IDL tools for data processing and instrument simulations

Philippe Zarka
&
Carine Briand

LESIA & USN, Obs. Paris-CNRS-PSL

General

- IDL runs on nancep nodes : type use IDLNenuFAR
- Needs licence tokens (alternative = GDL : compatibility ?)

```
. /cep/lofar/exelis/idl85/bin/idl_setup.bash
export LM_LICENSE_FILE=1700@jetons-n
```

- Standard for space radio astronomy, t-f measurements → beamforming mode
- Tools on /cep/lofar/nenufar/

Preparation of observations

- on /cep/lofar/nenufar/pro/general
- nenufar_calc.pro sensitivity, resolution

```
;-------------------------------------------------------------------------------
  pro NenuFAR_calc, nMAcore,nMArem, freq, $
      l, a1,aMA,aNen, thMA,FoV,thNen, Tsky,Tamp, SefdMA,SefdNen, SminTh,SminConf, $
      dmax=dmax, df=df, dt=dt, decoh=decoh, lofar=lofar, plot=plot, verbose=verbose, help=help
;-------------------------------------------------------------------------------
; computes the main characteristics of NenuFAR
;
; INPUTS
; nMAcore = number of Mini-Arrays in core
; nMArem = number of remote Mini-Arrays
; freq = frequency (Mhz) [scalar or vector]
;
; KEYWORDS
; dmax = max distance of remote MA (m)
; df = bandwidth (MHz)
; dt = integration time (sec)
; decoh = decoherence factor (1 if perfectiy coherent, ~4 if uncalibrated)
; /lofar => confusion according to vanHaarlem & al. 2013 [default = Condon 2002]
; /plot => display Mini-Arrays effective area
; /verbose => display results
;
; OUTPUTS
; l = wavelength (m)
; a1 = Aeff 1 antenna (m^2)
; aMA = Exact Aeff Mini-Array 19 antennas separated by 5.5 m with overlap (m^2)
; aNen = Aeff of Nenufar (core+remote MA) (m^2)
; thMA = 1D FoV of MA (deg)
; FoV = 1D FoV of MA (deg^2)
; thNen = Angular resolution of Nenufar (core+remote MA) (arcmin)
; Tsky = Sky temperature (K)
; Tamp = System temperature (sky+preamp) (K)
; SefdMA = SEFD of MA (Jy)
; SefdNen = SEFD of Nenufar (core+remote MA) (Jy)
; SminTh = Thermal noise (Jy)
; SminConf = Confusion noise (Jy)
```

Preparation of observations

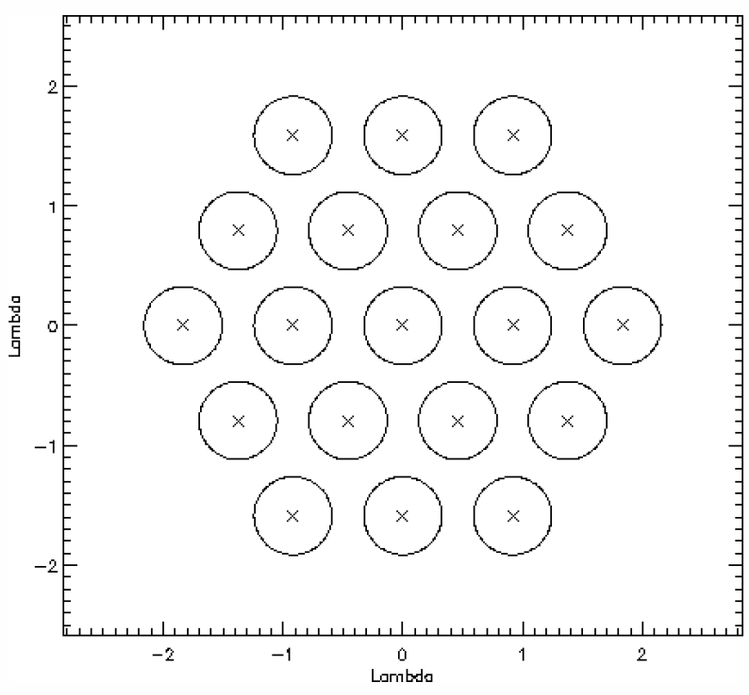
- on /cep/lofar/nenufar/pro/general
- nenufar_calc.pro sensitivity, resolution

```
IDL> nenufar_calc, /help

NenuFAR_calc, [IN]   nMAcore,nMArem, freq, $
              [OUT]  l, a1,aMA,aNen, thMA,FoV,thNen, Tsky,Tamp, SefdMA,SefdNen, SminTh,SminConf, $
              [KEY]  dmax=dmax, df=df, dt=dt, decoh=decoh, /lofar, /plot, /verbose
```

```
IDL> nenufar_calc, 56,0,50,df=3.,dt=60.,/plot,/verbose

Freq(MHz)= 50.0   Wavelength(m)=  6.0   nMAcore,remote=  56   0
dmax(m)=    400   df(MHz),dt(s)=  3.0    60.000   decoh= 1.0
Aeff dipole,MA,NenuFAR(m^2)=  12.0  228.0  12768.
Theta MA(deg),FoV MA(deg^2)=  13.8    149.   Theta NenuFAR(deg)=  0.86
Tsky,Tamp(K)=    5787.     645.   SEFD MA,NenuFAR(Jy)=    77854.     1390.
SminThermal,Confusion(Jy)=    0.1036    4.3197
```



Preparation of observations

- on /cep/lofar/nenufar/pro/general
- data_rate_vol.pro rates, volumes

```
data_rate_vol, /help
DATA_RATE_VOL, Nma,Nch(/sb),dt(sec),Df(MHz),Tobs(sec), D_tot(byte/s),V_tot(bytes), /BF, /IM, /WF, /SUM



data_rate_vol, 56, 64, 0.020, 75, 3600, /BF
Rate=      51.2  Kb/s/SB
Rate=      19.7  Mb/s
Rate=       9.8  Mb/s/node
Volume=    70.8  Gb   in   3600. sec



data_rate_vol, 56, 64, 1., 75, 3600, /IM
Rate=       3.3  Mb/s/SB
Rate=       1.3  Gb/s
Rate=     313.8  Mb/s/node
Volume=     4.5  Tb   in   3600. sec
```

