ALMA Proposal Preparation Tutorials

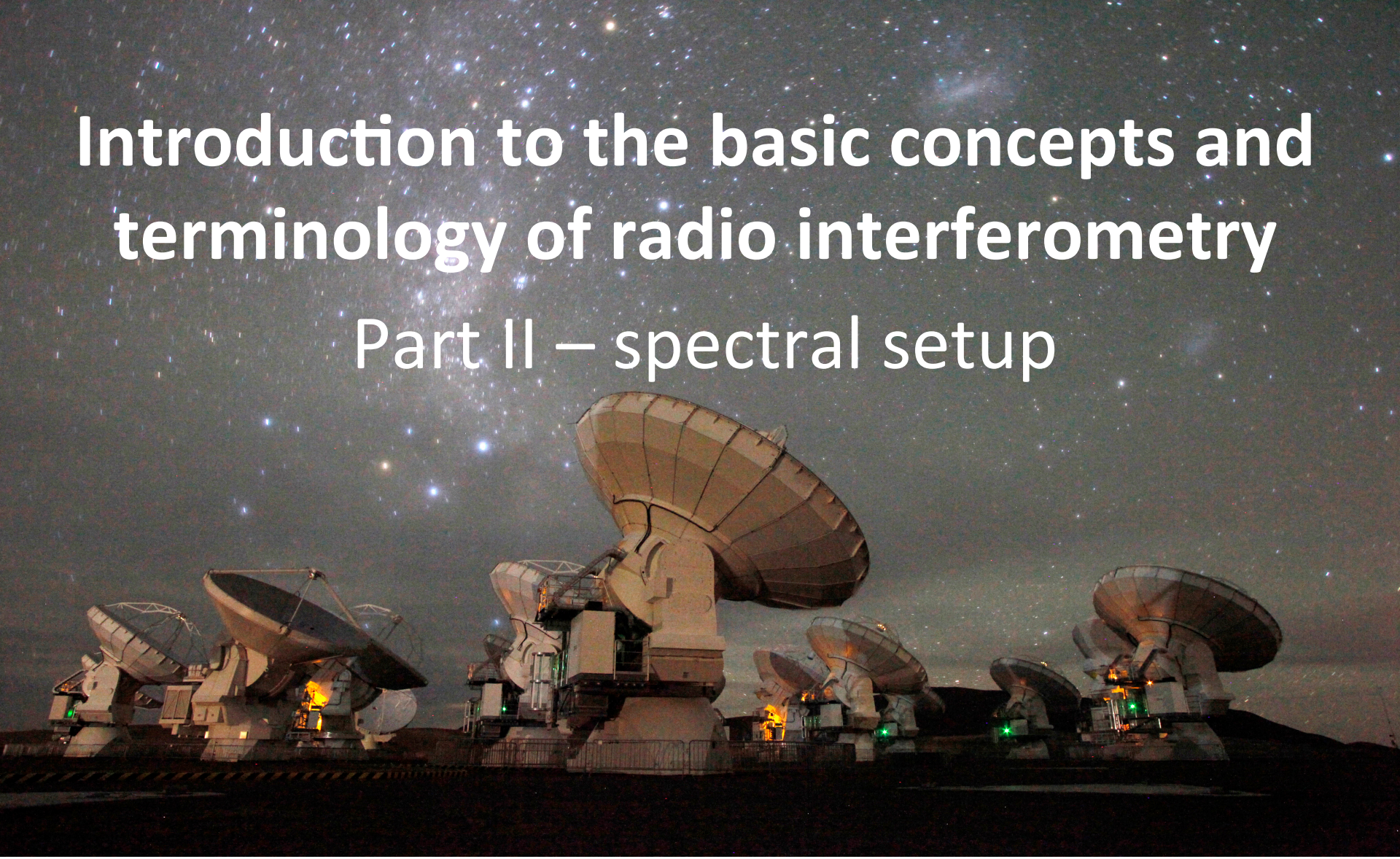
Argelander-Institut für Astronomie

EUROPEAN ARC
ALMA Regional Centre || Germany

ph1 Universität zu Köln

Introduction to the basic concepts and terminology of radio interferometry

Part II – spectral setup



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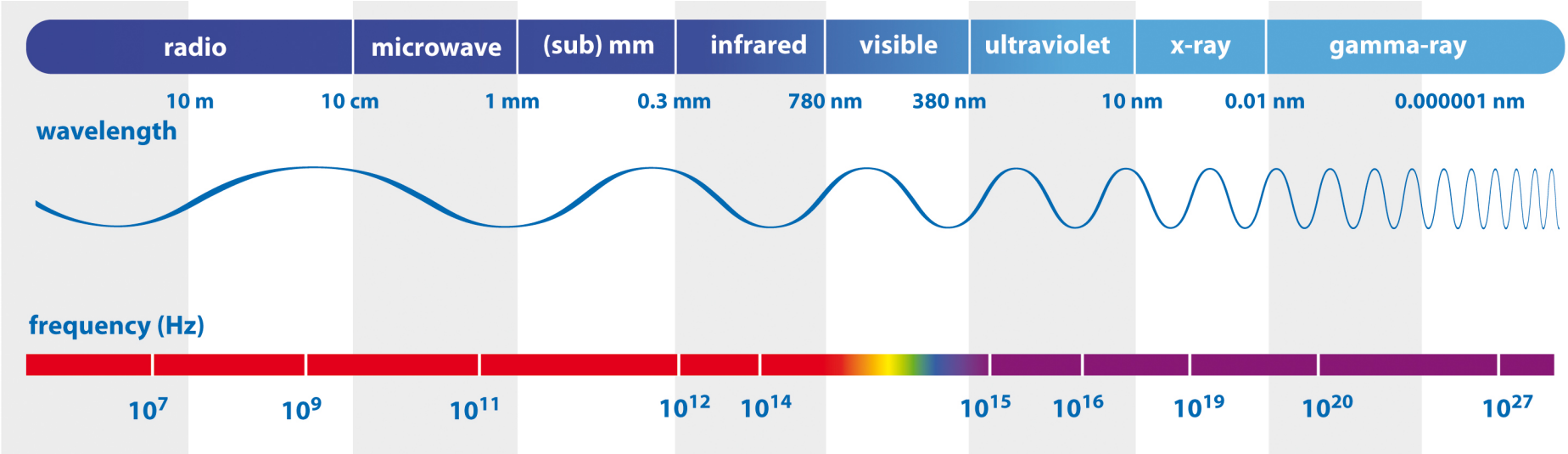
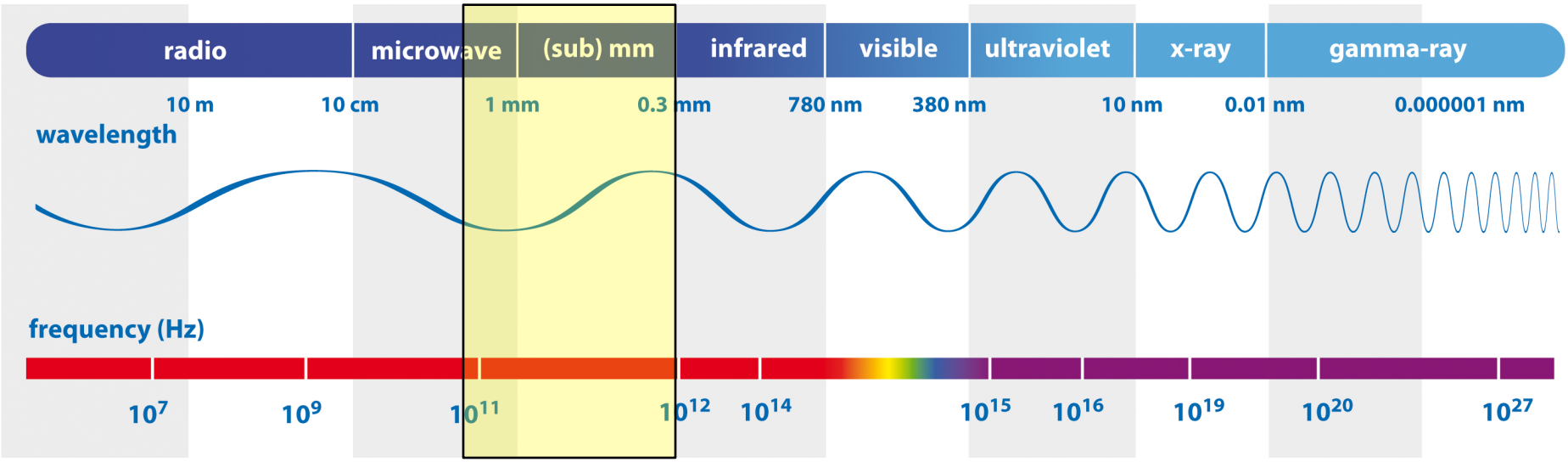
Key concepts to learn

Part 2

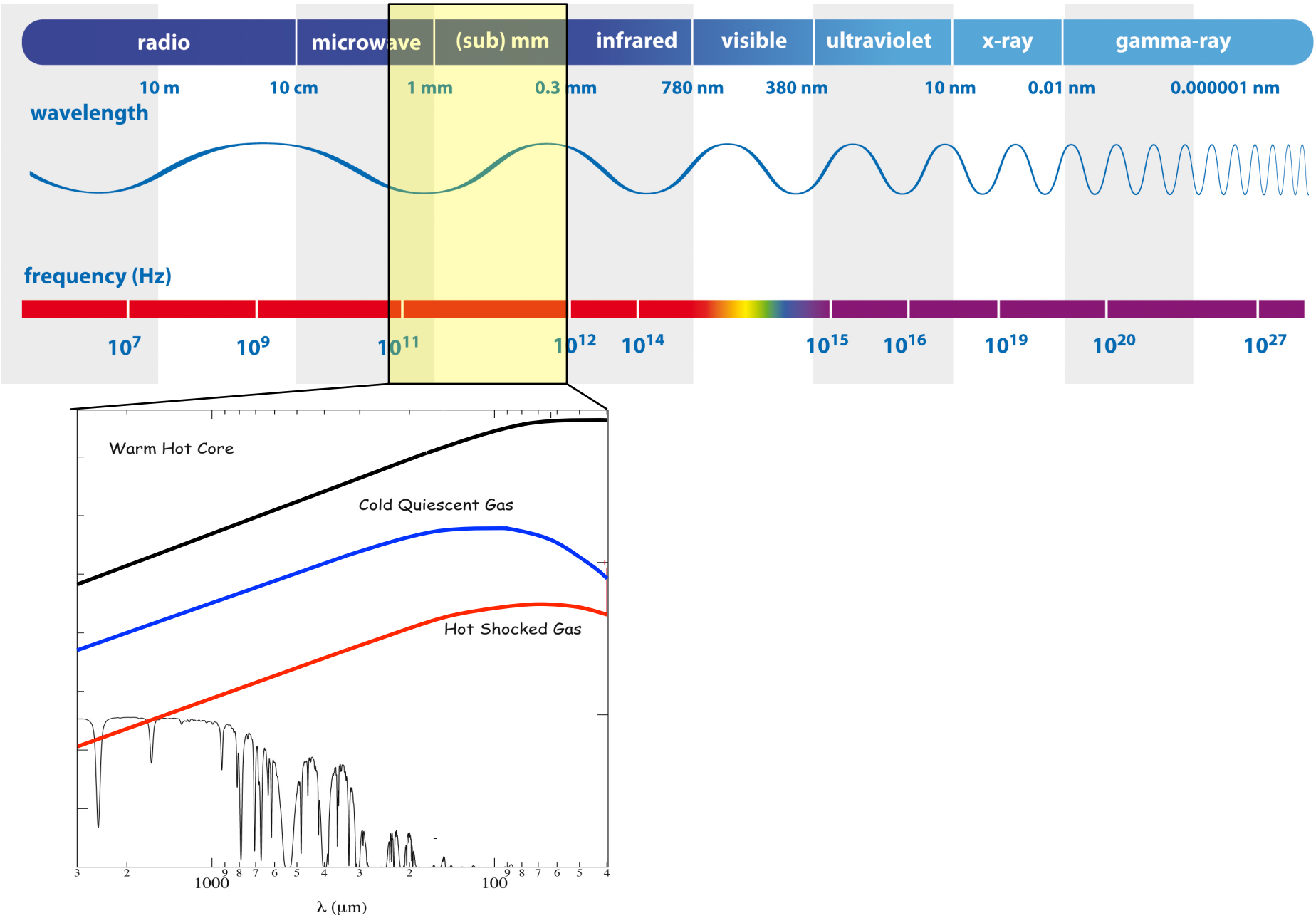
- Spectral lines
- Rest frequency
- Source velocity and redshift
- Line width
- Spectral resolution


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}

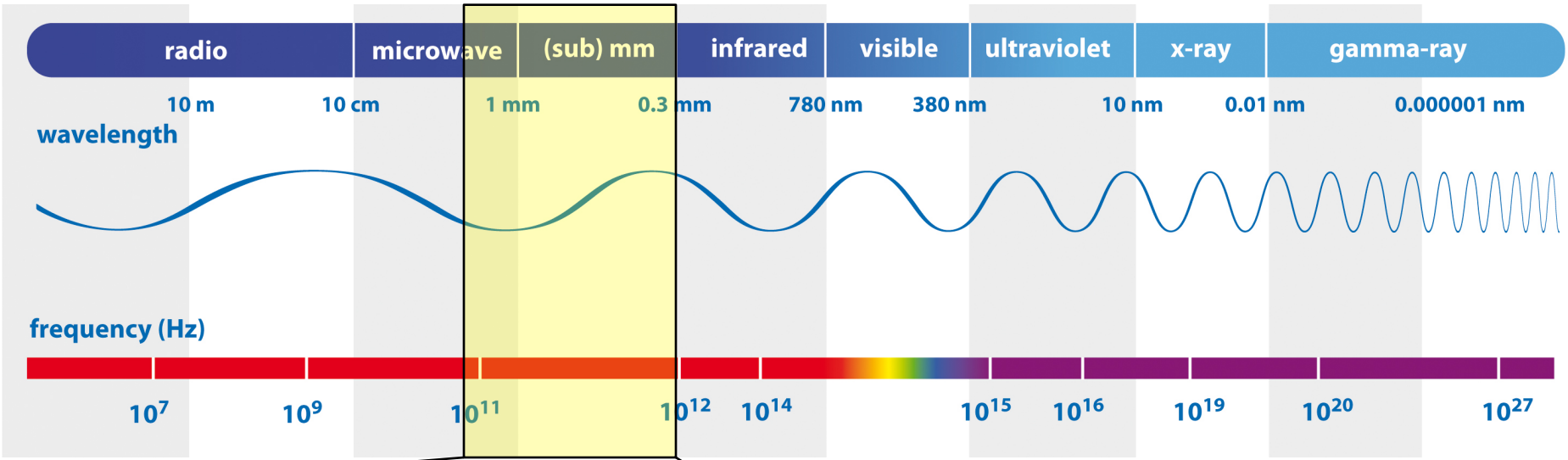


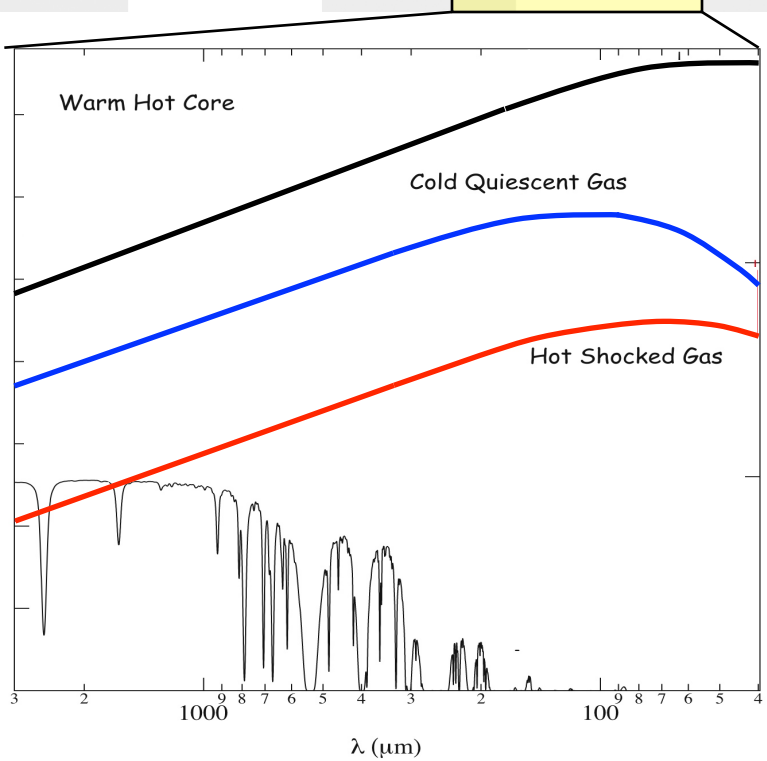
ALMA observable range

“**Cold Universe**”



continuum emission





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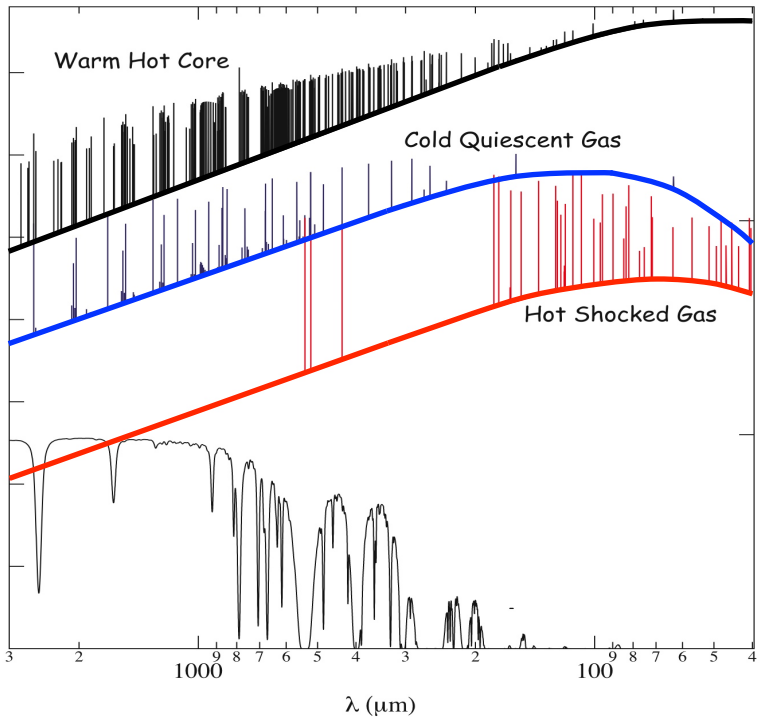
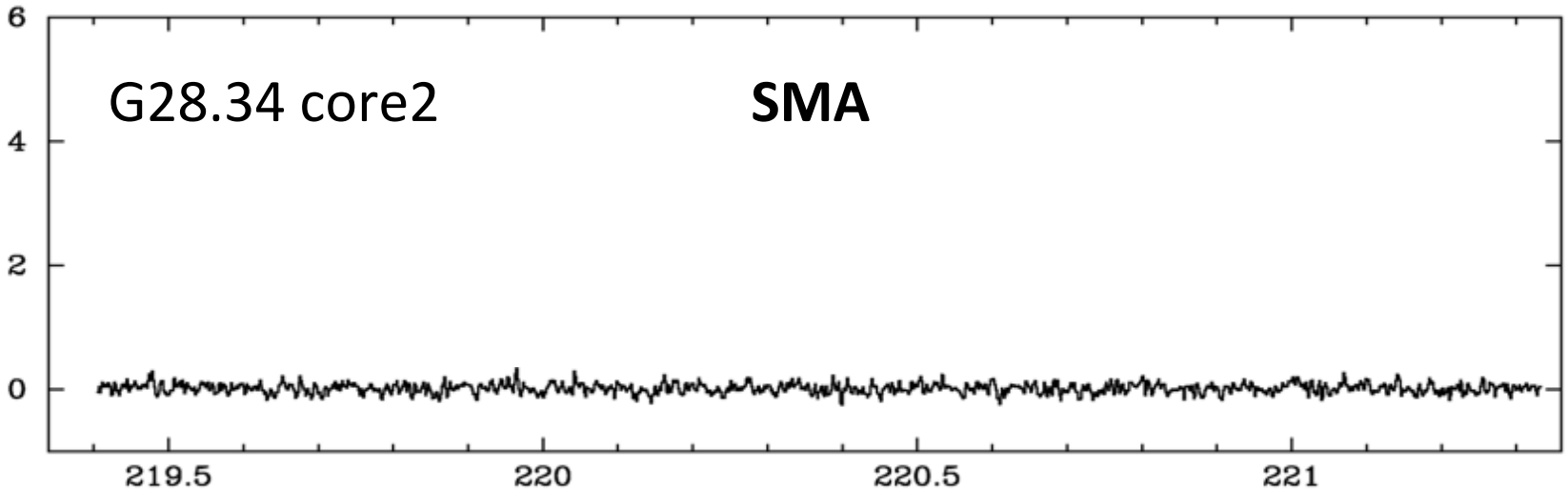


line emission

Can we detect spectral lines?



