

LOFAR

Low Frequency Array

=> most distant, high redshift Universe !?

Consortium of international partners...

Dutch ASTRON

USA Haystack Observatory (MIT)

USA Naval Research Lab

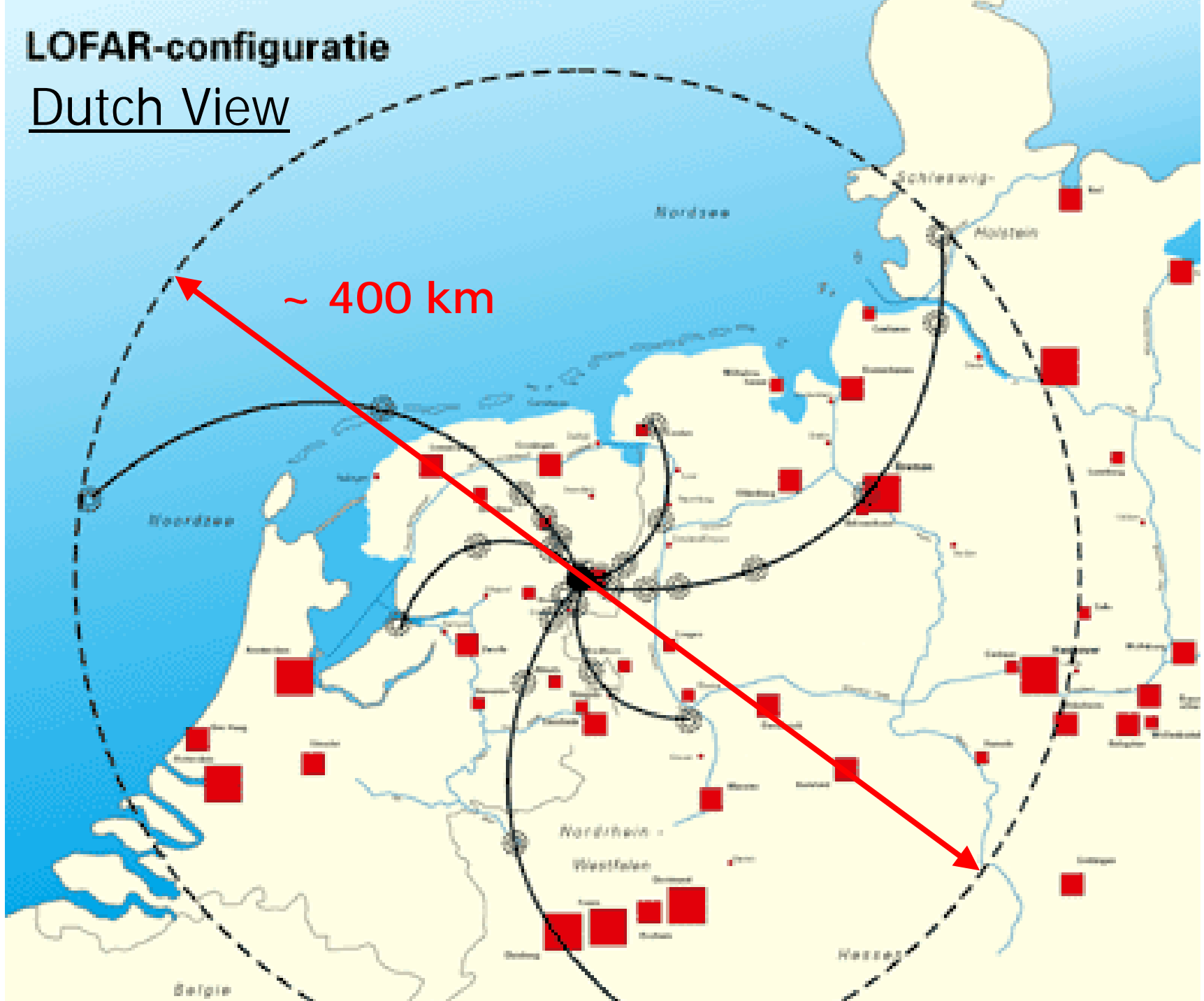
... `best site' = WA

Novel `technology telescope'

