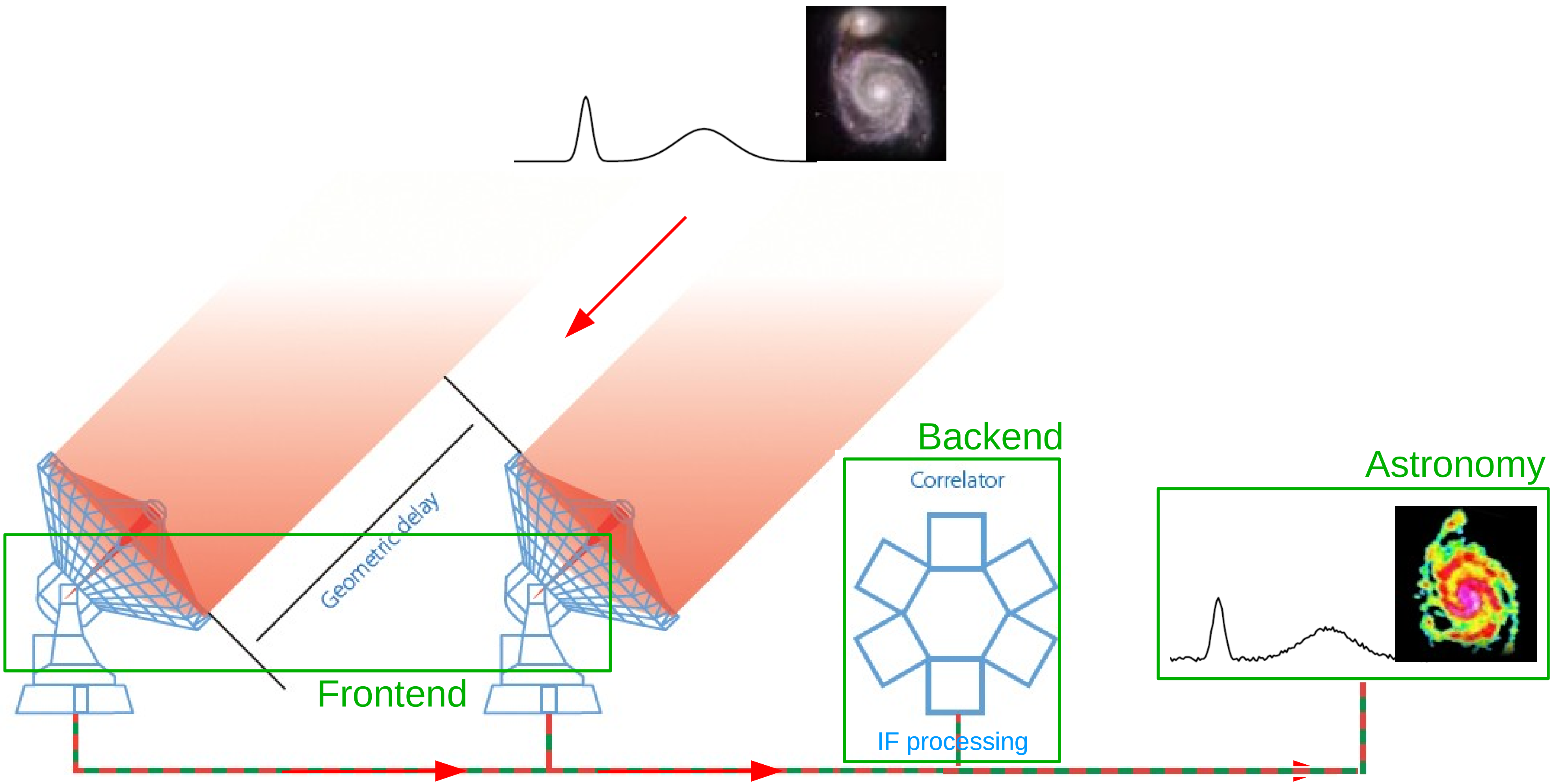
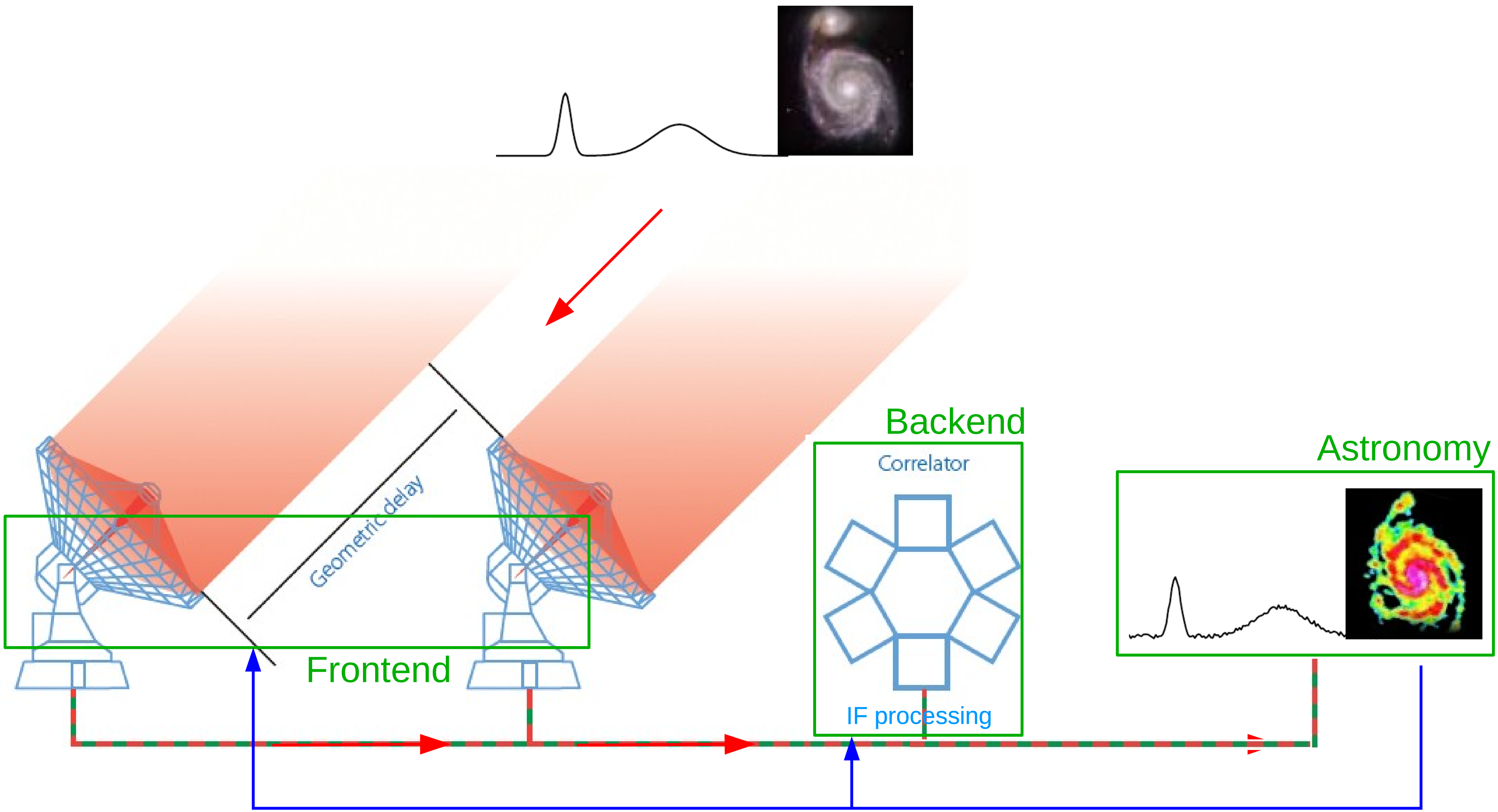
NOEMA spectral setups

Jeremie Boissier

Overview


Geometric delay
Frontend
Backend
Correlator
IF processing
Astronomy

Overview



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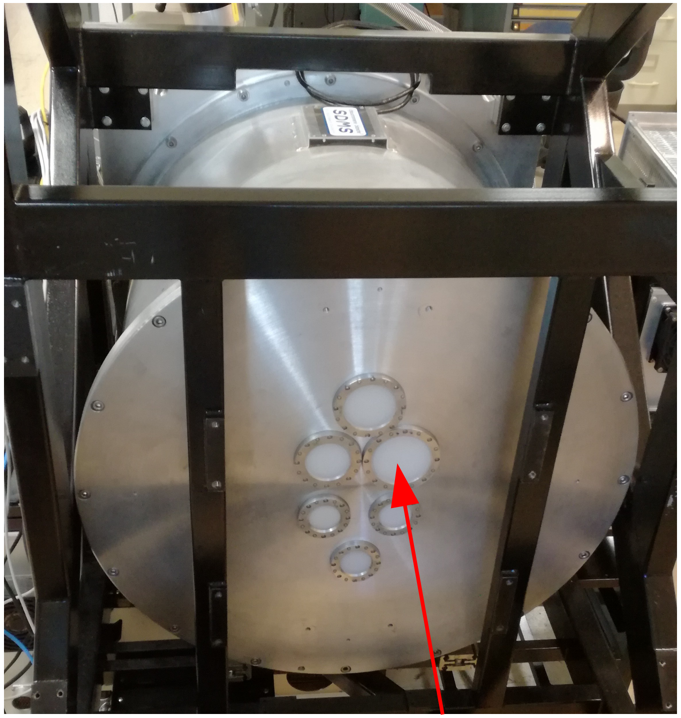
NOEMA receivers

NOEMA antennas are equipped with heterodyne receivers

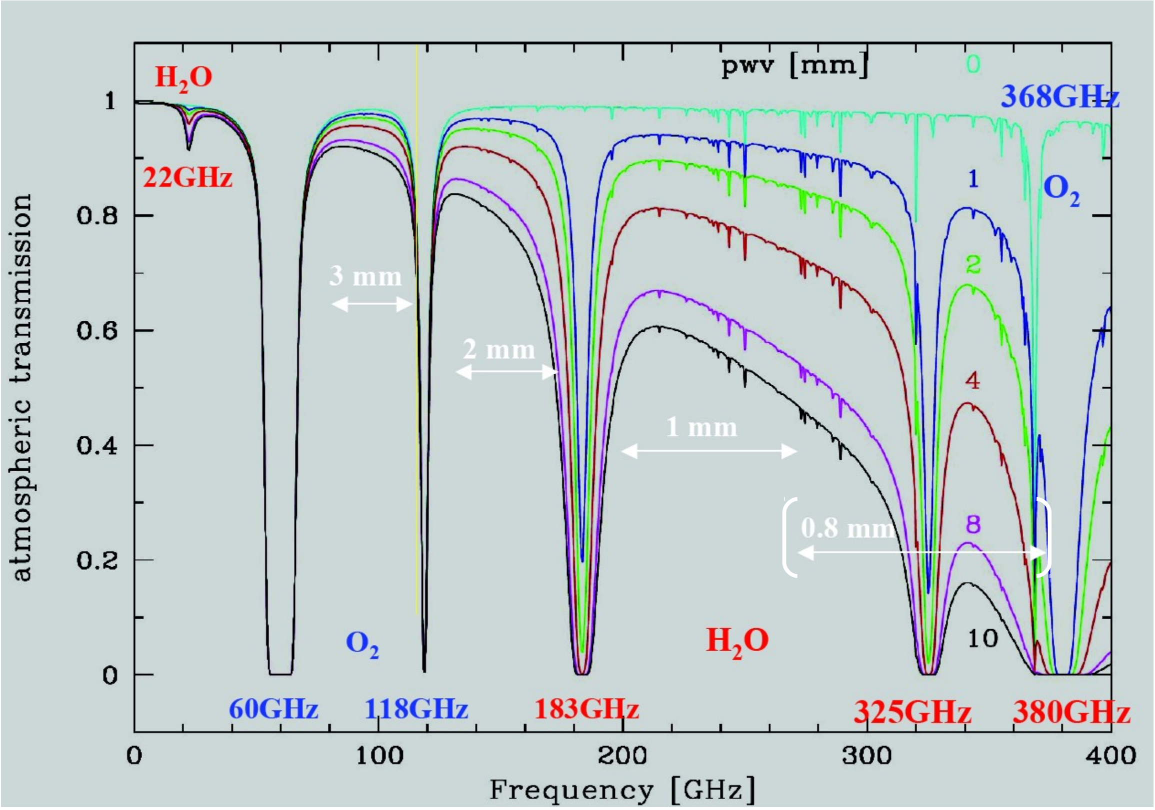
- Input: Radio frequency signal at ~mm wavelengths (~70-380GHz)
- Output: Slices of sky signal down converted to lower frequencies (~0-20GHz)

- Detecting devices are sensitive to narrow (~50-100 GHz) ranges of the spectrum
  - 4 **receiver bands** to cover 70 – 380 GHz range (i.e. 0.8 to 4.3 mm)

1 NOEMA receiver



Input of the 3mm receiver band



NOEMA receivers

Heterodyne systems

- Down-convert the spectrum
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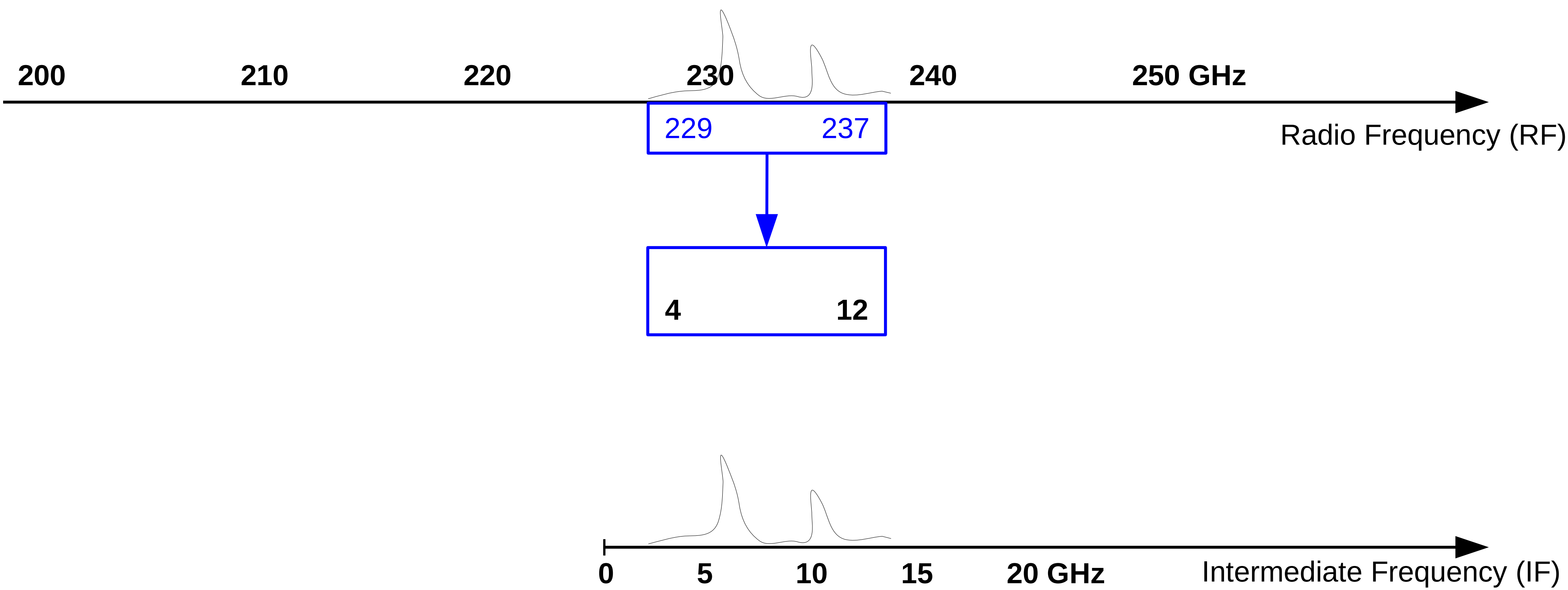
  to Intermediate Frequency (F_{IF} < 20 GHz)



NOEMA receivers

Heterodyne systems

- Down-convert the spectrum
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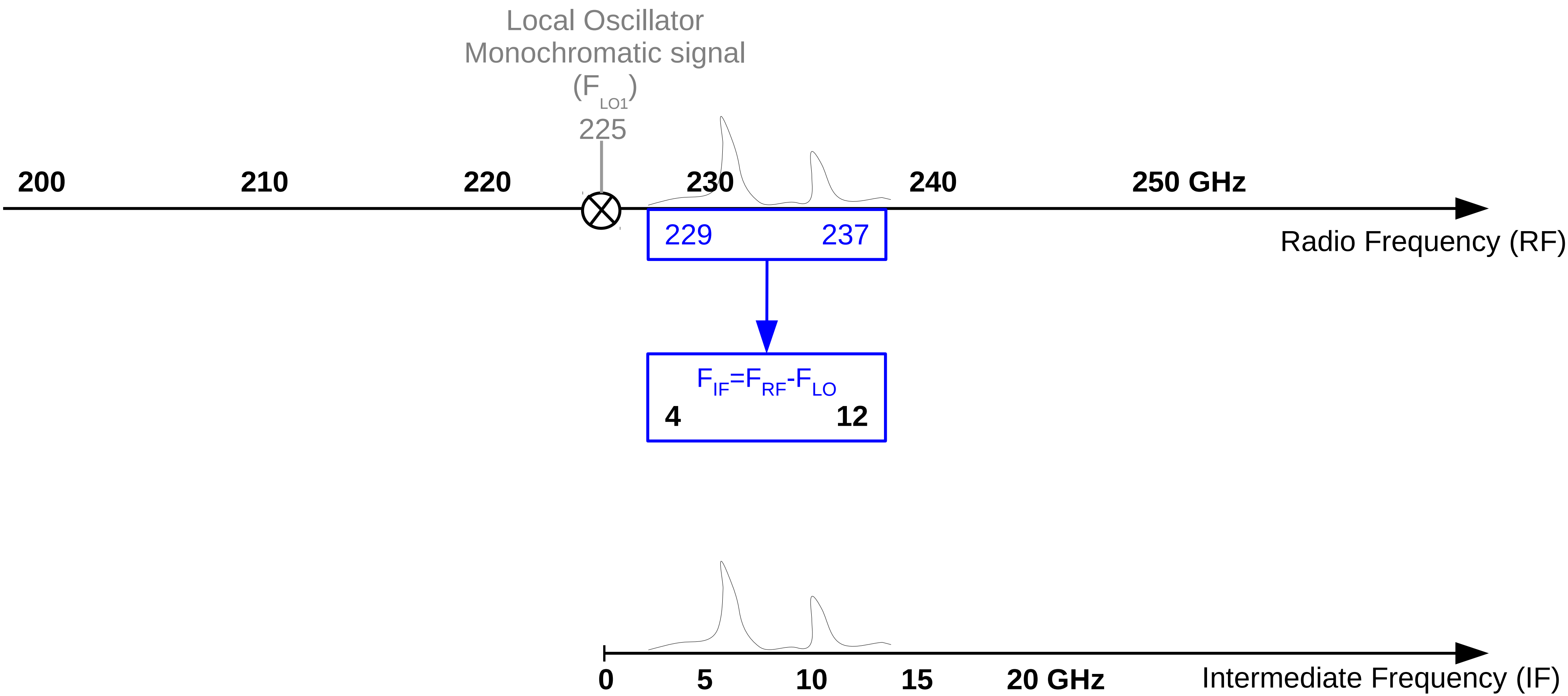
- Tuning the receiver = setting the FLO1 + optimizing some LO and Mixer parameters



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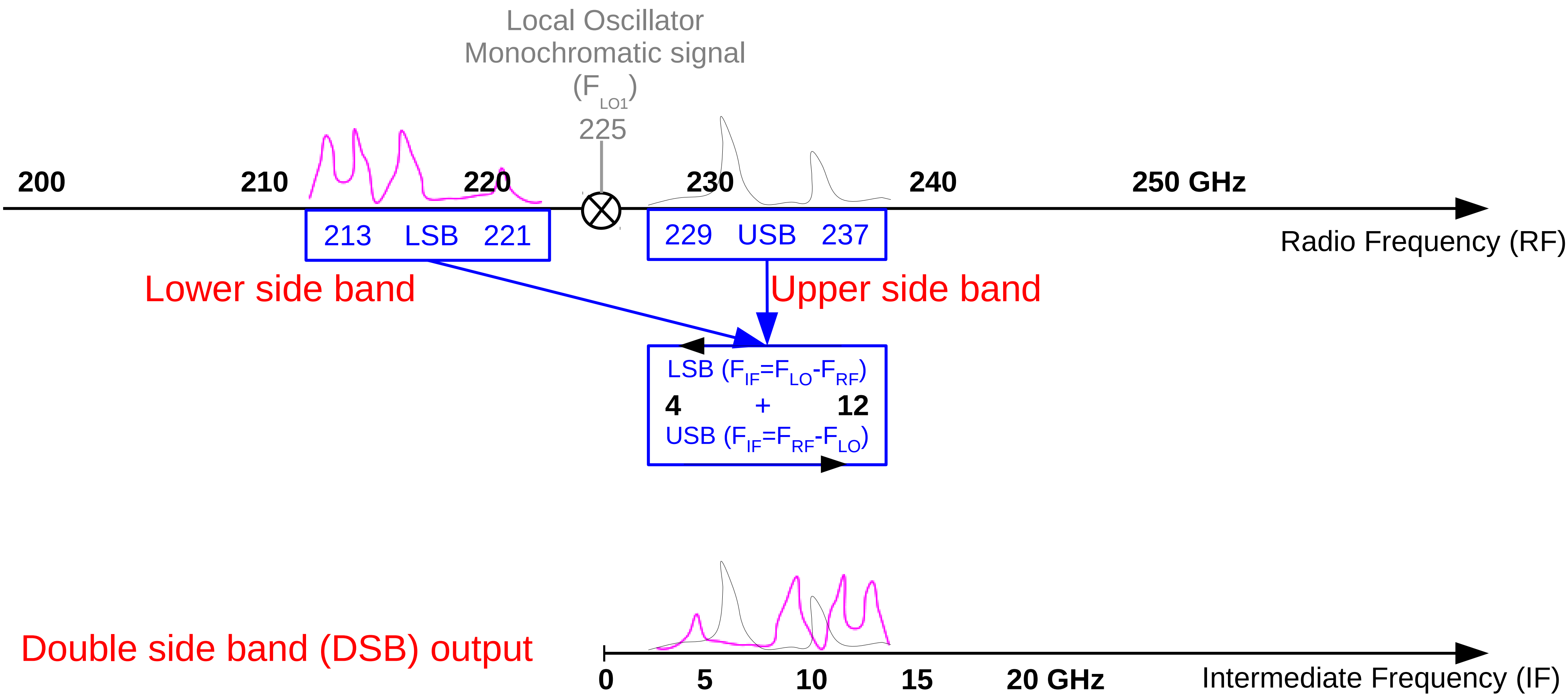

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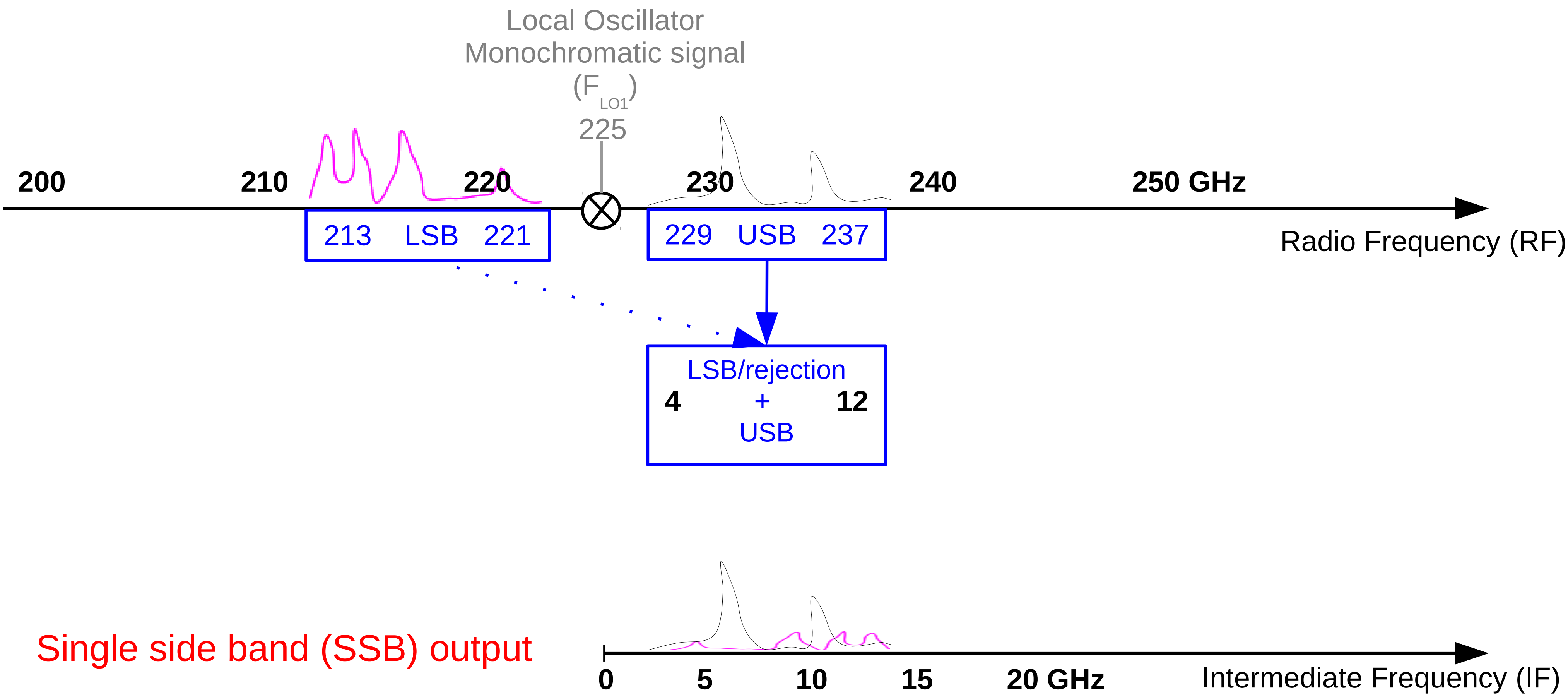