Zhang et al (2008)

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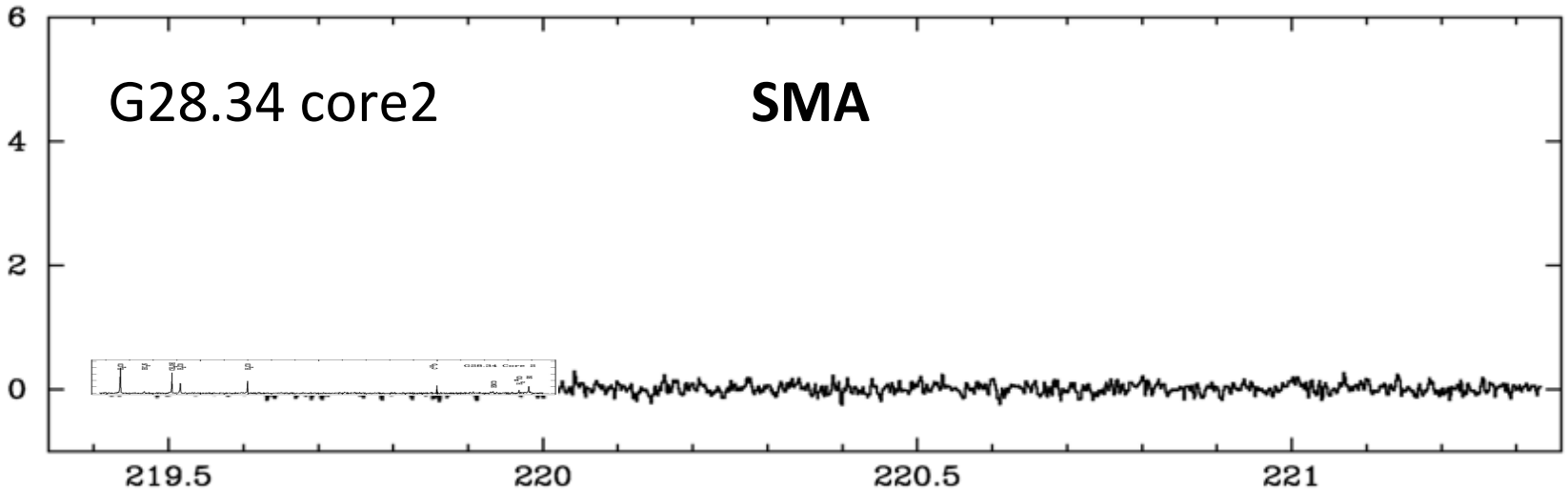

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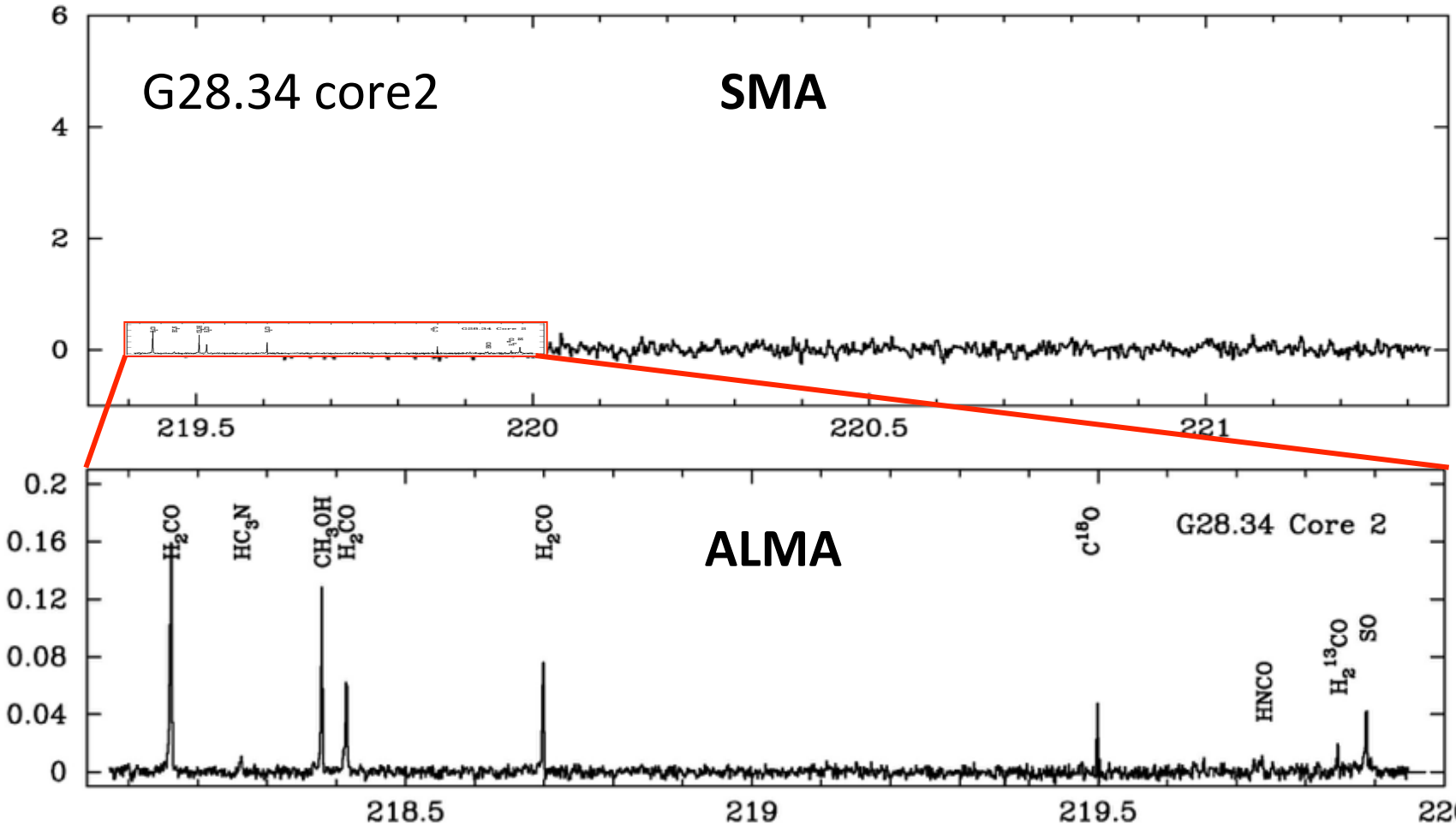

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Zhang et al (2014)

What do we need to know?

- **frequency of the lines to observe**
- velocity / redshift of the source
- line shape / velocity coverage and resolution
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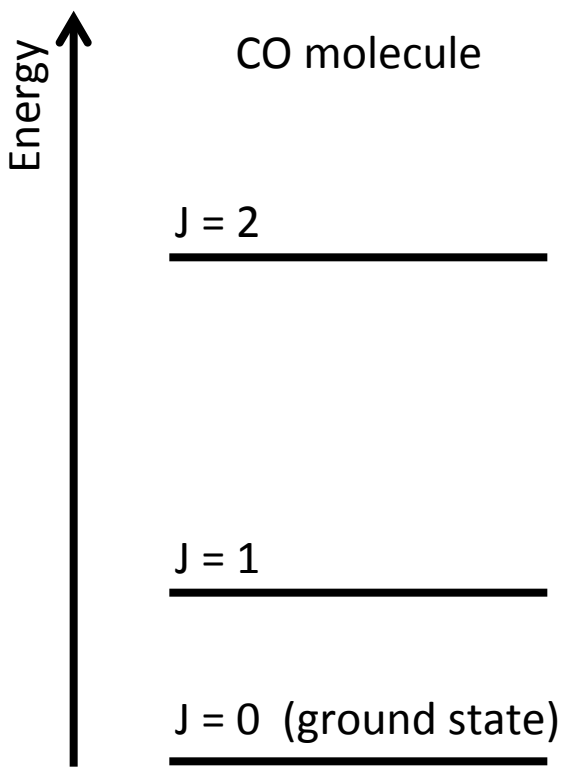
Basic concepts of spectral line observations

Rest frequency

Basic concepts of spectral line observations

<u>Rest frequency</u>

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



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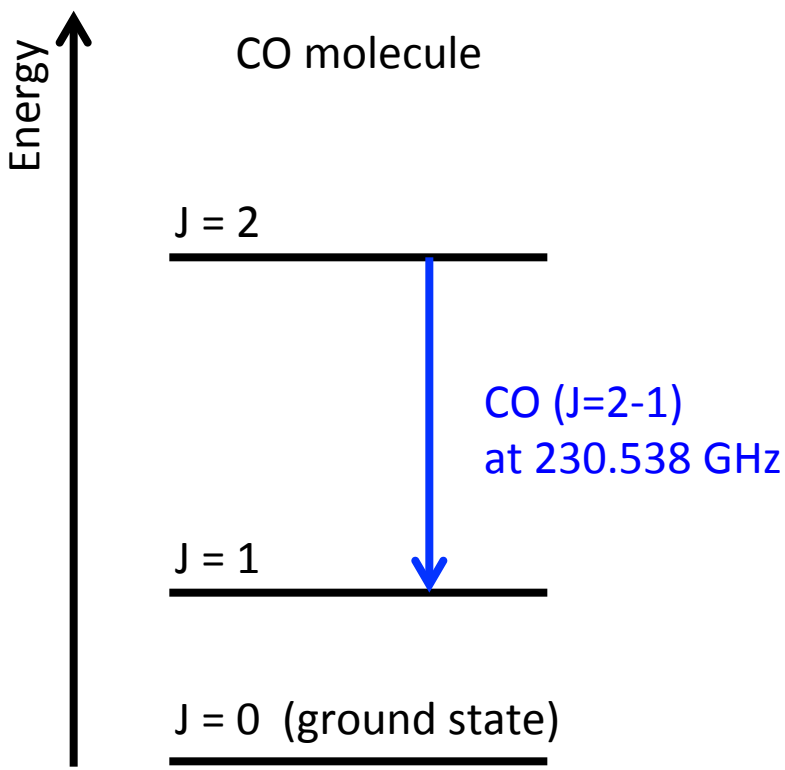

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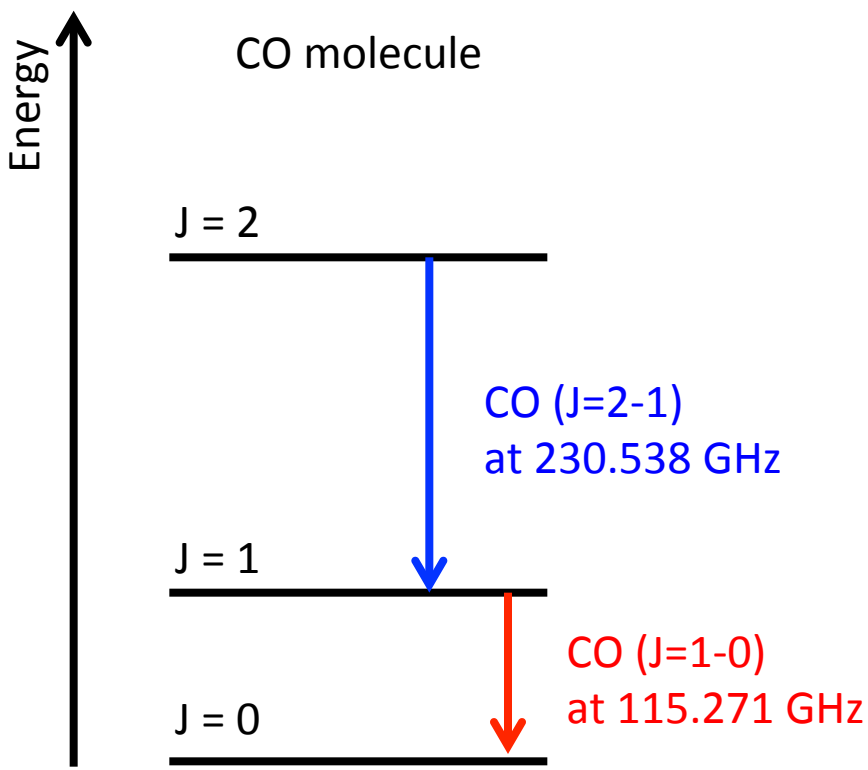

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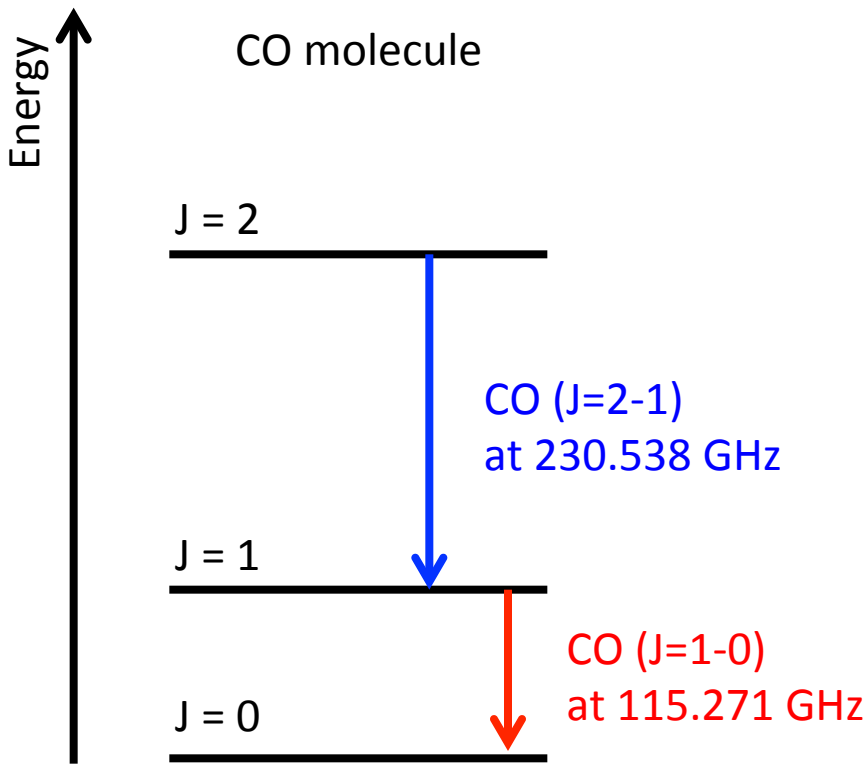

Rest frequencies can be found in molecular databases:

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

JPL
spec.jpl.nasa.gov

Splatalogue
www.splatalogue.net

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Velocity (Vlsr) / redshift (z)

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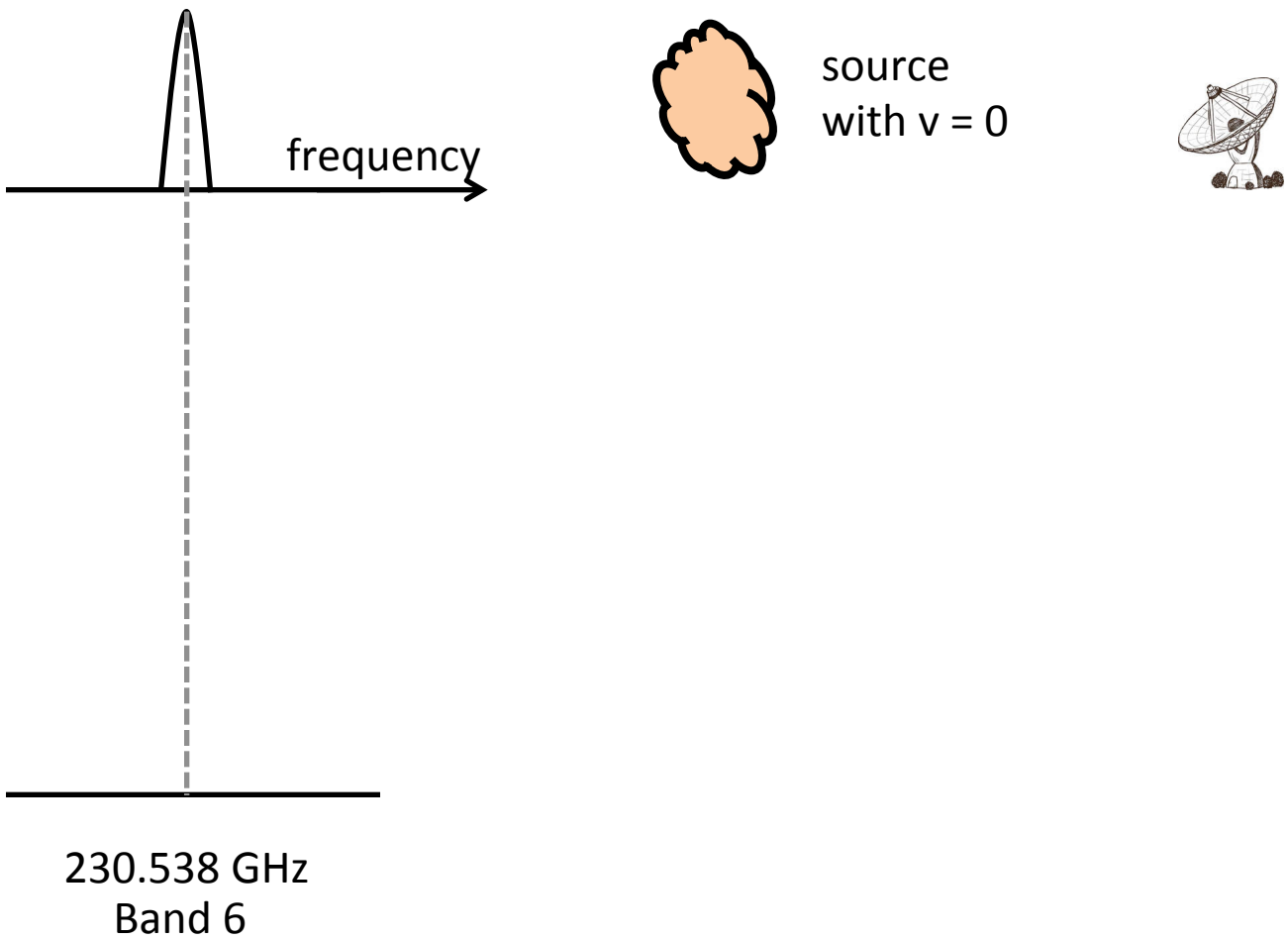