Reading statistics data

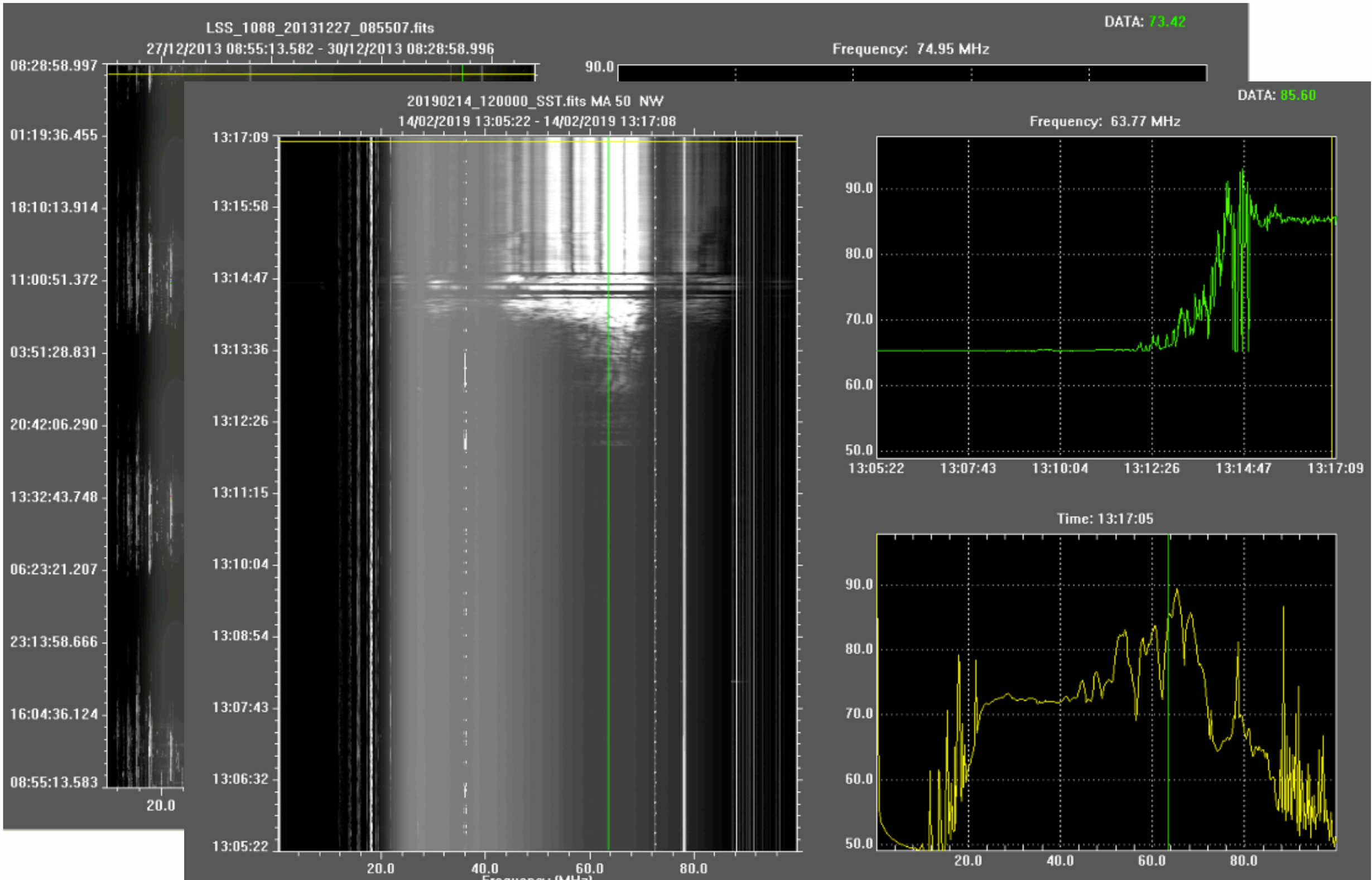
- BST (SST, XST) : Fits files

- Documentation (in French) on:
  - https://doc-nenufar.obs-nancay.fr/Soft-nenuFAR/Apropos.html
  - https://doc-nenufar.obs-nancay.fr/Soft-nenuFAR/Statistiques.html
  - https://doc-nenufar.obs-nancay.fr/Soft-nenuFAR/LectureSSTBSTIDL.html

- More tools to be put on /cep/lofar/nenufar/pro/statistics
  - read_nen_data.pro on /cep/lofar/nenufar/pro/statistics → decodes BST header for observation setup

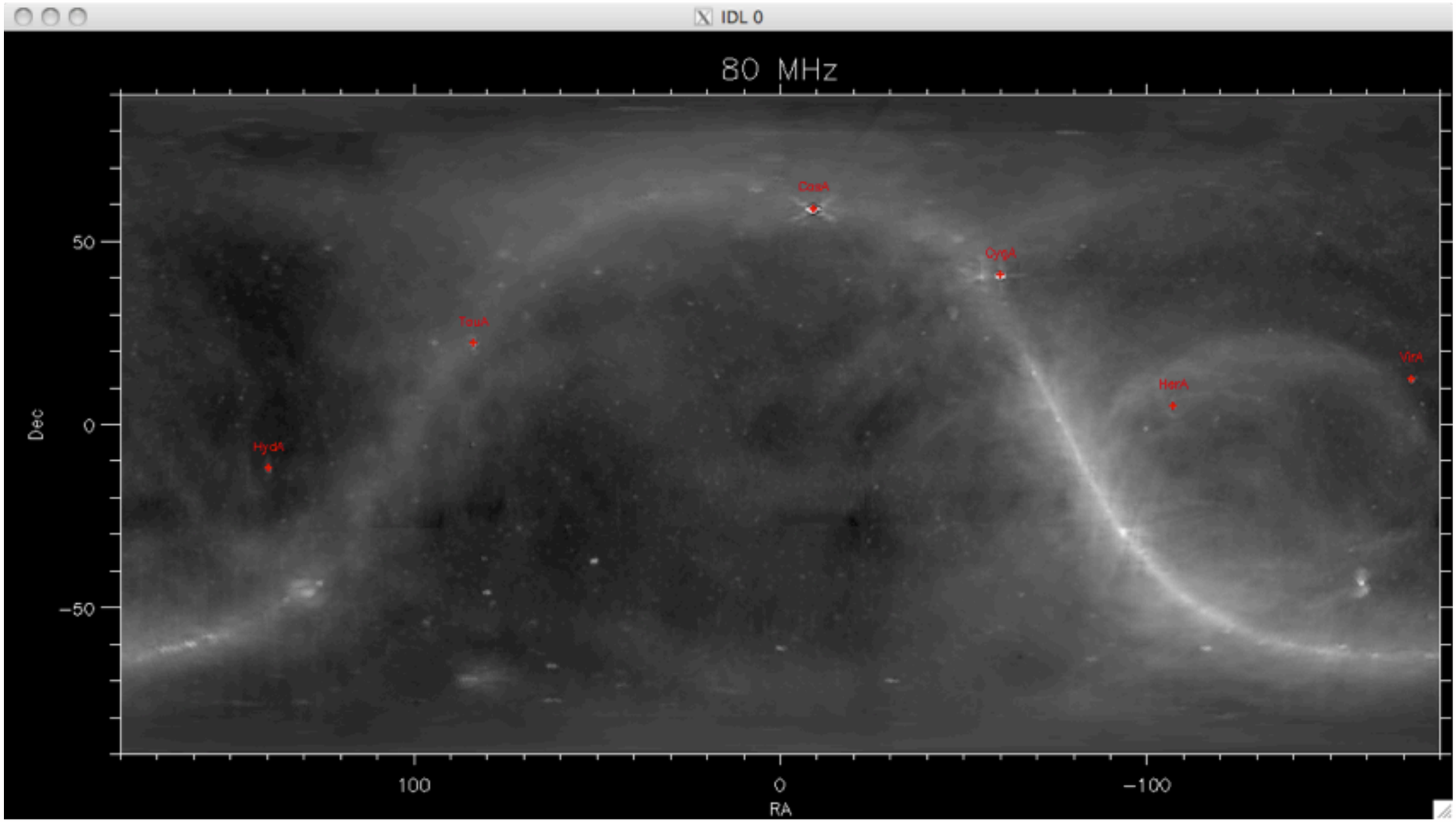
Reading statistics data

- Interactive display : display.pro & nenufarLib.pro on /cep/lofar/nenufar/contrib



