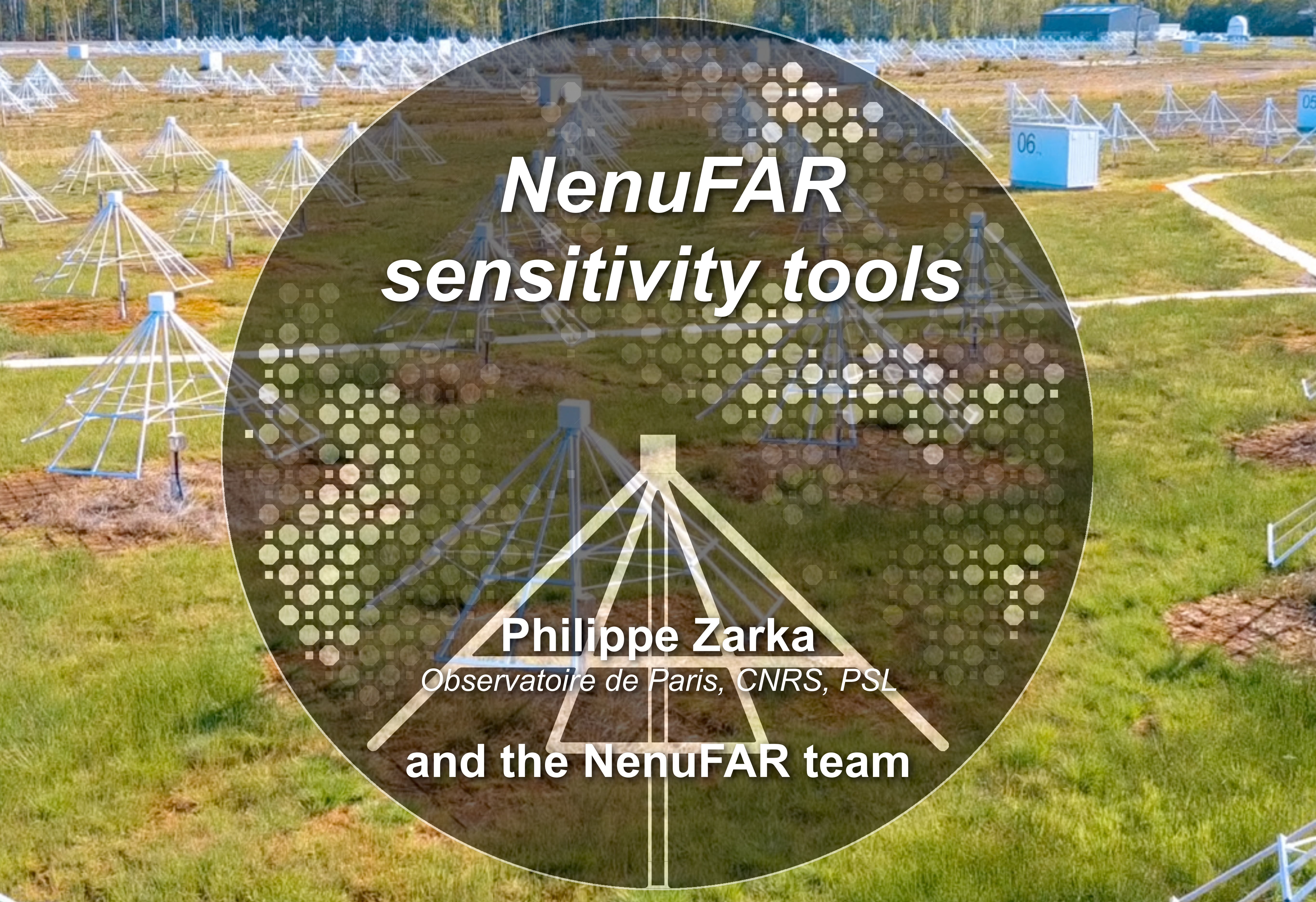

NenuFAR sensitivity tools

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and the NenuFAR team

- IDL : Standard for space radio astronomy, t-f measurements → beamforming mode

- IDL : Standard for space radio astronomy, t-f measurements → beamforming mode
- Runs on nancep nodes
- Needs licence tokens

```
In .bashrc
. /cep/lofar/exelis/idl85/bin/idl_setup.bash
export IDL_STARTUP="/home/philippe.zarka/.idlconf"

In .flexlmrc
*** the relevant license information ***

In .idlconf
!path= expand_path(‘+/cep/lofar/nenufar')+'/:'+!path
```

- Alternative = GDL : compatibility issues
- Tools on /cep/lofar/nenufar/pro/general → accessible to all nancep users
- All following text & IDL commands in /databf2/nenufar/workshop/SensitivityTools.txt

nenufar_calc

- Computes the main characteristics of NenuFAR : sensitivity, resolution …

nenufar_calc, nMAcore (scalar), nMArem (scalar), freq (scalar or vector, MHz)