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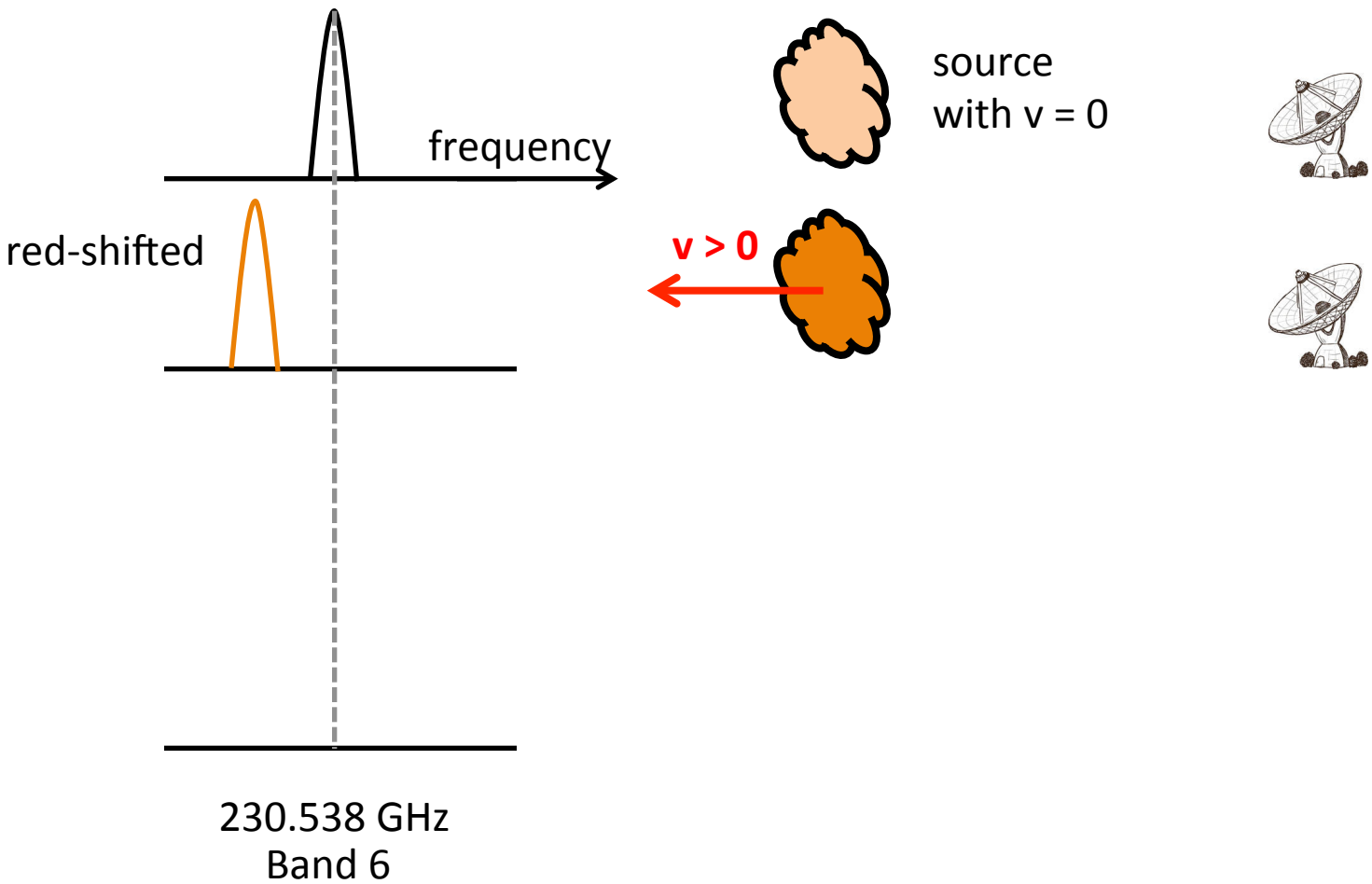

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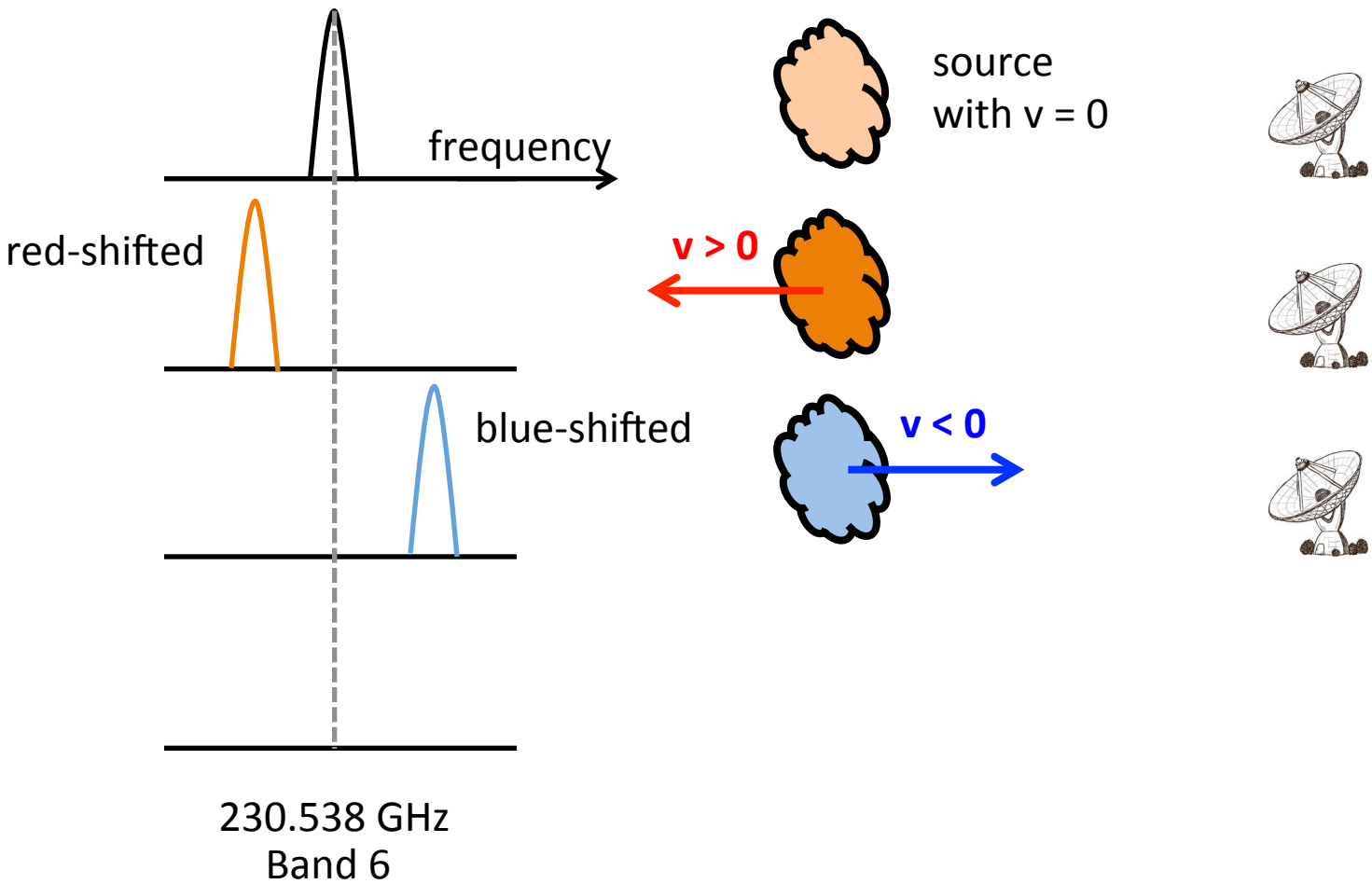

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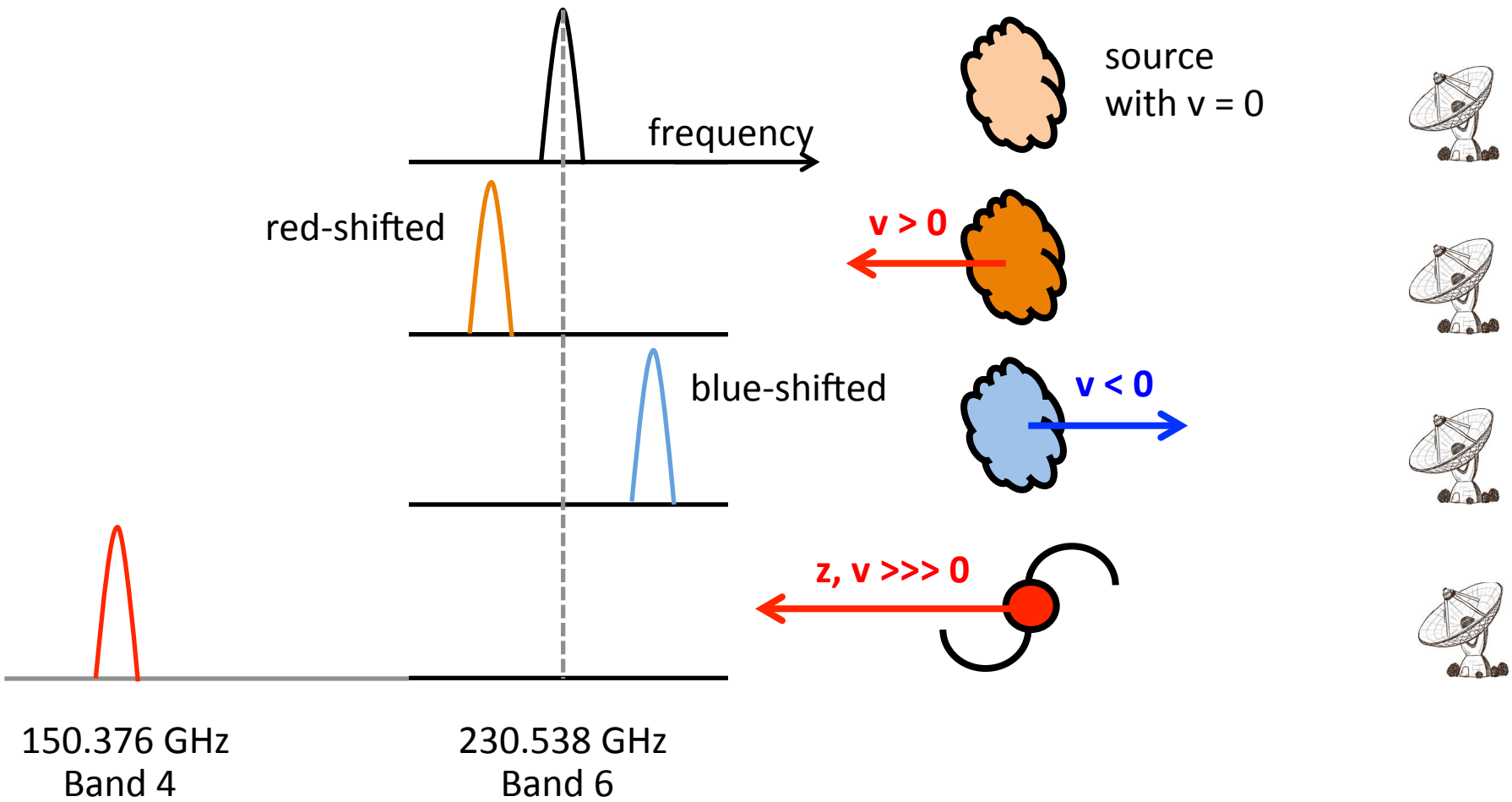

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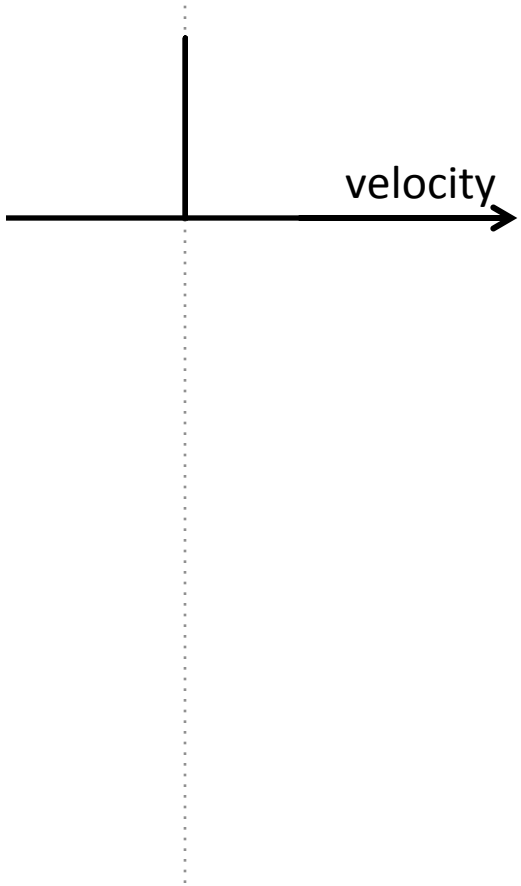

each spectral line has an exact frequency

Basic concepts of spectral line observations

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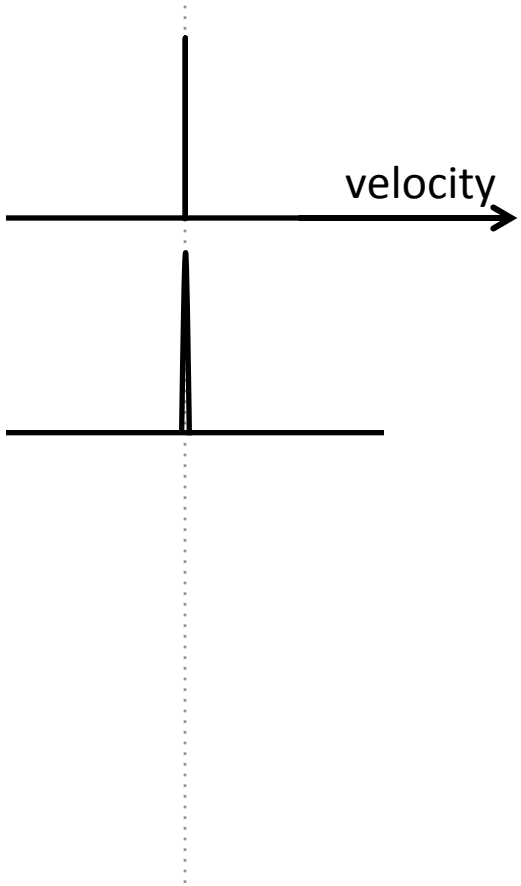

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natural broadening

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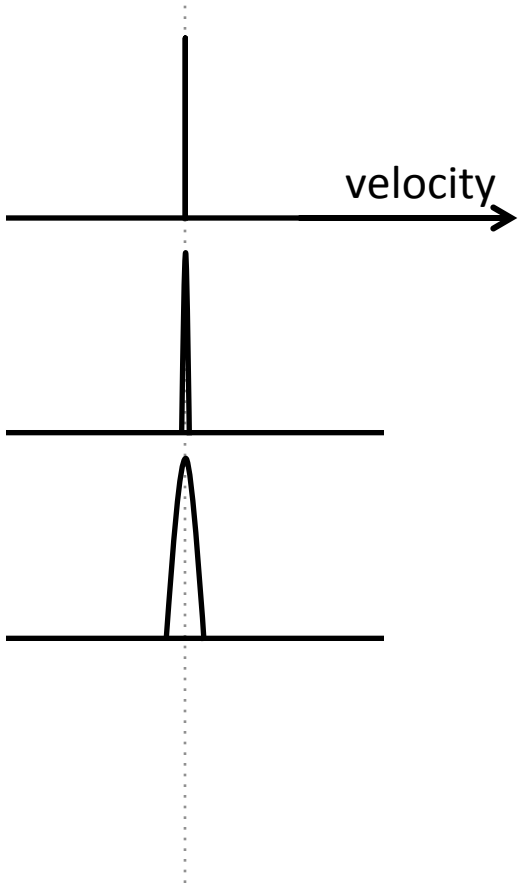

each spectral line has an exact frequency

natural broadening

thermal, microturbulent, pressure broadening

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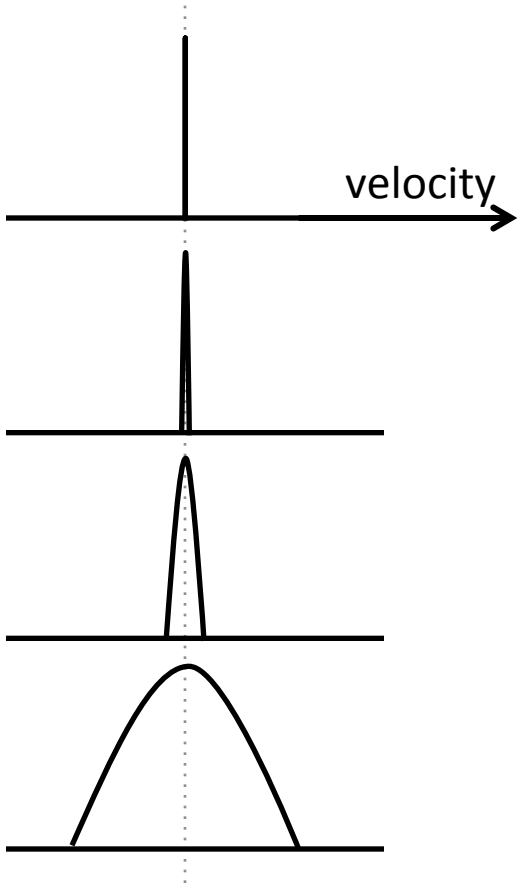

each spectral line has an exact frequency

natural broadening

thermal, microturbulent, pressure broadening

large-scale motions broadening

Basic concepts of spectral line observations

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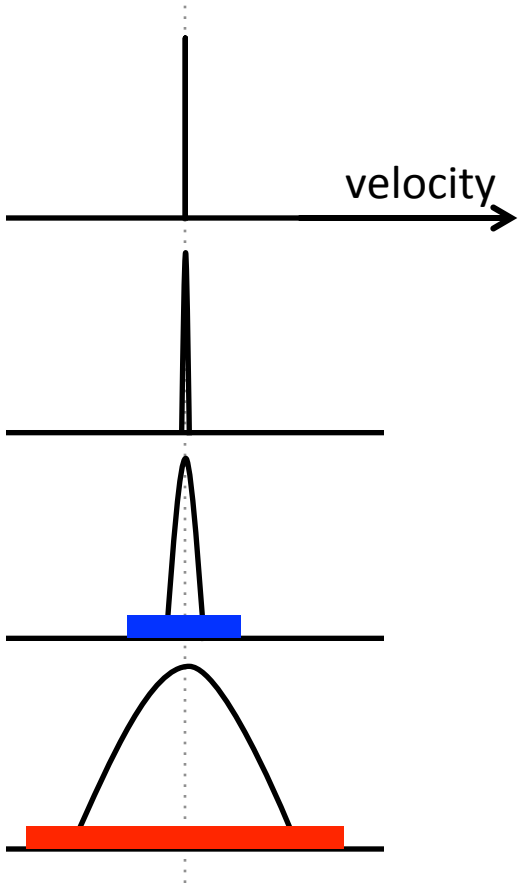

Depending on the linewidth of the line, you will cover a **narrower**/**broader** frequency (velocity) range

What do we need to know?