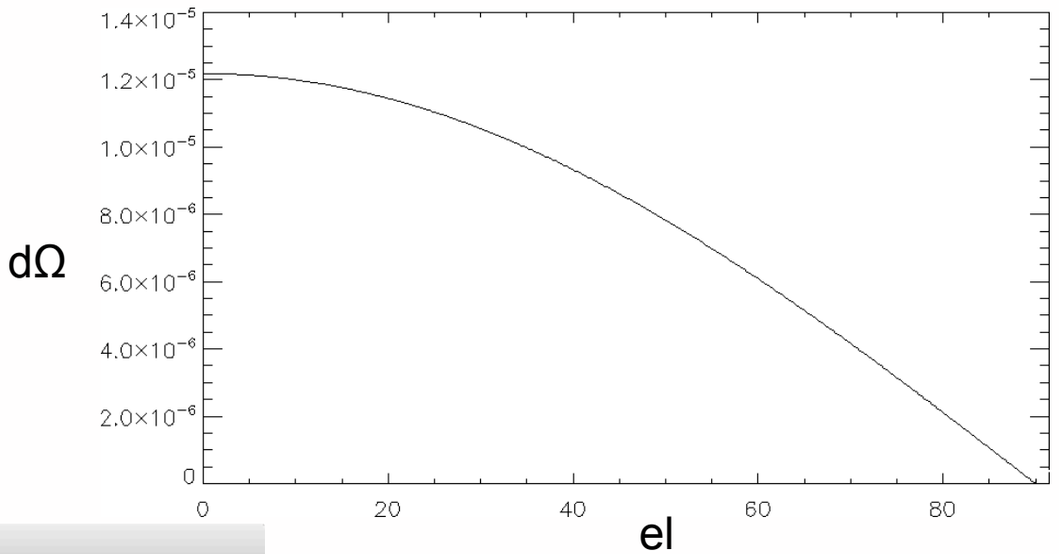
Simulations

- Instrument simulation + LFmap / GSM : to be put on /cep/lofar/nenufar/pro/simulations

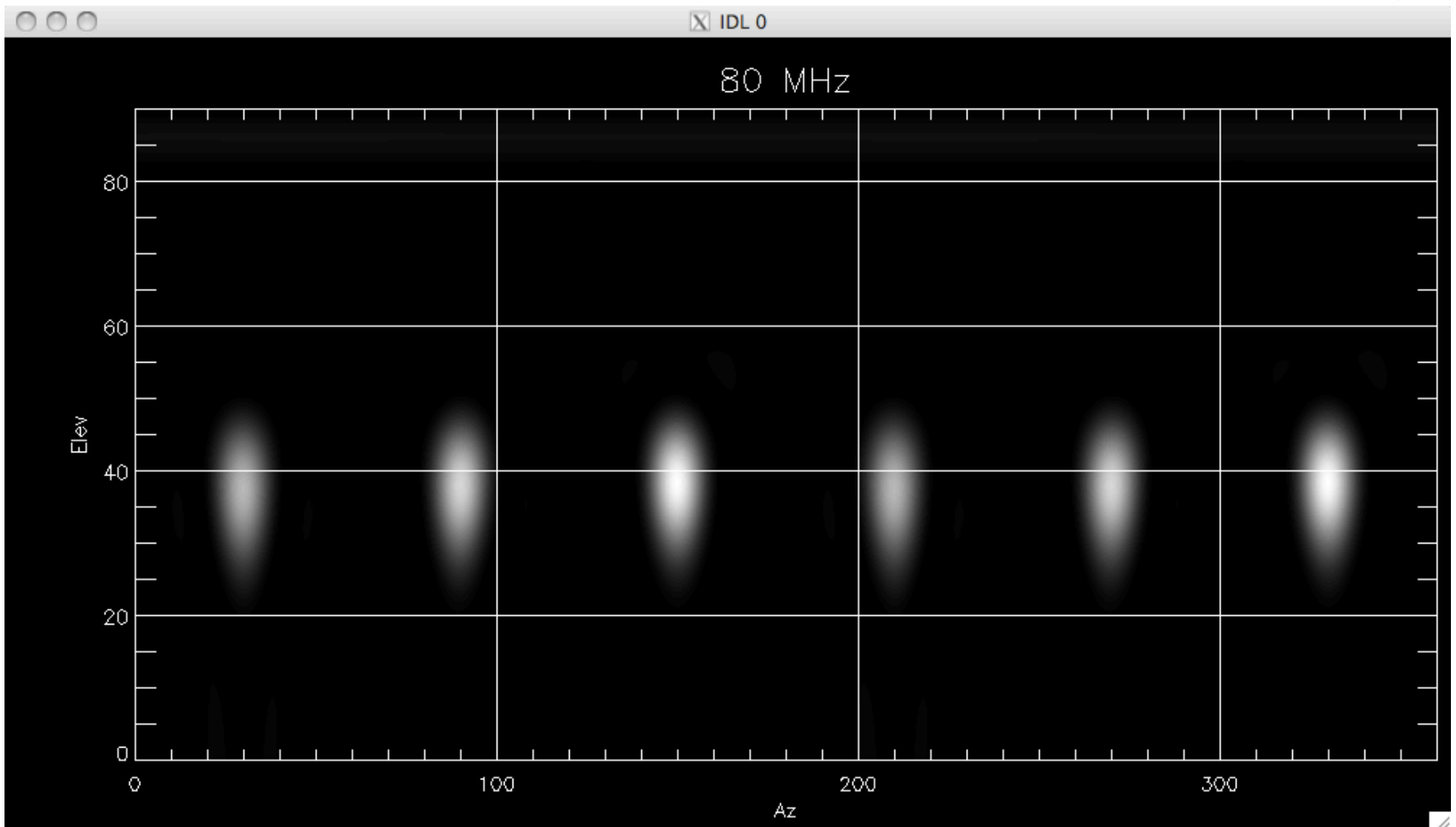


Simulations

- Instrument simulation + LFmap / GSM : to be put on /cep/lofar/nenufar/pro/simulations
  - At f, t : G(θ,φ) on a grid (el,az)
  - Projection of LFmap / GSM on local coordinates : map T(θ,φ)
  - $T_A(f) = 1/4\pi \iint G(\theta,\varphi)T(\theta,\varphi)\, d\Omega$ with $d\Omega = \cos\theta\, d\theta\, d\varphi$