nenufar_calc,/help

```
CALL
nenufar_calc, nMAcore,nMArem, freq, l, a1,aMA,aNen, thMA,FoV,thNen, Tsky,Tlna, SefdMA,SefdNen, SminTh,SminConf, $
              elev=elev, azim=azim, dmax=dmax, df=df, dt=dt, decoh=decoh, /lofar, /plot, /quiet

INPUTS
nMAcore = number of Mini-Arrays in core
nMArem  = number of remote Mini-Arrays
freq    = frequency (MHz) [scalar or vector]

KEYWORDS
elev   = elevation (°) [default=90]
azim   = azimuth (°) [default=0]
dmax   = max distance of remote MA (m) [default=400 or 3000]
df     = bandwidth (MHz) [default=1]
dt     = integration time (sec) [default=1]
decoh  = decoherence factor (1 if perfectly coherent, up to ~4 if uncalibrated) [default=1]
/lofar => confusion according to Cohen 2004 & vanHaarlem et al. 2013 [default = Condon 2002]
/plot  => display Mini-Arrays effective area
/quiet => does not print any output
/help  => extensive help
/hlp   => summary help

OUTPUTS [same size as freq]
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 (°)
FoV      = 2D FoV of MA (°^2)
thNen    = Angular resolution of Nenufar (core+remote MA) (arcmin)
Tsky     = Sky temperature (K)
Tlna     = System (preamp) temperature (K)
SefdMA   = SEFD of 1 MA (Jy)
SefdNen  = SEFD of Nenufar (core+remote MA) (Jy)
SminTh   = Thermal noise (Jy)
SminConf = Confusion noise (Jy)
```

nenufar_calc

nenufar_calc,/hlp

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

l = λ [m] = 300/freq [MHz]

a1 (antenna) = λ^2 /3

aMA computed by array_area.pro, with overlap, at zenith, or via nenufar_gain at (elev,azim)

nMA = nMAcore + nMArem

aNen = aMA * nMA

thMA = λ/25m

FoV = π thMA^2 /4

thNen = λ / dmax [arcmin]

nenufar_calc

$T_{sky} = 60 * \lambda^{2.55}$

Tlna → tabulated

SefdMA = 2K (Tsky+Tlna) / aMA

SefdNen = 2K (Tsky+Tlna) /aNen

SminTh = SefdNen * decoh /sqrt(2. * df[Hz] * dt[s])

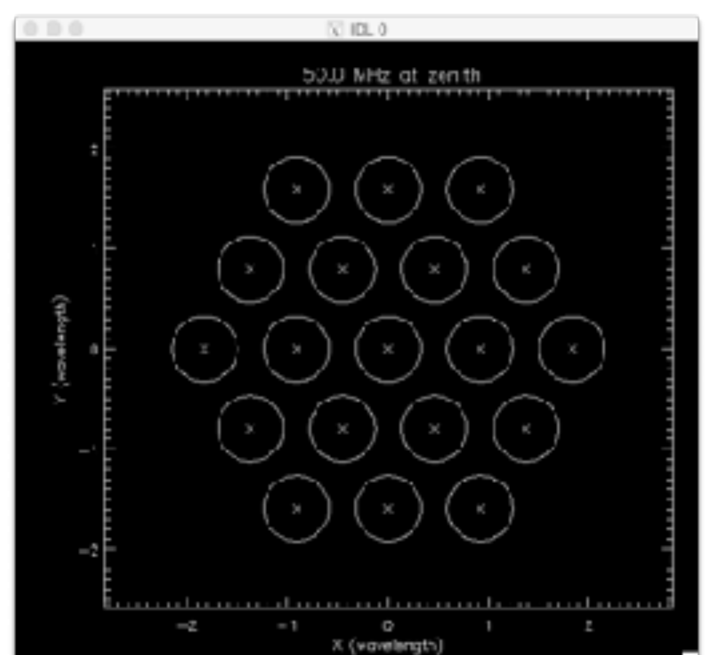
SminConf = 0.2 * freq[GHz]$^{-0.7}$ * thNen[arcmin]^{2} [Condon 2002]

SminConf = 29. * (freq[MHz]/74)$^{-0.7}$ * thNen[arcsec])$^{1.54}$ [Cohen 2004, van Haarlem et al. 2013]

nenufar_calc,56,0,50.

```
Freq(MHz)= 50.0     Wavelength(m)=  6.0     nMAcore + remote= 56 + 0
dmax(m)=   400     df(MHz),dt(s)=  1.0,     1.000     decoh= 1.0
Aeff dipole,MA,NenuFAR(m^2)=  12.0,  228.0,  12768.
Theta MA(°),FoV MA(°^2)=  13.8,    149.     Theta NenuFAR(°)=  0.86
Tsky,Tlna(K)=    5787.,     488.     SEFD MA,NenuFAR(Jy)=    75964.,     1356.
SminThermal,Confusion(Jy)=    0.959,    4.330
```

nenufar_calc,56,0,50.,/plot



nenufar_calc

Tsky = 60 * $\lambda^{2.55}$

Tlna → tabulated

SefdMA = 2K (Tsky+Tlna) / aMA

SefdNen = 2K (Tsky+Tlna) /aNen

SminTh = SefdNen * decoh /sqrt(2. * df[Hz] * dt[s])