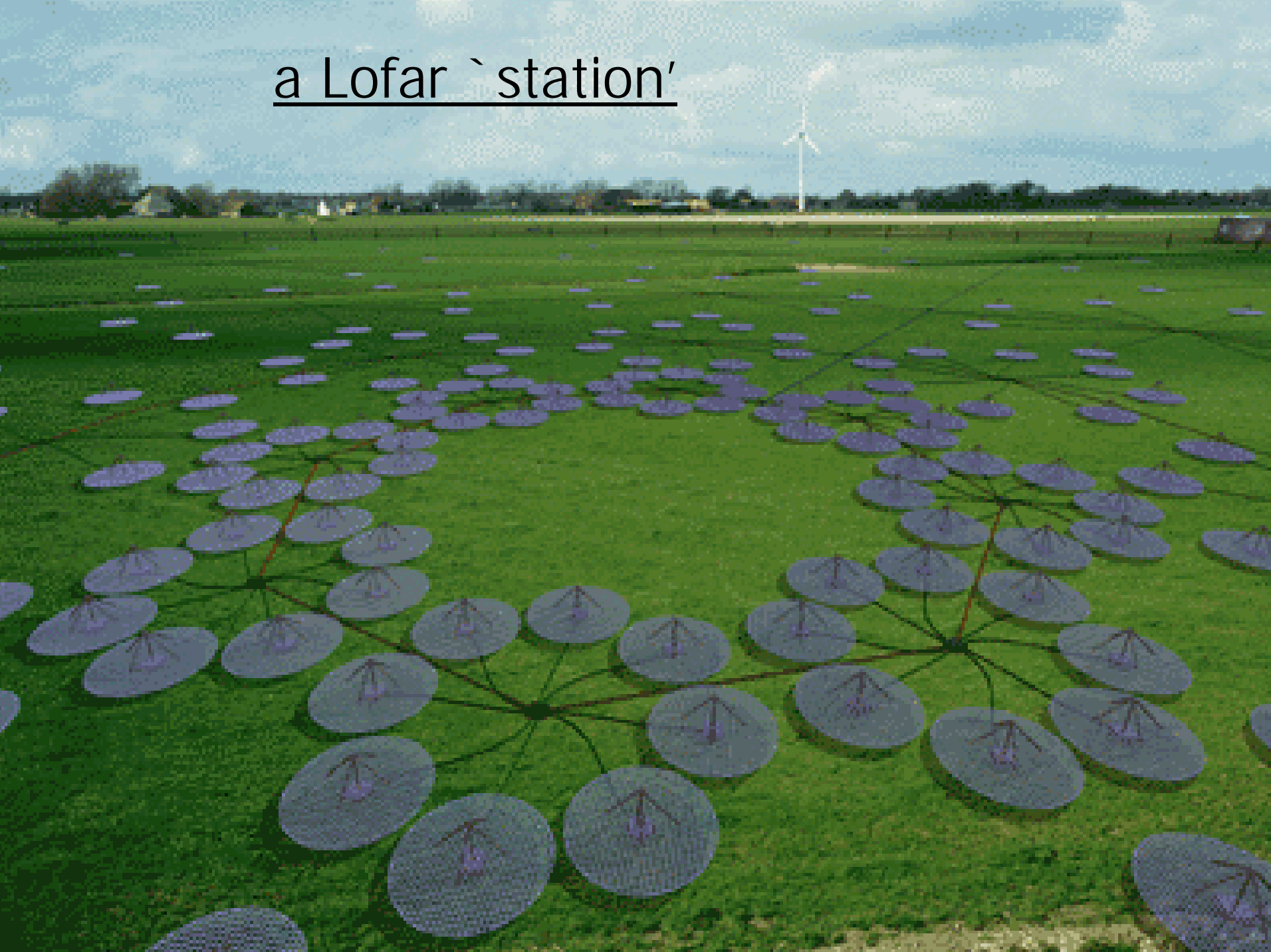
- array design => no moving parts (cheap)
- huge, fast data network
- huge collecting area
- multi-beaming