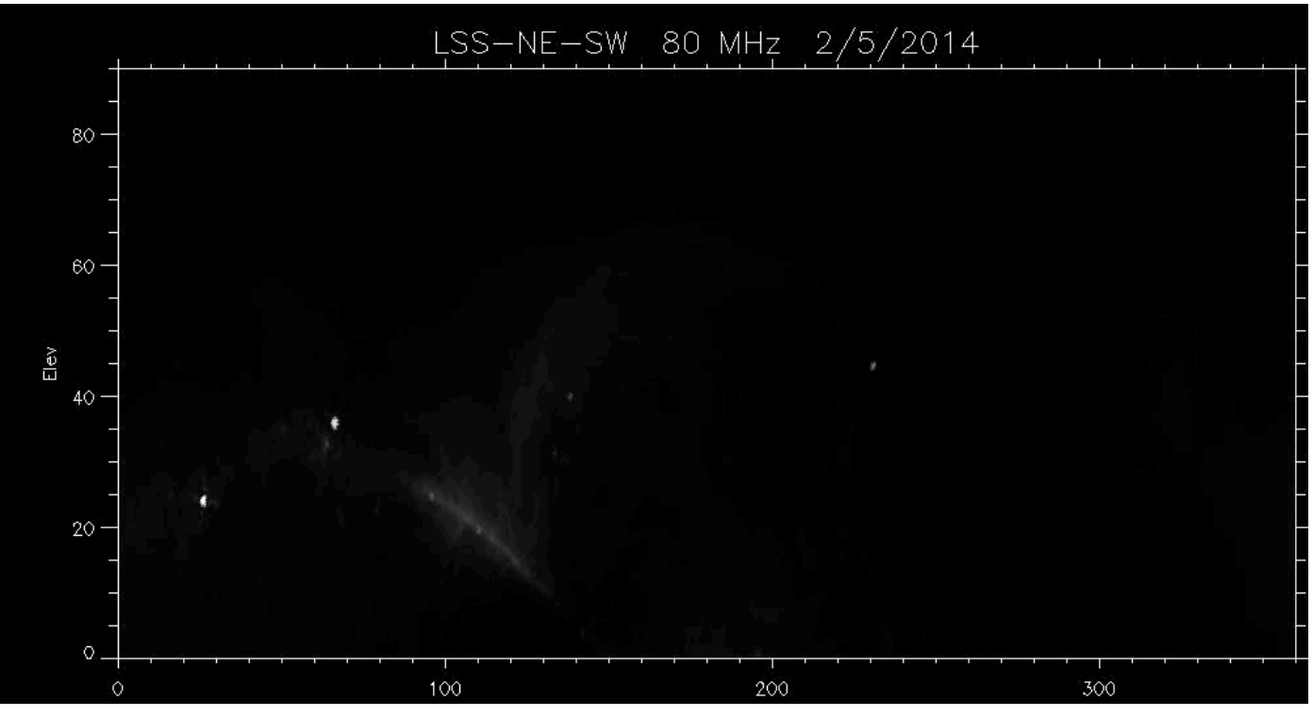
MA Gain at zenith (lin.) weighted

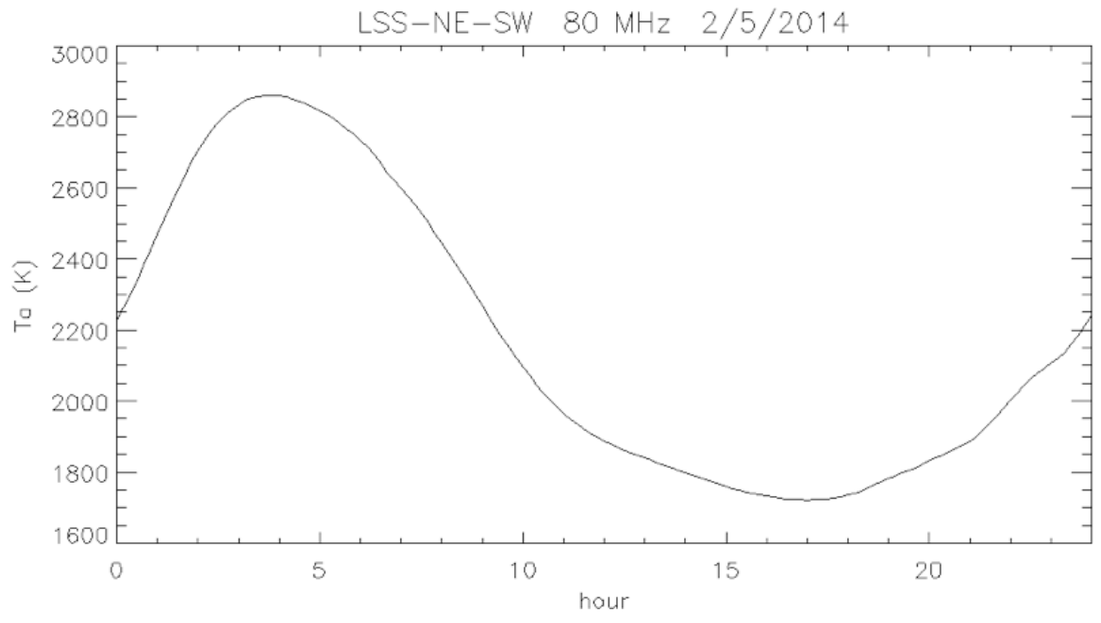


Simulations

- Antenna

SIMU_TIME_PROFILE, 'NenuFAR-Antenna-NE-SW', 80, 2,5,2014, Ta,TGmax, /MOVIE

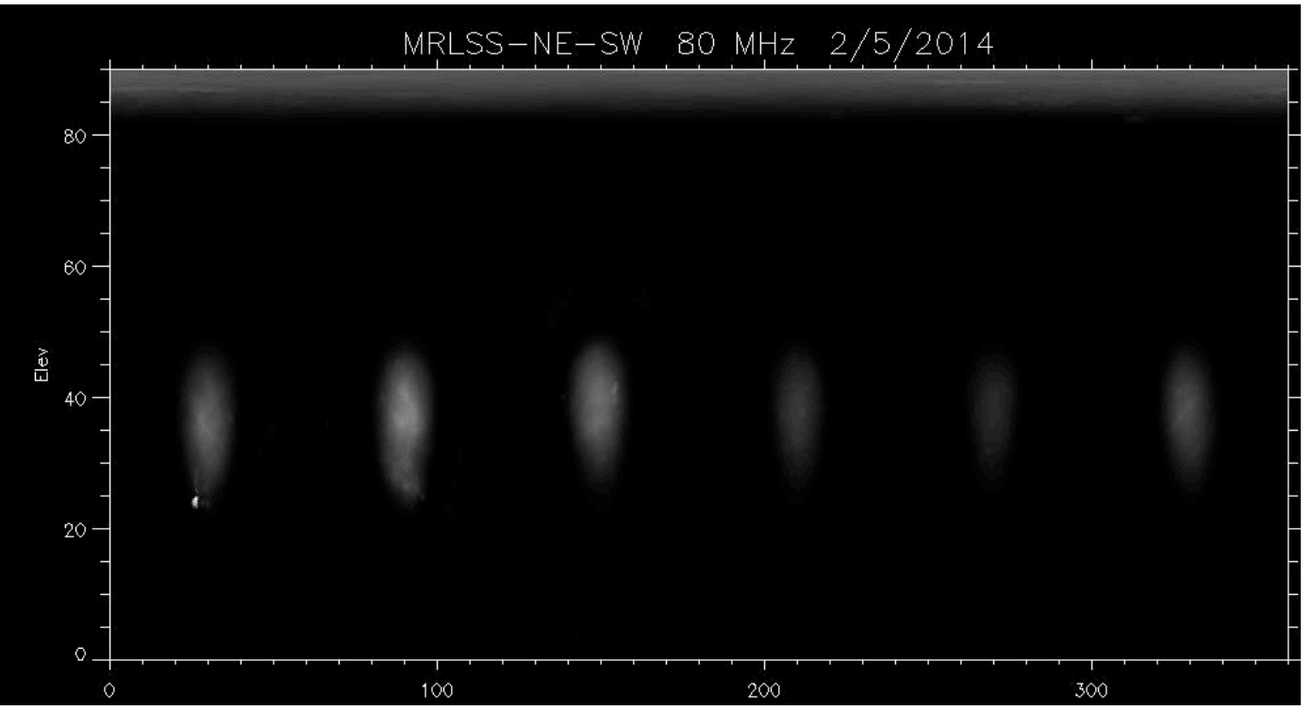