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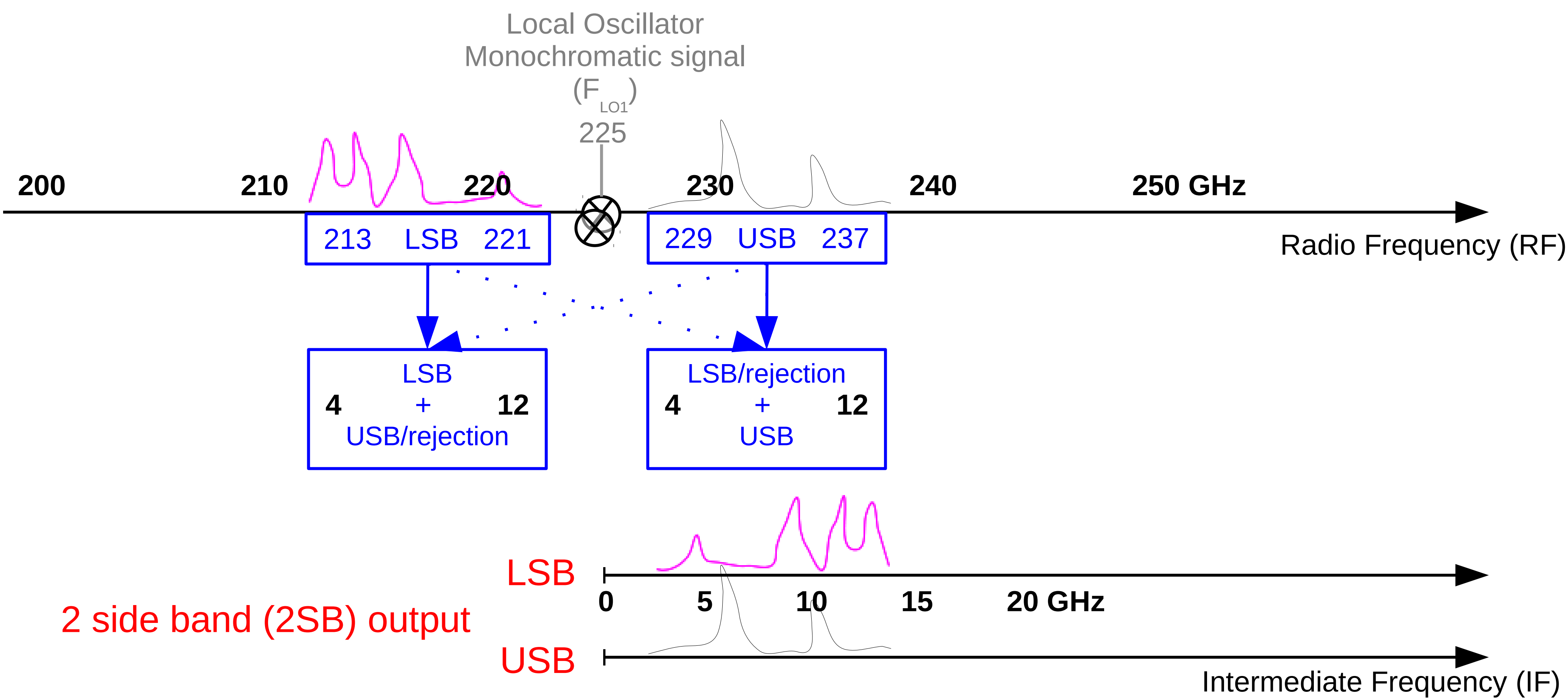

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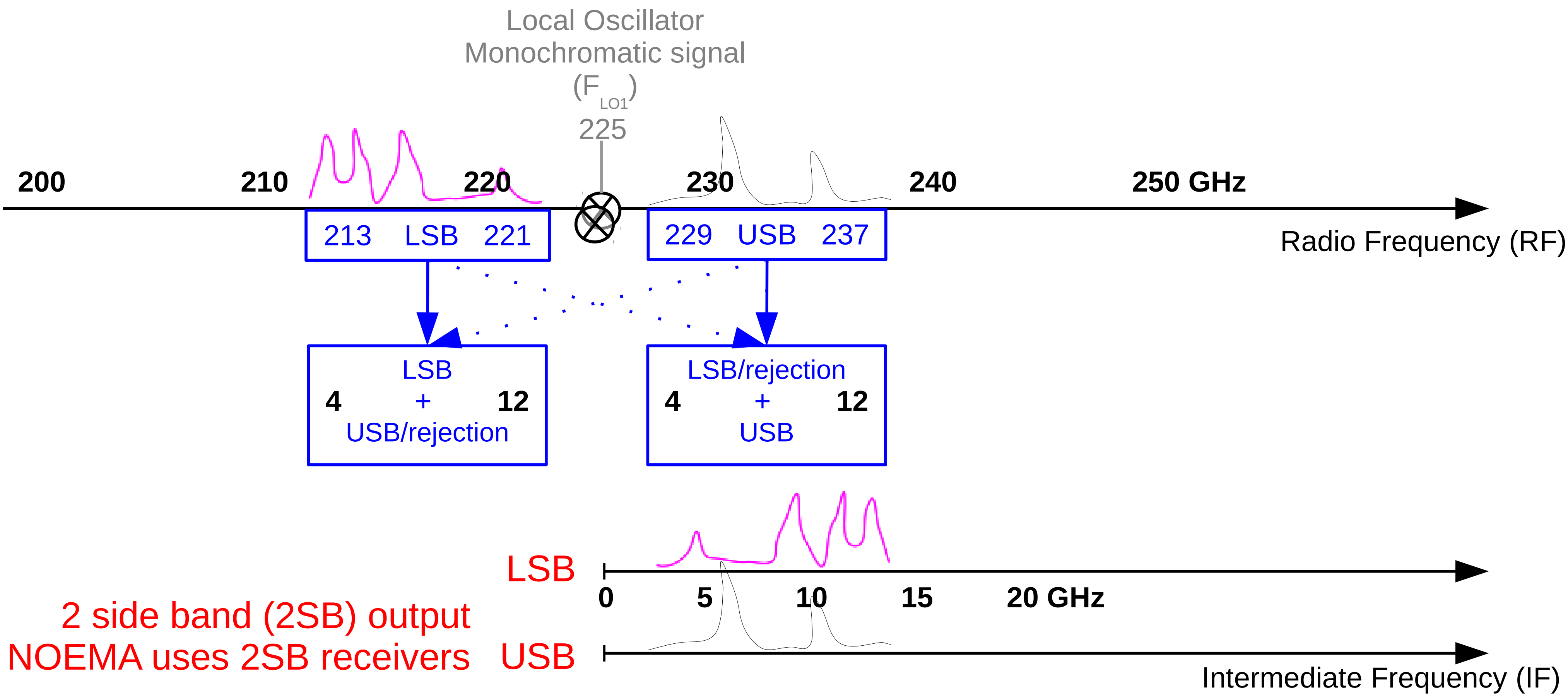


2 side band (2SB) output
NOEMA uses 2SB receivers

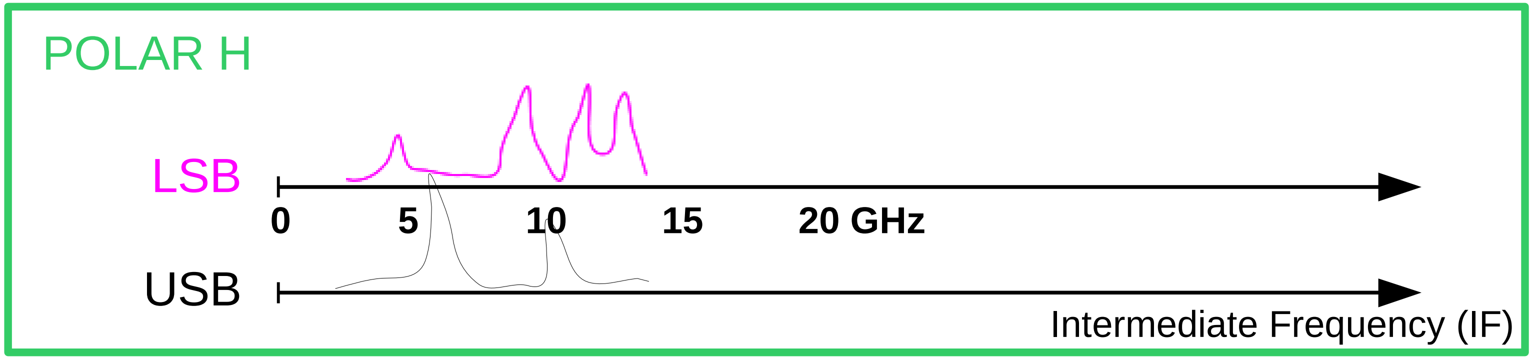
NOEMA receivers

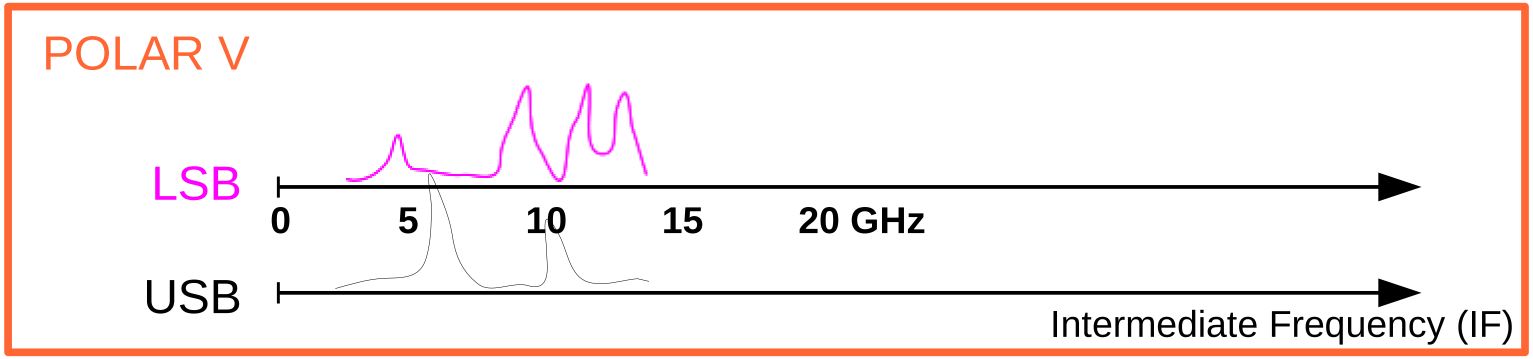
Dual polarization

- 1 NOEMA receiving system detects 1 linear polarization
- Detecting 2 orthogonal polarization
  - Gain factor of 2 on observing time
  - Possibility to do polarimetry (provided some hard and soft changes)
- Each receiver band contains 2 receiving systems: Horizontal and Vertical polarization
  - Separation grid on the incident path
  - Each receiver band contains 2 mixer-blocks (H,V) made of 2 mixers (USB,LSB)
- Receiver band output contains 4 slices of spectrum:

  HLSB HUSB VLSB VUSB

  They are all brought to the correlator room through optic fibers

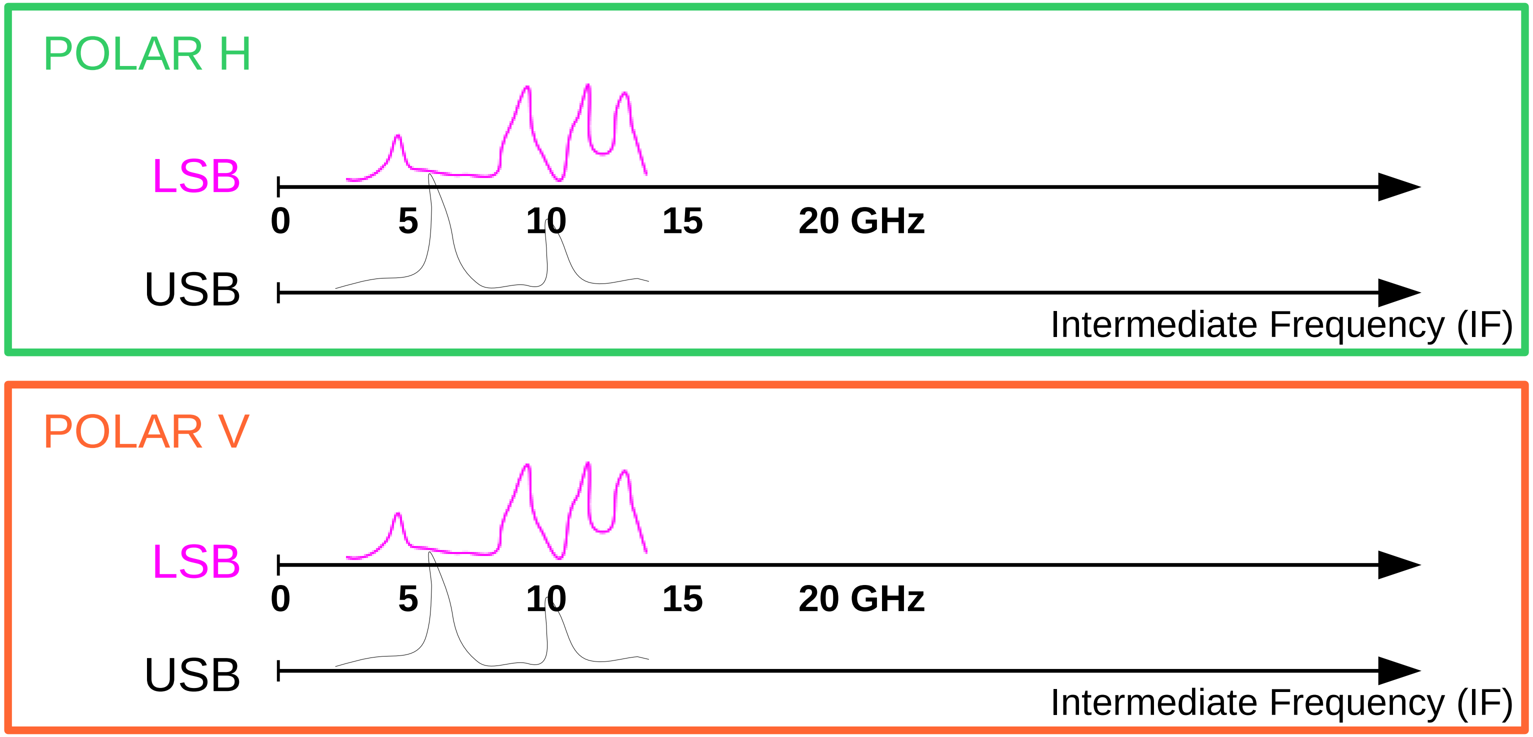




NOEMA receivers

Summary and nomenclature

- NOEMA antennas are equipped with 2SB, dual polarization, heterodyne receivers
  - Band 1: 72-116 GHz
  - Band 2: 127-179 GHz
  - Band 3: 200-276 GHz
  - Band 4: 275-373 GHz (2018)
- Tuning a receiver band = setting $F_{LO1} = F_{RF} +/- F_{IF}$
- Receiver output contains 4 slices of spectrum:
  - HLSB HUSB VLSB VUSB
  - Width= 8GHz
  - From 4 to 12 GHz in IF



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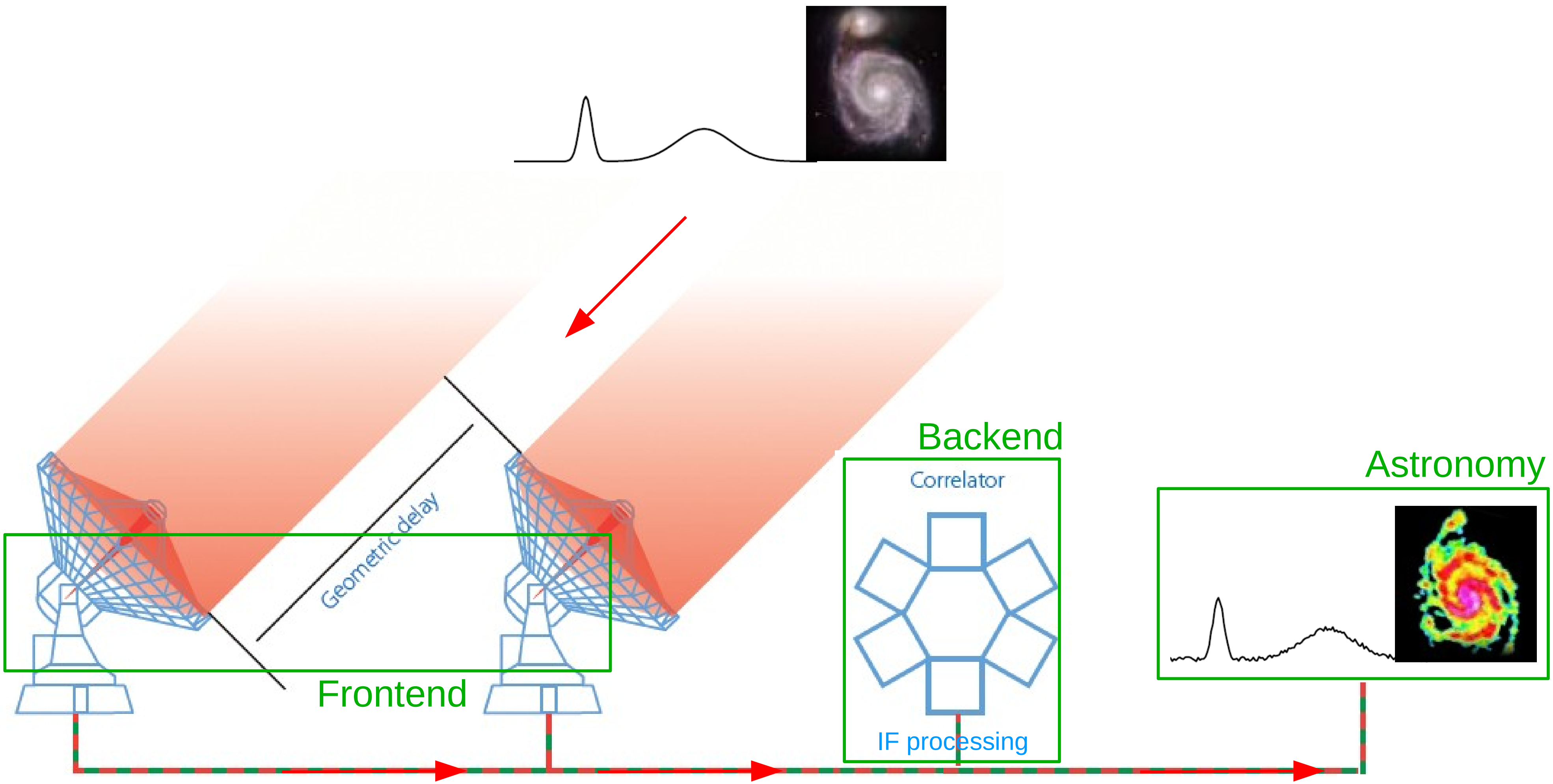
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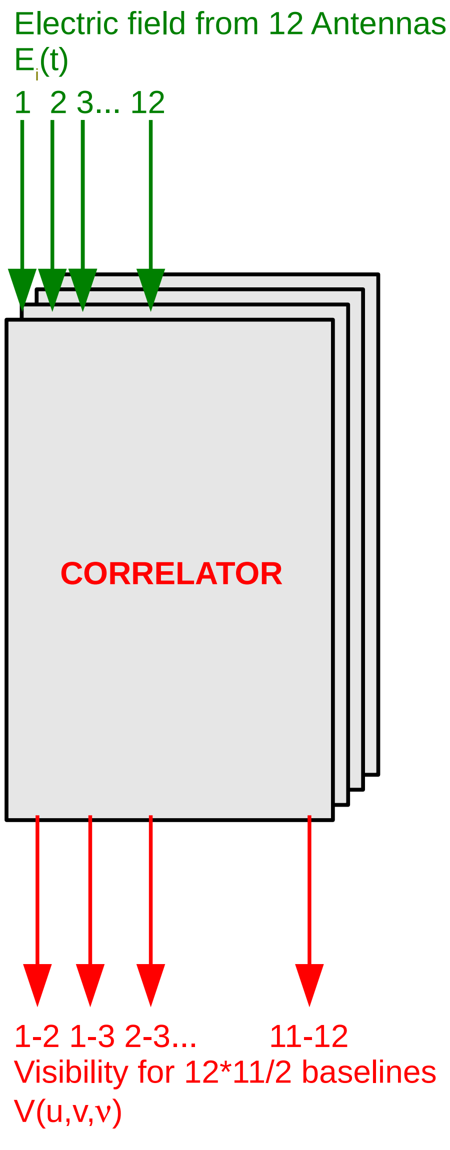
NOEMA correlator PolyFix

Very simplified view of a correlator



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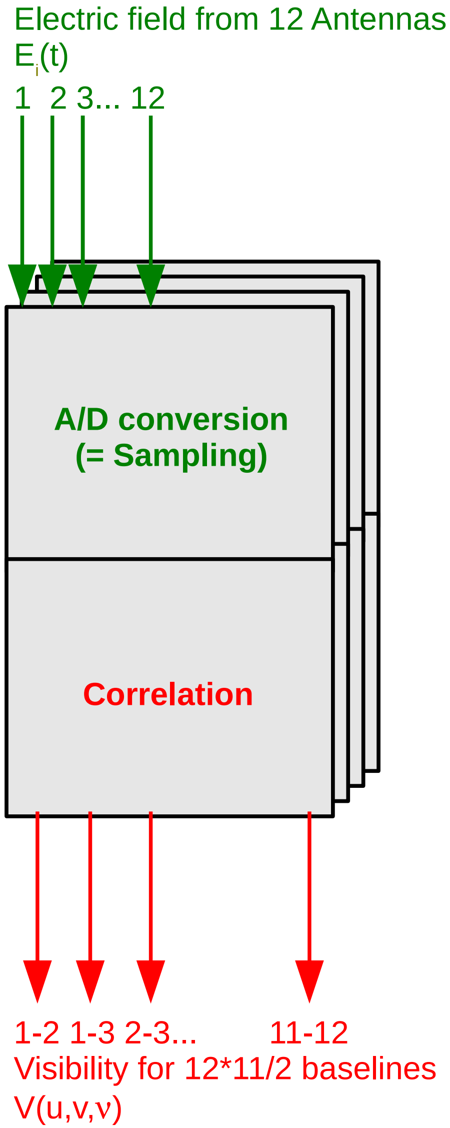
Less simplified view of a correlator (still much simpler than reality)



- Analog to Digital conversion
  - Correlator receives analogical signal from all the antennas
  - The wider the band, the higher the sampling rate, and the more difficult to implement
    - Converting 8 GHz bandwidth is challenging the best available ADC chips
      Choice to split the input bandwidth into 2 parts of 4GHz
      0-4 GHz Basebands
- Correlation

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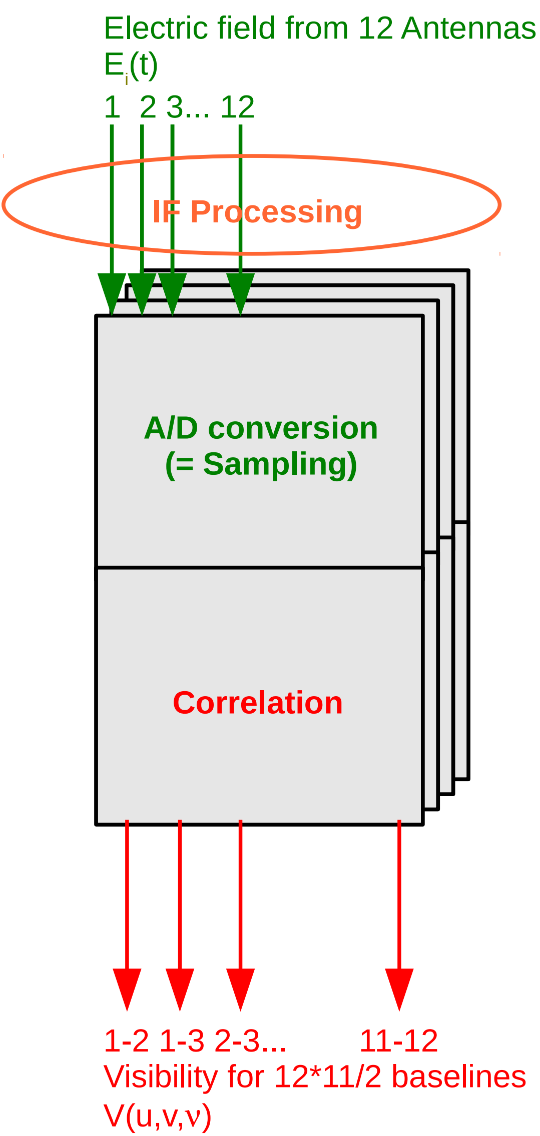

