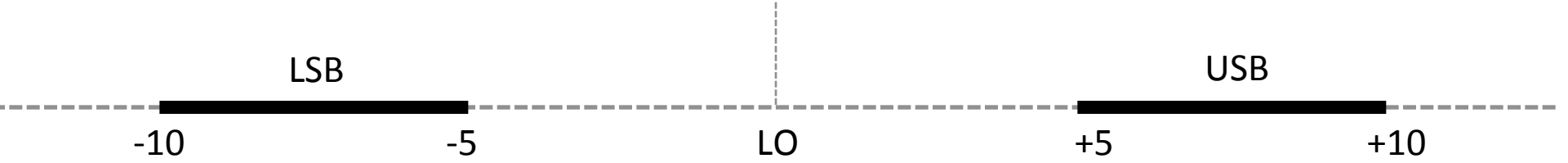
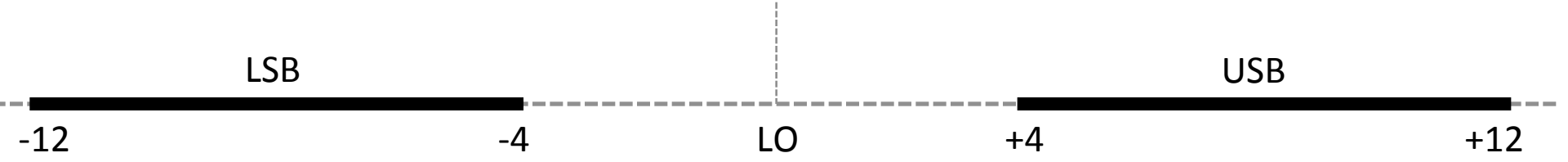


ALMA B9 / B10 DSB receivers 4-12 GHz



ALMA frequency bands & receivers

Band 3:	84 – 116 GHz	Band 7:	275 – 373 GHz
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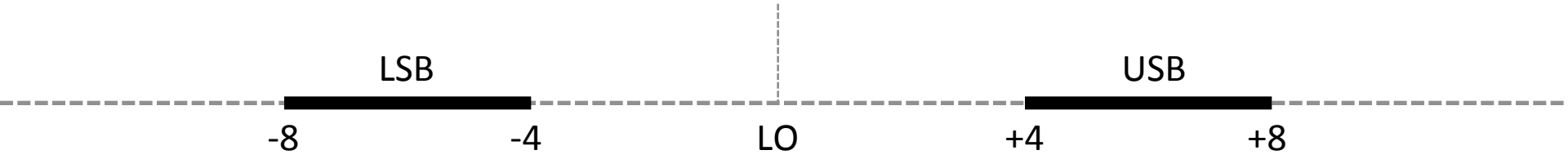

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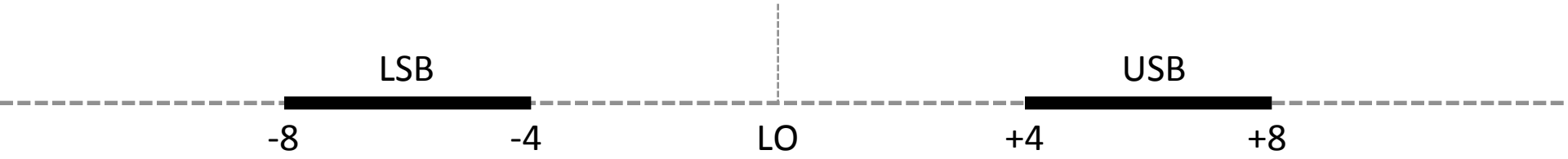

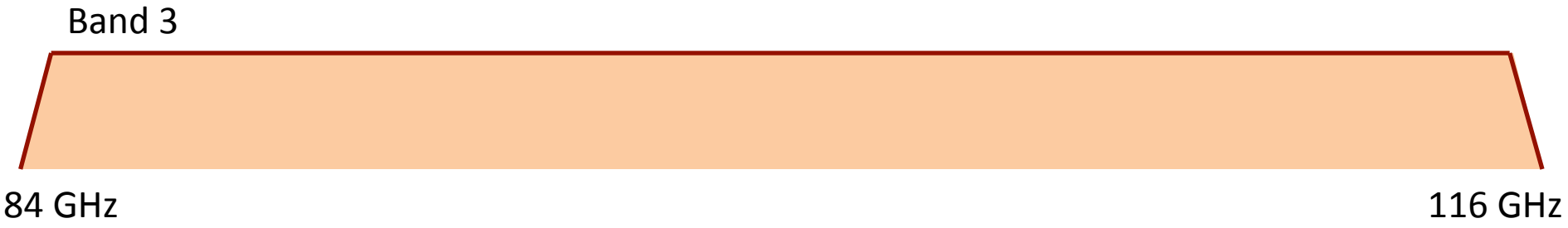

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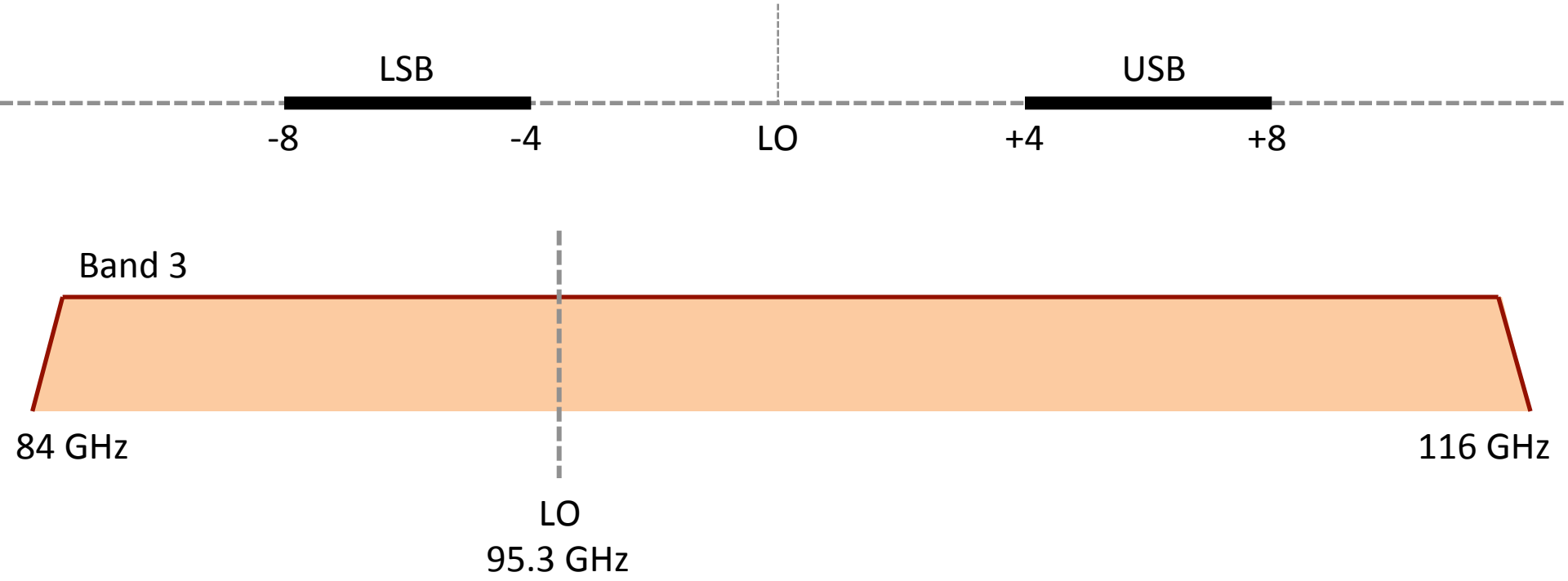

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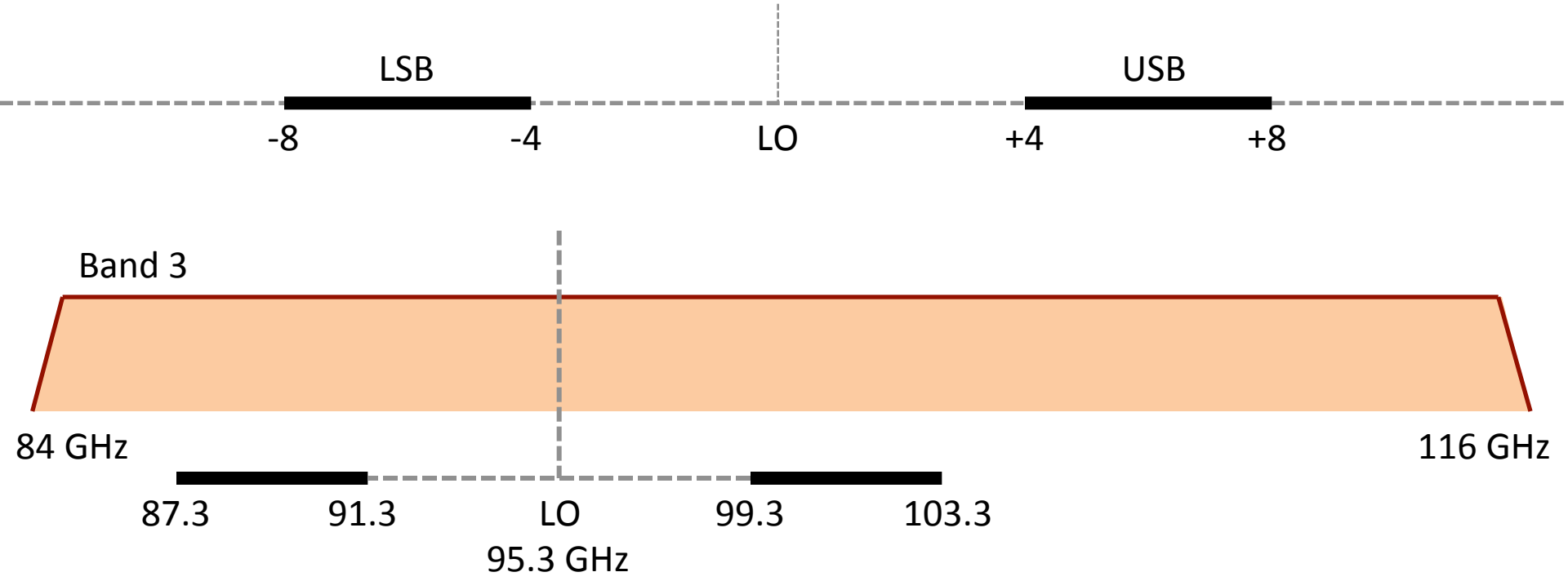

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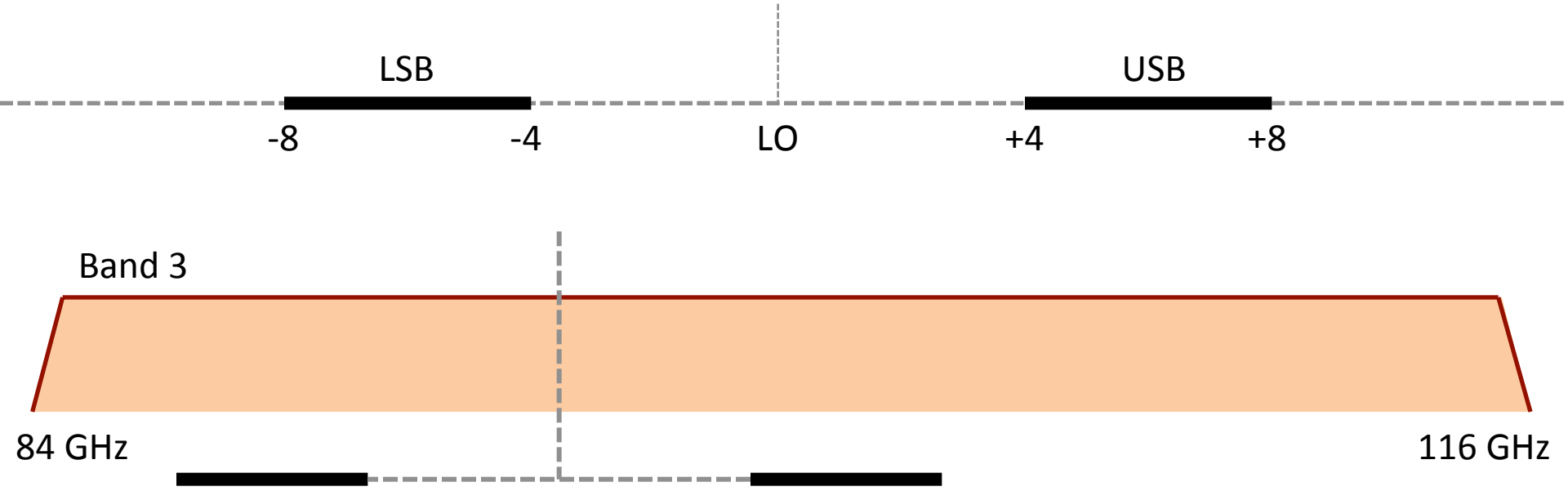

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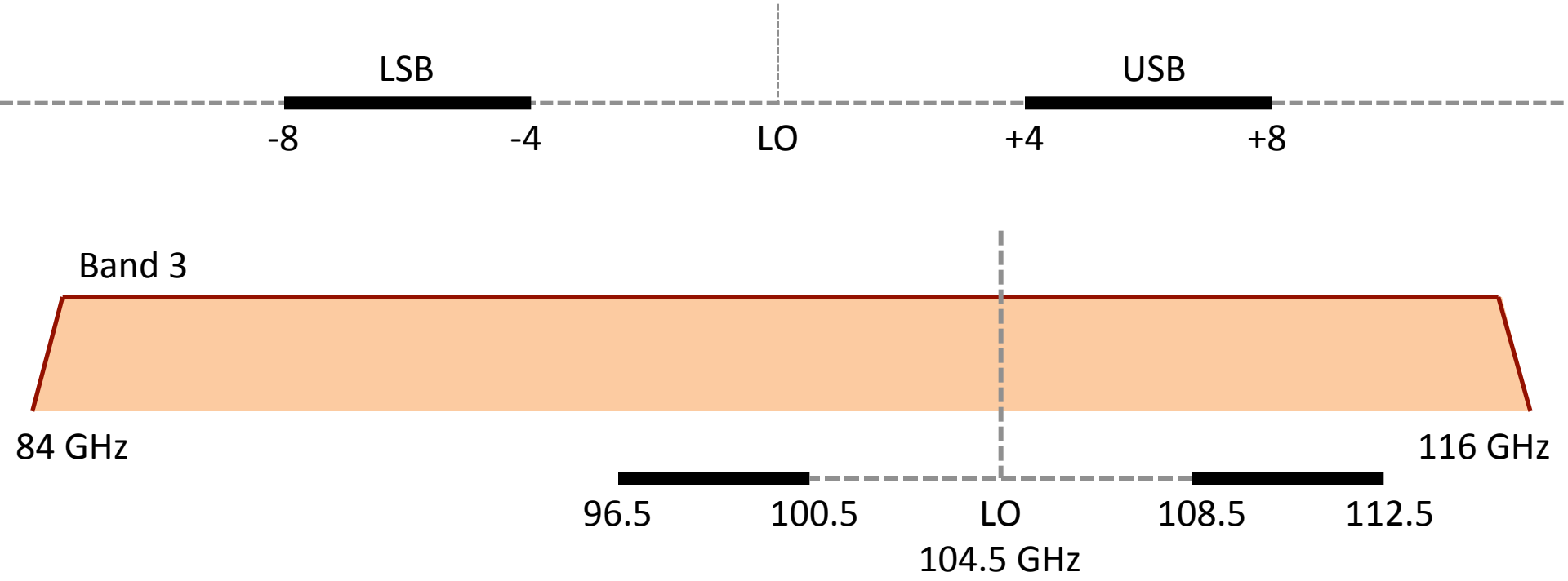

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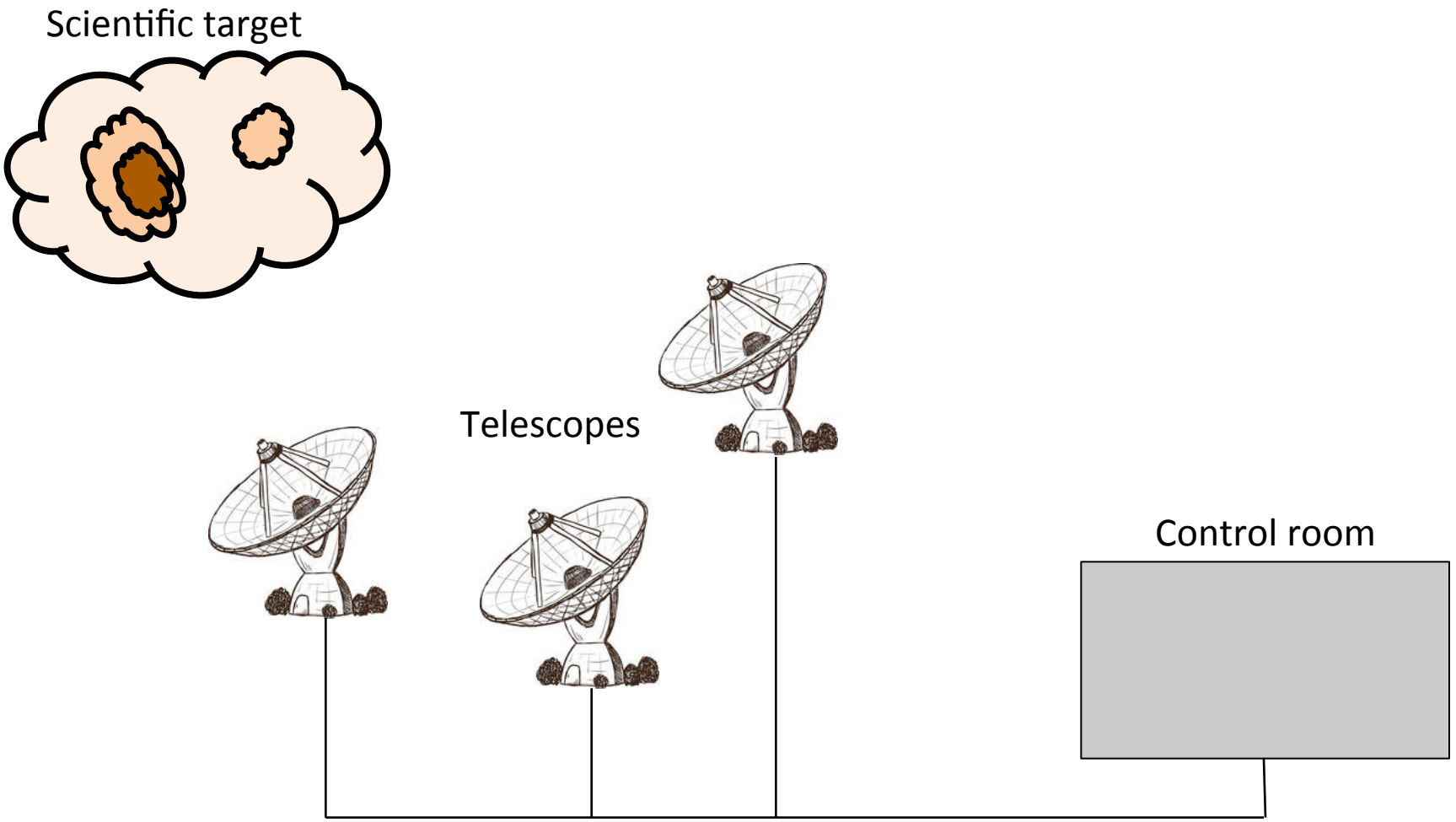
- velocity /redshift of the source
- bandwidth / velocity coverage
- spectral resolution
- polarization products

