Part 2:
spectral setup, receivers and correlator

German ARC: ALMA community days (March 2015)

Outline

Part 1: by S. Burkutean

- Introduction to aperture synthesis
- Interferometers: spatial filters

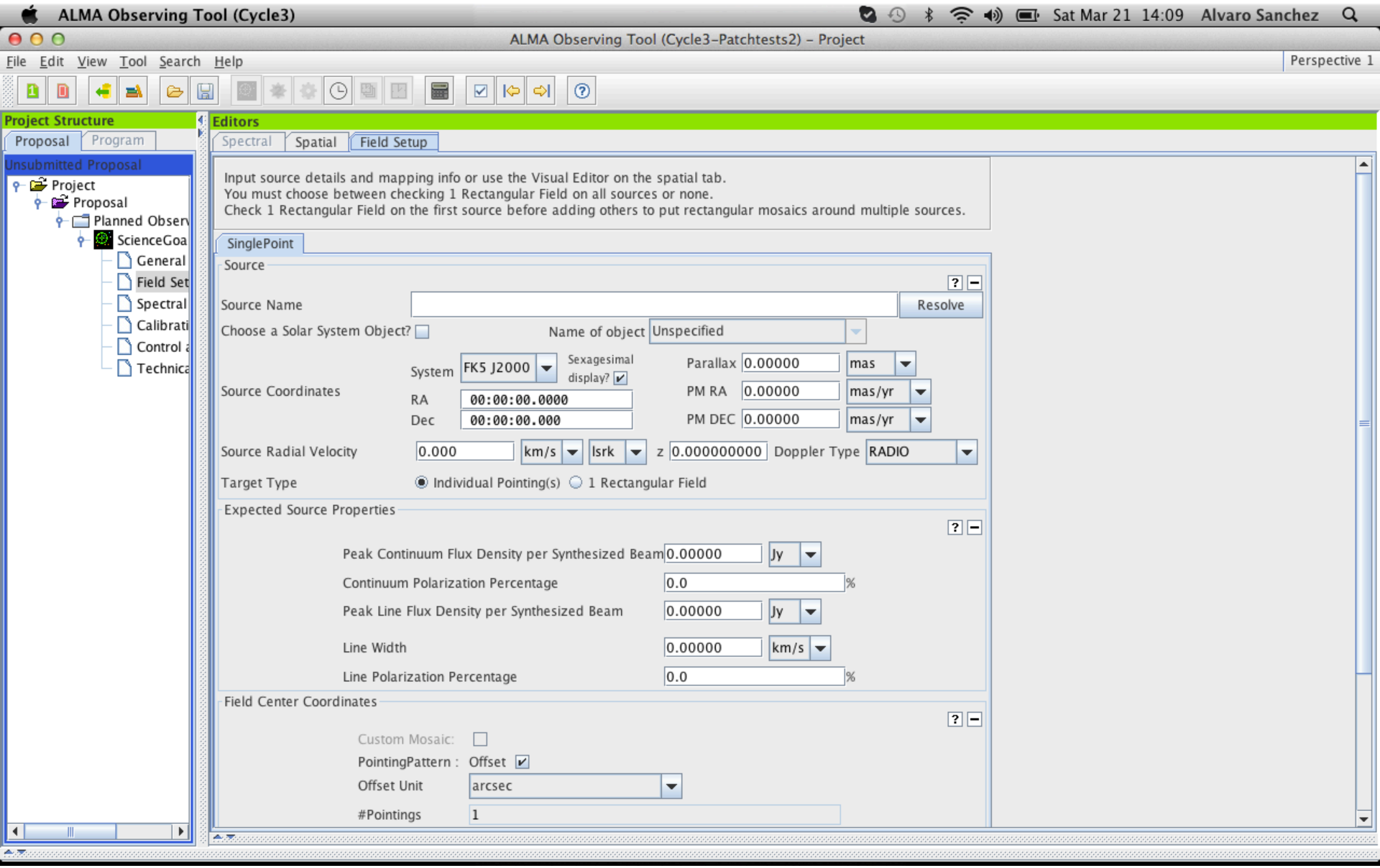
Part 2: by Á. Sánchez-Monge

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

Part 3: by T. Badescu

- The sensitivity of an interferometer
- A typical observing setup

Spectral setup in the almaOT



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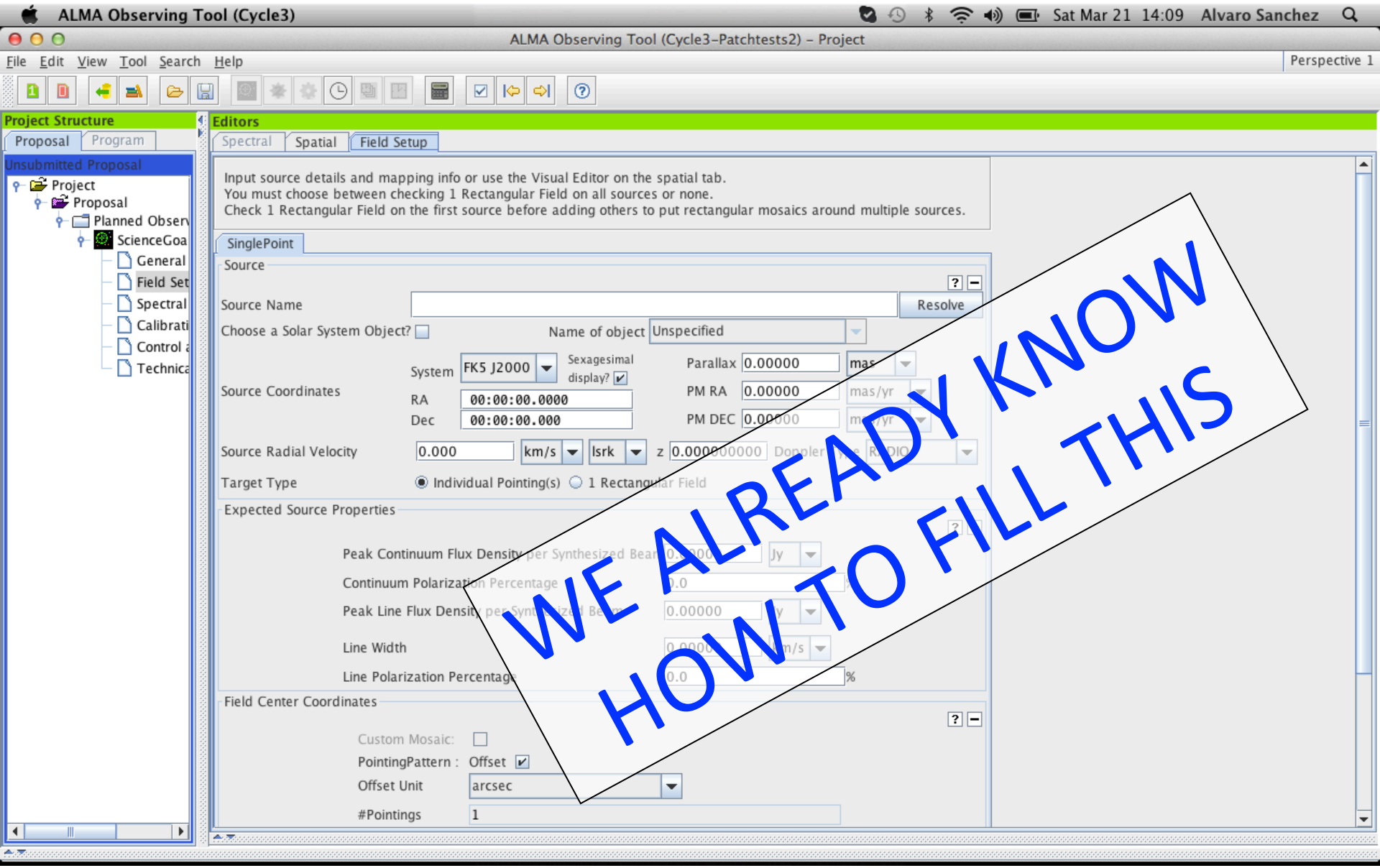

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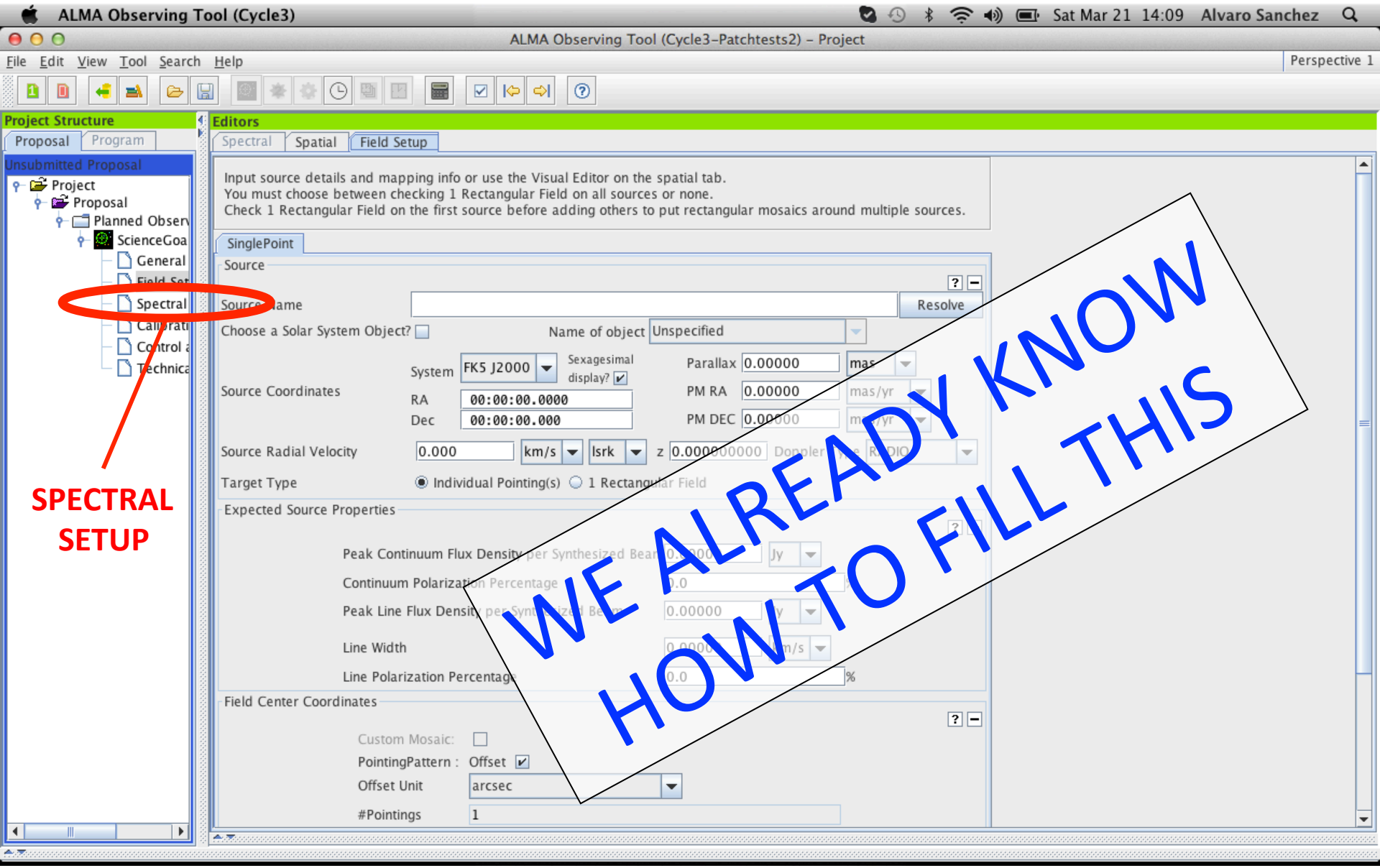

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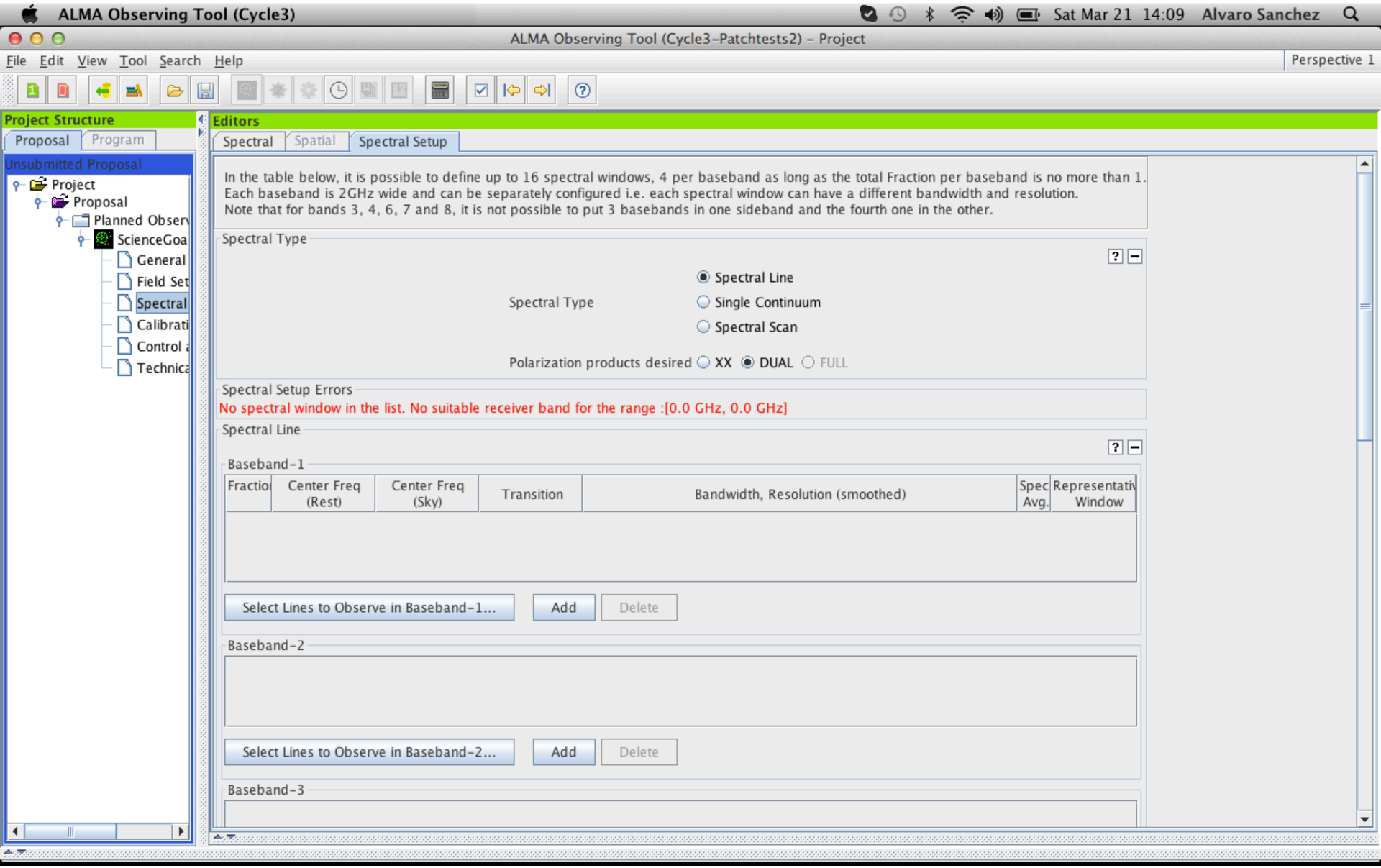

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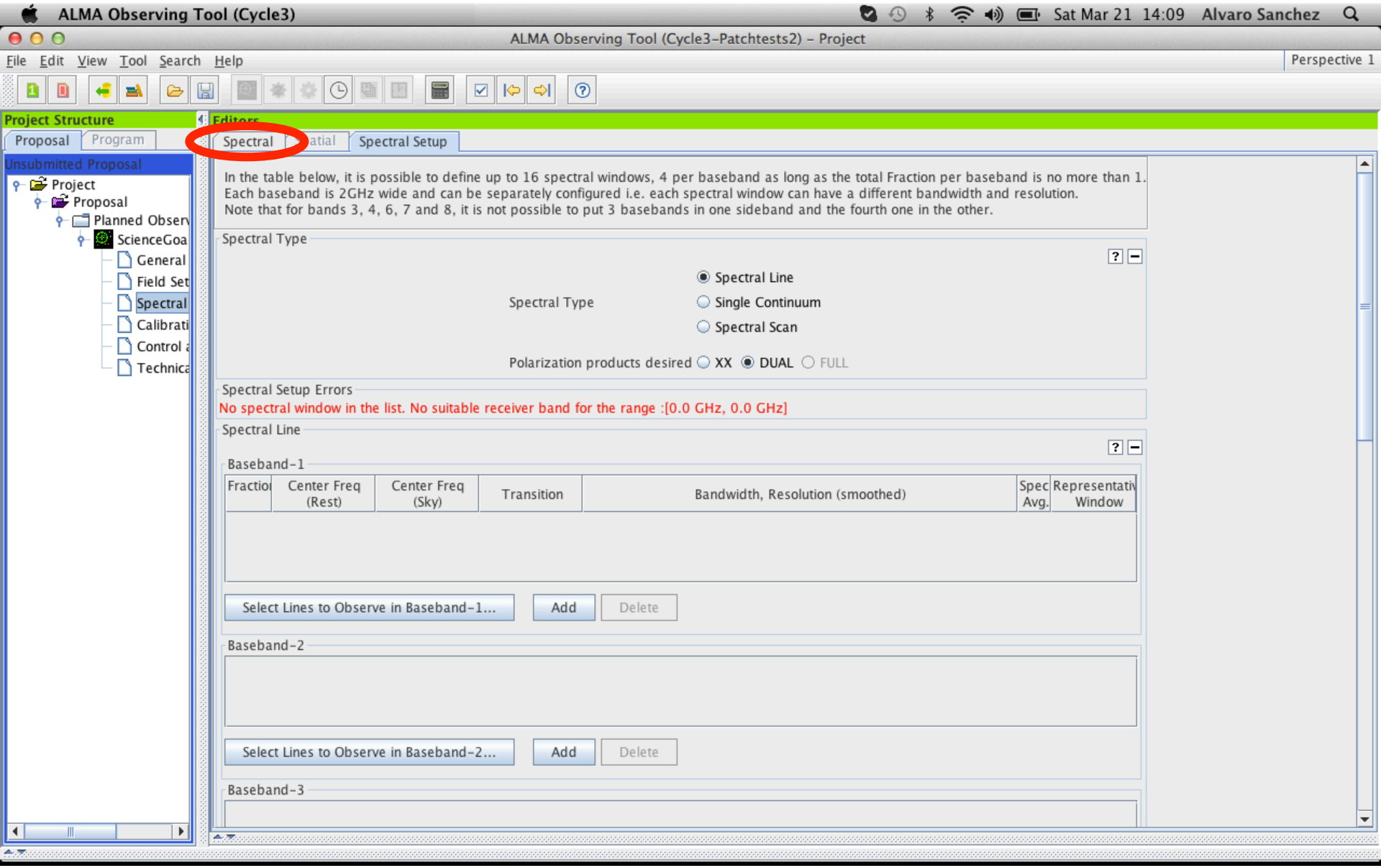

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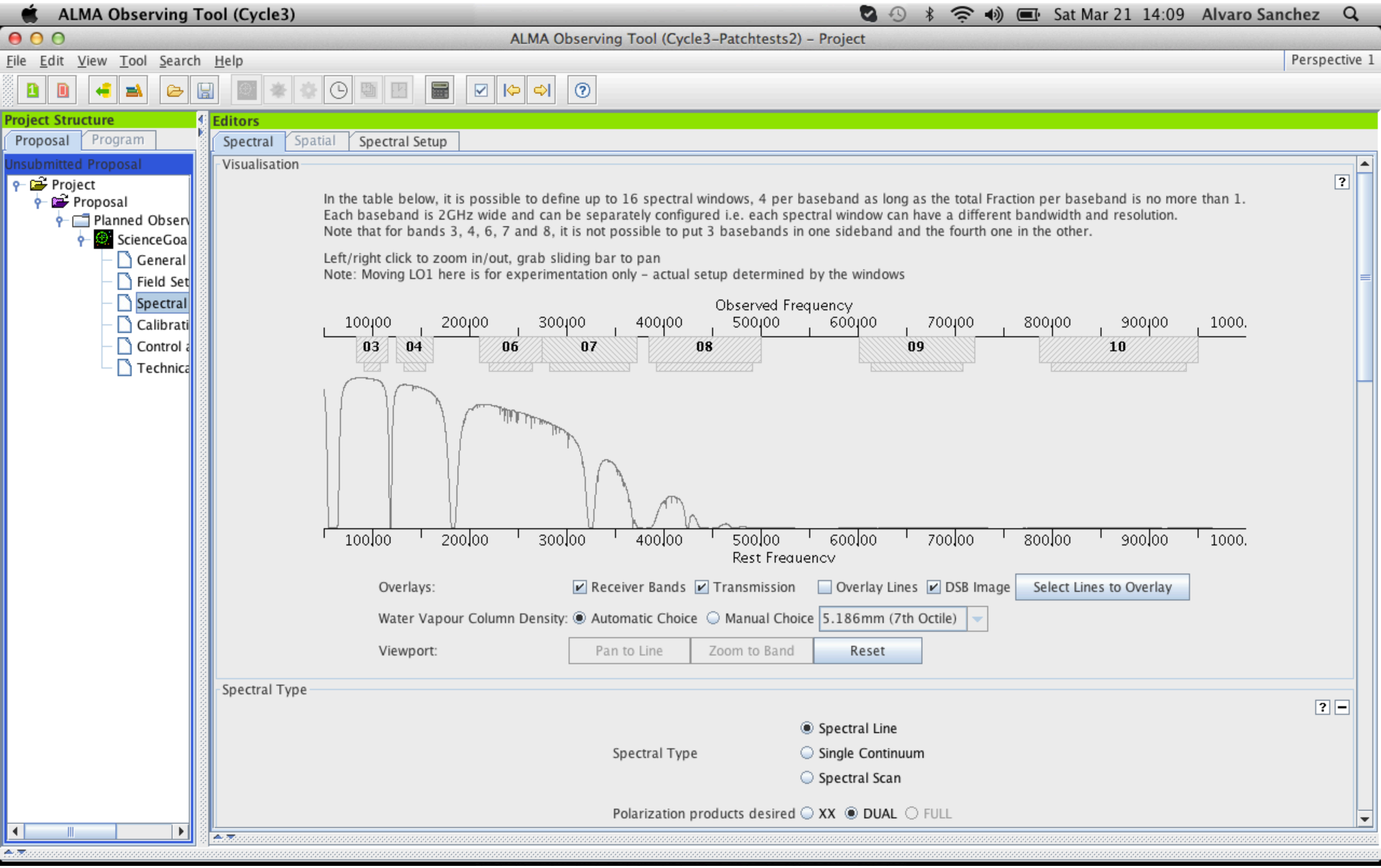

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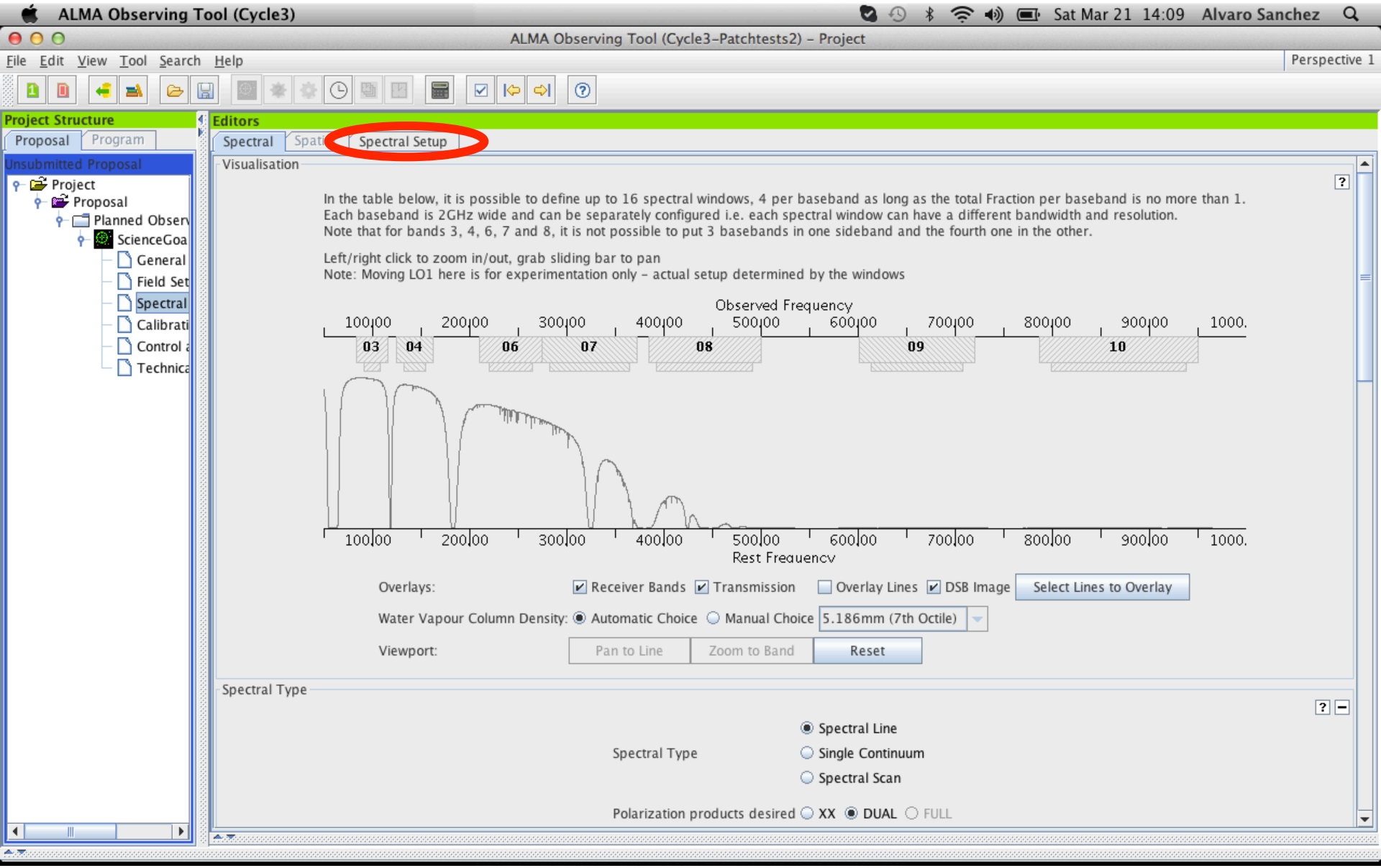

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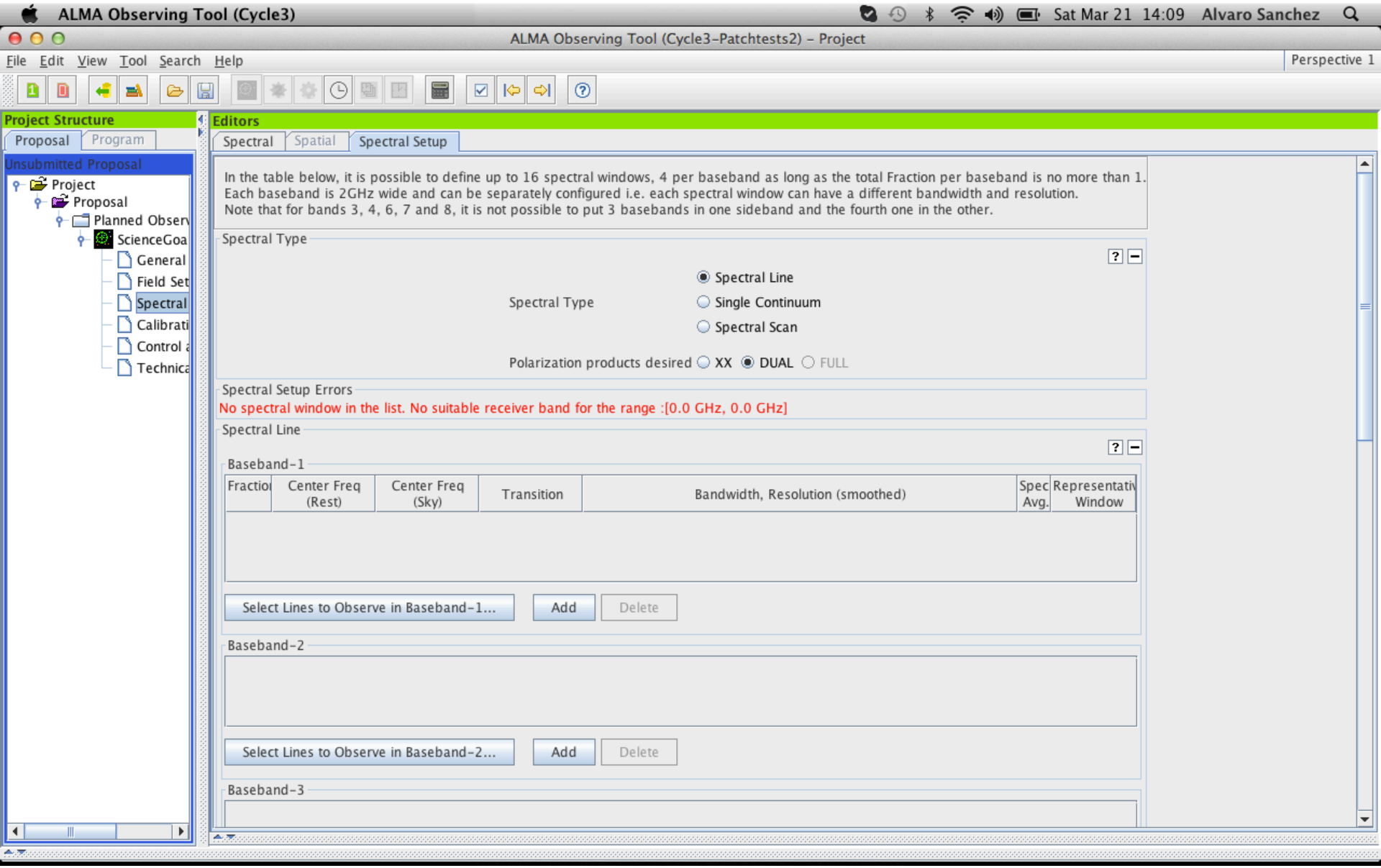

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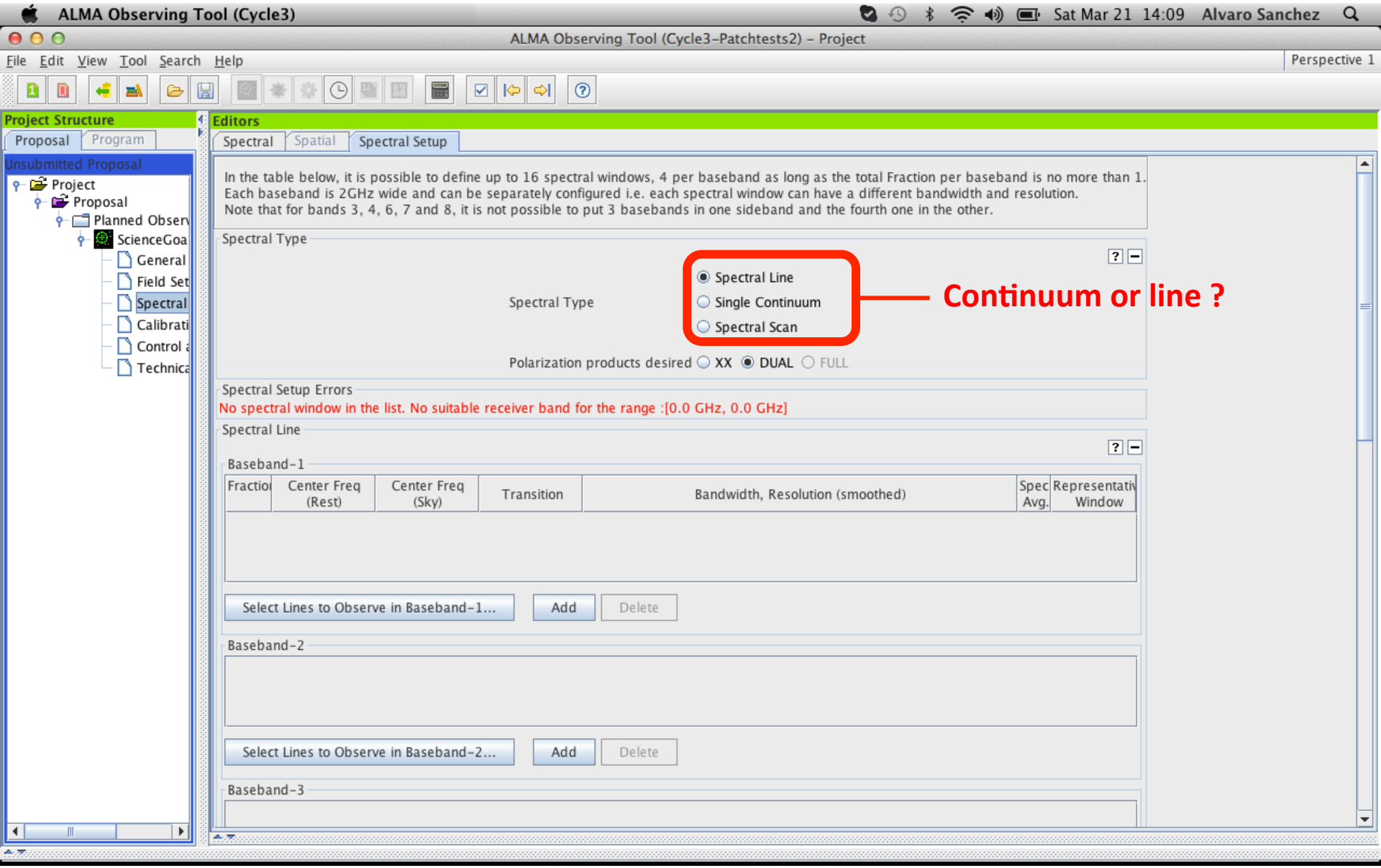