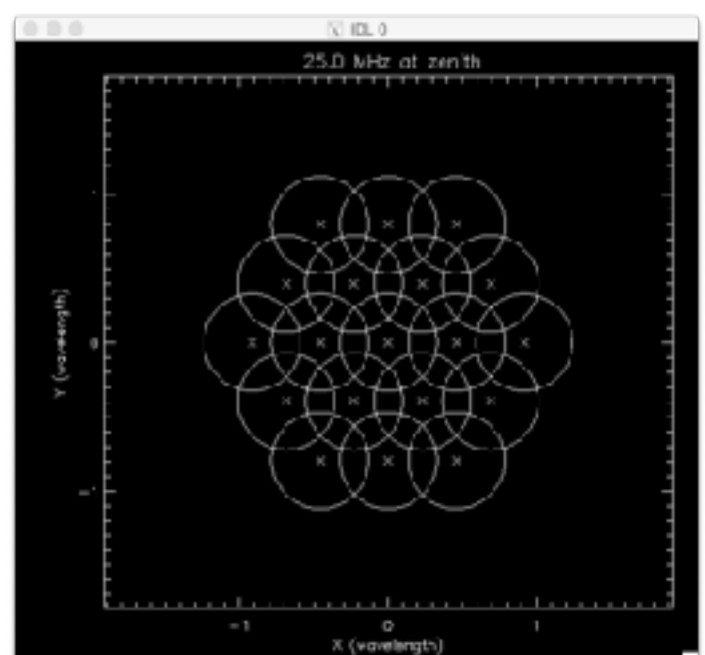
SminConf = 0.2 * freq[GHz]$^{-0.7}$ * thNen[arcmin]^{2} [Condon 2002]

SminConf = 29. * (freq[MHz]/74)$^{-0.7}$ * thNen[arcsec])$^{1.54}$ [Cohen 2004, van Haarlem et al. 2013]

nenufar_calc,56,0,25.

```
Freq(MHz)= 25.0     Wavelength(m)= 12.0     nMAcore + remote= 56 + 0
dmax(m)=   400     df(MHz),dt(s)=  1.0,     1.000     decoh= 1.0
Aeff dipole,MA,NenuFAR(m^2)=  48.0,  597.0,  33433.
Theta MA(°),FoV MA(°^2)=  27.5,    594.     Theta NenuFAR(°)=  1.72
Tsky,Tlna(K)=   33889.,    2094.     SEFD MA,NenuFAR(Jy)=   166351.,     2971.
SminThermal,Confusion(Jy)=    2.100,   28.136
```