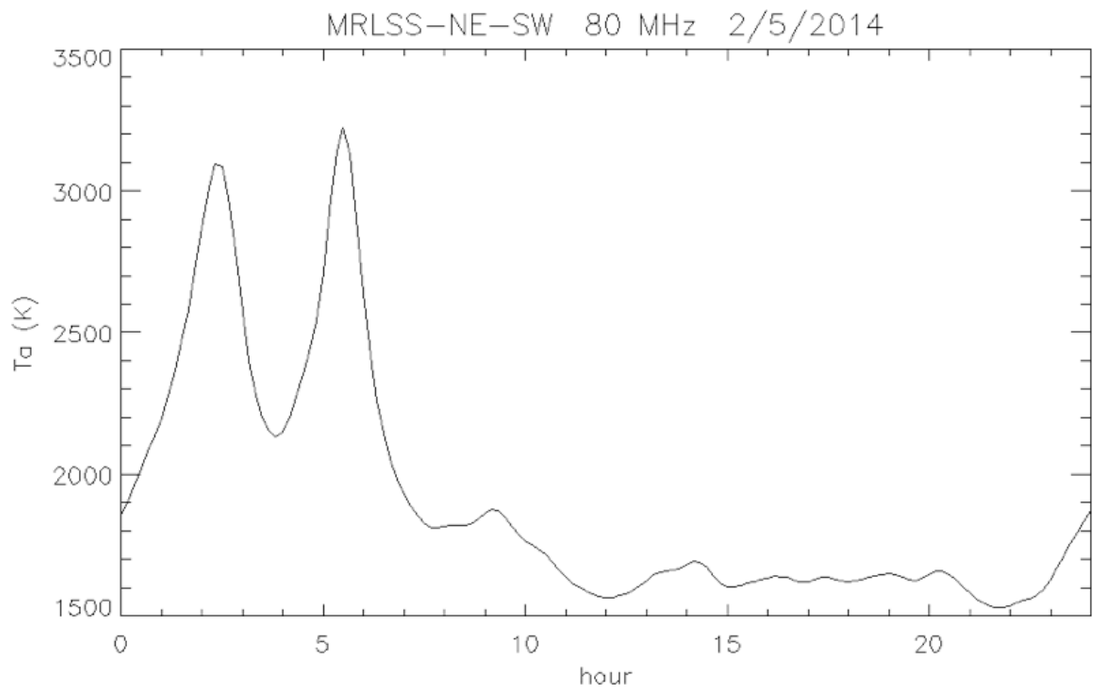


Simulations

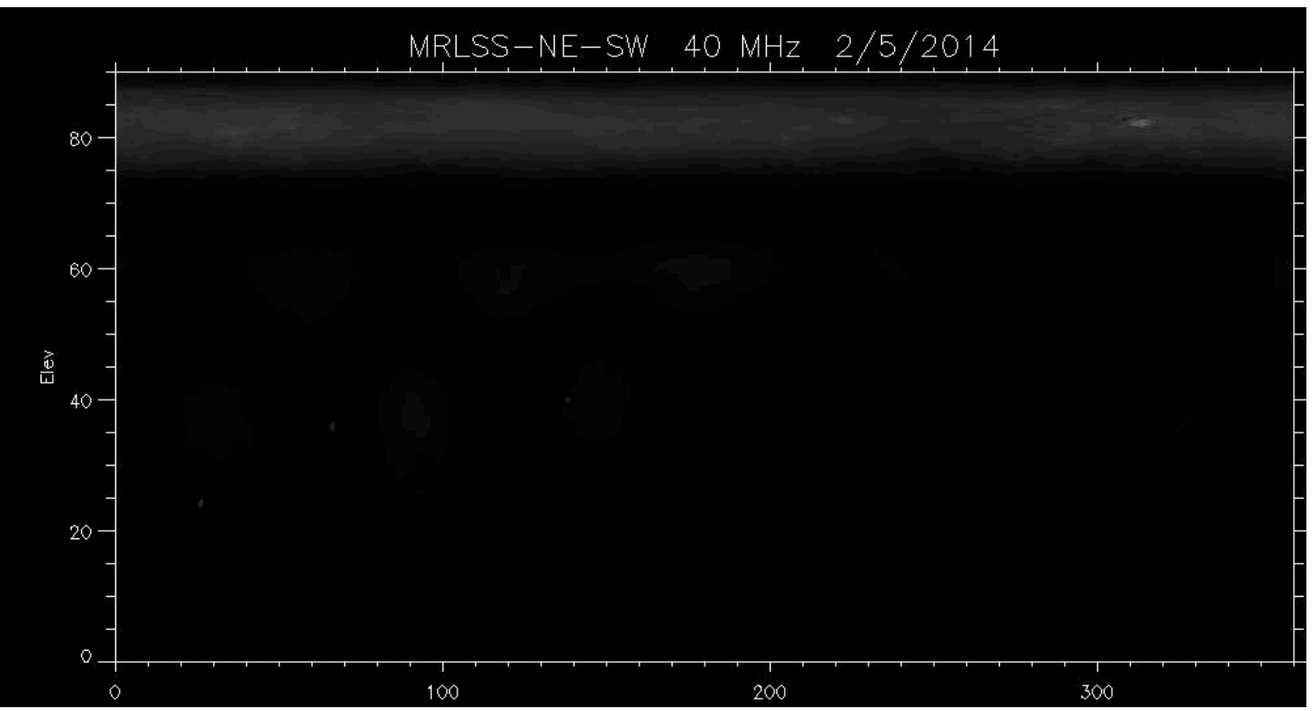
- Mini-Array

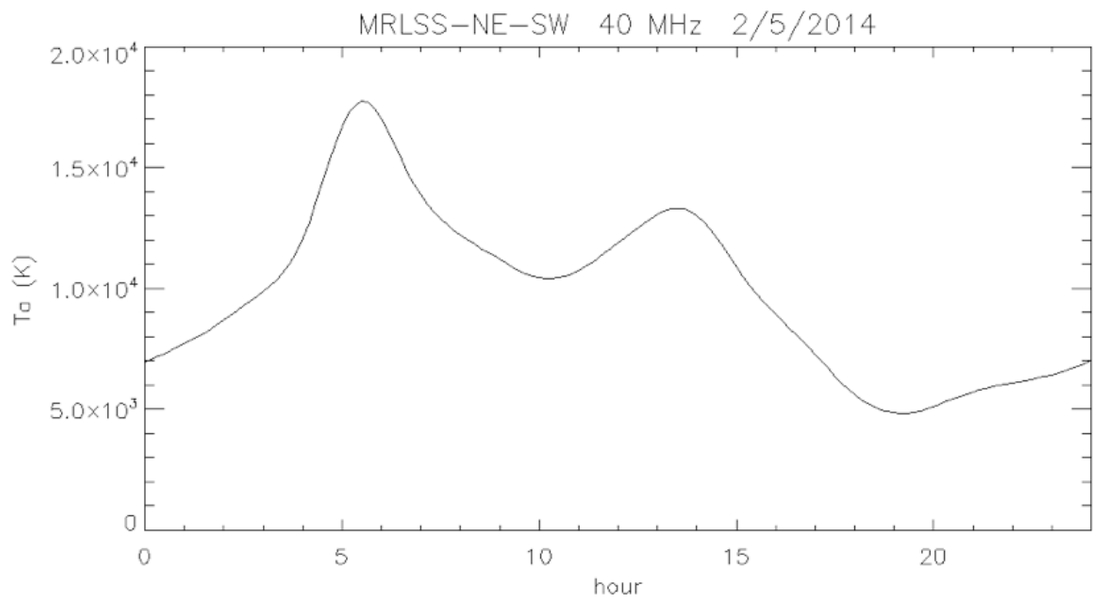
SIMU_TIME_PROFILE, 'NenuFAR-MA-NE-SW', 80, 2,5,2014, Ta,TGmax, /MOVIE, Imax=5