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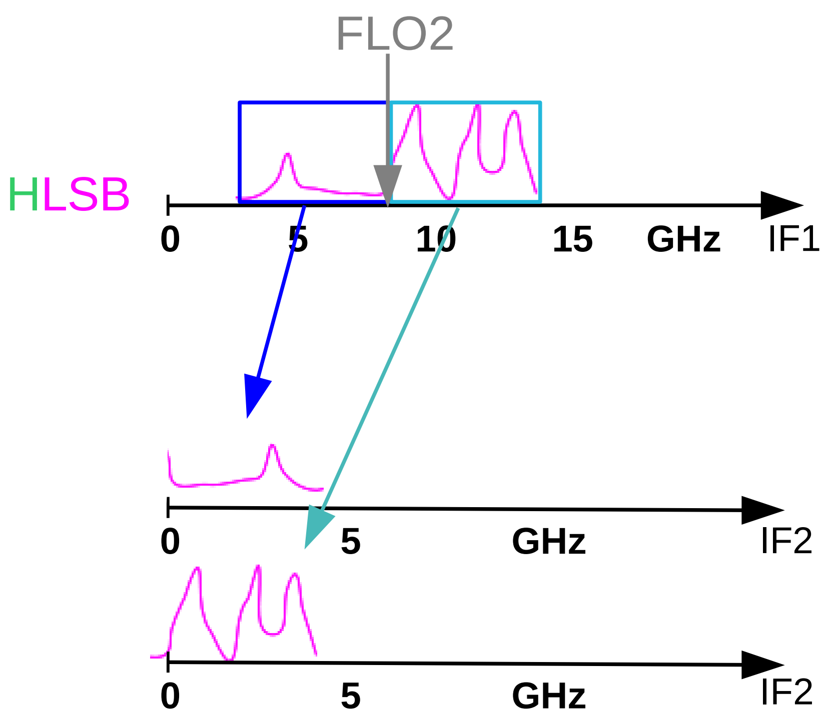
IF Processing

IF Processing

- Adapt the output of the receiver to the input of the correlator
  - 1 NOEMA receiver band delivers 4 x 8 GHz sidebands [4-12 GHz IF1]
  - 1 NOEMA correlator unit accepts 1 x 4 GHz [0-4 GHz IF2] x 12 antennas
- IF processor splits each sideband into 2 x 4GHz **basebands**
  - Downconvertion to 0-4GHz IF2



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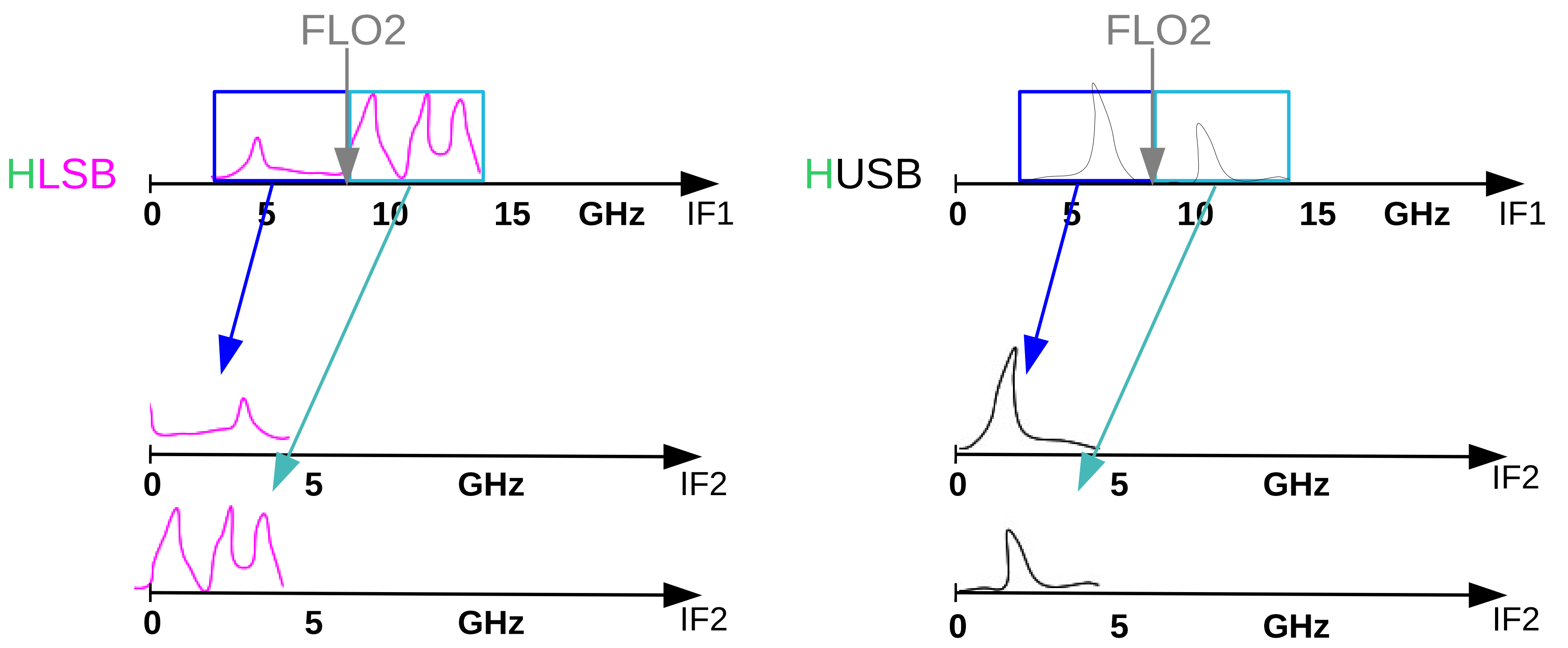

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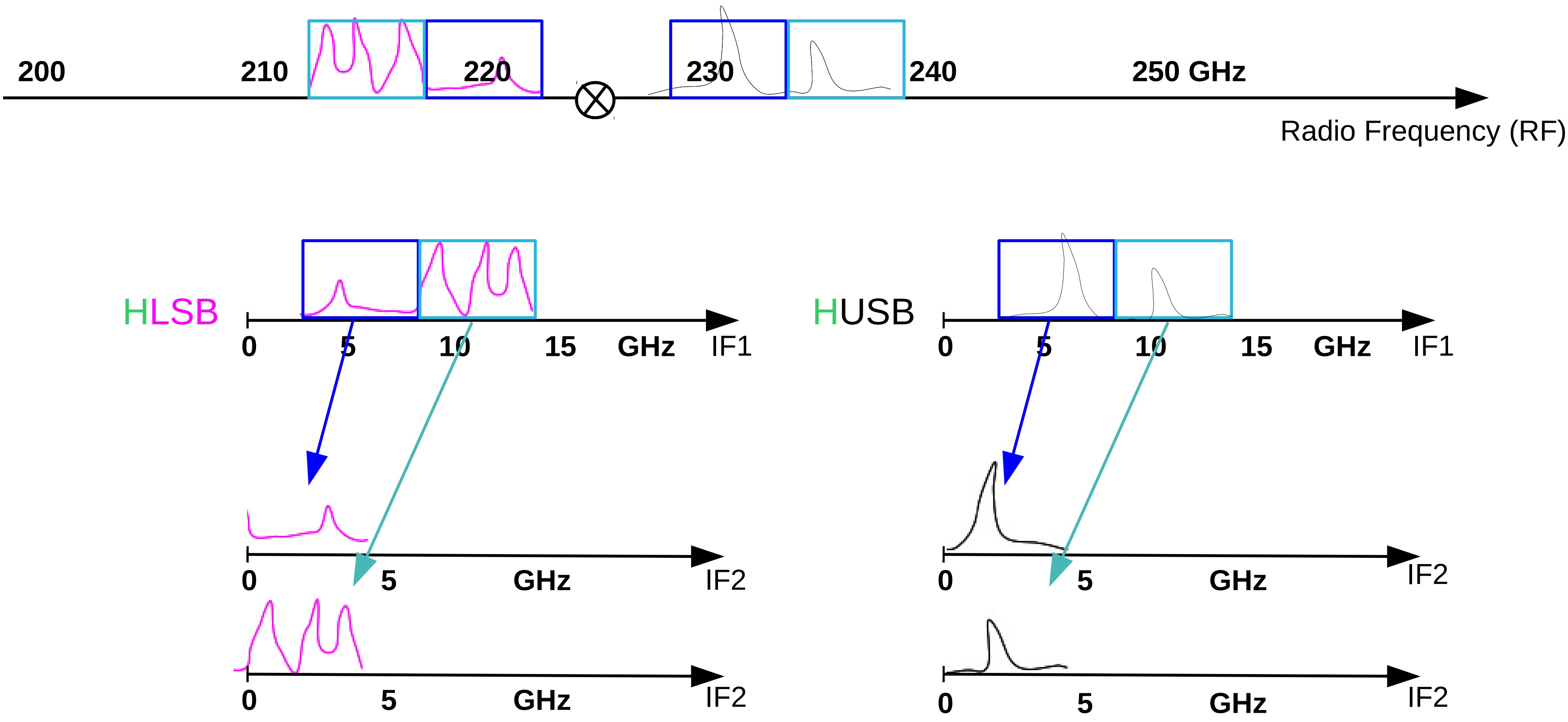

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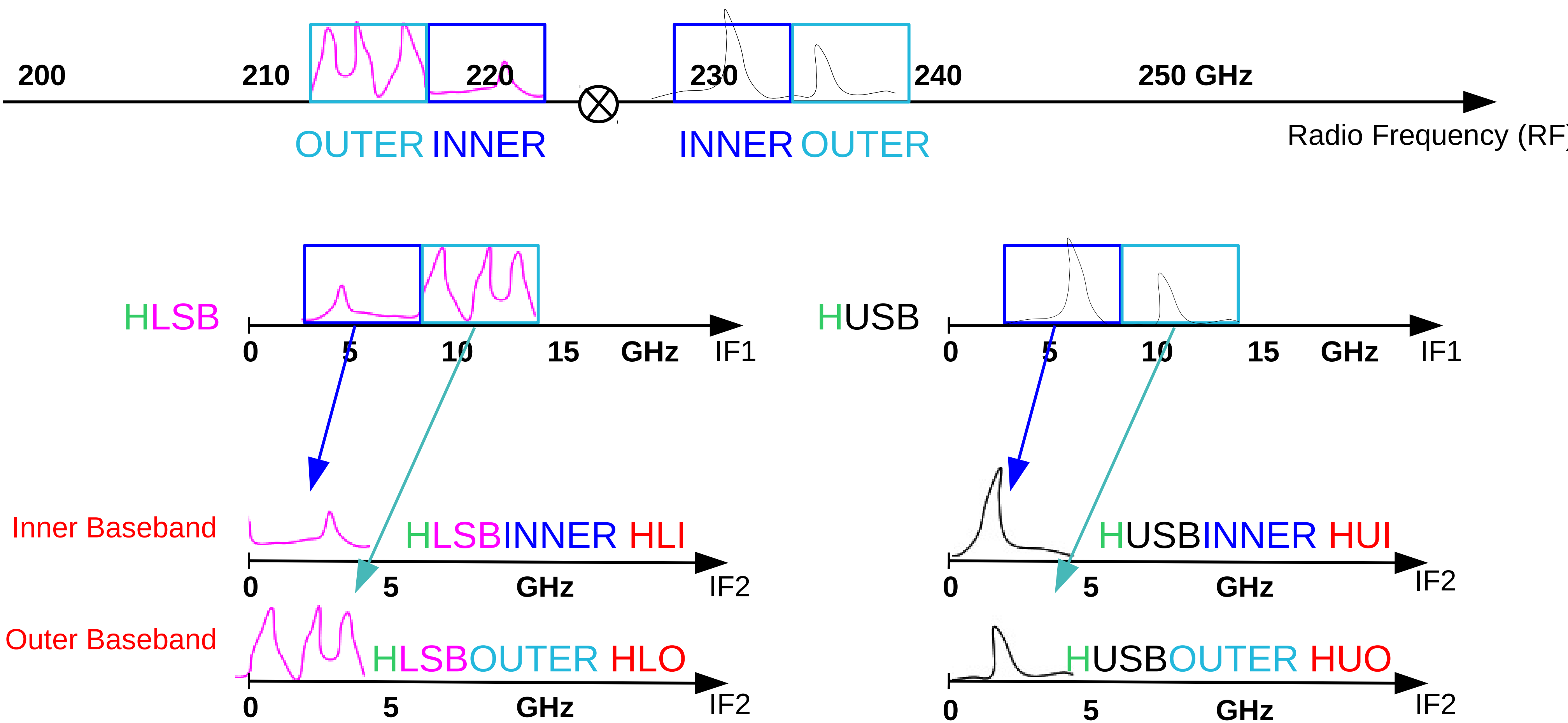

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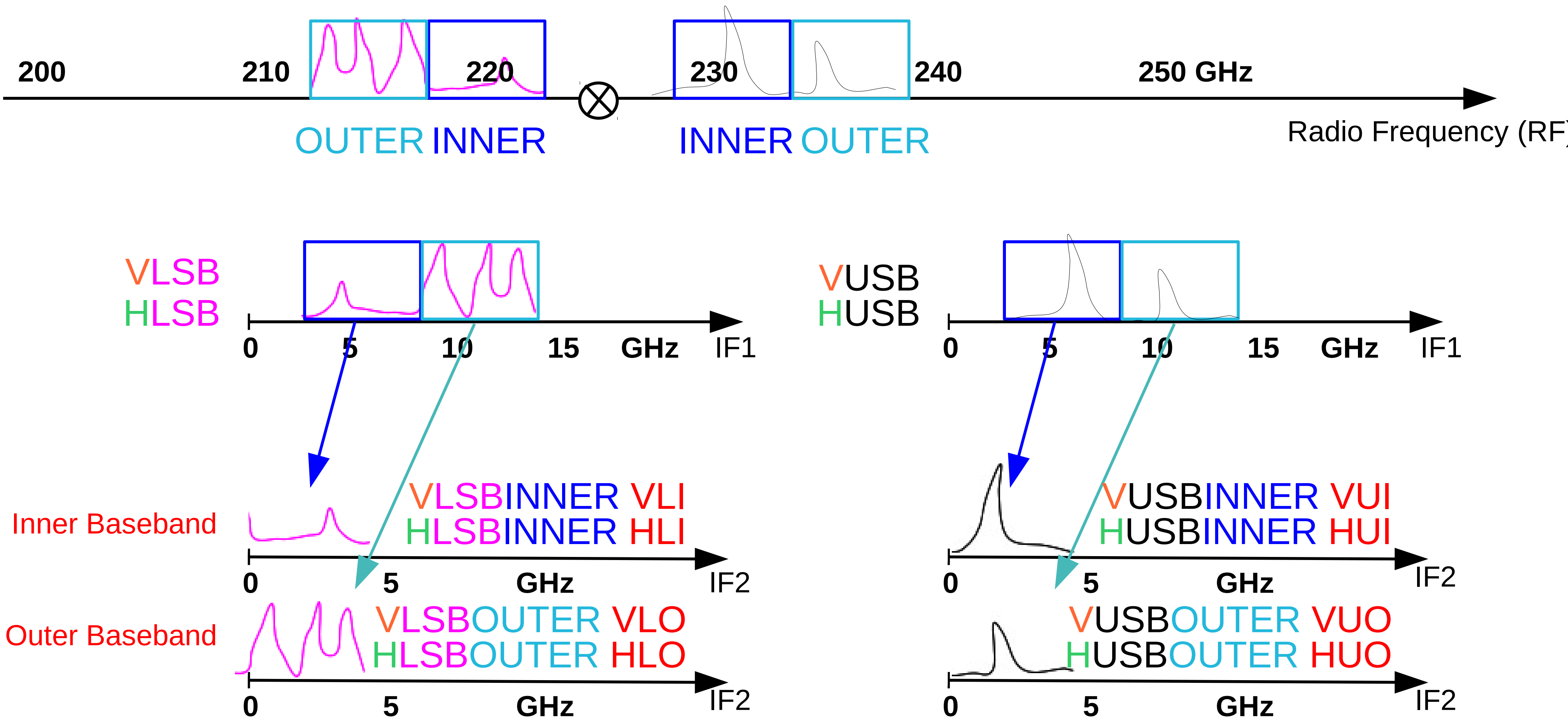
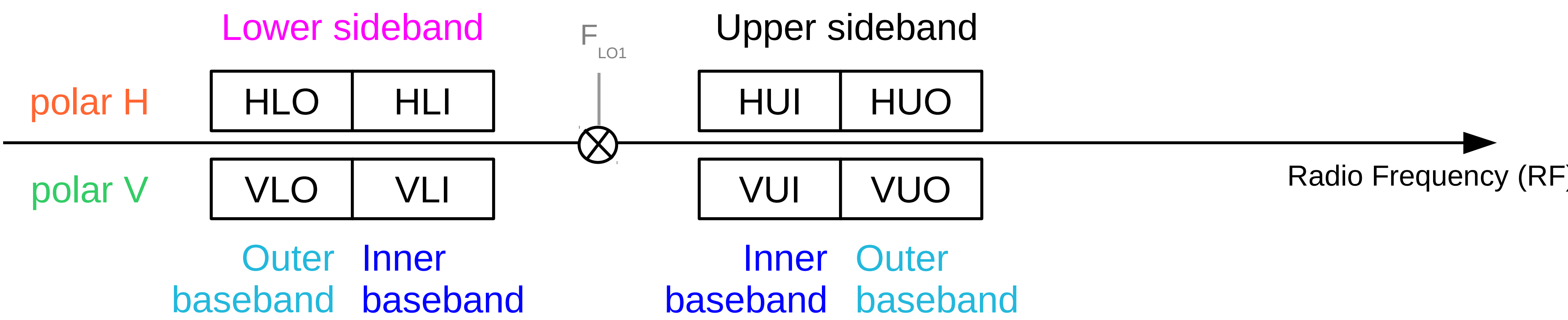


Nomenclature: Summary

8 Basebands (0-4 GHz IF2) feed 8 correlator units



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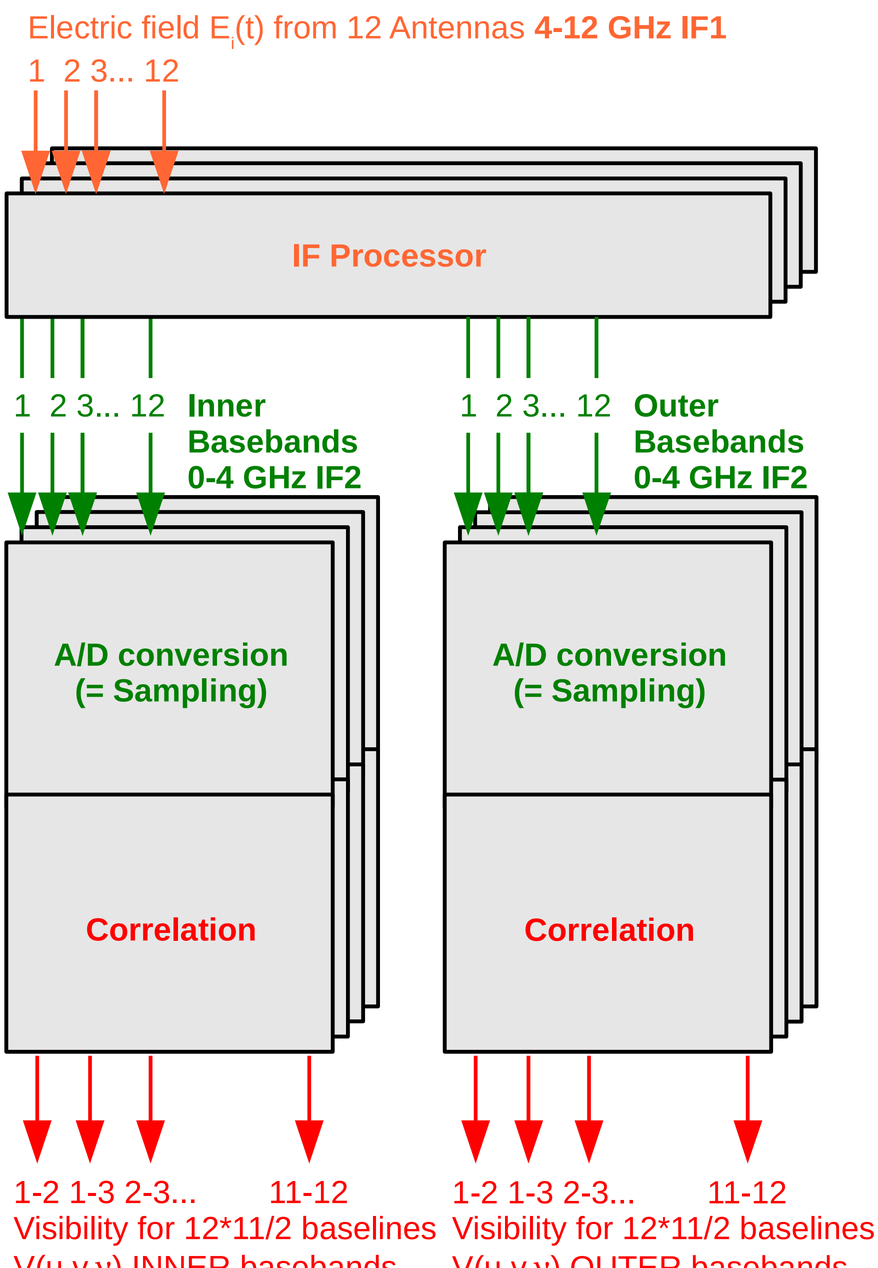

- IF Processor
  - Separate INNER and OUTER Basebands for the 4 receiver outputs (x12A)
- Analog to Digital conversion (ADC)
- Correlation

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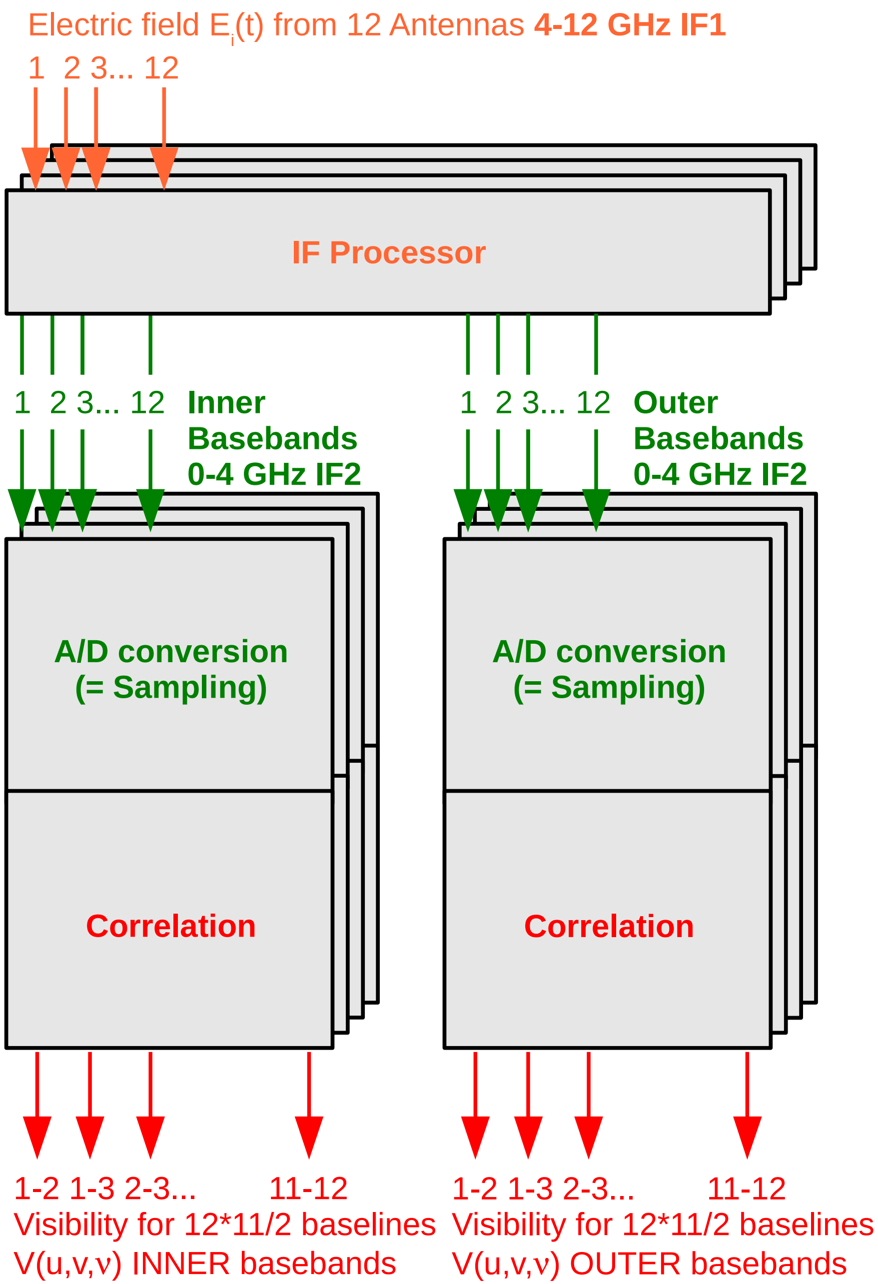