nenufar_calc,56,0,25.,/plot ⇒ overlap



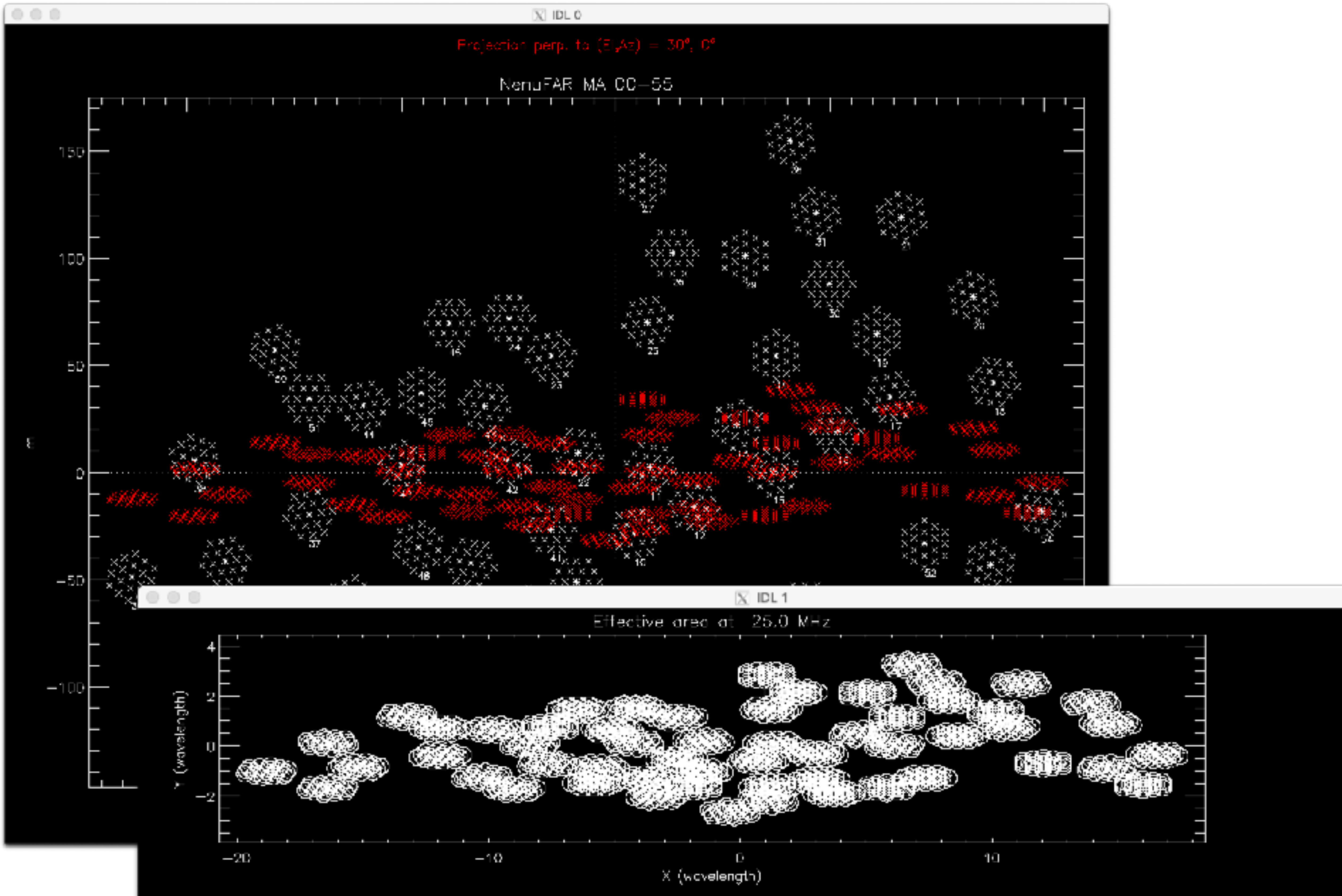
nenufar_calc

nenufar_calc,56,0,25.,elev=30. ⇒ lower aMA & aNen, higher SminThermal (same SminConf)

```
Freq(MHz)= 25.0     Wavelength(m)= 12.0     nMAcore + remote= 56 + 0
Elev,Azim(°)= 30,   0     dmax(m)=   400     df(MHz),dt(s)=  1.0,     1.000     decoh= 1.0
Aeff dipole,MA,NenuFAR(m^2)=  48.0,  260.6,  14596.
Theta MA(°),FoV MA(°^2)=  27.5,    594.     Theta NenuFAR(°)=  1.72
Tsky,Tlna(K)=   33889.,    2094.     SEFD MA,NenuFAR(Jy)=   381036.,     6804.
SminThermal,Confusion(Jy)=    4.811,   28.136
```

nenufar_calc

nenufar_calc,56,0,25.,elev=30.,/plot ⇒ cf. plots from nenufar_gain



nenufar_calc

freq=findgen(38)*2+10 ⇒ ramp 10-84 MHz by 2 MHz step

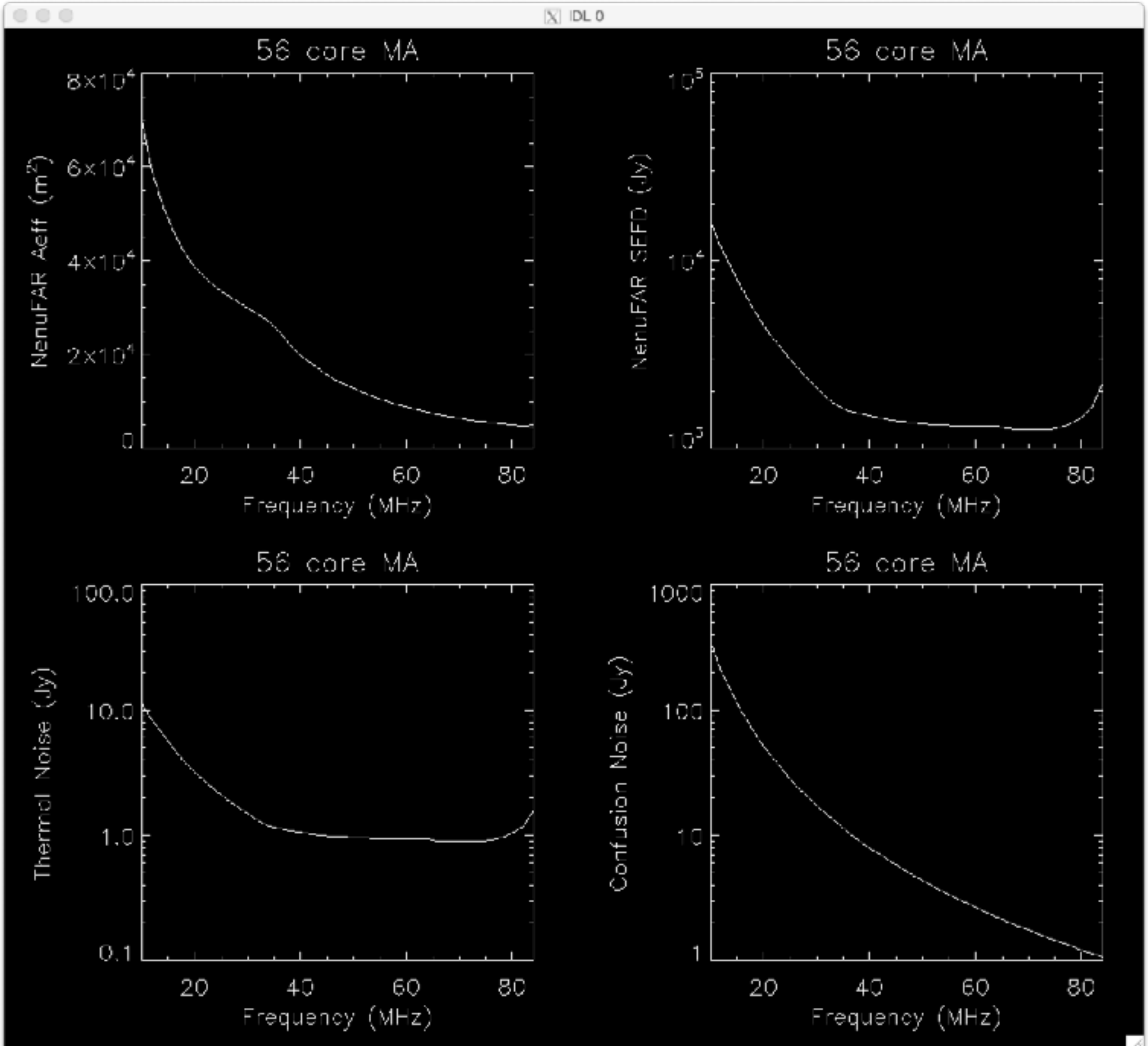
nenufar_calc,56,0,freq ⇒ impractical display