SIMU_TIME_PROFILE, 'NenuFAR-MA-NE-SW', 40, 2,5,2014, Ta,TGmax, /MOVIE, Imax=5





Reading UnDySPuTeD-tf data

- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :

```
;-------------------------------------------------------------------------------------------------------------
  pro READ_NU_SPEC, file, data,time,freq,beam,ndata, nt,dt,nf,df,ns, tmin=tmin,tmax=tmax, fmin=fmin,fmax=fmax, $
                    beams=beams, nchannels=nchannels, dm=dm, ntimes=ntimes, nstokes=nstokes, $
                    fflat=fflat, fclean=fclean, tclean=tclean, info=info, help=help
;-------------------------------------------------------------------------------------------------------------
; reads NenuFAR UnDySPuTeD data
; [INPUTS]
; from spectra file
; between tmin,tmax (s since file start) and fmin,fmax (MHz)  [default = all times & frequencies]
; within an optional list of beams
; integrating over nchannels=2^n per beamlet  [default = fftlen]
; after dedispersion at dm (pc.cm-3)  [default = 0, may be negative for dedispersing positive drifts]
; and over ntimes  [default = 1]
; nstokes=1 (I), 2 (Ix, Iy), 4 (full Stokes)
; if /info, only returns file structure description
; if /fflat then division by average spectrum
; fclean = Nsigmas for cleaning versus frequency within beamlets
; tclean = Nsigmas for cleaning versus time within beamlets
; [OUTPUT]
; data(t,f), time & freq ramps, beam # per channel
; ndata(t,f) = number of elementary data integrated per data element (after clean)
; nt,dt,nf,df,ns associated dimensions and resolutions
```

```
IDL> READ_NU_SPEC, /help

READ_NU_SPEC, file, data,time,freq,beam,ndata, nt,dt,nf,df,ns, tmin=tmin,tmax=tmax, fmin=fmin,fmax=fmax, $
       beams=beams, nchannels=nchannels, dm=dm, ntimes=ntimes, nstokes=nstokes, $
       fflat=fflat, fclean=fclean, tclean=tclean, info=info, help=help
```

Reading UnDySPuTeD-tf data

- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :

```
IDL> file='.../B1919+21_B1_TRACKING_BHR_20190212_123033_0.spectra'
IDL> READ_NU_SPEC,file,/info

First Effective Sample         :                    0
TIMESTAMP of first sample      :           1549974690
BLOCKSEQNUMBER of first sample :                    4
fftlen = N Channels / Beamlet  :           32
nfft2int                       :           32
FFToverlap 0/1                 :            0
apodisation                    :            0
nffte spectra / block          :           85
N Beamlets                     :          192
filesize                       :           5056706160
blocksize                      :      8358192
beamletsize                    :        43532
N blocks in file               :        605.00000
N frequency channels           :         6144
df (Hz)                        :        6103.5156
N time steps                   :        51425.000
dt (s)                         :     0.0052428800
dt per block (s)               :       0.44564480
Time (s) min,max               :        0.0000000       269.60986
Lane            0   Beam            0
Beamlet min,max :          192         383
Frequency (MHz) min,max :        37.500000       75.000000
```

Reading UnDySPuTeD-tf data

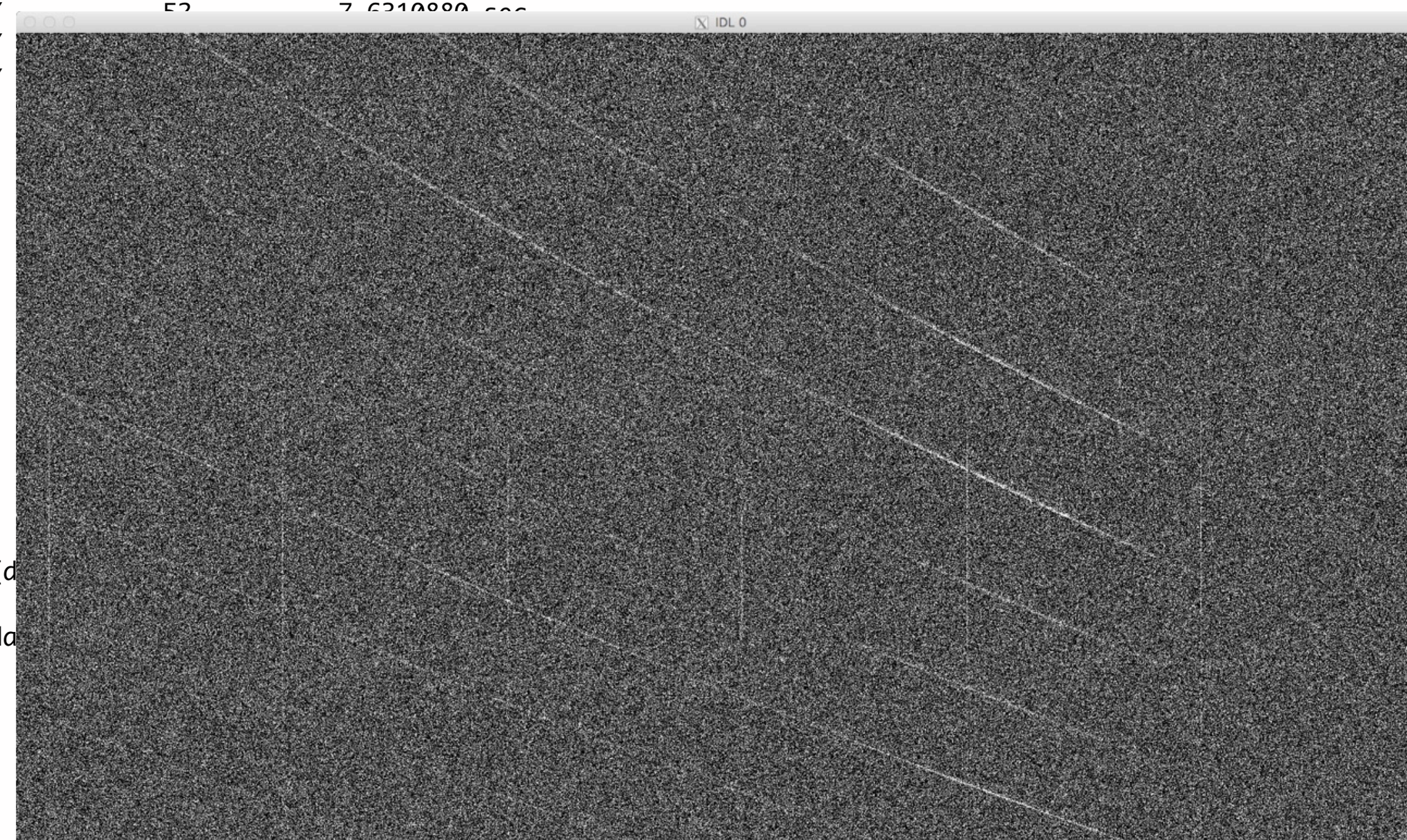
- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :

```
IDL> READ_NU_SPEC, file, data,time,freq,beam,ndata,nt,dt,nf,df,ns, fmin=44,fmax=54,nstokes=2,/fflat
% Compiled module: DT_DISP.
           0 /           52      2.8610229e-06 sec
          10 /           52          2.7919190 sec
          20 /           52          5.2021041 sec
          30 /           52          7.6310880 sec
          40 /
          50 /


IDL> help
BEAM
DATA
DF
DT
FILE
FREQ
NF
NS
NT
TIME
NDATA

IDL> x=reform(d

IDL> display_da
```

