NOEMA spectral setups

Jeremie Boissier
Overview

Frontend

Astronomy

Backend

Correlator

IF processing

Astronomy

2018, Oct. 05
NOEMA Spectral setups
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IF processing

Geometric delay

Astronomy
NOEMA receivers: Global picture

NOEMA observes at millimetre wavelength

- 4-0.8 mm
- 70-380 GHz
- Detecting devices operate in a narrower frequency range (~50-100 GHz)
  - 4 receiver bands to cover 70 – 380 GHz

1 NOEMA receiver

Input of the 3mm receiver band
NOEMA receivers: Principle

Heterodyne receivers

- Down-convert a small spectral range (few GHz) from Radio Frequency (50 < $F_{RF}$ < 500 GHz) to Intermediate Frequency ($F_{IF}$ < 20 GHz)
NOEMA receivers: Tuning

Heterodyne receivers

- Down-convert a small spectral range (few GHz) from Radio Frequency ($50 < F_{RF} < 500$ GHz) to Intermediate Frequency ($F_{IF} < 20$ GHz)
- Tuning the receiver = setting the FLO1 + optimizing some LO and Mixer parameters
NOEMA receivers: Tuning

Heterodyne receivers

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Local Oscillator
Monochromatic signal
($F_{LO1}$)

RF range is a technical characteristic of a given system. NOEMA: 4-12GHz
NOEMA receivers: IF output

Heterodyne receivers

- Down-convert a small spectral range (few GHz) from Radio Frequency ($50 < F_{RF} < 500$ GHz) to Intermediate Frequency ($F_{IF} < 20$ GHz)
- Tuning the receiver = setting the FLO1 + optimizing some LO and Mixer parameters

Diagram:

- Radio Frequency (RF)
- Intermediate Frequency (IF)
- Local Oscillator
- Monochromatic signal ($F_{LO1}$)
- Lower side band (LSB $F_{IF} = F_{LO1} - F_{RF}$)
- Upper side band (USB $F_{IF} = F_{RF} - F_{LO}$)
- Double side band (DSB) output

Values:

- 213 LSB 221
- 229 USB 237
- 4 LSB ($F_{IF} = F_{LO1} - F_{RF}$)
- 12 USB ($F_{IF} = F_{RF} - F_{LO}$)
NOEMA receivers: IF output

Heterodyne receivers

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

**Diagram:**

- Local Oscillator
- Monochromatic signal ($F_{LO1}$)
- Targeted sideband = SIGNAL
- Attenuated sideband = IMAGE
- Image sideband attenuated by ~10dB
**Heterodyne receivers**

- Down-convert a small spectral range (few GHz) from Radio Frequency ($50 < F_{RF} < 500$ GHz) to Intermediate Frequency ($F_{IF} < 20$ GHz)
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NOEMA receivers: IF output

Heterodyne receivers

- Down-convert a small spectral range (few GHz) from Radio Frequency ($50 < F_{RF} < 500$ GHz) to Intermediate Frequency ($F_{IF} < 20$ GHz)
- Tuning the receiver = setting the FLO1 + optimizing some LO and Mixer parameters

Diagram:
- Local Oscillator (LO1)
- Monochromatic signal ($F_{LO1}$)
- Radio Frequency (RF)
- Intermediate Frequency (IF)
- 2 side band (2SB) output
- NOEMA uses 2SB receivers
- LSB
- USB
- Correlator sideband separation adds 30 dB attenuation on image sideband
NOEMA receivers: Polarization

Incident electric field has a given polarization

\[ E(t) \]
Incident electric field has a given polarization

- 1 Feed horn selects 1 linear component
NOEMA receivers: Polarization

Incident electric field has a given polarization

- 1 Feed horn selects 1 linear component
- Separation grid on the incident path + 2 horns to get the 2 independent components

![Diagram showing polarization separation and two orthogonal polarizations](image)
NOEMA receivers: Polarization

Incident electric field has a given polarization

- 1 Feed horn selects 1 linear component
- Separation grid on the incident path + 2 horns to get the 2 independent components

1 polarization separation grid
2 horns
2 orthogonal polarizations
NOEMA receivers: Polarization

Dual polarization

- 1 NOEMA receiving system detects 1 linear polarization
- Detecting 2 orthogonal polarizations
  - Gain factor of 2 on observing time
  - Possibility to do polarimetry (provided hard and soft are designed for it)
- 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