nenufar_calc,56,0,freq,/plot ⇒ + many plots

nenufar_calc,56,0,freq, l, a1,aMA,aNen, thMA,FoV,thNen, Tsky,Tlna, SefdMA,SefdNen, SminTh,SminConf, /quiet

```
window,0,xs=1000,ys=900
!p.multi=[0,2,2]
plot,freq,aNen,/xsty,/ynoz,xtit='Frequency (MHz)',ytit='NenuFAR Aeff (m!U2!N)',tit='56 core MA',charsize=2.
plot_io,freq,SefdNen,/xsty,xtit='Frequency (MHz)',ytit='NenuFAR SEFD (Jy)',tit='56 core MA',charsize=2.
plot_io,freq,SminTh,/xsty,xtit='Frequency (MHz)',ytit='Thermal Noise (Jy)',tit='56 core MA',charsize=2.
plot_io,freq,SminConf,/xsty,xtit='Frequency (MHz)',ytit='Confusion Noise (Jy)',tit='56 core MA',charsize=2.
```

nenufar_calc



nenufar_calc

same with decoh=2.

/lofar => higher confusion

vary dmax, df, dt :

nenufar_calc,80,4,50, dmax=1500, df=20, dt=3600

```
Freq(MHz)= 50.0     Wavelength(m)=  6.0     nMAcore + remote= 80 + 4
dmax(m)=  1500     df(MHz),dt(s)= 20.0,  3600.000     decoh= 1.0
Aeff dipole,MA,NenuFAR(m^2)=  12.0,  228.0,  19152.
Theta MA(°),FoV MA(°^2)=  13.8,    149.     Theta NenuFAR(arcmin)= 13.75
Tsky,Tlna(K)=    5787.,     488.     SEFD MA,NenuFAR(Jy)=    75964.,      904.
SminThermal,Confusion(Jy)=    0.002,    0.308
```

etc.

nenufar_calc

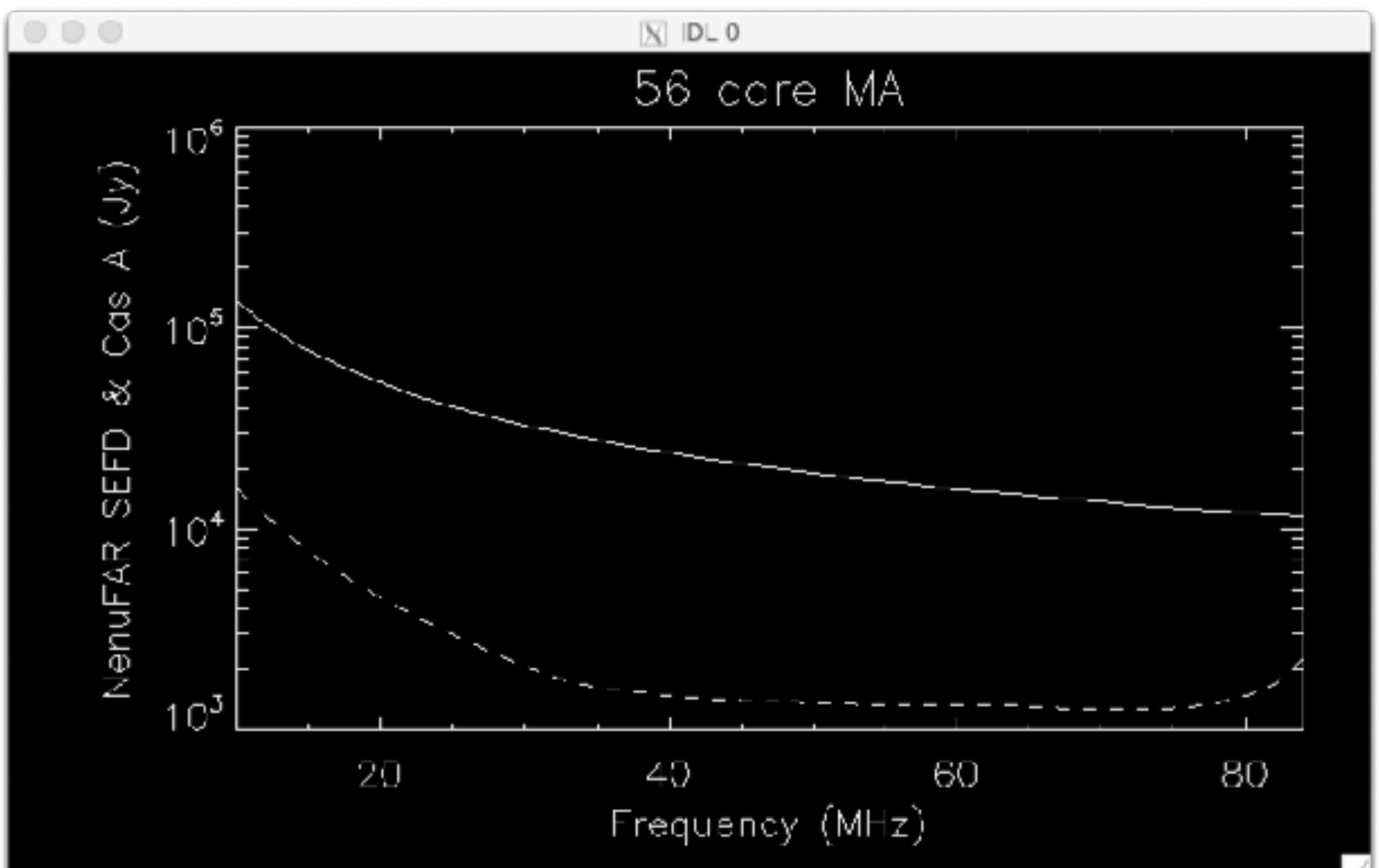
Adding a strong source (e.g. A-team) to NenuFAR's SEFD

nenufar_calc,56,0,freq, l, a1,aMA,aNen, thMA,FoV,thNen, Tsky,Tlna, SefdMA,SefdNen, SminTh,SminConf, /quiet