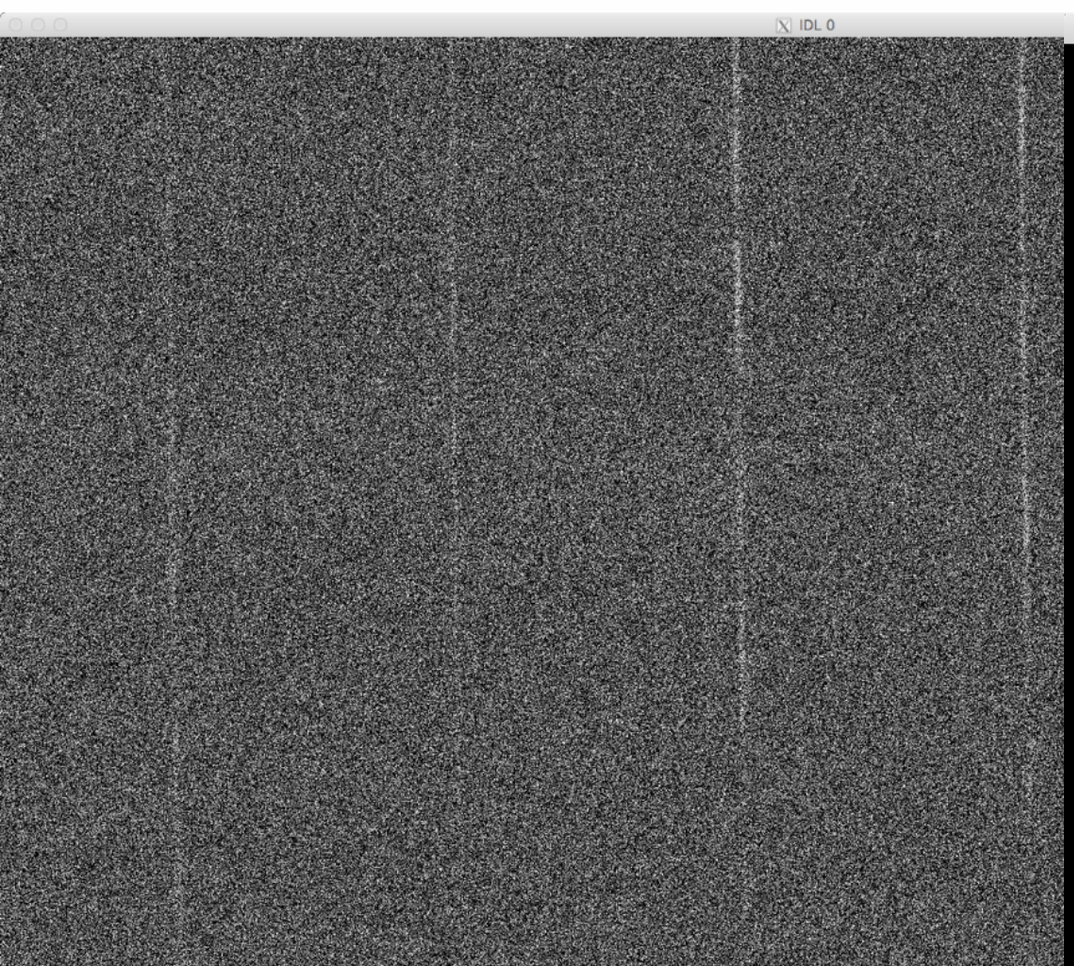


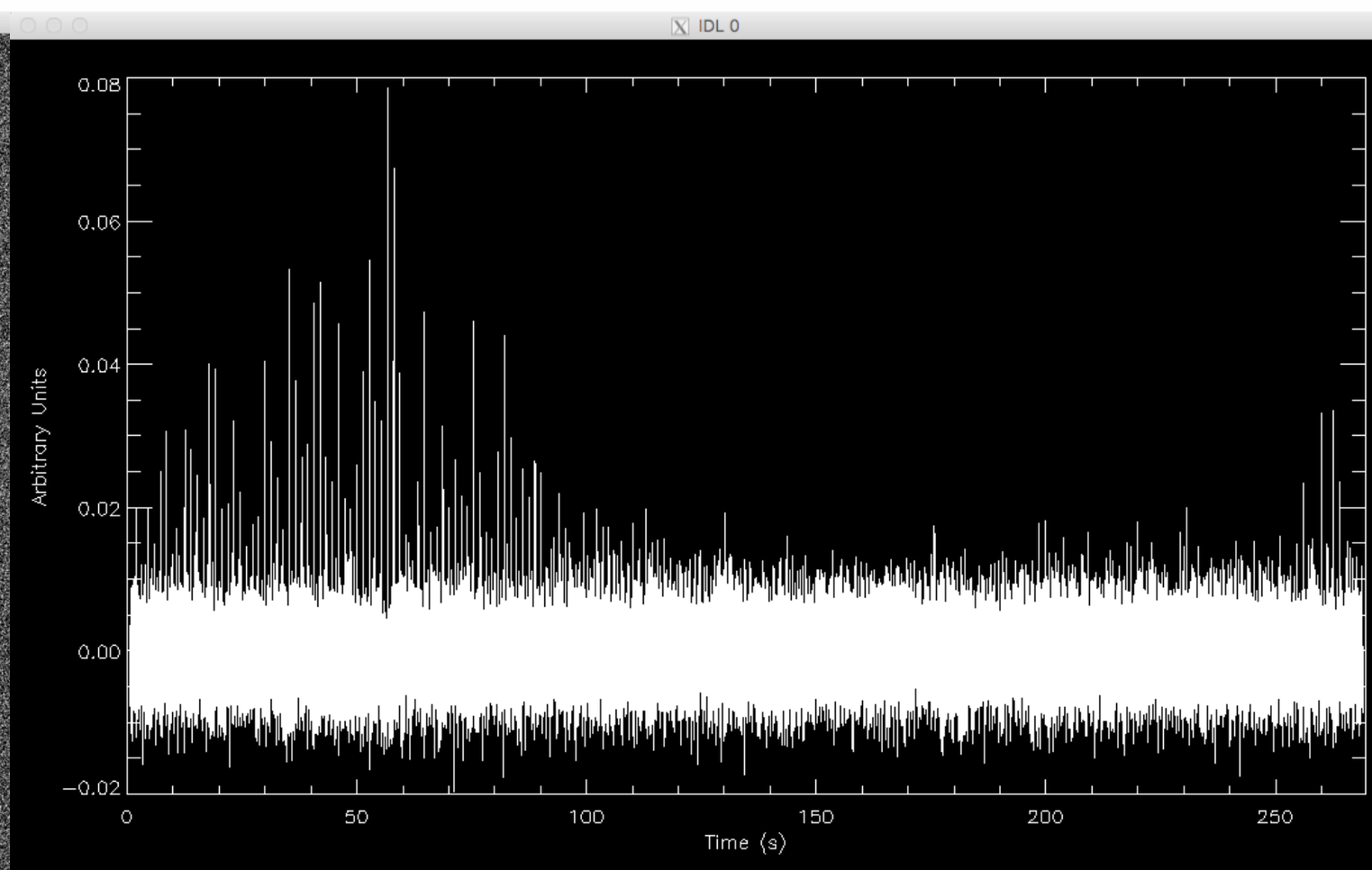
Reading UnDySPuTeD-tf data

- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :

```
IDL> xd=de_disp(x,freq,12.4405d0,dt,max(freq))
IDL> display_data,xd>0.9<1.3,1800
```