LOFAR-configuratie

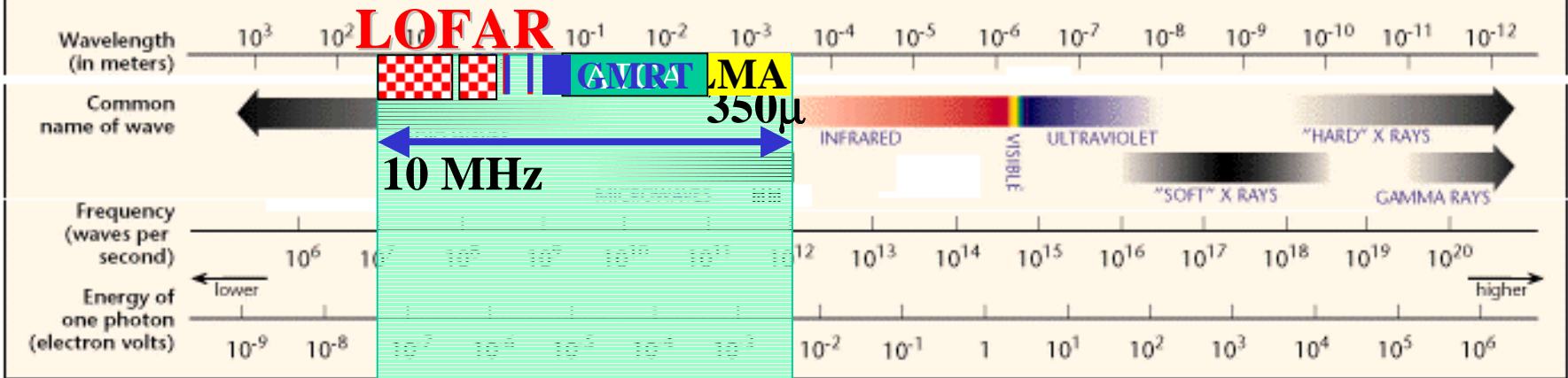
Dutch View



a Lofar `station'