SCasA, freq, Scas

```
Cas A flux density spectrum (Jy) over frequency ramp freq (MHz) from [de Gasperin et al. 2020 & UTR-2]
```

plot_io,freq,Scas,/xsty,yra=[min(SefdNen),max(Scas)],xtit='Frequency (MHz)',ytit='NenuFAR SEFD & Cas A (Jy)',tit='56 core MA',charsize=2.
oplot,freq,SefdNen,line=2

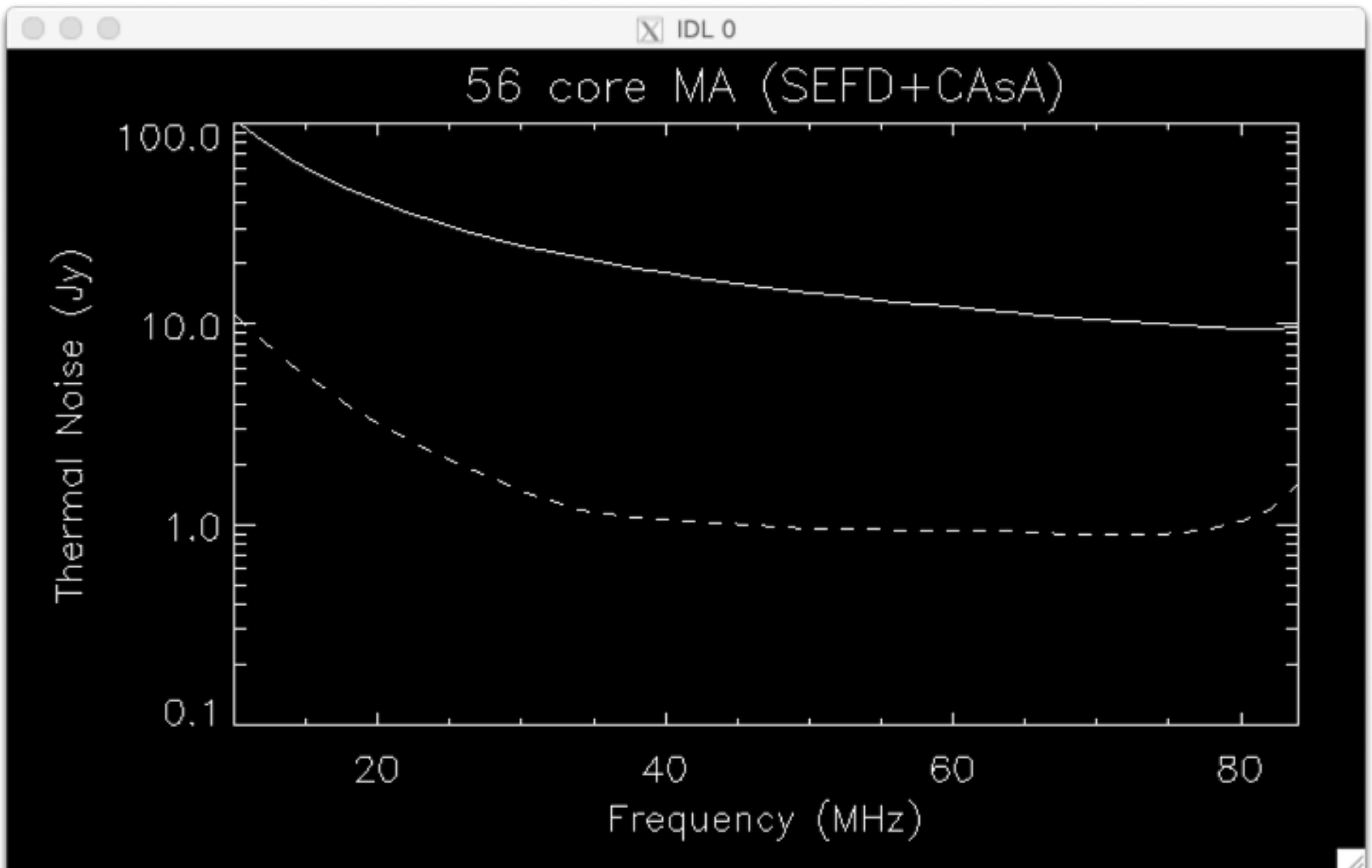


nenufar_calc

Stot = SefdNen + Scas

SminTh = Stot/sqrt(2*1.e6*1) ⇒ Stot * decoh /sqrt(2 * df[Hz] * dt[s])

```
plot_io,freq,SminTh,/xsty,xtit='Frequency (MHz)',ytit='Thermal Noise (Jy)',tit='56 core MA (SEFD+CAsA)',charsize=2.,line=2
oplot,freq,SminTh
```



nenufar_gain

- Theoretical gain of NenuFAR for a pointing at elev,azim, freq

nenufar_gain, elev(°), azim(°), freq (MHz) (all scalars)