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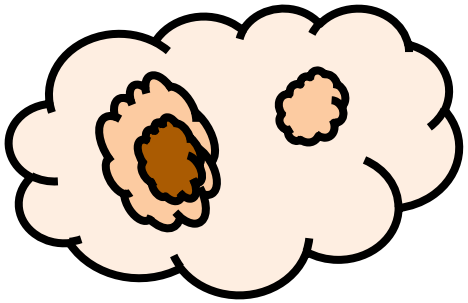
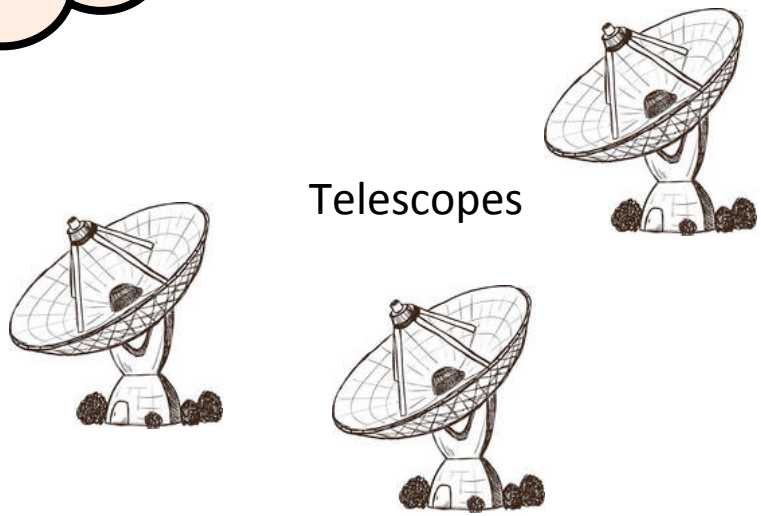
Spectral observations in a radiotelescope

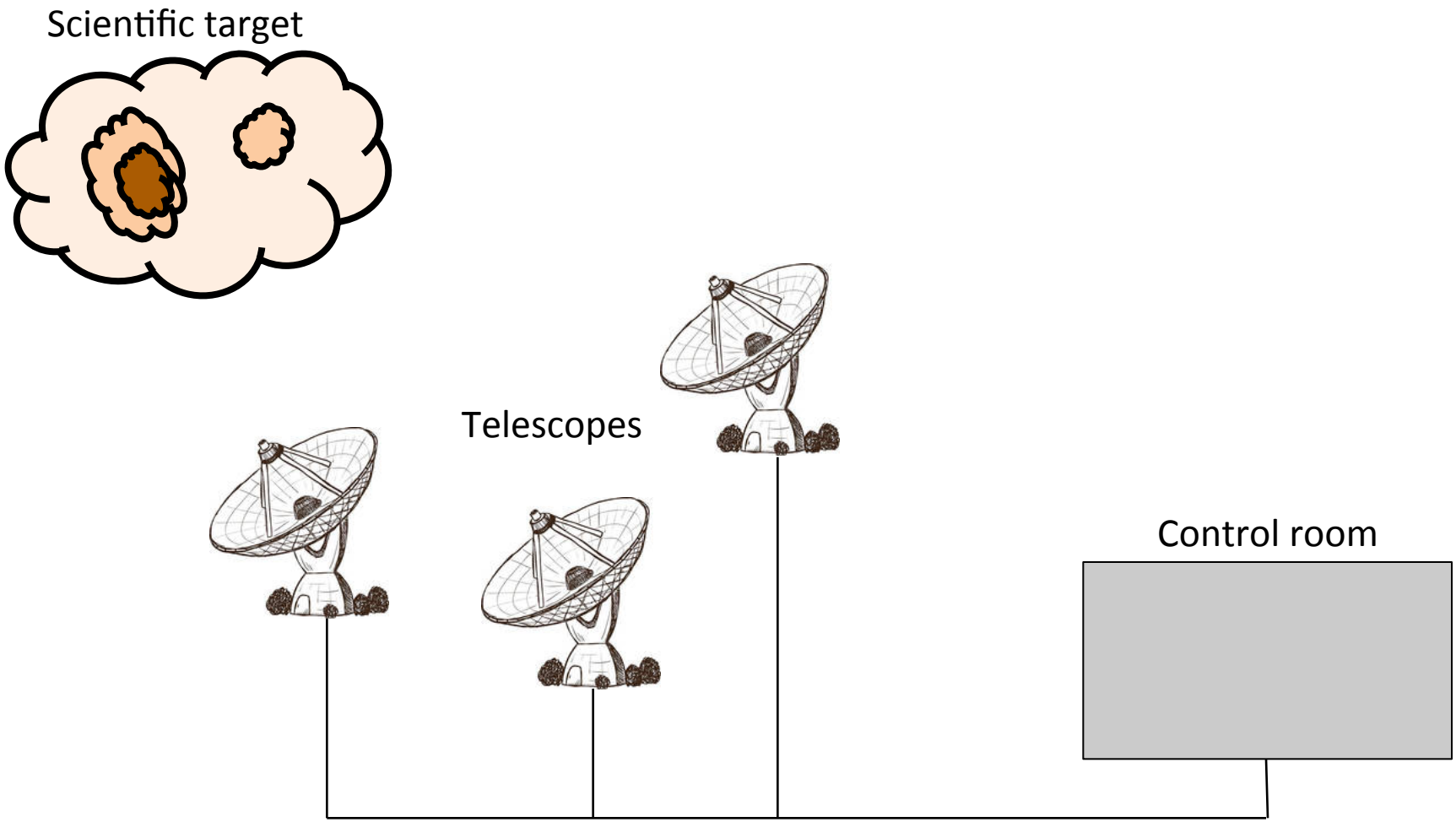
- frequency bands
- receivers
- correlator

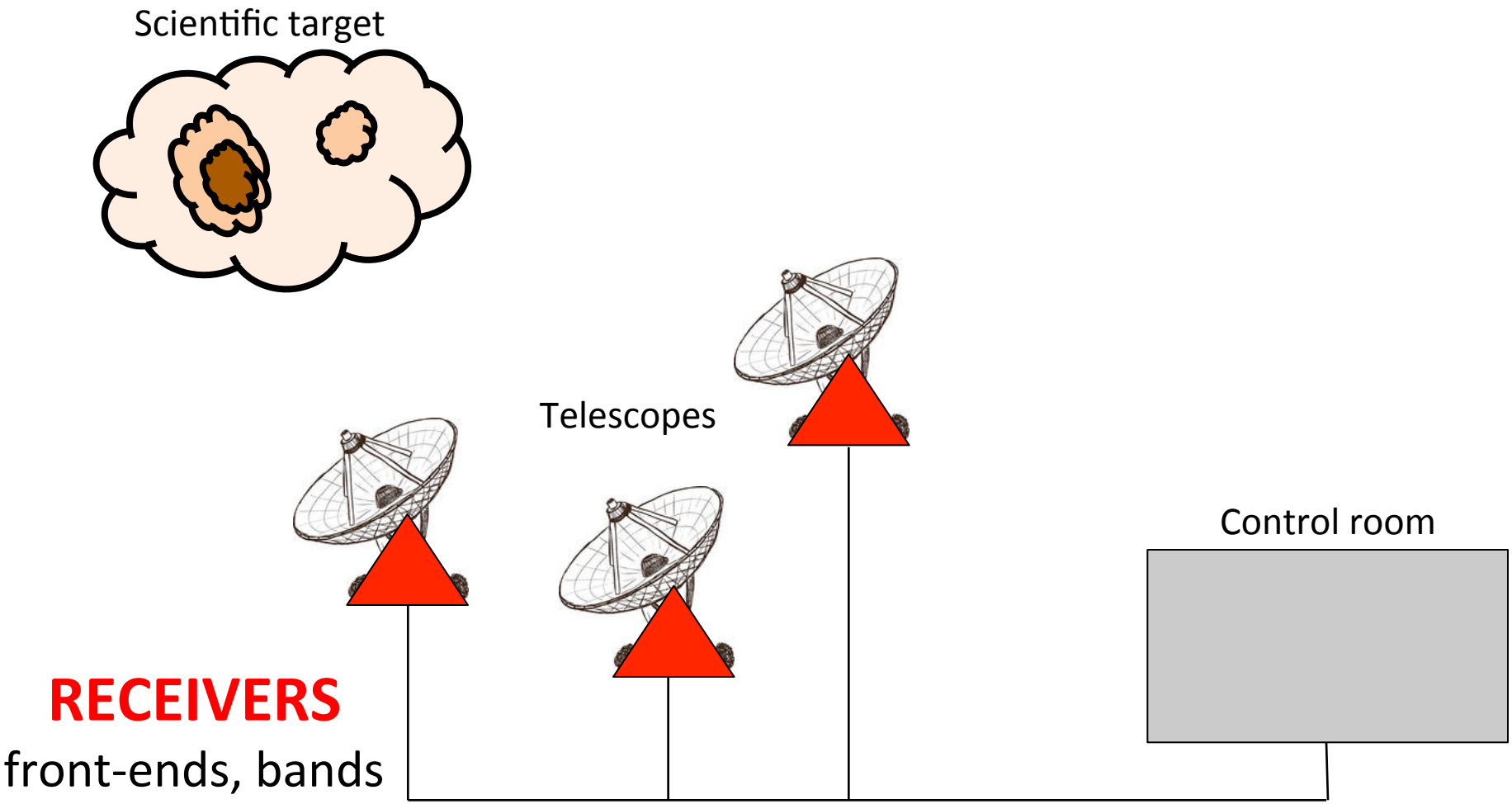
Scientific target

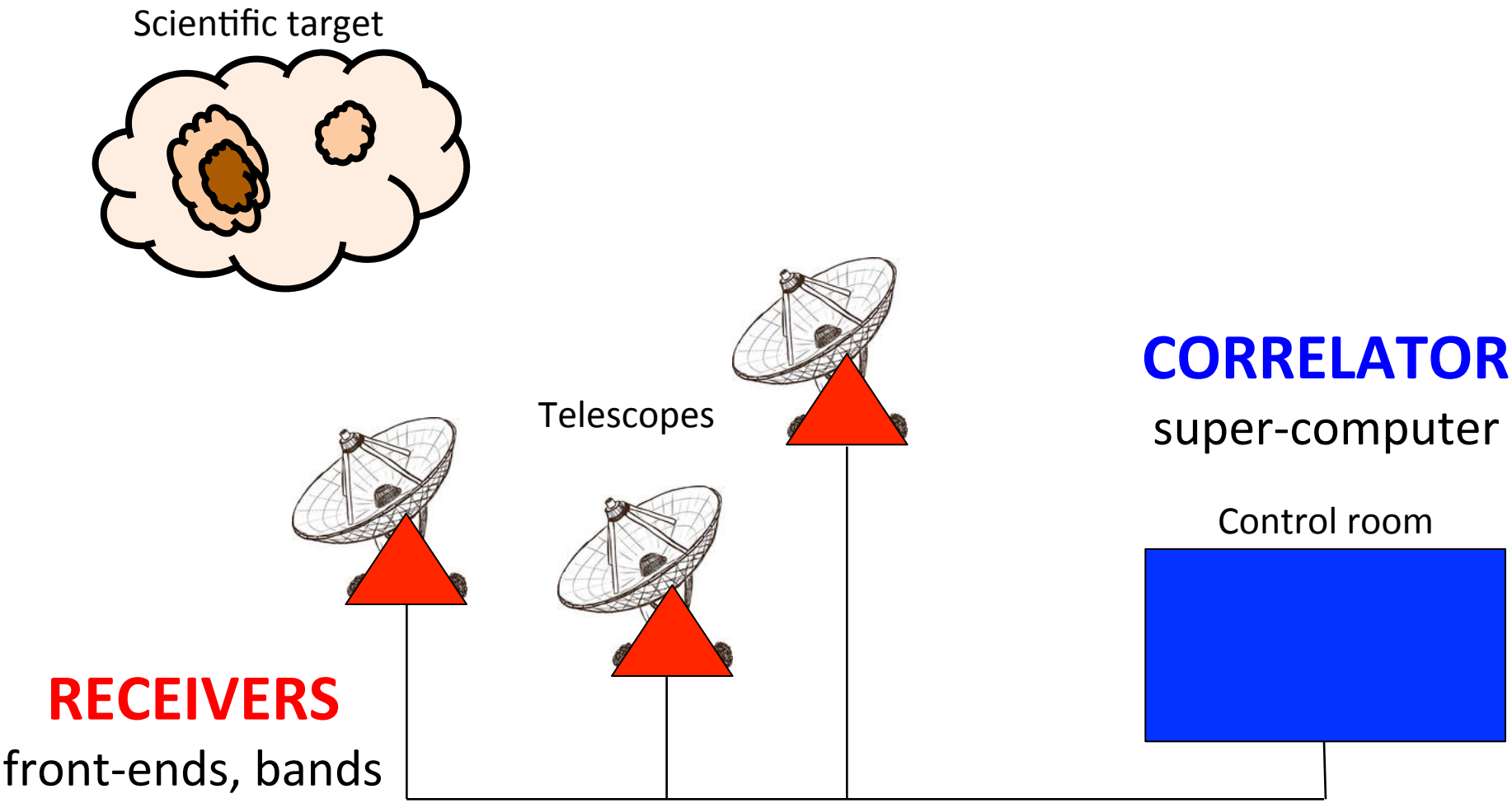


Telescopes




Scientific target
Telescopes
Control room


Scientific target
Telescopes
Control room
RECEIVERS
front-ends, bands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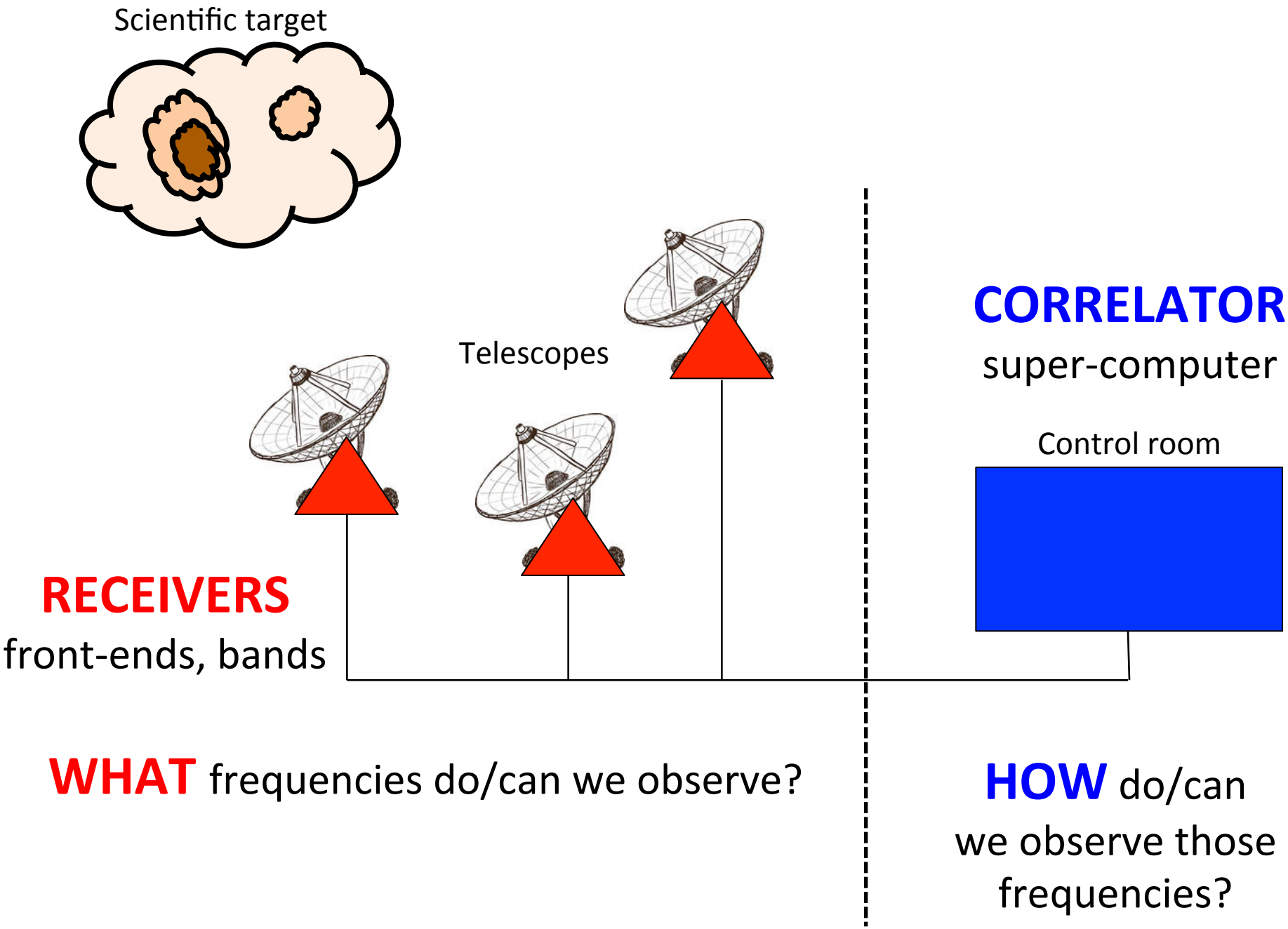
Scientific target
Telescopes
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front-ends, bands
WHAT frequencies do/can we observe?
HOW do/can we observe those frequencies?