THE ELECTROMAGNETIC SPECTRUM



LOFAR

AVRCA MA

350µ

10 MHz

ground based radio techniques

THE ELECTROMAGNETIC SPECTRUM

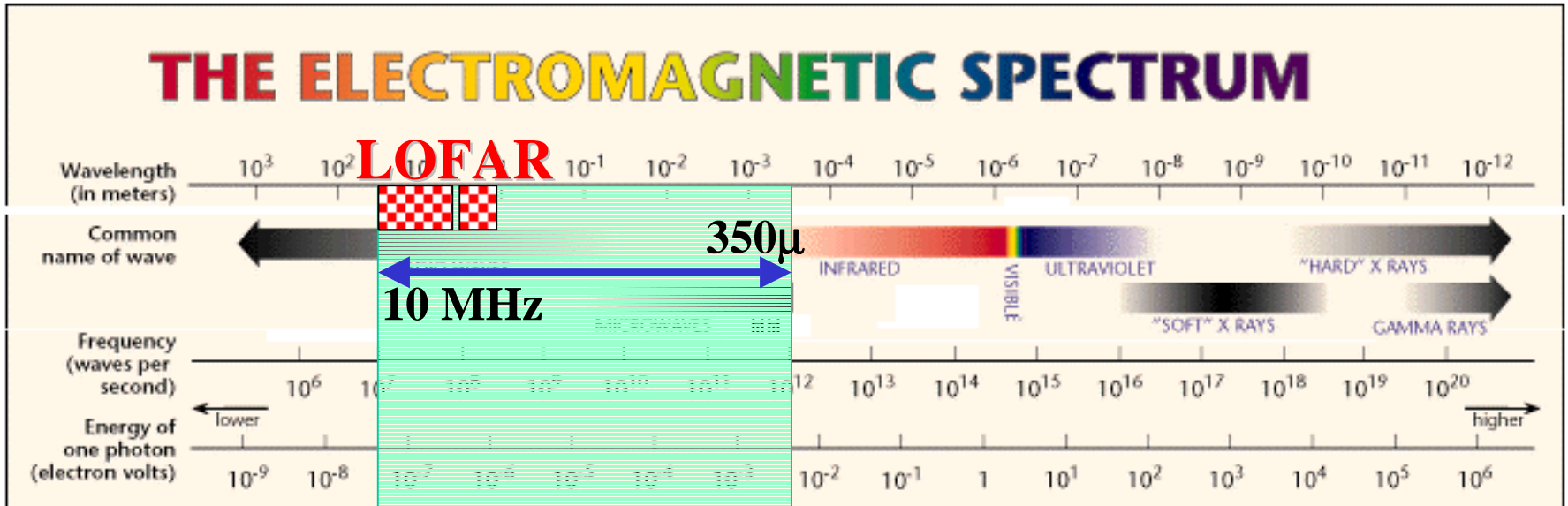
LOFAR



10 MHz

350μ

**ground based
radio techniques**



...this workshop... mm λ astronomy...

ALMA

LOFAR

Similarities:

sky noise
rapid phase variation

atmosphere
atmosphere

Gal. Synchrotron
ionosphere

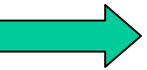
Differences:

solid angle of
receiving element
survey

tiny (λ/D of dish)
mosaic

nearly all sky
all-sky calibration

Top 4 LOFAR astronomical science drivers



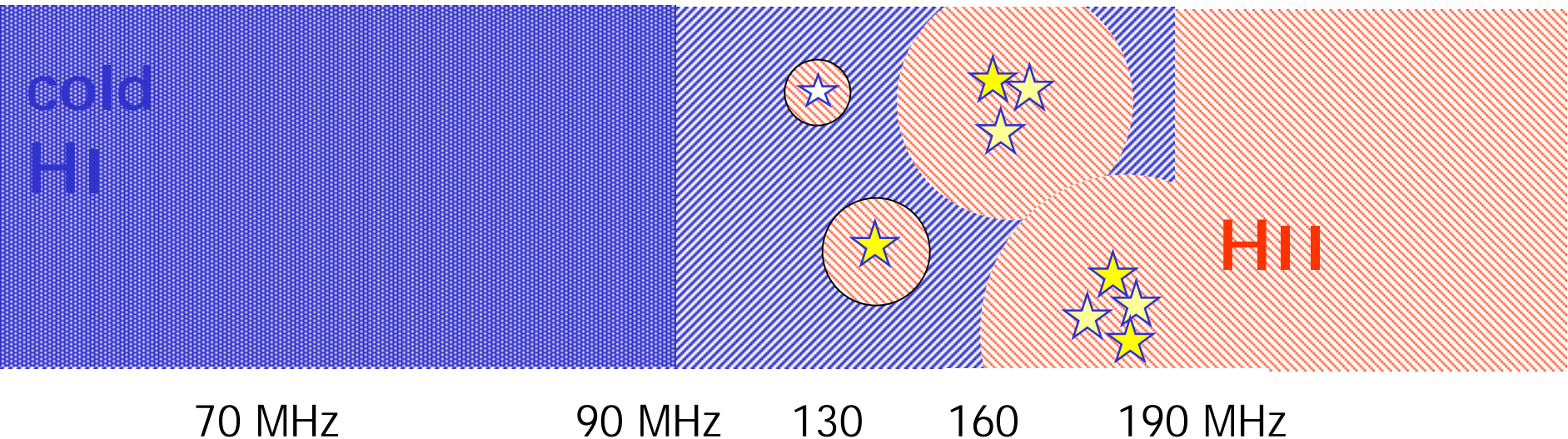
- 21cm emission/absorption from Epoch of Reionisation
- mapping the neutral clouds in IGM as first sources of ionising radiation appear at redshifts between 7 and 20(?)

Top LOFAR astronomical science drivers

- 21cm emission/absorption from Epoch of Reionisation
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$\tau_{UV} < 1$... (Gunn-Peterson Effect)

Z = 20 15 10 8 7 ↓ 6



WMAP result $\Rightarrow Z \sim 15$ to 20

2 EoRs ??? ... or...

prolonged, patchy EoR ???