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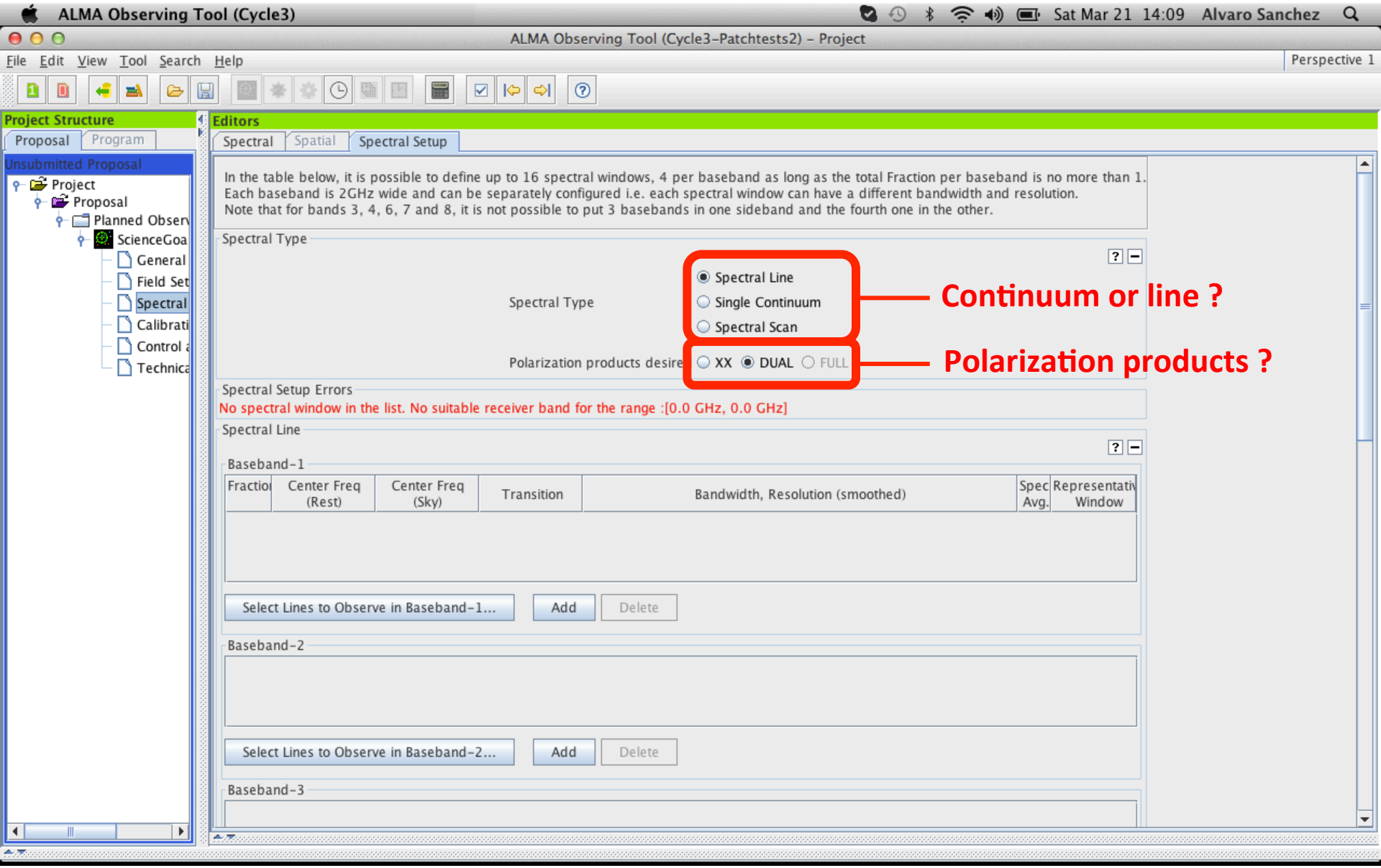

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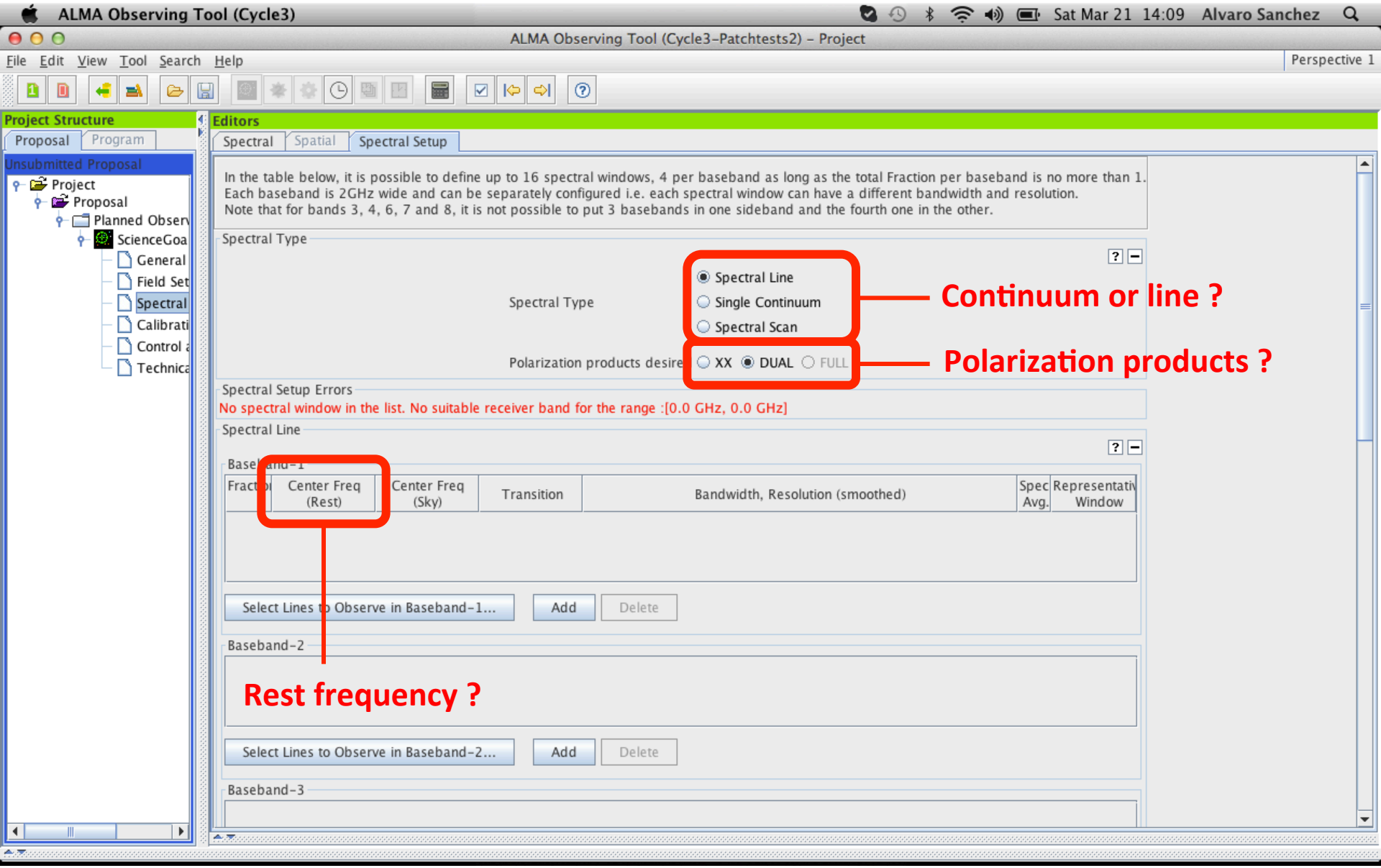

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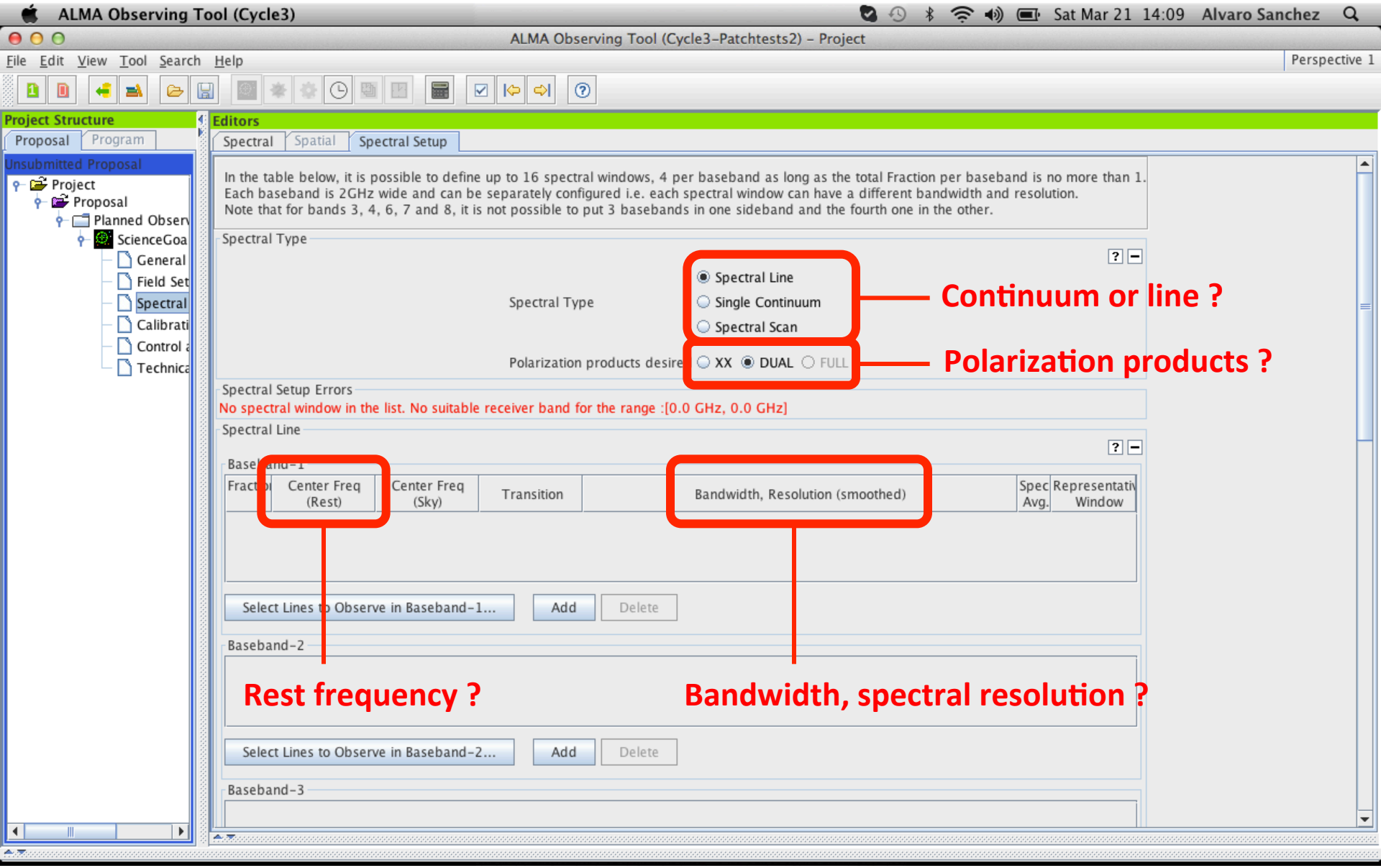
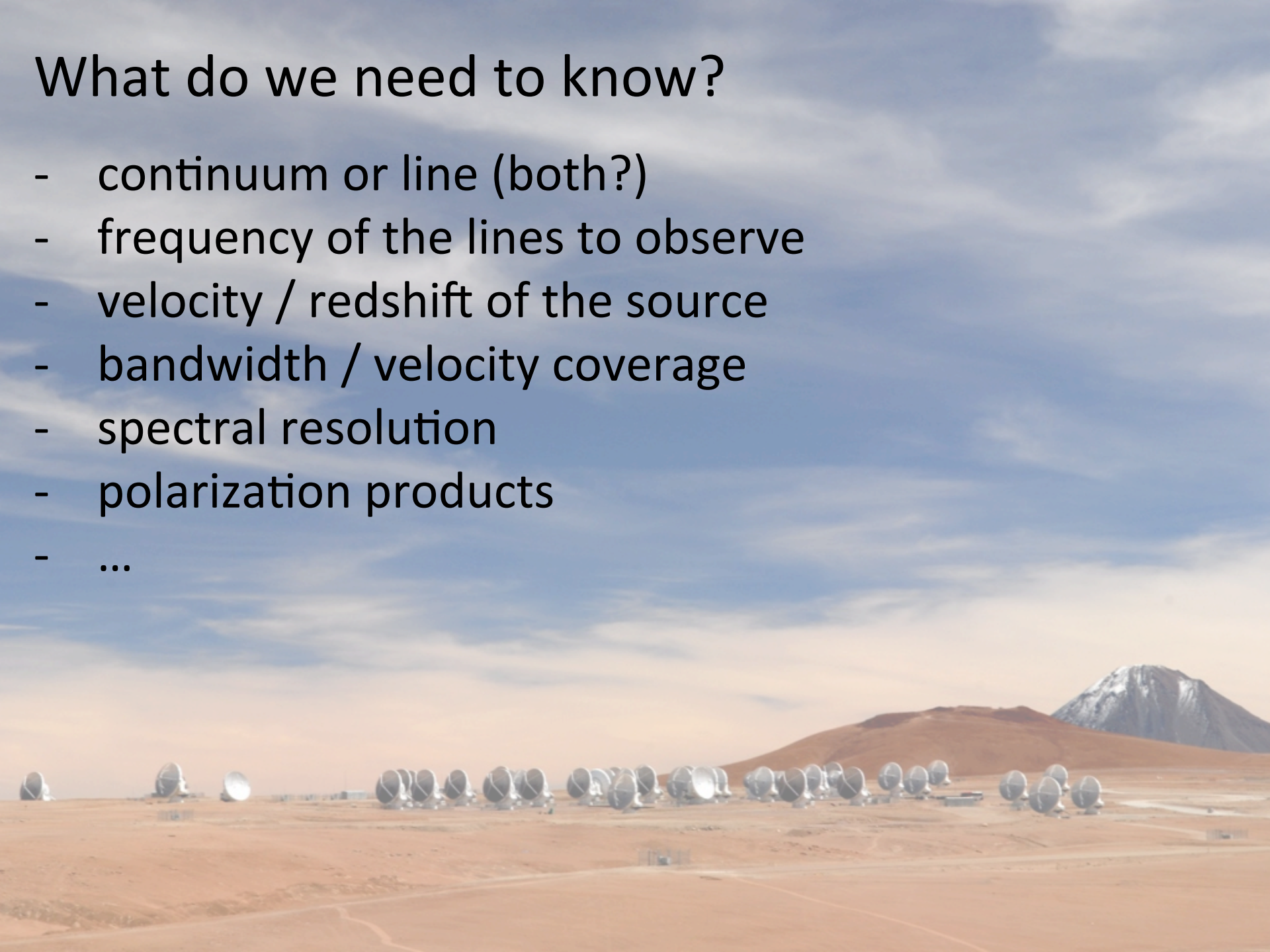


What do we need to know?

- 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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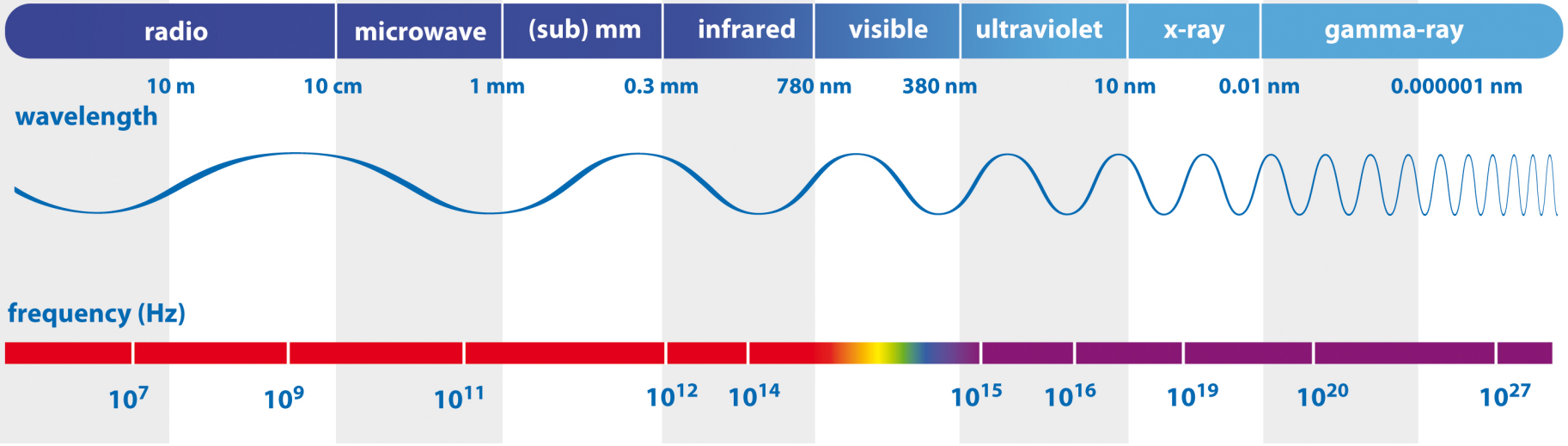
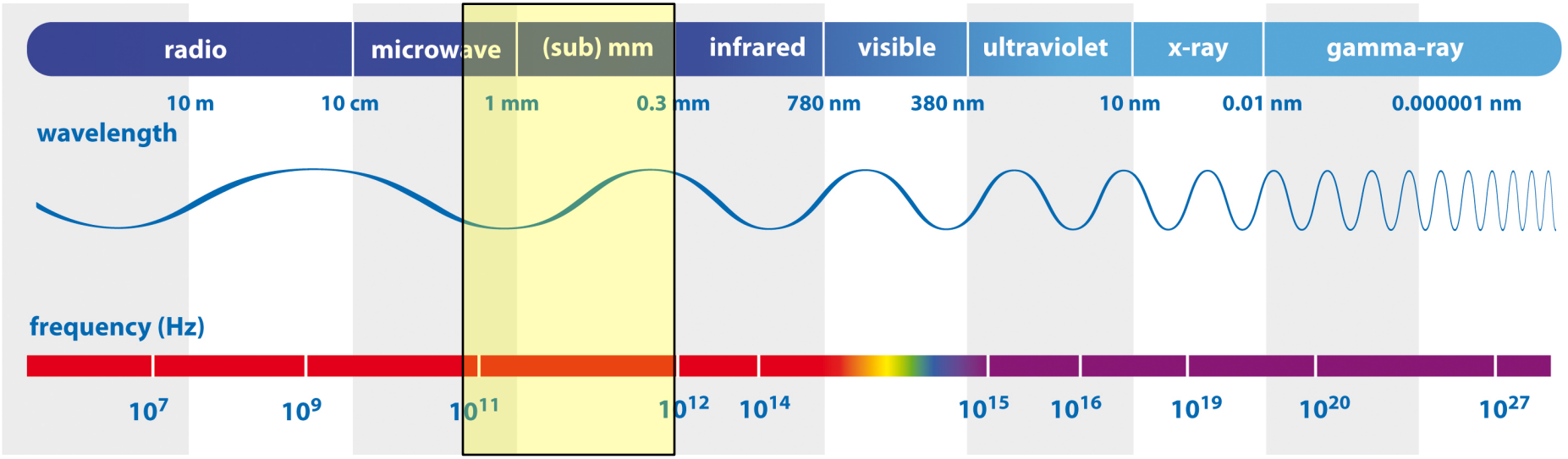
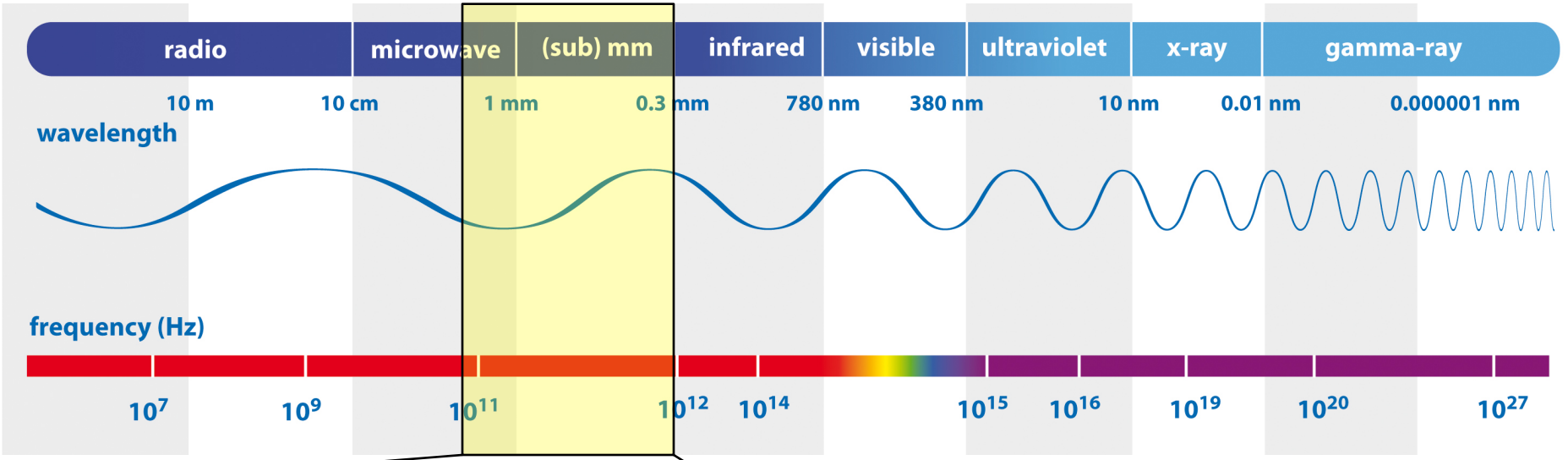
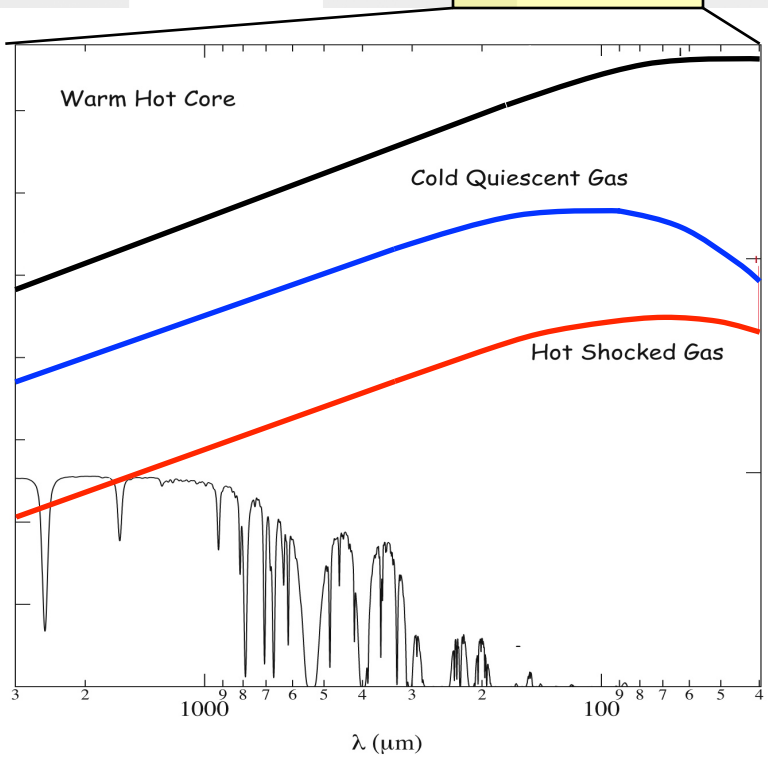

radio
microwave
(sub) mm
infrared
visible
ultraviolet
x-ray
gamma-ray
10 m
10 cm
1 mm
0.3 mm
780 nm
380 nm
10 nm
0.01 nm
0.000001 nm
wavelength
frequency (Hz)
10^7
10^9
10^11
10^12
10^14
10^15
10^16
10^19
10^20
10^27



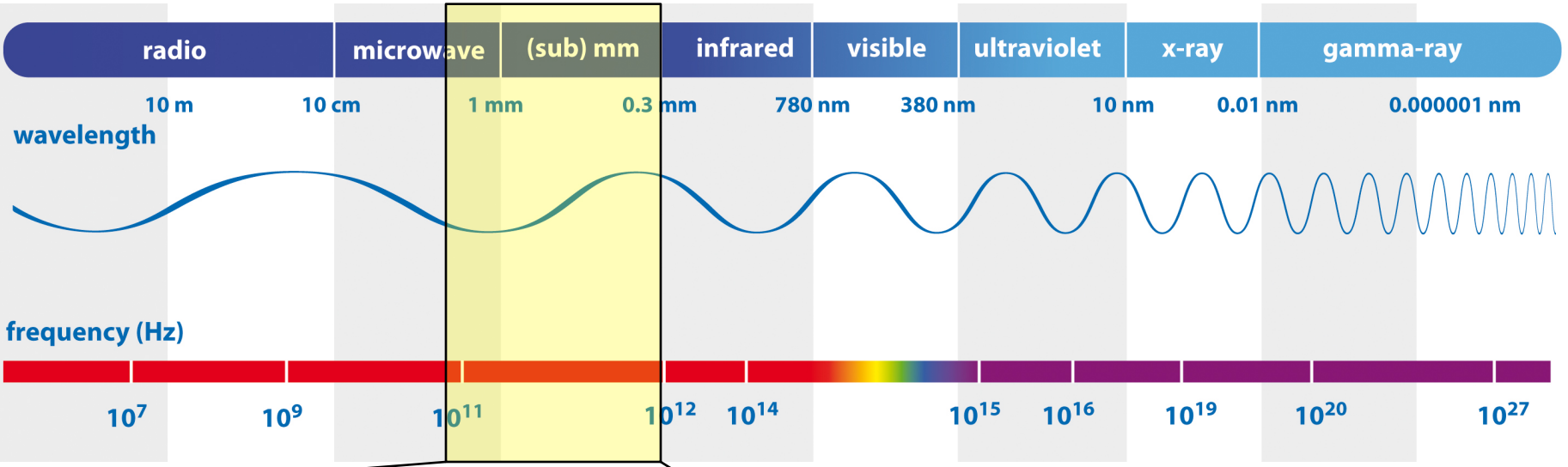
ALMA observable range

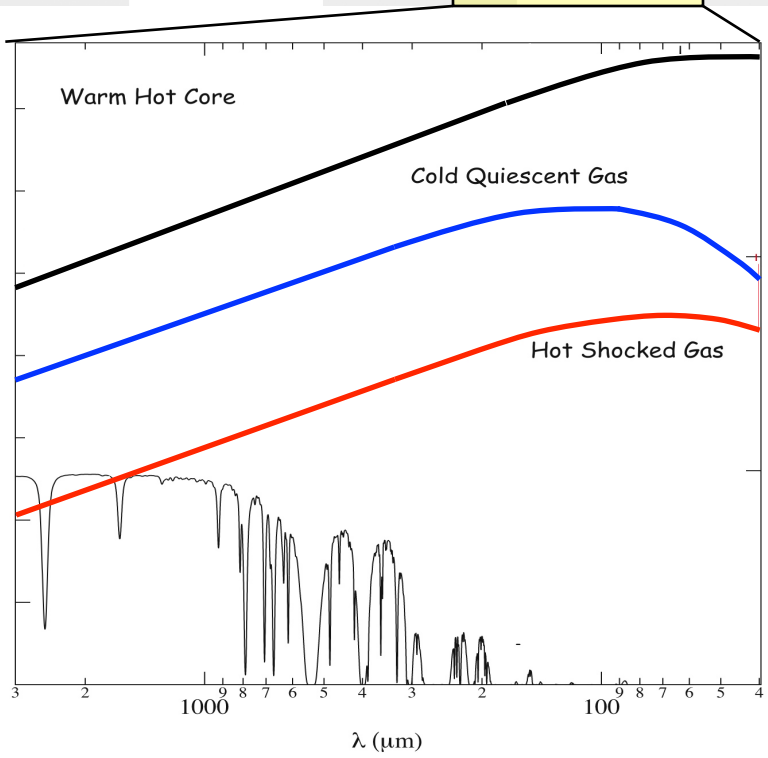
"**Cold Universe**"

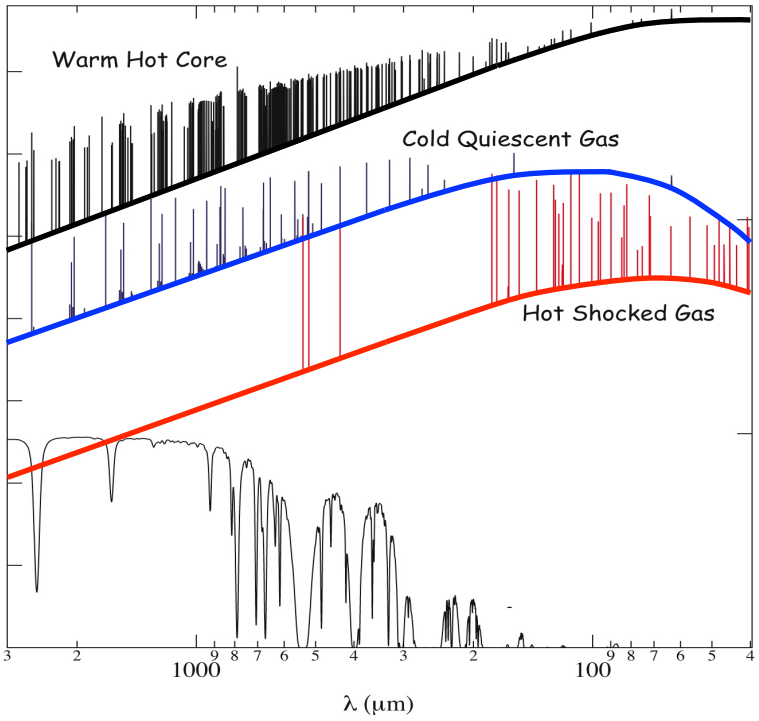




continuum emission







continuum emission

line emission

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

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

- 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)

What do we need to know?