Spectral observations in a radio-interferometer

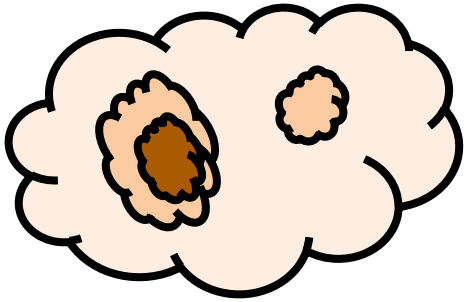
- frequency bands
- receivers
- **correlator**

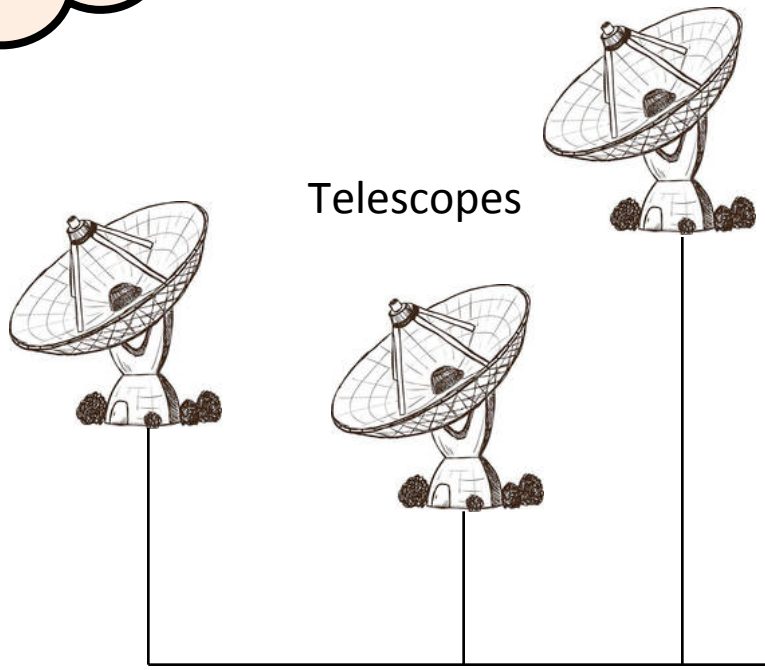
ALMA correlator



ALMA correlator

Scientific target





CORRELATOR:
Super-computer that accepts signals from element antennas, calculates cross-correlation of them, and produces complex visibilities that are used to synthesize images.

Keeps coherence in the complex visibilities, by providing delay and phase tracking to adjust wavefronts of received signals before correlation.

ALMA correlator

ALMA CORRELATOR:
one of the four ‘quadrants’ of the ALMA correlator

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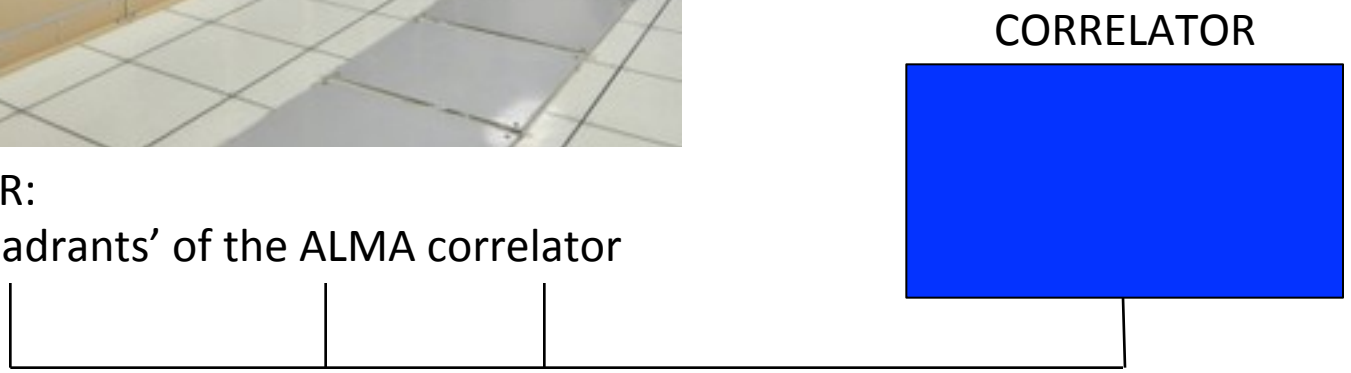

ALMA correlator

ALMA CORRELATOR:
one of the four ‘quadrants’ of the ALMA correlator

Physically:

- 1 correlator = 4 quadrants
- 1 quadrant = 1 baseband

- **ALMA correlator = 4 basebands**

- **Each baseband** processes
  - 64 antennas (2016 baselines)
  - 2 polarizations
  - **2 GHz** input

- Each baseband can be centered anywhere in the incoming 8 GHz

ALMA correlator / 4 basebands

basebands

information from 64 antennas

2 GHz input

up to 8192 channels

2 polarizations Horizontal / Vertical

up to 4 polarization products (HH, VV, HV, VH)

ALMA correlator / 4 basebands

<u>basebands</u>

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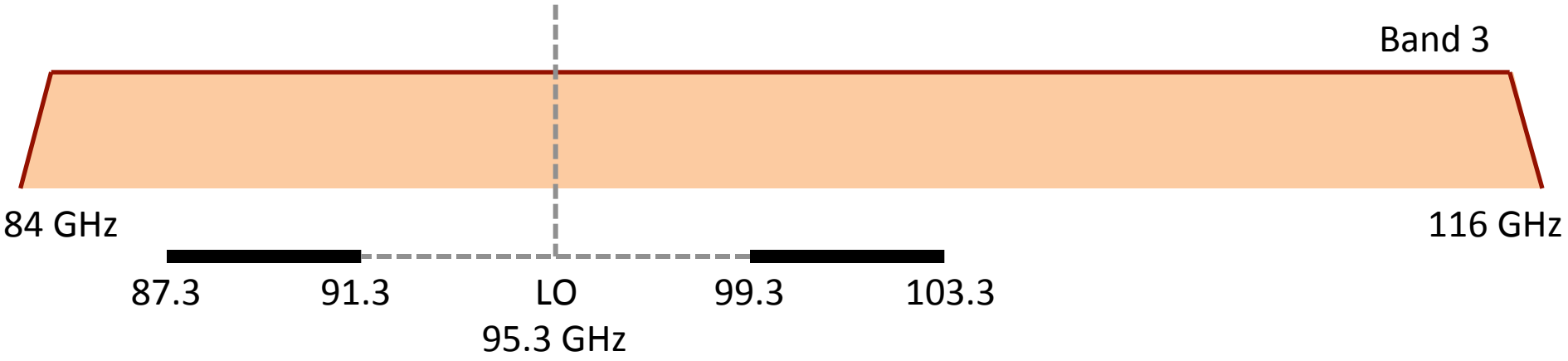

ALMA correlator / 4 basebands

<u>basebands</u>

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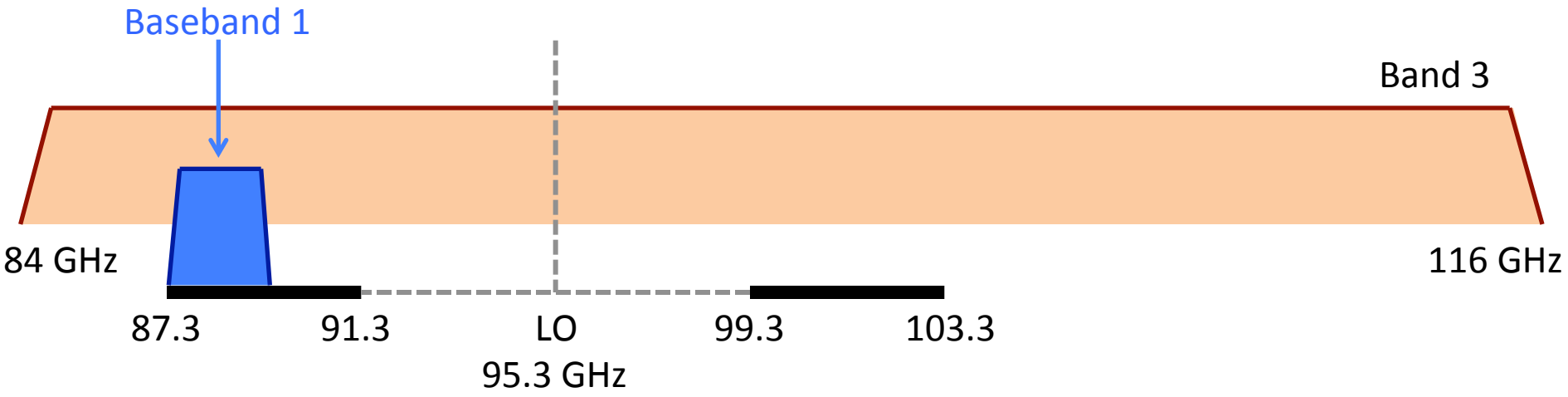

ALMA correlator / **4 basebands**

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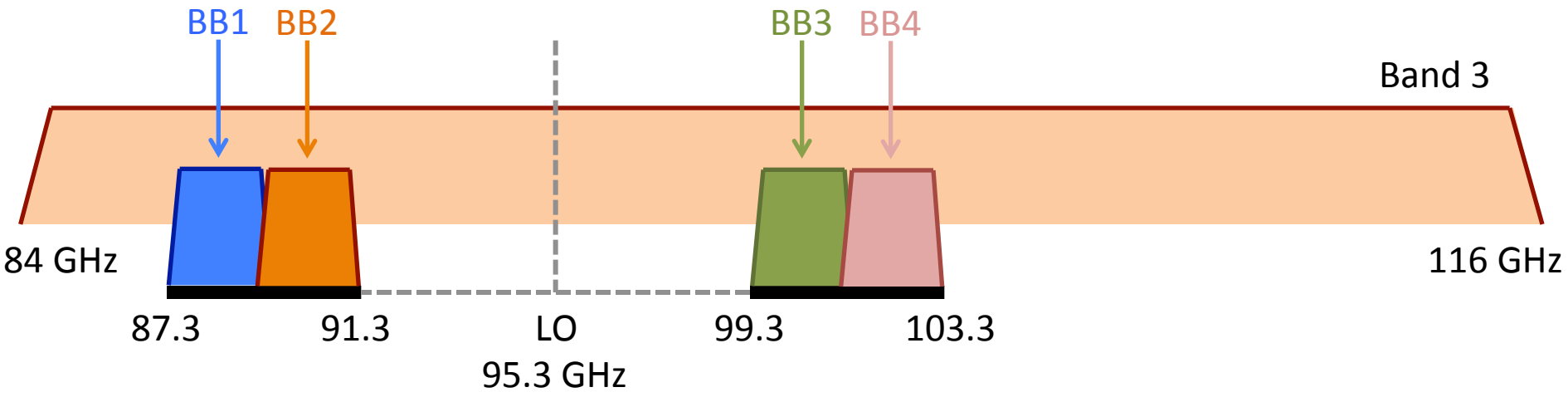

ALMA correlator / **4 basebands**

<u>basebands</u>

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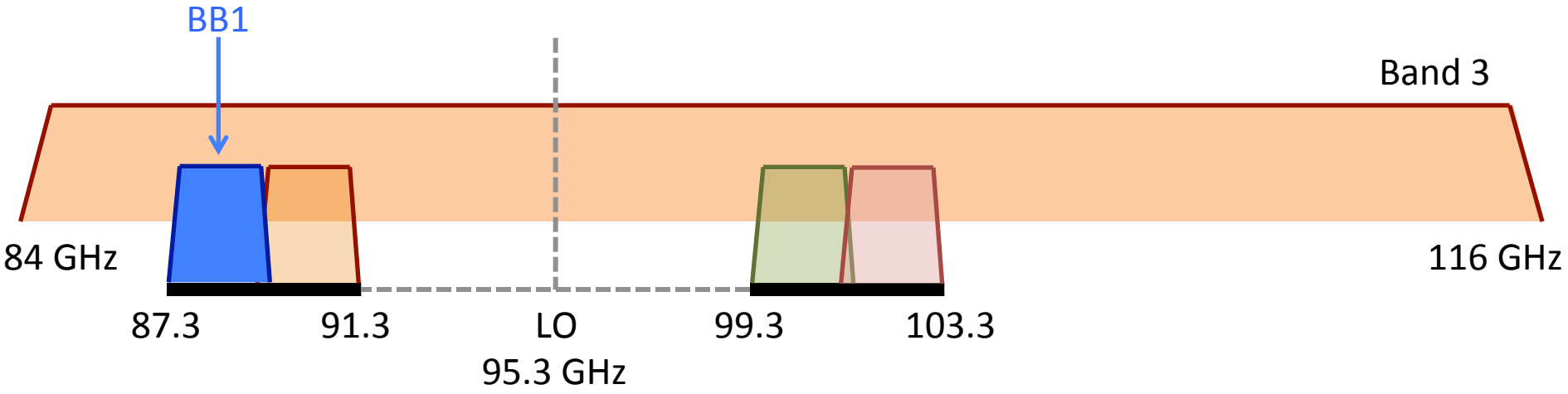

ALMA correlator / **4 basebands**

basebands

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ALMA correlator / **4 basebands**

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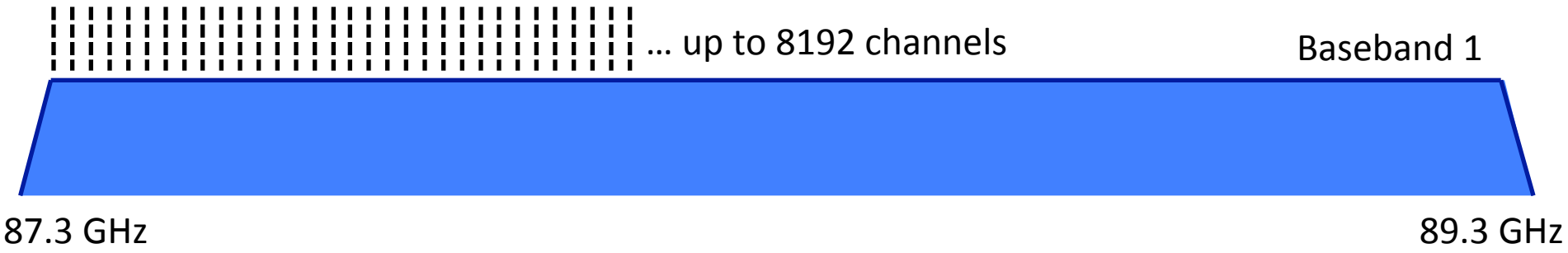

ALMA correlator / **4 basebands**

basebands

information from 64 antennas

2 GHz input

up to **8192 channels**

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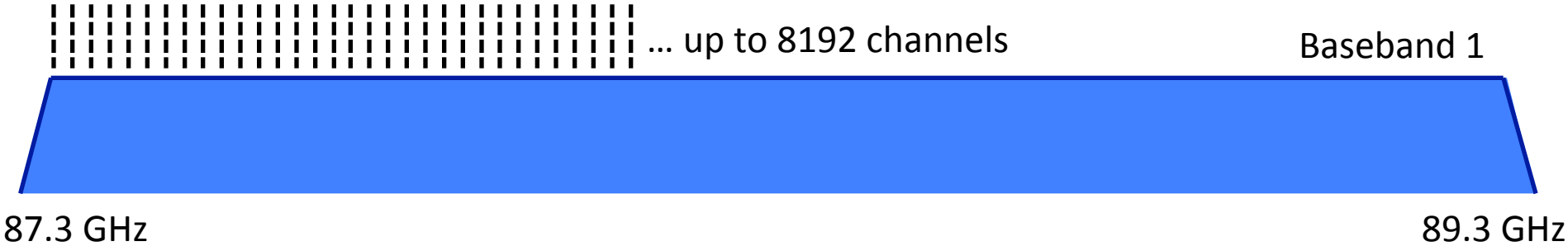
channel width (**spectral resolution**):

2 GHz / 8192 = 244 kHz



ALMA correlator / **4 basebands**

<u>basebands</u>

information from 64 antennas

2 GHz input

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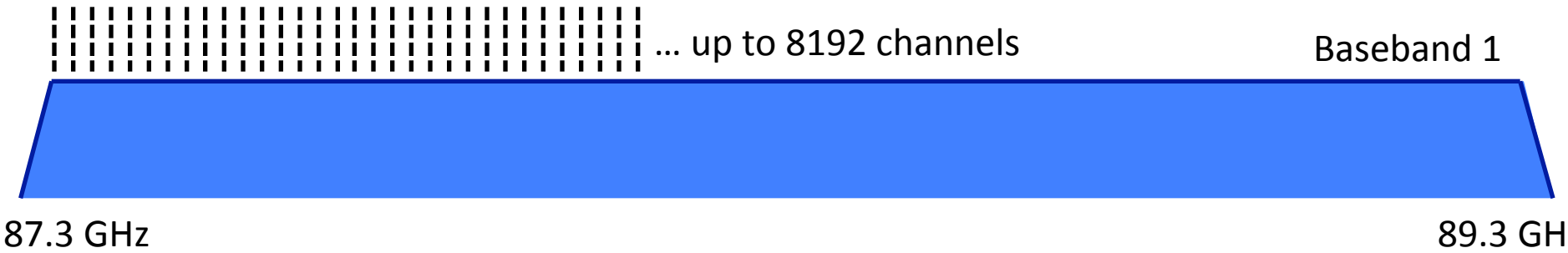

bandwidth = 2 GHz / resolution = 244 kHz … **not fixed!**

ALMA correlator

Bandwidth – Spectral resolution

BW	2 GHz	8192 channels x 1 polz	244 kHz resol.
BW	1 GHz	8192 channels x 1 polz	122 kHz resol.
BW	500 MHz	8192 channels x 1 polz	61 kHz resol.
BW	250 MHz	8192 channels x 1 polz	30 kHz resol.
BW	125 MHz	8192 channels x 1 polz	15 kHz resol.
BW	64 MHz	8192 channels x 1 polz	7.5 kHz resol.
BW	32 MHz	8192 channels x 1 polz	3.8 kHz resol.
continuum mode		256 channels x 1 polz	7.5 MHz resol.