$Z = 20$

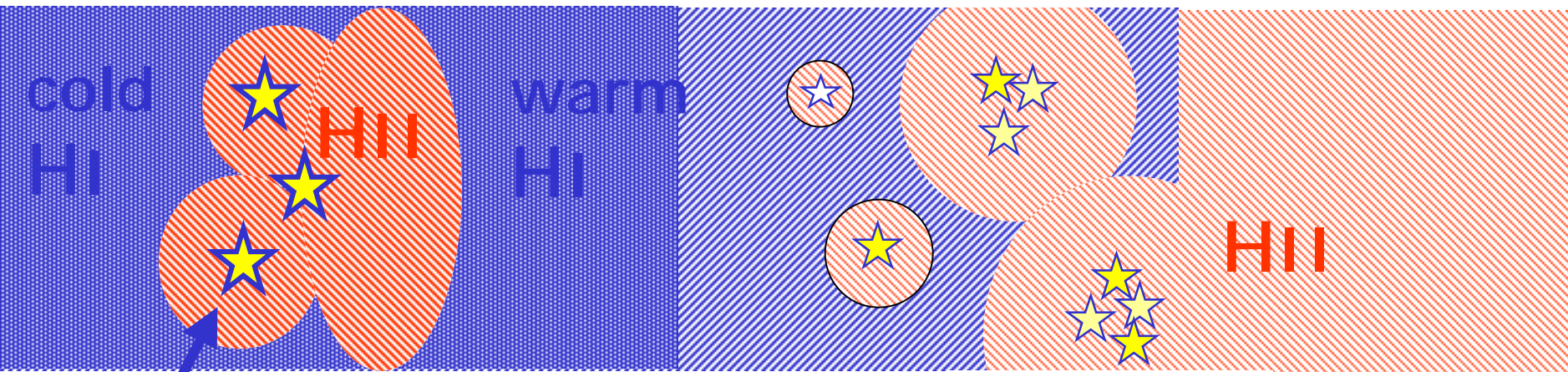
15

10

8

7

6



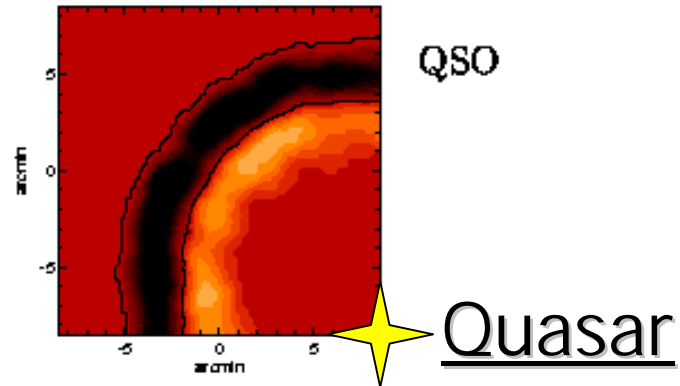
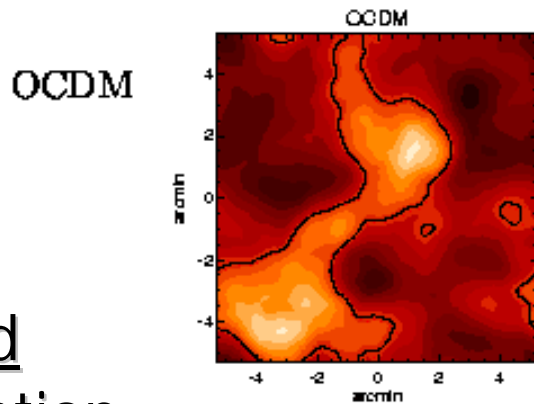
Pop III stars: @ 500 Solar mass

LOFAR and SKA ...