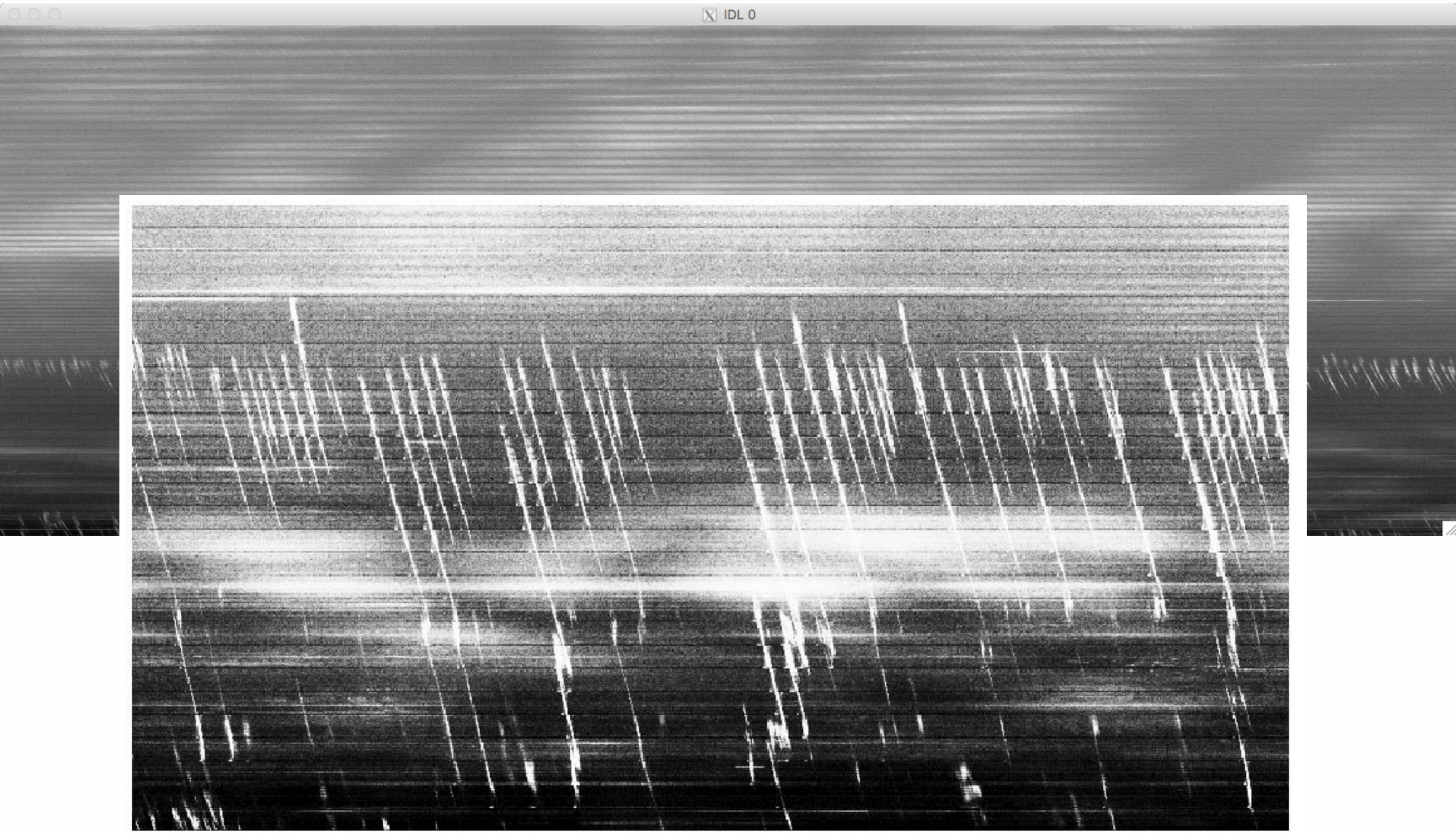
```
IDL> xdt=reform(rebin(xd,nt,1))
IDL> p=1.337261142d0
IDL> p/dt
      255.06232109069825
IDL> plot,time,xdt-smooth(xdt,255),/xsty,xtit='Time (s)',ytit='Arbitrary Units',charsize=1.5
```





Reading UnDySPuTeD-tf data

- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :



Reading UnDySPuTeD-tf data

- Reading / pre-processing on-the-fly : read_nu_spec.pro (+ display_data.pro) on /cep/lofar/nenufar/pro/undysputed :

```
; [TBD]
; implement filling ndata, different fflat methods (background, median...), fclean, tclean
; weight by spectral response within beamlet depending on N Channels / Beamlet
; calculate and calibrate Stokes parameters from raw X & Y auto/cross-correlations
```

- Tool box from UTR-2 & LOFAR on /cep/lofar/nenufar/pro/idl_tools :
  - background, RFI mitigation (incl. AOflagger tools), plotting, various utilities ...

- LOFAR BF pipeline [Turner et al., A&A 2018] soon to be adapted to NenuFAR :
  - RFI mitgation + weak source detection from On + Offs observations

- Provide feedback on Astronomers page

/cep/lofar/nenufar/

```
/cep/lofar/nenufar/
Astro_Lib_IDL  contrib  nenufar-tf  pro

contrib:
display.pro  nenufarLib.pro  README

nenufar-tf:
Coeffs16384Kaiser-quant.dat             LOFAR-Bandpass-Correction-nfft-064.dat  nenufar_raw.py
LOFAR-Bandpass-Correction-nfft-016.dat  LOFAR-Bandpass-Correction-nfft-128.dat  nenufar_tf.py
LOFAR-Bandpass-Correction-nfft-032.dat  LOFAR-Bandpass-Correction-nfft-256.dat

pro:
general  idl_tools  simulations  statistics  undysputed

pro/general:
array_area.pro  data_rate_vol.pro  kmgt_bytes.pro  nenufar_calc.pro

pro/idl_tools:
adjust_lin.pro  bitarray_to_bytearray.pro  dyn_n.pro          le_auto_.pro          ps_to_pdf.pro     smoothing.pro
aj_amj.pro      bytearray_to_bitarray.pro  dyn.pro            le_auto.pro           rebinne.pro       spdynps.pro
aj_t97.pro      c_ang.pro                  examine.pro        le_auto_s.pro         reduce_array.pro  subtract_background.pro
amj_aj.pro      correl.pro                 exit_ps.pro        lightning.pro         rfi_mitigate.pro  sumthr.pro
ang_dist.pro    de_disp.pro                extpath.pro        make_background.pro   set_ps.pro        t97_aj.pro
annot.pro       delpath.pro                hms_s.pro          patrol.pro            s_hms.pro         test_de_disp.pro
background.pro  dir_separator.pro          interpol_circ.pro  prime_decomp.pro      sign.pro          tex_frex.pro
batch_conv.pro  dt_disp.pro                launch_sumthr.pro  ps_pdf.pro            SIR.pro           tfex.pro

pro/simulations:

pro/statistics:
read_nen_data.pro

pro/undysputed:
display_data.pro  read_nu_spec.pro  script.pro
```