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

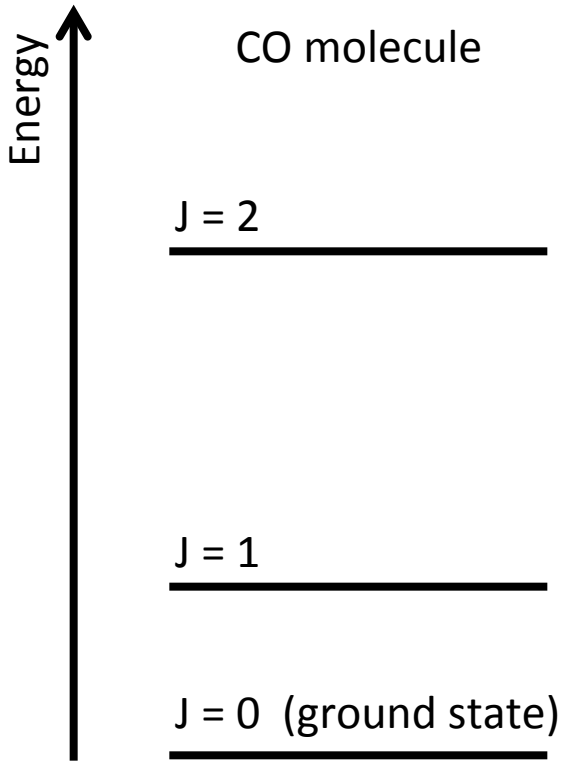
Basic concepts of spectral line observations

Rest frequency

Basic concepts of spectral line observations

Rest frequency

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



Basic concepts of spectral line observations

Rest frequency

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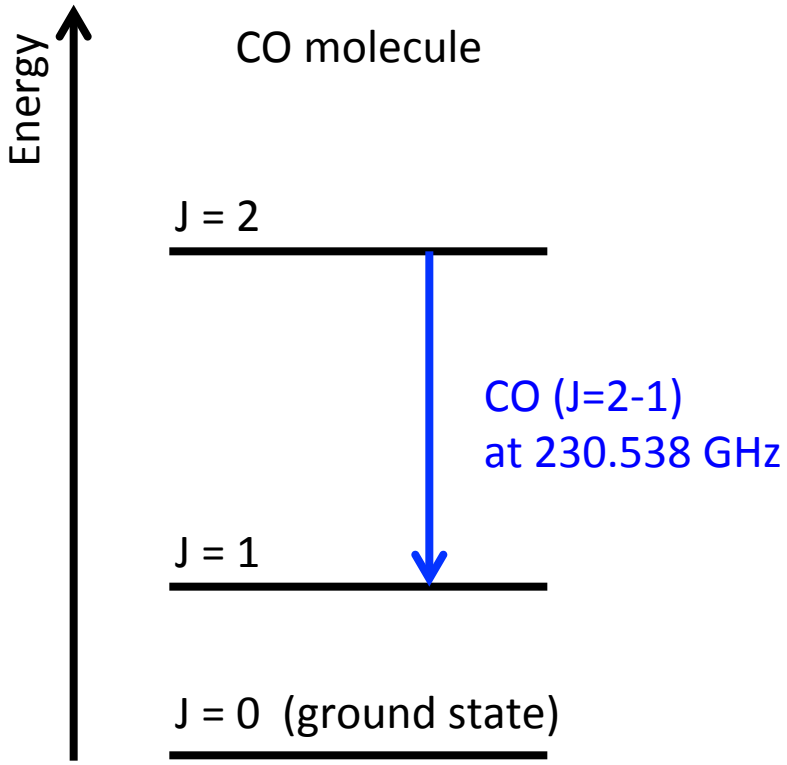

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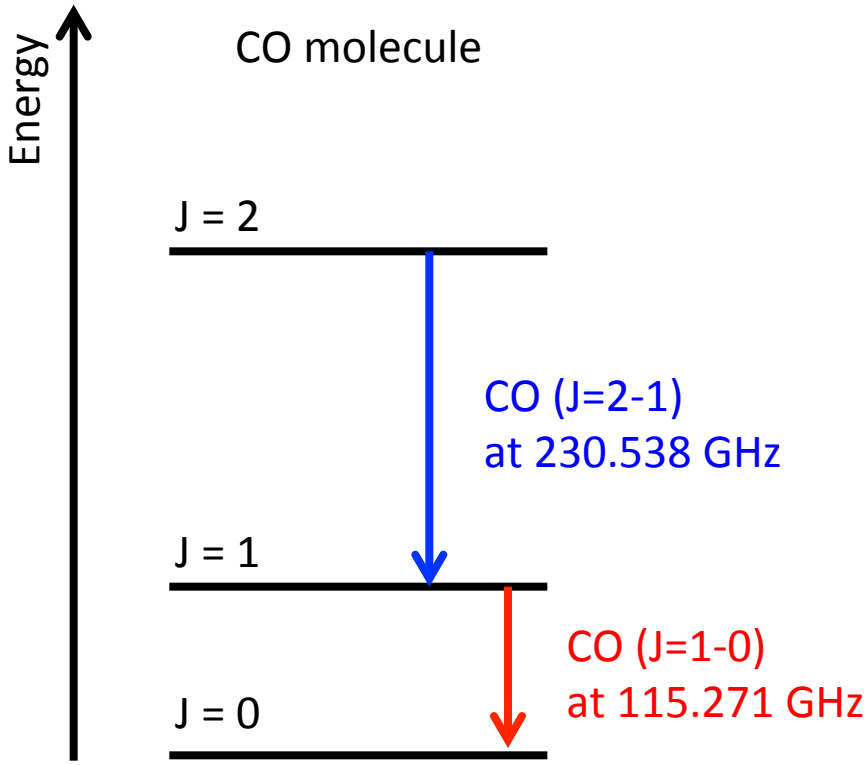

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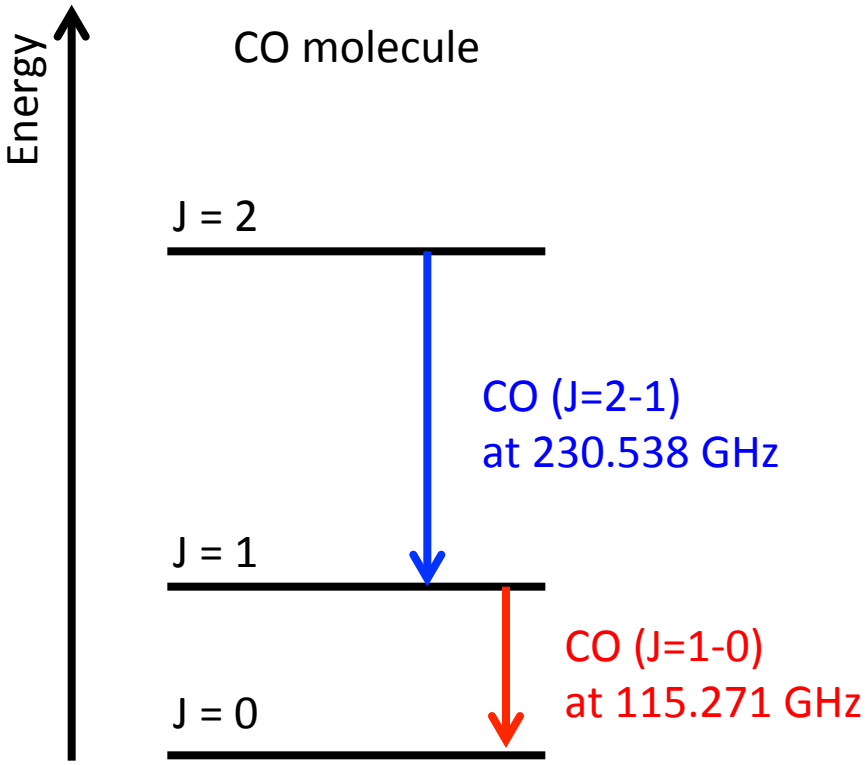

Rest frequencies can be found in molecular databases:

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

JPL
spec.jpl.nasa.gov

Splatalogue
www.splatalogue.net

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Basic concepts of spectral line observations

Velocity (Vlsr) / redshift (z)

Basic concepts of spectral line observations

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… from rest to sky frequencies ("**doppler effect**")

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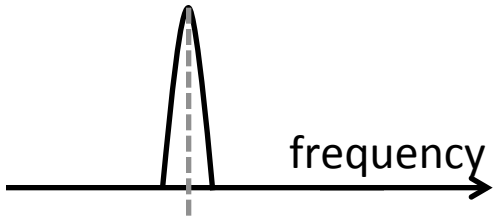


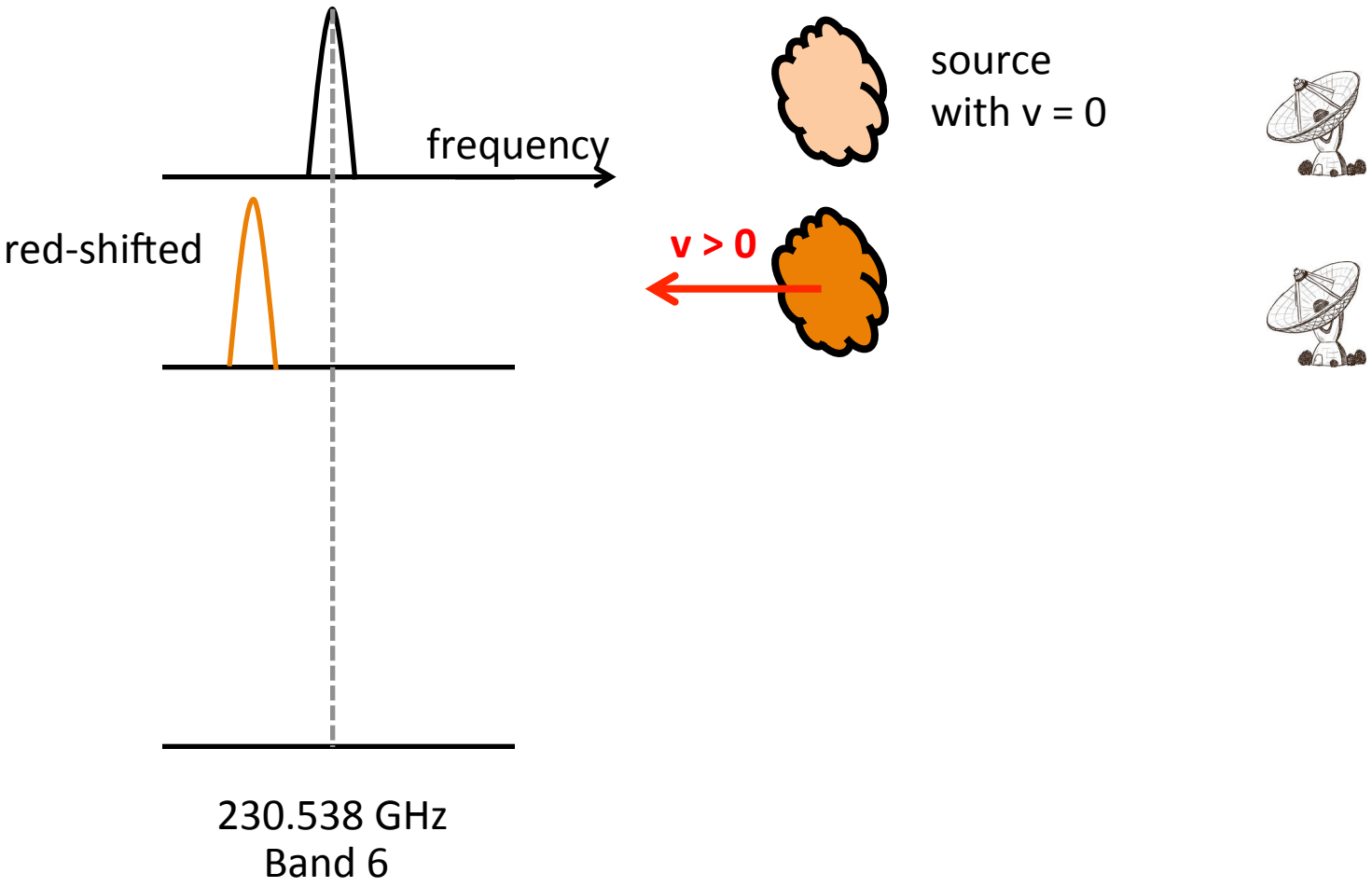
source
with v = 0

230.538 GHz
Band 6

Basic concepts of spectral line observations

Velocity (Vlsr) / redshift (z)

… from rest to sky frequencies ("**doppler effect**")



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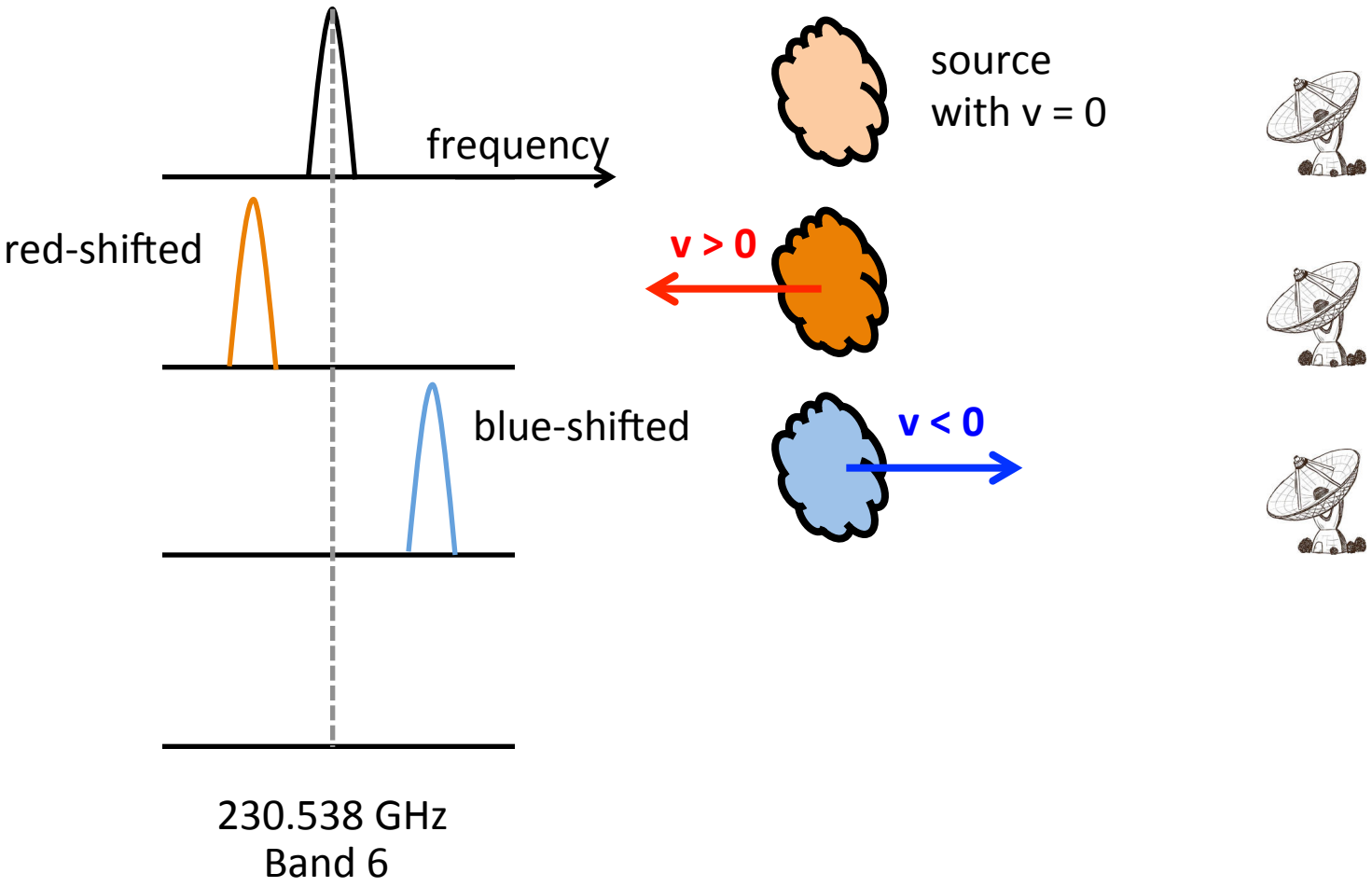

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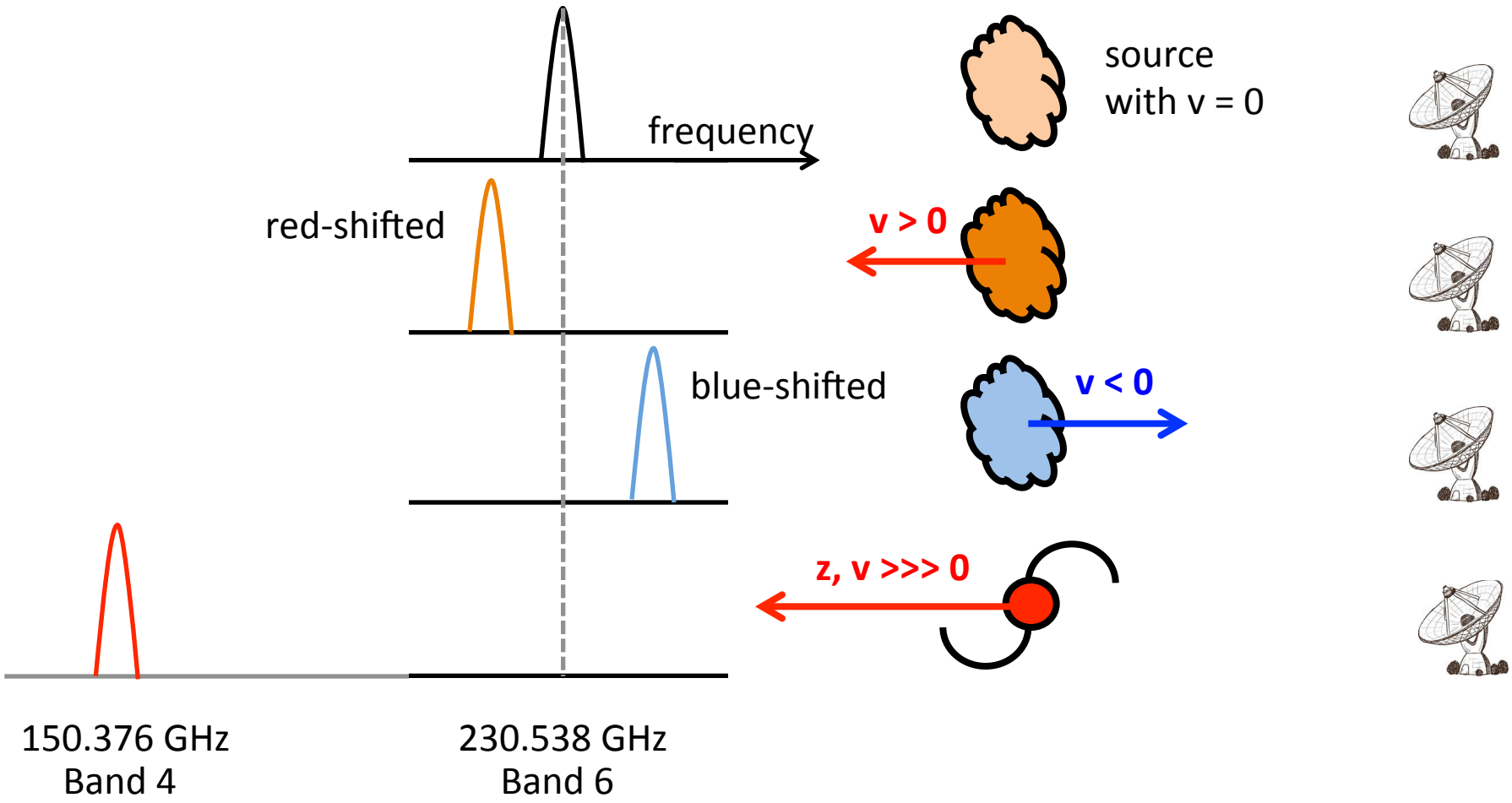

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the spectral line will have a width that depends on the properties of the object you are studying

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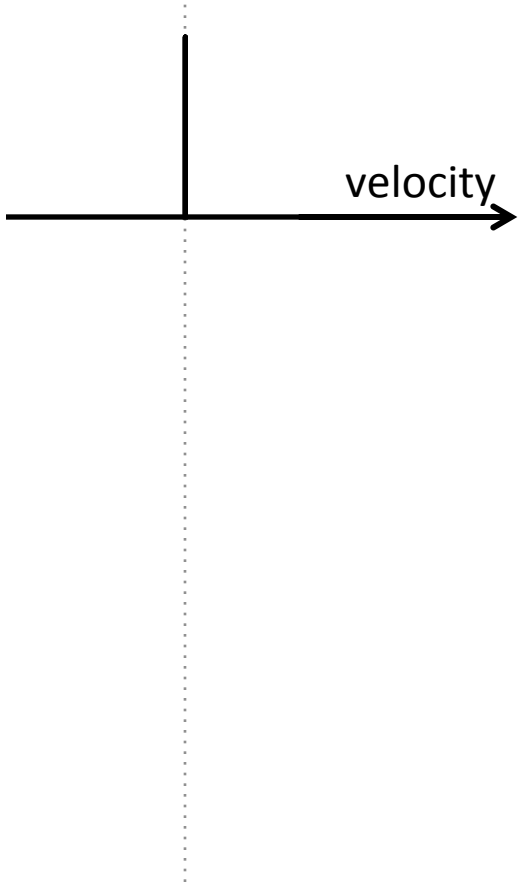

each spectral line has an exact frequency

Basic concepts of spectral line observations

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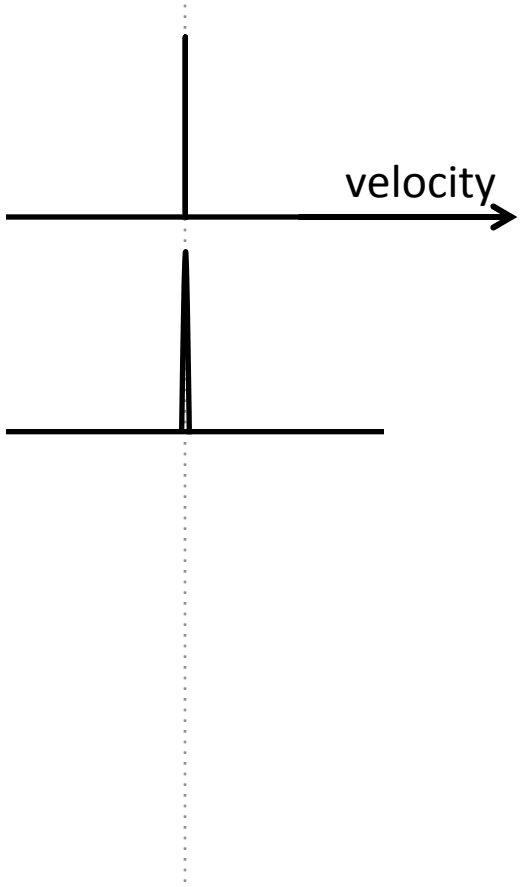

each spectral line has an exact frequency

natural broadening

Basic concepts of spectral line observations

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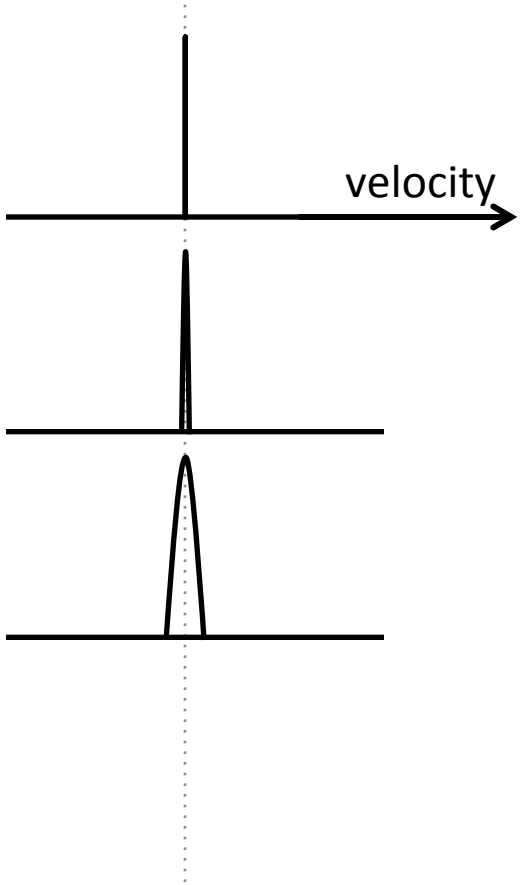

each spectral line has an exact frequency

natural broadening

thermal, microturbulent, pressure broadening

Basic concepts of spectral line observations

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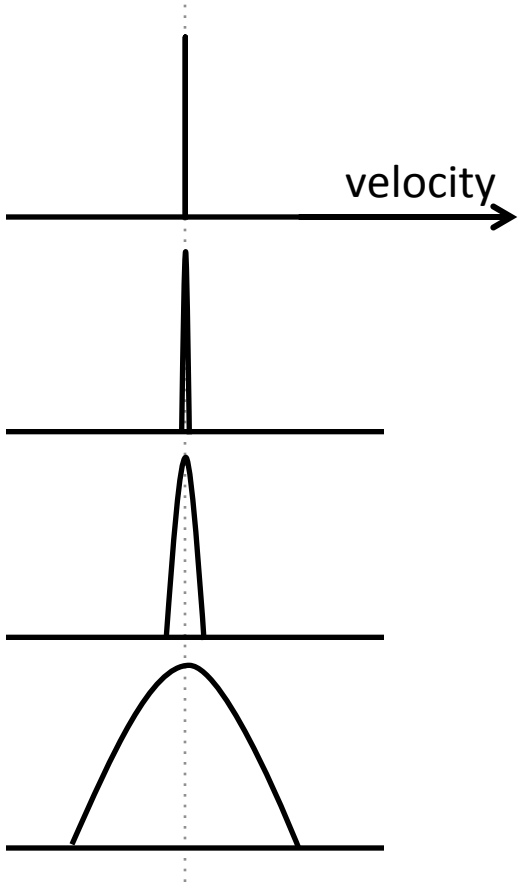

each spectral line has an exact frequency

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large-scale motions broadening

Basic concepts of spectral line observations

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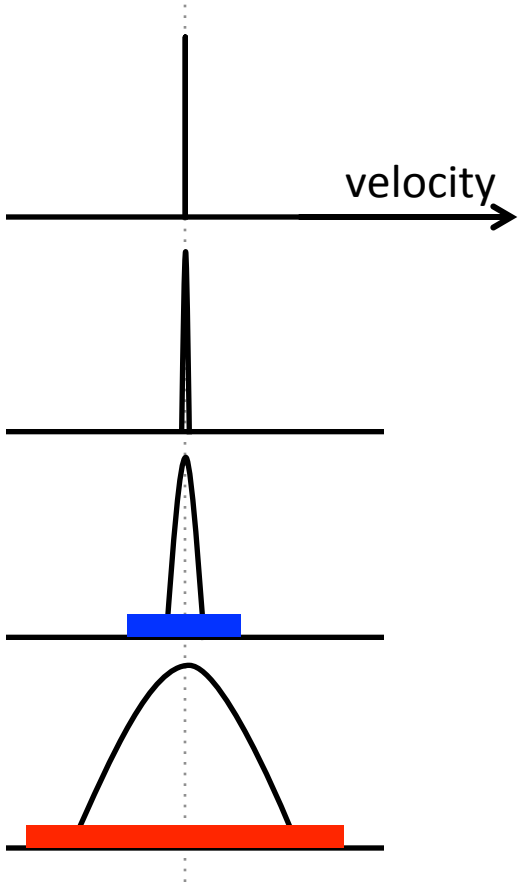
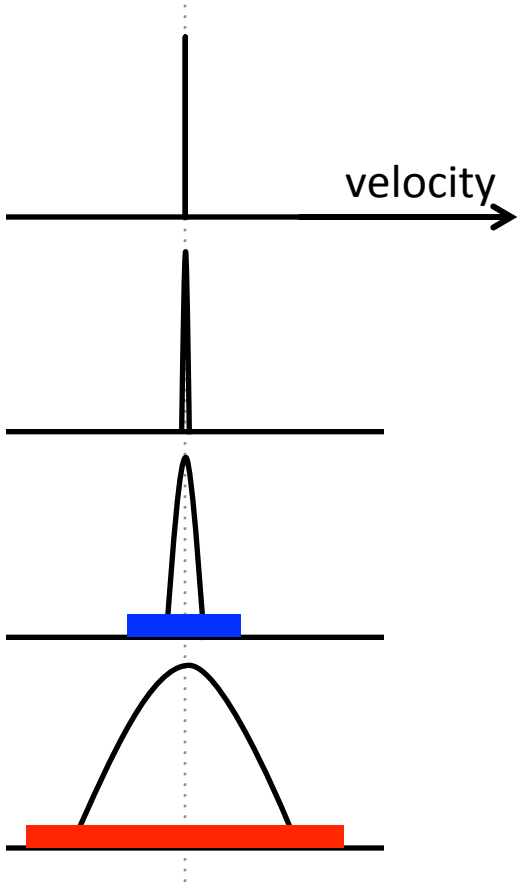


Depending on the linewidth of the line, you will cover a **narrower**/**broader** frequency (velocity) range

Basic concepts of spectral line observations

Linewidth (Δv)

the spectral line will have a width that depends on the properties of the object you are studying



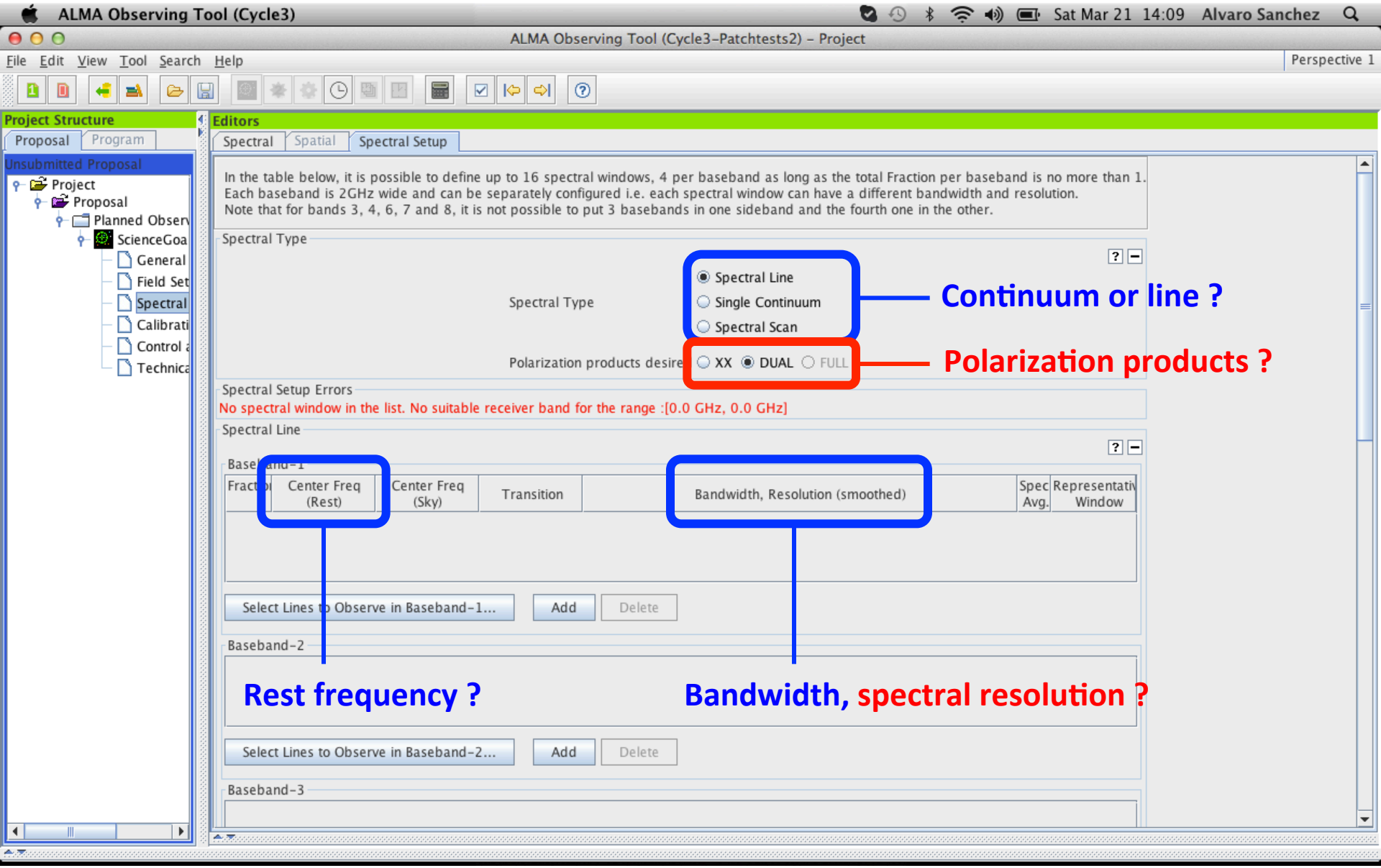
velocity linewidth (km/s)

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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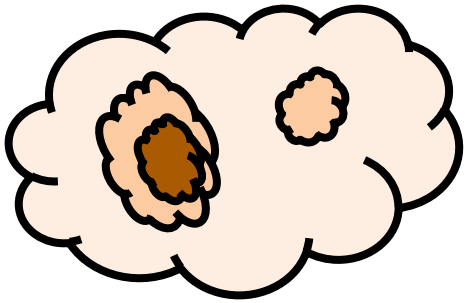
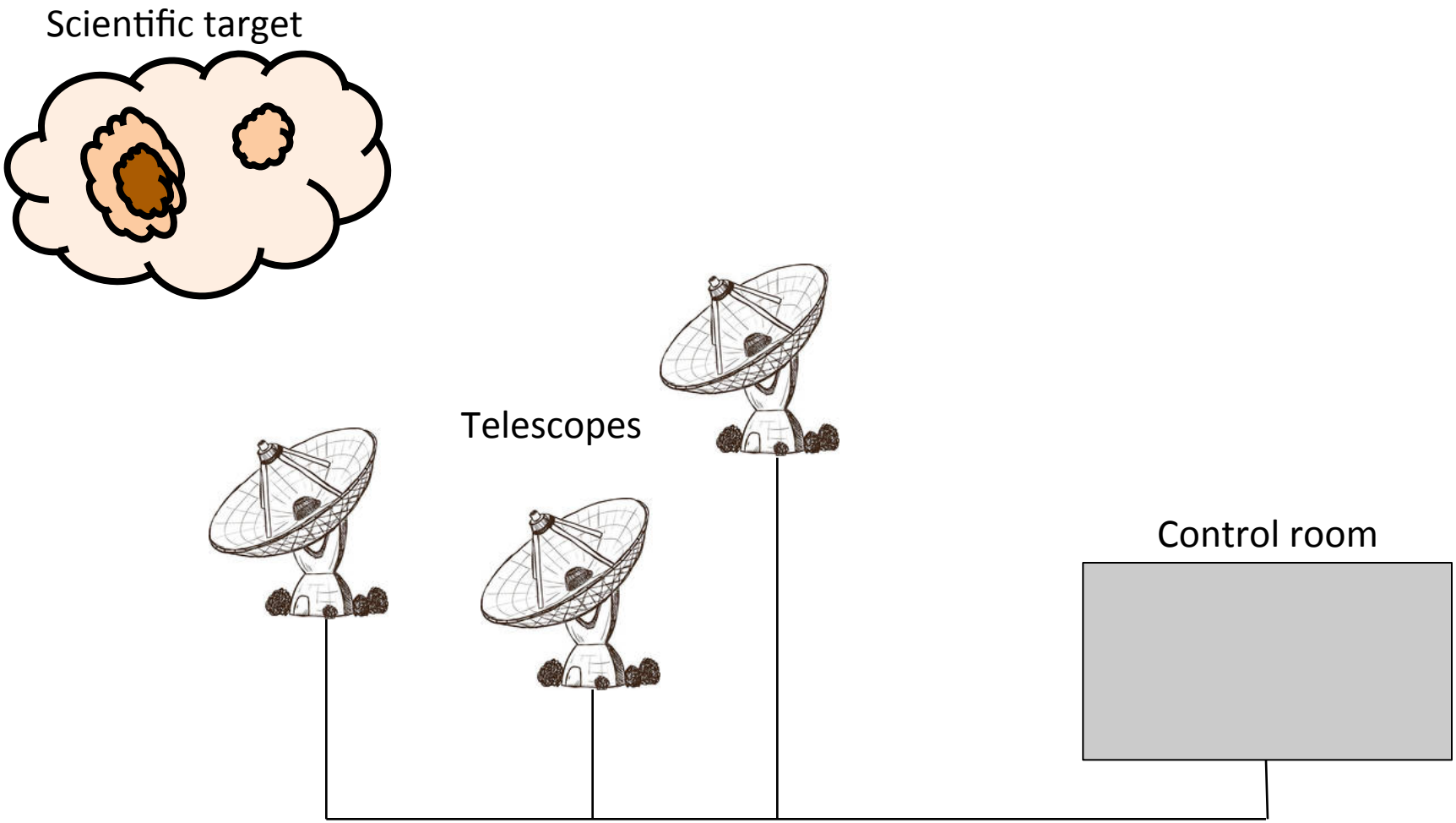
Spectral observations in a radio-interferometer