Sensitivity to Spatial Structure

* Numerical simulations: Tozzi, Madau, Meiksin, Rees 2000
of the Radio Sky

distributed
star formation

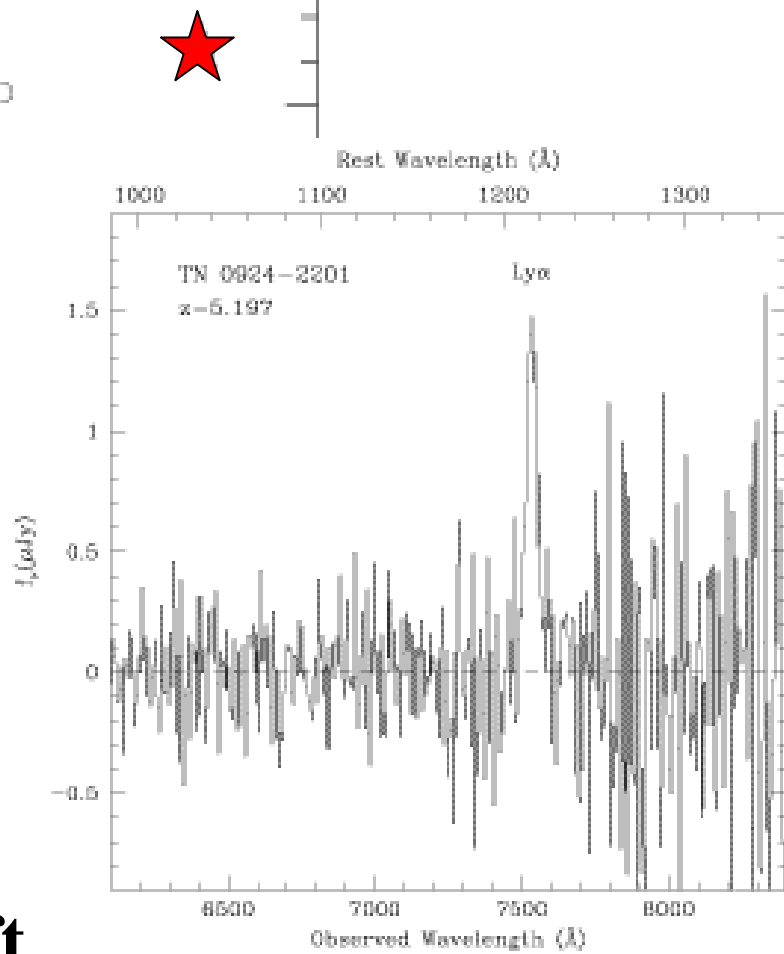
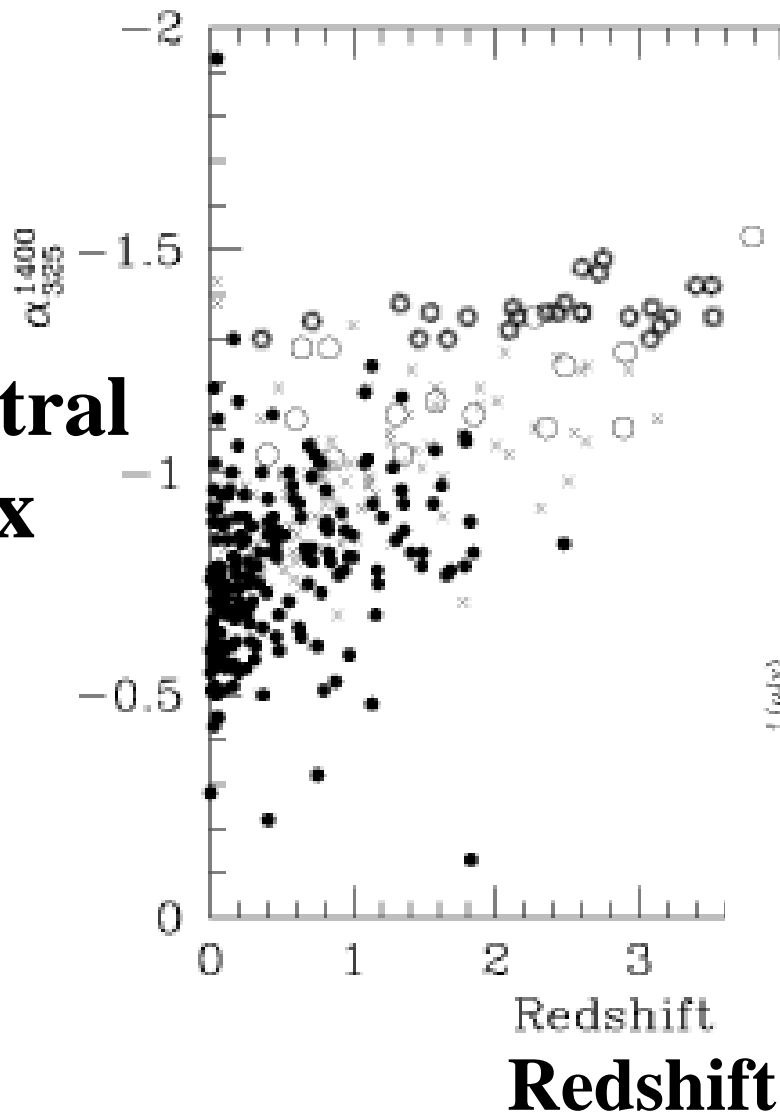