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
- Tuning a receiver band = setting $F_{LO1} = F_{RF} \pm F_{IF}$
  - IF range: 4-12 GHz
- Receiver output contains 4 slices of spectrum:
  - HLSB HUSB VLSB VUSB
Overview

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2018, Oct. 05

NOEMA Spectral setups
NOEMA Correlator: PolyFiX

Very simplified view of a correlator

Electric field from 12 Antennas
$E_i(t)$
1 2 3... 12

1-2 1-3 2-3... 11-12
Visibility for 12*11/2 baselines $V(u,v,\nu)$
NOEMA Correlator: PolyFiX

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

- Correlation
NOEMA Correlator: PolyFiX

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Electric field from 12 Antennas
\[ E_i(t) \]

1 2 3... 12

IF Processing

A/D conversion (= Sampling)

Correlation

Visibility for \( 12 \times 11/2 \) baselines
\[ V(u,v,v) \]
NOEMA Correlator: 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
  - Down conversion to 0-4GHz IF2
NOEMA Correlator: IF Processing

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Summary and nomenclature

- 8 Basebands (0-4 GHz IF2) feed 8 correlator units
NOEMA Correlator: PolyFiX

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

- Electric field $E_i(t)$ from 12 Antennas 4-12 GHz IF1

- IF Processor
  - Separate INNER and OUTER Basebands for the 4 receiver outputs (x12A)

- Analog to Digital conversion (ADC)

- Correlation

- Inner Basebands 0-4 GHz IF2
- Outer Basebands 0-4 GHz IF2

1-2 1-3 2-3... 11-12
Visibility for 12*11/2 baselines $V(u,v,v)$ INNER basebands

1-2 1-3 2-3... 11-12
Visibility for 12*11/2 baselines $V(u,v,v)$ OUTER basebands

A/D conversion (= Sampling)

Correlation

ADC conversion (= Sampling)
NOEMA Correlator: PolyFiX

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

- IF Processor
  - Separate INNER and OUTER Basebands for the 4 receiver outputs (x12A)

- Analog to Digital conversion (ADC)
  - ADC
  - Polyphase filter bank
    Basebands split into 64MHz Chunks
    Antenna based signal, time domain

- Correlation

Electric field $E_i(t)$ from 12 Antennas 4-12 GHz IF1

Visibility for $12 \times 11/2$ baselines $V(u,v,\nu)$ INNER basebands

Visibility for $12 \times 11/2$ baselines $V(u,v,\nu)$ OUTER basebands
Antenna signal digital processing

- Input: 0-4 GHz baseband (x 12 antennas)
- Signal is digitized
- Baseband is split into 64 chunks of 64 MHz on a fixed grid
  - "Overlapping Polyphase Filter Bank"
  - Digital down conversion of the signal to 64 chunks going from -32 to 32 MHz in IF3
NOEMA Correlator: PolyFiX

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

- **IF Processor**
  - Separate INNER and OUTER Basebands for the 4 receiver outputs (x12A)

- **Analog to Digital conversion (ADC)**
  - ADC
  - Polyphase filter bank
    Basebands split into 64MHz Chunks
    Antenna based signal, time domain

- **Correlation**
  - FX process
    1. Fourier transform (antenna based spectrum)
    2. Cross spectrum (baseline based spectrum)

Electric field $E_i(t)$ from 12 Antennas 4-12 GHz IF1

Visibility for 12*11/2 baselines $V(u,v,\nu)$ INNER basebands

Visibility for 12*11/2 baselines $V(u,v,\nu)$ OUTER basebands
NOEMA correlator: PolyFiX

Input:
- Time domain
- Antenna based

Output
- Frequency domain
- Baseline based

“Young’s hole representation”
- Convolution of Ant signal
- Fourier transform to get spectrum

\[ V = \text{FT}(E_1 \ast E_2^*) \]

Fourier transform:
\[ \text{FT}(f \ast g) = \text{FT}(f) \cdot \text{FT}(g) \]
NOEMA correlator: PolyFiX

Input:
- Time domain
- Antenna based

Output
- Frequency domain
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“Young’s hole representation”
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Fourier transform:
\[ \text{FT}(f \ast g) = \text{FT}(f) \cdot \text{FT}(g) \]
NOEMA Correlator: Digital signal processing

Spectral capabilities

- Fourier Transform of the signal for all chunks
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA
- PolyFiX capabilities (1 unit):

![Graph showing spectral setup with chunk number and IF2 frequency](image-url)
NOEMA Correlator: Digital signal processing