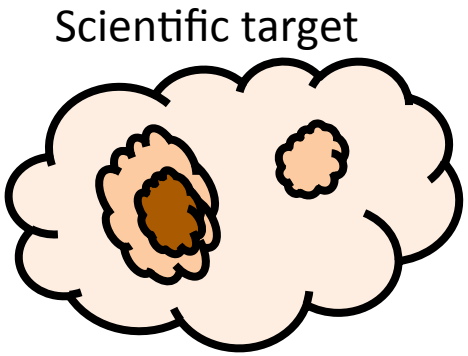
- frequency bands
- receivers
- correlator

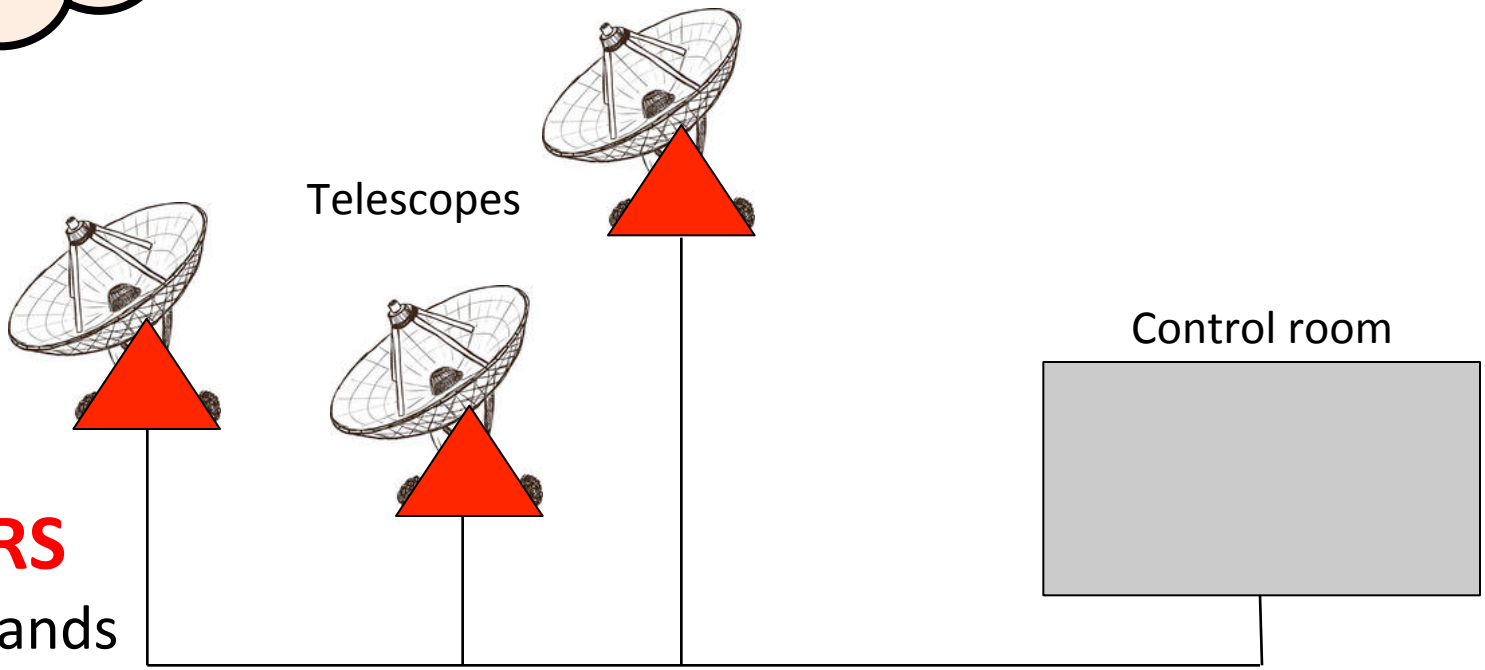
Scientific target



Telescopes

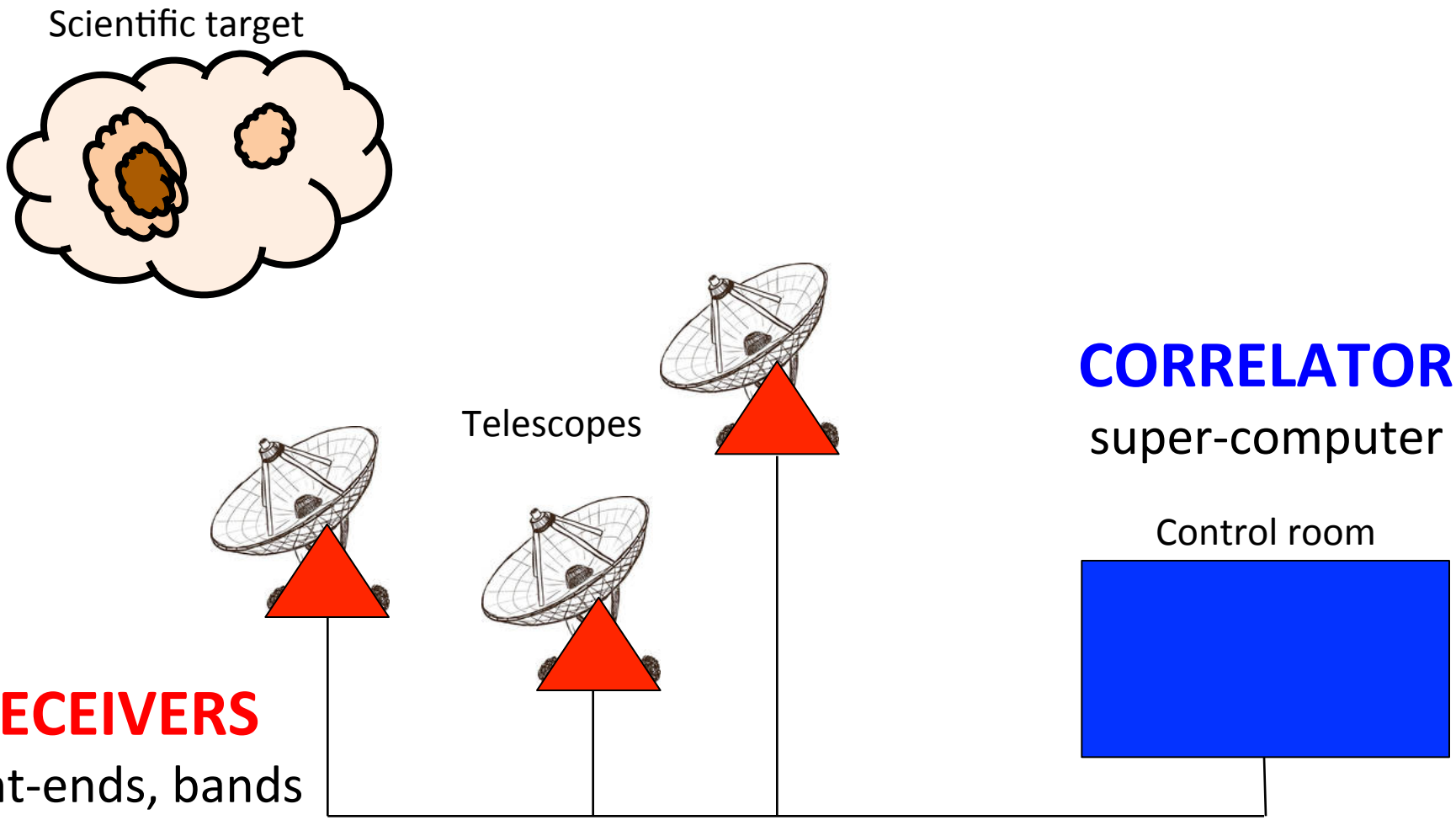

Scientific target
Telescopes
Control room



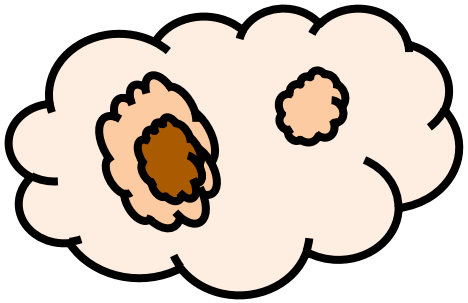


RECEIVERS

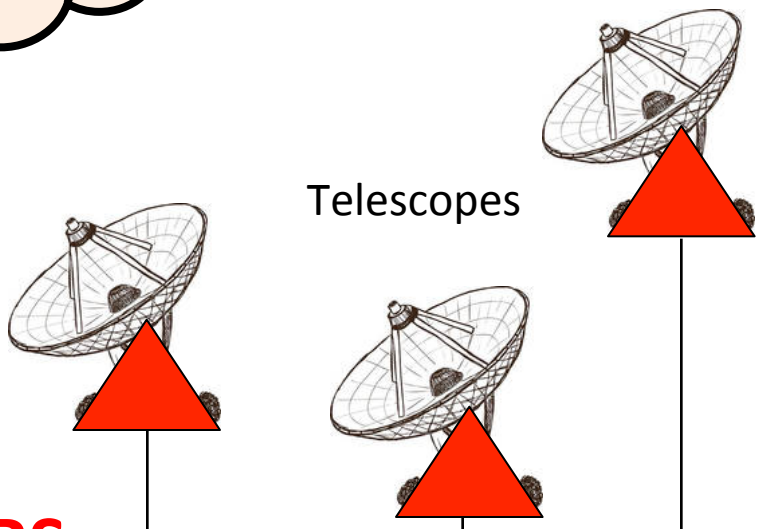
front-ends, bands


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

Scientific target



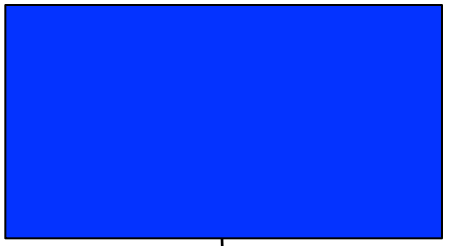
Telescopes



CORRELATOR

super-computer

Control room



RECEIVERS

front-ends, bands

WHAT frequencies do/can we observe?

HOW do/can we observe those frequencies?

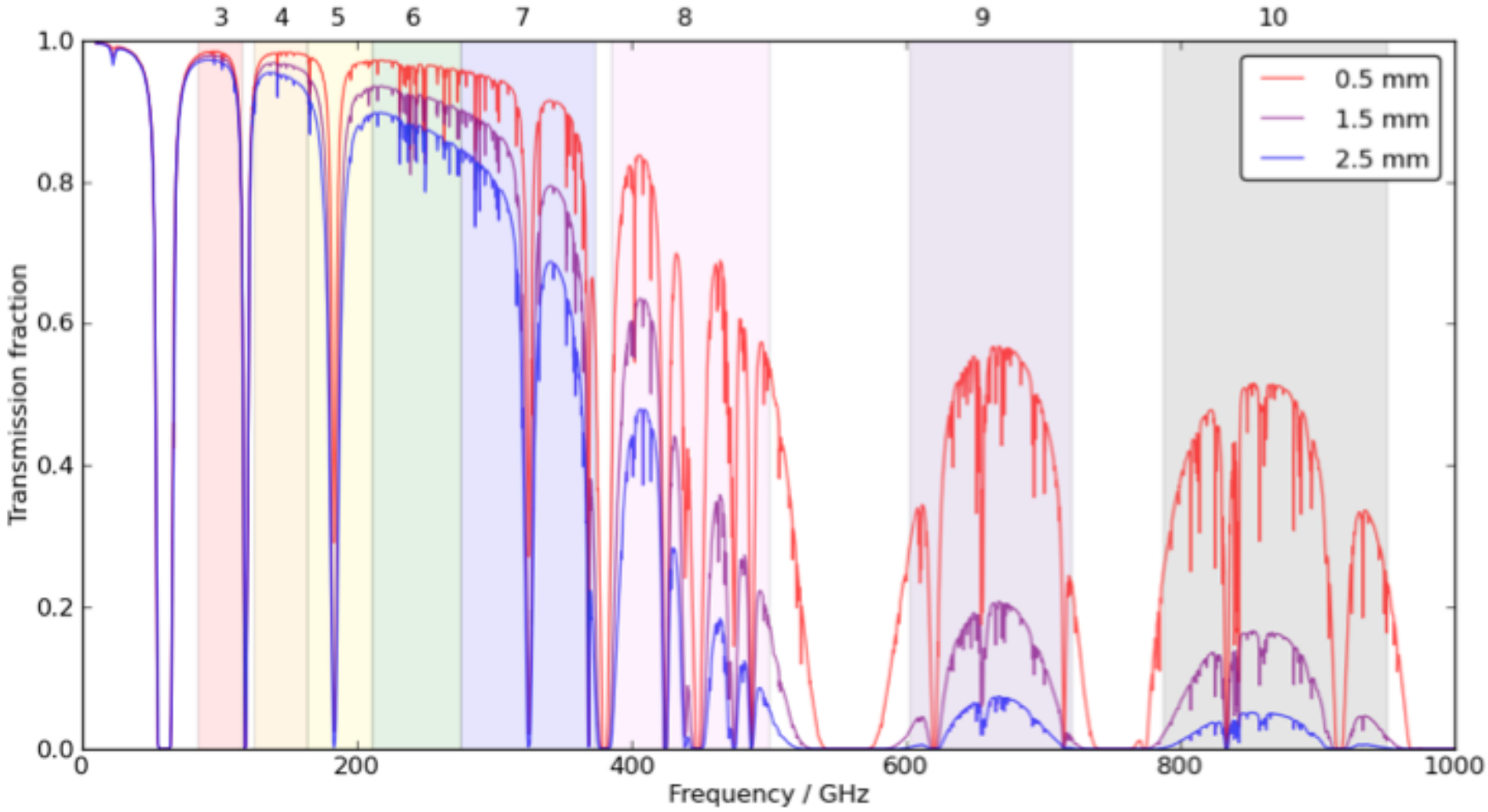
What do we need to know?

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

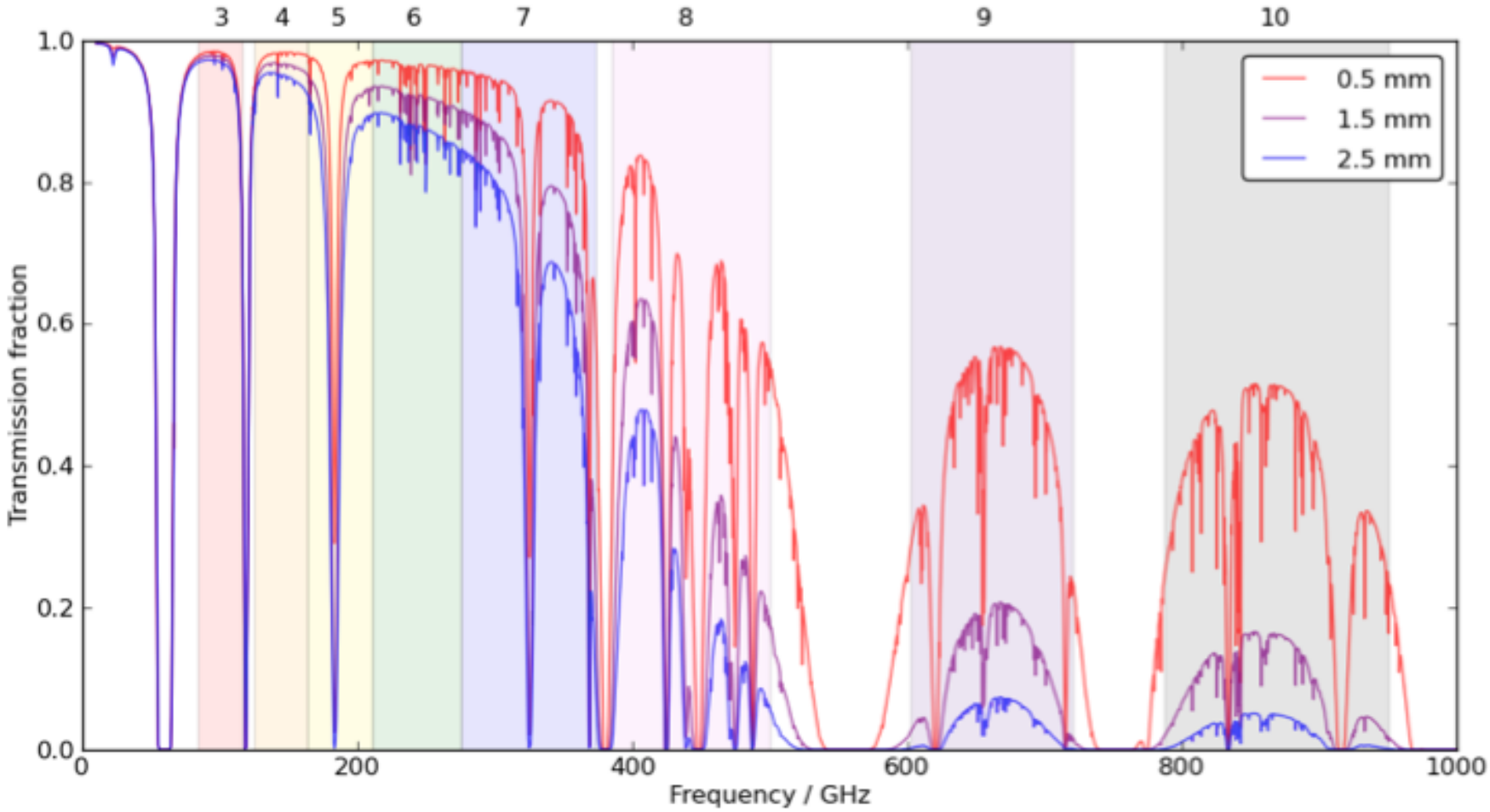
Spectral observations in a radio-interferometer

- **frequency bands**
- receivers
- correlator

ALMA frequency bands



ALMA frequency bands



Band 3: 84 – 116 GHz

Band 4: 125 – 163 GHz

Band 6: 211 – 275 GHz

Band 7: 275 – 373 GHz

Band 8: 385 – 500 GHz

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

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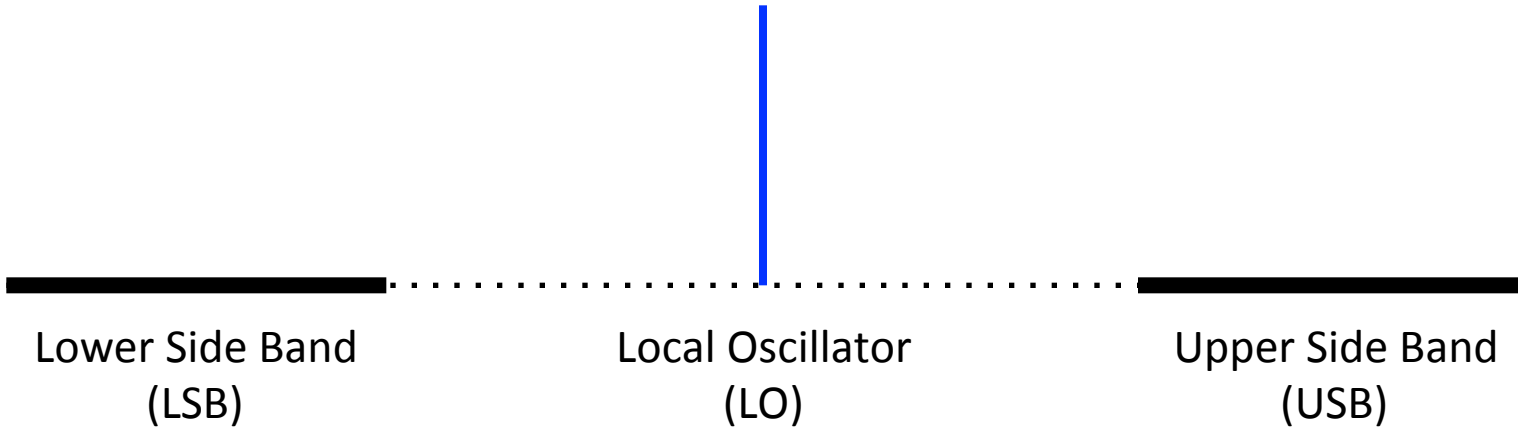
Spectral observations in a radio-interferometer

- frequency bands
- **receivers**
- correlator

ALMA receivers

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



ALMA receivers

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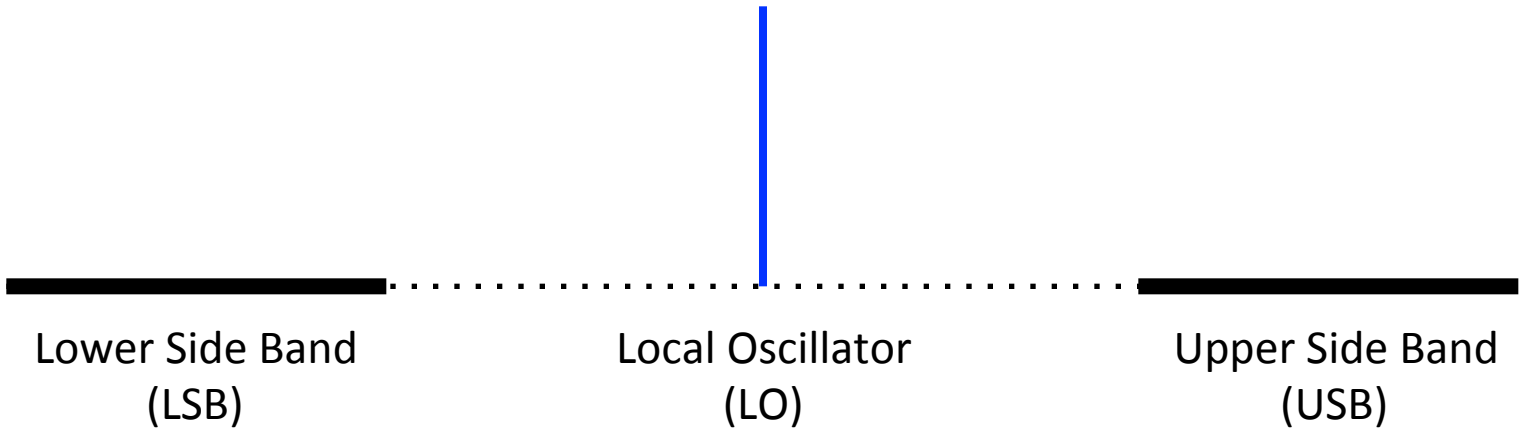
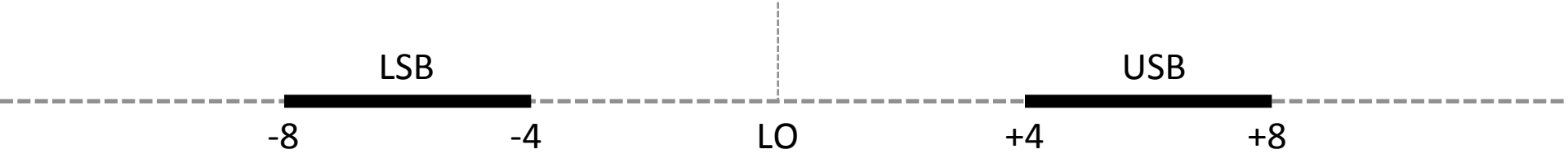


Heterodyne receivers can be:

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



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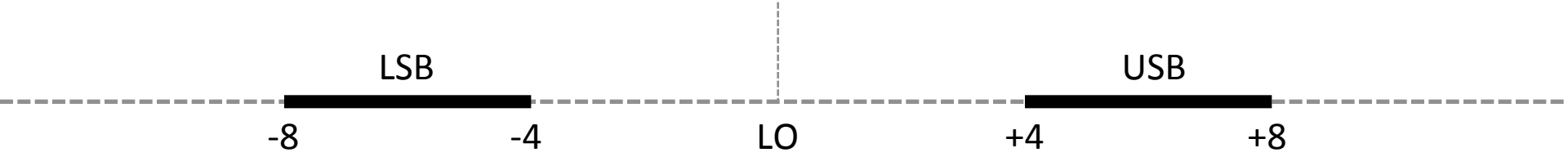
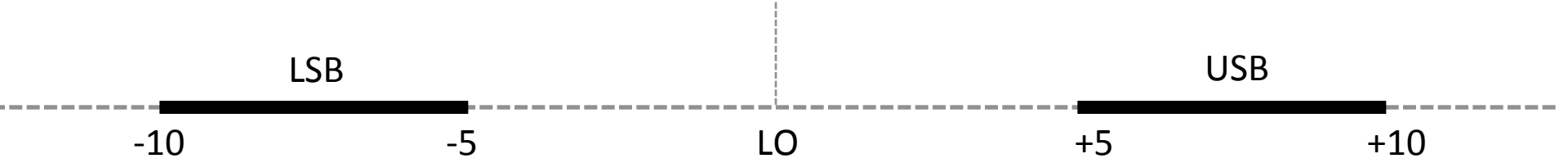


ALMA B6 2SB receivers 5-10 GHz



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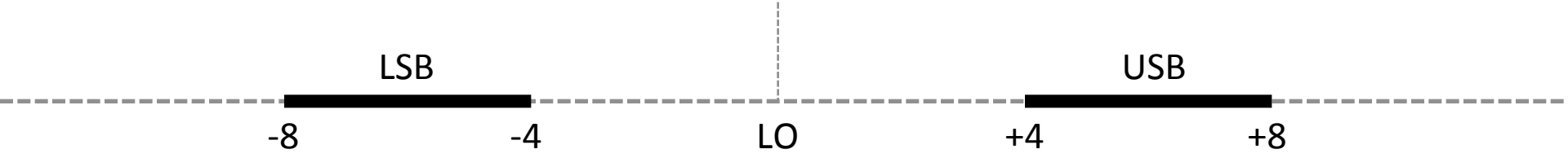

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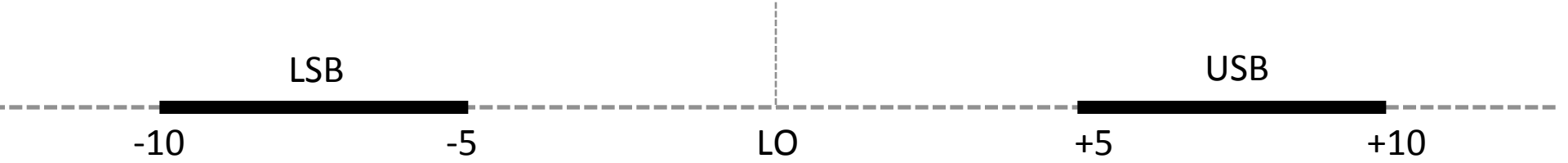
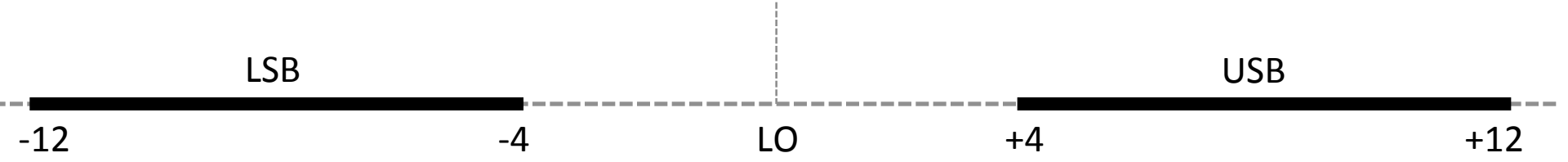


ALMA B9 / B10 DSB receivers 4-12 GHz



ALMA frequency bands & receivers

Band 3:	84 – 116 GHz	Band 7:	275 – 373 GHz
Band 4:	125 – 163 GHz	Band 8:	385 – 500 GHz
Band 6:	211 – 275 GHz	Band 9/10:	602 – 720 GHz / 787 – 950 GHz

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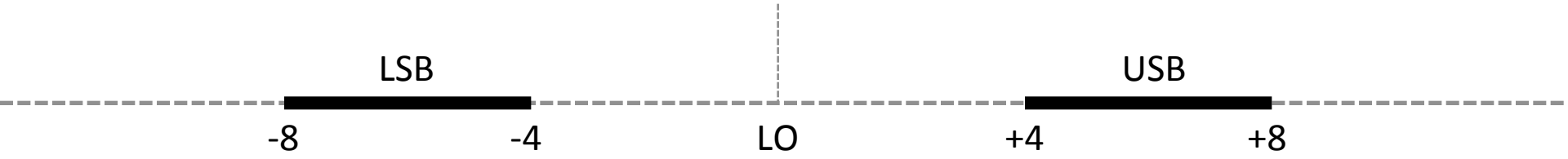

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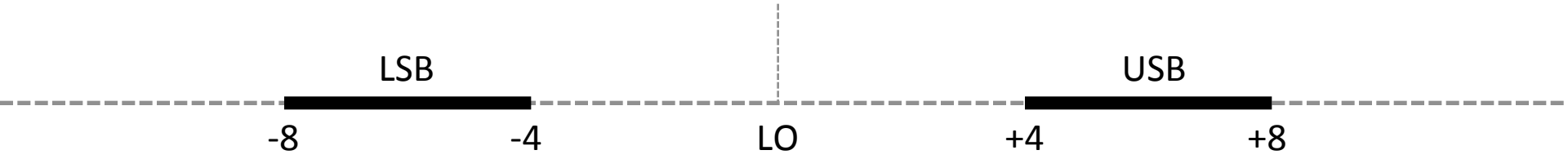

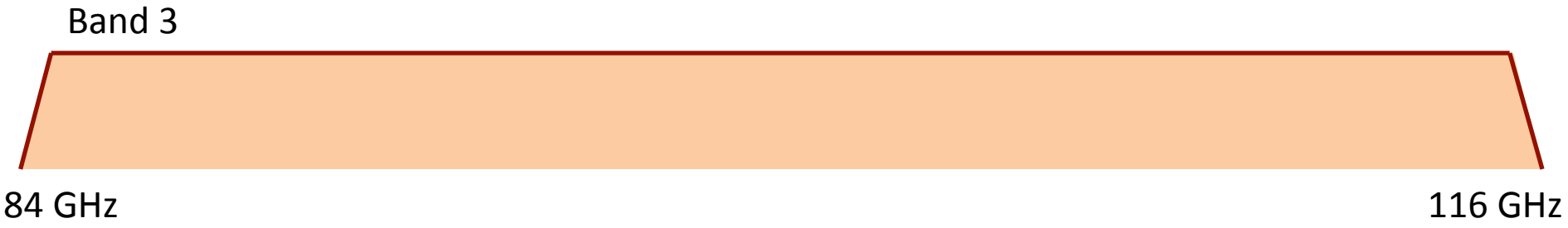

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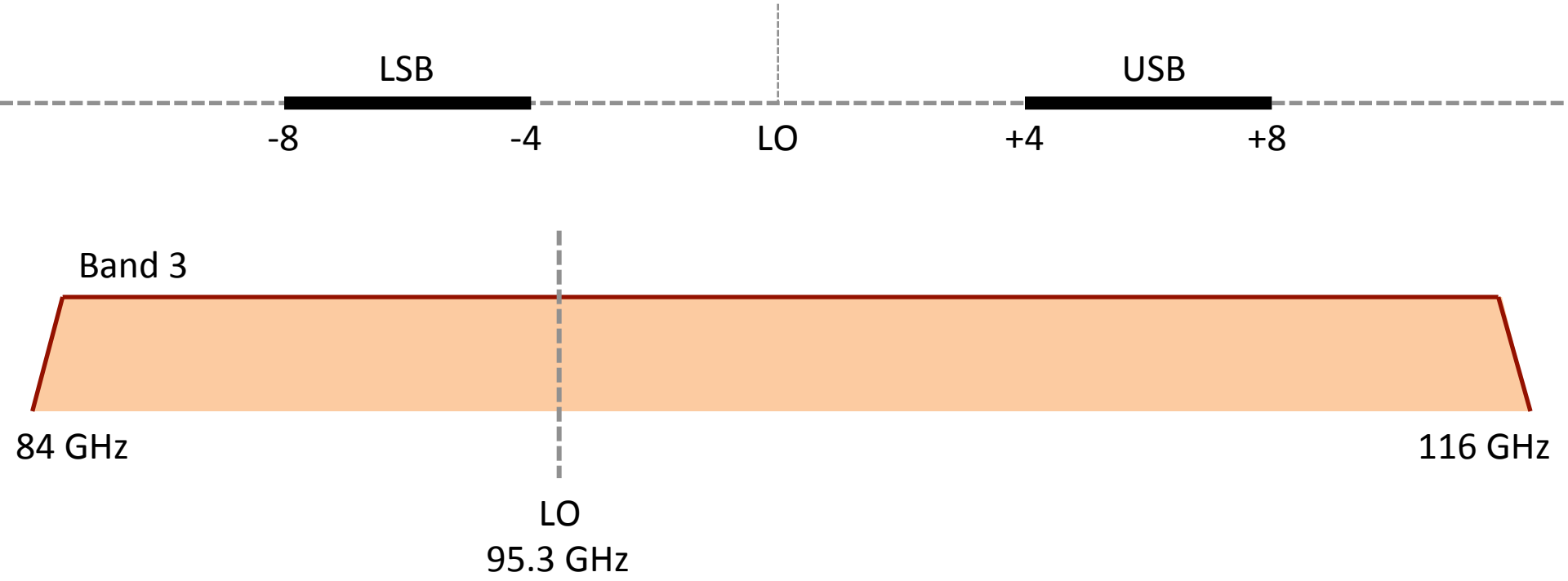