ALMA correlator

Bandwidth – Spectral resolution

BW	**2 GHz**	8192 channels x 1 polz	**244 kHz** resol.
BW	1 GHz	8192 channels x 1 polz	122 kHz resol.
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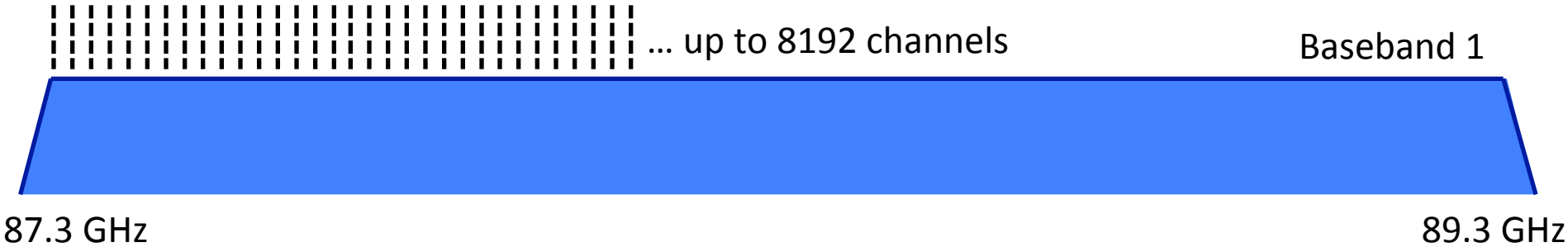

ALMA correlator

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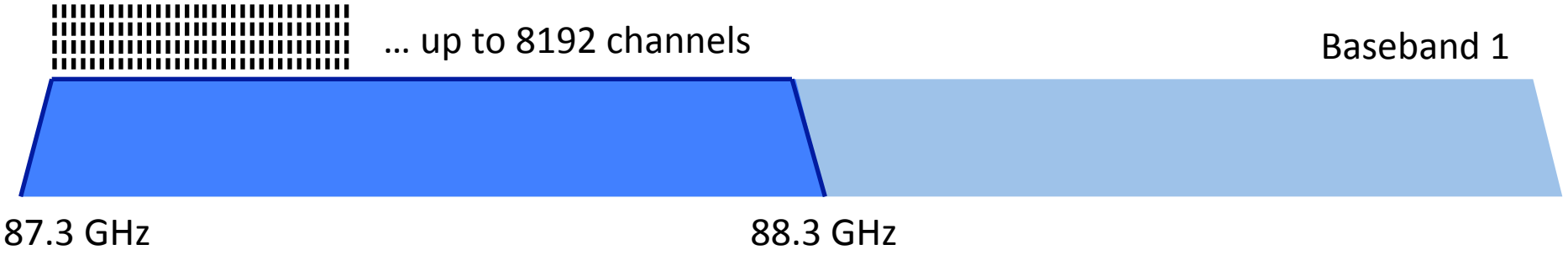

ALMA correlator

Bandwidth – Spectral resolution **1 polz (H or V)**

BW	2 GHz	8192 channels x 1 polz	244 kHz resol.
BW	1 GHz	8192 channels x 1 polz	122 kHz resol.
BW	500 MHz	8192 channels x 1 polz	61 kHz resol.
BW	250 MHz	8192 channels x 1 polz	30 kHz resol.
BW	125 MHz	8192 channels x 1 polz	15 kHz resol.
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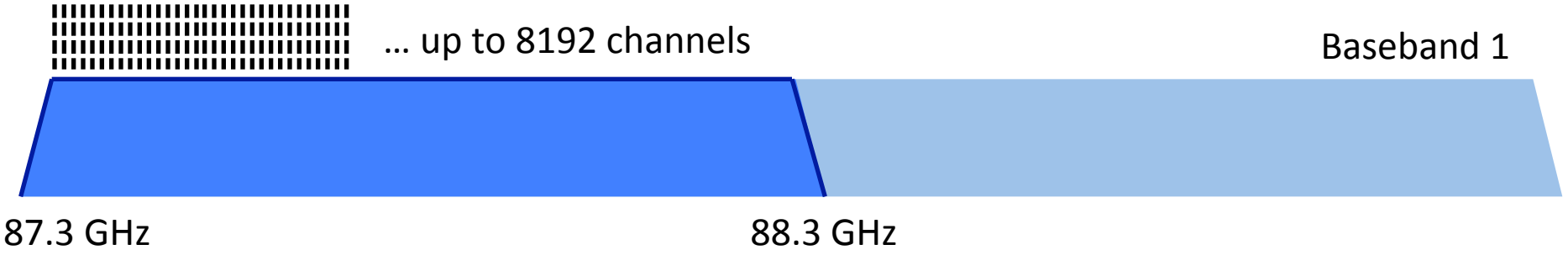
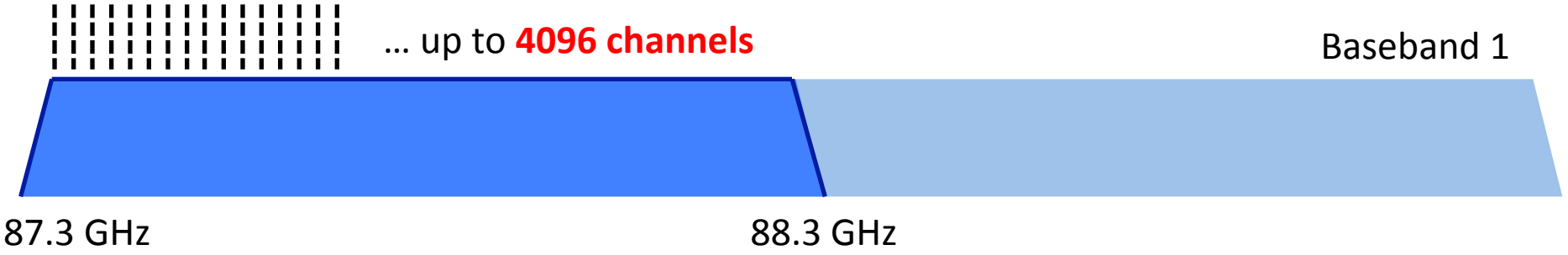
continuum mode		256 channels x 1 polz	7.5 MHz resol.



ALMA correlator

Bandwidth – Spectral resolution **2 polz (H and V)**

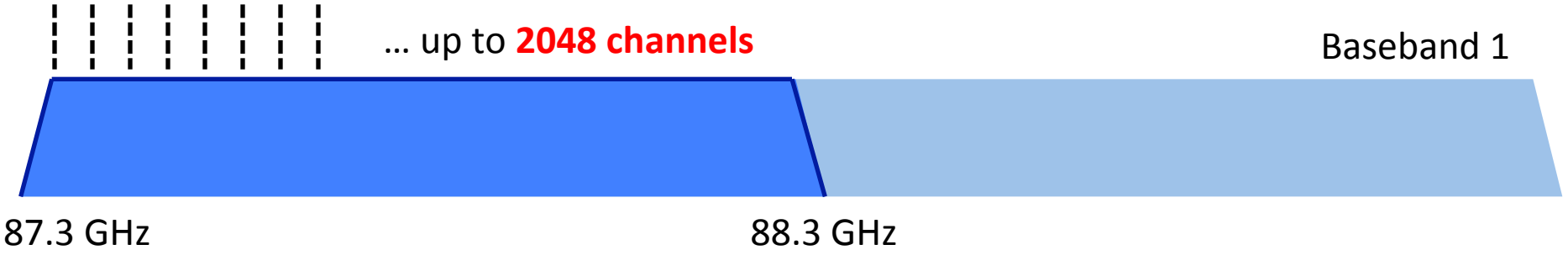
BW	2 GHz	4096 channels x 2 polz	488 kHz resol.
BW	1 GHz	4096 channels x 2 polz	244 kHz resol.
BW	500 MHz	4096 channels x 2 polz	122 kHz resol.
BW	250 MHz	4096 channels x 2 polz	61 kHz resol.
BW	125 MHz	4096 channels x 2 polz	30 kHz resol.
BW	64 MHz	4096 channels x 2 polz	15 kHz resol.
BW	32 MHz	4096 channels x 2 polz	7.5 kHz resol.
continuum mode		128 channels x 2 polz	15 MHz resol.



ALMA correlator

Bandwidth – Spectral resolution **4 polz (HH, VV, HV, VH)**

BW	2 GHz	2048 channels x 4 polz	976 kHz resol.
BW	1 GHz	2048 channels x 4 polz	488 kHz resol.
BW	500 MHz	2048 channels x 4 polz	244 kHz resol.
BW	250 MHz	2048 channels x 4 polz	122 kHz resol.
BW	125 MHz	2048 channels x 4 polz	61 kHz resol.
BW	64 MHz	2048 channels x 4 polz	30 kHz resol.
BW	32 MHz	2048 channels x 4 polz	15 kHz resol.
continuum mode		64 channels x 4 polz	31 MHz resol.



ALMA correlator

Polarization products (HH, VV, HV, VH)

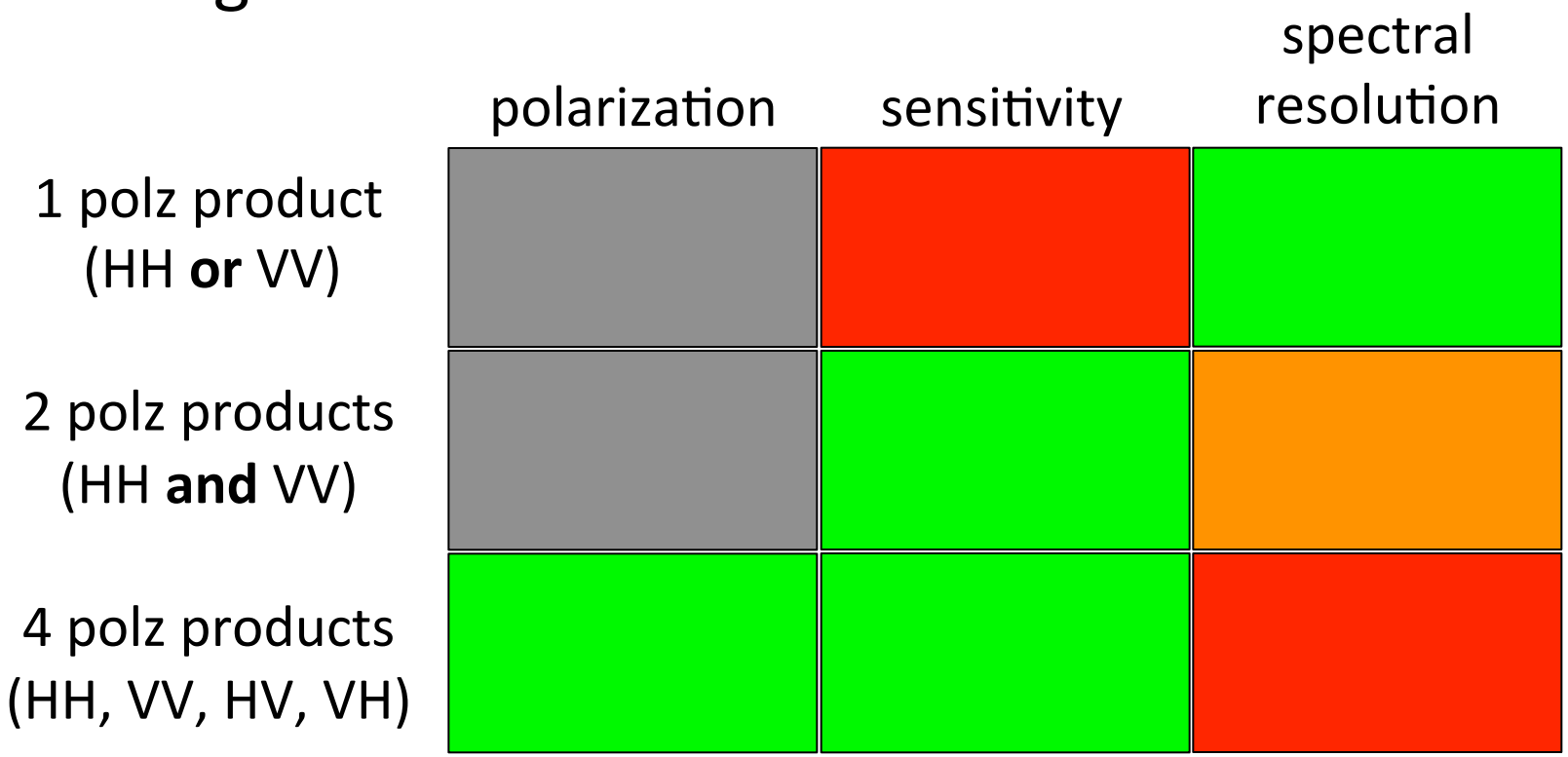
the four are necessary for polarization studies

ALMA correlator

<u>Polarization products (HH, VV, HV, VH)</u>

the four are necessary for polarization studies

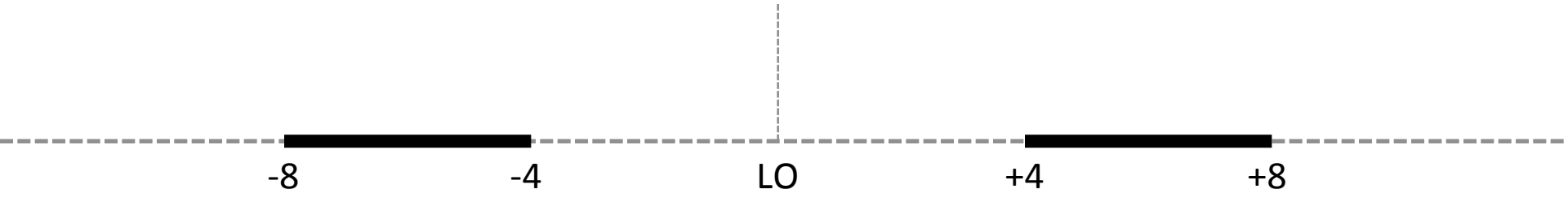
message to take home …



ALMA correlator (examples)

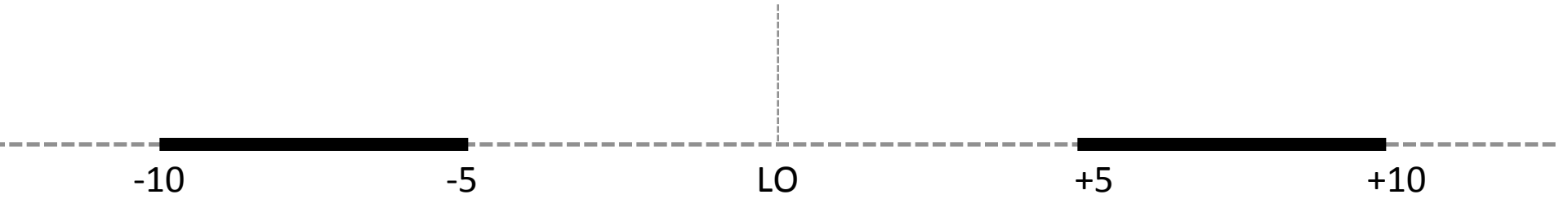
ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



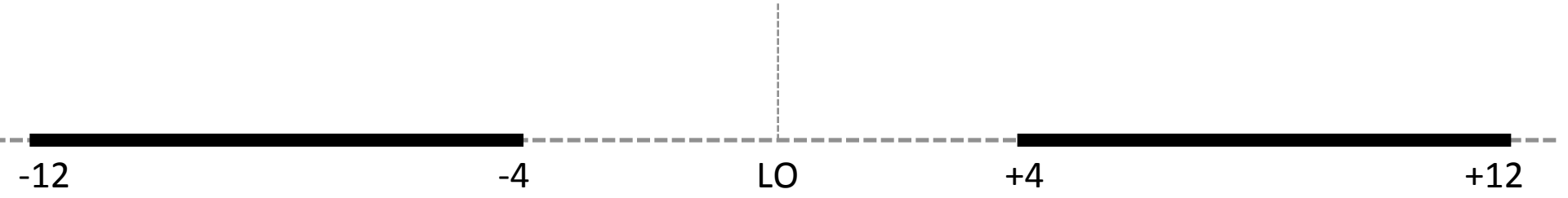
ALMA B6

2SB receivers 5-10 GHz



ALMA B9 / B10

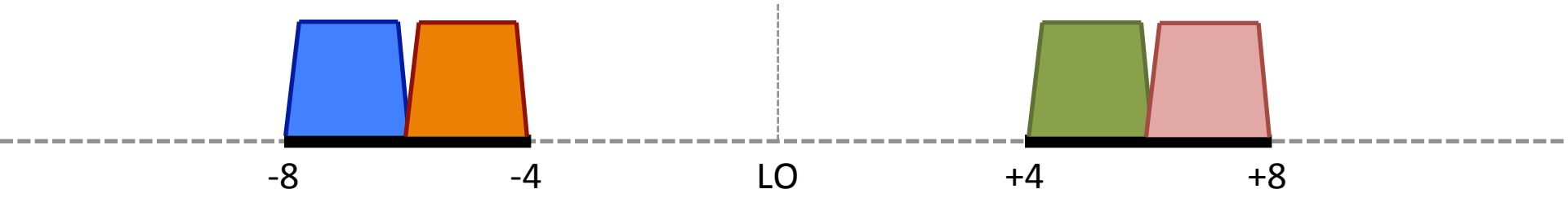
DSB receivers 4-12 GHz



ALMA correlator (examples)