Spectral capabilities

- **Fourier Transform of the signal for all chunks**
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA
- **PolyFiX capabilities (1 unit):**
  - 64 chunks (i.e. whole baseband ~4 GHz) at 2 MHz channel spacing
Spectral capabilities

- Fourier Transform of the signal for all chunks
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- PolyFiX capabilities (1 unit):
  - 64 chunks (i.e. whole baseband ~4 GHz) at 2 MHz channel spacing
    AND
  - 16 chunks (~1 GHz) at 62.5 kHz channel spacing
NOEMA Spectral setups

Spectral capabilities

- **Fourier Transform of the signal for all chunks**
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA
- **PolyFiX capabilities (1 unit):**
  - 64 chunks (i.e. whole baseband ~4 GHz) at 2 MHz channel spacing
    - AND
  - 16 chunks (~1 GHz) at 62.5 kHz channel spacing
- **Computation of cross spectra**
  - Channel per channel multiplication
  - Spectrum Base\(_{i,j}\) = Spectrum A\(_i\) x Spectrum A\(_j^*\)
  - Integration during 31.25 ms
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 channel spacing
- With the default mode:
  - 1 Correlator Unit output is made of:
    - 1 low resolution spectral window (made of 64 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)
FPGA reprogramming: correlator modes

- Fourier Transform of the signal for all chunks
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA

PolyFiX Spectral capabilities

- PolyFiX default mode:
  - 64 chunks (i.e. whole baseband ~4 GHz) at 2 MHz channel spacing
    AND
  - 16 chunks (~1 GHz) at 62.5 kHz channel spacing
NOEMA Correlator: PolyFiX modes

FPGA reprogramming: correlator modes

- Fourier Transform of the signal for all chunks
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA

PolyFiX Spectral capabilities

- **PolyFiX continuum + high resolution mode:**
  - 64 chunks (i.e. whole baseband ~4 GHz) at 2 MHz channel spacing
    - AND
  - 8 chunks (~0.5 GHz) at 31.25 kHz channel spacing
FPGA reprogramming: correlator modes

- Fourier Transform of the signal for all chunks
  - Number of points of the FT defines the channel spacing of the final visibility spectra
  - Limitation is computing resources in FPGA

PolyFiX Spectral capabilities

- PolyFiX survey mode:
  - 64 chunks (i.e. whole baseband ~4 GHz) at 250 kHz channel spacing
NOEMA Correlator: PolyFiX modes

Spectral capabilities:

- **Capabilities for a single unit**
- **Mode 1: Continuum + Lines**
  - 64 chunks at Low resolution (2MHz); total bandwidth ~4 GHz
  - **AND** 16 chunks at High resolution (62.5kHz); bandwidth 64 MHz each
  - Unique mode since delivery in 2017
- **Mode 2: Survey**
  - 64 chunks at 250 kHz; total bandwidth ~4GHz MHz
  - Later
- **Other modes: Continuum and high resolution lines**
  - Similar to mode 1 with higher resolution in less chunks
  - Even later

<table>
<thead>
<tr>
<th></th>
<th>1 Unit</th>
<th>All Units</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mode 1 (2017):</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuum + Lines</td>
<td>64 chunks (~4GHz) at 2 MHz resolution</td>
<td>~16 GHz x 2 polar with 2 MHz channels</td>
</tr>
<tr>
<td></td>
<td>AND</td>
<td><strong>AND</strong></td>
</tr>
<tr>
<td></td>
<td>16 chunks at 62.5 kHz resolution*</td>
<td></td>
</tr>
<tr>
<td><strong>Mode 2: Survey</strong></td>
<td>64 chunks (~4GHz) at 250 kHz resolution</td>
<td>~16 GHz x 2 polar with 250 kHz channels</td>
</tr>
<tr>
<td>Other modes:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Continuum + High</td>
<td>64 chunks (~4GHz) at 2 MHz resolution</td>
<td>&lt;16 GHz x 2 Polar with 2 MHz channels</td>
</tr>
<tr>
<td>Resolution</td>
<td>AND</td>
<td><strong>AND</strong></td>
</tr>
<tr>
<td></td>
<td>8/4/2 chunks at 31.25/15.625/7.8125 kHz</td>
<td></td>
</tr>
<tr>
<td>resolution*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*High resolution chunks chosen among the 64 of the **fixed** filter bank
NOEMA Spectral setups

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

- **IF Processor**
  - Separate INNER and OUTER Basebands for the 4 receiver outputs (x12A)

- **Analog to Digital conversion (ADC)**
  - ADC
  - Polyphase filter bank
    Basebands split into 64MHz Chunks
    Antenna based signal, time domain