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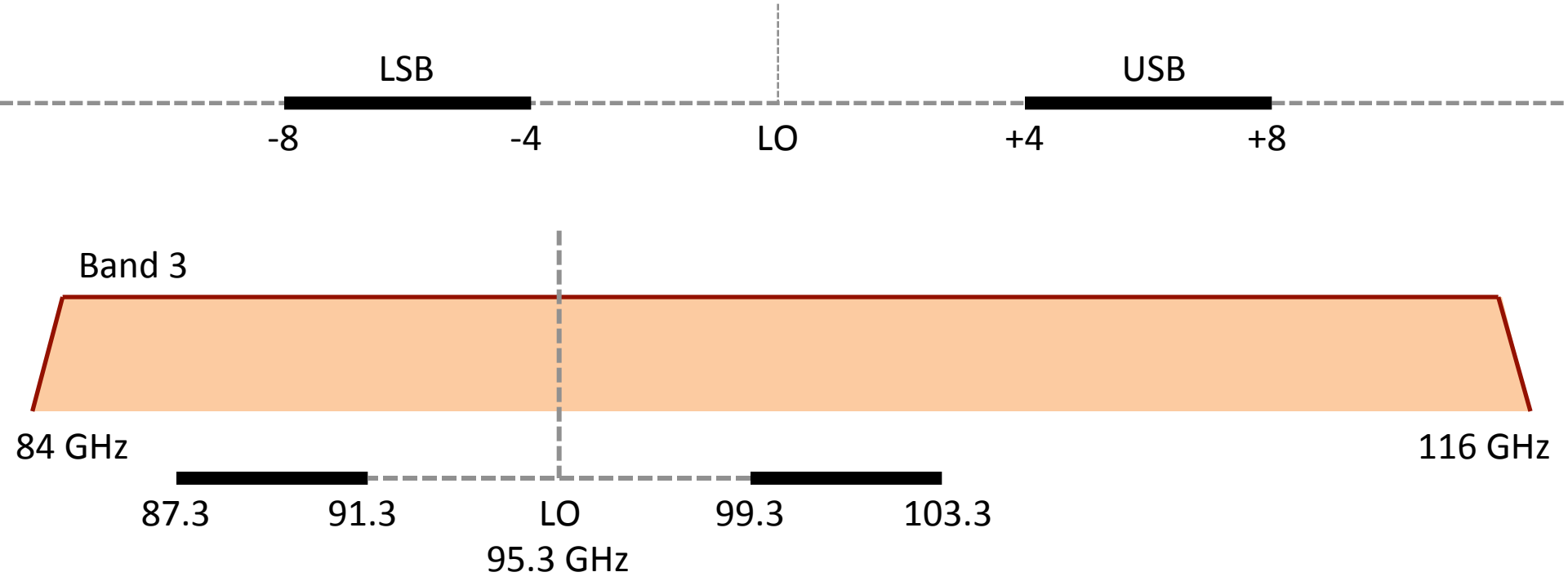

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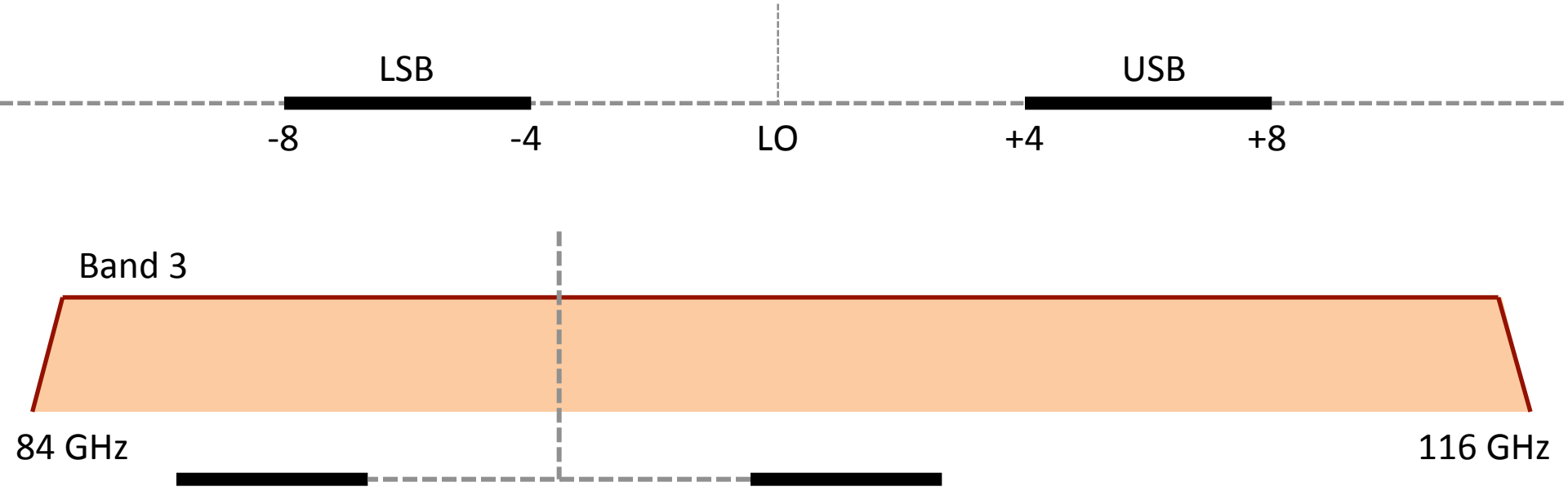

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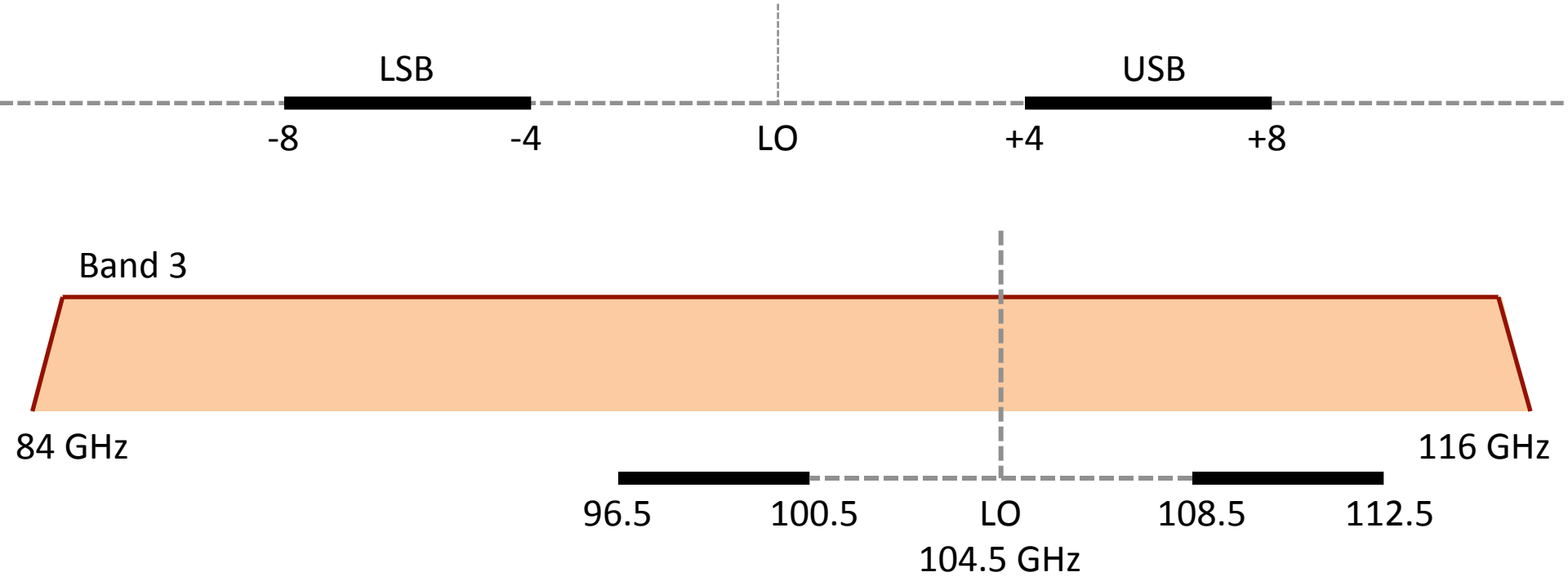


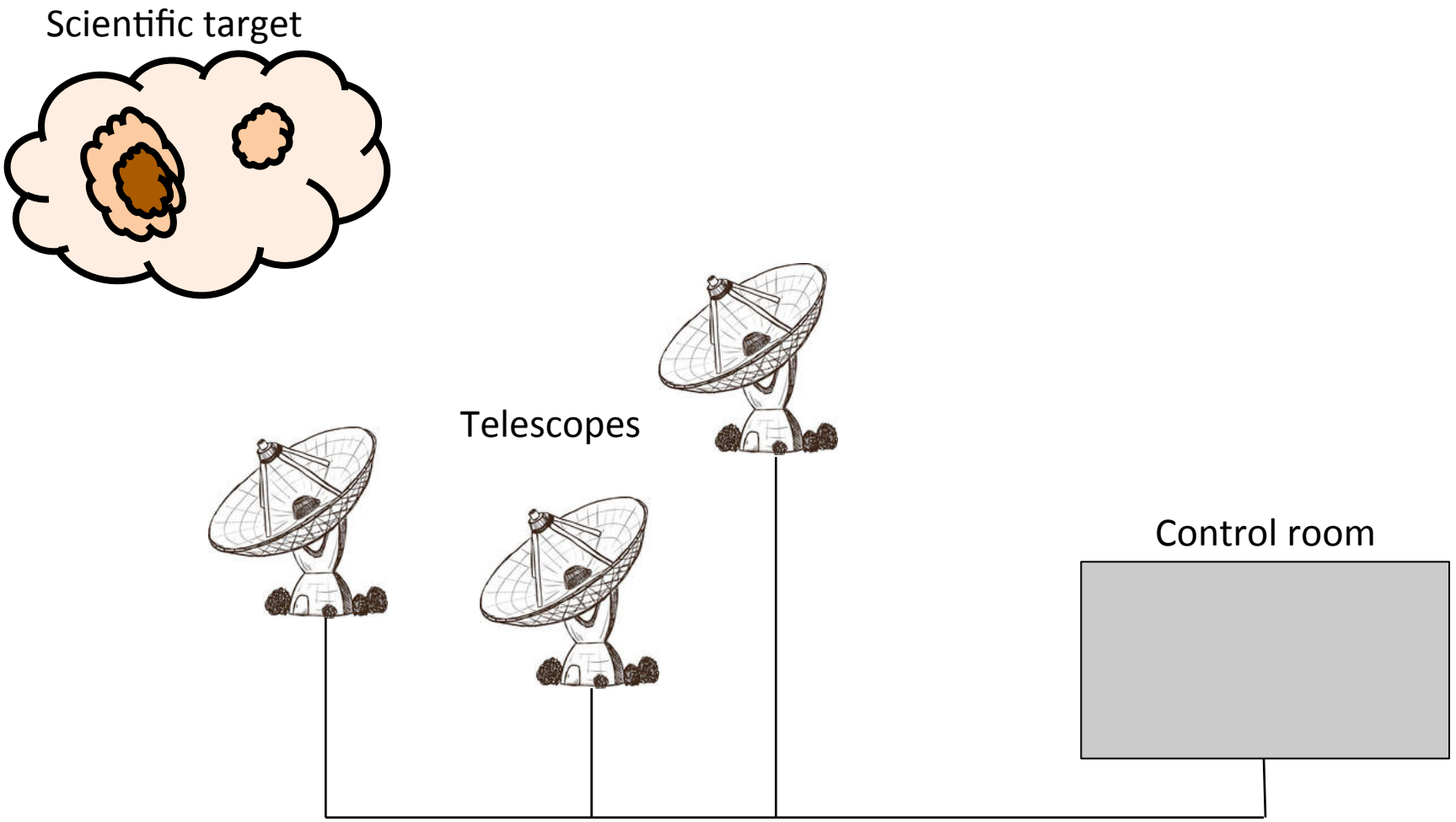
What do we need to know?

- 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

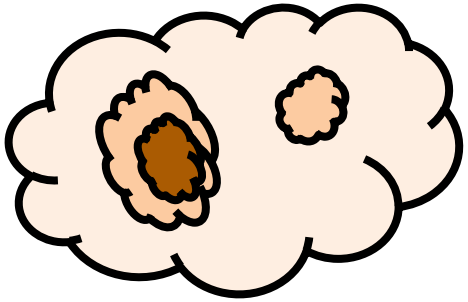
- frequency bands
- receivers
- **correlator**

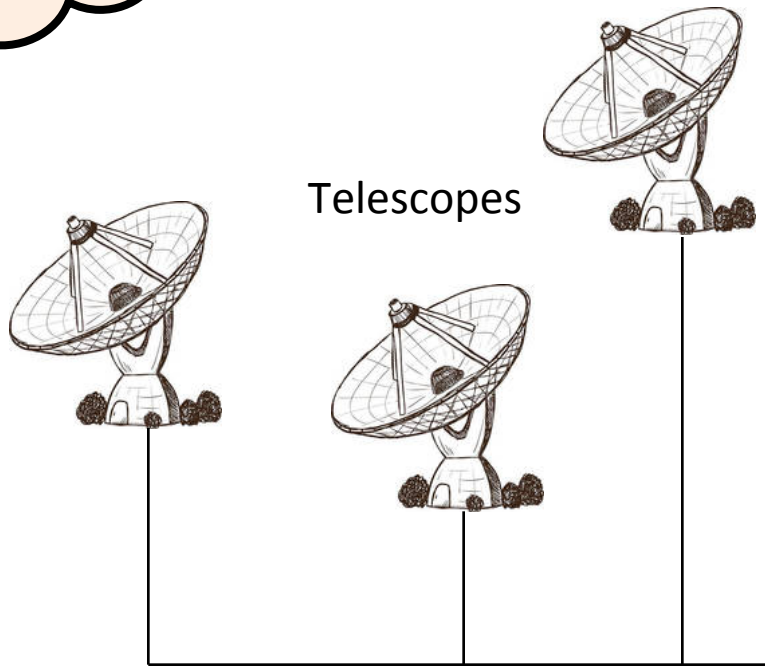
ALMA correlator



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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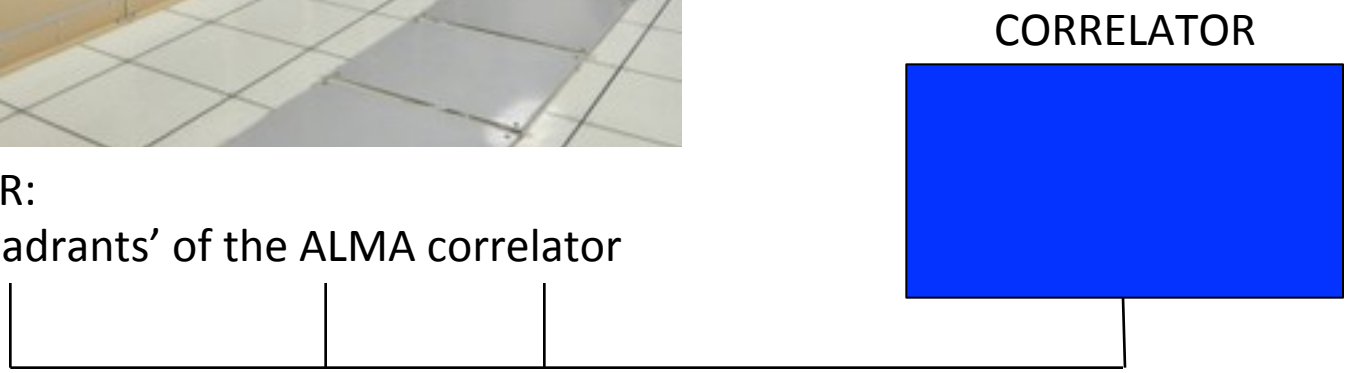

ALMA correlator

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

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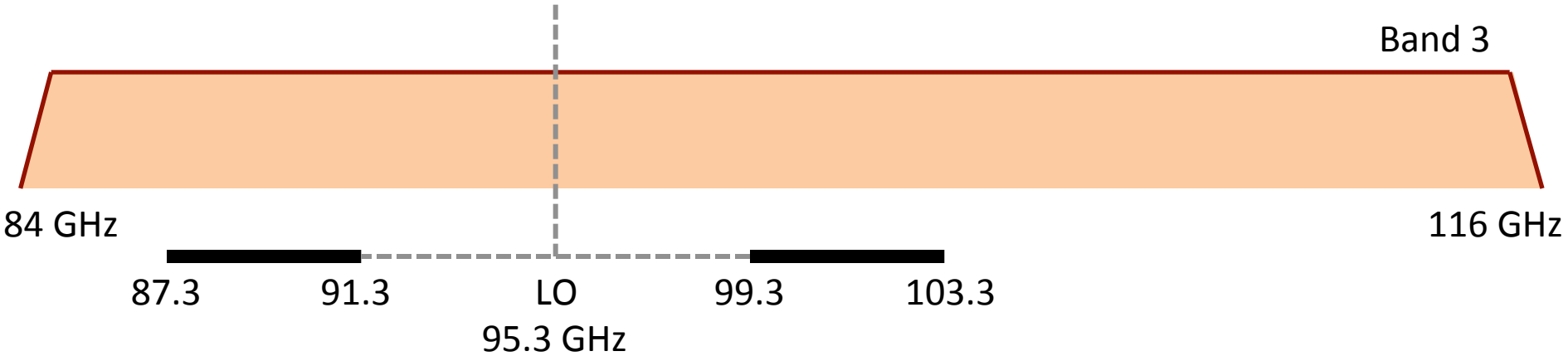

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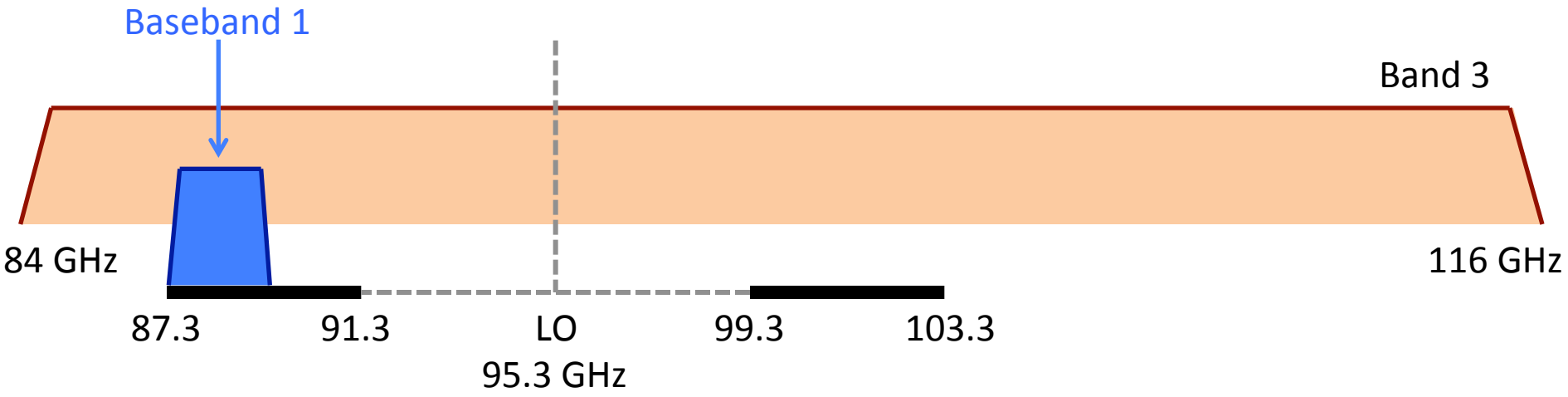

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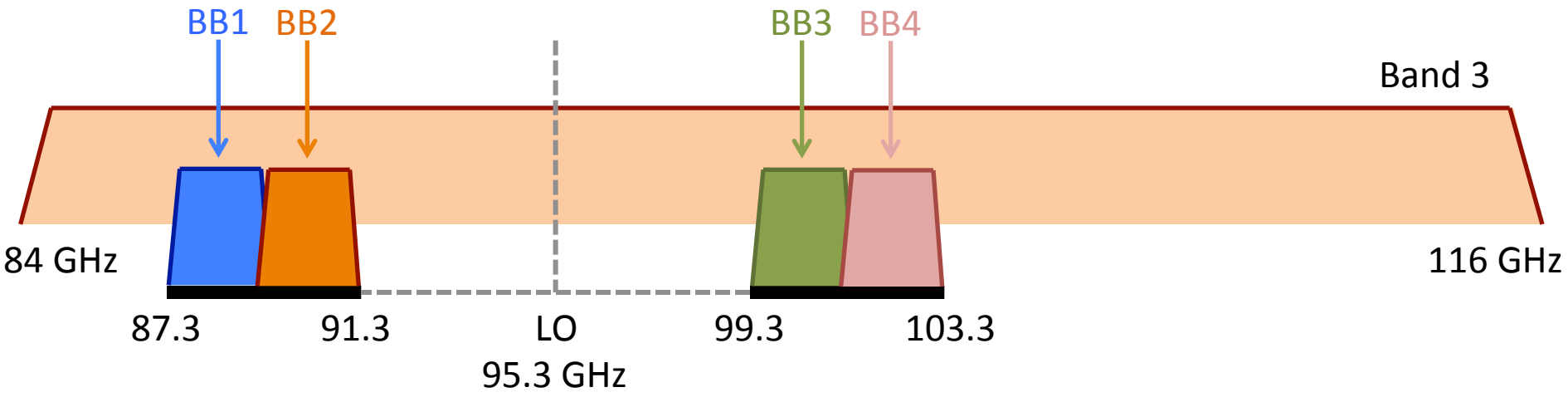

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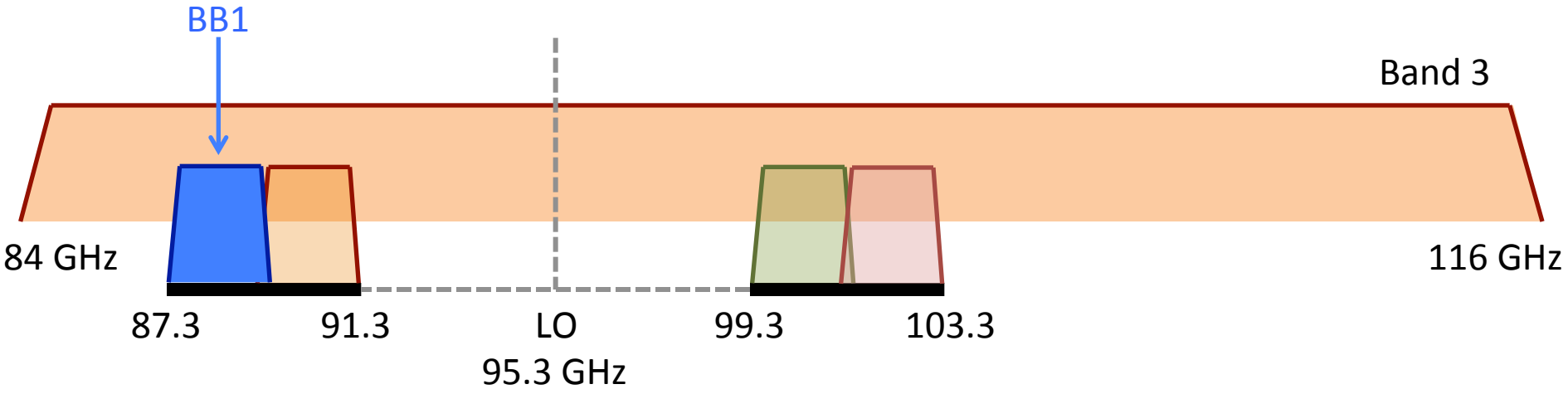

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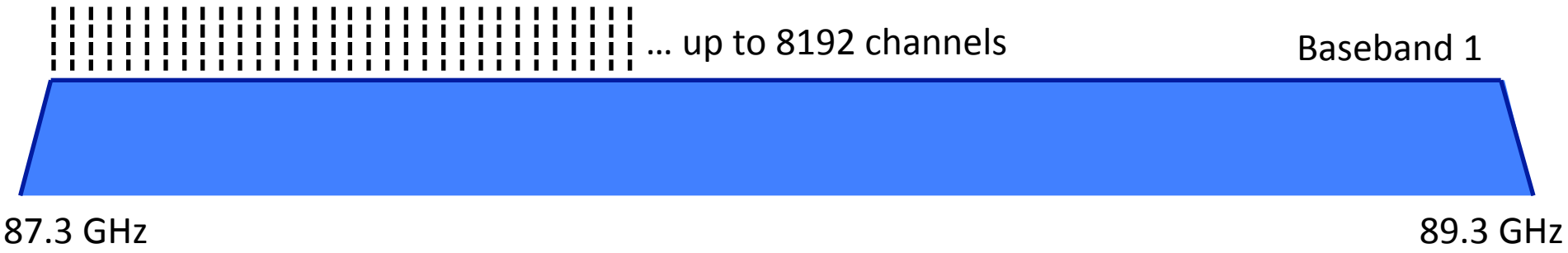

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basebands

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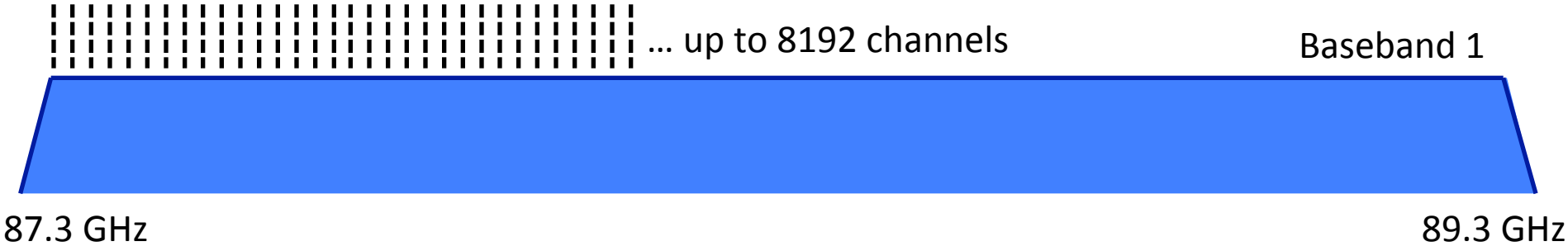
channel width (**spectral resolution**):

2 GHz / 8192 = 244 kHz



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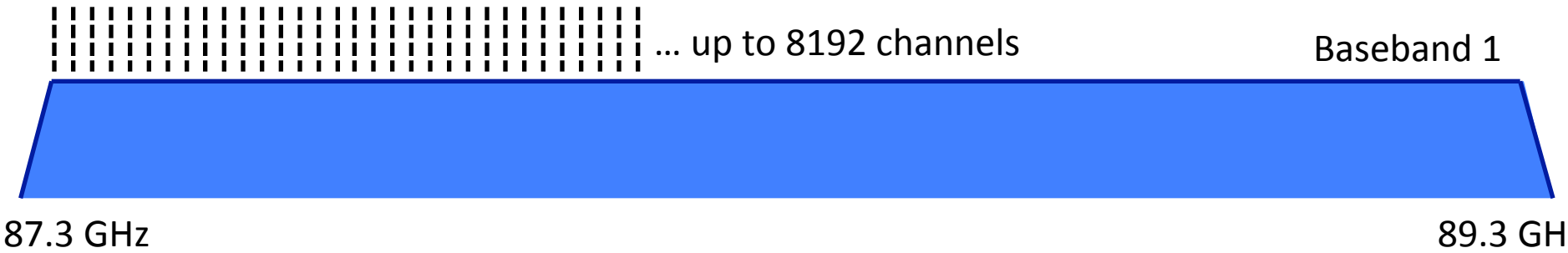

bandwidth = 2 GHz / resolution = 244 kHz … **not fixed!**

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

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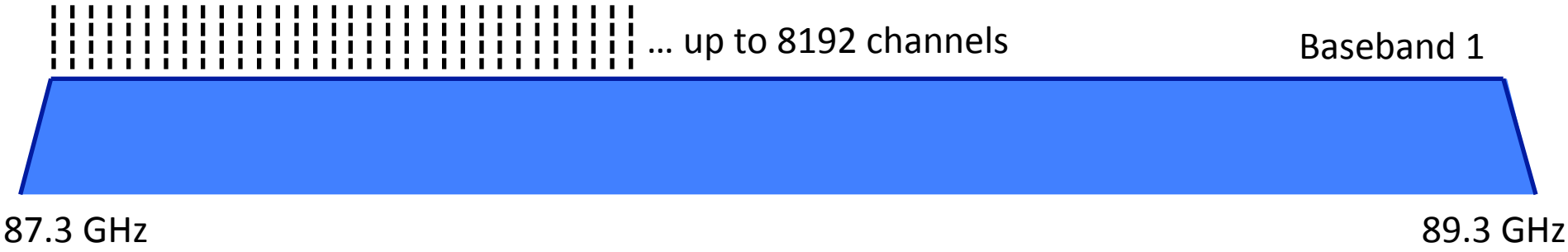

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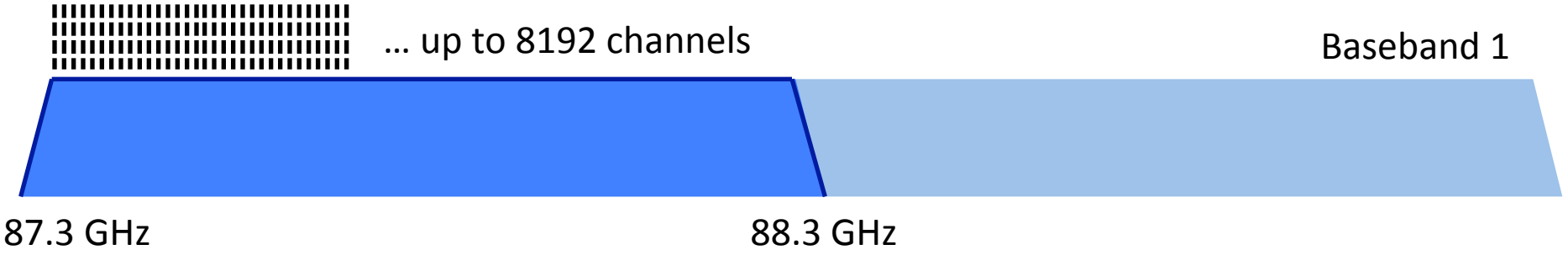

ALMA correlator

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.
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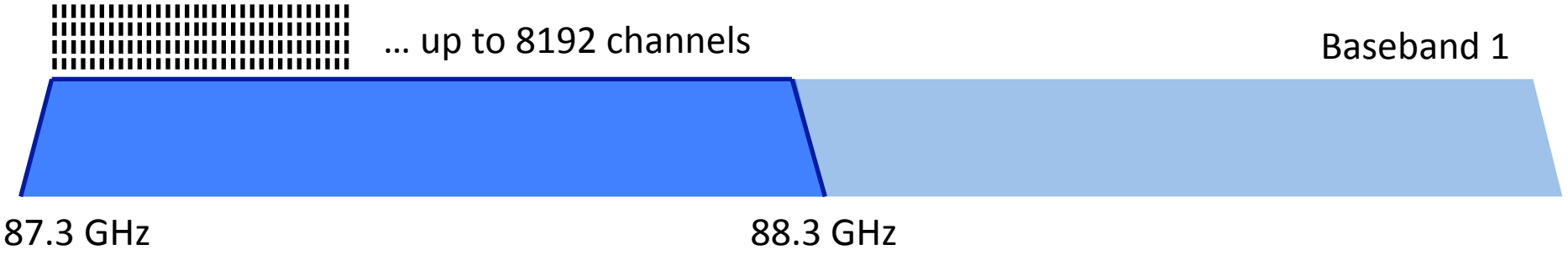
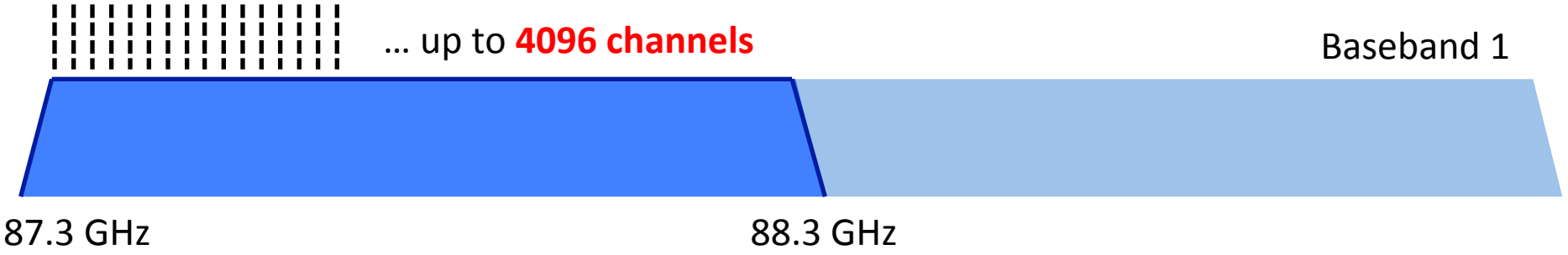
continuum mode		256 channels x 1 polz	7.5 MHz resol.