⇒ core only, up to 56 MA presently tabulated, soon updated to 80, then 96

⇒ takes into account array factor and antenna gains

nenufar_gain,/help

```
Computes the theoretical gain of current NenuFAR configuration
      for a pointing at elev,azim and frequency freq

CALL
nenufar_gain, elev,azim, freq, ae, g_array,g_NE,g_NW, /accurate,/plot,/quiet

INPUTS
elev, azim = elevation, azimuth (deg.) [scalars]
freq       = frequency (MHz) [scalar]

KEYWORDS
nMA = nMA => if less than maximum available
/accurate => accurate (<0.1%) and longer calculation of Aeff
/plot     => display Mini-Arrays effective area & antennas layout
/quiet    => does not print any output
/help     => extensive help
/hlp      => summary help

OUTPUTS
ae      = effective area of NenuFAR core [m^2]
g_array = array gain                     [linear value]
g_NE    = array & NE_SW antenna gain     [linear value]
g_NW    = array & NW_SE antenna gain     [linear value]
aMA     = effective area of 1 MA         [m^2]
```

nenufar_gain

- Theoretical gain of NenuFAR for a pointing at elev,azim, freq

nenufar_gain, elev(°), azim(°), freq (MHz) (all scalars)

⇒ core only, up to 56 MA presently tabulated, soon updated to 80, then 96

⇒ takes into account array factor and antenna gains

nenufar_gain,/hlp

```
nenufar_gain, [IN]   elev,azim, freq, $
              [OUT]  ae, g_array,g_NE,g_NW, aMA, $
              [KEY]  nMA=nMA, /accurate, /plot, /quiet
```

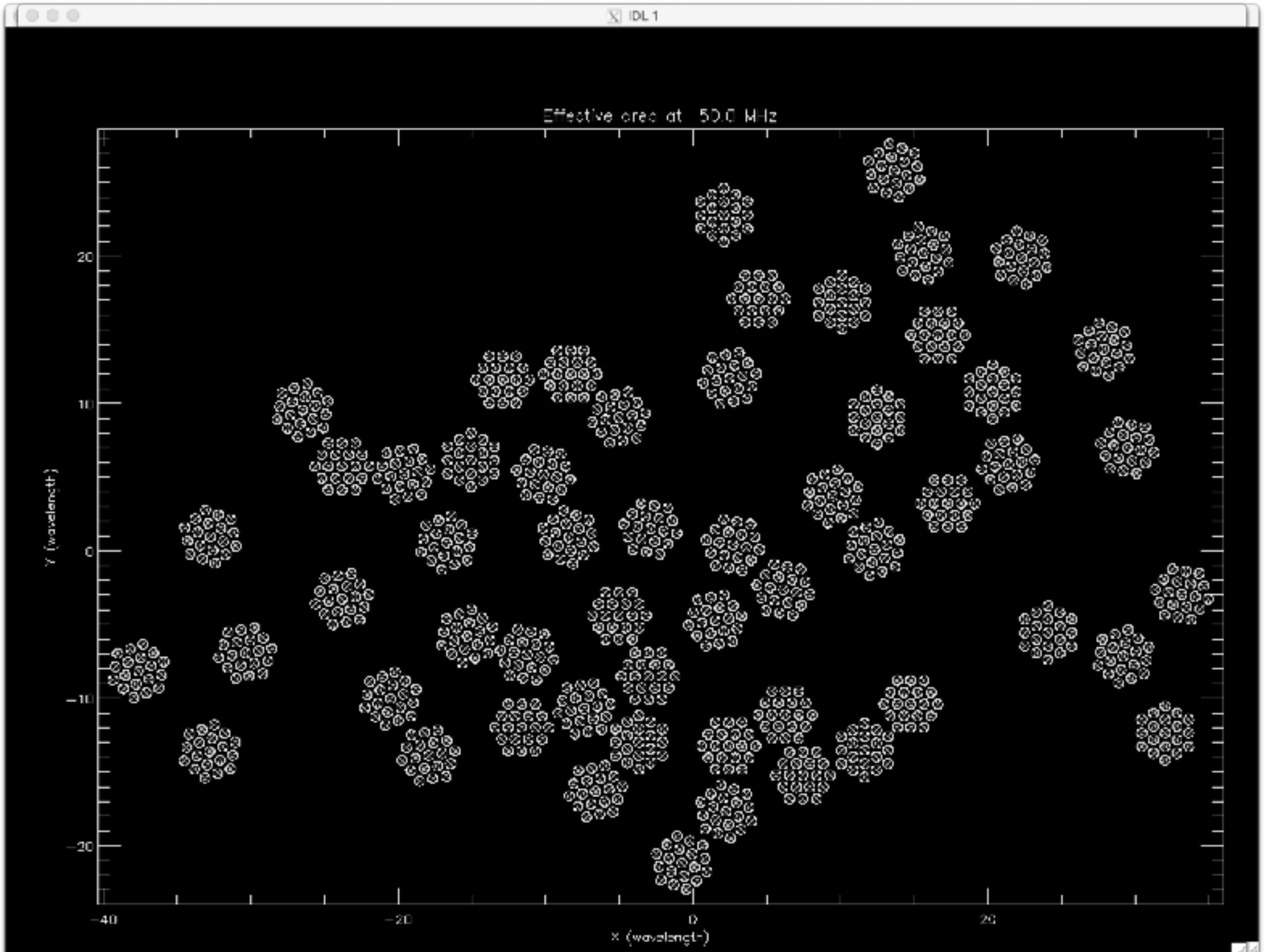
nenufar_gain

nenufar_gain,90,0,50

```
Elevation = 90°,   Azimuth = 0°,   Frequency = 50 MHz
n Mini-Arrays      =            56
Ae Array           =       12768.0 m^2
Gain Array         =       4456.87 =       36.4903 dB
Gain Array * NE_SW =       17459.4 =       42.4203 dB
Gain Array * NW_SE =       17459.4 =       42.4203 dB
Ae 1 MA           =       228.000 m^2
```