What do we need to know?

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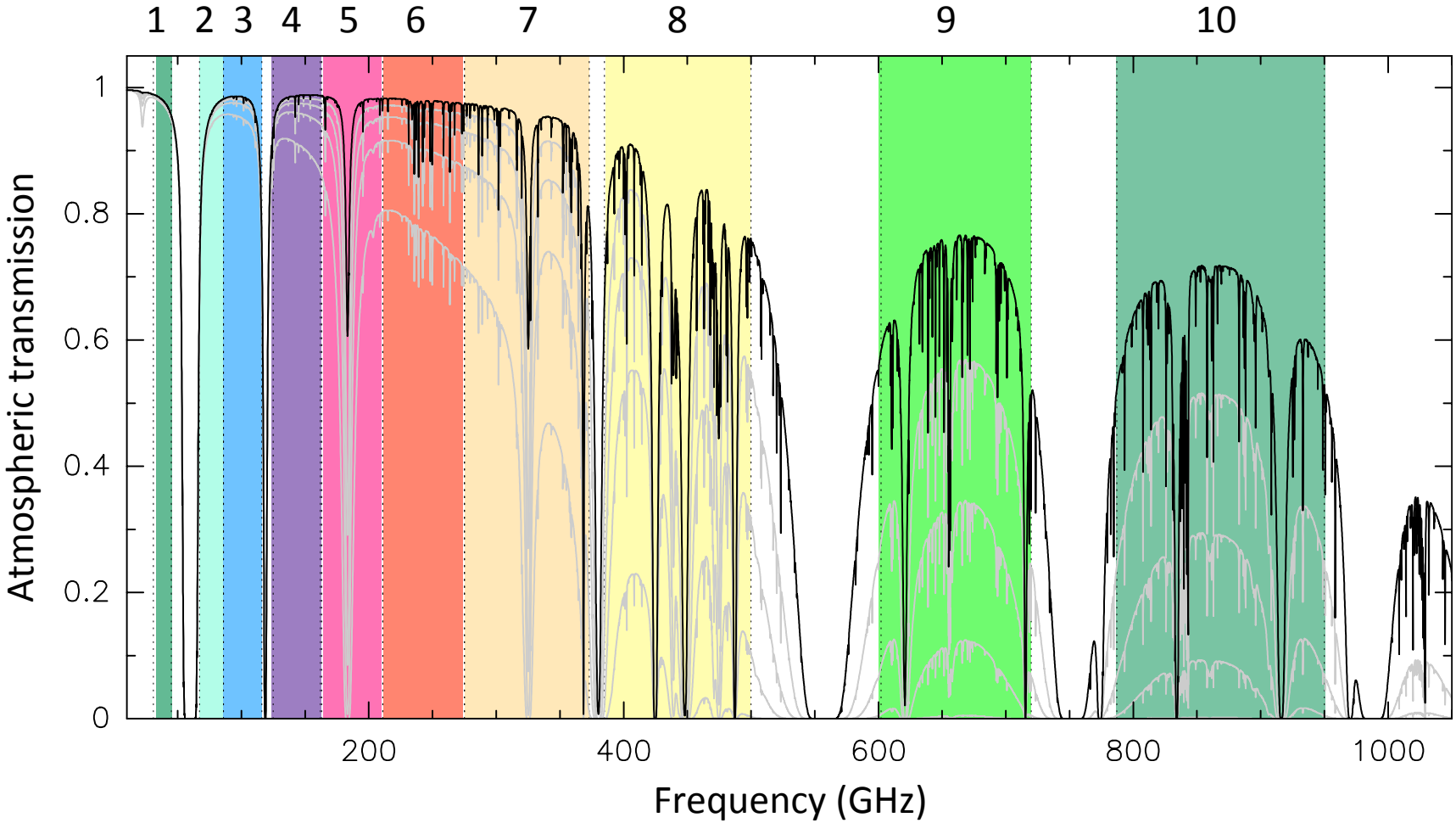
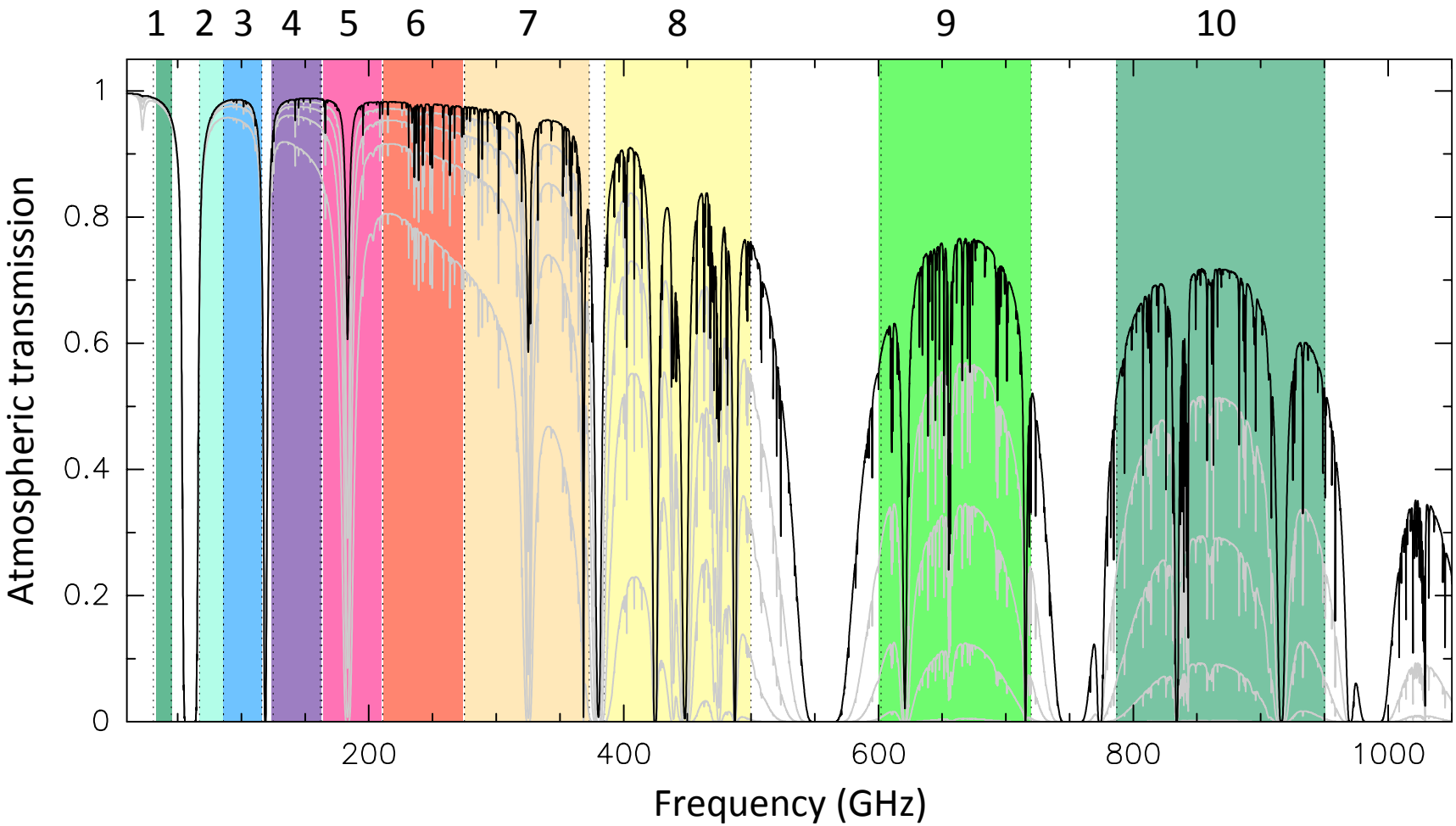
Spectral observations in a radiotelescope

- **frequency bands**
- receivers
- spectral resolution (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 radiotelescope

- frequency bands
- **receivers**
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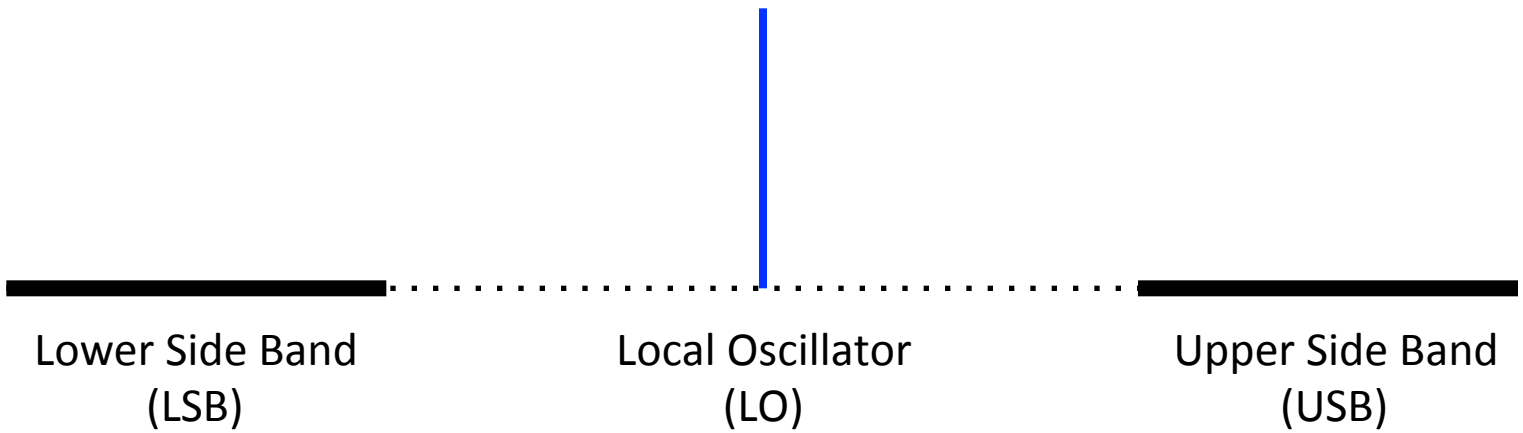
ALMA receivers

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



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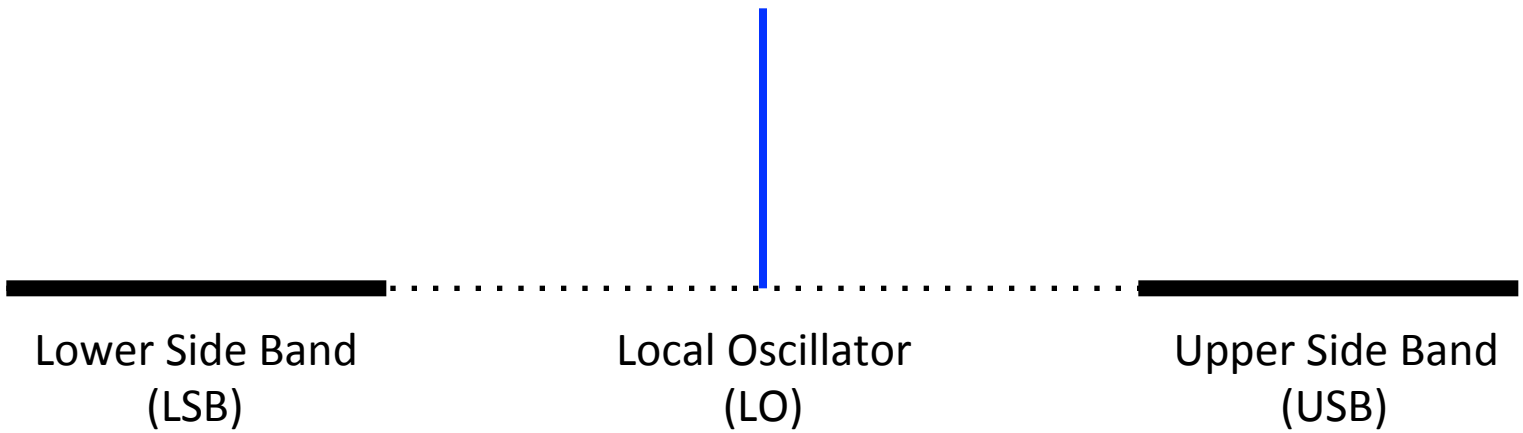
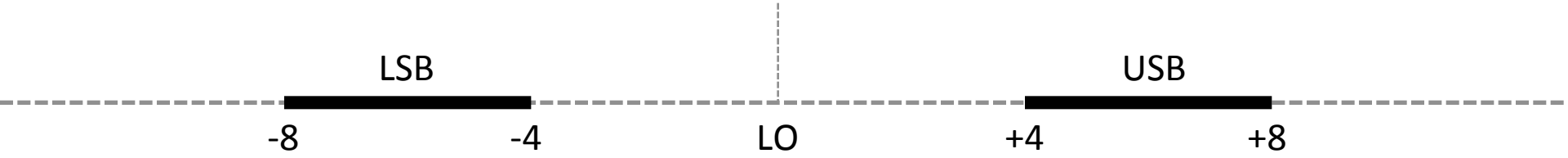


Heterodyne receivers can be:

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



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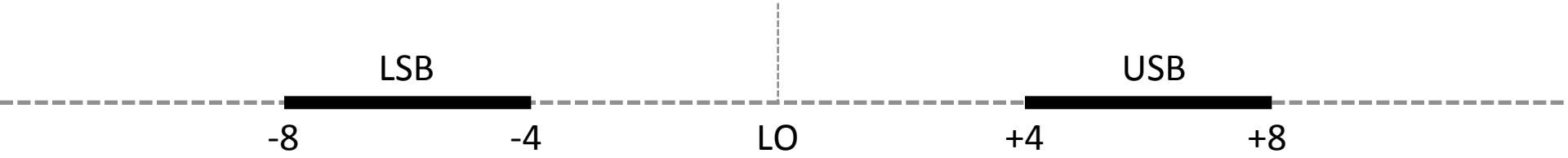
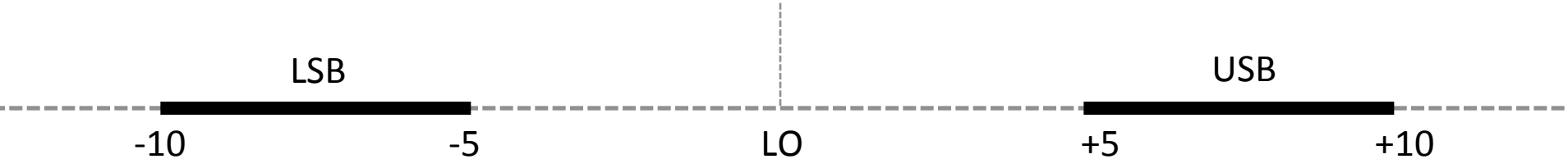


ALMA B6 2SB receivers 5-10 GHz



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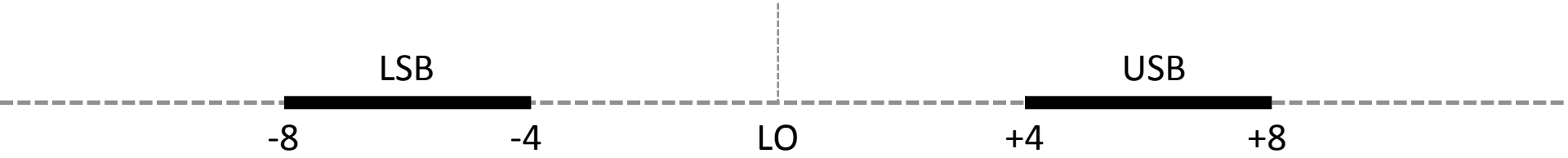

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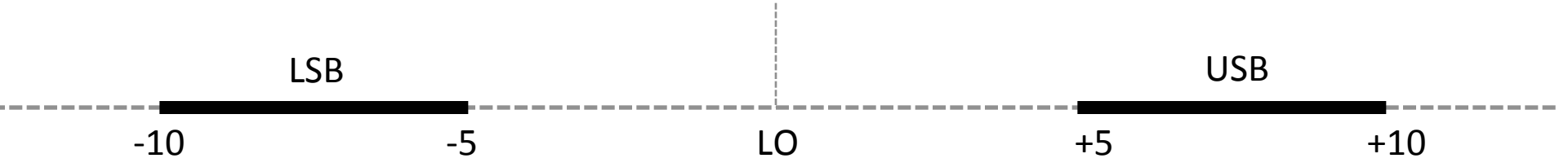
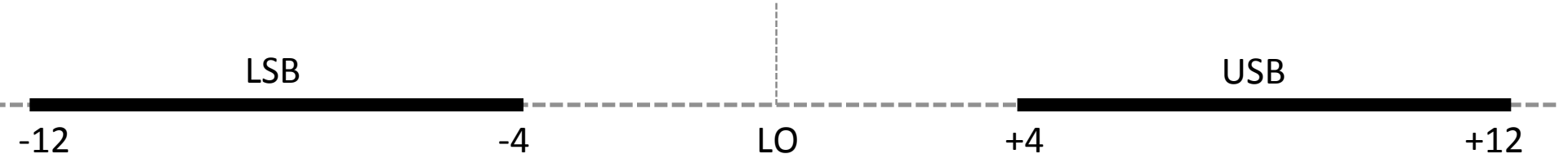


ALMA B9 / B10 DSB receivers 4-12 GHz



ALMA frequency bands & receivers

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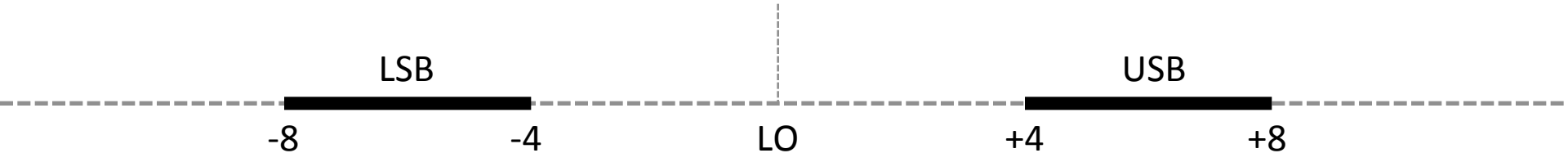