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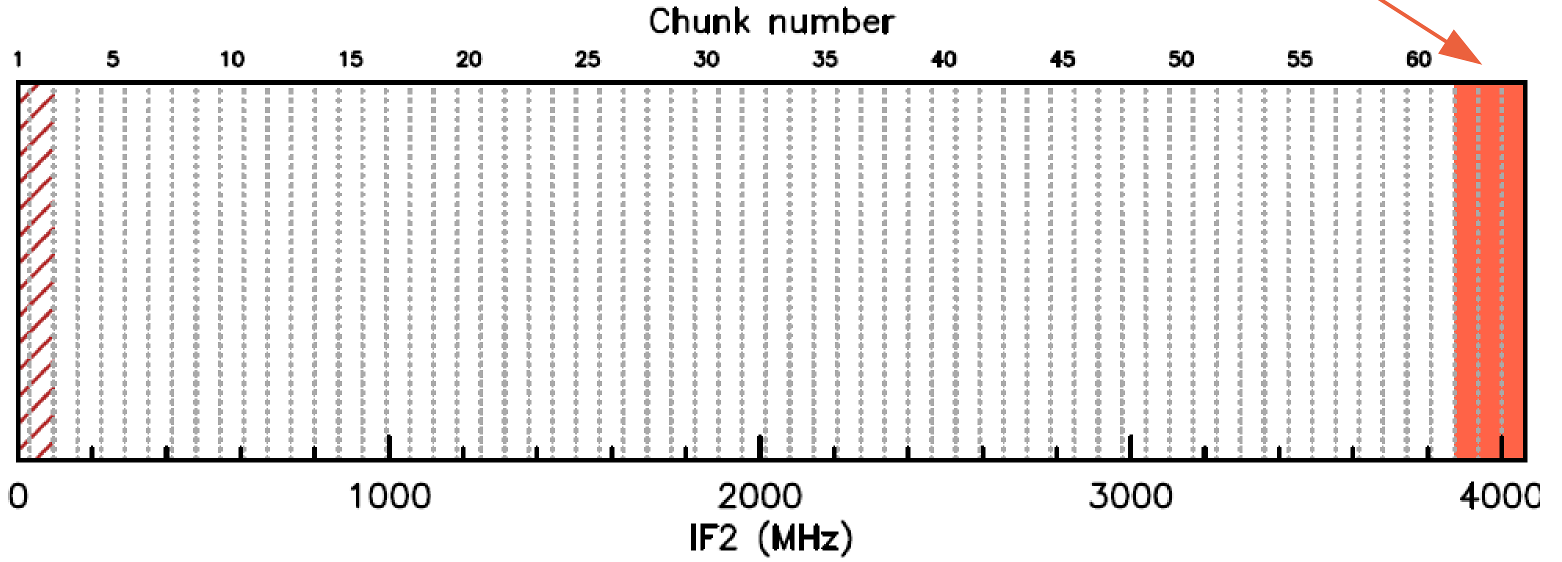
  - **XF (e.g. widex)**
    1. Cross correlation (time domain)
    2. Then Fourier transform (frequency domain)
  - **FX (PolyFix)**
    1. Fourier transform (frequency domain)
    2. Cross spectrum (frequency domain)
       Multiplication of the spectra of 2 antennas

NOEMA correlator: POLYFIX

8 identical and independent correlator units

- Input: 0-4 GHz baseband (x 12 antennas)
- Signal is digitized
- Baseband is split in **64 Chunks** of 64 MHz on a fixed grid
  - “Overlapping Polyphase Filter Bank”
  - Last 3 chunks thrown away (antialiasing filter)
    Effective bandwidth=3872 MHz



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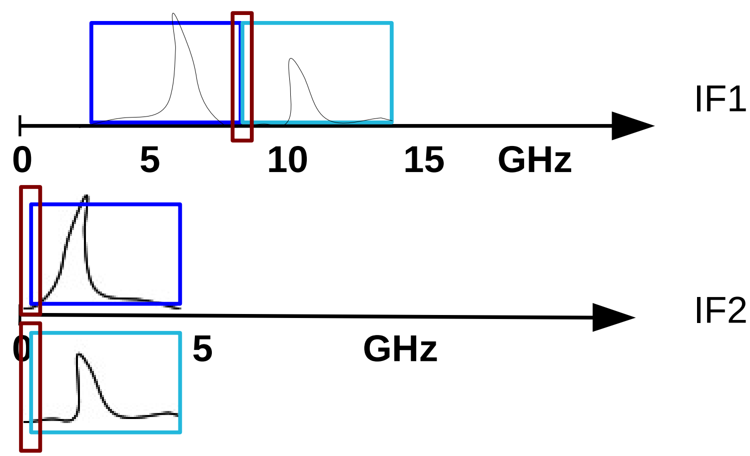
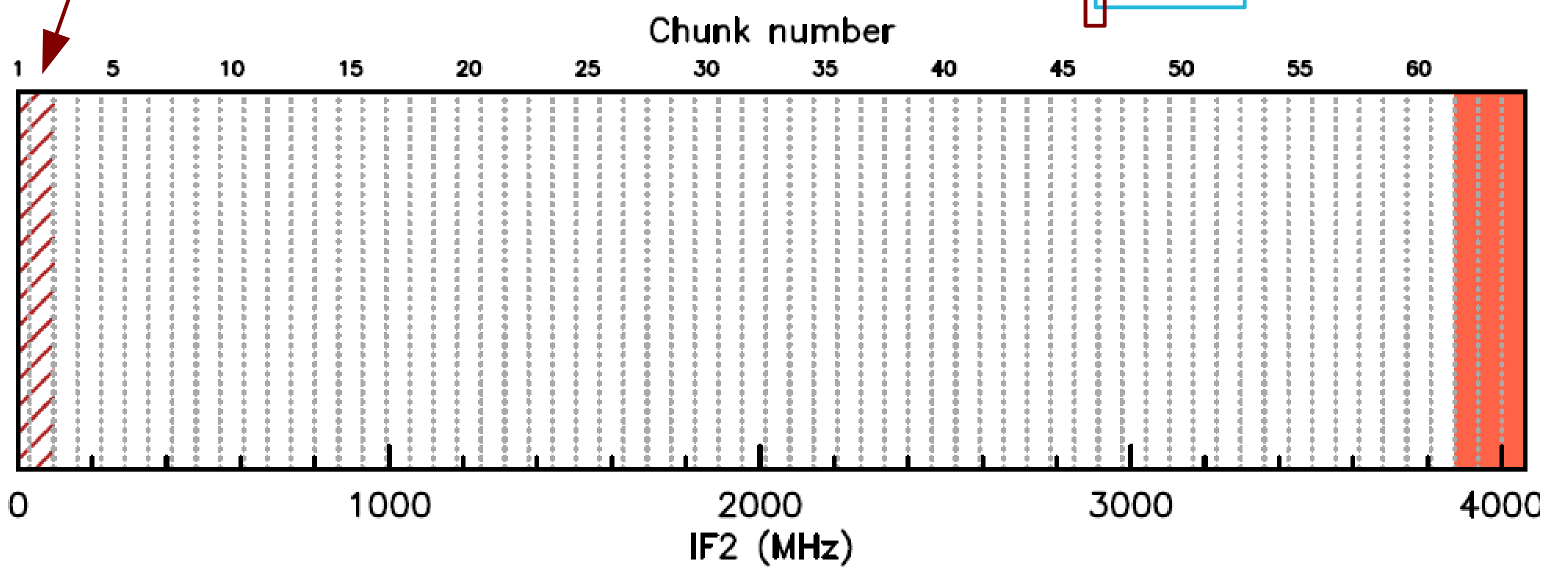
  - Confusion zone affecting first ~2 chunks





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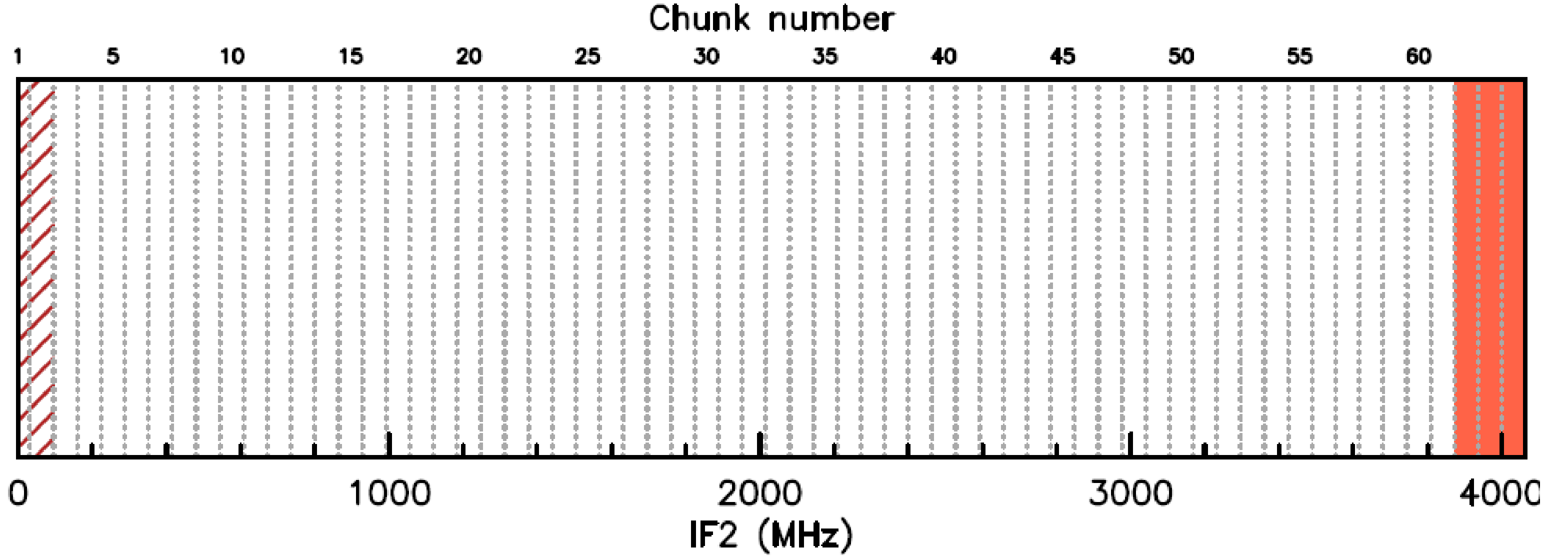
    Effective bandwidth=3872 MHz
  - Confusion zone affecting first ~2 chunks
- Then Fourier Transforms and cross multiplication (FX)
  - Re-programmable: **Correlator modes**
  - Choice of the mode is done by correlator unit
    - i.e. different basebands can be processed using different modes



NOEMA correlator: POLYFIX

Correlator Modes:

- Capabilities for a single unit
- **Mode 1**: Continuum + Lines
  - 61 chunks at Low resolution (2MHz); total bandwidth 3872 MHz

  AND 16 chunks at High resolution (62.5kHz); bandwidth 64 MHz each
  - Unique mode at delivery in 2017
- **Mode 2**: Survey
  - 61 chunks at 250 kHz; total bandwidth 3872 MHz
  - Later
- **Mode 3**: Continuum and high resolution lines
  - Similar to mode 1 with higher resolution in less chunks
  - Even later

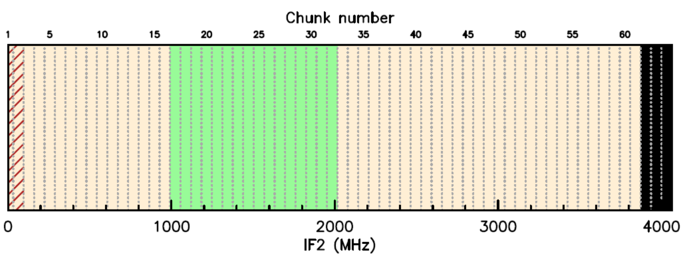
	1 Unit	All Units
Mode 1 (2017): Continuum + Lines	61 chunks (3872 MHz) at 2 MHz resolution **AND** 16 chunks at 62.5 kHz resolution*	~16 GHz x 2 polar with 2 MHz channels **AND** 8 GHz with 62.5kHz channels*
Mode 2: Survey	61 chunks (3872 MHz) at 250 kHz resolution	~16 GHz x 2 polar with 250 kHz channels
Mode 3: Continuum + High Resolution	<61 chunks (3872 MHz) at 2 MHz resolution AND 8/4/2 chunks at 31.25/15.625/7.8125 kHz resolution*	<16 GHz x 2 Polar with 2 MHz channels AND 4/2/1 GHz with 31.25/15.625/7.8125kHz channels*

*High resolution chunks chosen among the 61 of the **fixed** filter bank

Nomenclature: Backend

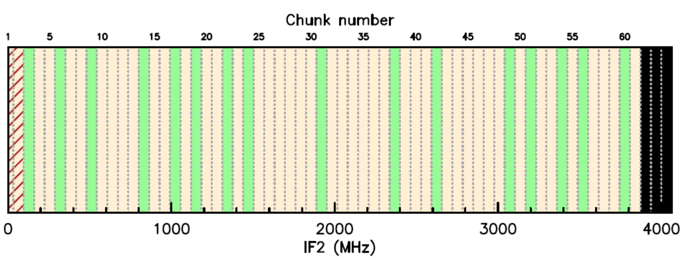
Spectral windows

- The output of the correlator is a number of **spectral windows**
- In a given baseband, a **spectral window** is
  a set of contiguous chunks at the same spectral resolution
- With the default mode:
  - 1 Correlator Unit output is made of:
    - 1 low resolution spectral window (made of 61 chunks)
    - $1<n_{spw}<16$ high resolution spectral windows (made of $16>n_{chunks}>1$ chunks)



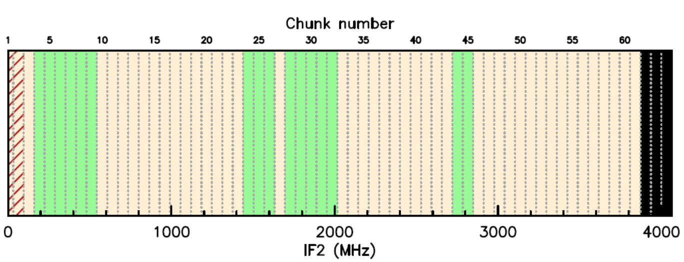
1 low resolution SPW (3872 MHz wide, 2000 kHz channels)

1 high resolution SPW (1024 MHz wide, 62.5 kHz channels)



1 low resolution SPW (3872 MHz wide, 2000 kHz channels)

16 high resolution SPW (64 MHz wide each, 62.5 kHz channels)



1 low resolution SPW (3872 MHz wide, 2000 kHz channels)

4 high resolution SPW
(widths: 384, 192, 320, 128 MHz, 62.5 kHz channels)

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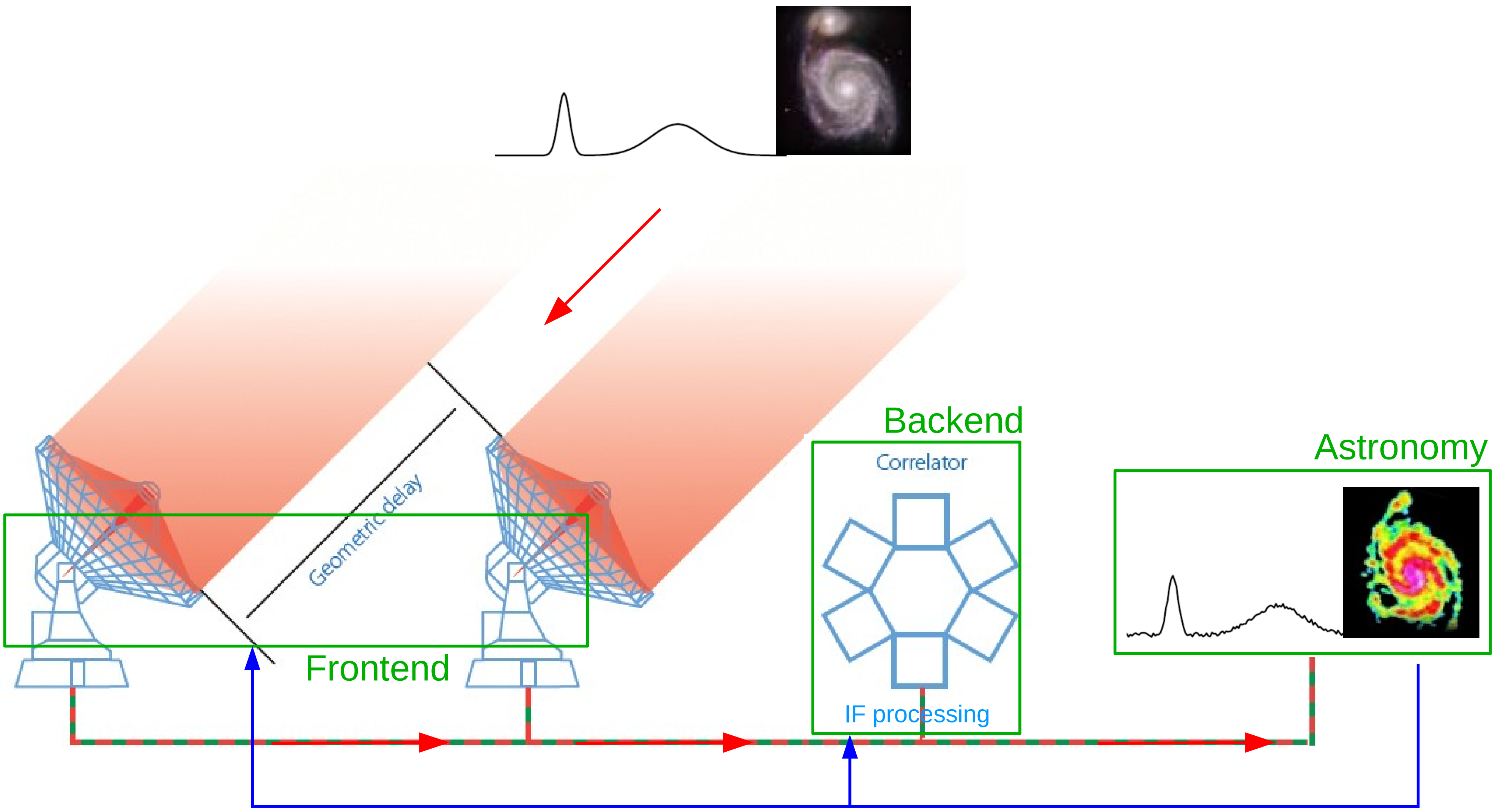
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How to prepare NOEMA spectral observations

Disclaimer:

Preparing NOEMA setups in ASTRO is a new functionnality

First release in GILDAS sep16b

All commands are likely to be modified. Plots are very likely to evolve

Use ASTRO in Gildas

```
$astro
OBSERVATORY NOEMA
TIME
```

Define a source (with a given velocity or redshift)

```
SOURCE
```

Define a receiver band tuning

```
TUNING
```

Select a/some baseband(s) **+ associated correlator mode**

```
BASEBAND
```

Define flexible spectral windows (in the selected BB)

- Select the 16 high resolution chunks

```
SPW
```

Examine my current settings

```
LIST
PLOT
```

Remove a spectral window

```
RESET
```

Get a final script

```
SETUP
```

Other useful commands:

Get some help

```
HELP COMMAND
```

Show molecular lines on frequency plots

```
SET LINES ON
```

Choose line profile to be drawn

```
SET LINES GAUSS 100
```

Change the catalog of lines

```
CATALOG Myfile.lin /LINE
```

Choose the frequency axis

```
SET FREQUENCY Main Second
```

NOEMA setups in ASTRO

Prepare the environment:

```
OBSERVATORY NOEMA
TIME 00:00:00.0 20-OCT-2016

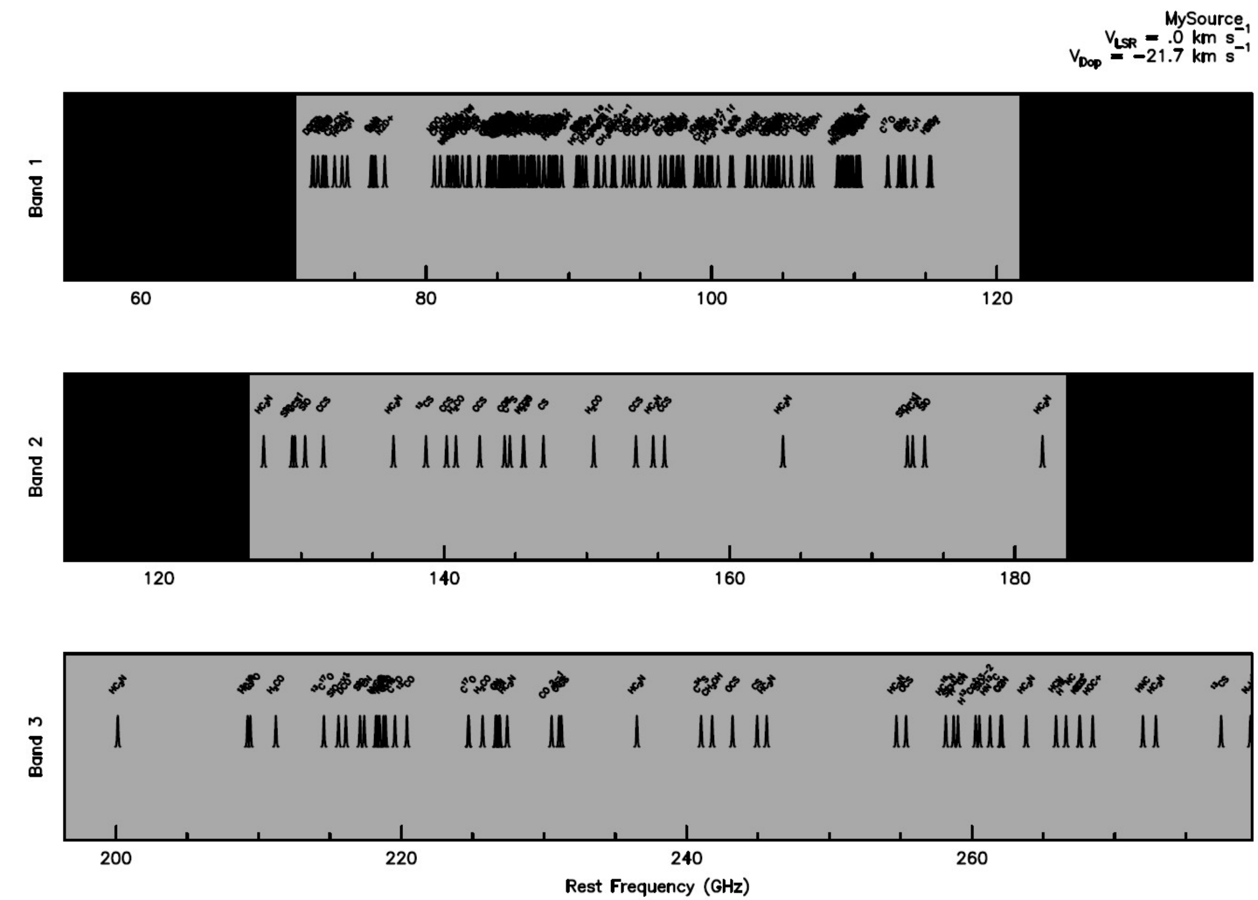
SOURCE MySource EQ 2000 10:00:00.0 20:00:00.0 LSR 0
    MySource    Azimuth -121.78699    Elevation  -2.75186
    MySource    V(S/OBS) =   -21.668 [S/LSR=  0.000,LSR/G=  4.952,G/OBS=-26.620]
    MySource    Redshift      0.000
! SOURCE must be entered to enable Doppler computations

SET LINES GAUSS 100
! Lines from the catalog will be indicated by a gaussian (width=100MHz)
```

NOEMA setups in ASTRO

Define the receiver tuning

```
TUNING ! Display the coverage of available receiver bands
       ! Nothing actually DONE, only plot
   I-TUNING,  Showing the coverage of NOEMA receiver bands
```