↔
10 arcmin

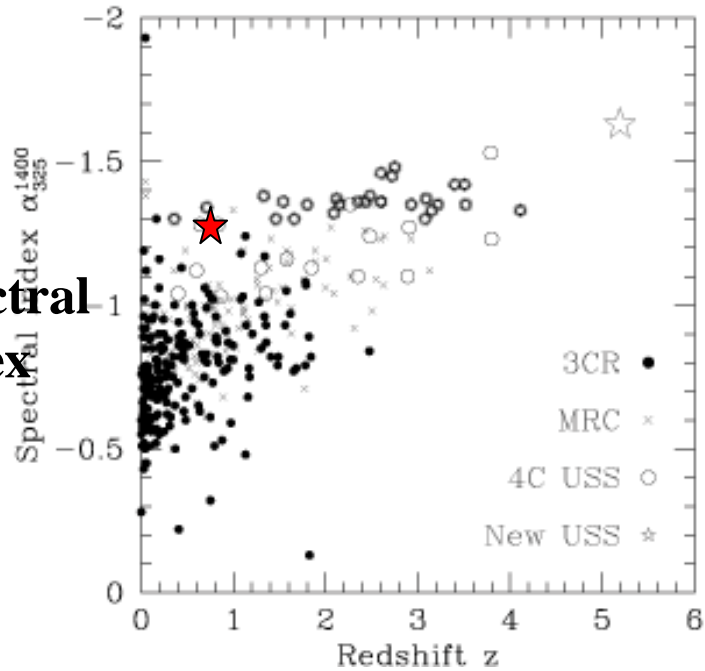
Top 4 LOFAR astronomical science drivers

- 21cm emission/absorption from Epoch of Reionisation
 - mapping of neutral clouds in IGM as first sources of ionising radiation appear at redshifts between 7 and 20(?)
- Highest redshift radio sources
 - Steep spectrum selection ($\alpha < -2$) \Rightarrow 1 source per sample of $\sim 30,000$
 - \Rightarrow catalog of background radio sources for intervening HI absorption