nenufar_gain

nenufar_gain,90,0,50,/plot



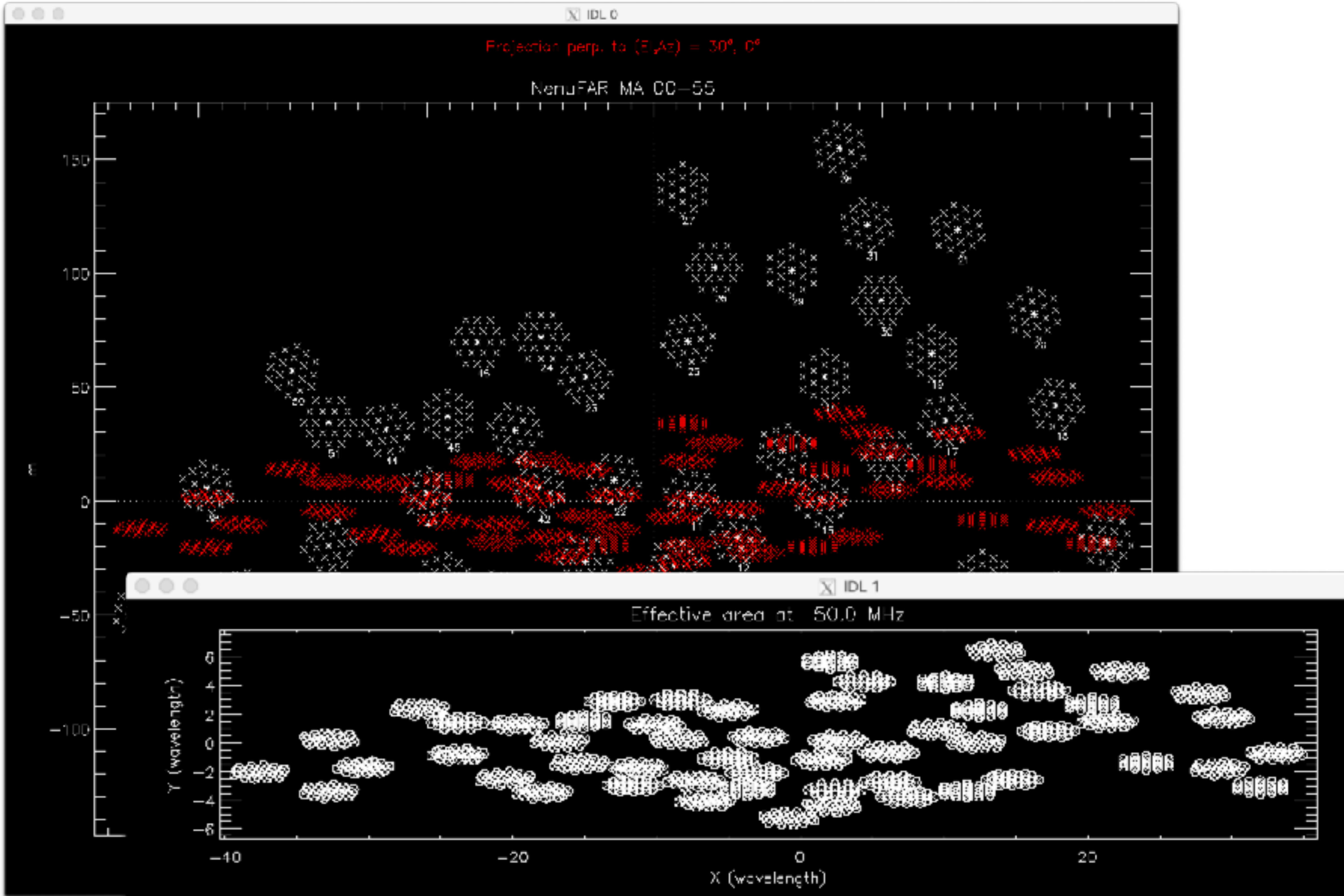
nenufar_gain

nenufar_gain,30,0,50

```
Elevation = 30°,   Azimuth = 0°,   Frequency = 50 MHz
n Mini-Arrays      =           56
Ae Array           =      8350.02 m^2
Gain Array         =      2914.71 =        34.6460 dB
Gain Array * NE_SW =      4136.14 =        36.1660 dB
Gain Array * NW_SE =      4136.14 =        36.1660 dB
Ae 1 MA           =      149.108 m^2
```

nenufar_gain

nenufar_gain,30,0,50,/plot



nenufar_gain

nenufar_gain,30,100,50, nMA=30

```
Elevation = 30°,   Azimuth = 100°,   Frequency = 50 MHz
n Mini-Arrays      =           30
Ae Array           =       4515.93 m^2
Gain Array         =       1576.36 =       31.9765 dB
Gain Array * NE_SW =       2310.23 =       33.6365 dB
Gain Array * NW_SE =       2165.98 =       33.3565 dB
Ae 1 MA           =       150.531 m^2
```

nenufar_gain

nenufar_gain,30,100,50, nMA=30,/plot