ALMA correlator

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

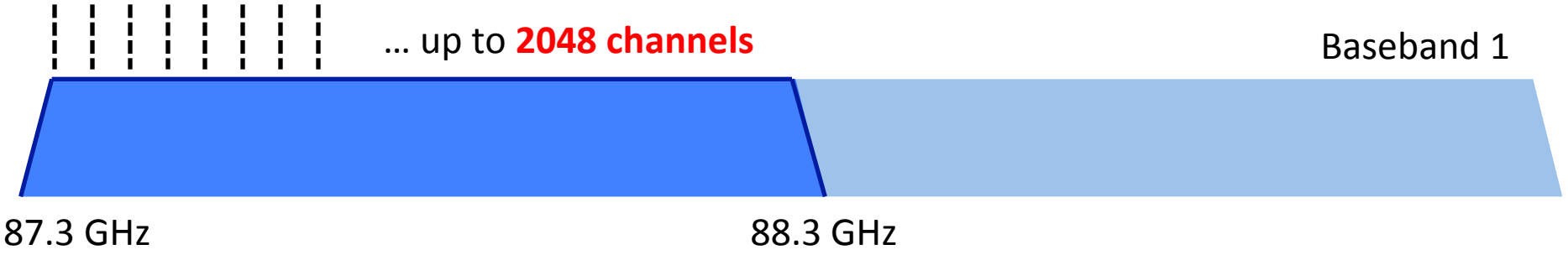
BW	2 GHz	4096 channels x 2 polz	488 kHz resol.
BW	1 GHz	4096 channels x 2 polz	244 kHz resol.
BW	500 MHz	4096 channels x 2 polz	122 kHz resol.
BW	250 MHz	4096 channels x 2 polz	61 kHz resol.
BW	125 MHz	4096 channels x 2 polz	30 kHz resol.
BW	64 MHz	4096 channels x 2 polz	15 kHz resol.
BW	32 MHz	4096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

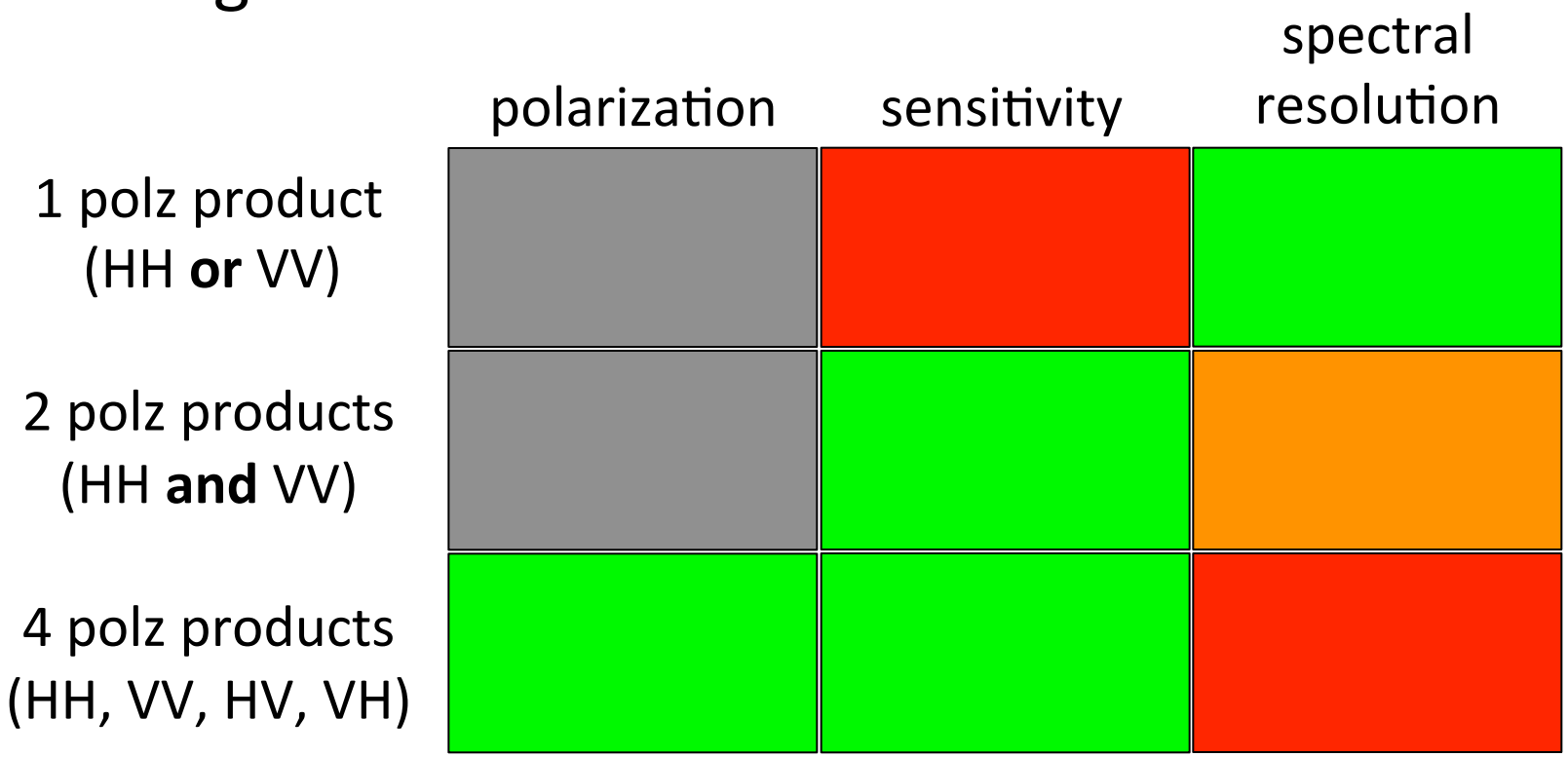
the four are necessary for polarization studies

ALMA correlator

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

the four are necessary for polarization studies

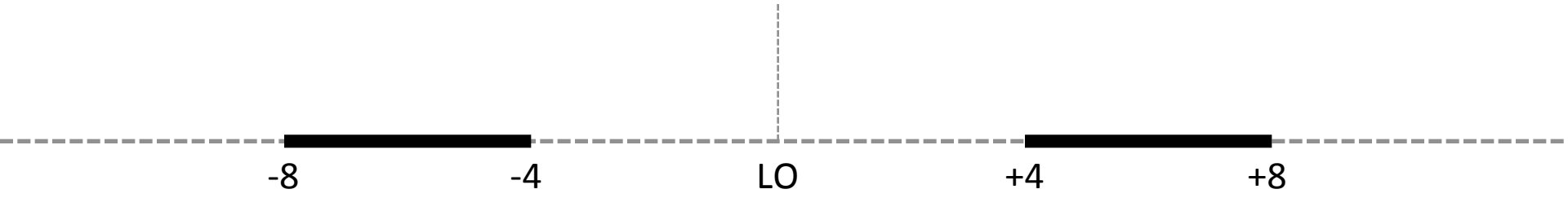
message to take home …



ALMA correlator (examples)

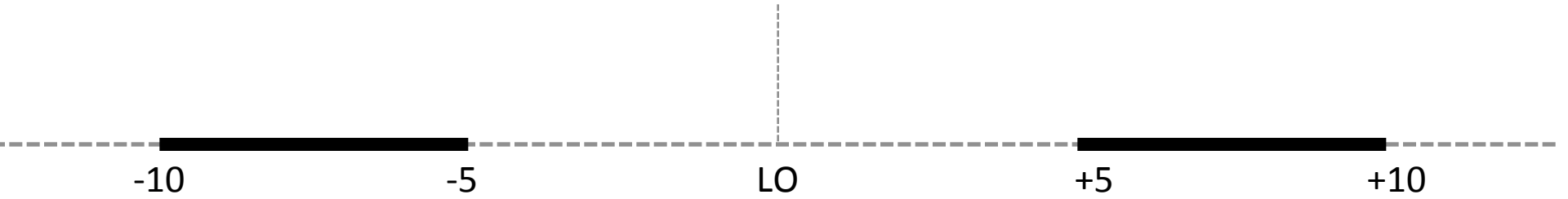
ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



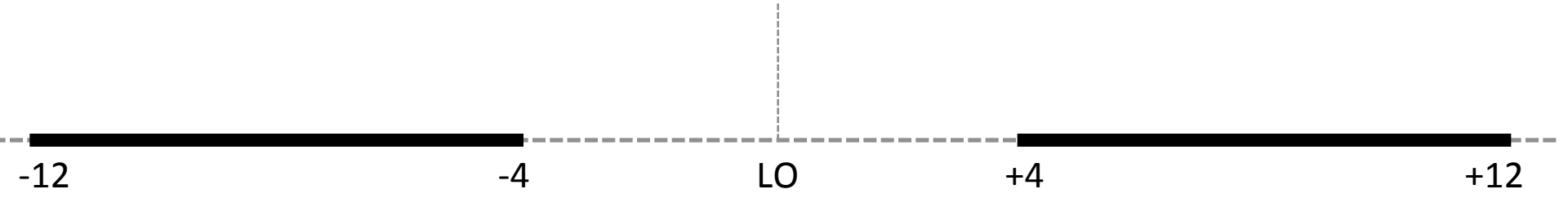
ALMA B6

2SB receivers 5-10 GHz



ALMA B9 / B10

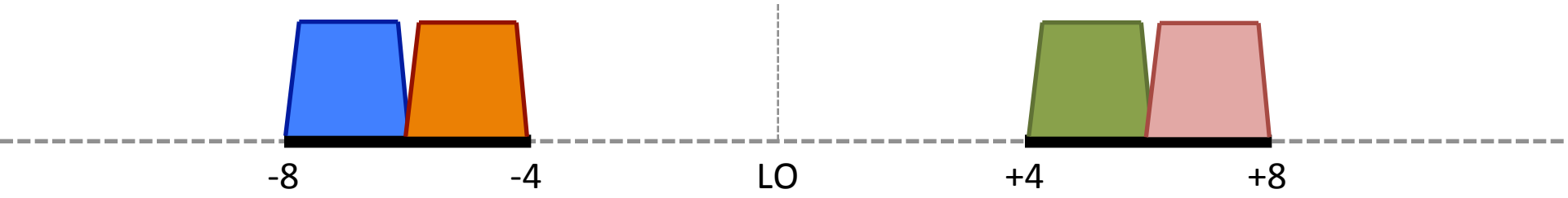
DSB receivers 4-12 GHz



ALMA correlator (examples)

ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



ALMA B6

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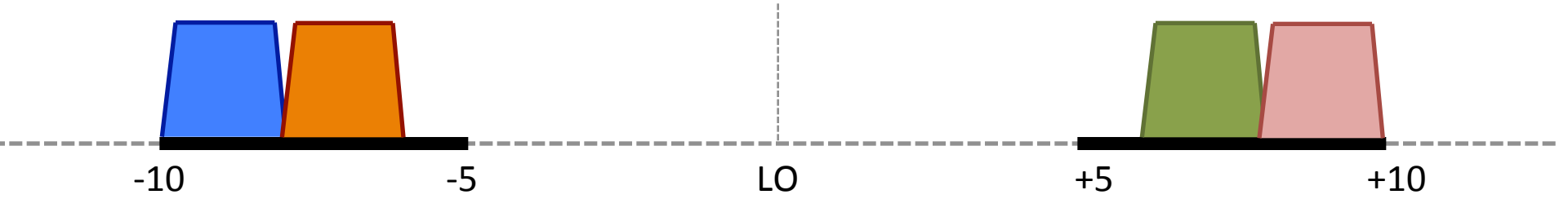
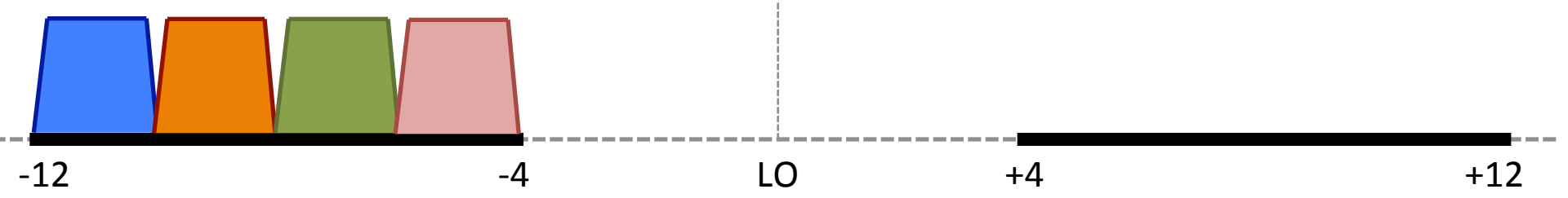


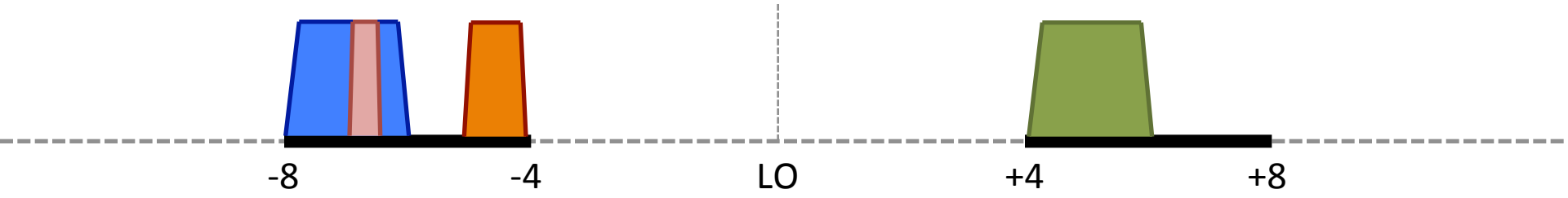
ALMA B9 / B10

DSB receivers 4-12 GHz



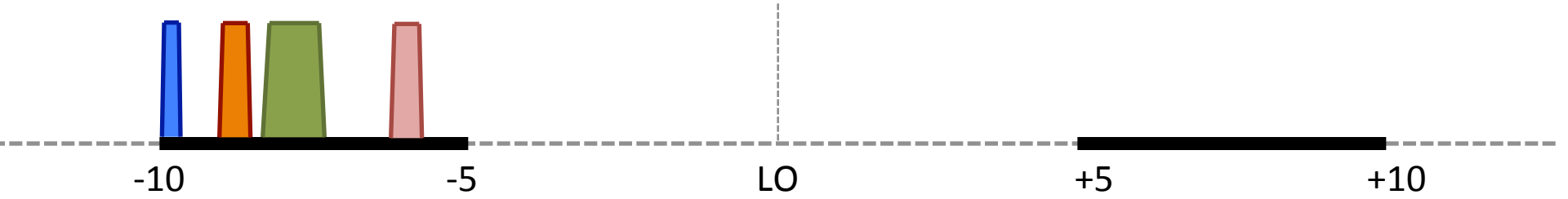
ALMA correlator (examples)

ALMA B3 / B4 / B5 / B7 / B8



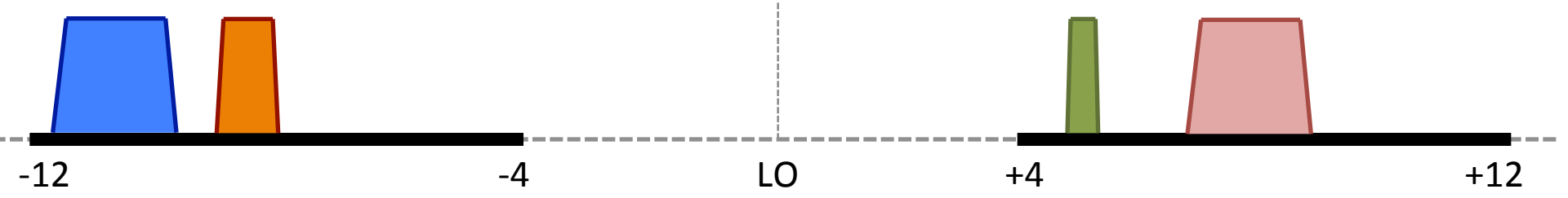
2SB receivers 4-8 GHz

ALMA B6



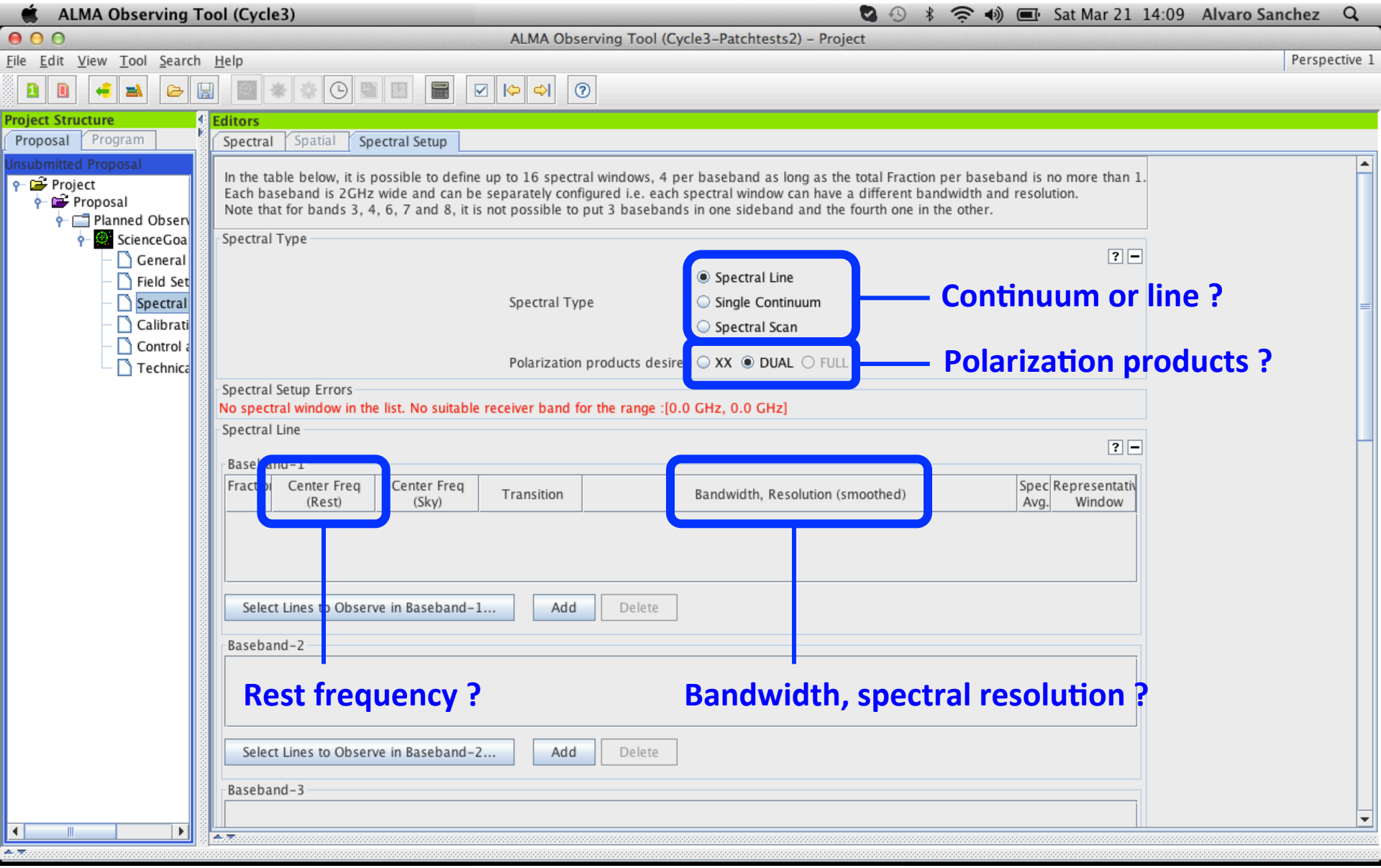
2SB receivers 5-10 GHz

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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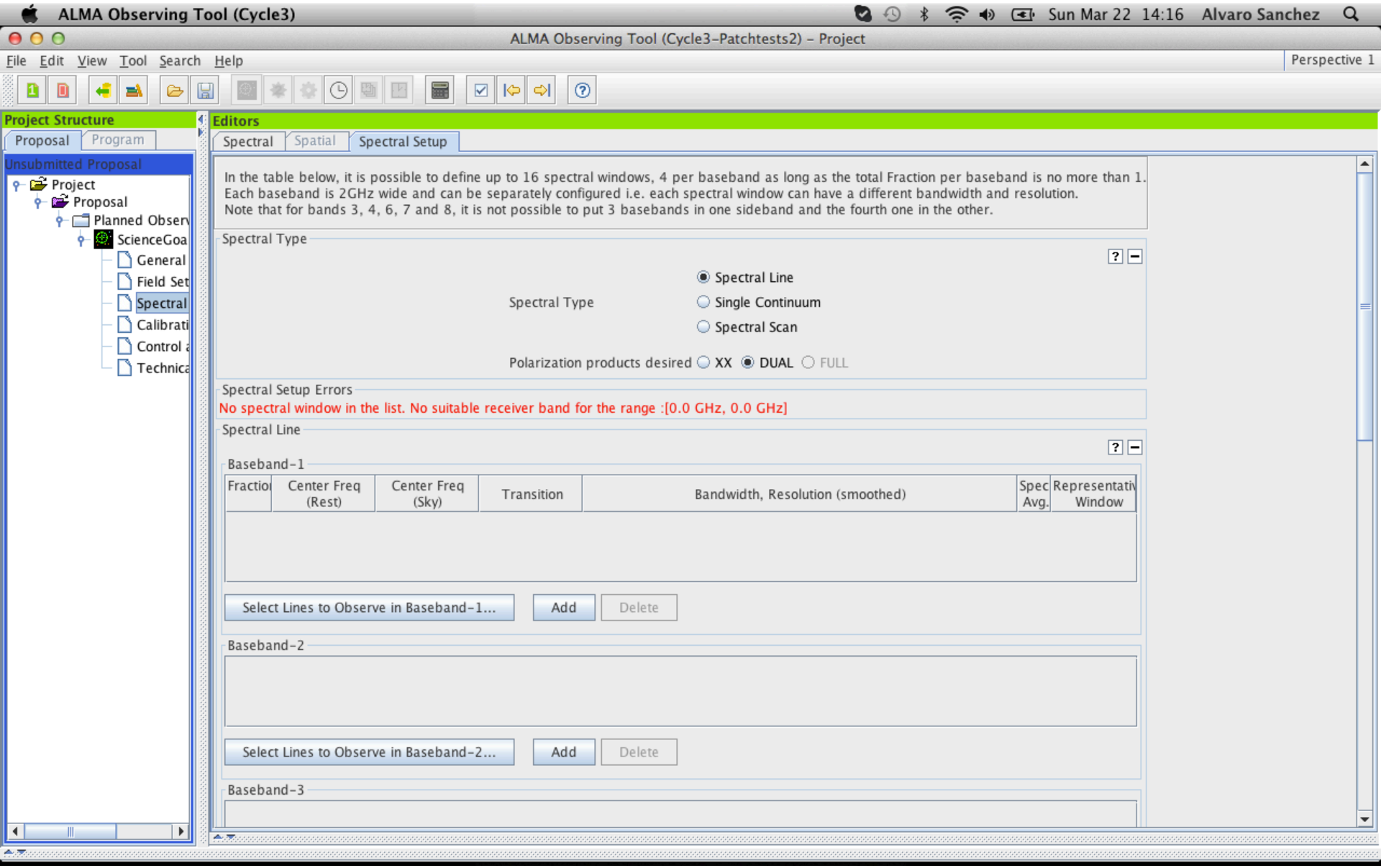
For our ALMA observations we would need:

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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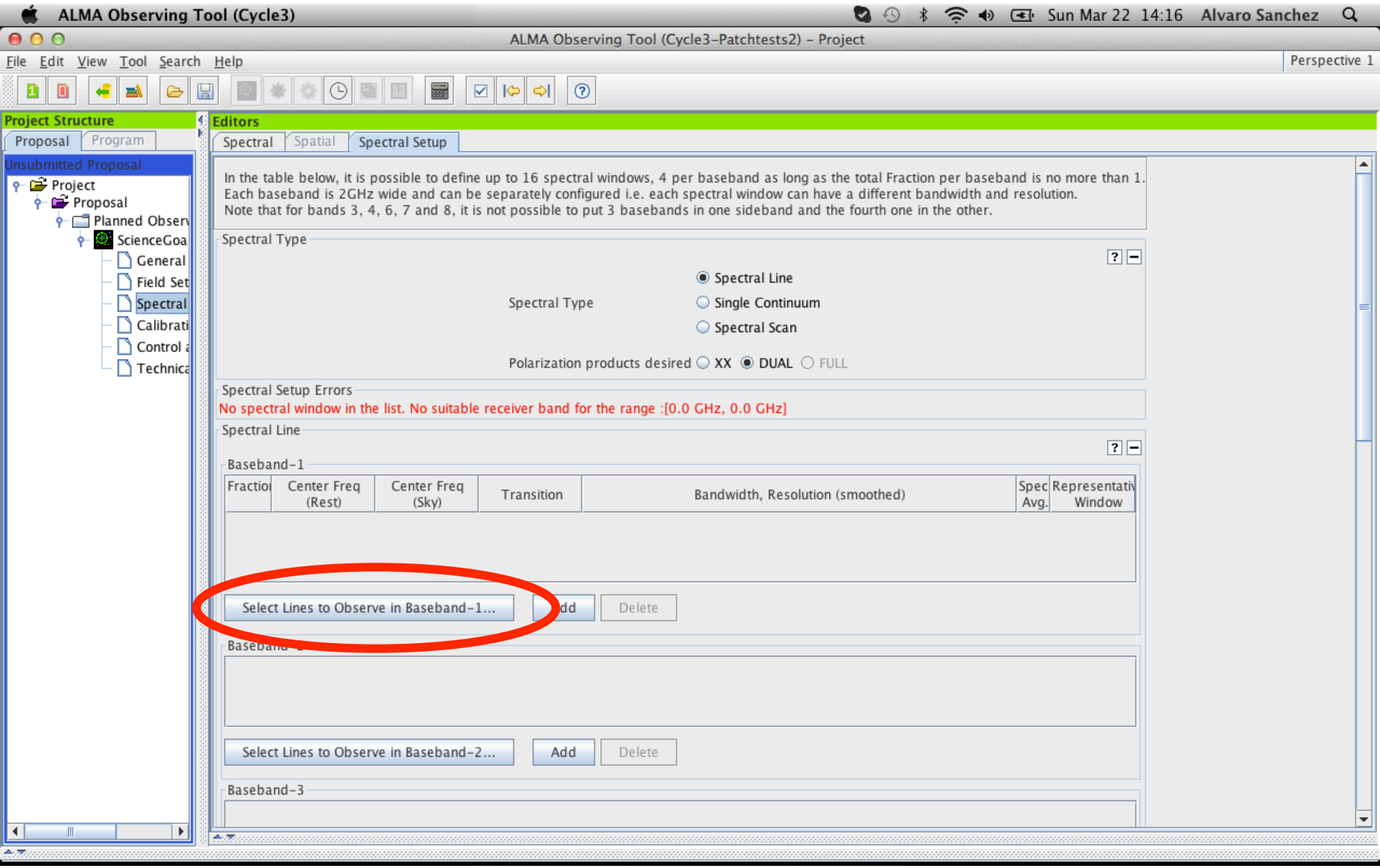

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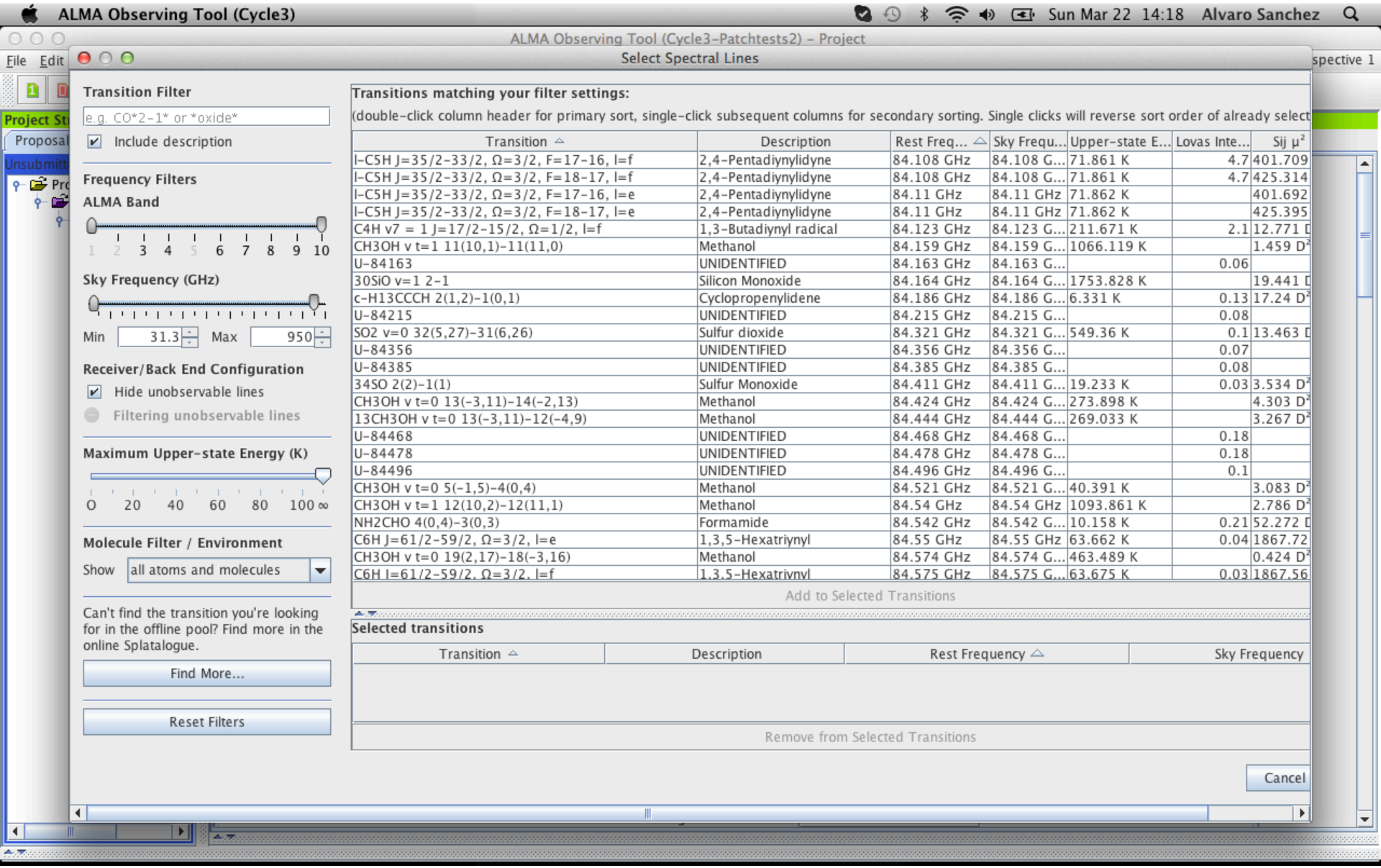