NOEMA setups in ASTRO

Define the receiver tuning

```
TUNING ! Display the coverage of available receiver bands
TUNING 230.538 LSB 6500 ! tune 230.538 REST at 6500 IF1 in LSB
    I-TUNING,  Resetting tuning
    I-TUNING,  Selecting the Band_3 band of the NOEMA receiver
    I-TUNING,   FRF     =  230.55466 GHz
    I-TUNING,   FLO1    =  237.05466 GHz
    I-TUNING,   FLOTUNE =  237.03800 GHz
    I-TUNING,  Original tuning does not match the grid
    I-TUNING,  Tuning automatically shifted to the IF Frequency = 6462.000 MHz
    I-TUNING,  This corresponds to a shift of 38.000 MHz
    I-TUNING,  Actual command:
    TUNING 230.538 LSB 6462.000
    I-TUNING,  Selecting the Band_3 band of the NOEMA receiver
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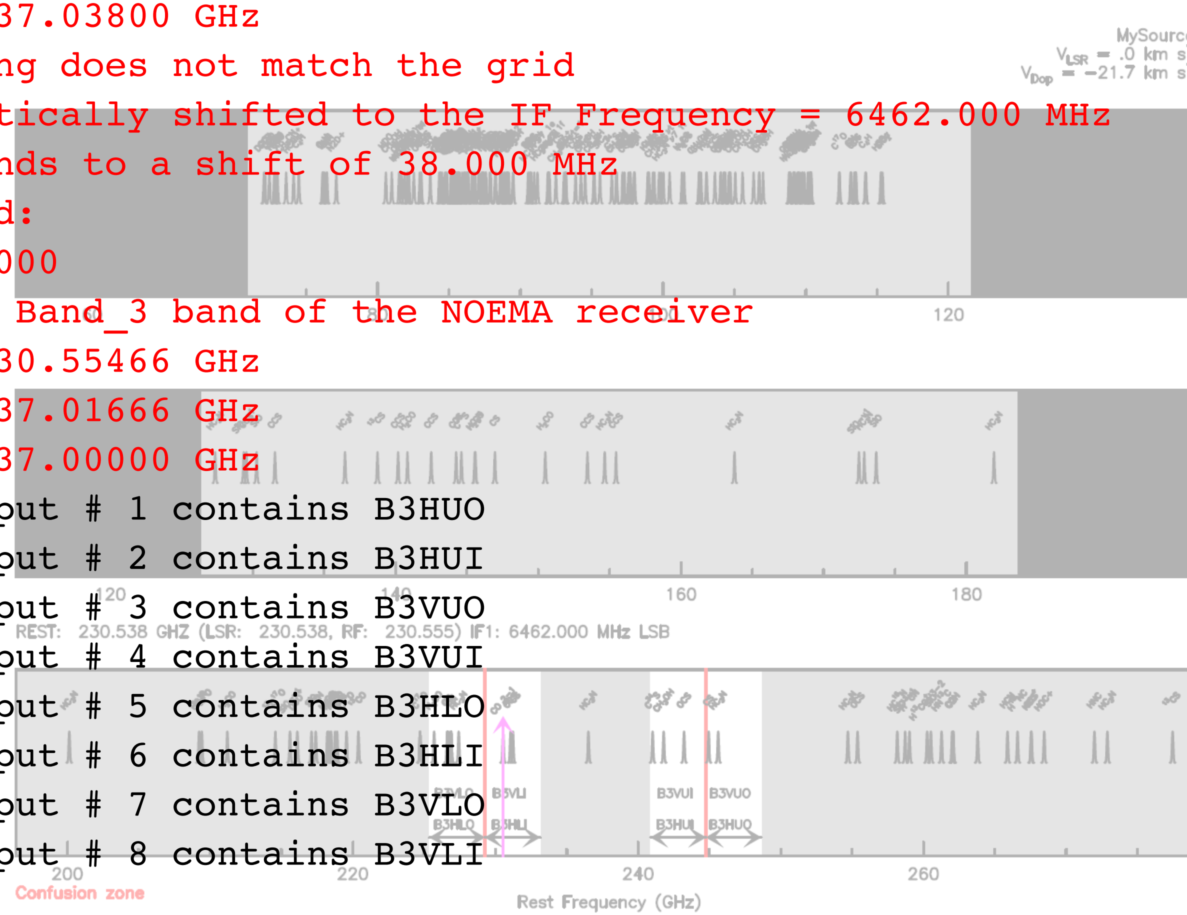
    I-TUNING,   FLO1    =  237.01666 GHz
    I-TUNING,   FLOTUNE =  237.00000 GHz
    I-TUNING,  Correlator input # 1 contains B3HUO
    I-TUNING,  Correlator input # 2 contains B3HUI
    I-TUNING,  Correlator input # 3 contains B3VUO
    I-TUNING,  Correlator input # 4 contains B3VUI
    I-TUNING,  Correlator input # 5 contains B3HLO
    I-TUNING,  Correlator input # 6 contains B3HLI
    I-TUNING,  Correlator input # 7 contains B3VLO
    I-TUNING,  Correlator input # 8 contains B3VLI
```



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    I-TUNING,   FLO1     =
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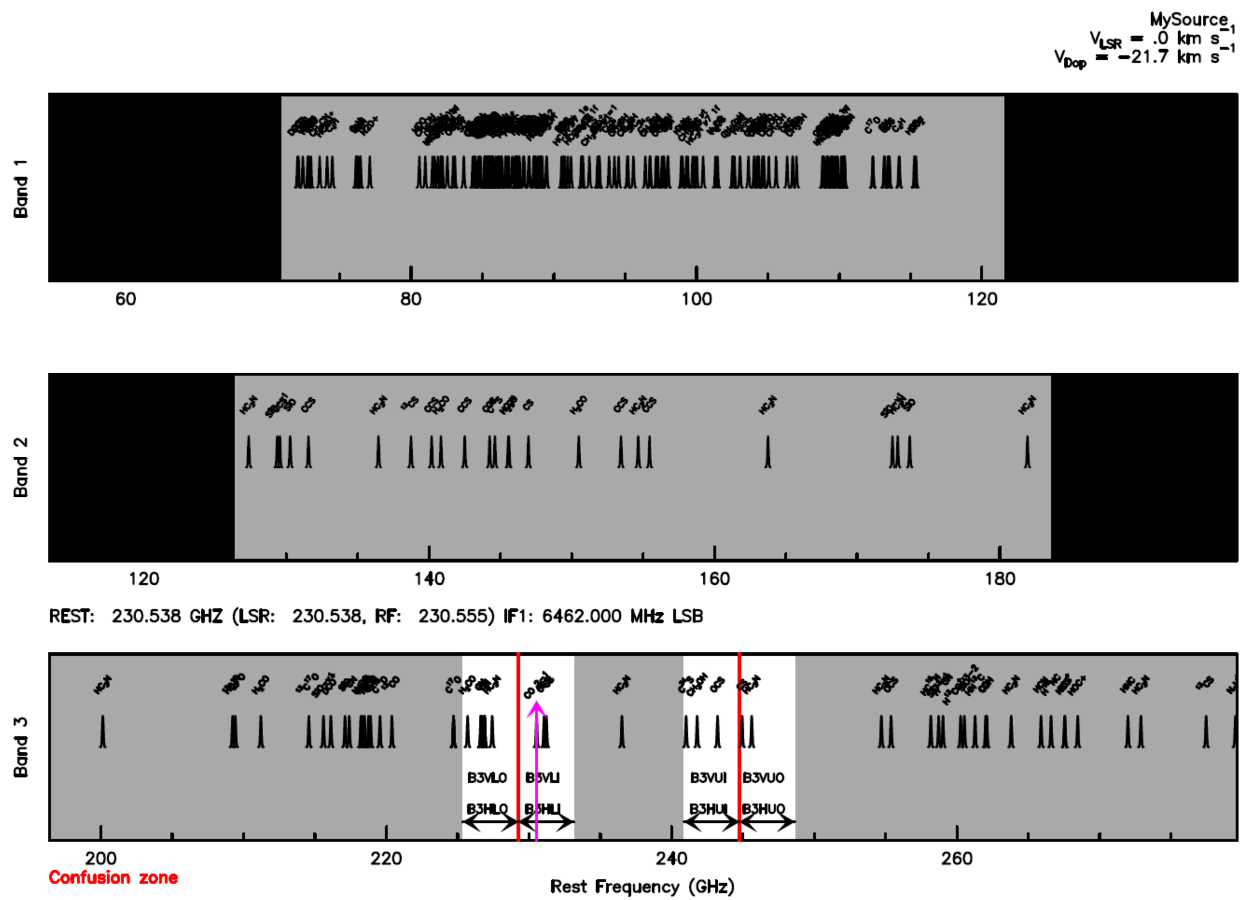
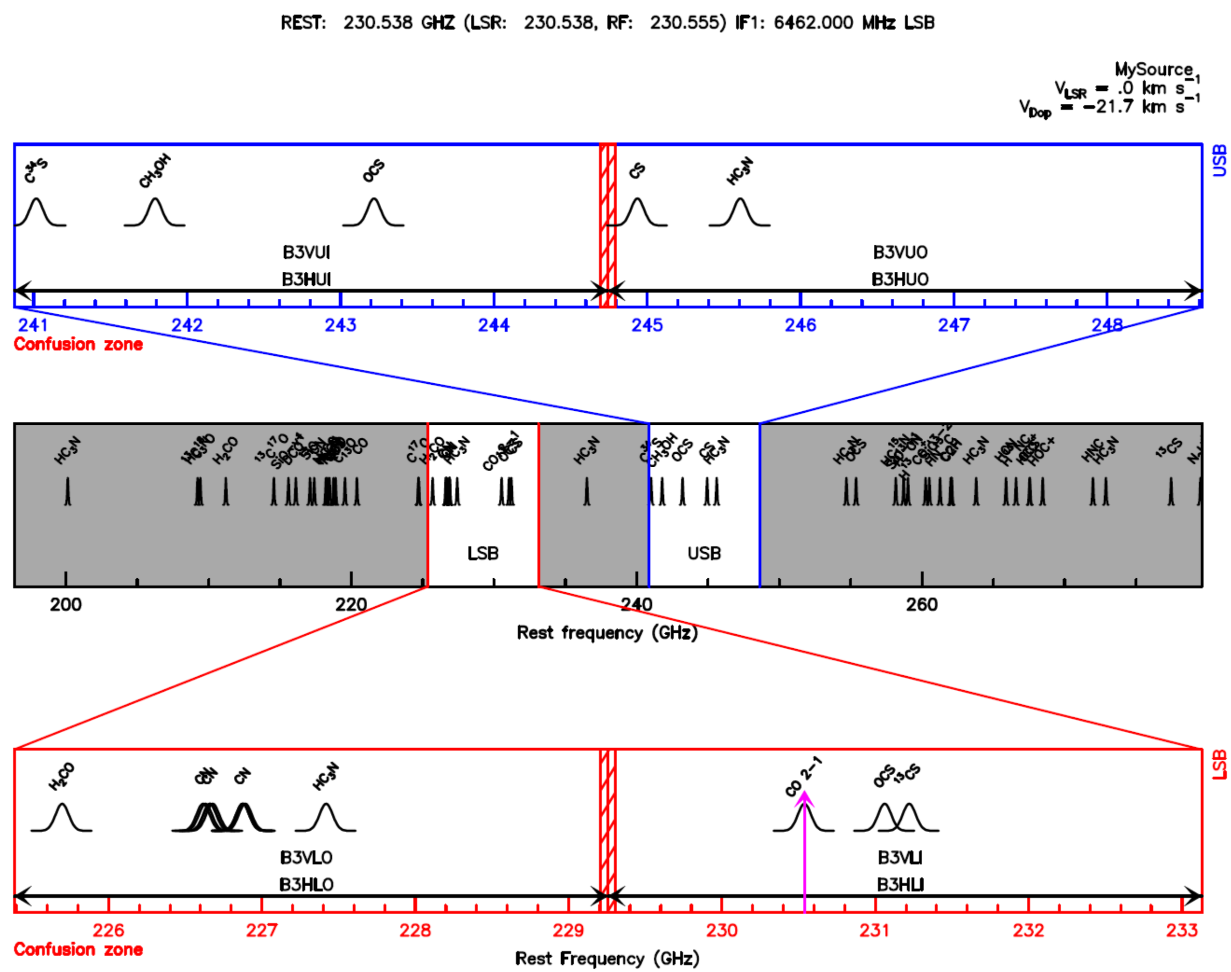
    I-TUNING,  Correlator i
```



NOEMA setups in ASTRO

Define the receiver tuning

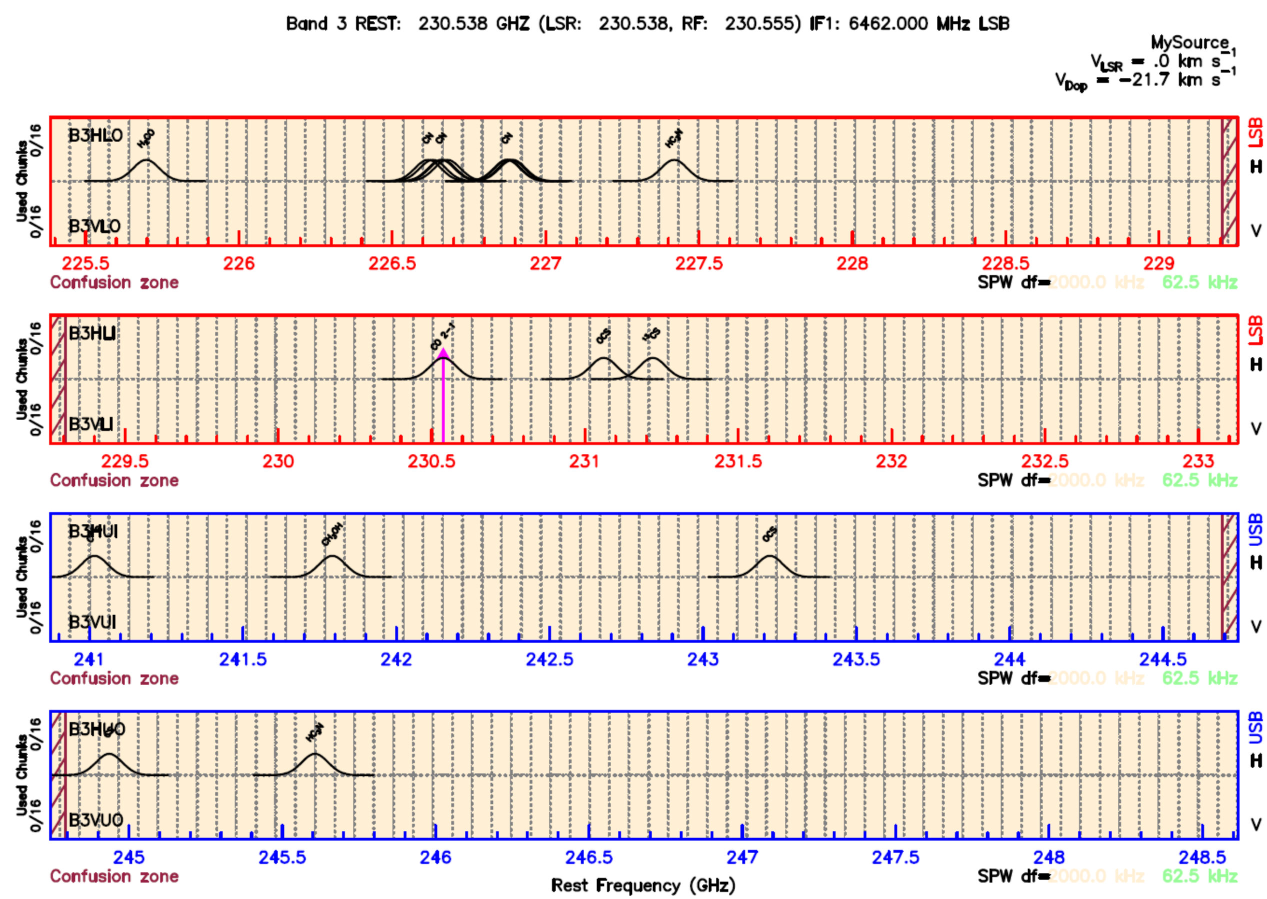
```
TUNING ! Display the coverage of available receiver bands
TUNING 230.538 LSB 6500 /ZOOM ! tune 230.538 REST at 6500 IF1 in LSB
    I-TUNING,  Resetting tuning
    I-TUNING,  Selecting the Band_3 band of the NOEMA receiver
    I-TUNING,   FRF      =  230.55466 GHz
    I-TUNING,   FLO1     :
    I-TUNING,   FLOTUNE  :
    I-TUNING,  Original
    I-TUNING,  Tuning au
    I-TUNING,  This corr
    I-TUNING,  Actual co
    TUNING 230.538 LSB 6
    I-TUNING,  Selecting
    I-TUNING,   FRF      :
    I-TUNING,   FLO1     :
    I-TUNING,   FLOTUNE  :
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
    I-TUNING,  Correlato
```



NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

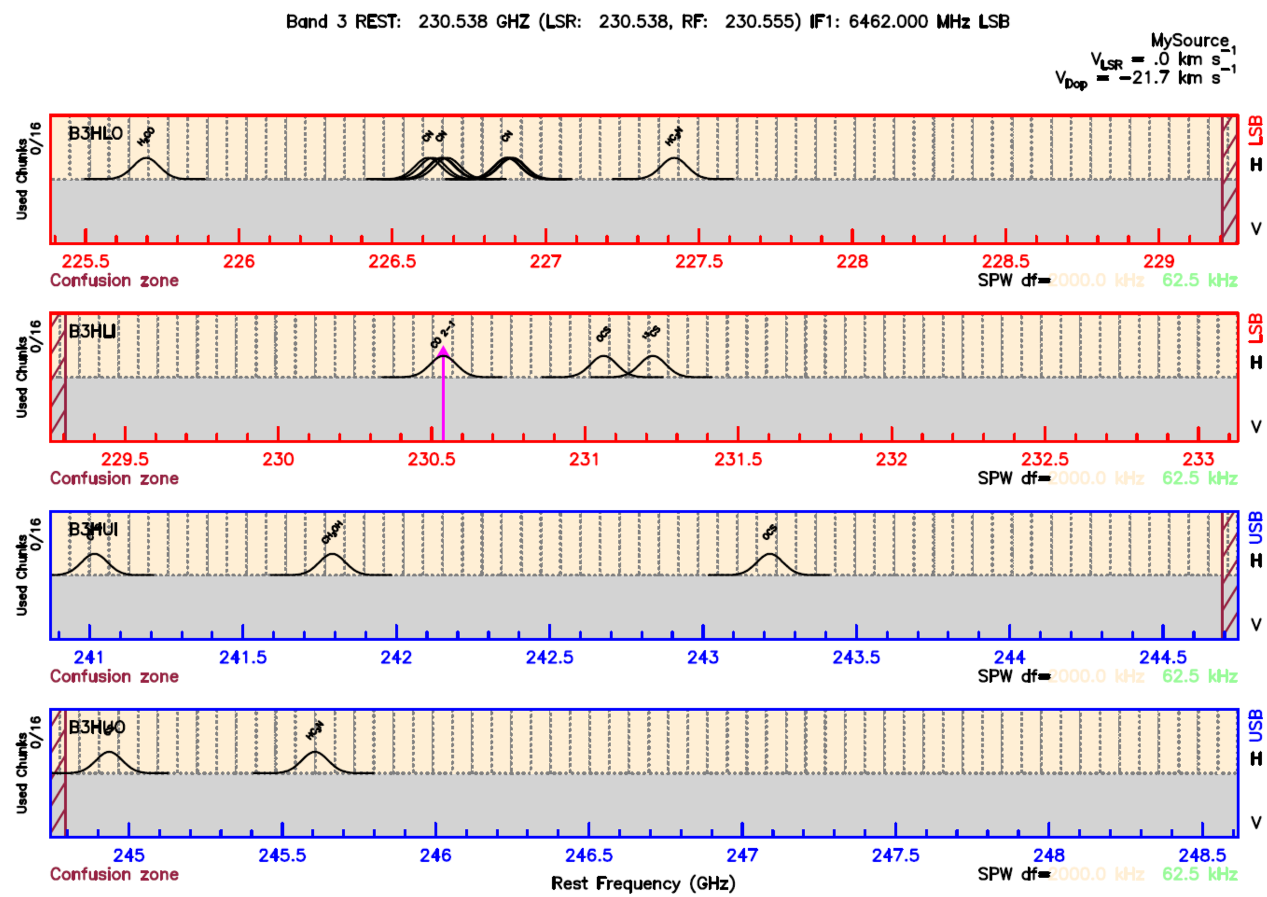
```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                     combination of H/V,U/L,O/I
BASEBAND   ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
```



NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

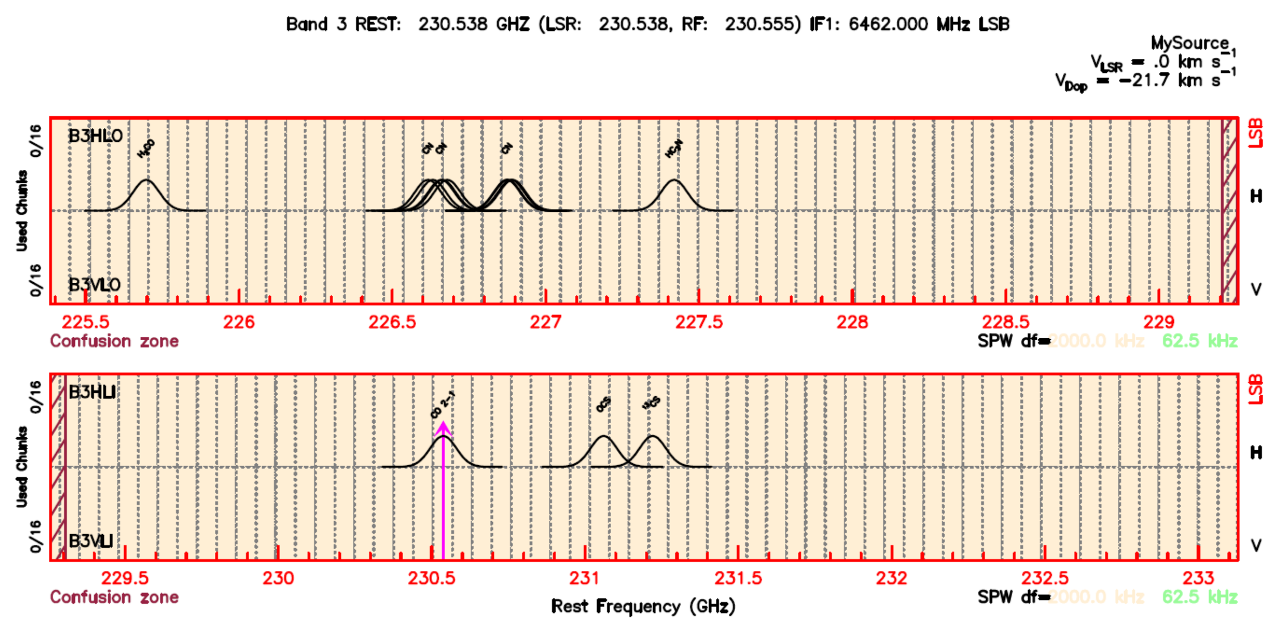
```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                   combination of H/V,U/L,O/I
BASEBAND   ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
BASEBAND H ! H polar selected: H x (U+L) x (O+I) = 4 basebands
```



NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

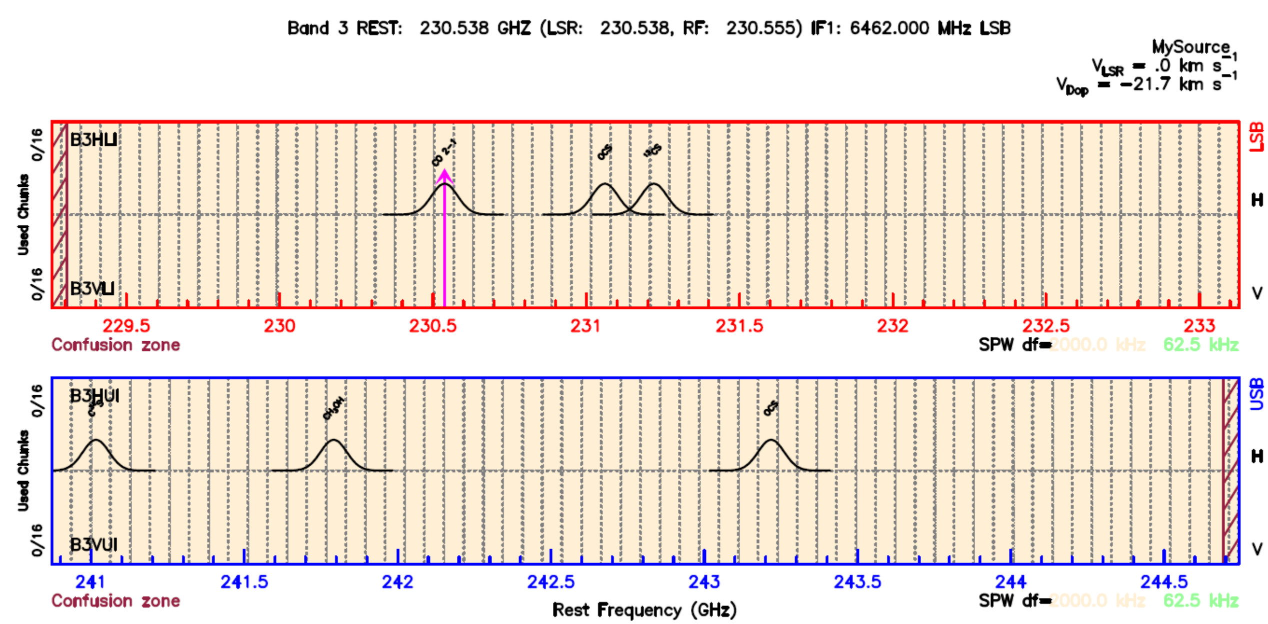
```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                           combination of H/V,U/L,O/I
BASEBAND   ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
BASEBAND H ! H polar selected: H x (U+L) x (O+I) = 4 basebands
BASEBAND L ! Lower sideband : (H+V) x L x (O+I) = 4 basebands
```



NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

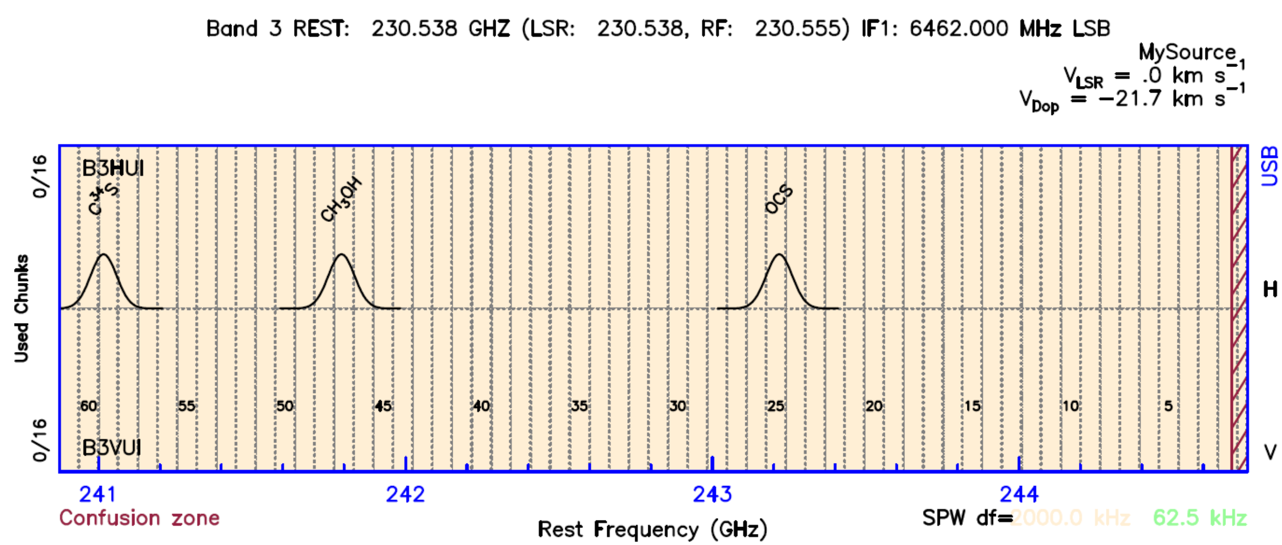
```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                   combination of H/V,U/L,O/I
BASEBAND   ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
BASEBAND H ! H polar selected: H x (U+L) x (O+I) = 4 basebands
BASEBAND L ! Lower sideband : (H+V) x L x (O+I) = 4 basebands
BASEBAND I ! Inner basebands: (H+V) x (U+L) x I = 4 basebands
```



NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                            combination of H/V,U/L,O/I
BASEBAND    ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
BASEBAND H ! H polar selected: H x (U+L) x (O+I) = 4 basebands
BASEBAND L ! Lower sideband : (H+V) x L x (O+I) = 4 basebands
BASEBAND I ! Inner basebands: (H+V) x (U+L) x I = 4 basebands
BASEBAND UI ! Upper SB, Inner BB: (H+V) x U x I = 2 basebands
```