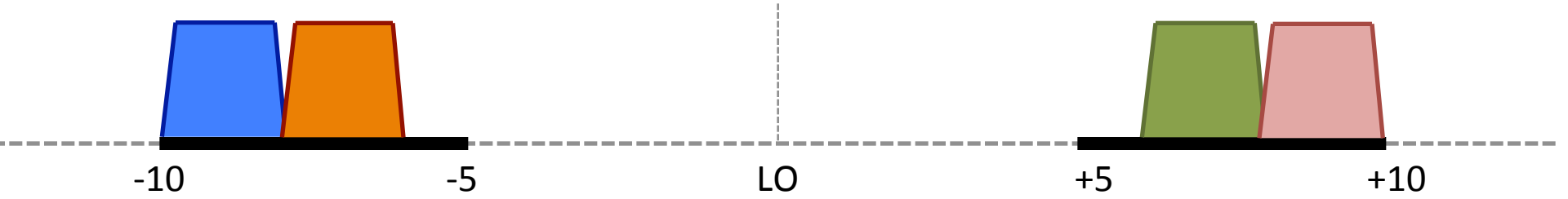
ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



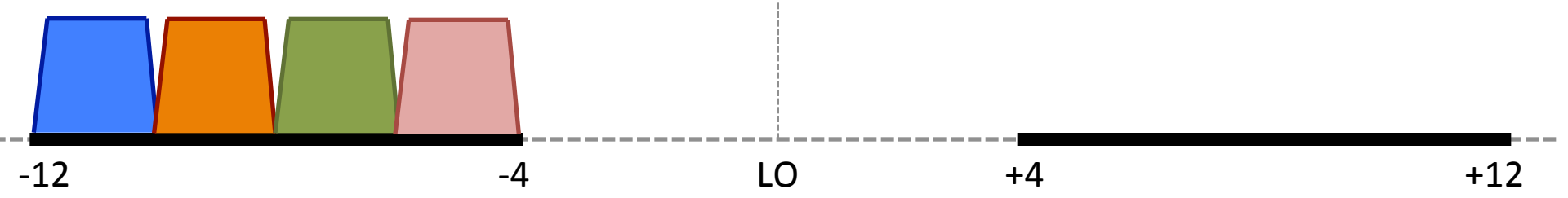
ALMA B6

2SB receivers 5-10 GHz



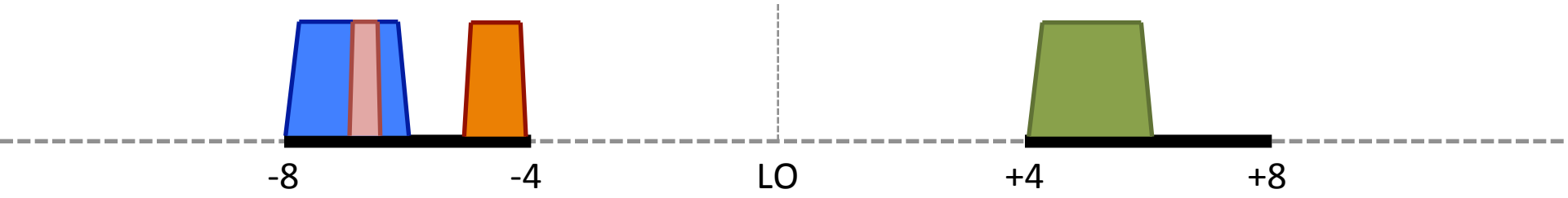
ALMA B9 / B10

DSB receivers 4-12 GHz



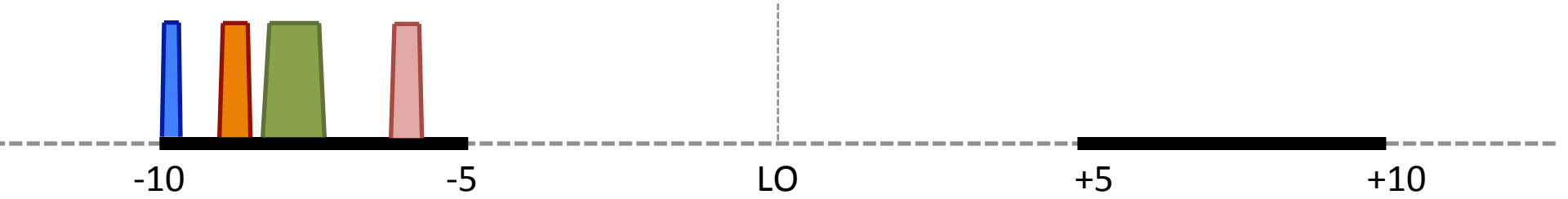
ALMA correlator (examples)

ALMA B3 / B4 / B5 / B7 / B8



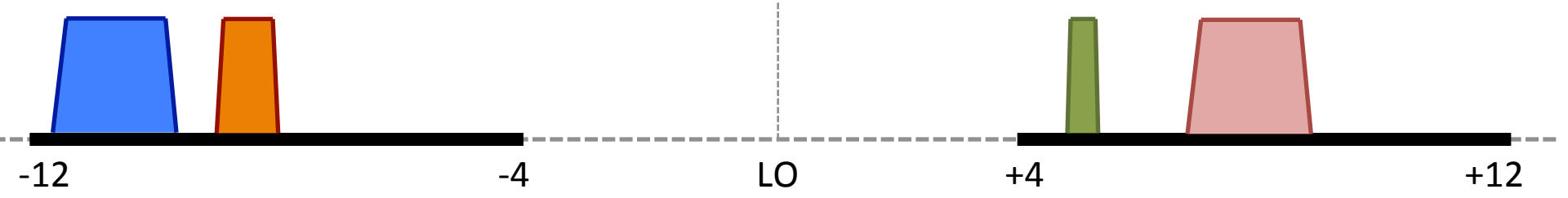
2SB receivers 4-8 GHz

ALMA B6



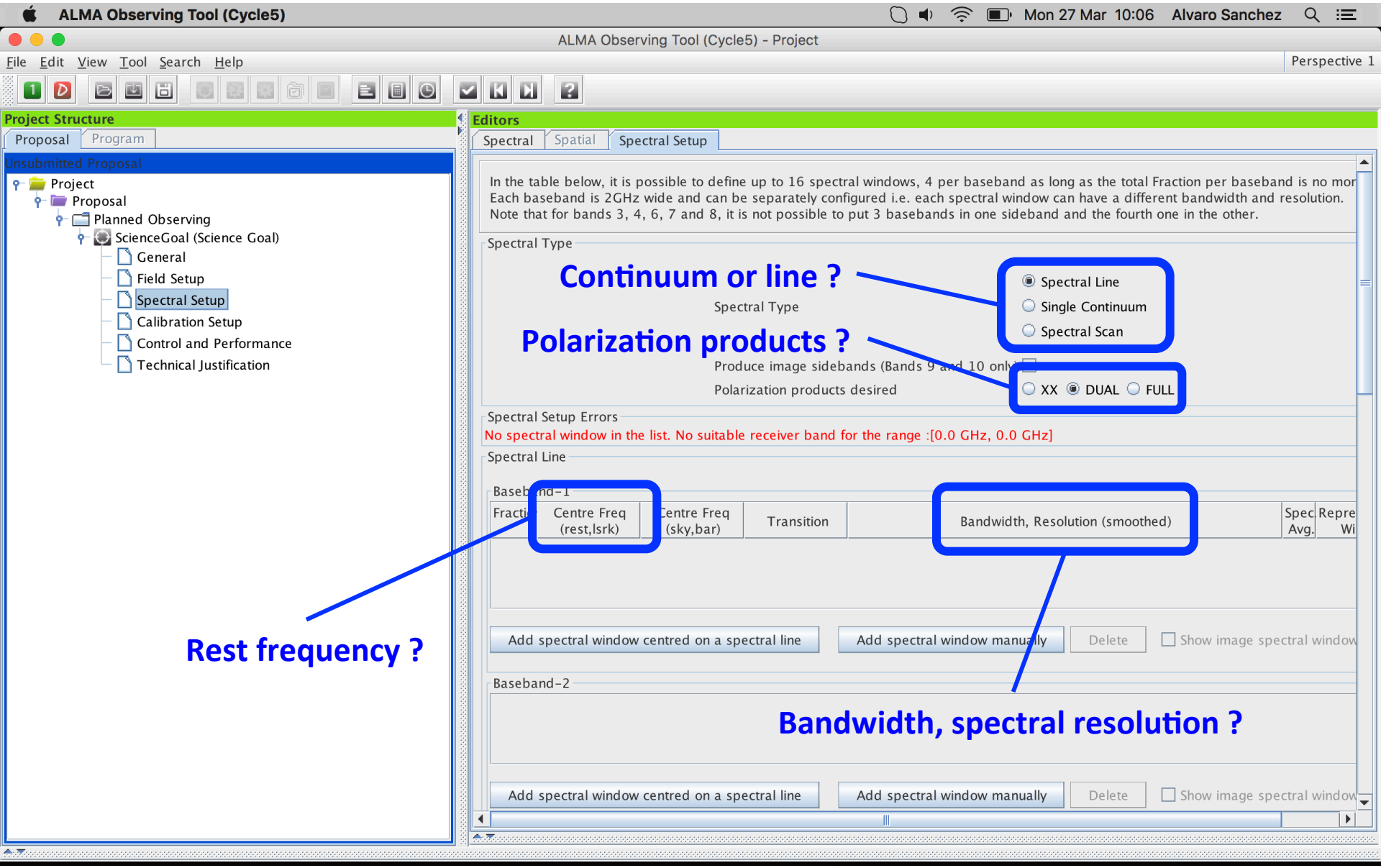
2SB receivers 5-10 GHz

ALMA B9 / B10



DSB receivers 4-12 GHz

Spectral setup in the almaOT



Spectral setup in the almaOT (EXAMPLE)

We want to observe three lines in our target:

HCN(1-0), HCO^+(1-0) and $H^{13}CO^+$(1-0)

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HCN(1-0) → Δv = 7 km/s

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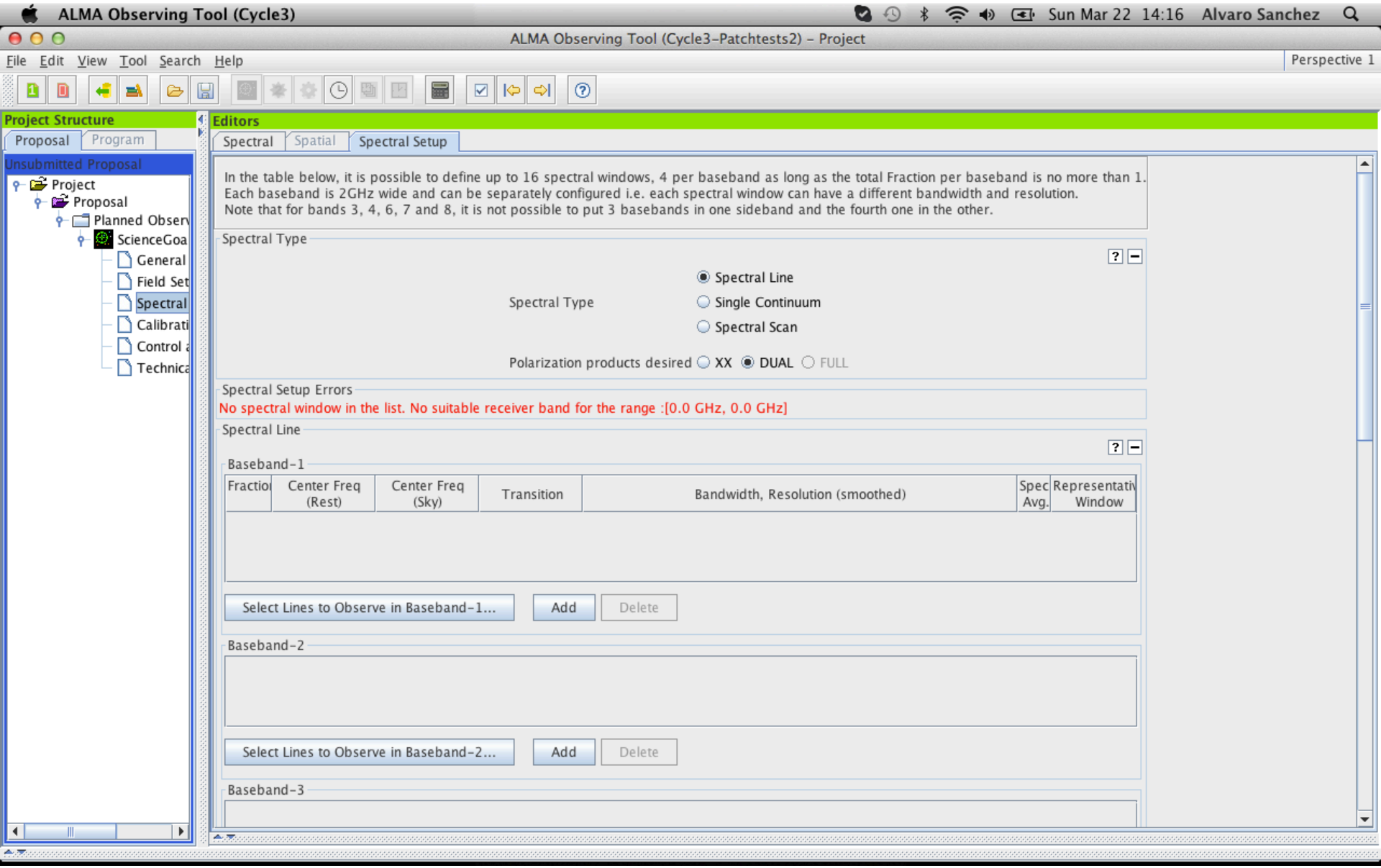
For our ALMA observations we would need:

Bandwidth	> 20 km/s	to properly cover the extend of the lines
Resolution	< 0.7 km/s	for the HCN and HCO^+ lines
	< 0.3 km/s	for the $H^{13}CO^+$ line

Spectral setup in the almaOT (EXAMPLE)



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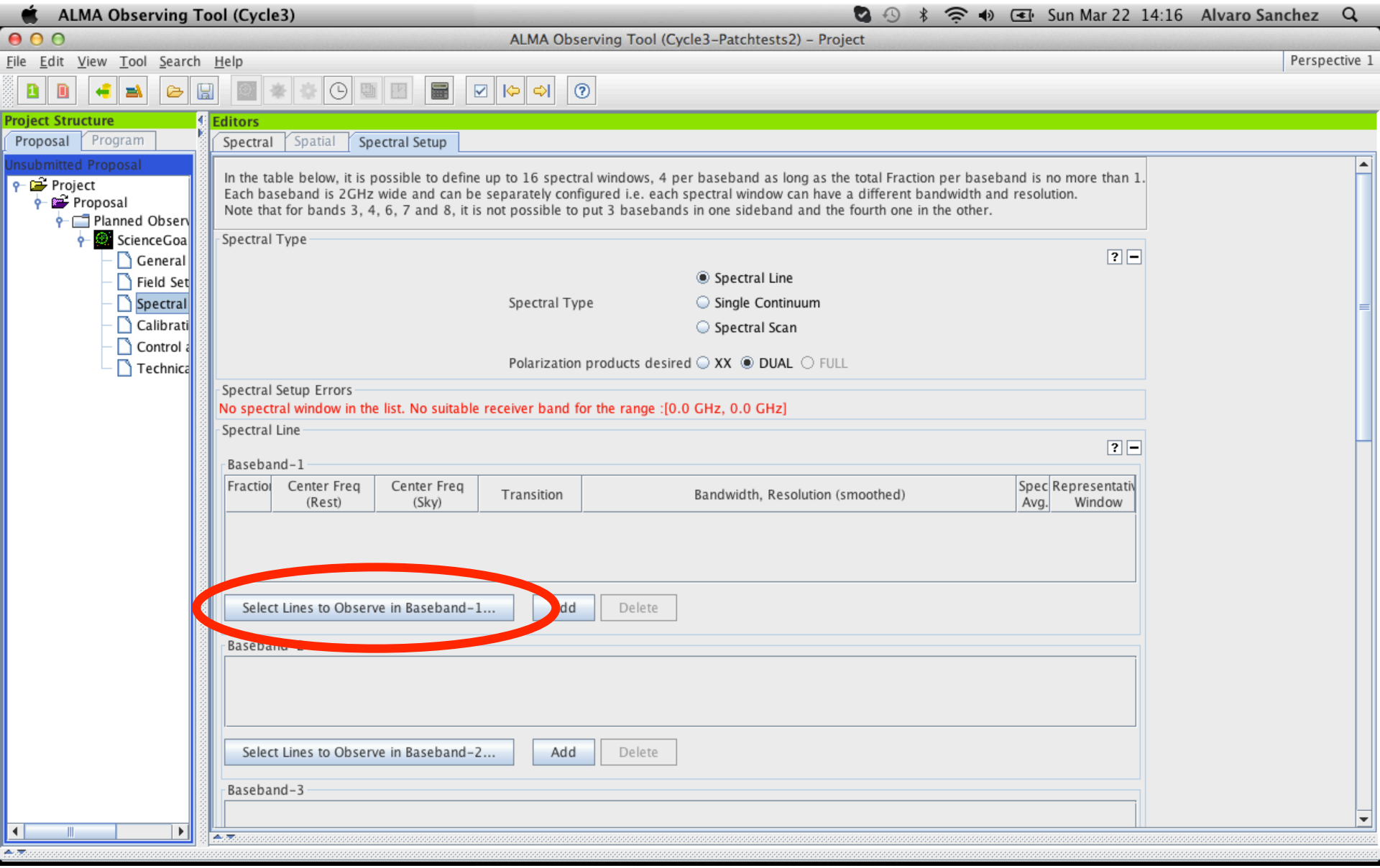