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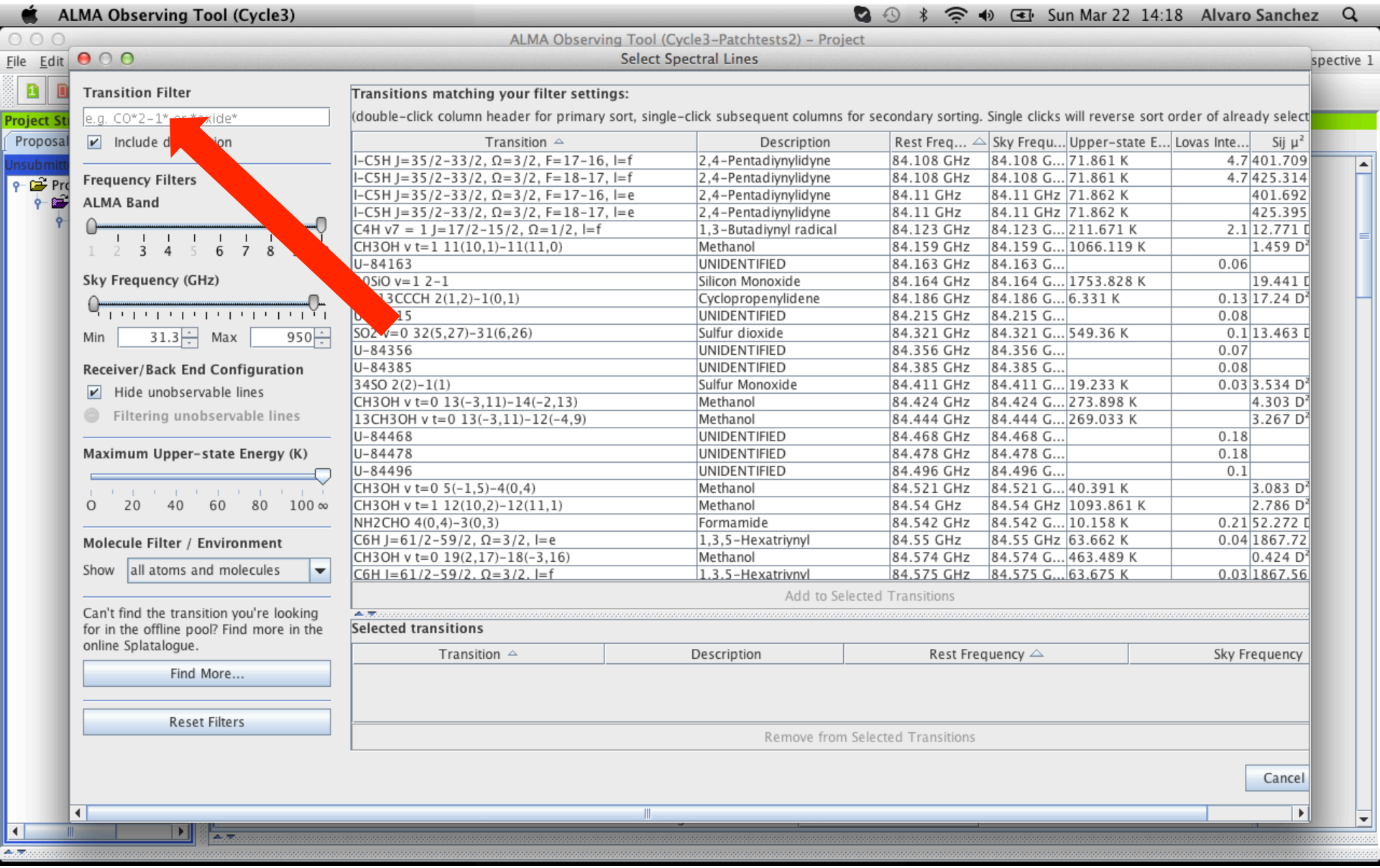

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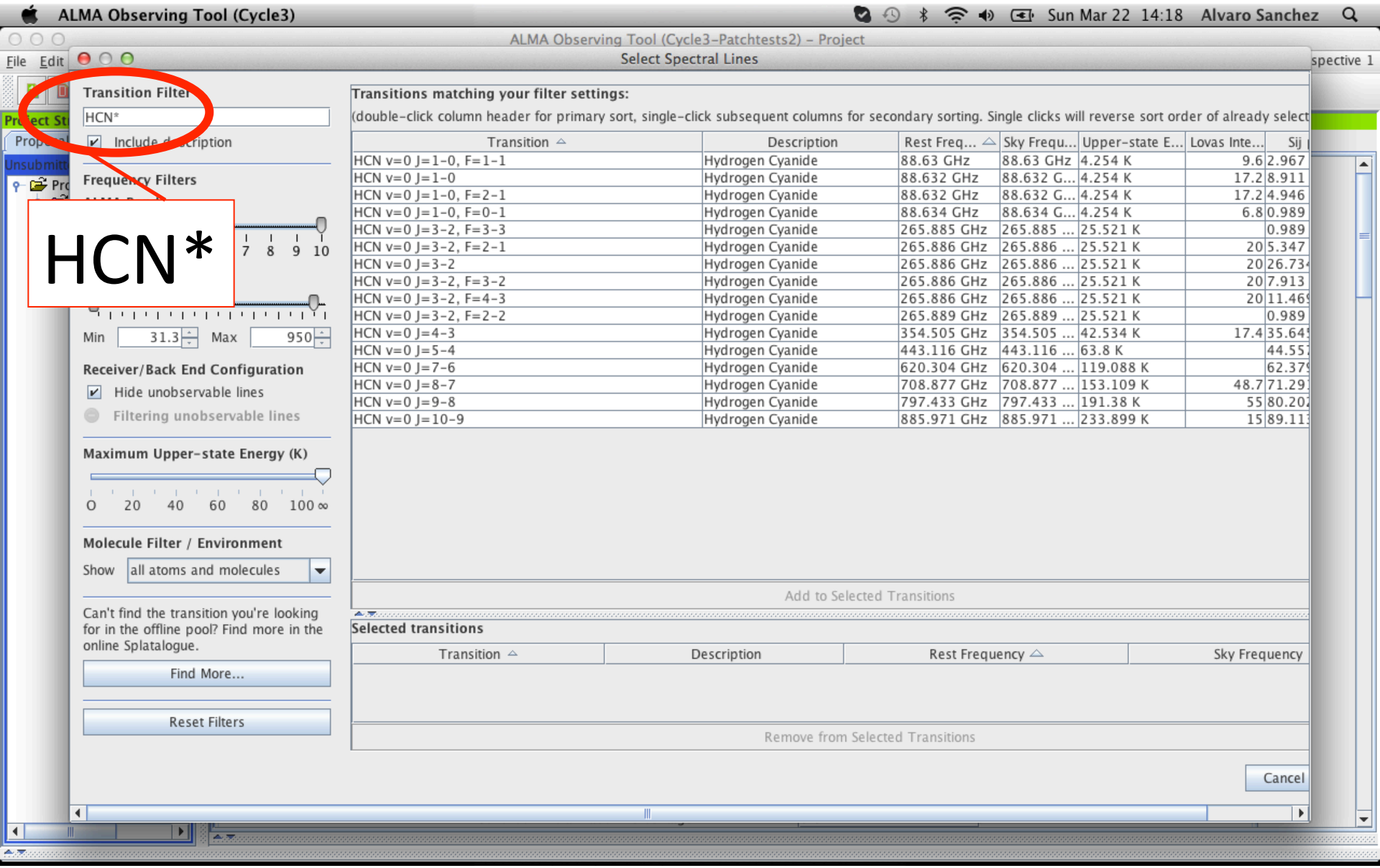
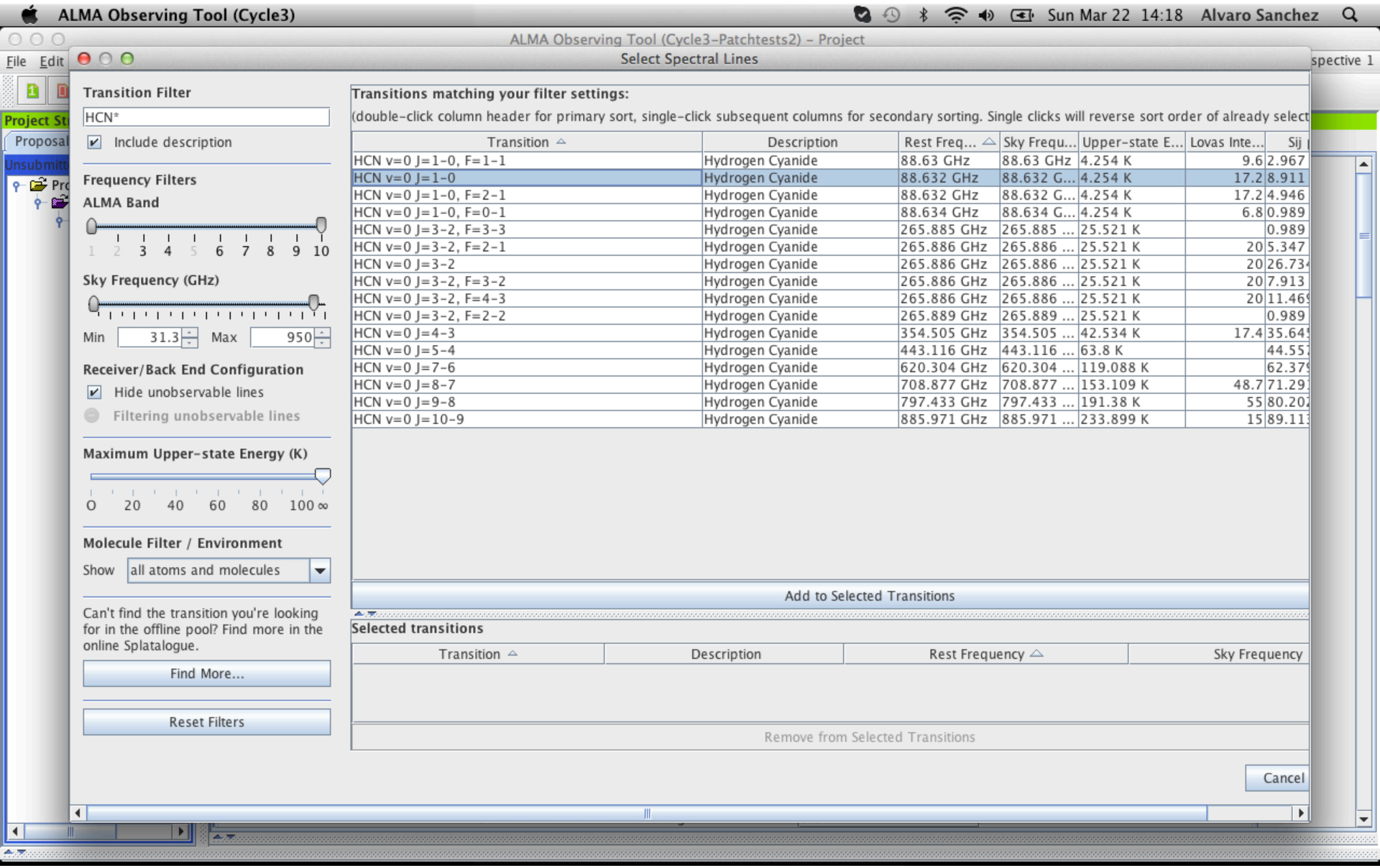
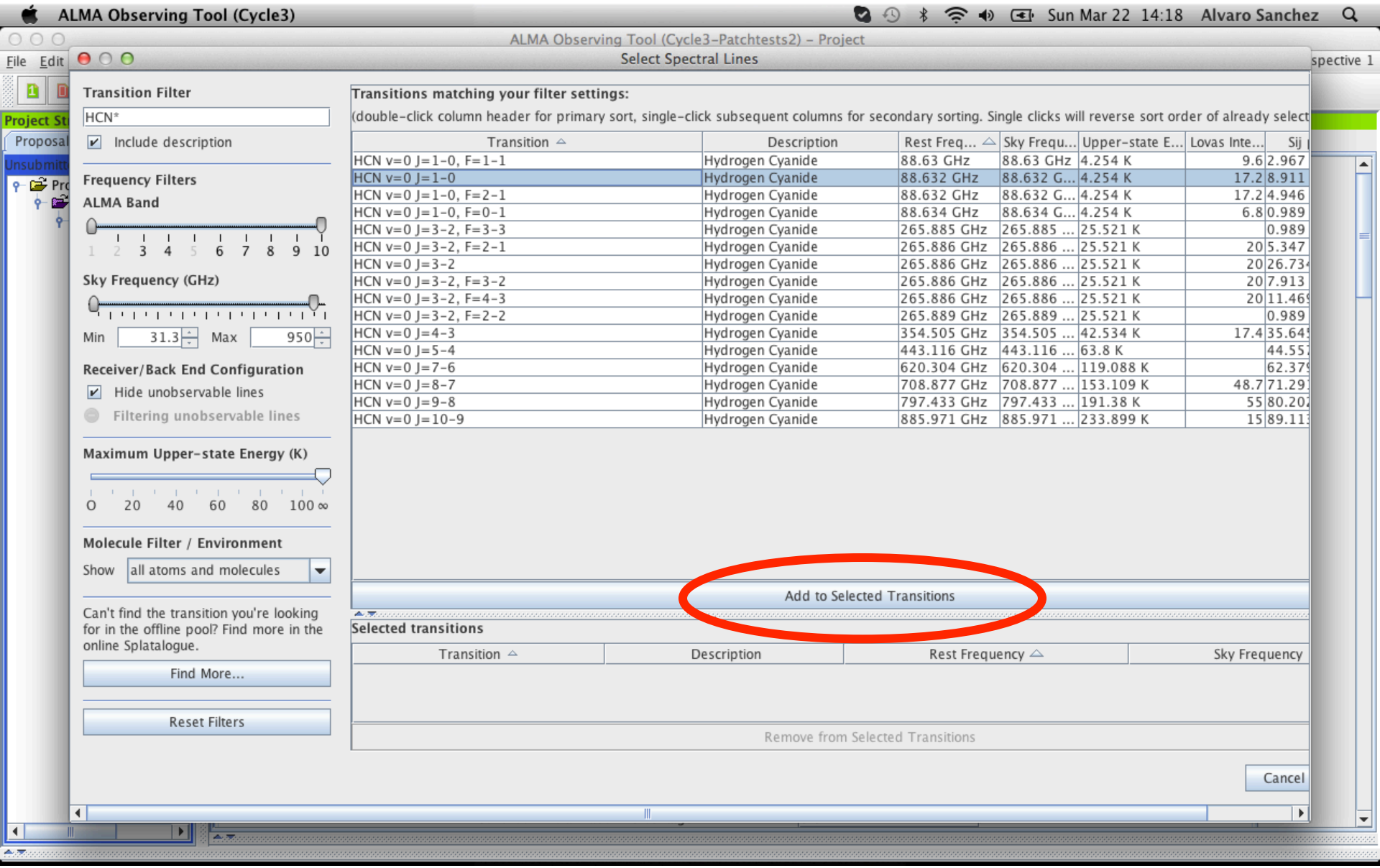


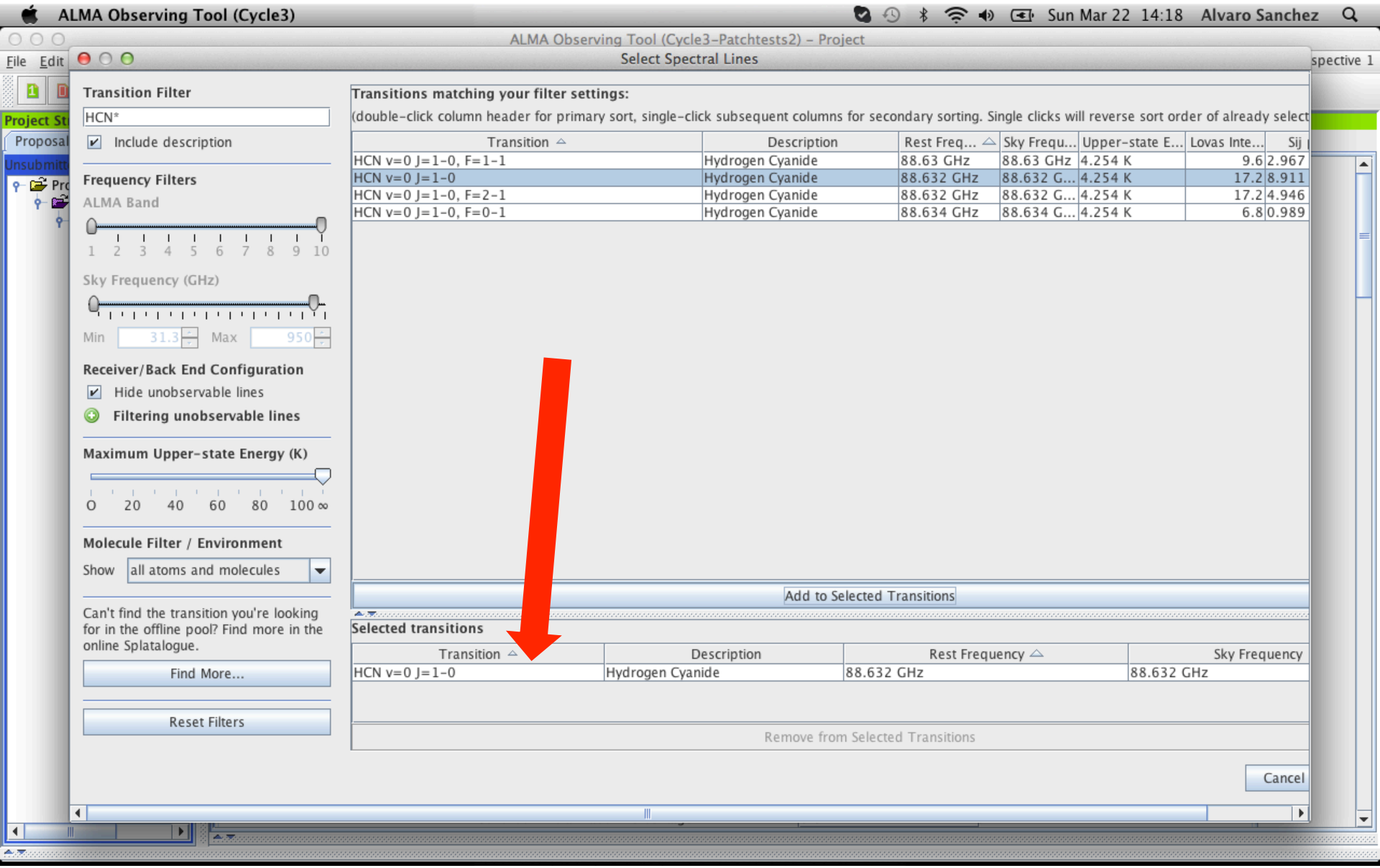
Spectral setup in the almaOT (EXAMPLE)



Spectral setup in the almaOT (EXAMPLE)



Spectral setup in the almaOT (EXAMPLE)



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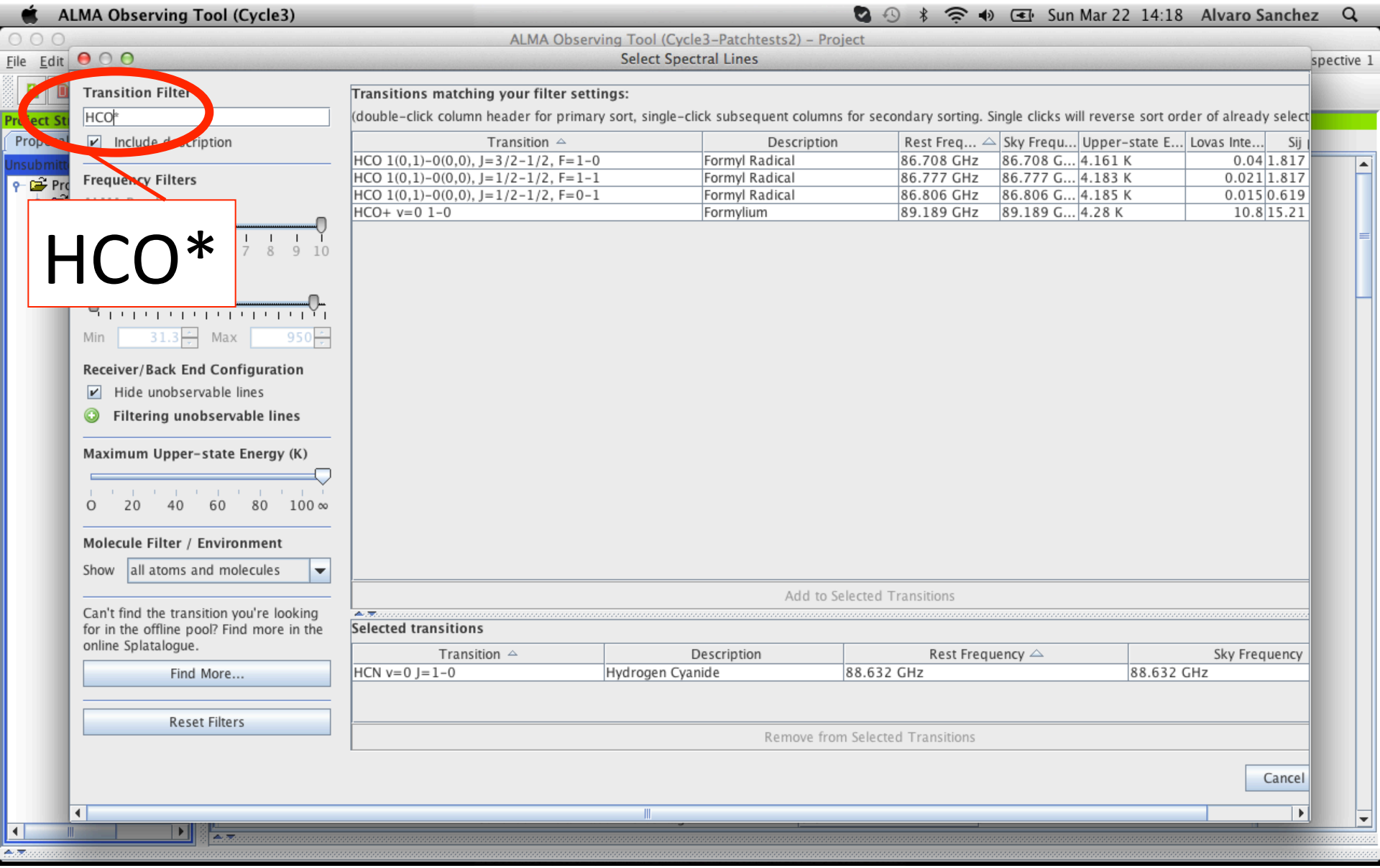

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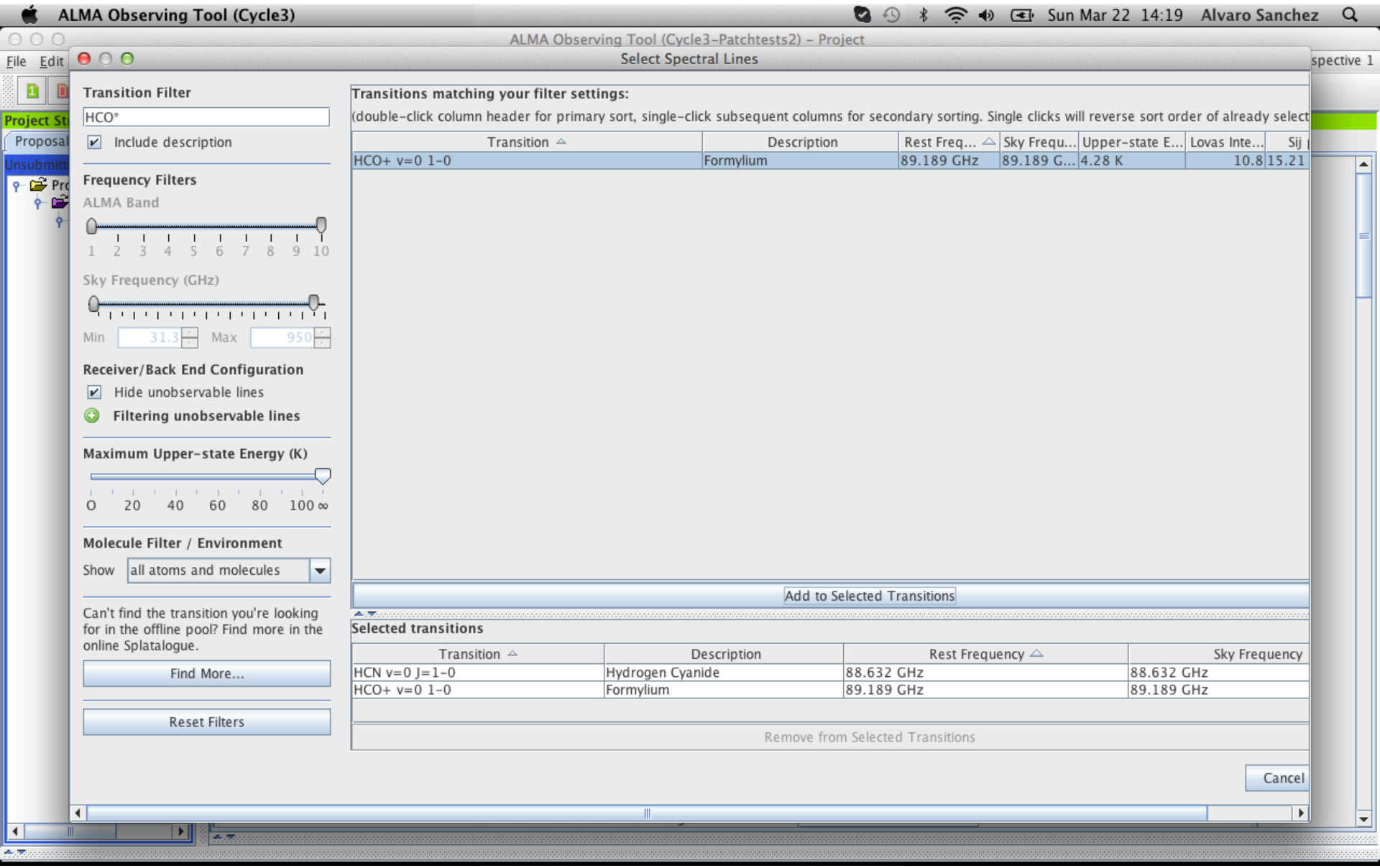

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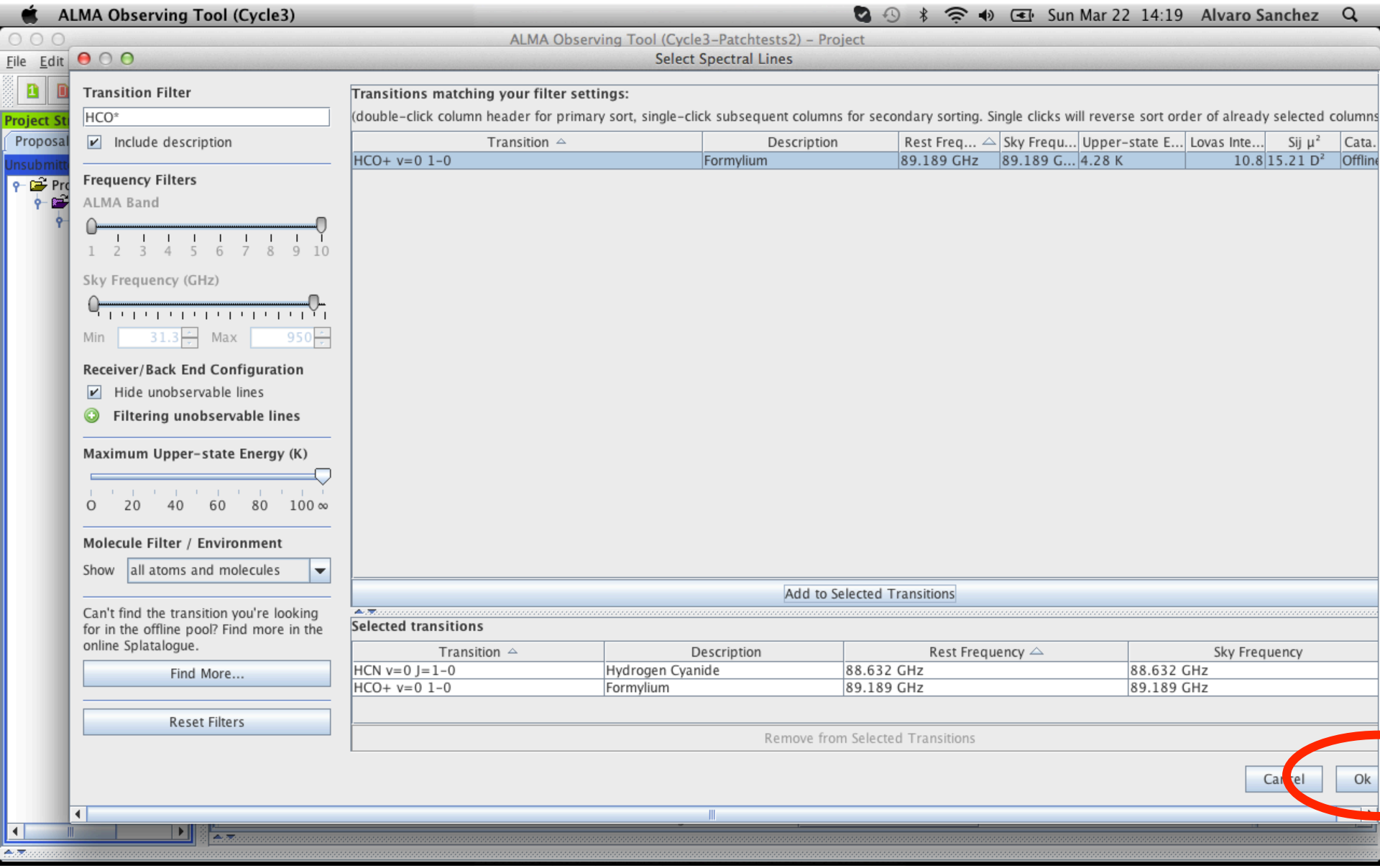

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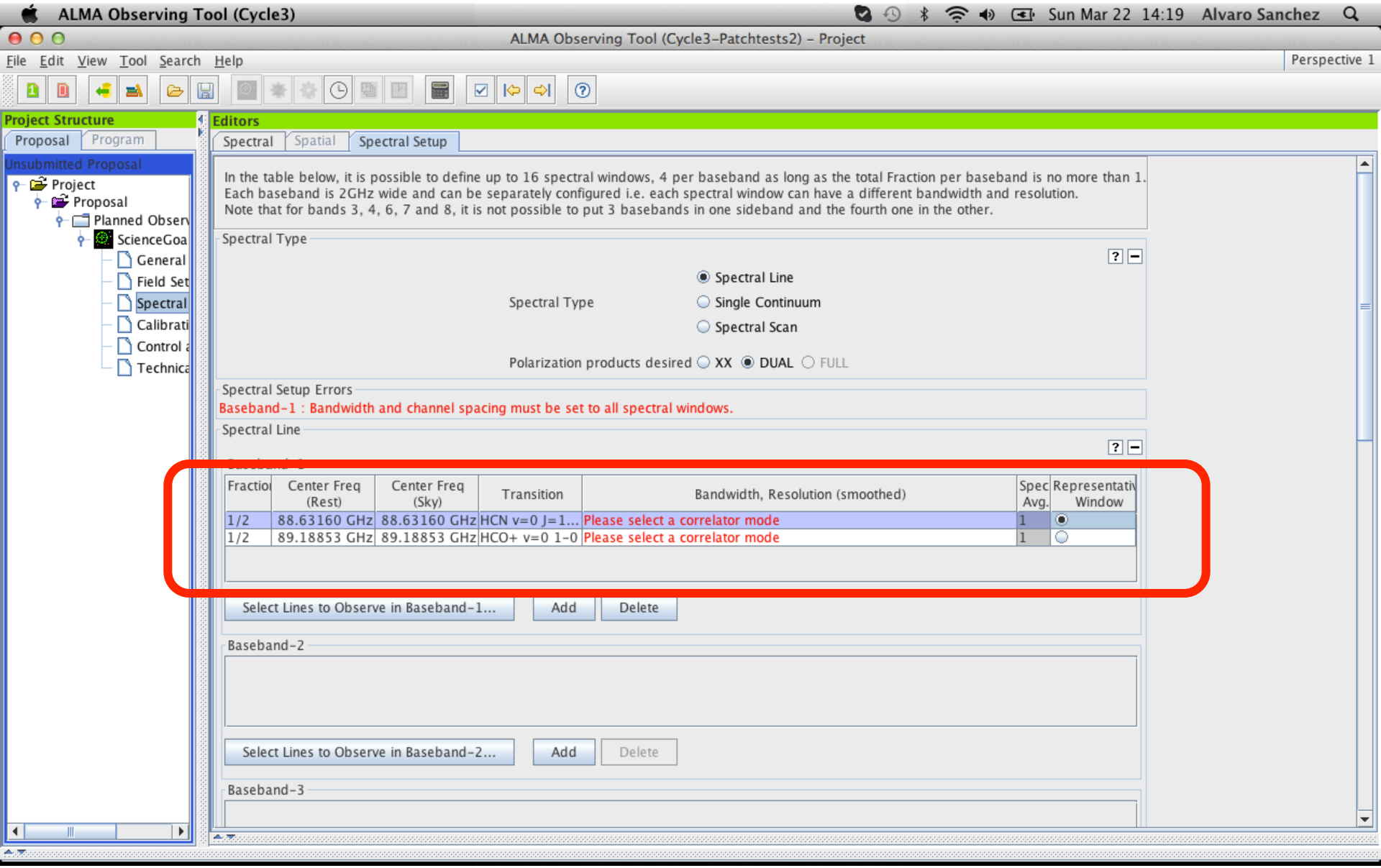