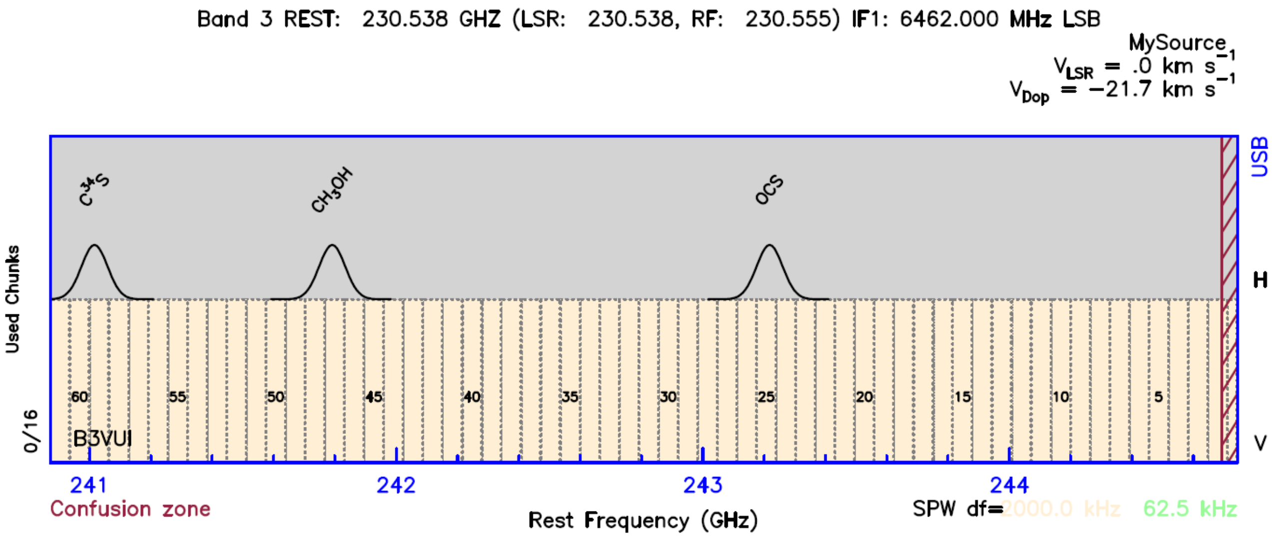


NOEMA setups in ASTRO

Select a/some basebands and assign a correlator mode

```
BASEBAND Mode SelectionCode
! Mode not useful yet, omitted
! Selection code = baseband identification
                  combination of H/V,U/L,O/I
BASEBAND   ! No selection: (H+V) x (U+L) x (O+I) = 8 basebands
BASEBAND H ! H polar selected: H x (U+L) x (O+I) = 4 basebands
BASEBAND L ! Lower sideband : (H+V) x L x (O+I) = 4 basebands
BASEBAND I ! Inner basebands: (H+V) x (U+L) x I = 4 basebands
BASEBAND UI ! Upper SB, Inner BB: (H+V) x U x I = 2 basebands
BASEBAND VUI ! V, Upper SB, Inner BB: V x U x I = 1 baseband
```

```
BASEBAND [H|V][U|L][O|I] /RESET
! Remove all existing spw
from the selected baseband(s)
```



NOEMA setups in ASTRO

Define Spectral Windows

```
BASEBAND VUI
SPW /FREQUENCY 243.25 0.3
! 1 SPW covering a range centered at 243.25 with a width of 300 MHz
    I-SPW,  SPW fits in unit 4 B3VUI
    I-SPW,  Spectral window covers chunks 22 to 27
    I-SPW,  Unit B3VUI High_Res is used at 38%
LIST
    I-LIST,  9 spectral windows defined:
    SPW  1 in B3HLO: df = 2000.000 kHz, Chunks  1 to 61, REST  225384.37 to 229256.09 MHz
    [...]
    SPW  8 in B3VUO: df = 2000.000 kHz, Chunks  1 to 61, REST  244742.97 to  248614.69 MHz
    SPW  9 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
```

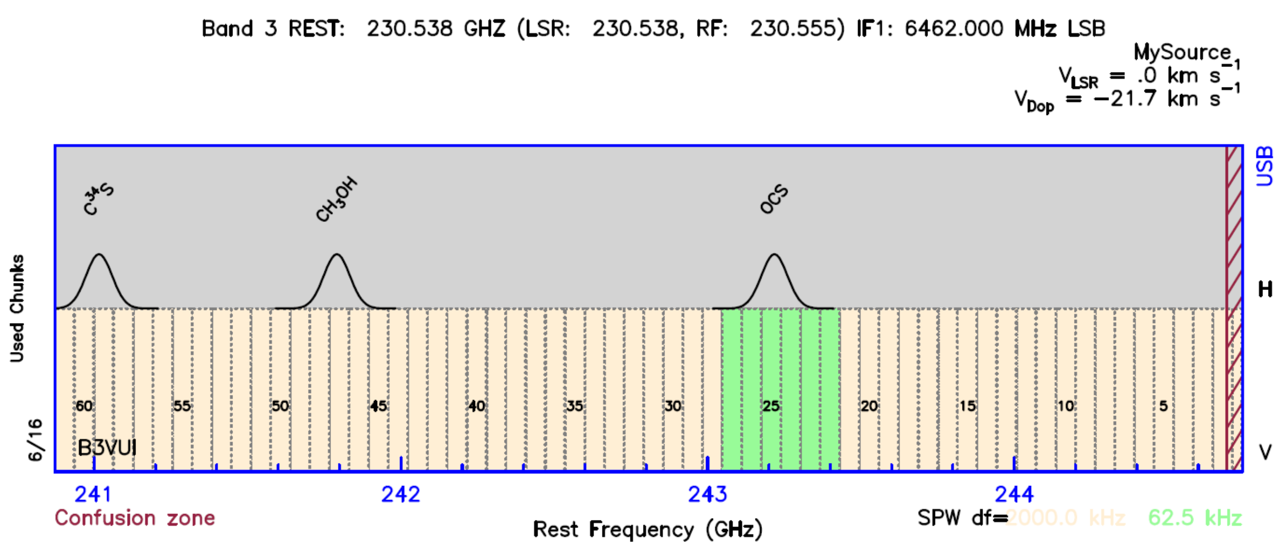
Nota Bene:

Actual coverage is not exactly 300 MHz

(6 x 64=384 MHz)

The system uses the chunks necessary to cover the requested range

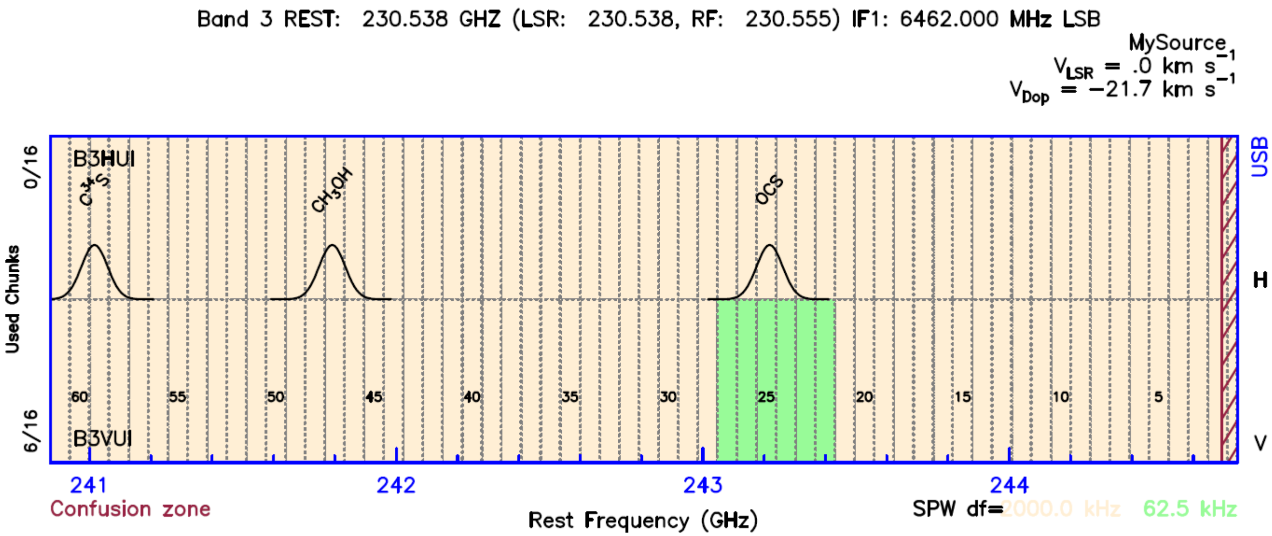
Chunks are on a fixed grid, with a fix width



NOEMA setups in ASTRO

Define Spectral Windows

BASEBAND UI



NOEMA setups in ASTRO

Define Spectral Windows

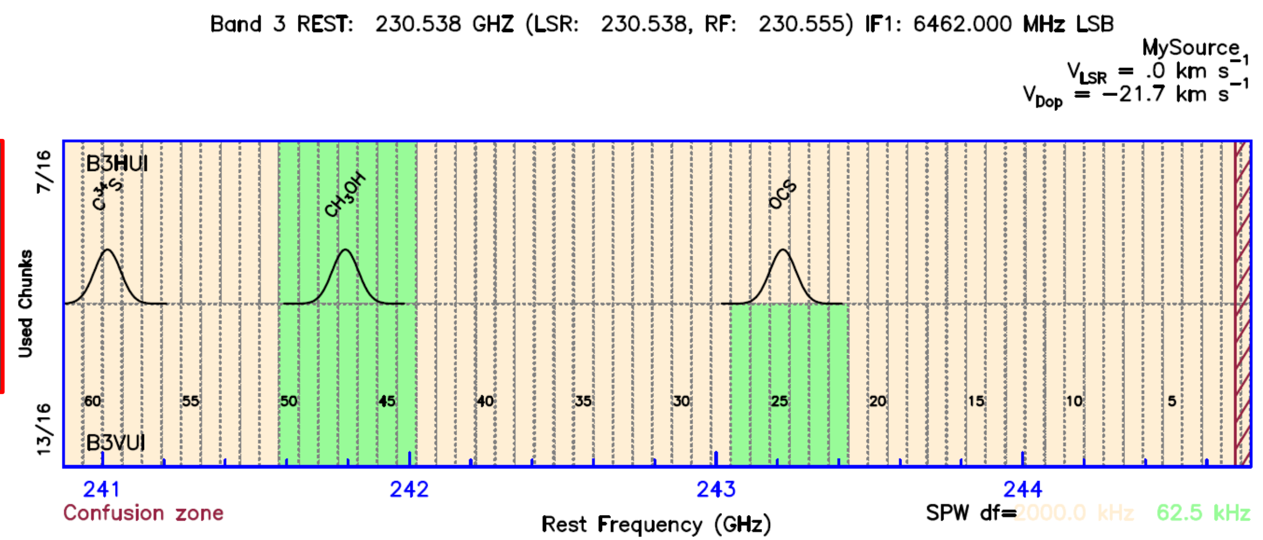
```
BASEBAND UI
SPW /RANGE 241.6 242 ! SPW from 241.6 to 242 in H and V (2SPW)
    I-SPW,  SPW fits in unit 2 B3HUI
    I-SPW,  Spectral window covers chunks 44 to 50
    I-SPW,  Unit B3HUI High_Res is used at 44%
    I-SPW,  SPW fits in unit 4 B3VUI
    I-SPW,  Spectral window covers chunks 44 to 50
    I-SPW,  Unit B3VUI High_Res is used at 81%
LIST
    I-LIST, 11 spectral windows defined:
    [...]SPW  1 in B3HLO: df = 2000.000 kHz, Chunks  1 to 61, REST  225384.37 to 229256.09 MHz
    SPW  8 in B3VUO: df = 2000.000 kHz, Chunks  1 to 61, REST  244742.97 to  248614.69 MHz
    SPW  9 in B3HUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz
    SPW 10 in B3VUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz
    SPW 11 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
```

Nota Bene:

Actual SPW width is not exactly 400 MHz

(7 x 64 = 448 MHz)

Chunks are on a fixed grid, with a fix width



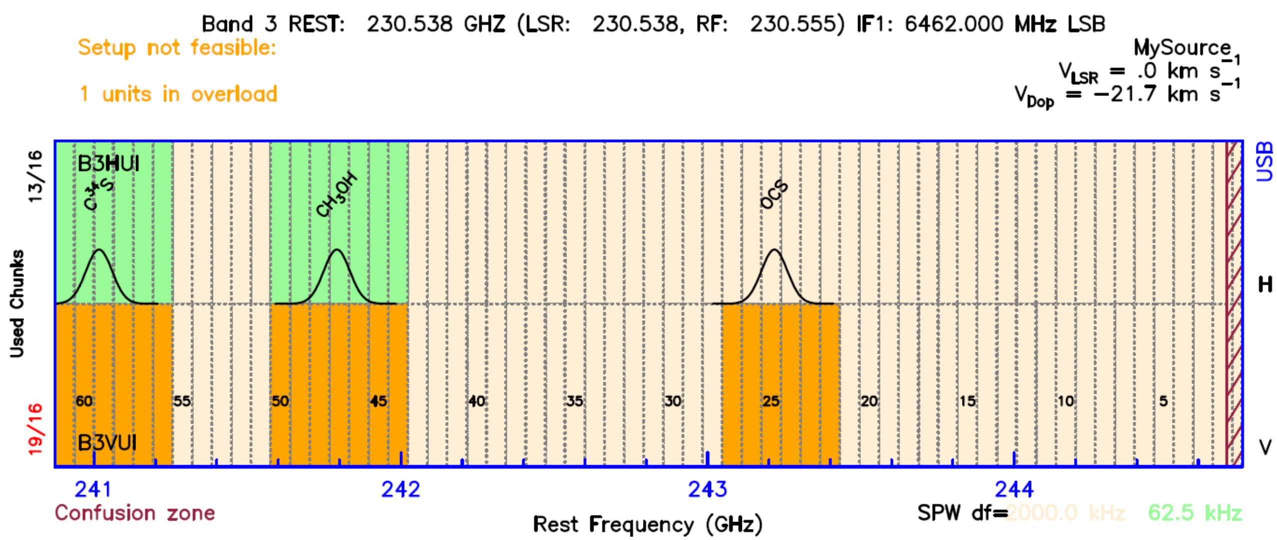
NOEMA setups in ASTRO

Define Spectral Windows

```
BASEBAND UI
SPW /CHUNK 56 to 61 ! 2 SPW defined by chunk numbers
    I-SPW,  Unit B3HUI High_Res is used at 81%
    I-SPW,  Unit B3VUI High_Res is used at 119%
    W-SPW,  You are using more resources than available
! Setup using more than 16 high res chunks in VUI
```

Nota Bene:

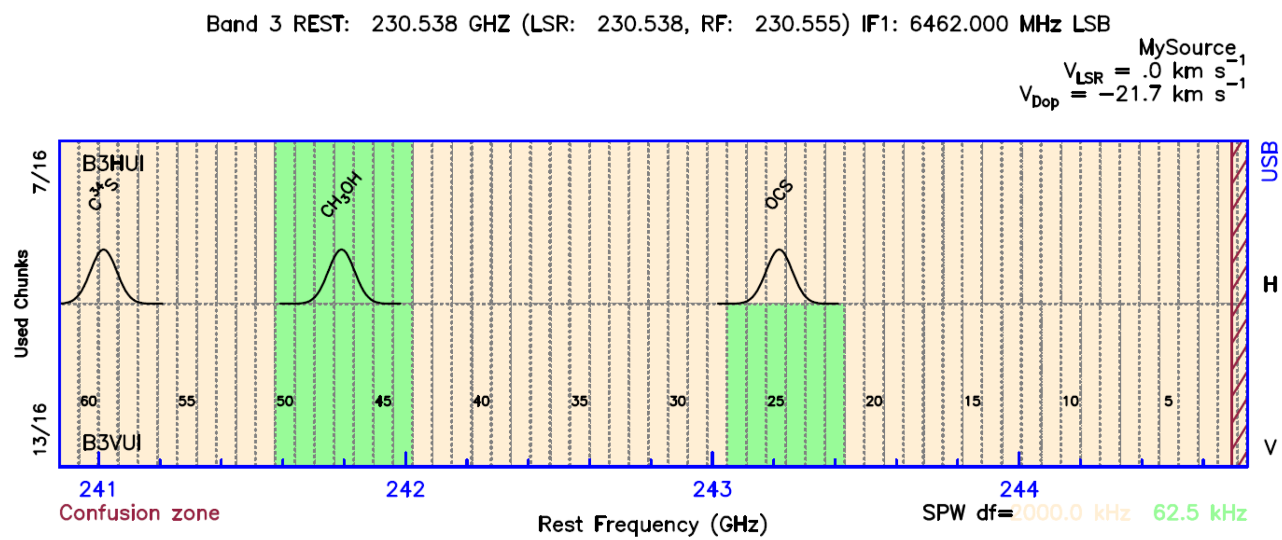
/CHUNK option available only when the baseband selection continas only 1 frequency range (eventually dual polars)



NOEMA setups in ASTRO

Define Spectral Windows

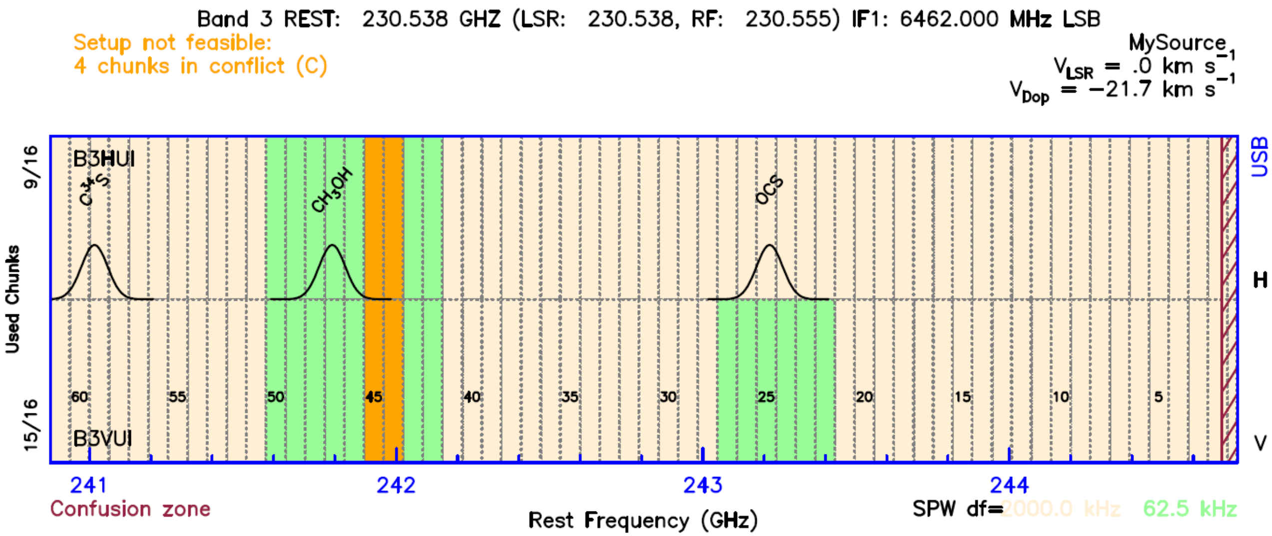
```
BASEBAND UI
SPW /CHUNK 56 to 61 ! 2 SPW defined by chunk numbers
    I-SPW,  Unit B3HUI High_Res is used at 81%
    I-SPW,  Unit B3VUI High_Res is used at 119%
    W-SPW,  You are using more resources than available
! Setup using more than 16 high res chunks in VUI
RESET LAST
    I-RESET,  Resetting Spectral Window # 10
    I-RESET,  Resetting Spectral Window # 9
    I-LIST,  11 spectral windows defined:
    SPW  1 in B3HLO: df = 2000.000 kHz, Chunks  1 to 61, REST  225384.37 to  229256.09 MHz
    [...]
    SPW  9 in B3HUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz
    SPW 10 in B3VUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz
    SPW 11 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
```



NOEMA setups in ASTRO

Define Spectral Windows

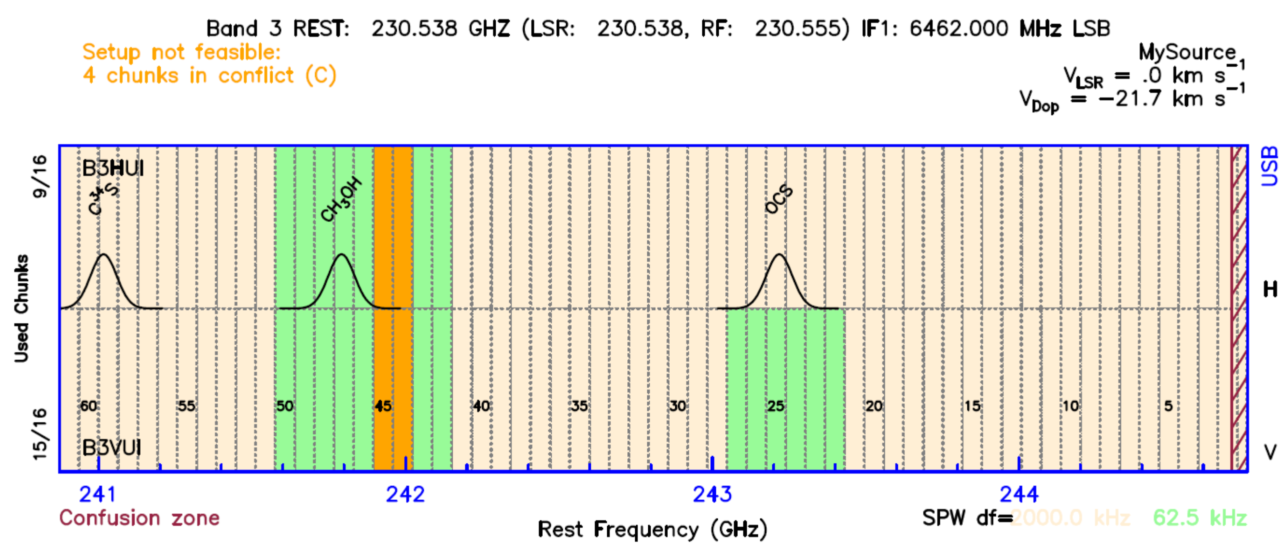
```
BASEBAND UI
SPW /CHUNK 42 to 45
    I-SPW,  Unit B3HUI High_Res is used at 56%
    I-SPW,  Unit B3VUI High_Res is used at 94%
    W-SPW,  SPW #9 uses conflicting chunk(s)
    W-SPW,  SPW #10 uses conflicting chunk(s)
    W-SPW,  SPW #11 uses conflicting chunk(s)
    W-SPW,  SPW #12 uses conflicting chunk(s)
! Setup using several times the same chunks
```