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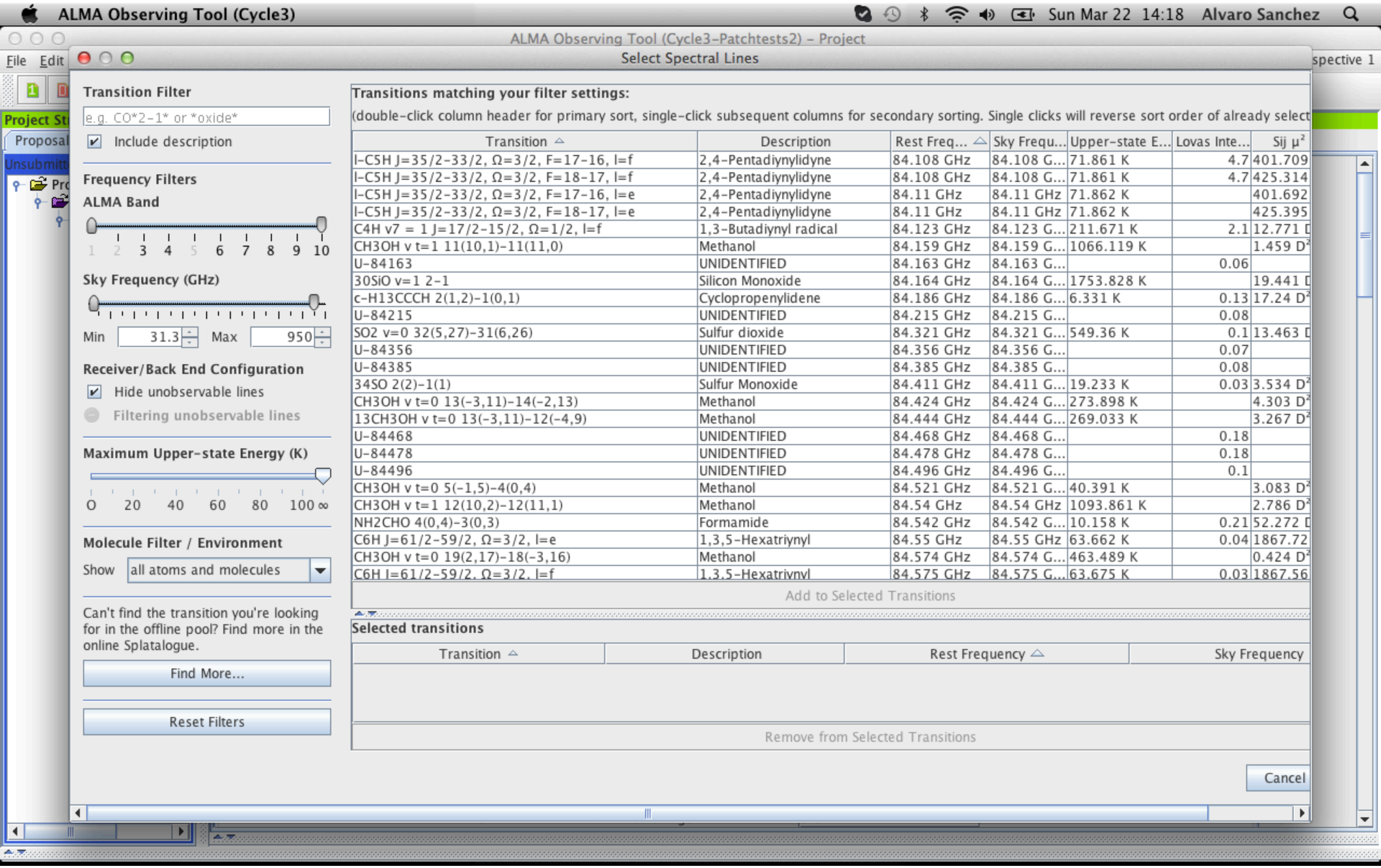

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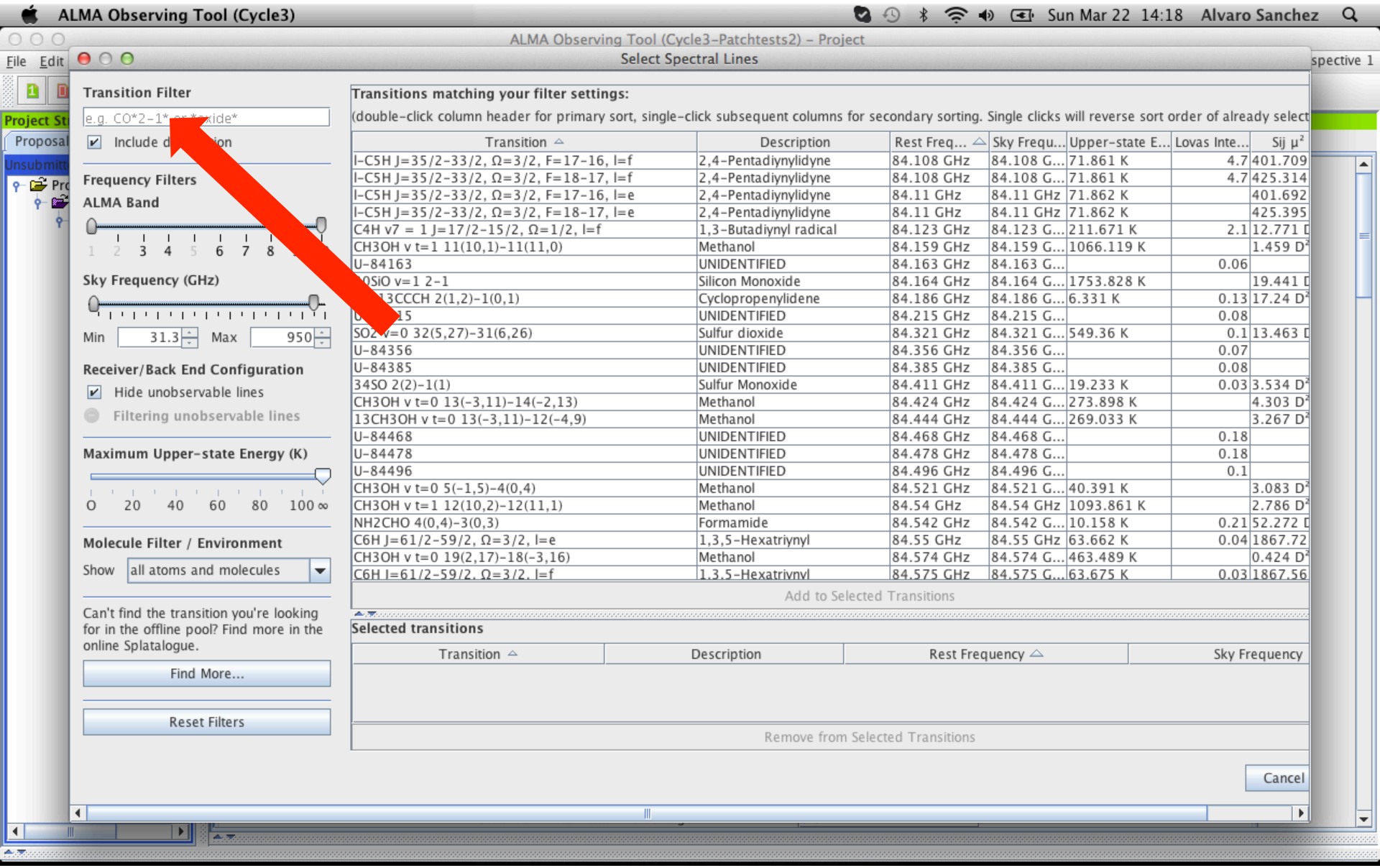

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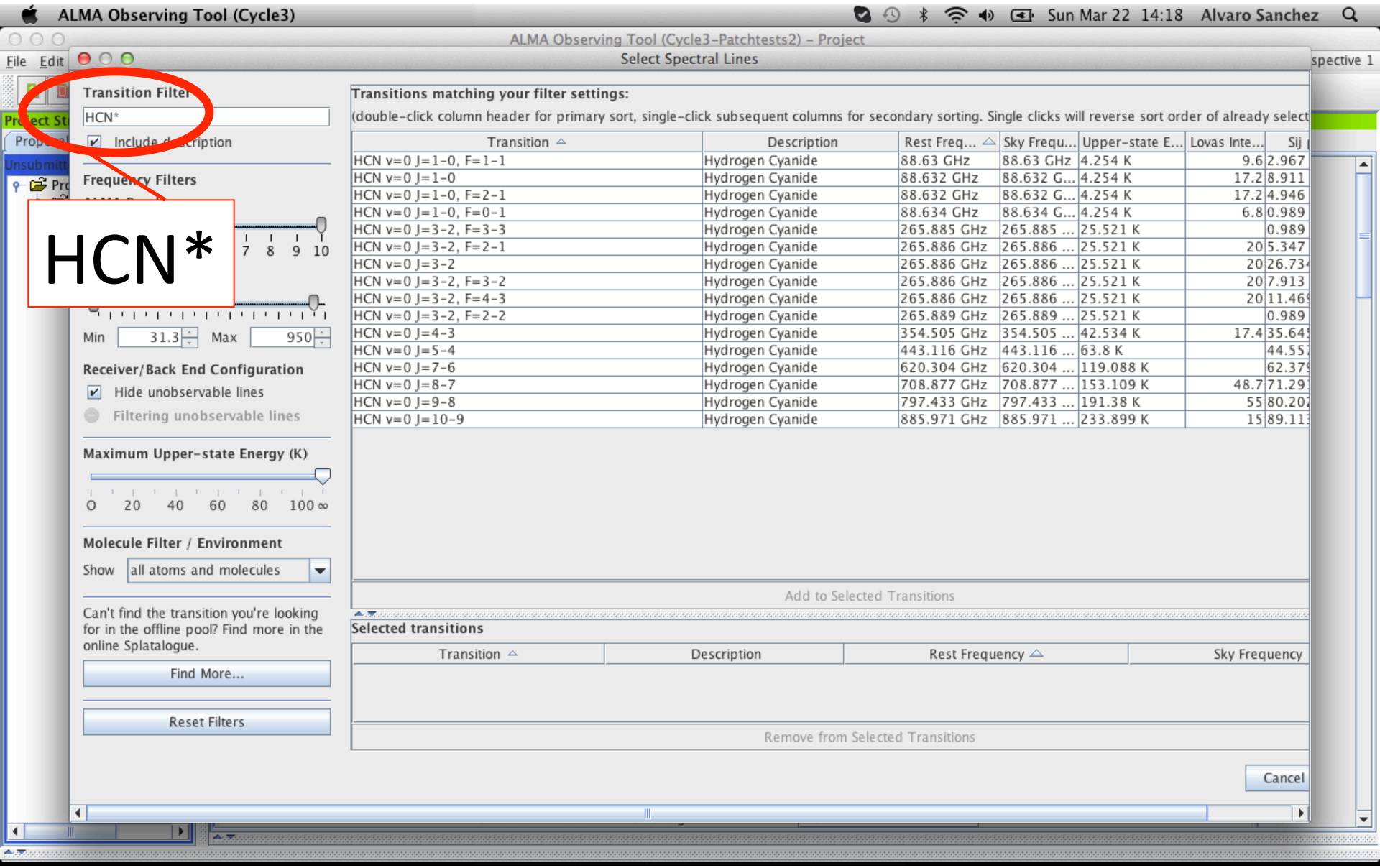

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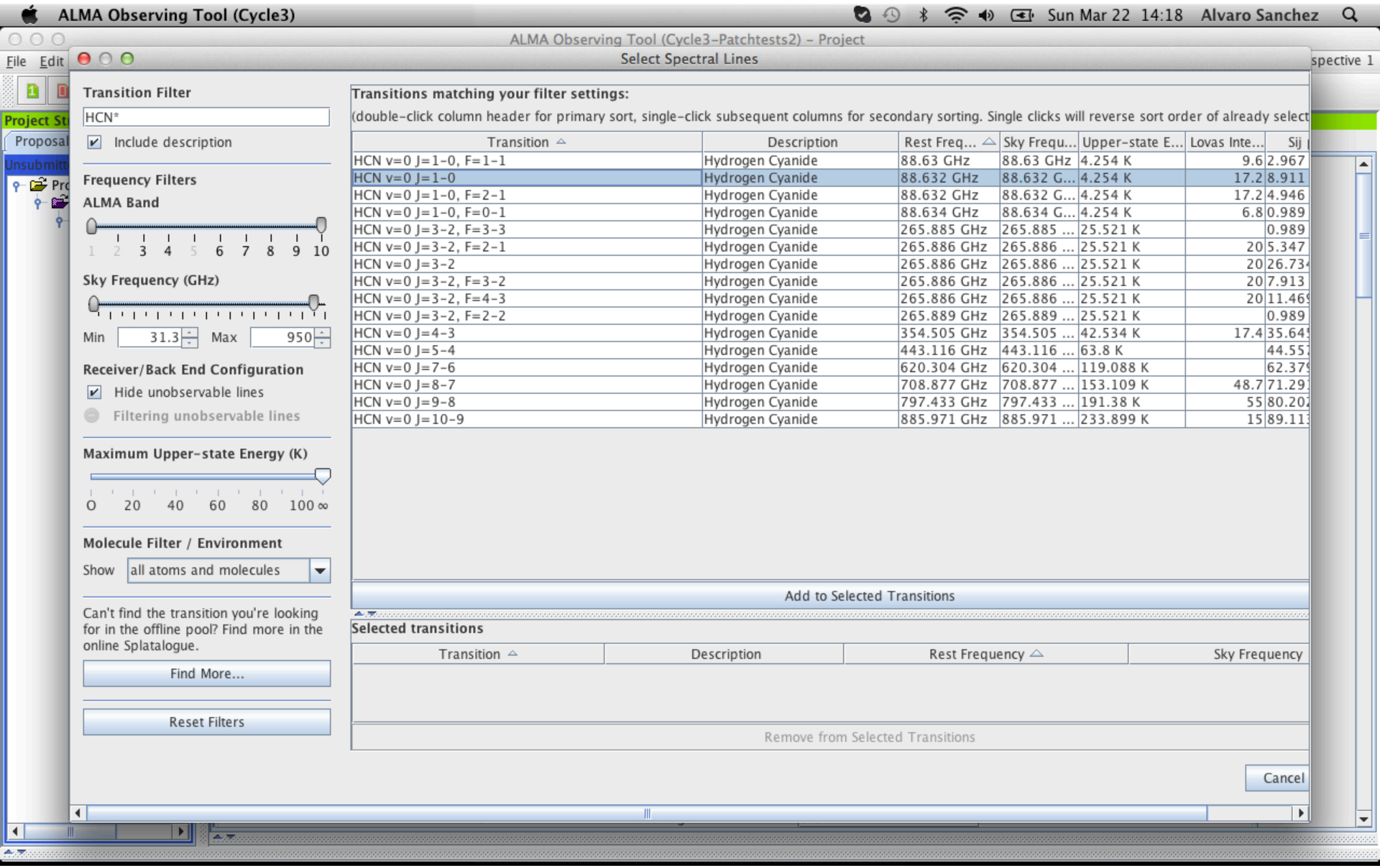

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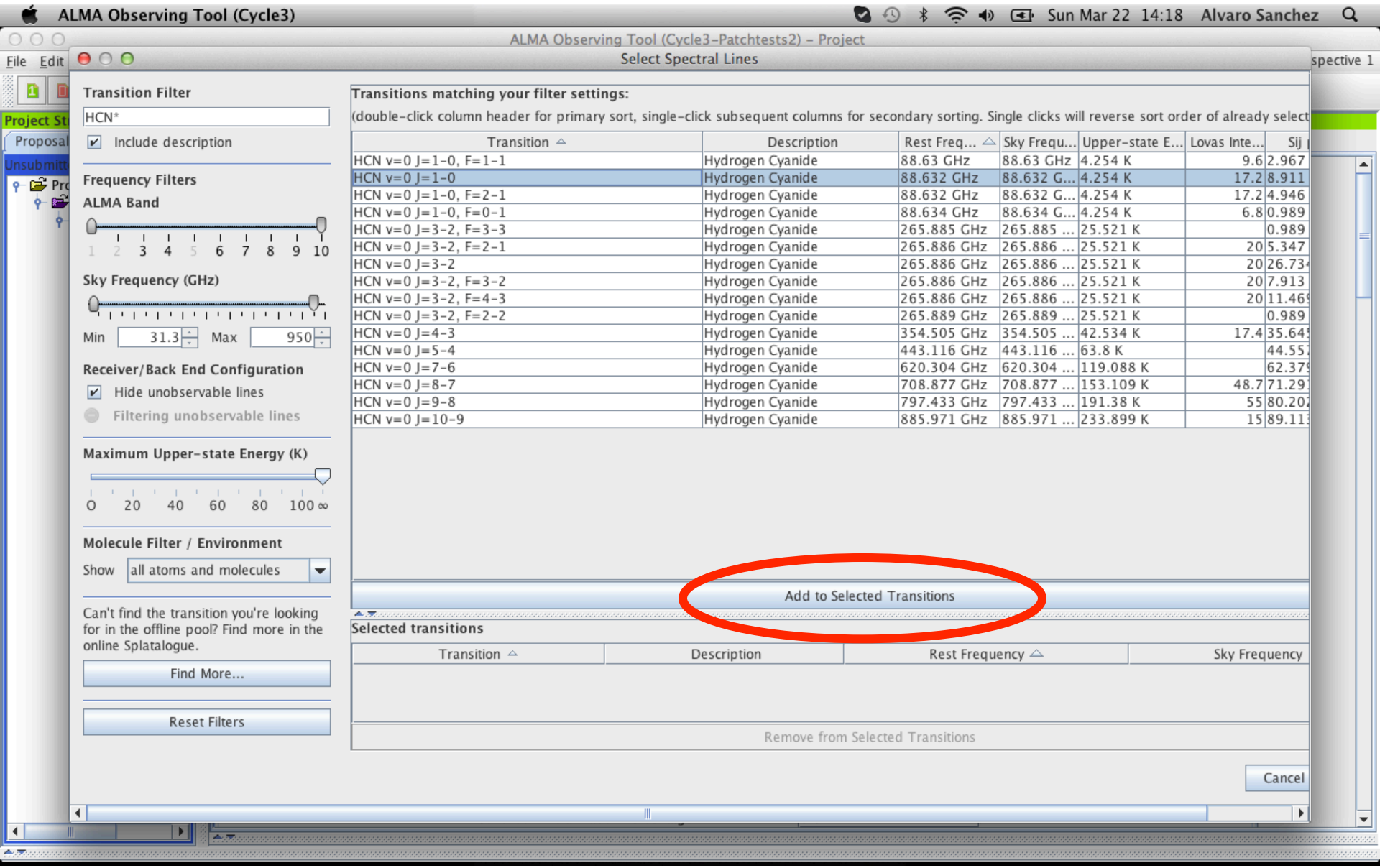