- **Correlation**
  - FX process
    1. Fourier transform (antenna based spectrum)
    2. Cross spectrum (baseline based spectrum)
NOEMA Correlator: PolyFiX

A more realistic view of a PolyFiX Unit (1: Sampler part, mode 2MHz)
A more realistic view of a PolyFiX unit (2: Correlation part, mode 2MHz/62.5 kHz)
NOEMA correlator: PolyFiX

Spectral limitations

- Spurious lines at 0 and 3872 MHz IF2
- LO2 zone: bad performance in first ~10 MHz
- Last 100-200MHz with degraded performances (ADC anti aliasing filter)
  Effective bandwidth=3872 MHz
NOEMA Correlator: Summary

Radio Frequency (RF)

Lower sideband

7.744GHz

Upper sideband

7.744GHz

polar H

HLO  HLI

3.872GHz  3.872GHz

polar V

VLO  VLI

3.872GHz  3.872GHz

Outer baseband

Inner baseband

F_{LO1}
Overview

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Astronomy
How to prepare NOEMA spectral observations

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
  PROPOSAL

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

The online proposal submission system needs an ASTRO script to set up the technical parameters of the required observations.
Prepare the environment:

```plaintext
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)
```
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

![Graph showing the coverage of NOEMA receiver bands 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
- I-TUNING, FRF = 230.55466 GHz
- 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
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 =

**I-TUNING,** Original tuning
**I-TUNING,** Tuning automatic
**I-TUNING,** This corresponds to...
**I-TUNING,** Actual command:

**TUNING 230.538 LSB 6462**

**I-TUNING,** Selecting the...
**I-TUNING,** FRF =
**I-TUNING,** FLO1 =
**I-TUNING,** FLOTUNE =
**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
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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 auto :
I-TUNING, This corre :
I-TUNING, Actual corre :
TUNING 230.538 LSB 6500
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 Selection Code

! 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 Selection**

(! 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 Selection Code
! 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 Selection Code

! 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 Selection Code
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! 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
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
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
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
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

(MySource1)

$V_{LSR} = 0 \text{ km s}^{-1}$

$V_{Dop} = -21.7 \text{ km s}^{-1}$
NOEMA setups in ASTRO

Visualize current state

PLOT

PLOT /RECEIVER
NOEMA setups in ASTRO

Visualize current state

PLOT
PLOT /RECEIVER
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
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
PROPOSAL /FILE file.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
- \( F_{RF} = F_{REST} \times \text{DopplerFactor} \)
  - 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
  - Earth Doppler corrected on real time
    - Doppler tracking: \( F_{LO} \) changes with time
  - Source LSR taken into account
    - \( F_{LO} \) is shifted
  - Redshift not corrected
    - Compute redshifted frequency and assume \( z \) and LSR = 0
      - ASTRO can help (\texttt{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/Output 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
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
Example with redshifted source

SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Output 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/Output 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
Example with redshifted source

```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Output 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
Example with redshifted source

```
SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Output 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
```
Example with redshifted source

SET FREQUENCY REST LSR ! Main axis=REST, Secondary=LSR
! Main axis = Lower axis on plot + Input/Output 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)

Radio Frequency (RF)

F_{LO1}

<table>
<thead>
<tr>
<th></th>
<th>Lower sideband</th>
<th>Upper sideband</th>
</tr>
</thead>
<tbody>
<tr>
<td>polar H</td>
<td>HLO</td>
<td>HUI</td>
</tr>
<tr>
<td></td>
<td>HLI</td>
<td>HUO</td>
</tr>
<tr>
<td>polar V</td>
<td>VLO</td>
<td>VUI</td>
</tr>
<tr>
<td></td>
<td>VLI</td>
<td>VUO</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Mode 1 (2017): Continuum + Lines</th>
<th>1 Unit</th>
<th>All Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mode 1 (2017): Continuum + Lines</td>
<td>64 chunks (3872 MHz) at 2 MHz resolution AND 16 chunks at 62.5 kHz resolution*</td>
<td>~16 GHz x 2 polar with 2 MHz channels AND 8 GHz with 62.5kHz channels*</td>
</tr>
</tbody>
</table>

| Mode 2: Survey | 64 chunks (3872 MHz) at 250 kHz resolution | ~16 GHz x 2 polar with 250 kHz channels |
| Other modes: Continuum + High Resolution | 64 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 64 of the fixed filter bank

Use Gildas\ASTRO to prepare NOEMA spectral setups!