NOEMA setups in ASTRO

Define Spectral Windows

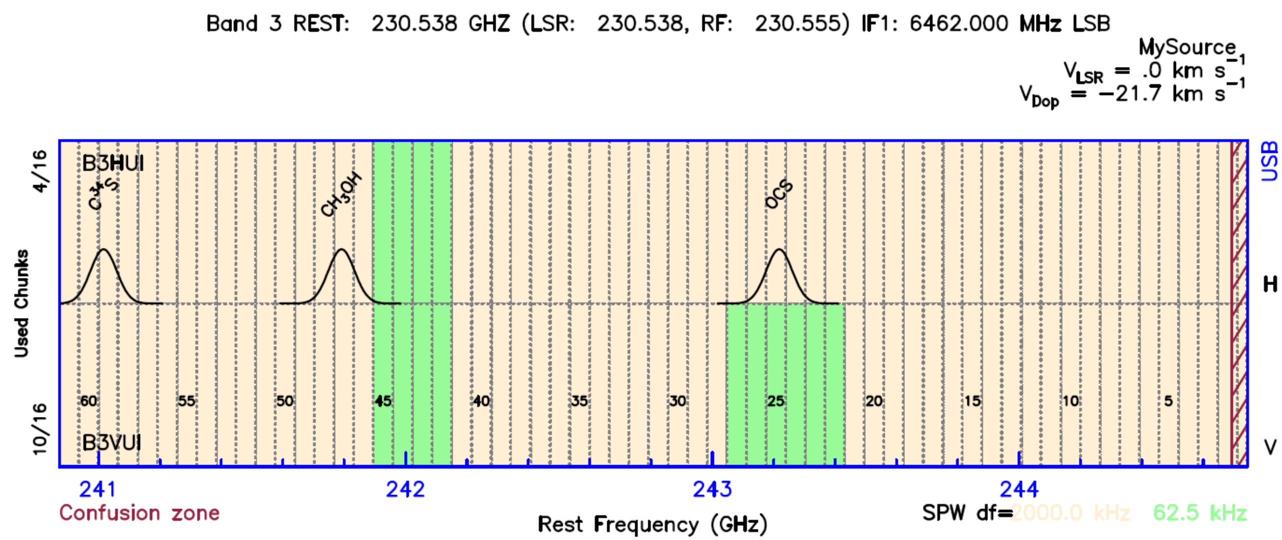
```
BASEBAND UI
SPW /CHUNK 42 to 45
! Setup using several times the same chunks
LIST
[...]
SPW  9 in B3HUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz !Conflict!
SPW 10 in B3VUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz !Conflict!
SPW 11 in B3HUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz !Conflict!
SPW 12 in B3VUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz !Conflict!
SPW 13 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
```



NOEMA setups in ASTRO

Define Spectral Windows

```
BASEBAND UI
SPW /CHUNK 42 to 45
! Setup using several times the same chunks
LIST
[...]
SPW  9 in B3HUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz !Conflict!
SPW 10 in B3VUI: df =   62.500 kHz, Chunks 44 to 50, REST  241575.20 to  242023.17 MHz !Conflict!
SPW 11 in B3HUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz !Conflict!
SPW 12 in B3VUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz !Conflict!
SPW 13 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
RESET 9 10
[...]
SPW  9 in B3HUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz
SPW 10 in B3VUI: df =   62.500 kHz, Chunks 42 to 45, REST  241895.18 to  242151.16 MHz
SPW 11 in B3VUI: df =   62.500 kHz, Chunks 22 to 27, REST  243047.10 to  243431.07 MHz
```

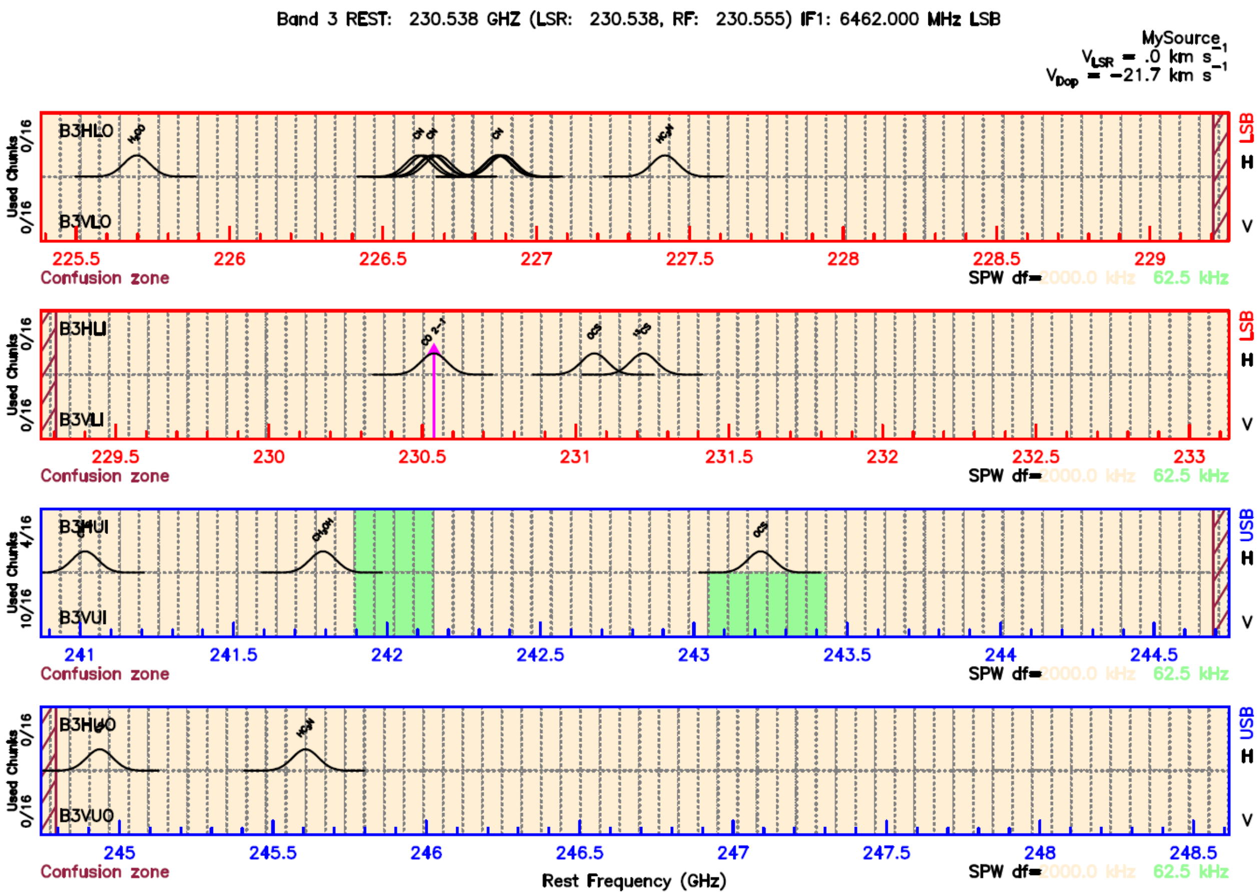


NOEMA setups in ASTRO

Visualize current state

PLOT

PLOT /RECEIVER

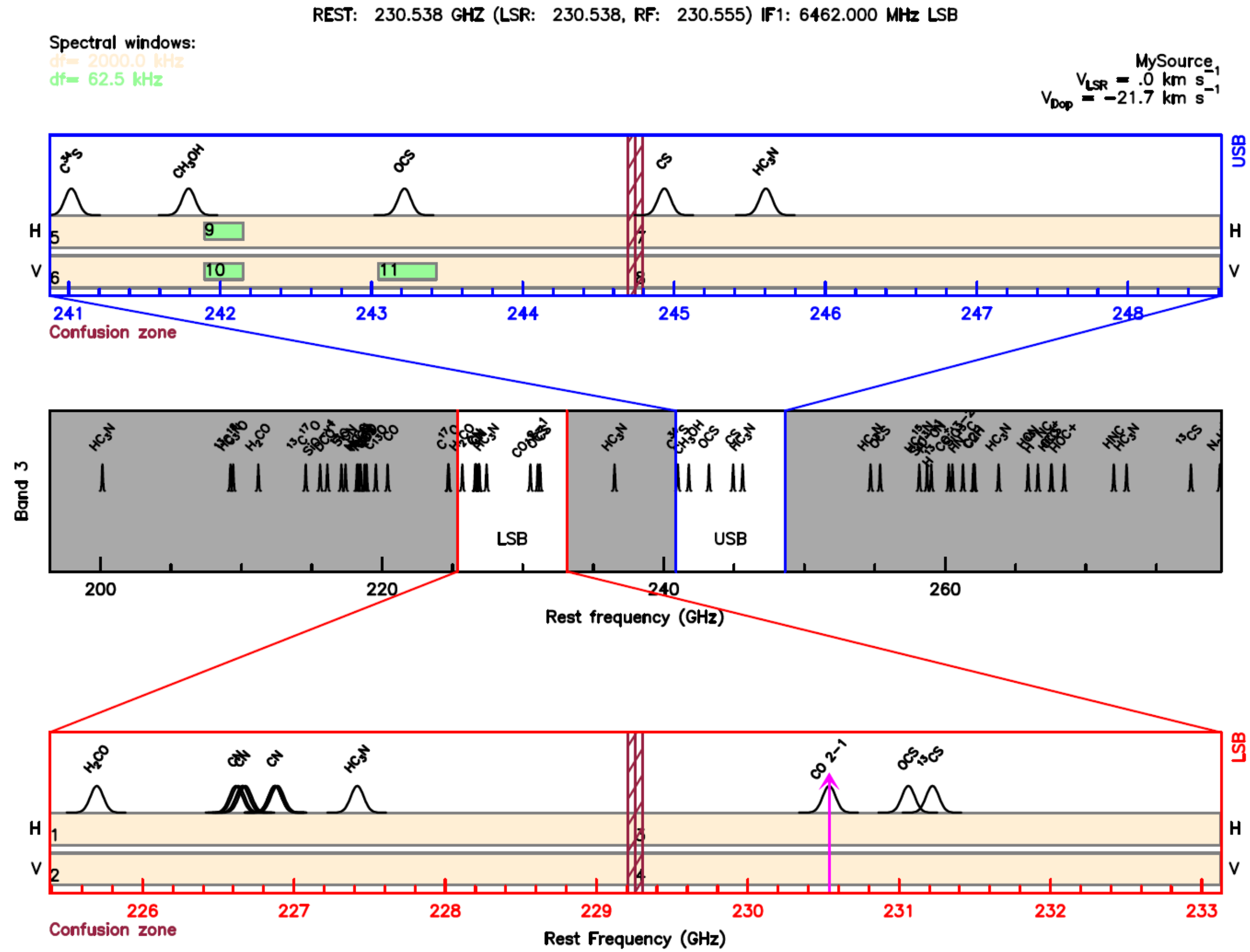


NOEMA setups in ASTRO

Visualize current state

PLOT

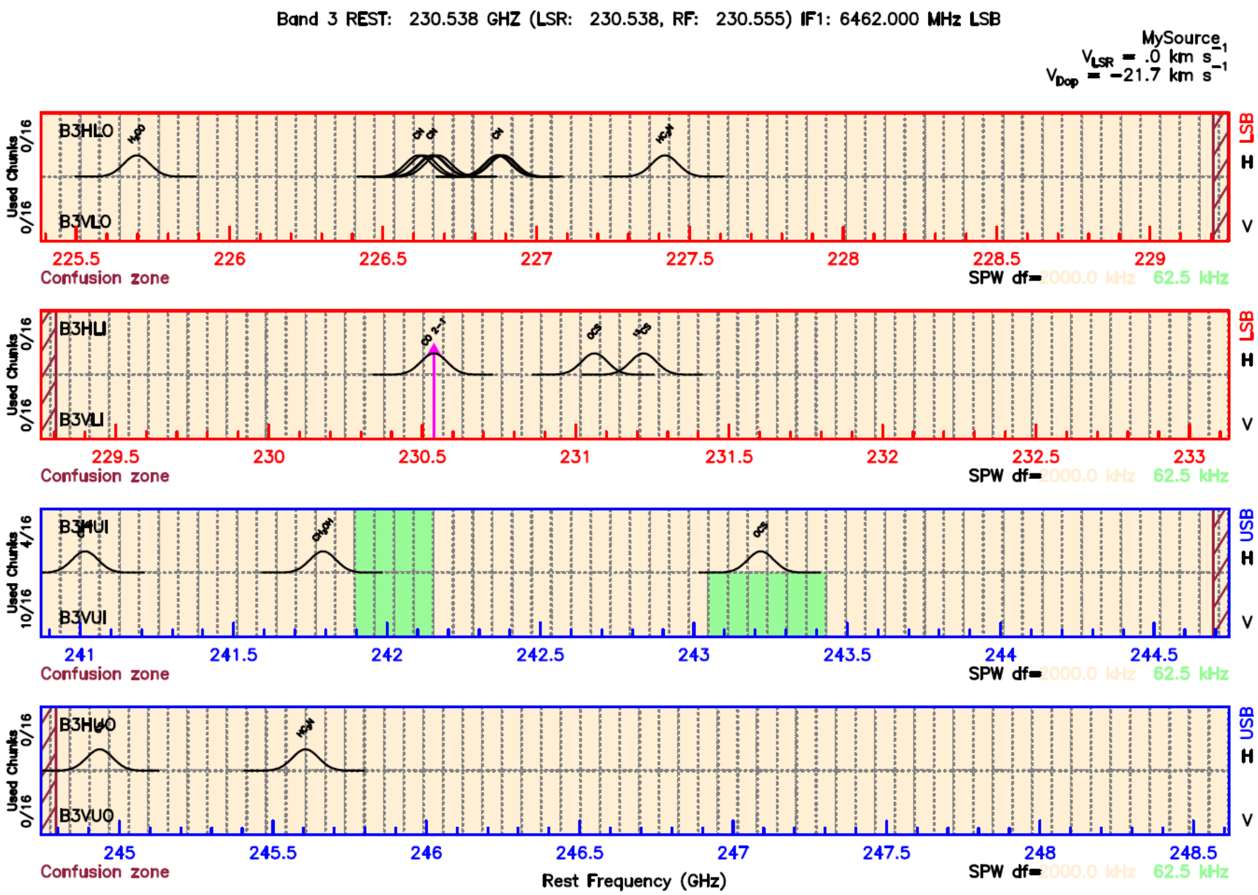
PLOT /RECEIVER



NOEMA setups in ASTRO

Define Spectral Windows

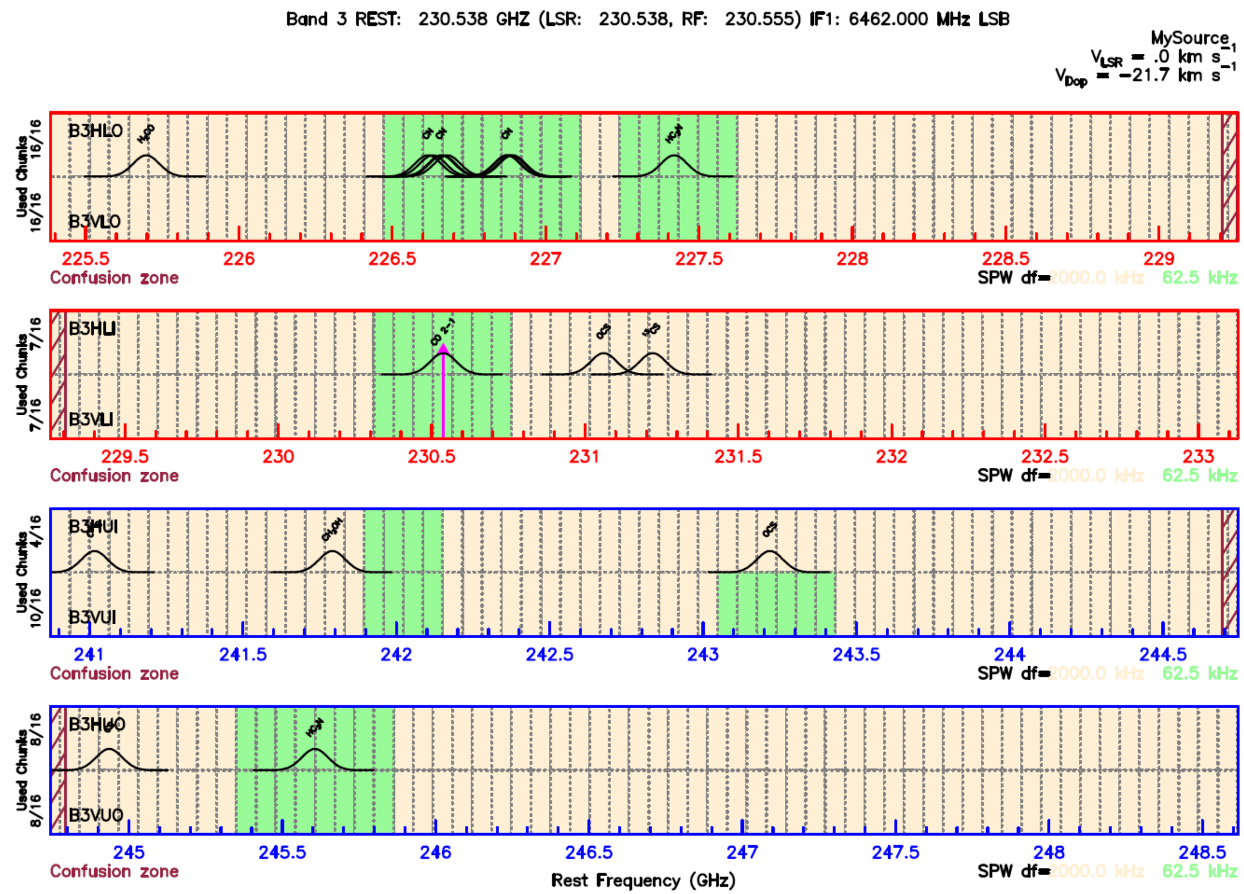
```
BASEBAND ! All basebands selected
```



NOEMA setups in ASTRO

Define Spectral Windows

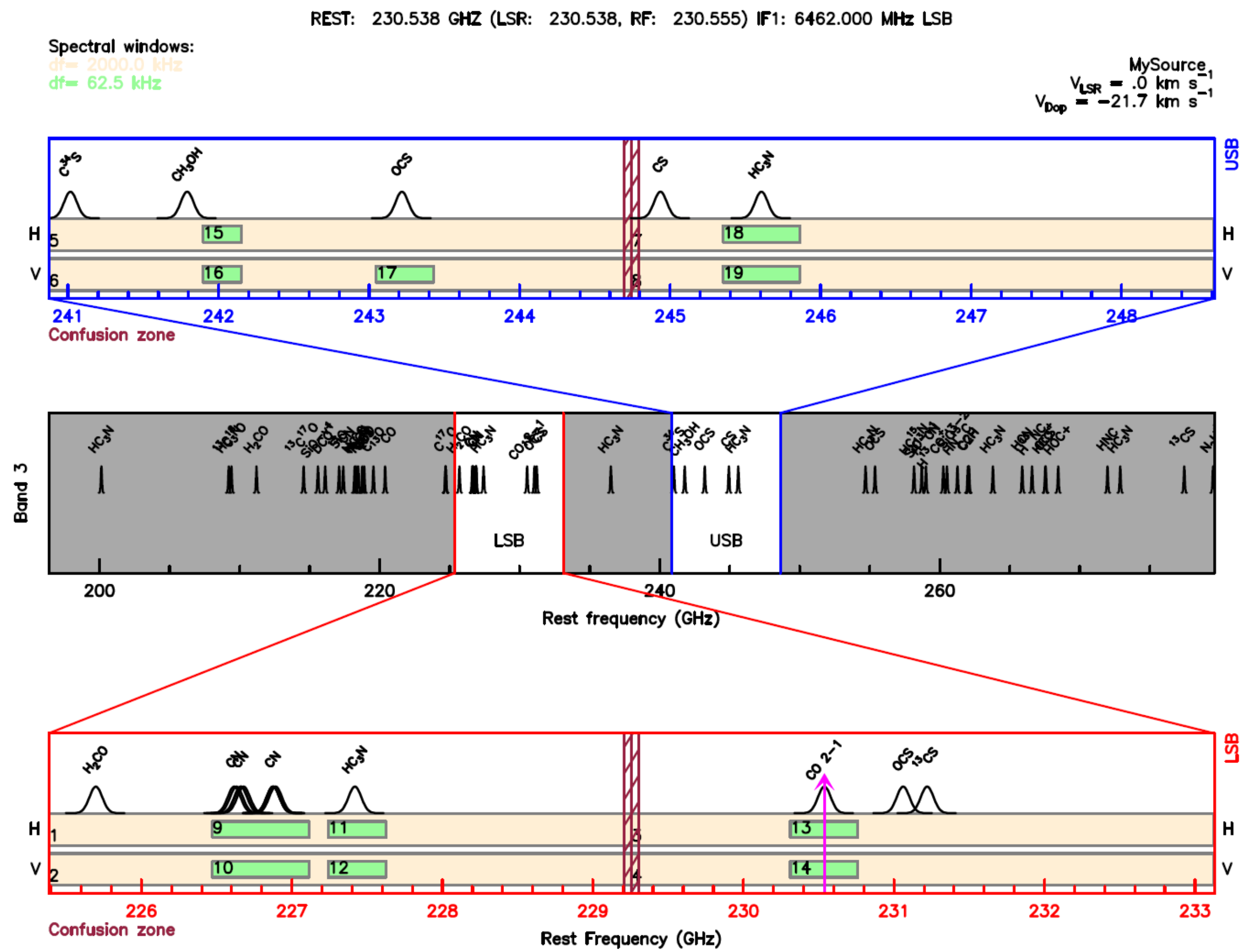
```
BASEBAND ! All basebands selected
SPW /FREQUENCY 230.538 0.4
SPW /RANGE 226.5 227.1
SPW /RANGE 227.3 227.6
SPW /FREQUENCY 245.6 0.4
```



NOEMA setups in ASTRO

Define Spectral Windows

```
BASEBAND ! All basebands selected
SPW /FREQUENCY 230.538 0.4
SPW /RANGE 226.5 227.1
SPW /RANGE 227.3 227.6
SPW /FREQUENCY 245.6 0.4
PLOT /RECEIVER
SETUP /FILE MyFile.astro
! write the minimal series
of commands to come back
to the current configuration
and to set up the instrument
```