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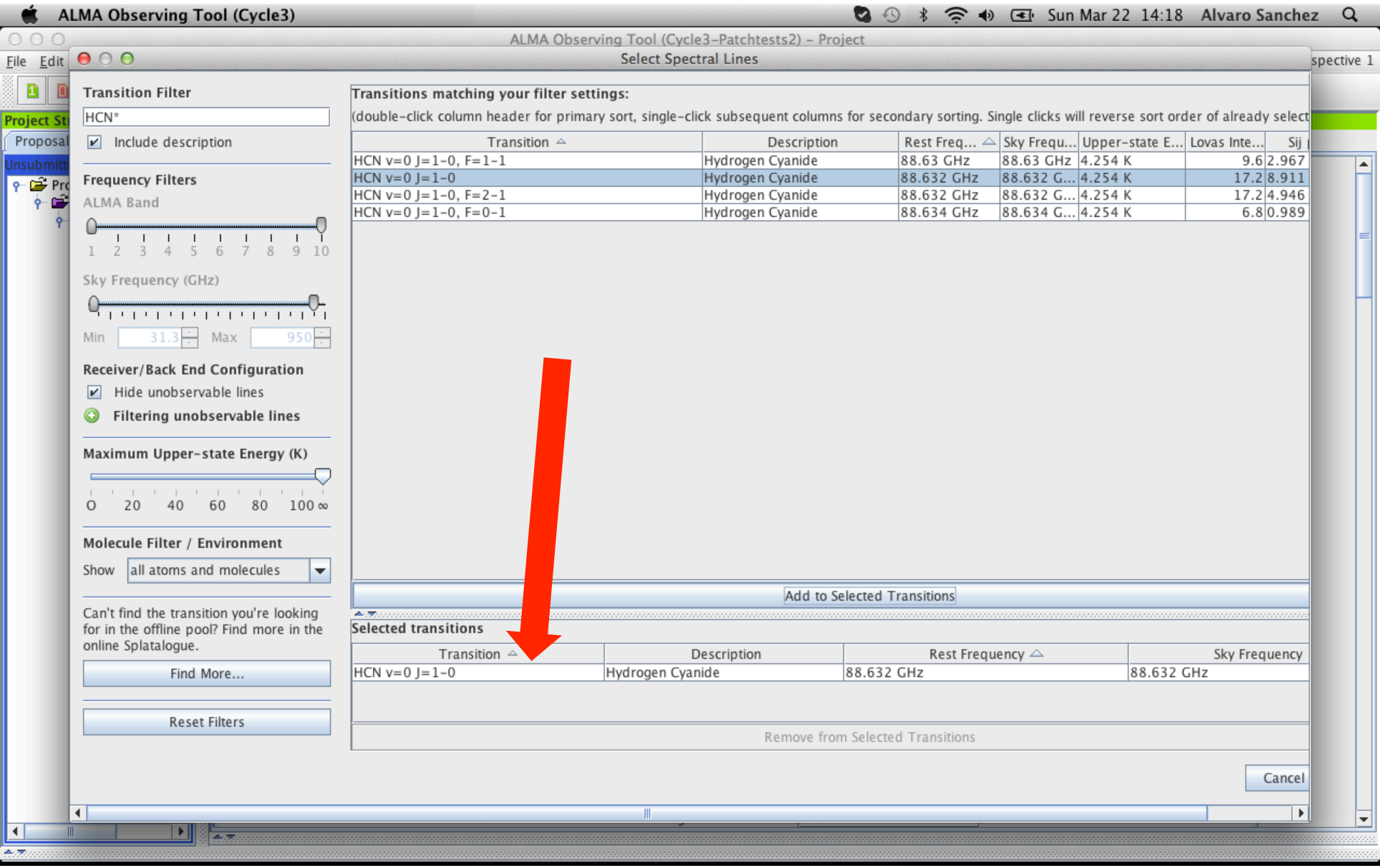

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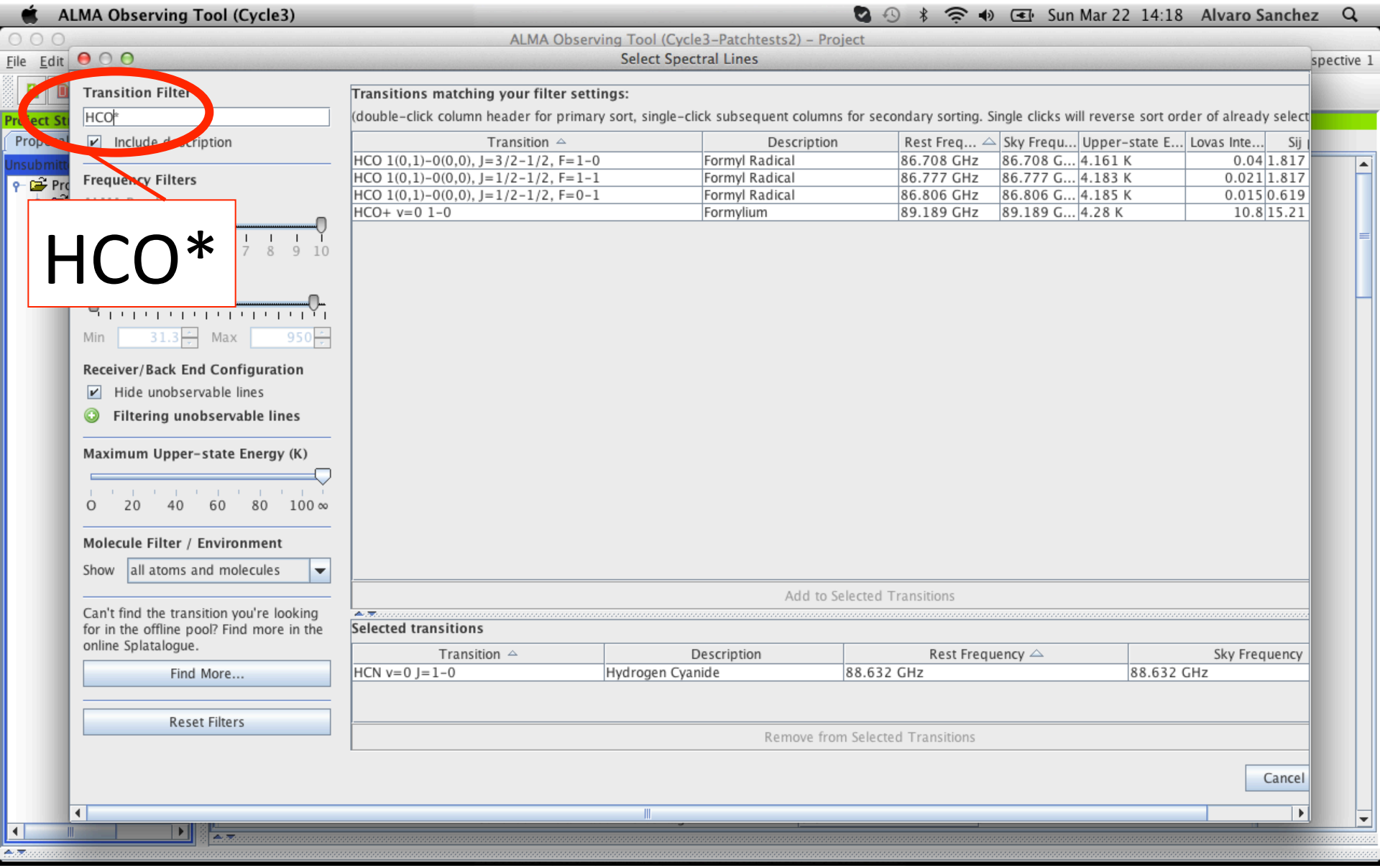

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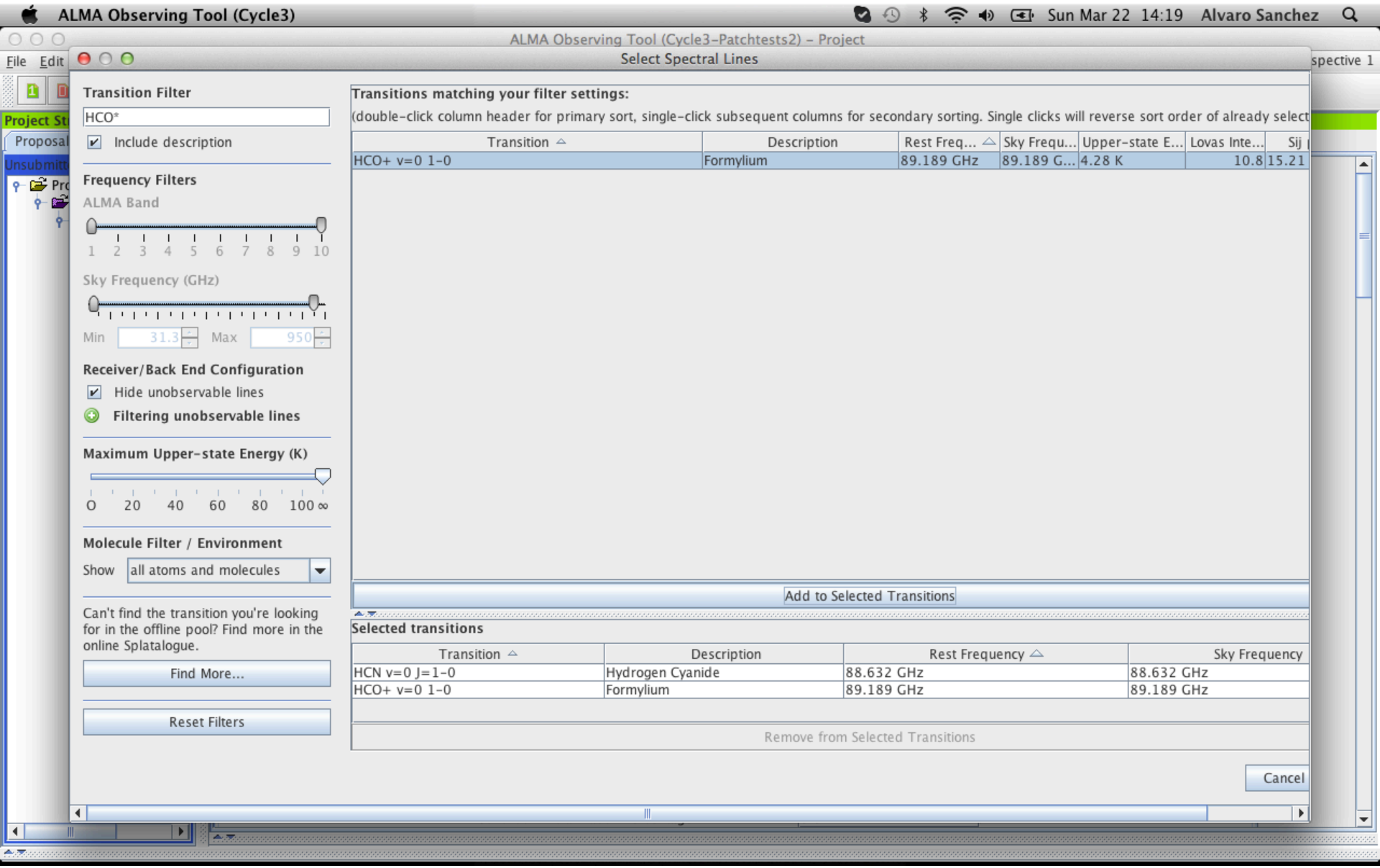

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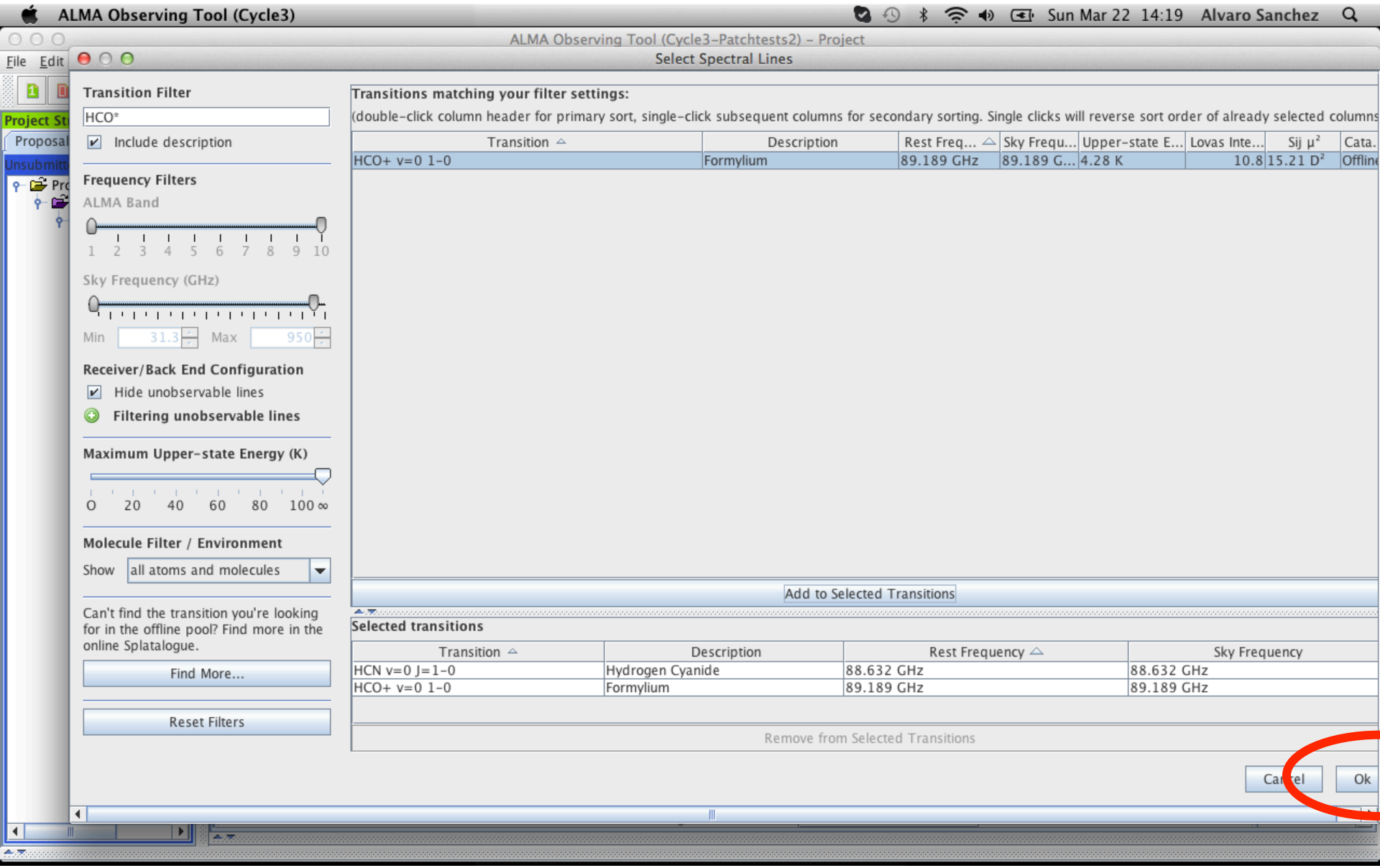