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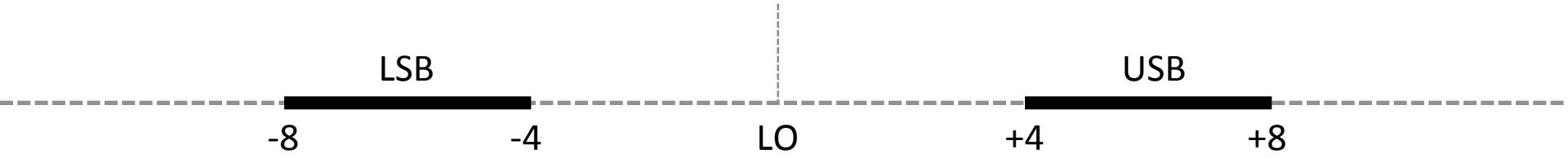

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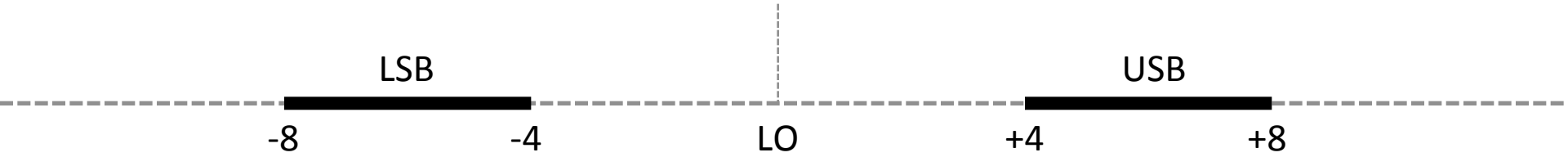

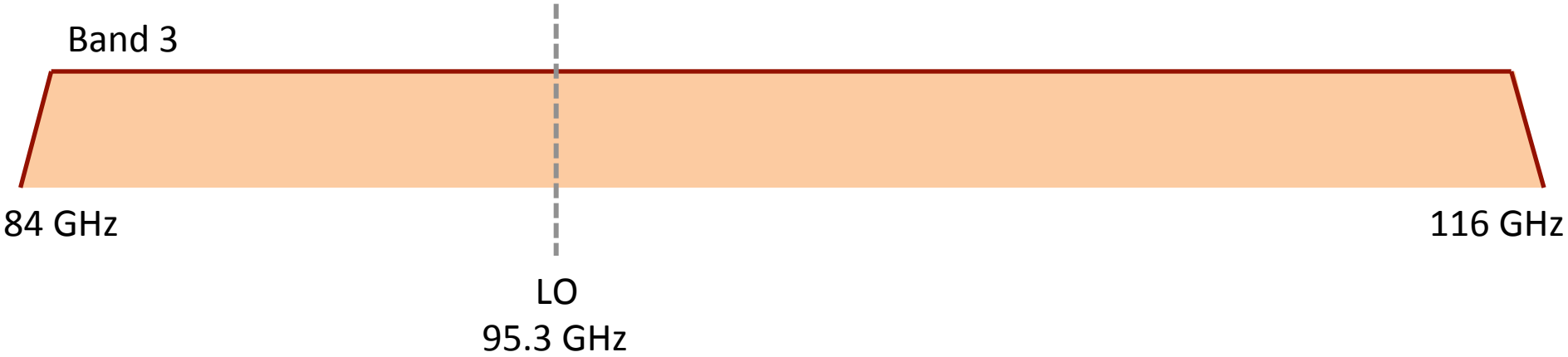

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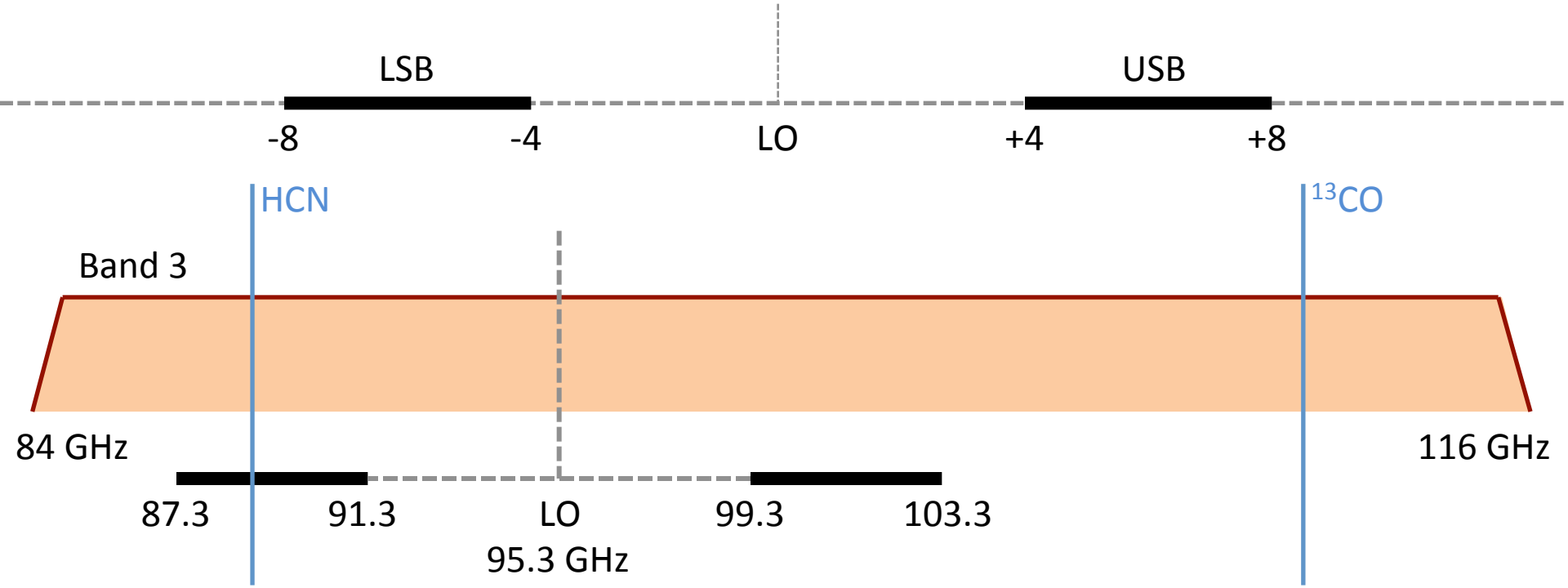

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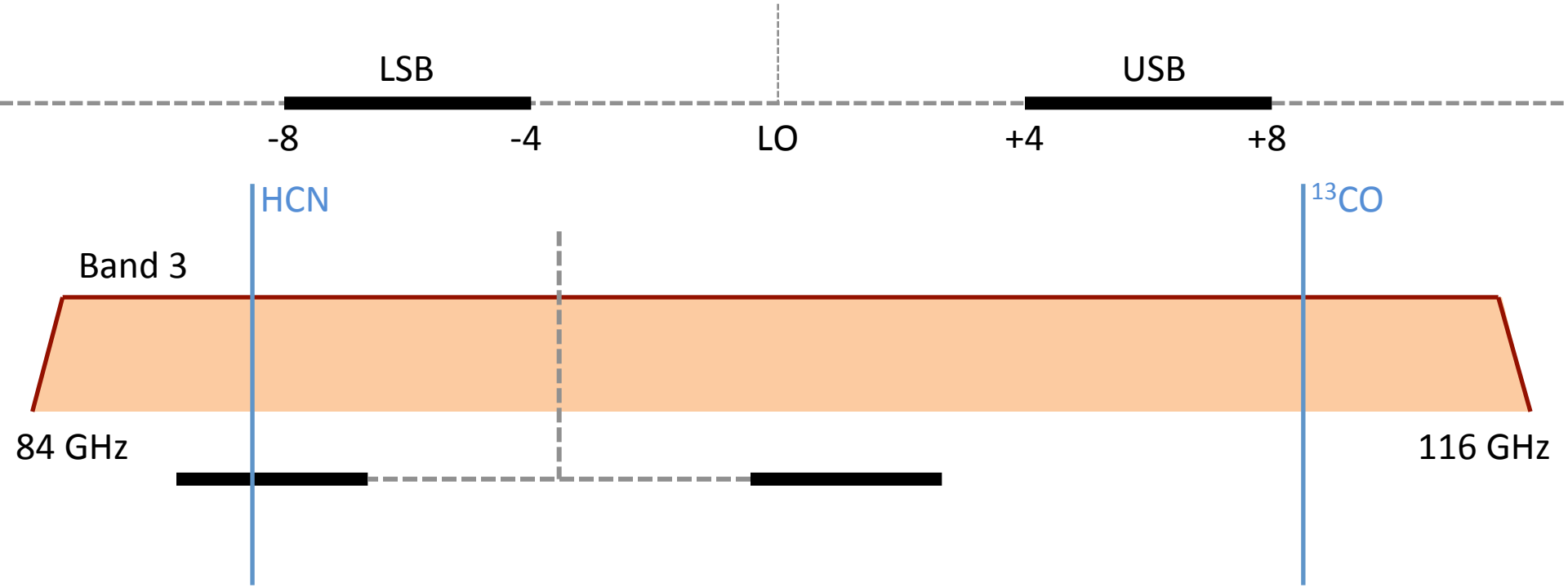
ALMA B3 / B4 / B5 / B7 / B8 2SB receivers 4-8 GHz



ALMA frequency bands & receivers

Band 3:	84 – 116 GHz	Band 7:	275 – 373 GHz
Band 4:	125 – 163 GHz	Band 8:	385 – 500 GHz
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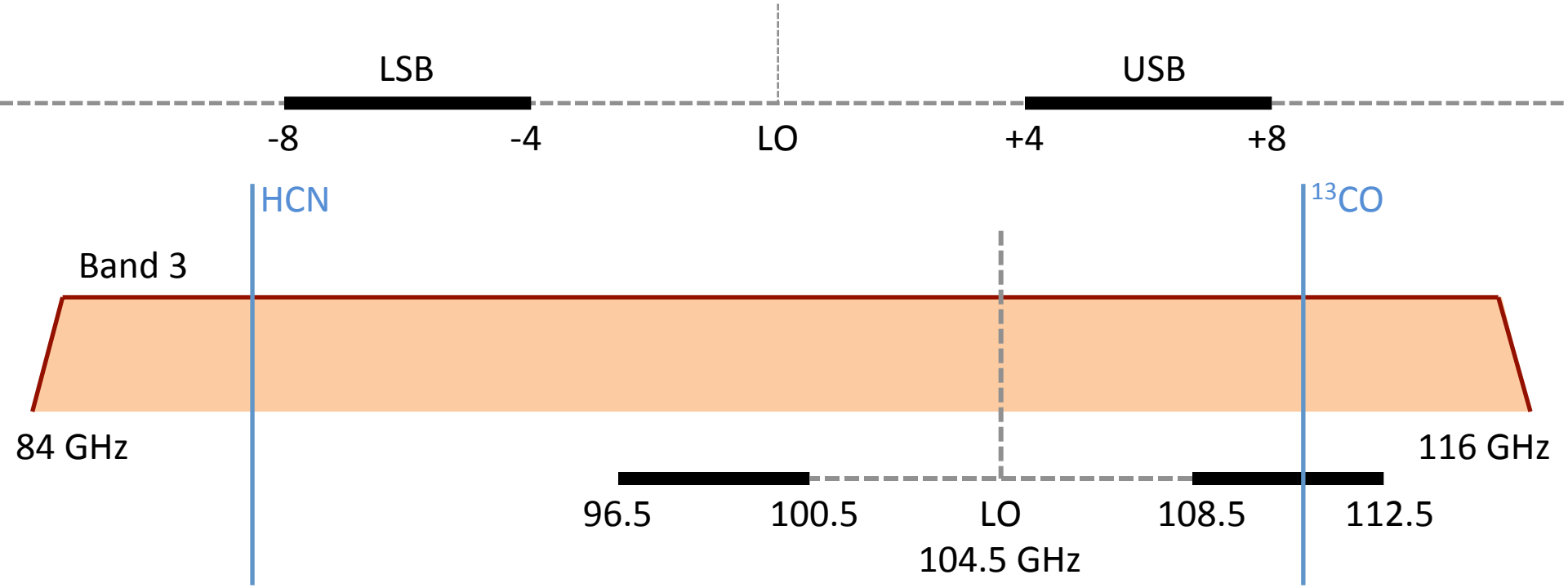
ALMA B3 / B4 / B5 / B7 / B8 2SB receivers 4-8 GHz



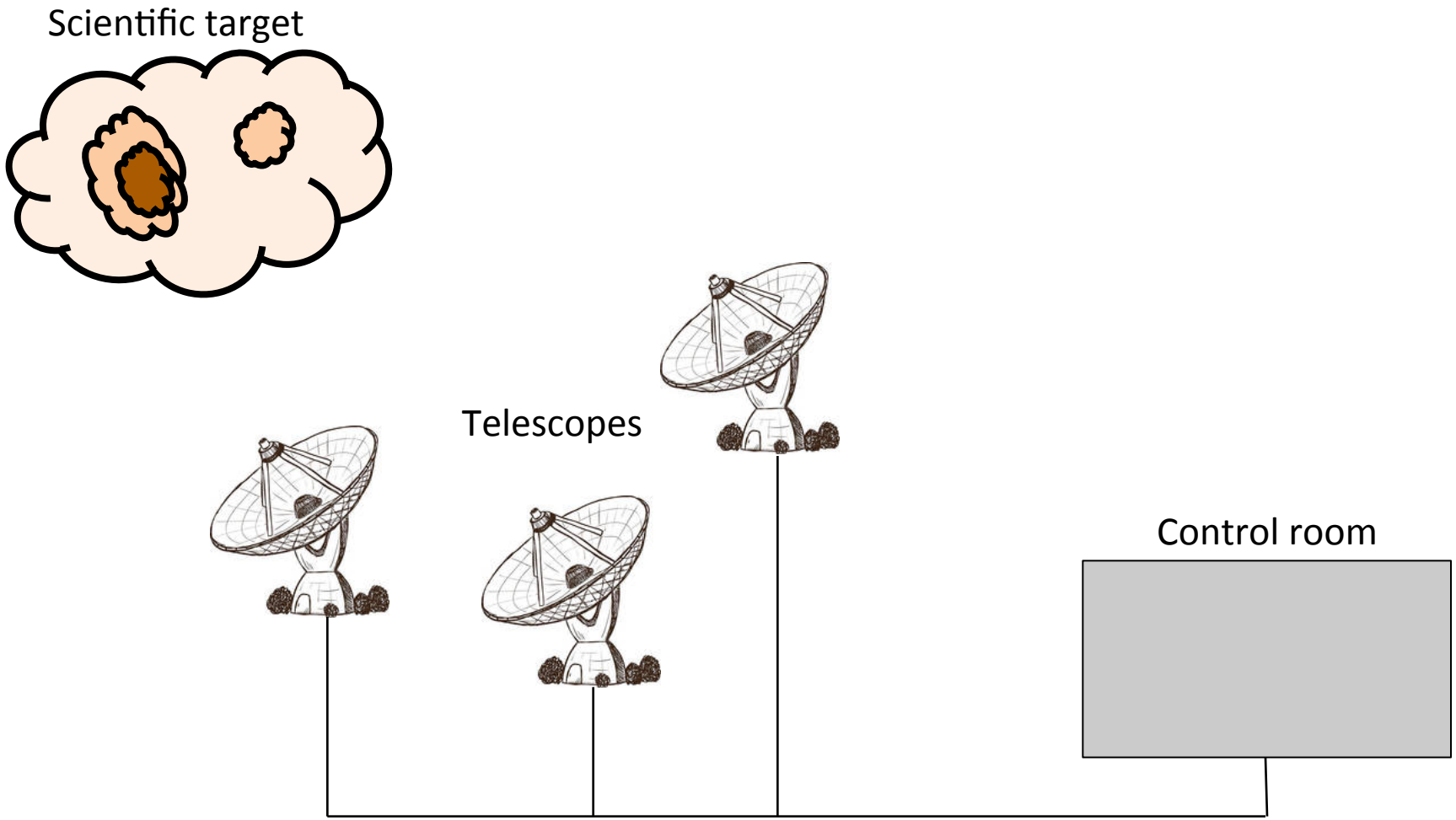
What do we need to know?

- frequency of the lines to observe
- velocity /redshift of the source
- line shape / velocity coverage and resolution
- …

Spectral observations in a radiotelescope

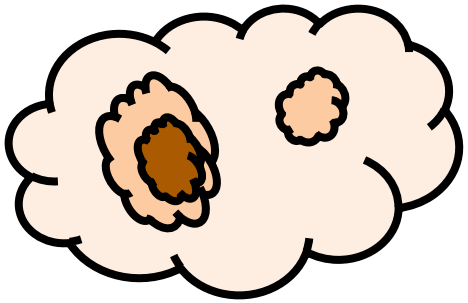
- frequency bands
- receivers
- **spectral resolution (correlator)**

ALMA correlator



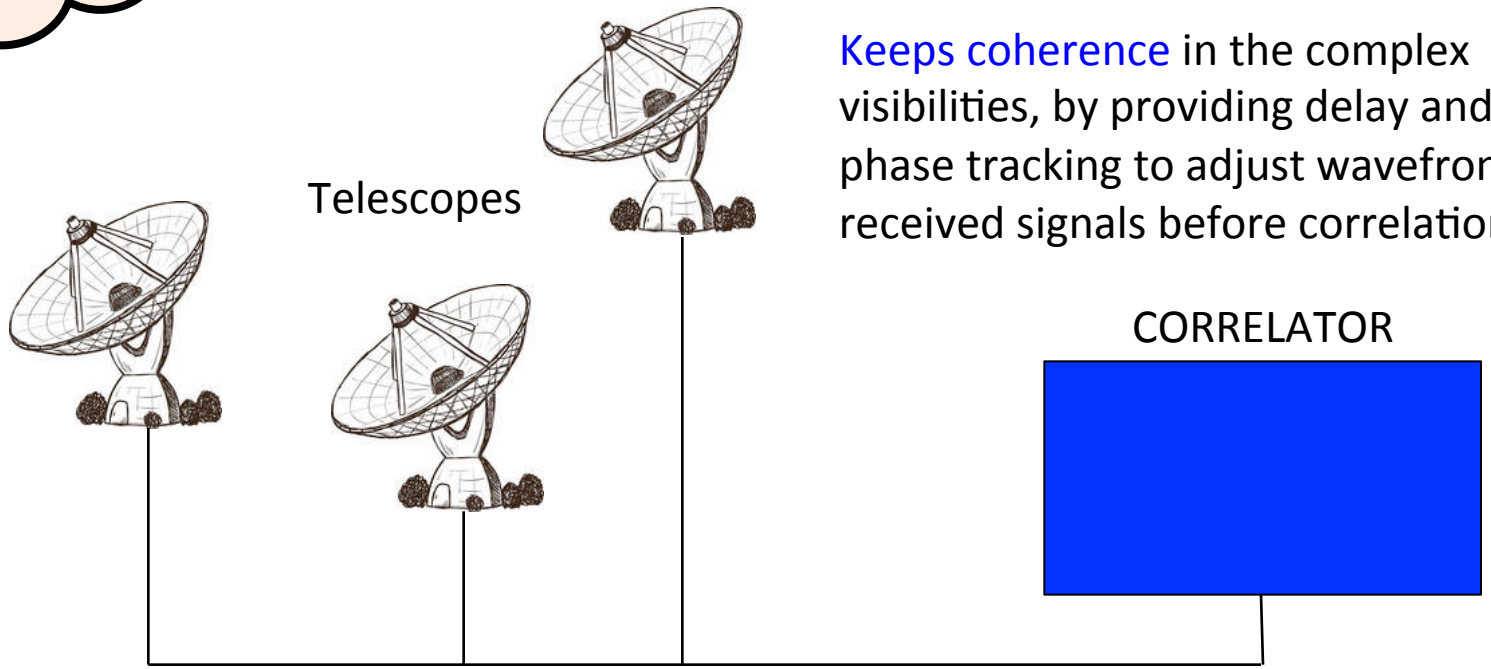
ALMA correlator

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.