NOEMA spectral setups in ASTRO

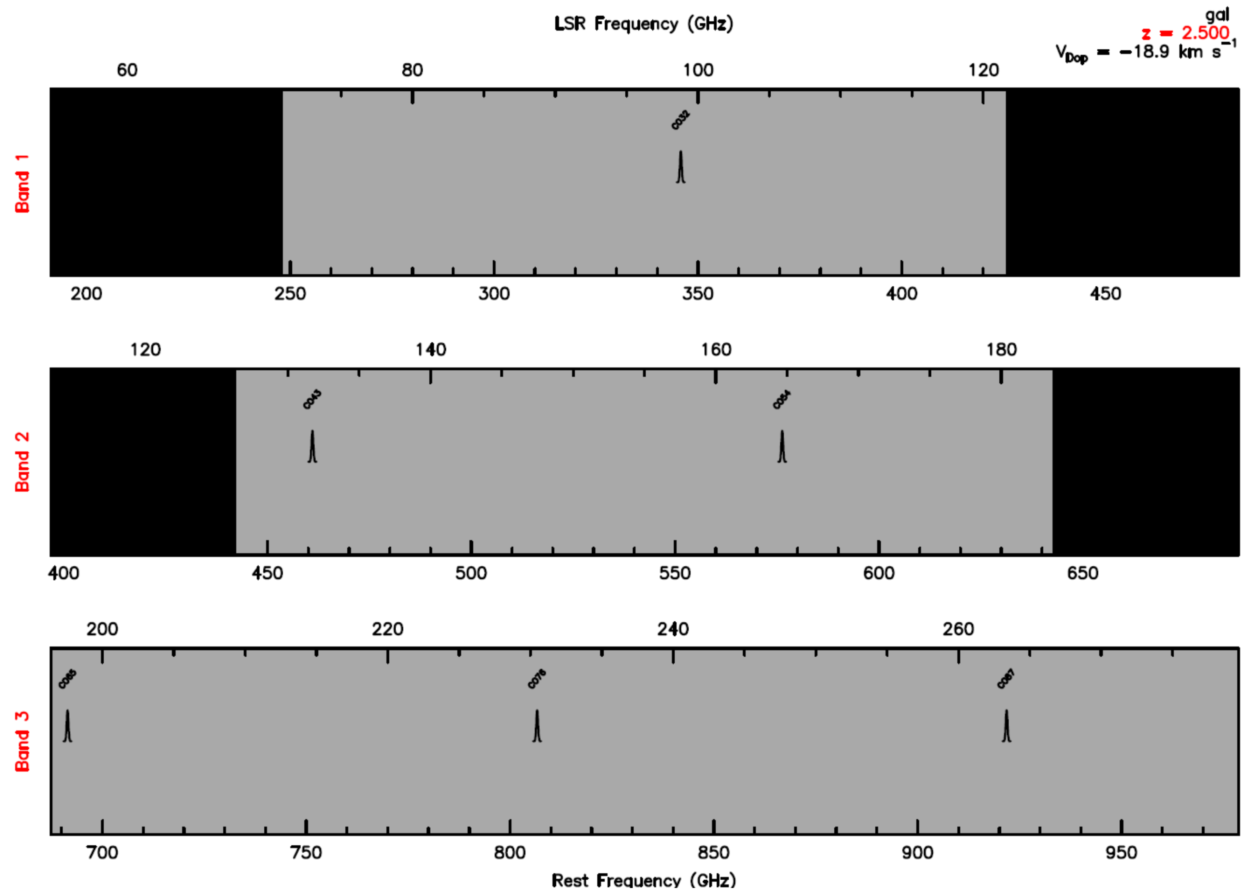
Frequency axes

- All previous ASTRO plots were in REST frequency
- Actual frequency in the receiver is RF
- $F_{RF} = F_{REST}$ x DopplerFactor
  - Observatory contribution:
    - Earth rotation + revolution (<30 km/s ~ 10 MHz @ 100 GHz)
      Varies with time
  - Source contribution:
    - LSR velocity (~100 km/s ~ 30 MHz @ 100 GHz)
    - Redshift
      - 350GHz REST @ z=2.5 observed at ~100 GHz in RF
- Doppler corrections at NOEMA
  - Source LSR taken into account
    - F_{LO} is shifted
  - Earth Doppler corrected on real time (Doppler tracking)
    - F_{LO} changes with time
  - Redshift not corrected
    - Compute redshifted frequency and assume z and LSR = 0
    - ASTRO can help (`SET FREQUENCY [LSR|REST]`)

NOEMA spectral setups in ASTRO

Example with redshifted source

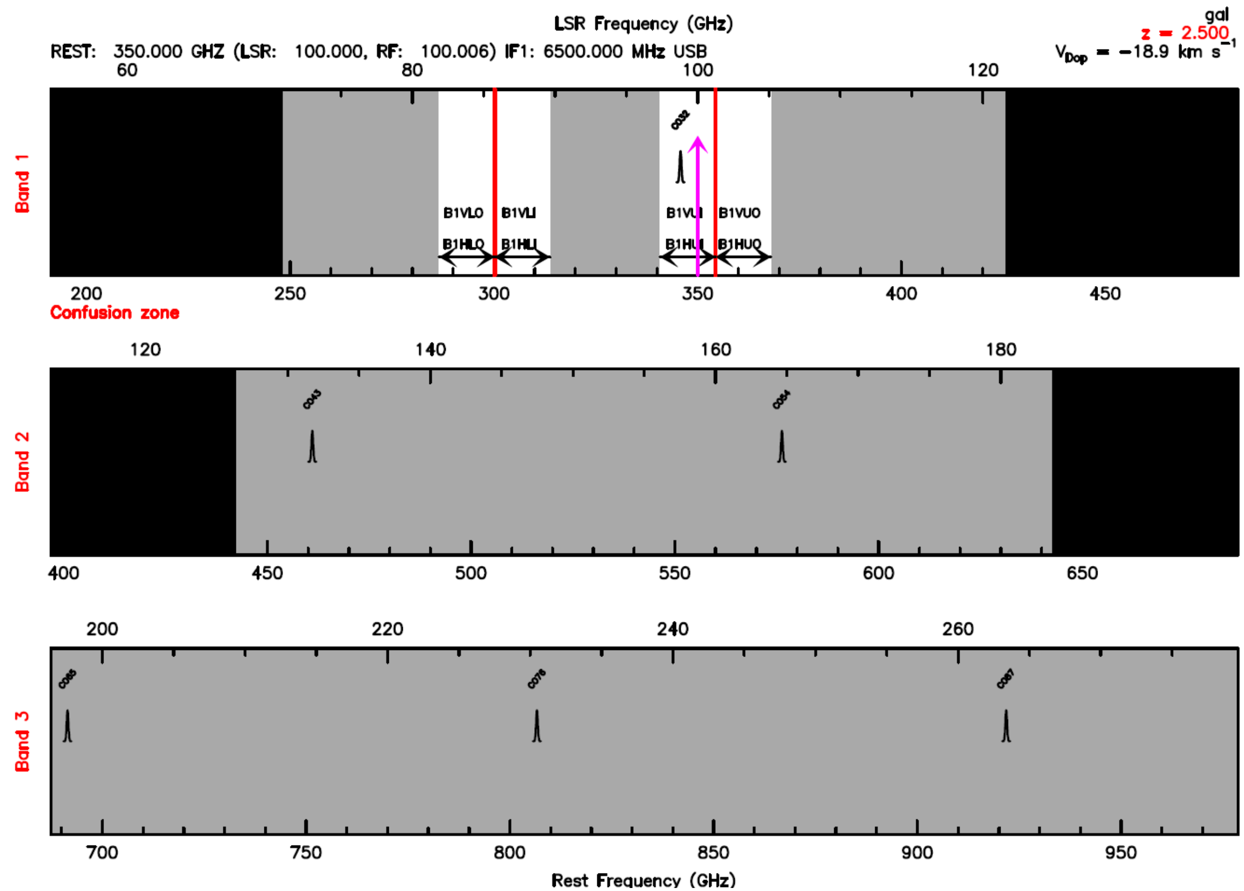
```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
```



NOEMA spectral setups in ASTRO

Example with redshifted source

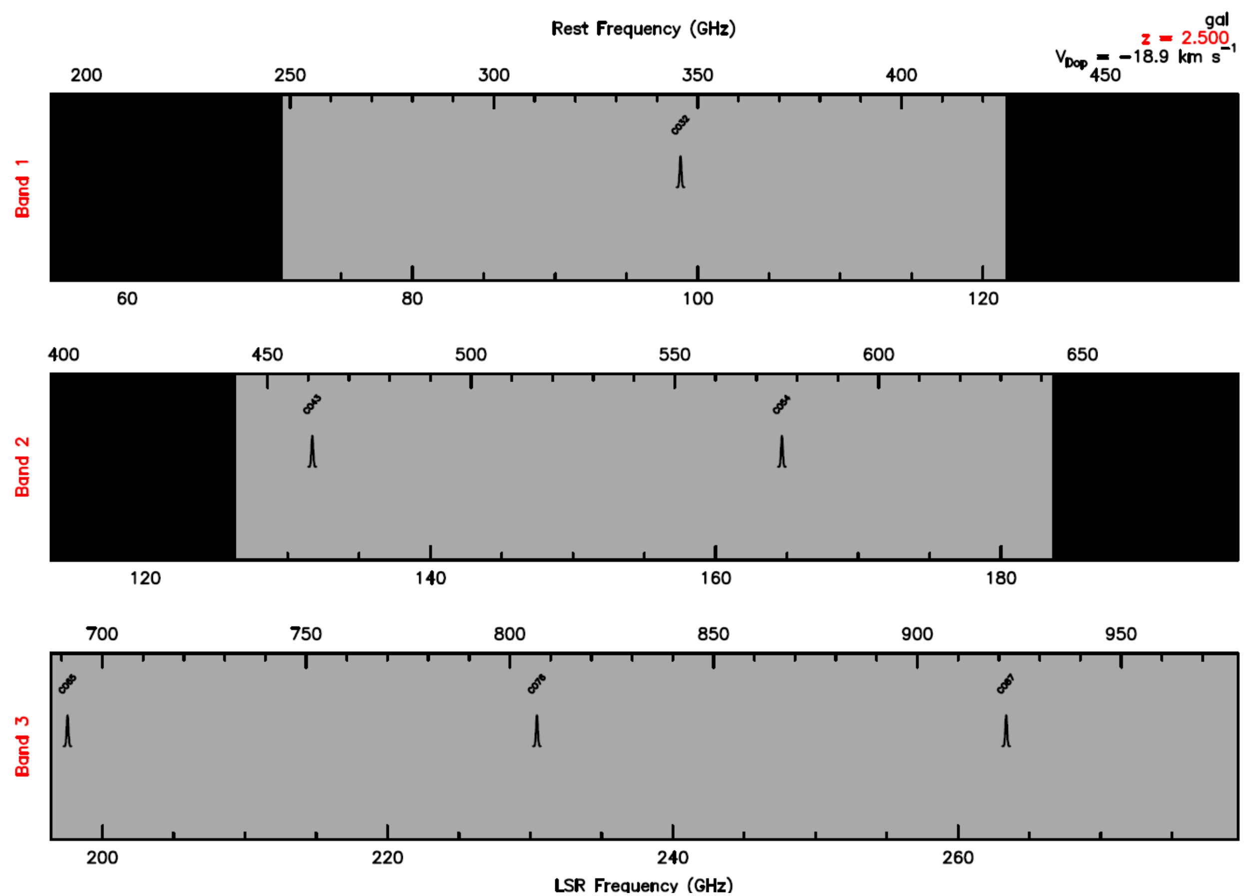
```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
```



NOEMA spectral setups in ASTRO

Example with redshifted source

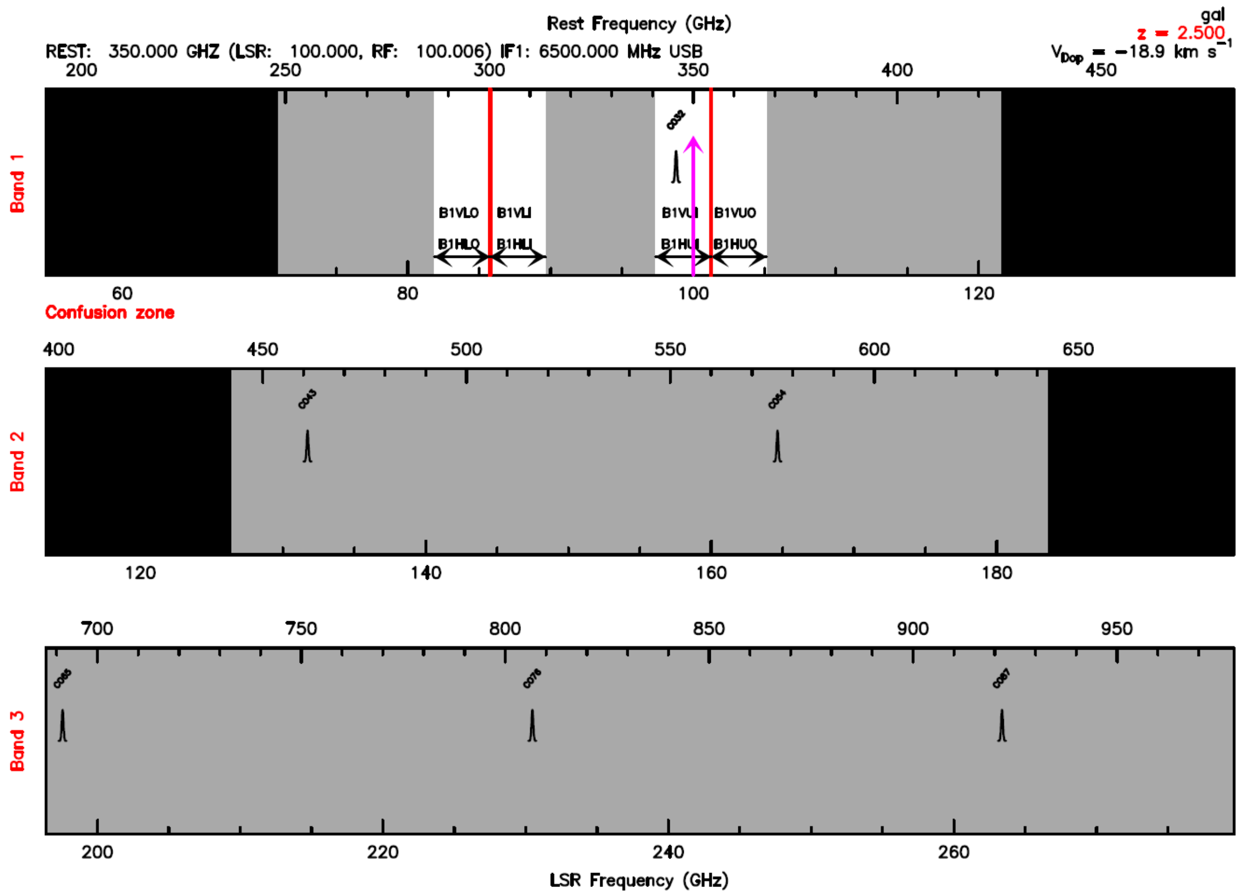
```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
SET FREQ LSR REST
TUNING
```



NOEMA spectral setups in ASTRO

Example with redshifted source

```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
SET FREQ LSR REST
TUNING
TUNING 100 USB 6500
```

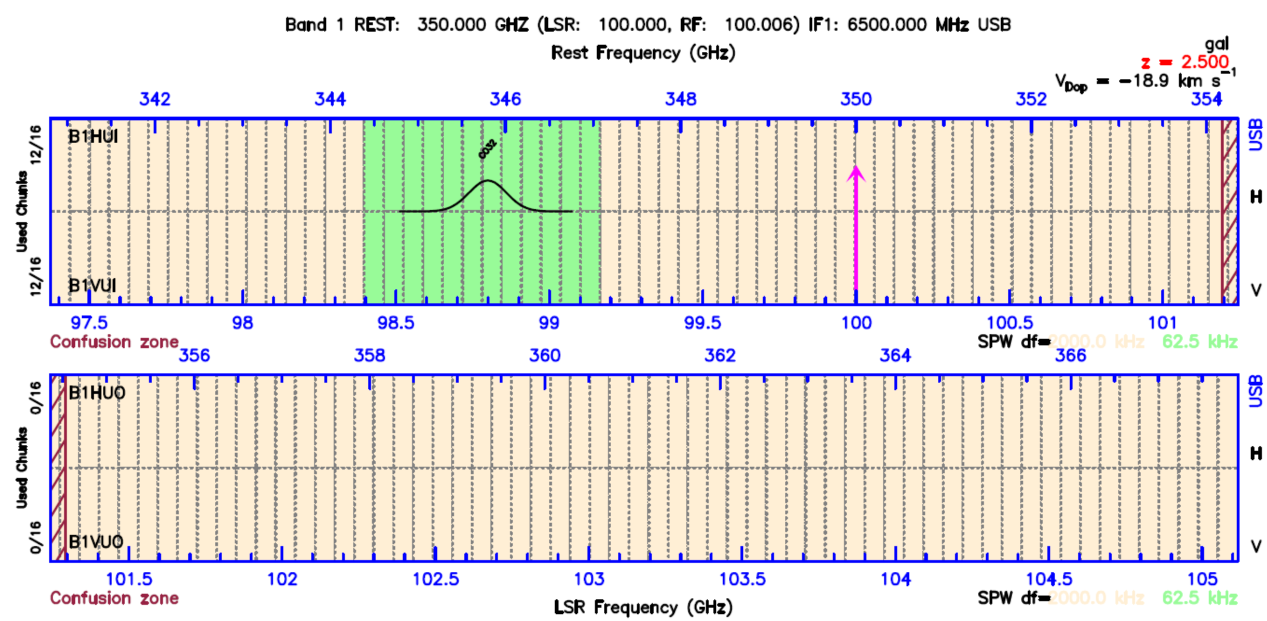


NOEMA spectral setups in ASTRO

Example with redshifted source

```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
SET FREQ LSR REST
TUNING
TUNING 100 USB 6500
BASEBAND U
SPW /FREQUENCY 98.8 0.7
```

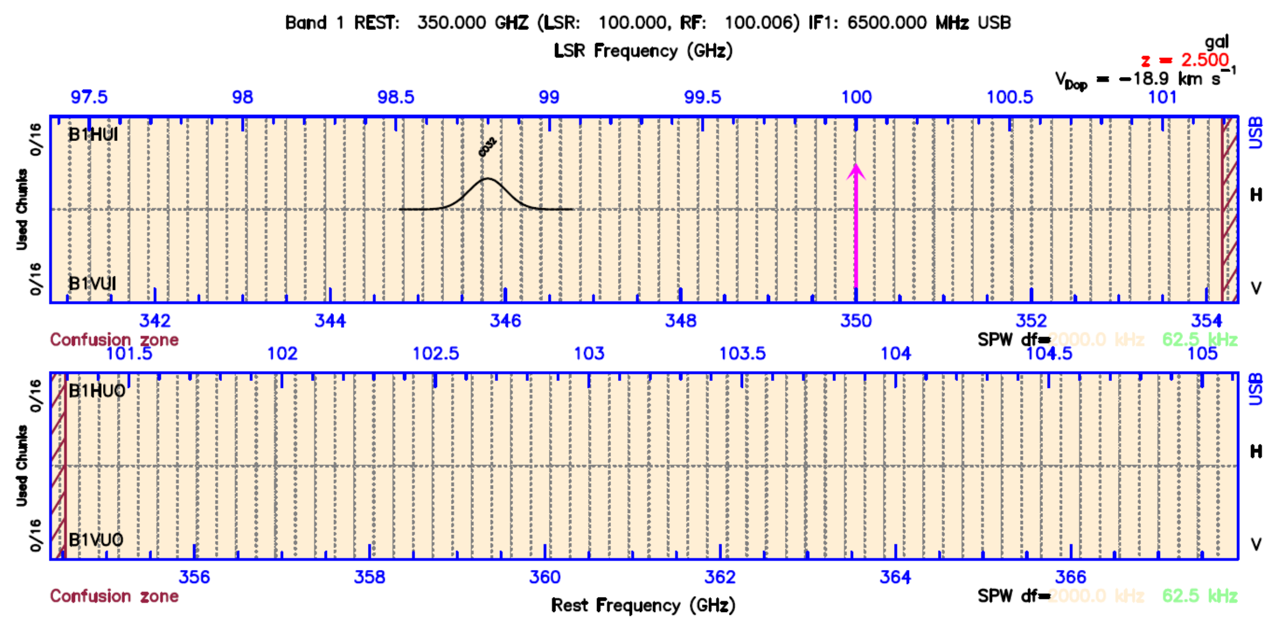
Chunks 34 to 45



NOEMA spectral setups in ASTRO

Example with redshifted source

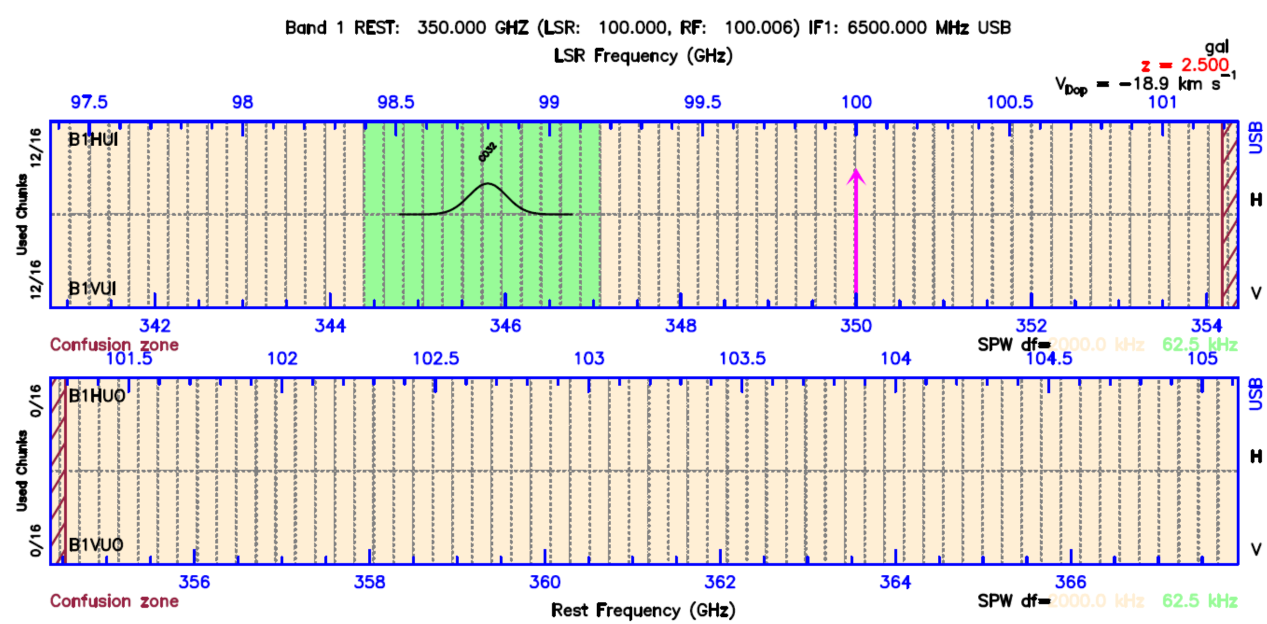
```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
SET FREQ LSR REST
TUNING
TUNING 100 USB 6500
BASEBAND U
SPW /FREQUENCY 98.8 0.7
    Chunks 34 to 45
RESET
SET FREQ REST LSR
BASEBAND U
```



NOEMA spectral setups in ASTRO

Example with redshifted source

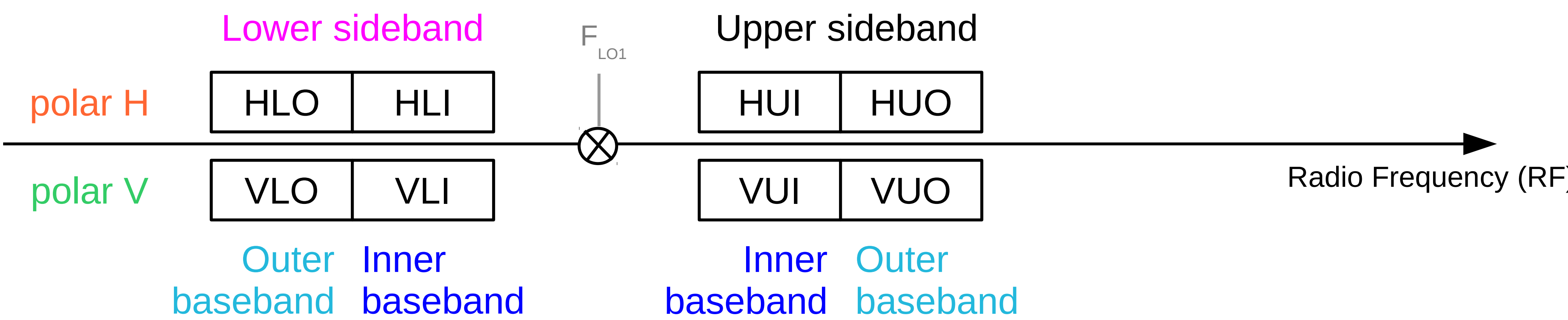
```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Ouput in terminal
CATA CO.DAT /LINE ! Local file with only CO transitions
SET LINES GAUSS 500
SOURCE GAL EQ 2000 10 10 RED 2.5
TUNING
TUNING 350 USB 6500
SET FREQ LSR REST
TUNING
TUNING 100 USB 6500
BASEBAND U
SPW /FREQUENCY 98.8 0.7
    Chunks 34 to 45
RESET
SET FREQ REST LSR
BASEBAND U
SPW /FREQ 345.8 2.45
! 98.8*3.5=345.8, 0.7*3.5=2.45
    Chunks 34 to 45
```



Summary

2SB, dual polar, receivers

- 4-12 GHz IF1 split into 2 basebands (0-4GHz IF2)



8 Basebands (0-4GHz) feed 8 Correlator units

	1 Unit	All Units
Mode 1 (2017): Continuum + Lines	61 chunks (3872 MHz) at 2 MHz resolution **AND** 16 chunks at 62.5 kHz resolution*	~16 GHz x 2 polar with 2 MHz channels **AND** 8 GHz with 62.5kHz channels*
Mode 2: Survey	61 chunks (3872 MHz) at 250 kHz resolution	~16 GHz x 2 polar with 250 kHz channels
Mode 3: Continuum + High Resolution	<61 chunks (3872 MHz) at 2 MHz resolution AND 8/4/2 chunks at 31.25/15.625/7.8125 kHz resolution*	<16 GHz x 2 Polar with 2 MHz channels AND 4/2/1 GHz with 31.25/15.625/7.8125kHz channels*

*High resolution chunks chosen among the 61 of the **fixed** filter bank