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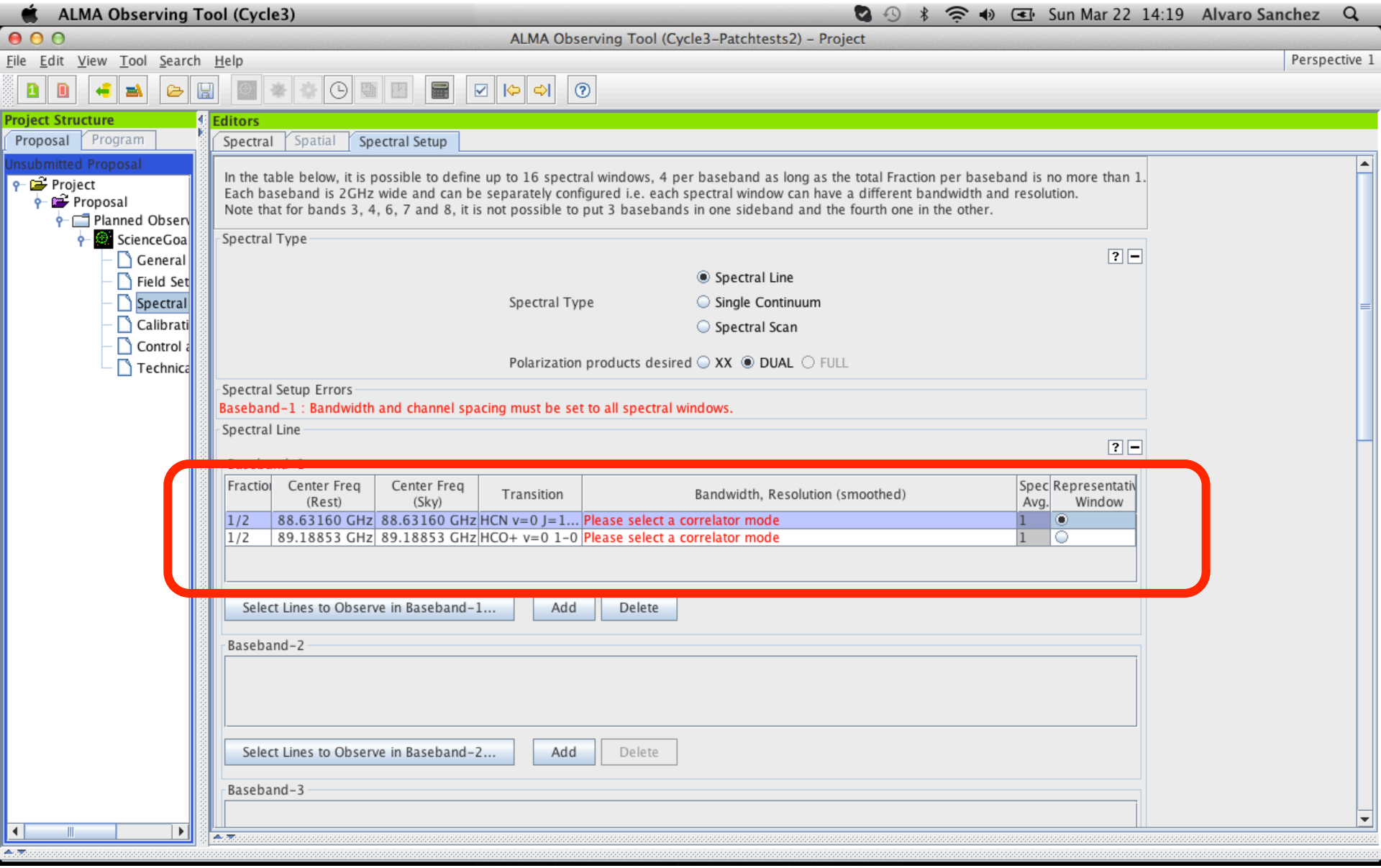

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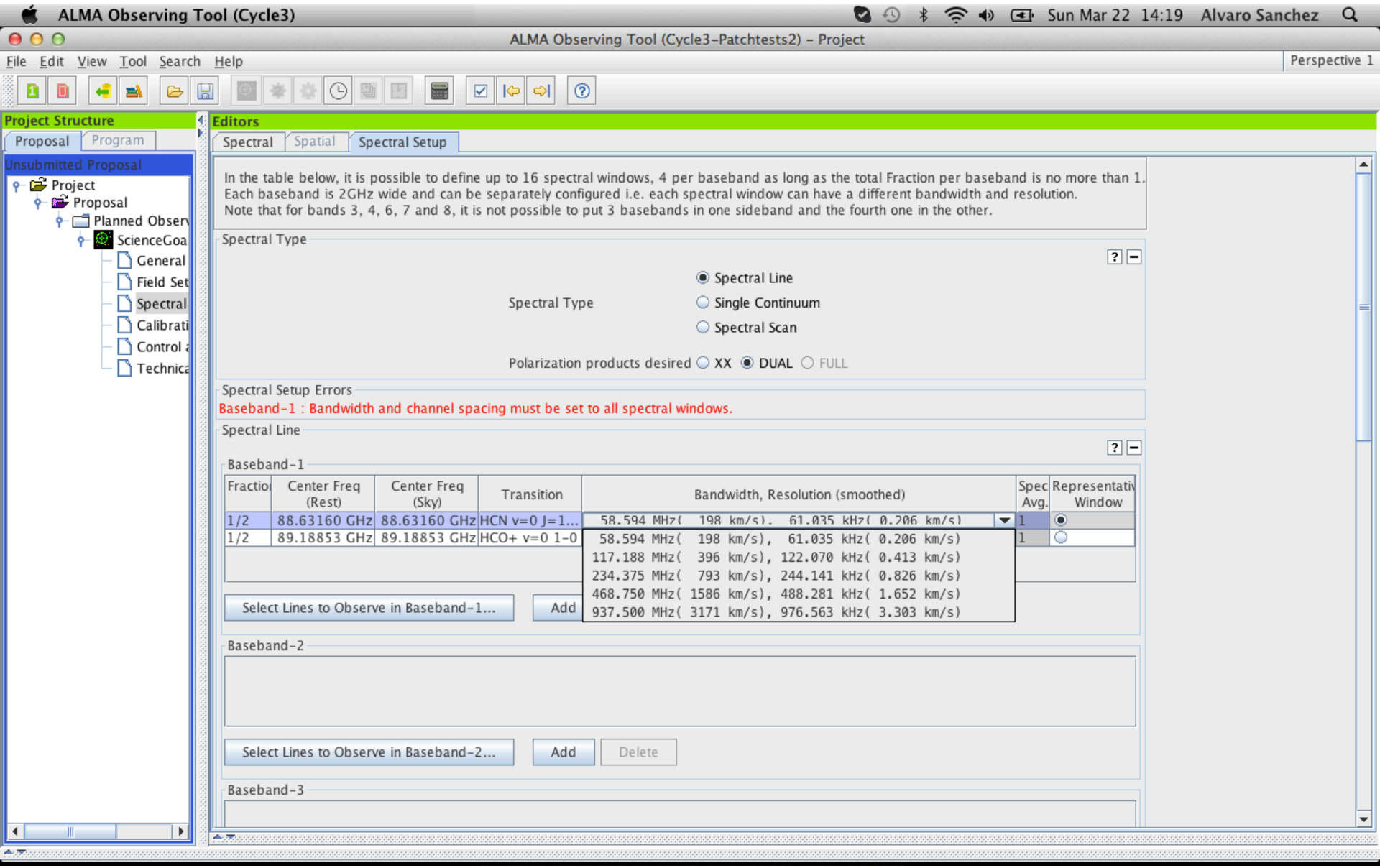

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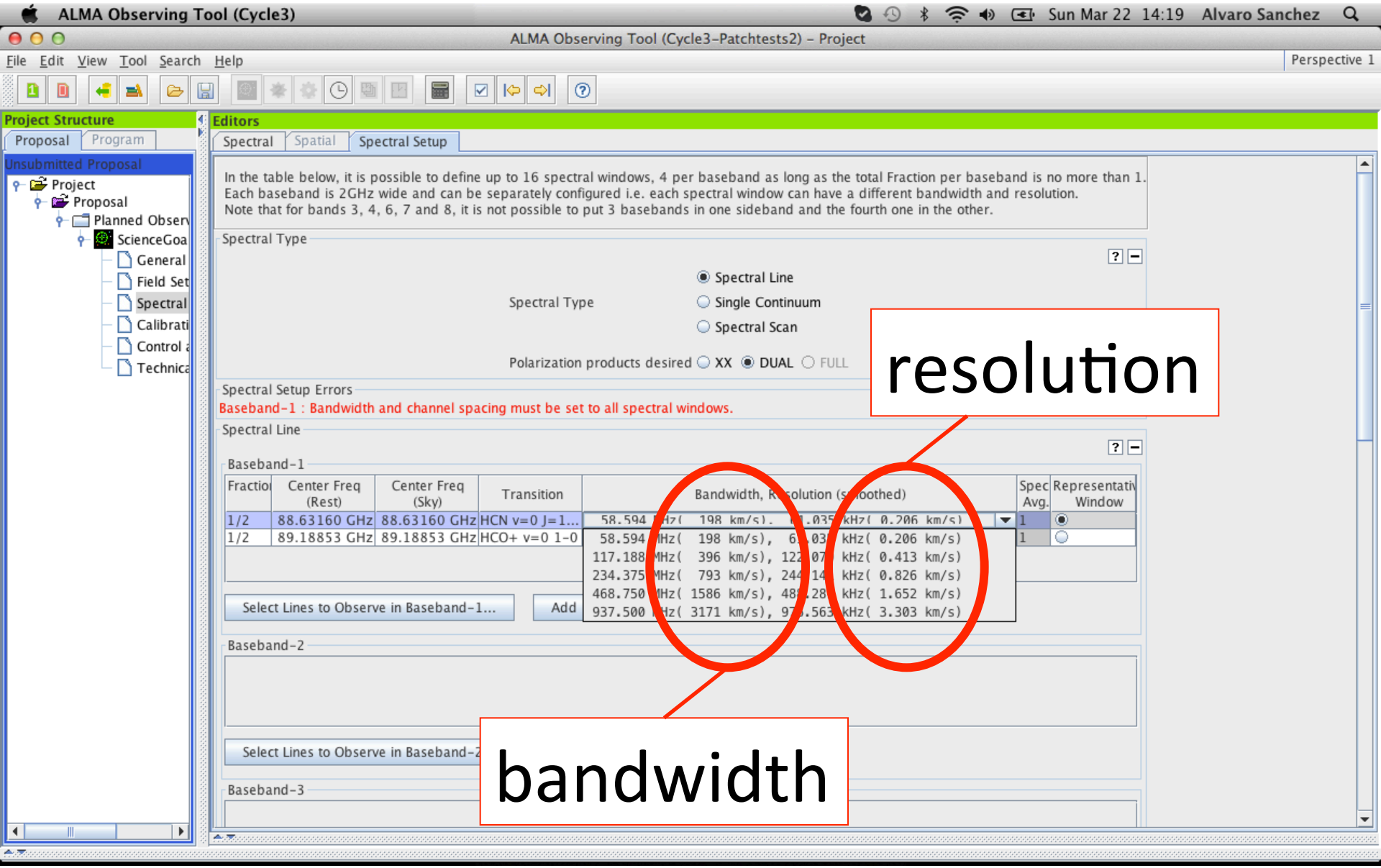
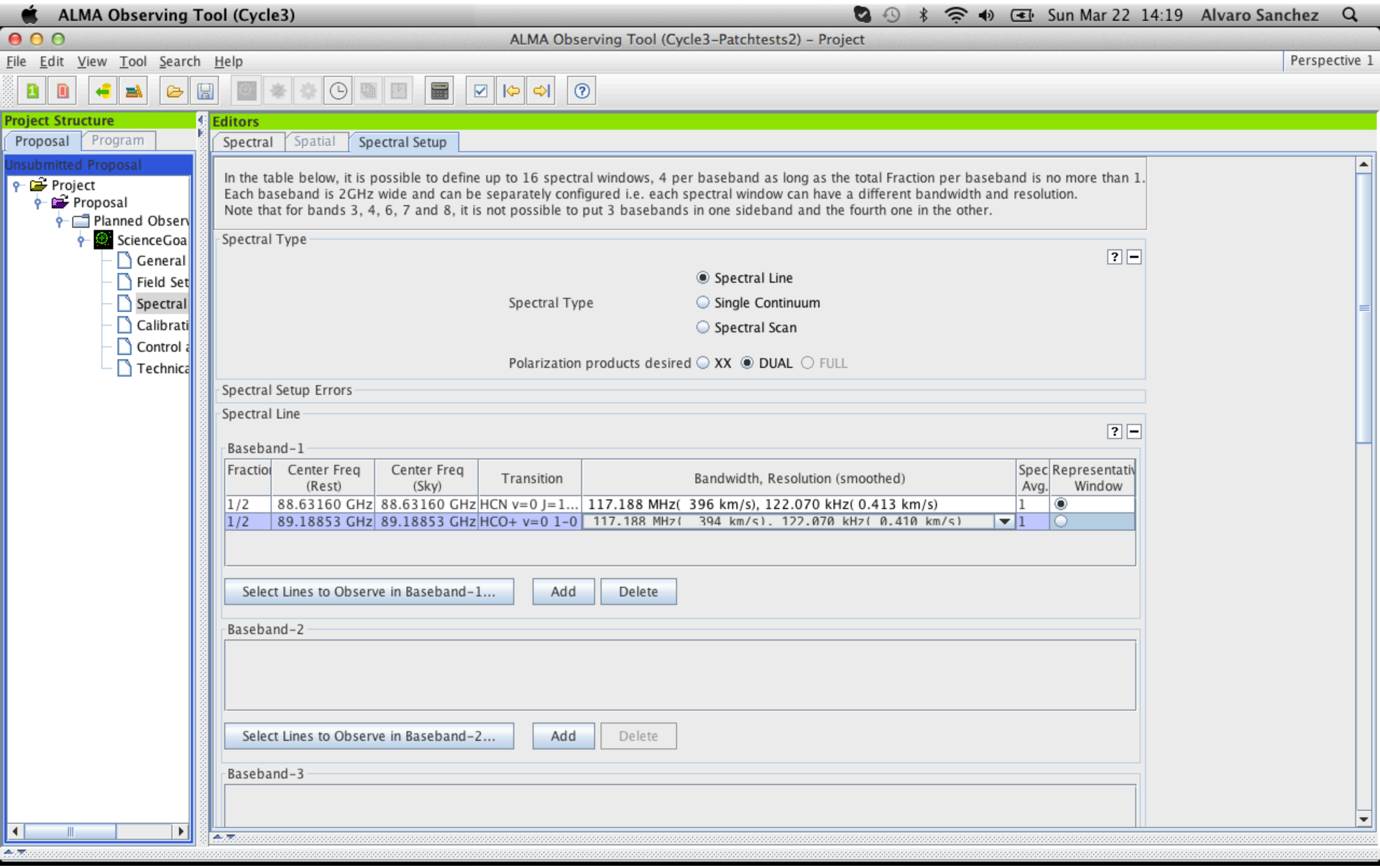


Spectral setup in the almaOT (EXAMPLE)



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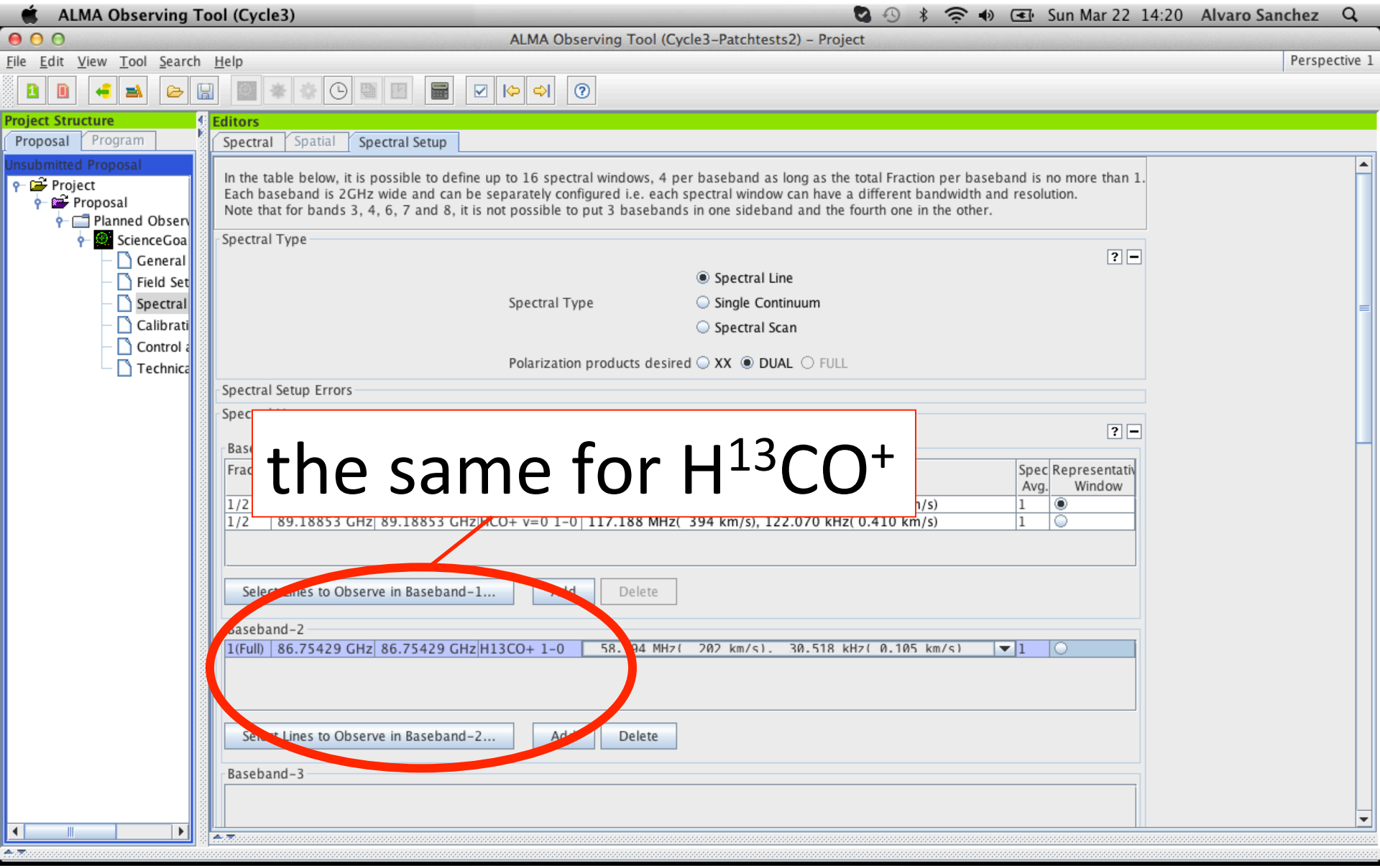
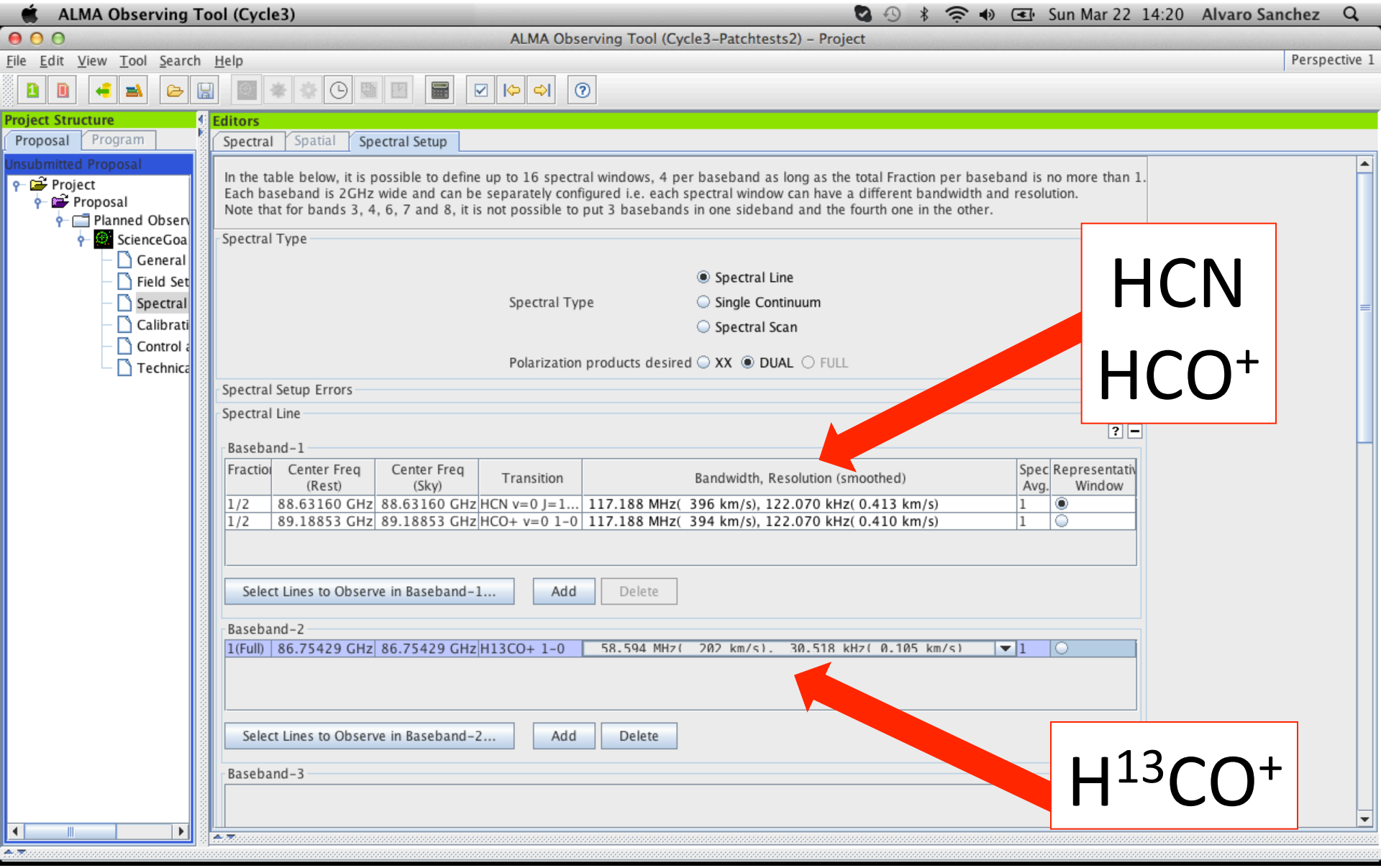