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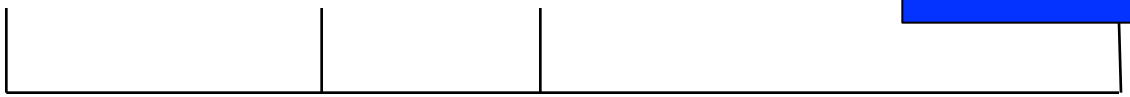
CORRELATOR

ALMA CORRELATOR:
one of the four 'quadrants' of the ALMA correlator



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

basebands

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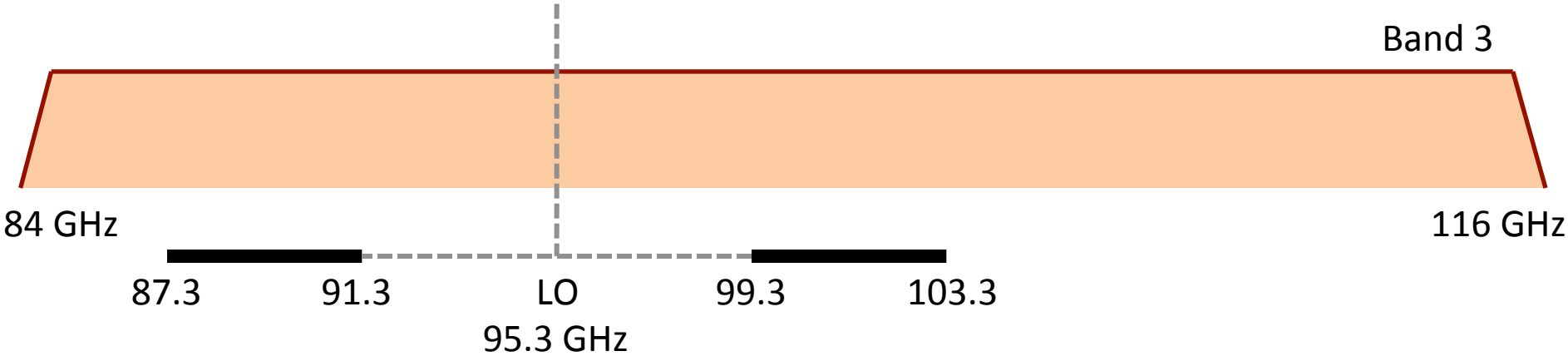

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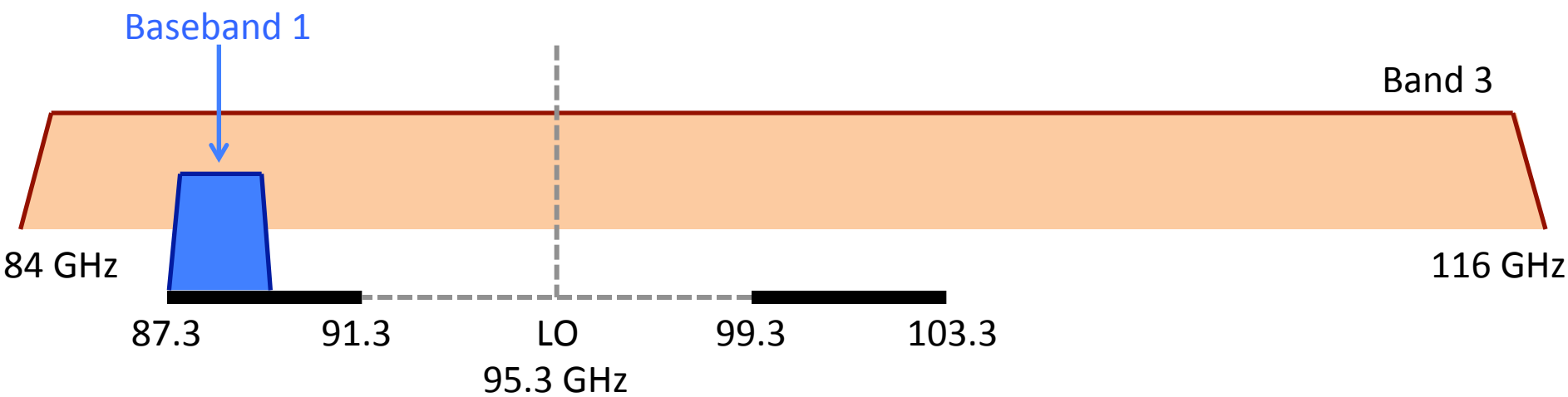

ALMA correlator / **4 basebands**

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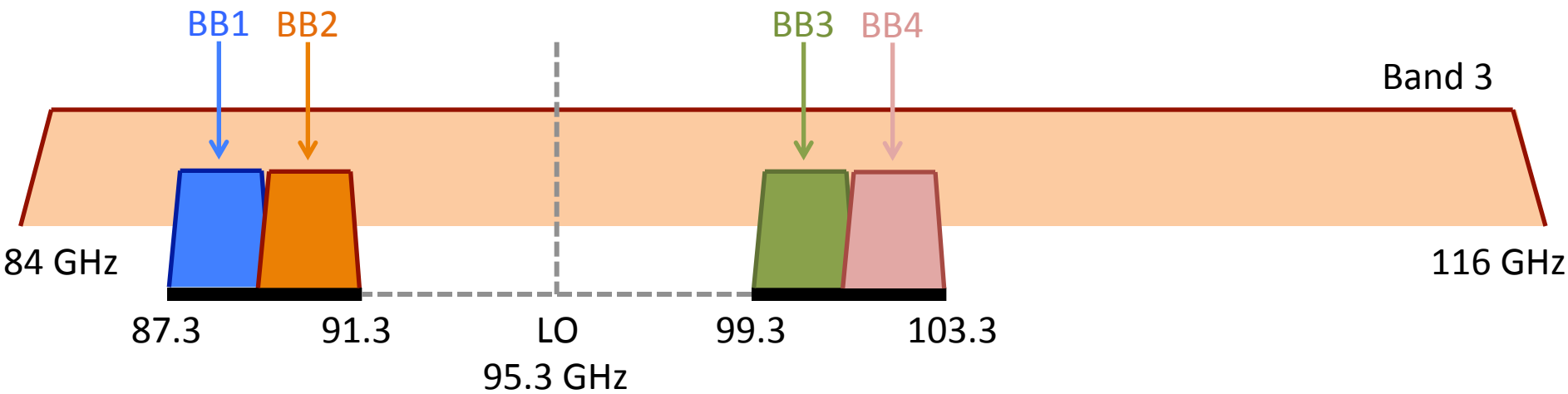

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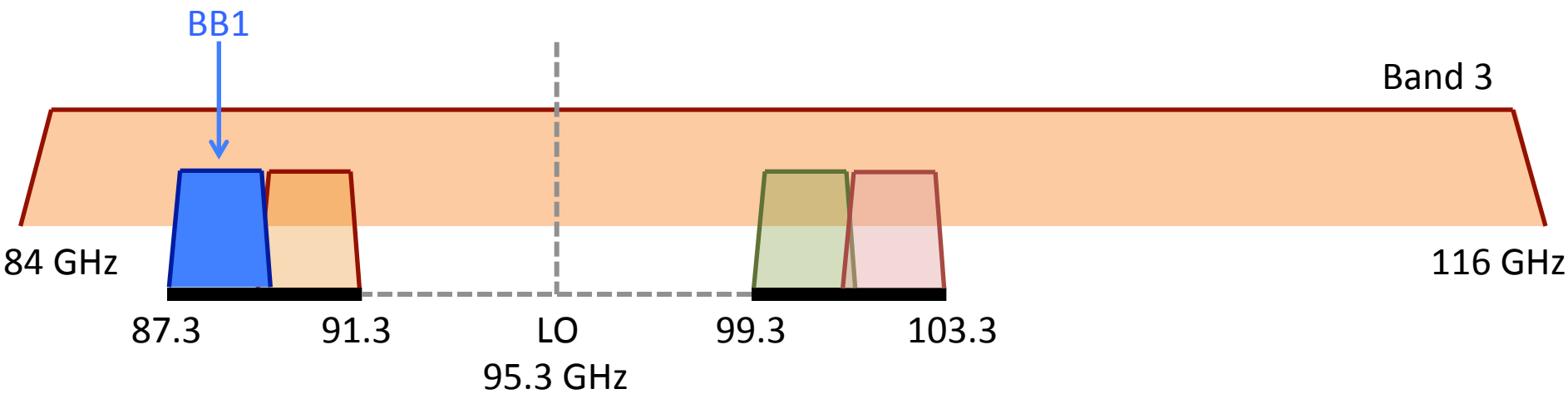

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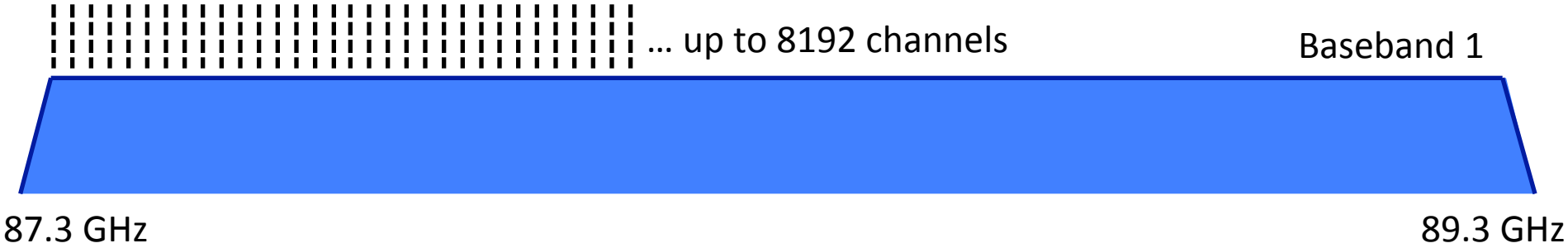


ALMA correlator / **4 basebands**

basebands

information from 64 antennas

2 GHz input

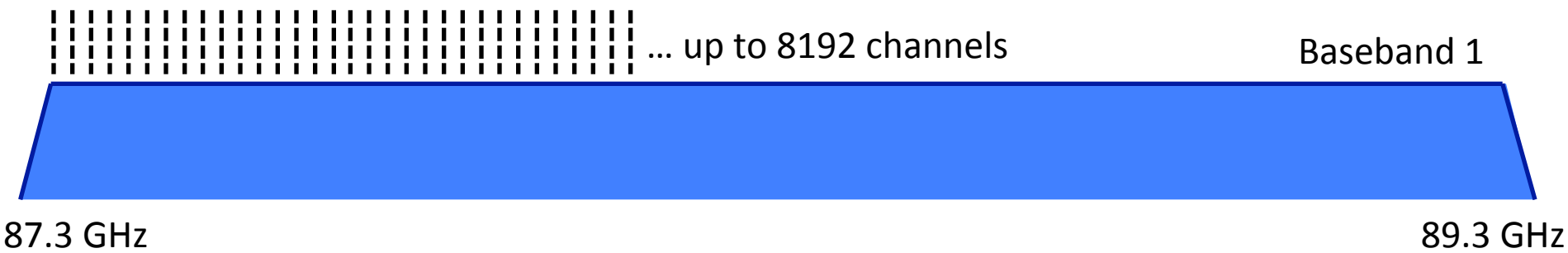
up to **8192 channels**

2 polarizations Horizontal / Vertical

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

channel width (**spectral resolution**):

2 GHz / 8192 = 244 kHz



ALMA correlator / **4 basebands**

basebands

information from 64 antennas

2 GHz input

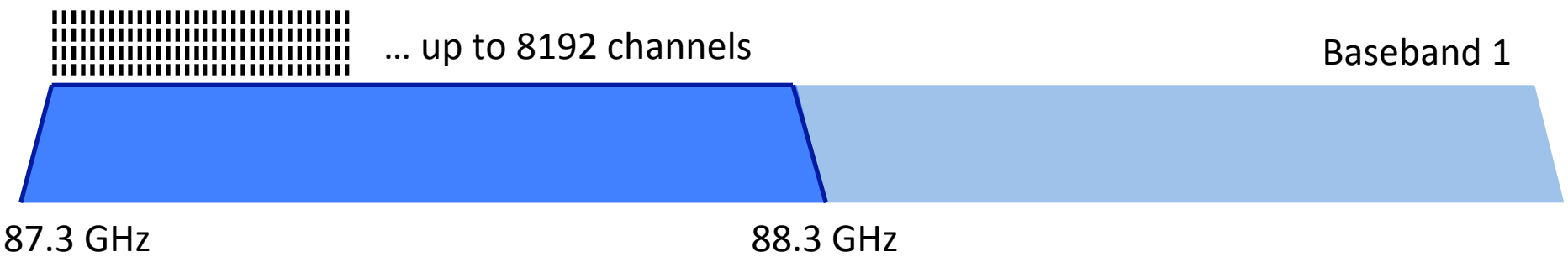
up to **8192 channels**

2 polarizations Horizontal / Vertical

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

channel width (**spectral resolution**):

1 GHz / 8192 = 122 kHz



ALMA correlator / **4 basebands**

basebands

information from 64 antennas

2 GHz input

up to **8192 channels**

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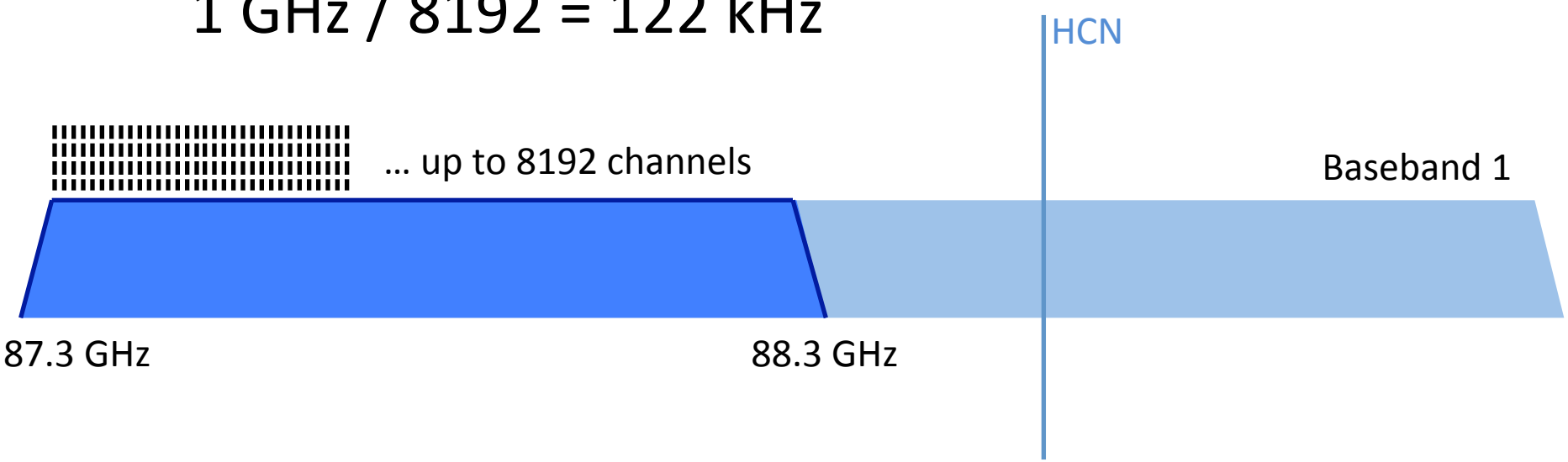


ALMA correlator / **4 basebands**

basebands

information from 64 antennas

2 GHz input

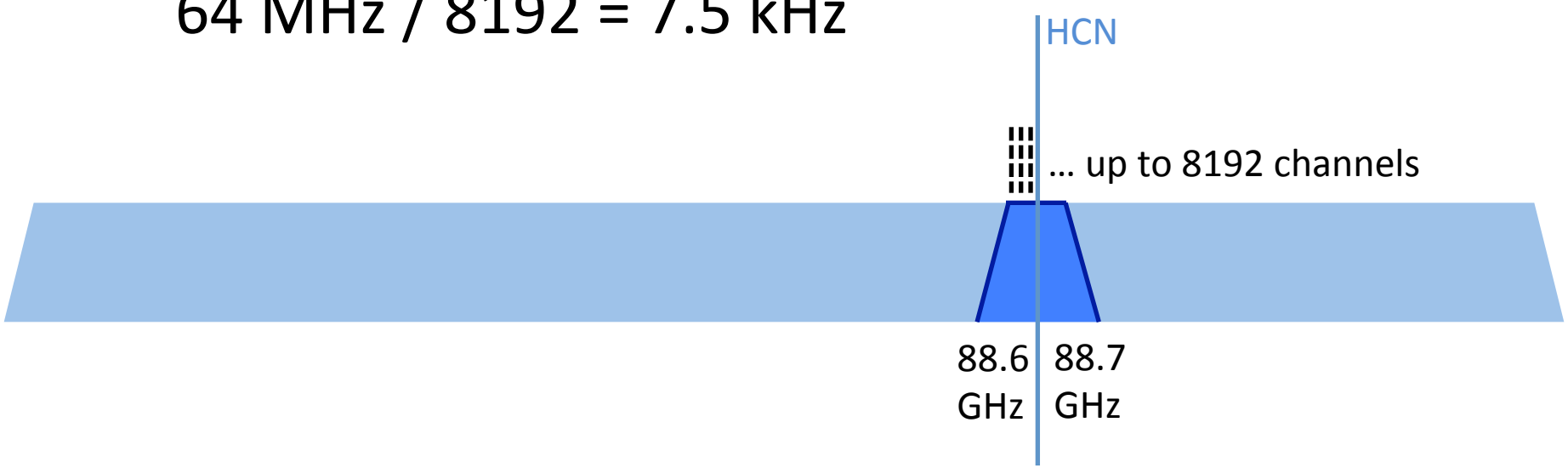
up to **8192 channels**

2 polarizations Horizontal / Vertical

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

channel width (**spectral resolution**):

64 MHz / 8192 = 7.5 kHz



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.
BW	500 MHz	8192 channels x 1 polz	61 kHz resol.
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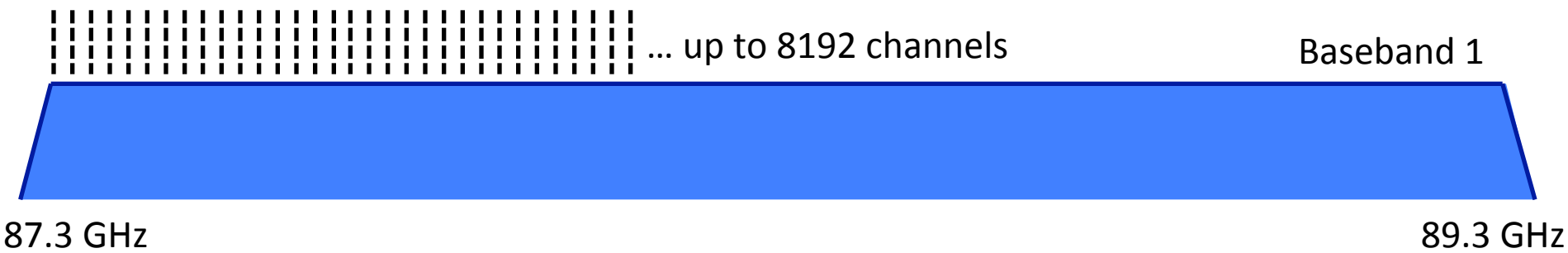
BW	32 MHz	8192 channels x 1 polz	3.8 kHz resol.
continuum mode		256 channels x 1 polz	7.5 MHz resol.