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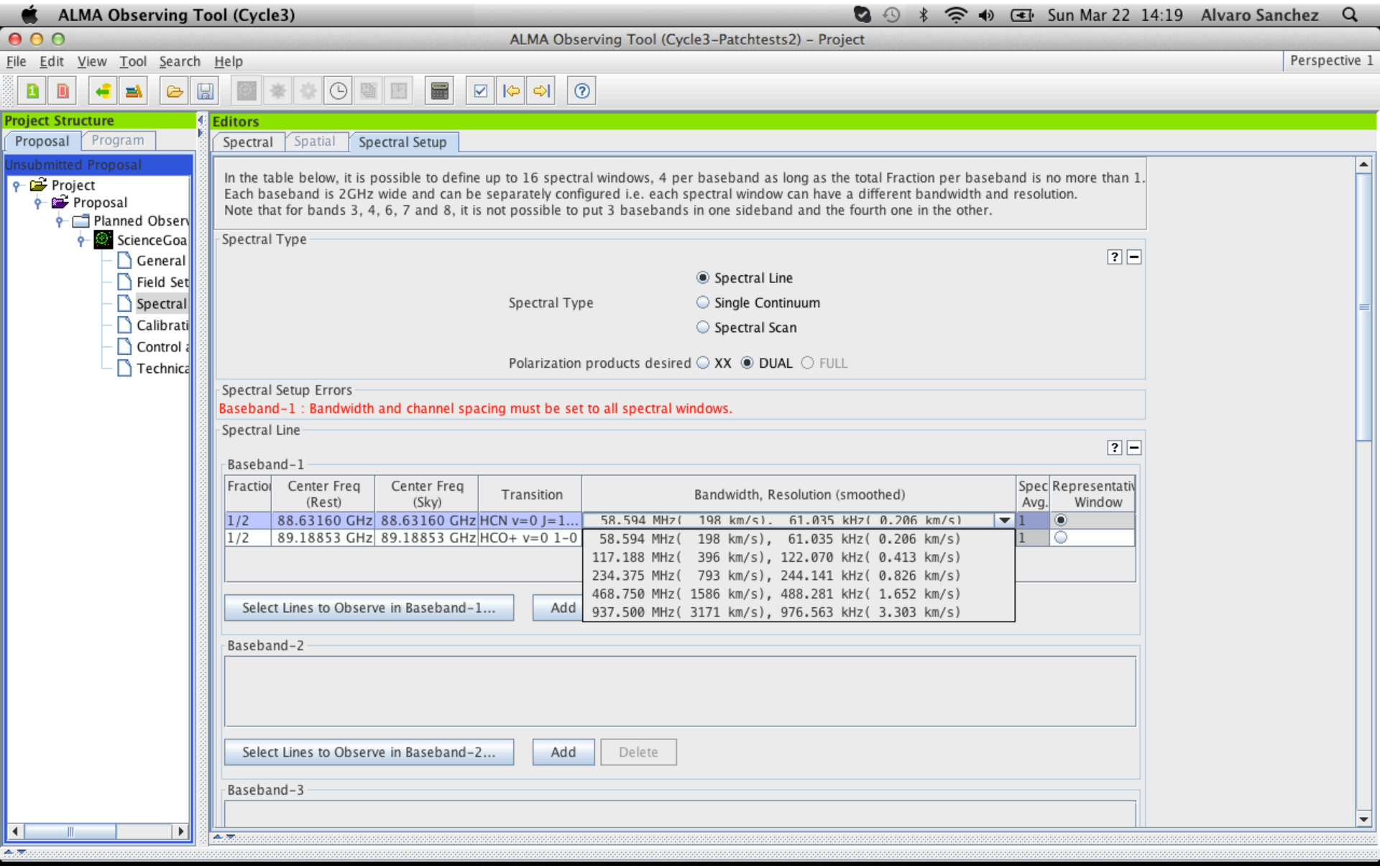

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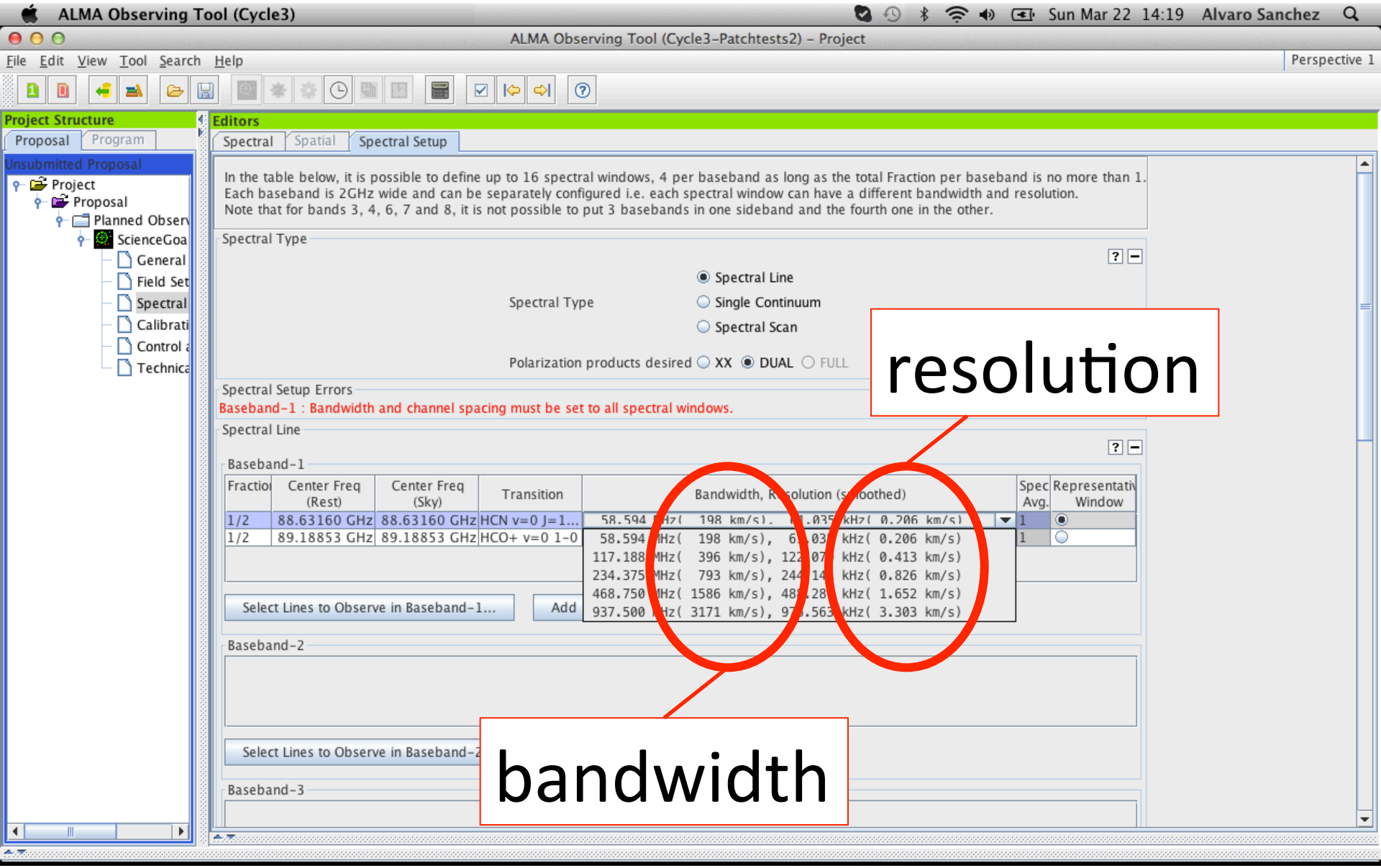

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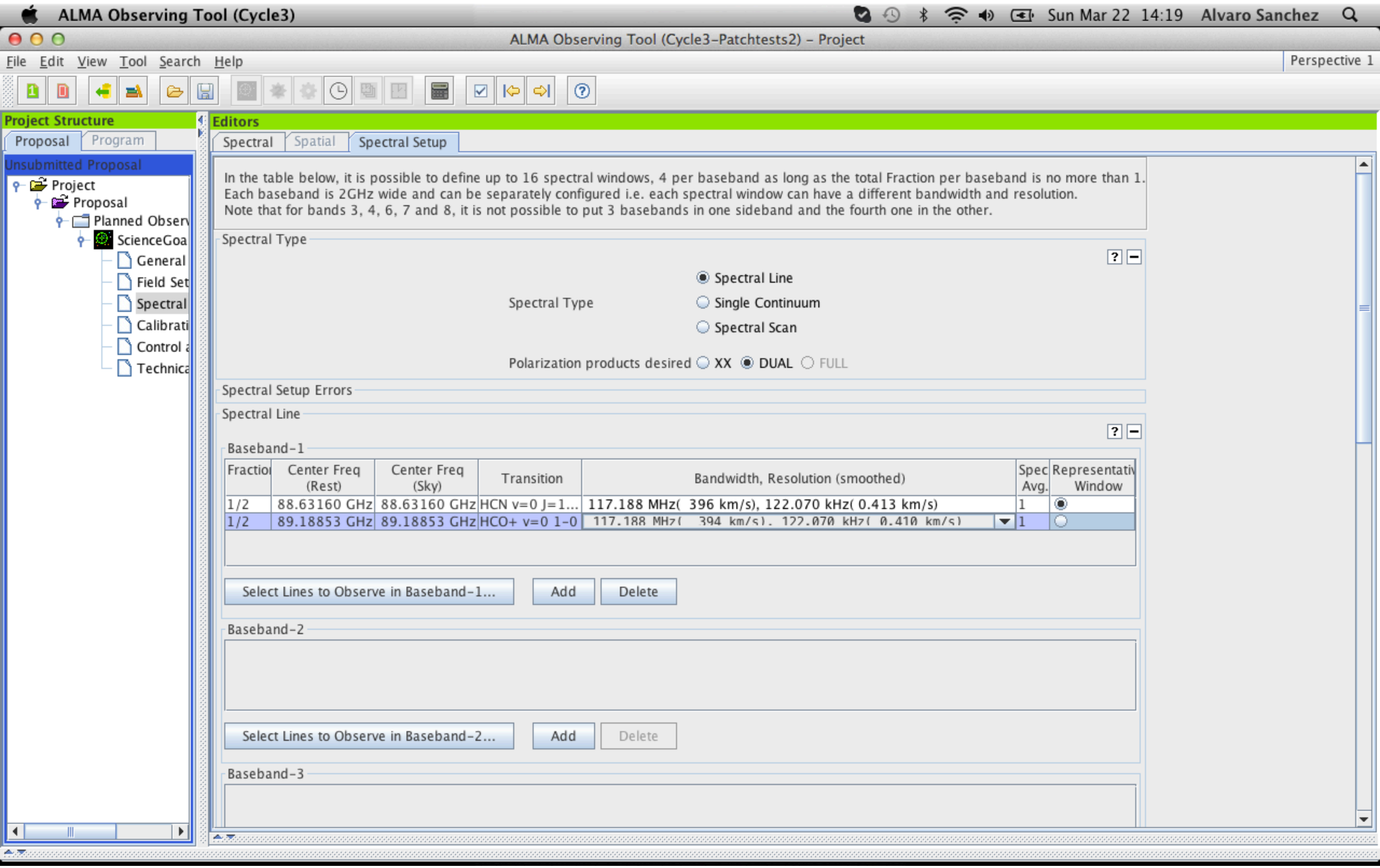

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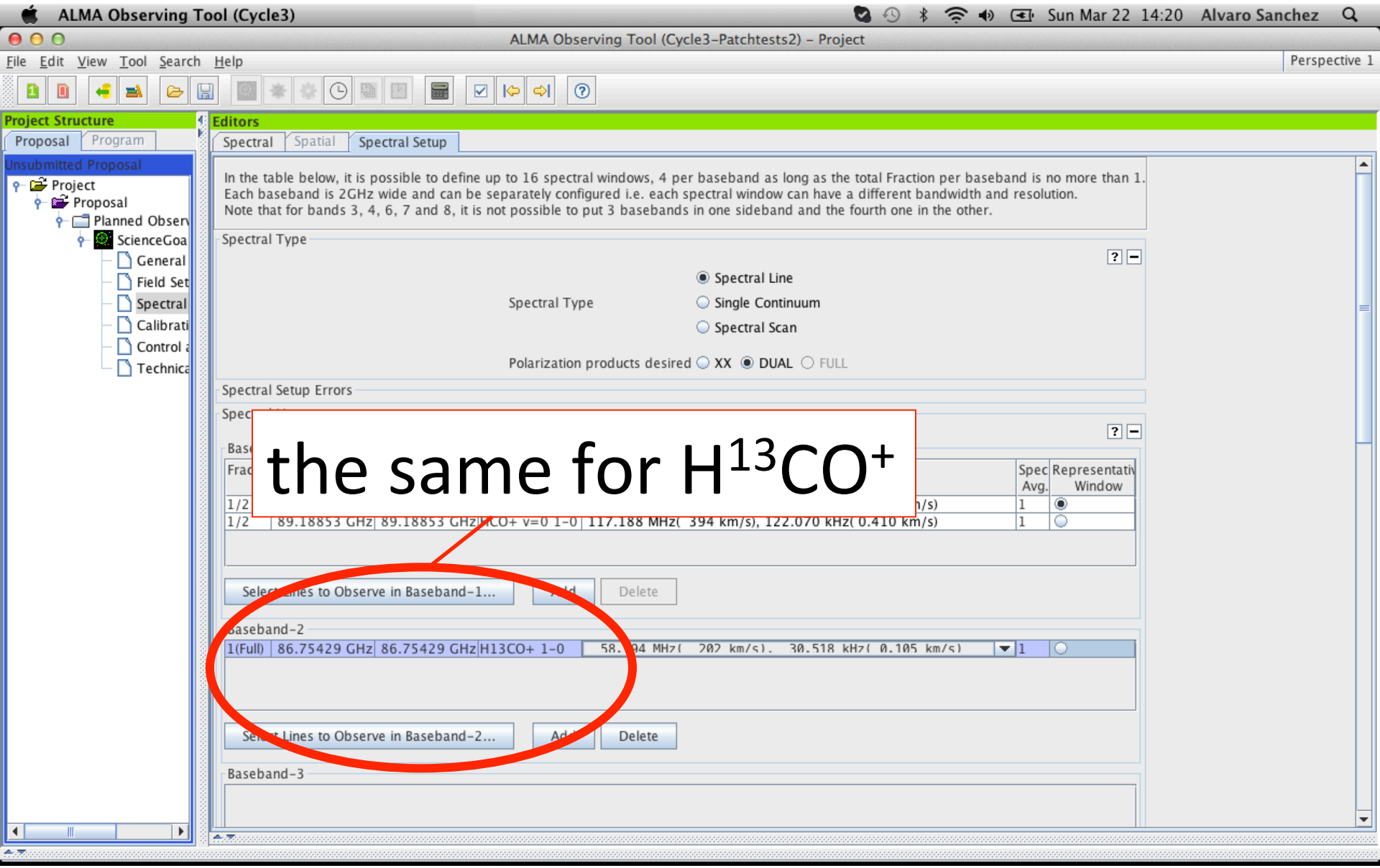

the same for $H^{13}CO^+$

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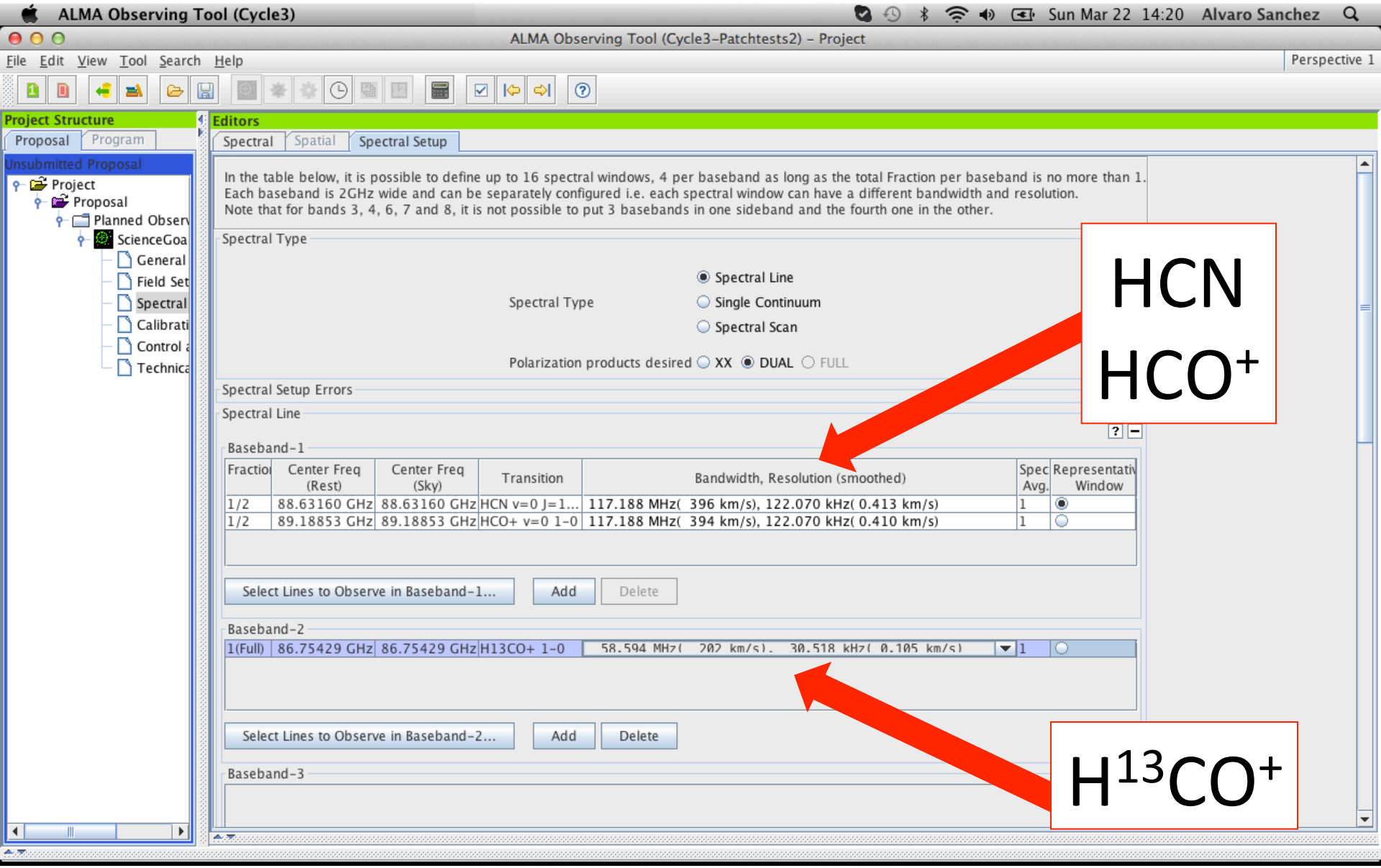

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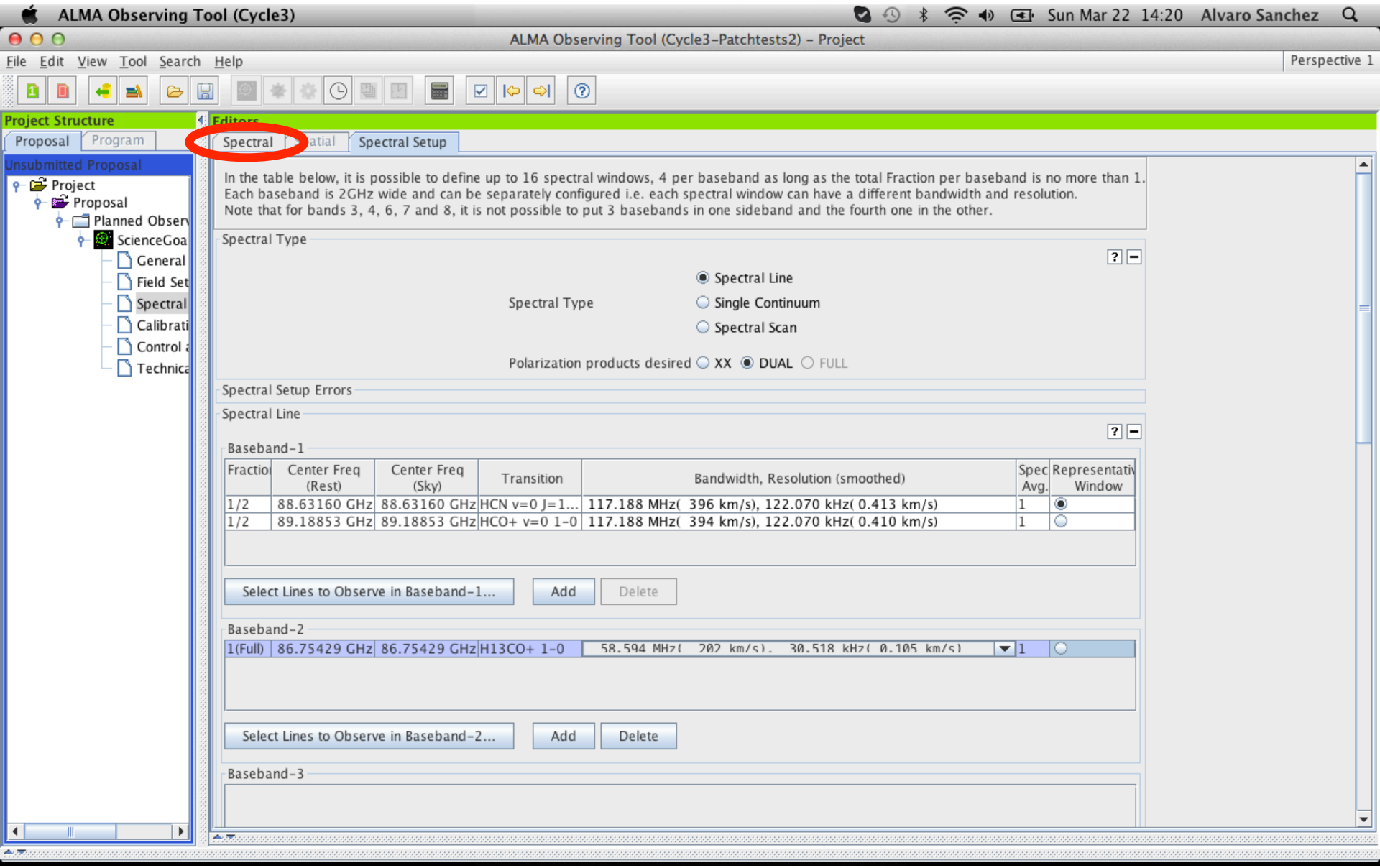

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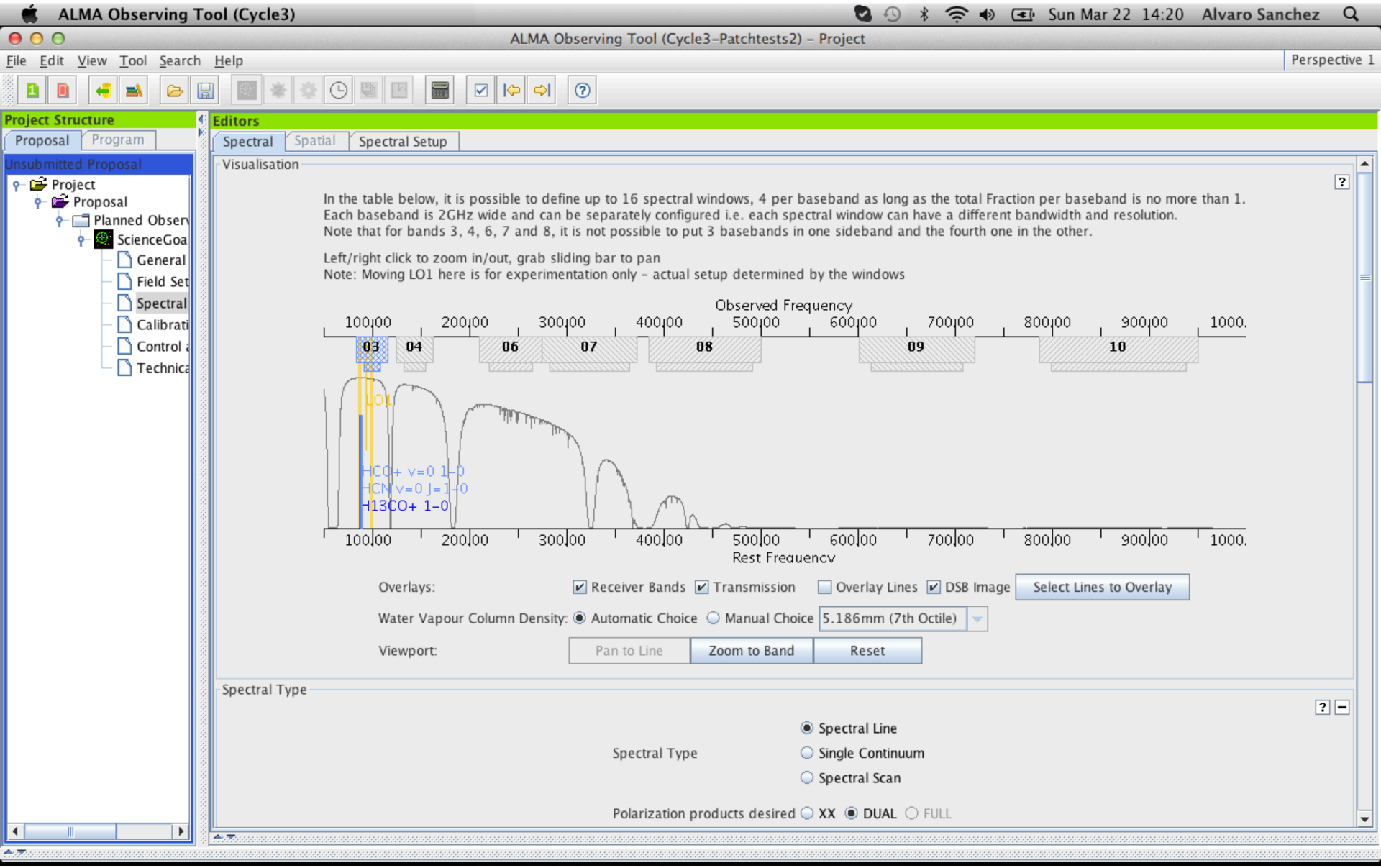

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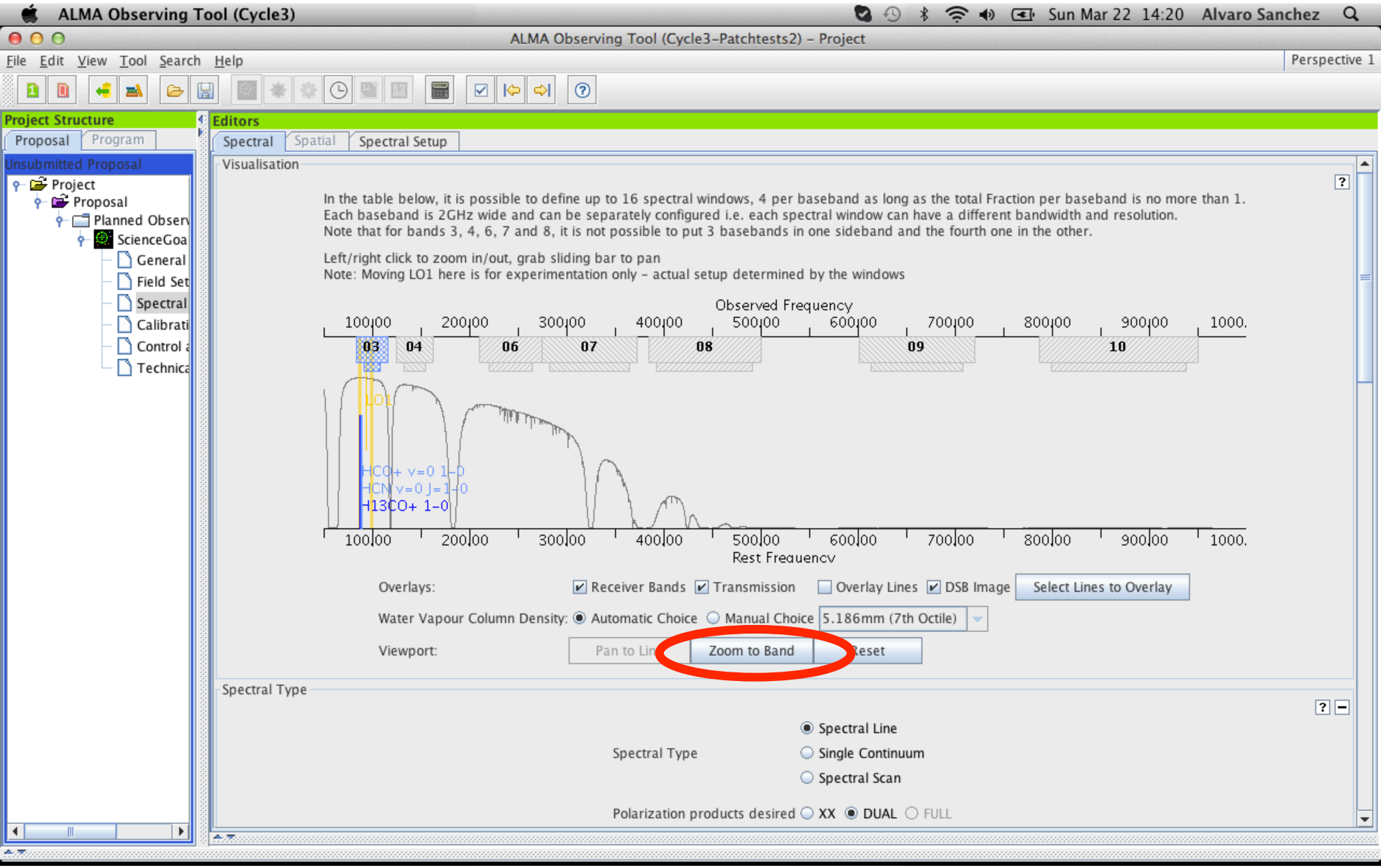

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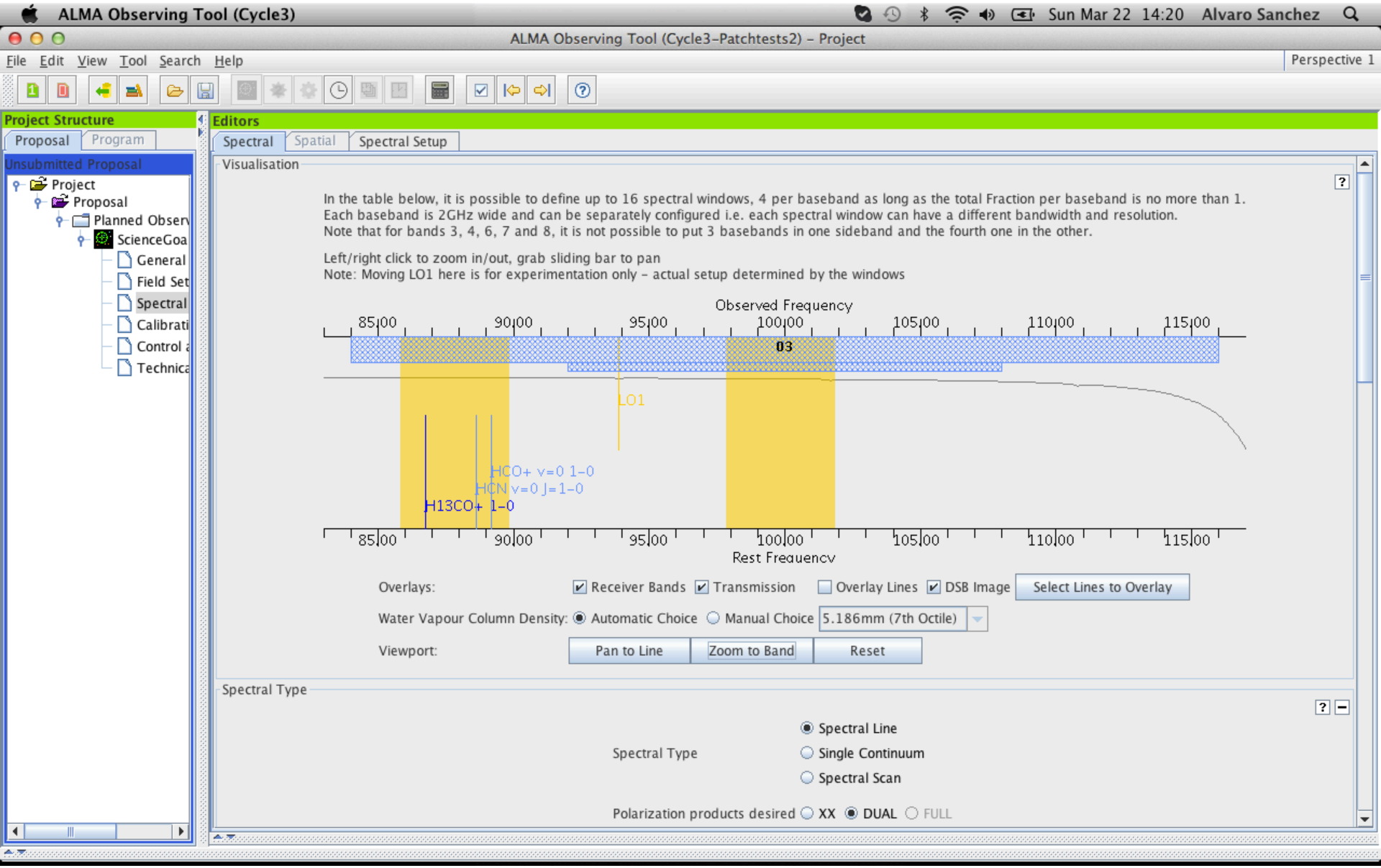


Break #2
German ARC: ALMA community days (March 2015)