the same for $H^{13}CO^+$

Spectral setup in the almaOT (EXAMPLE)



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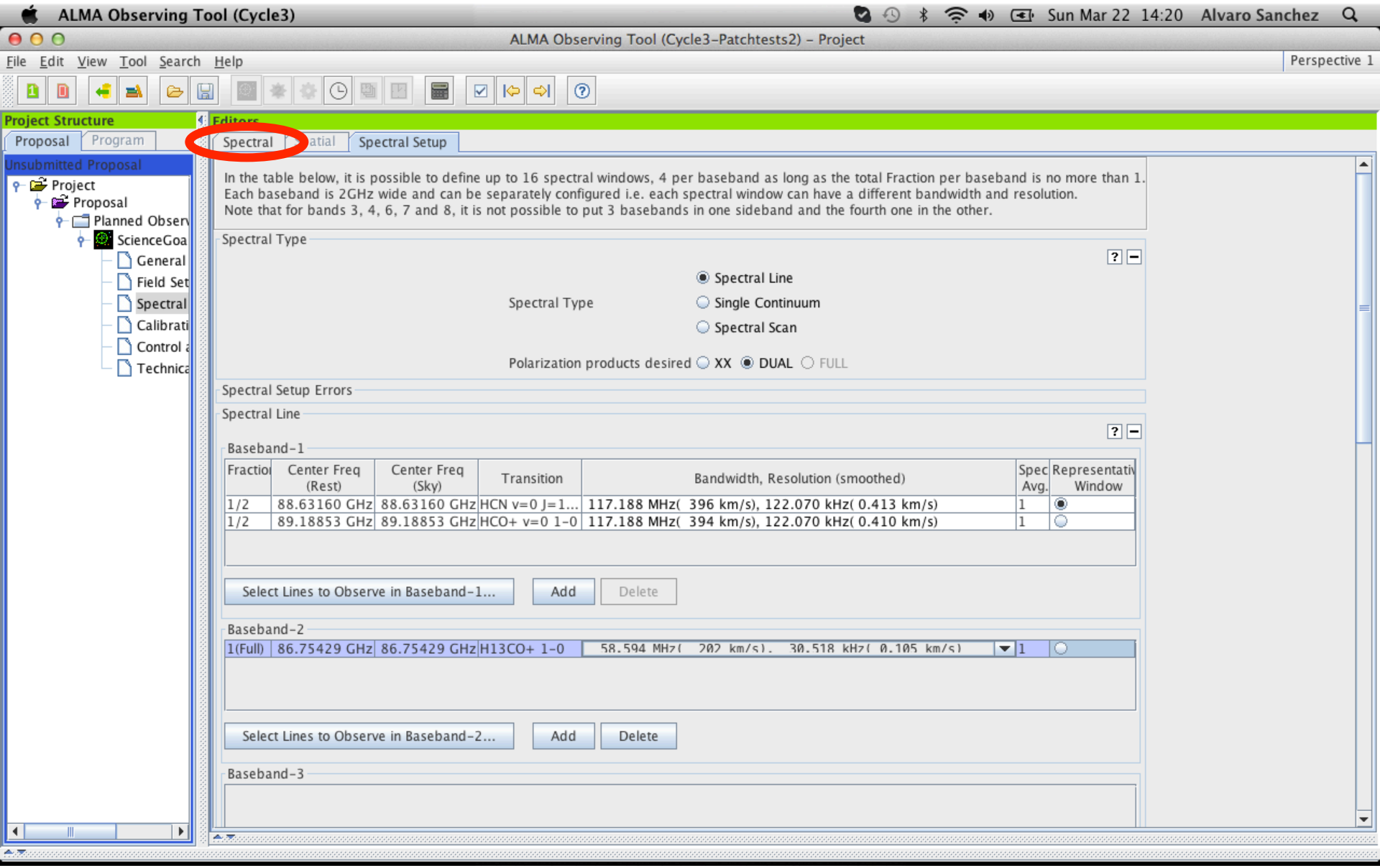

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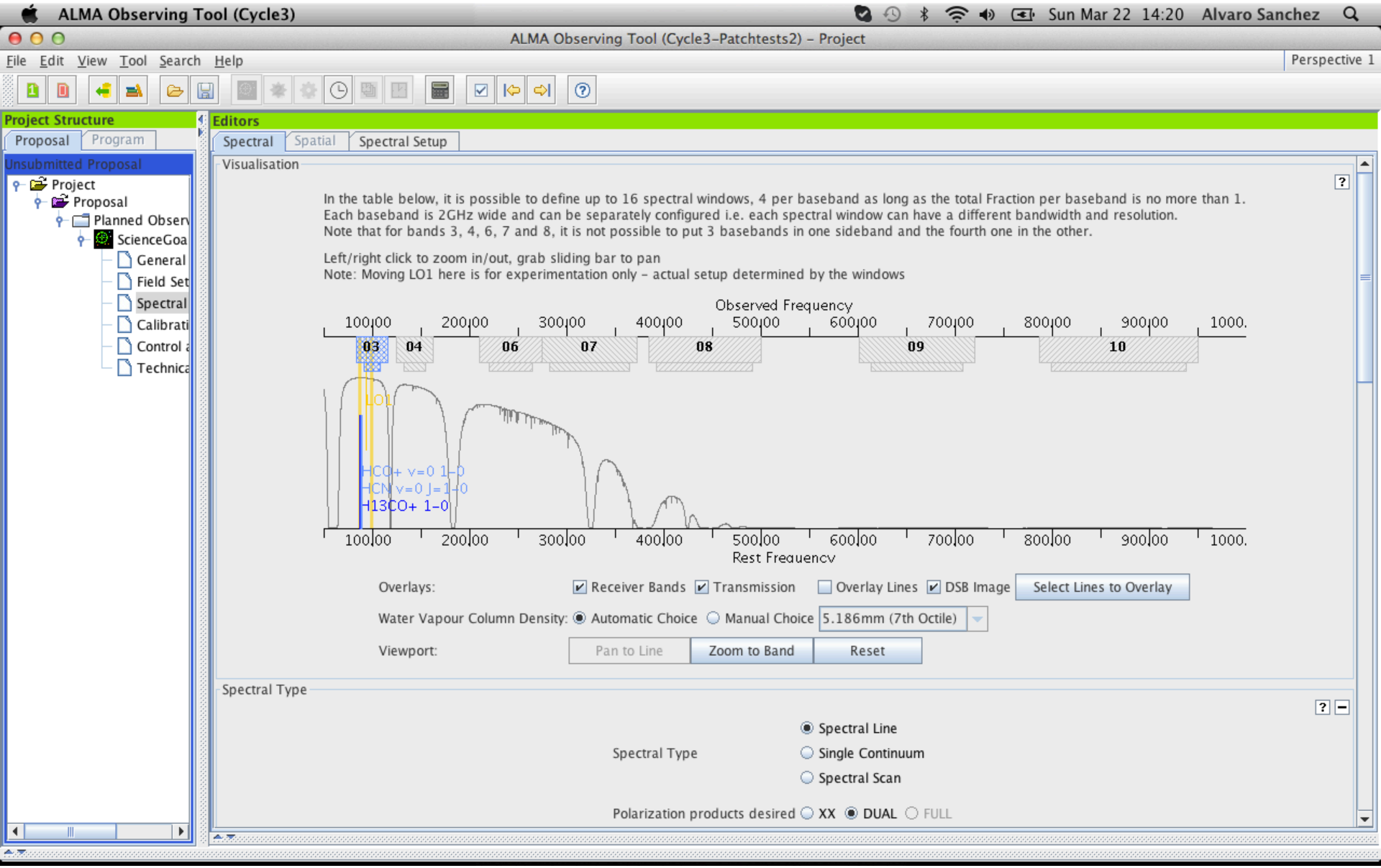

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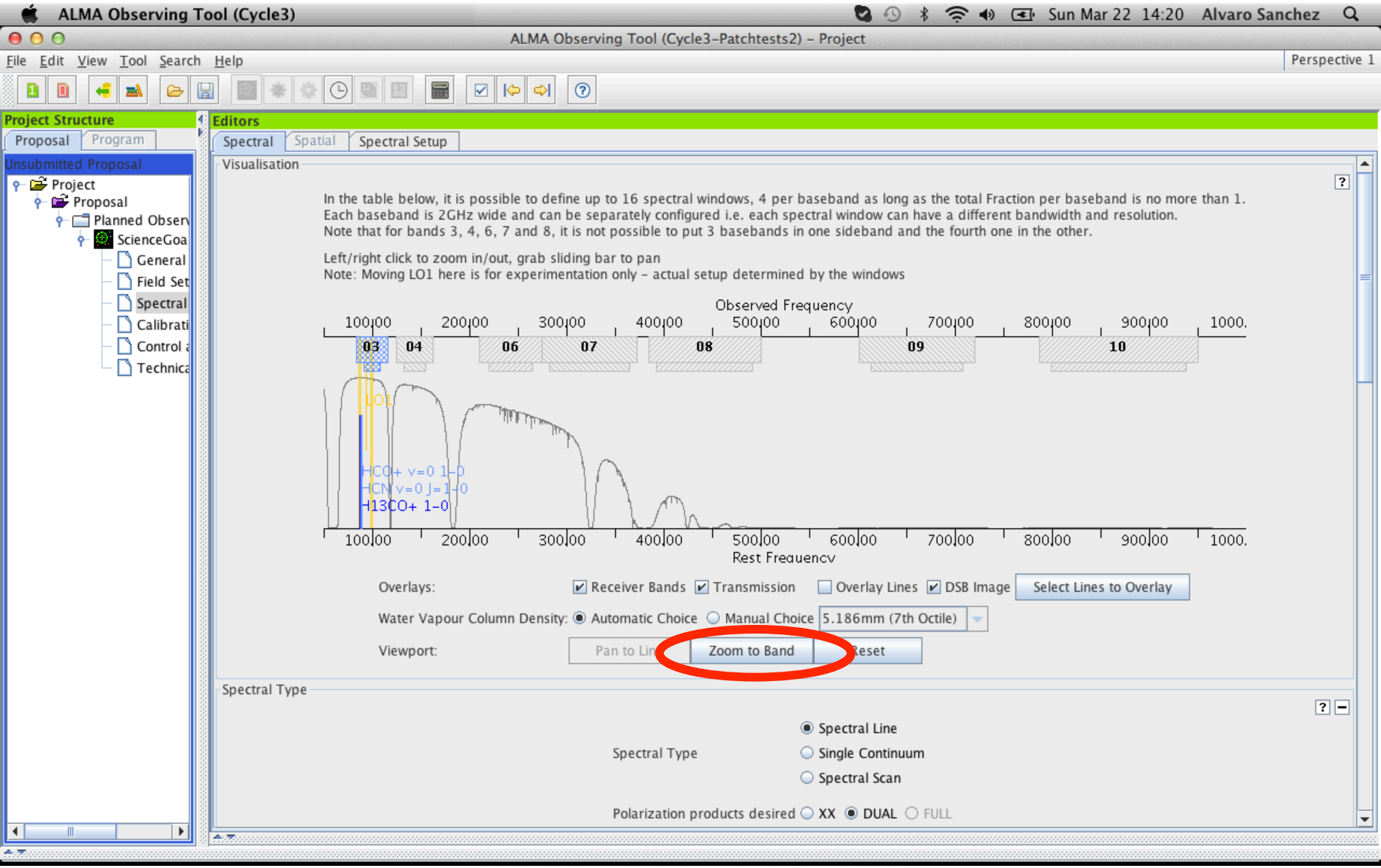

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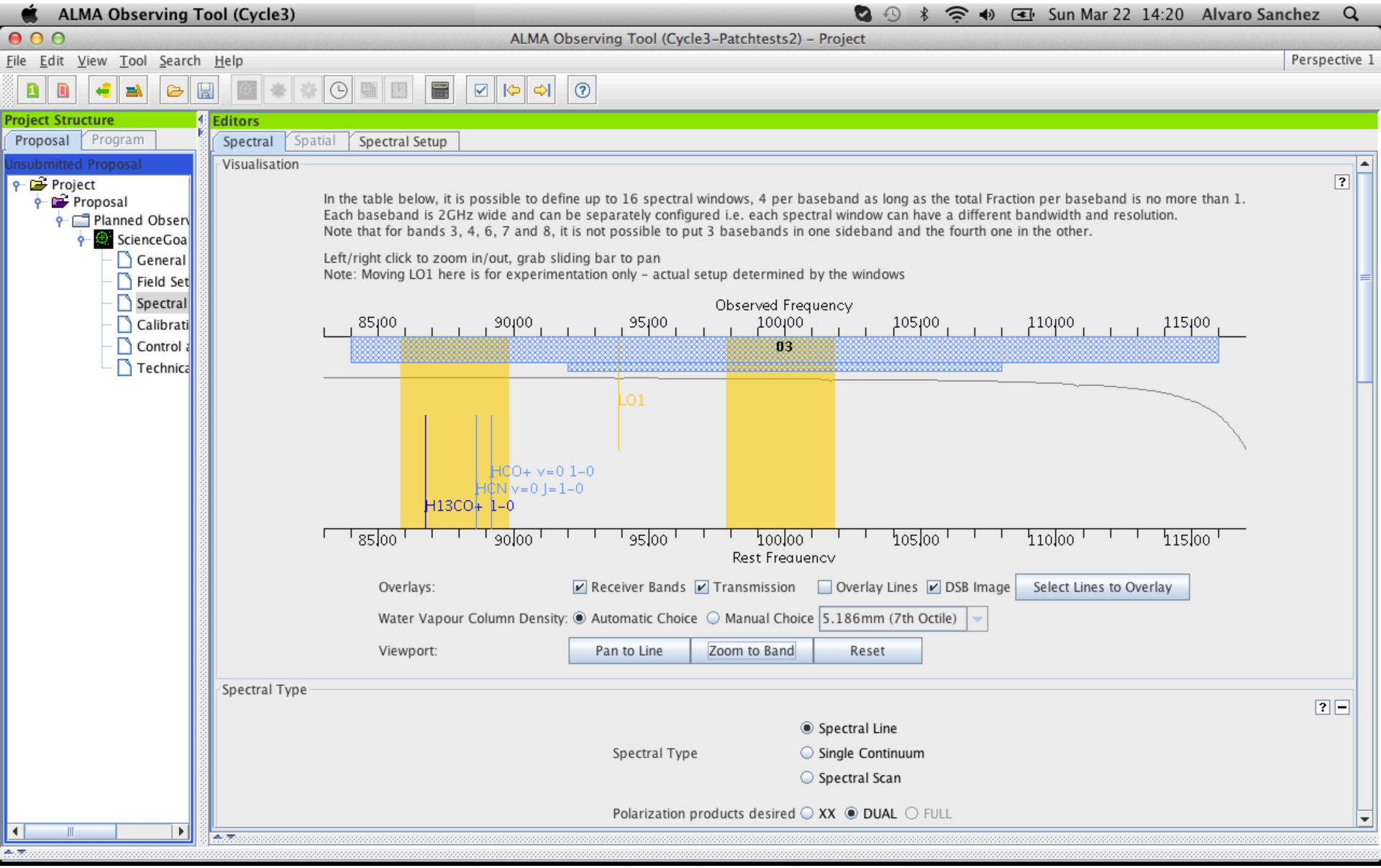

Break #2