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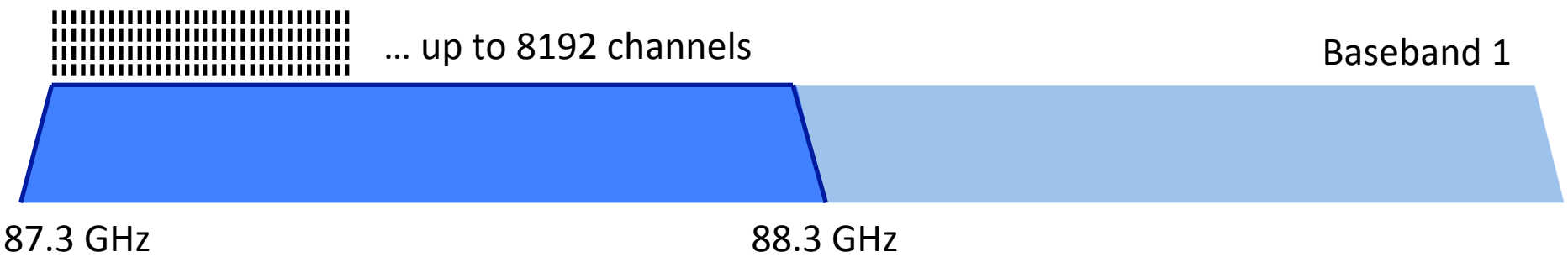
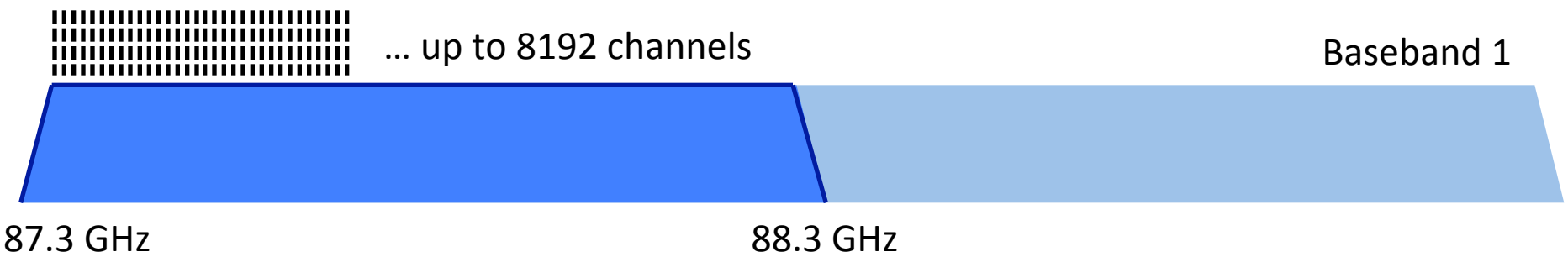
continuum mode		256 channels x 1 polz	7.5 MHz resol.



ALMA correlator

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

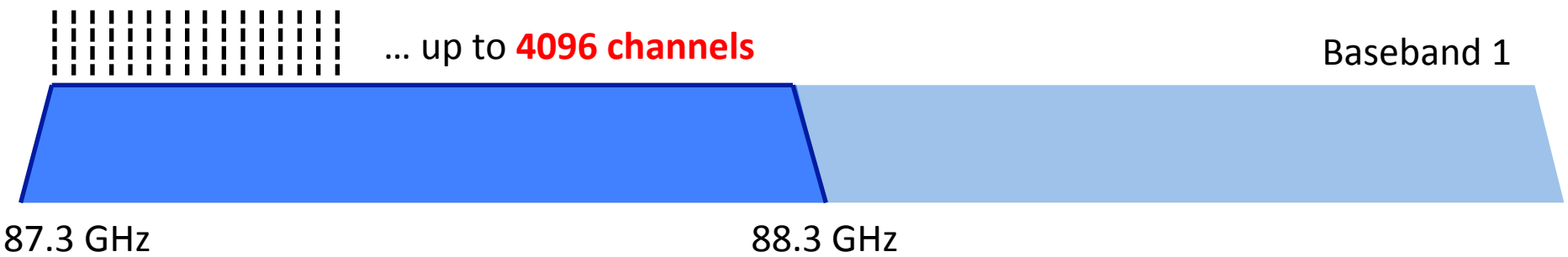
BW	2 GHz	8192 channels x 1 polz	244 kHz resol.
BW	1 GHz	8192 channels x 1 polz	122 kHz resol.
BW	500 MHz	8192 channels x 1 polz	61 kHz resol.
BW	250 MHz	8192 channels x 1 polz	30 kHz resol.
BW	125 MHz	8192 channels x 1 polz	15 kHz resol.
BW	64 MHz	8192 channels x 1 polz	7.5 kHz resol.
BW	32 MHz	8192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



ALMA correlator

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

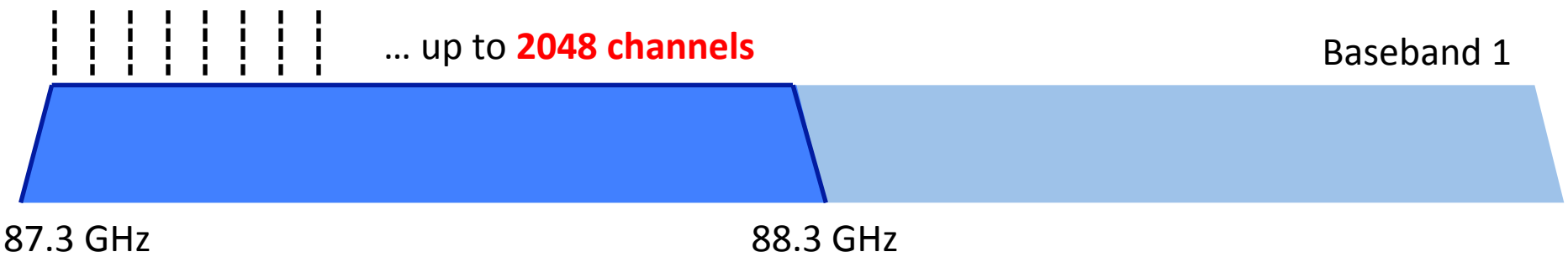
BW	2 GHz	4096 channels x 2 polz	488 kHz resol.
BW	1 GHz	4096 channels x 2 polz	244 kHz resol.
BW	500 MHz	4096 channels x 2 polz	122 kHz resol.
BW	250 MHz	4096 channels x 2 polz	61 kHz resol.
BW	125 MHz	4096 channels x 2 polz	30 kHz resol.
BW	64 MHz	4096 channels x 2 polz	15 kHz resol.
BW	32 MHz	4096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

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

the four are necessary for polarization studies

ALMA correlator

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

the four are necessary for polarization studies

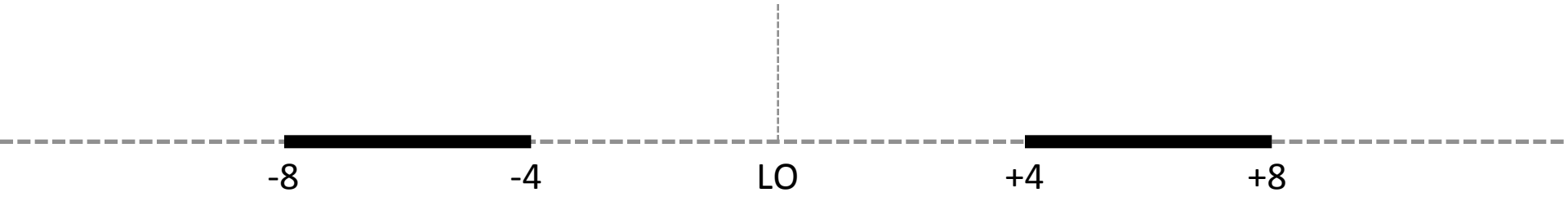
message to take home …

	polarization	sensitivity	spectral resolution
1 polz product (HH **or** VV)			
2 polz products (HH **and** VV)			
4 polz products (HH, VV, HV, VH)			

ALMA correlator (examples)

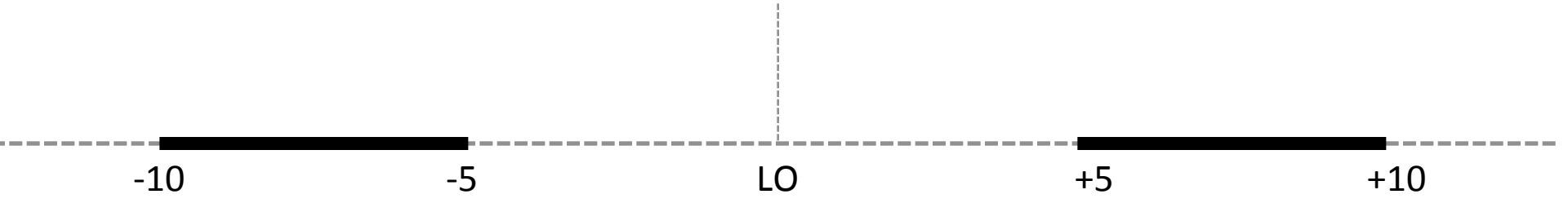
ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



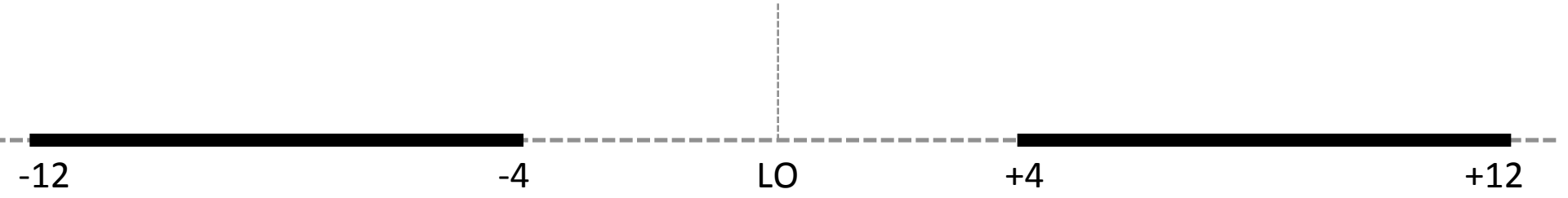
ALMA B6

2SB receivers 5-10 GHz



ALMA B9 / B10

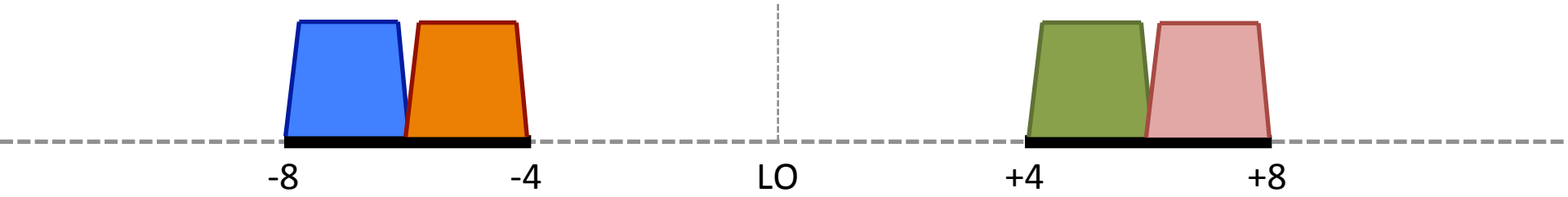
DSB receivers 4-12 GHz



ALMA correlator (examples)

ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



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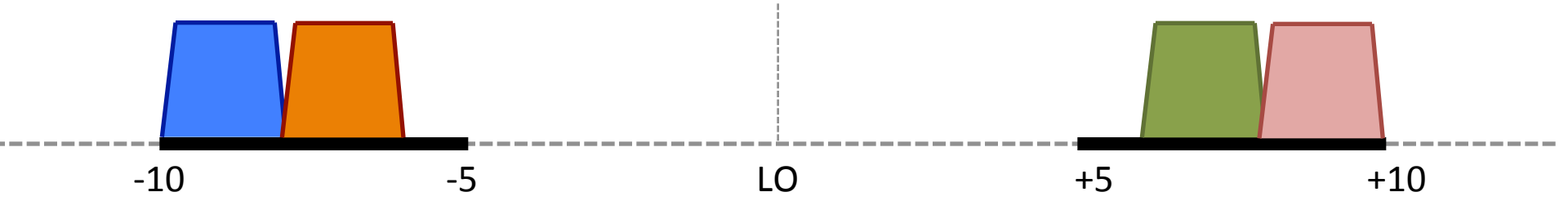
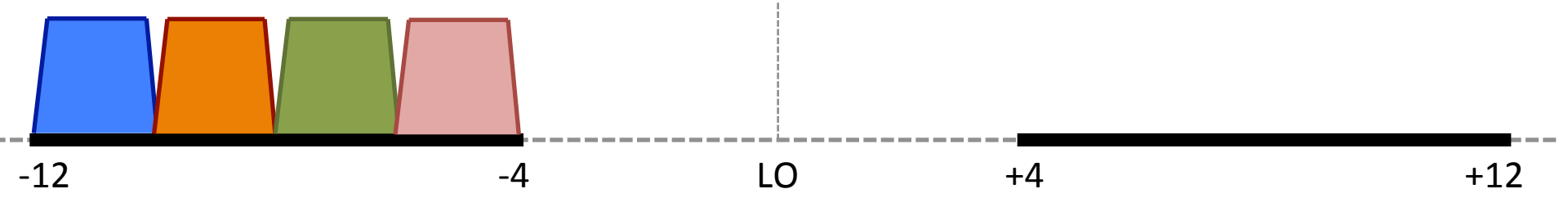
2SB receivers 5-10 GHz



ALMA B9 / B10

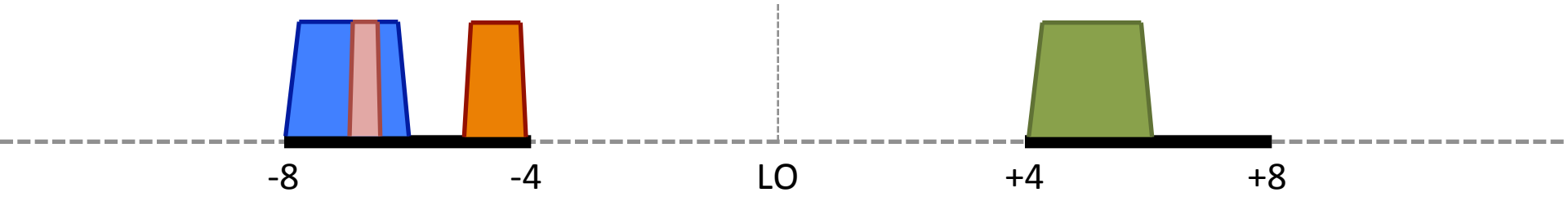
DSB receivers 4-12 GHz



ALMA correlator (examples)

ALMA B3 / B4 / B5 / B7 / B8

2SB receivers 4-8 GHz



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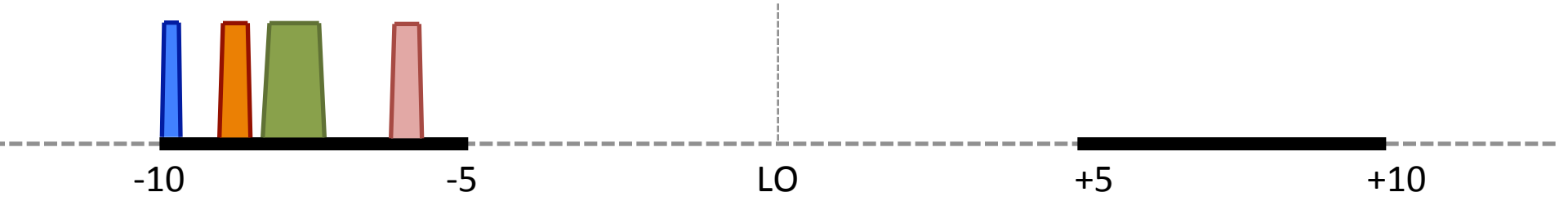

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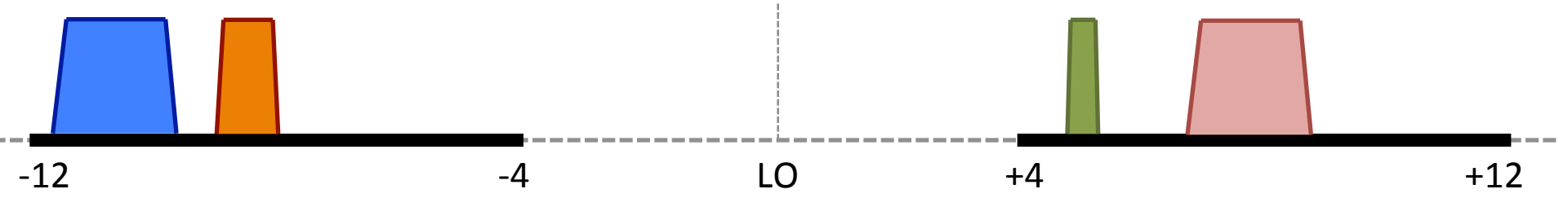

Key concepts that we have learned

Part 2

- Spectral lines
- Rest frequency
- Source velocity and redshift
- Line width
- Spectral resolution

Questions?

Contact us at arc@astro.uni-bonn.de

Argelander-Institut für Astronomie

ALMA

EUROPEAN ARC
ALMA Regional Centre || Germany

ph1 Universität zu Köln