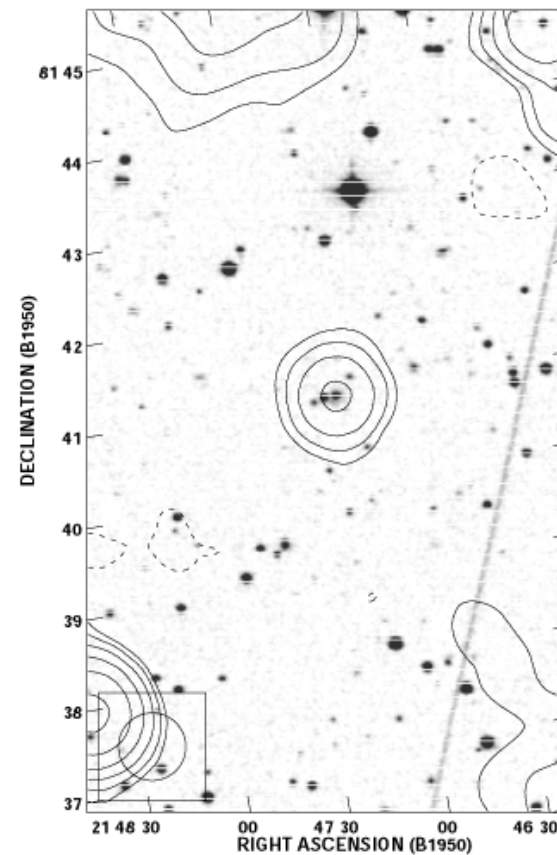
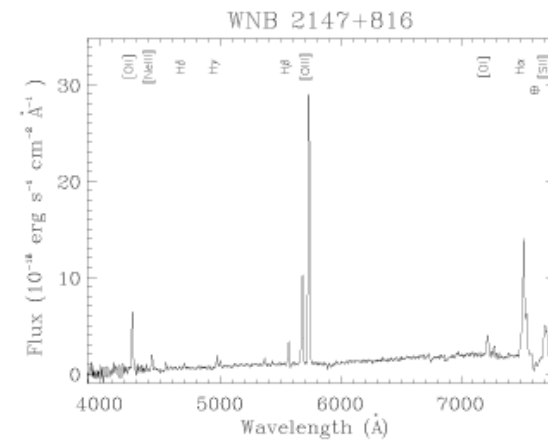
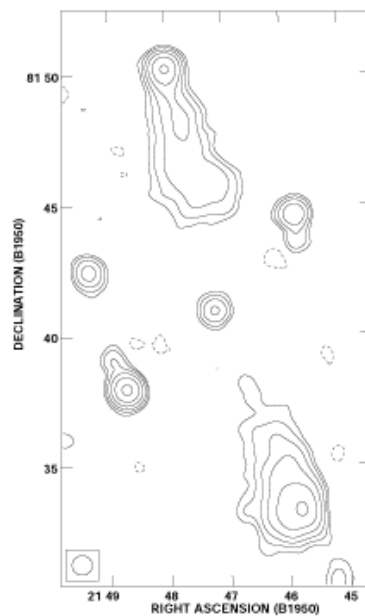
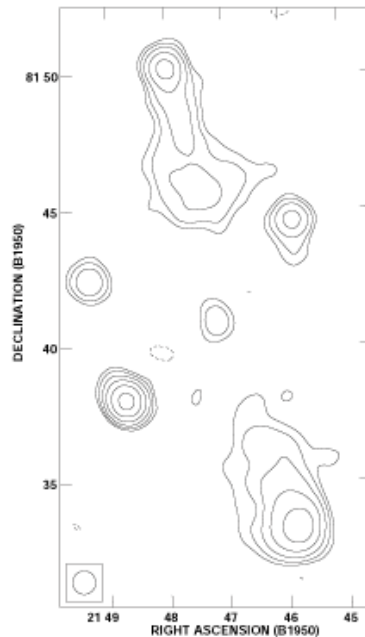
Spectral Index



**Spectral
Index**



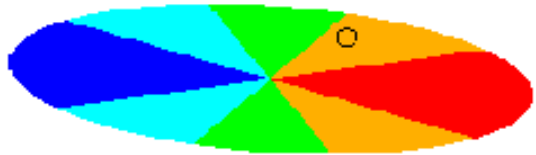
Redshift



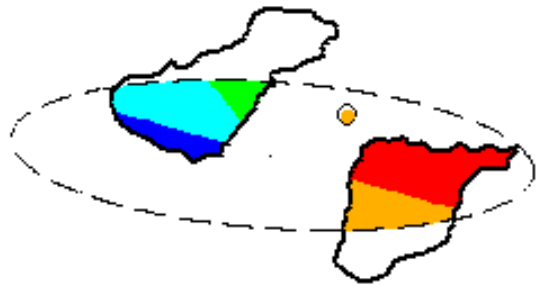
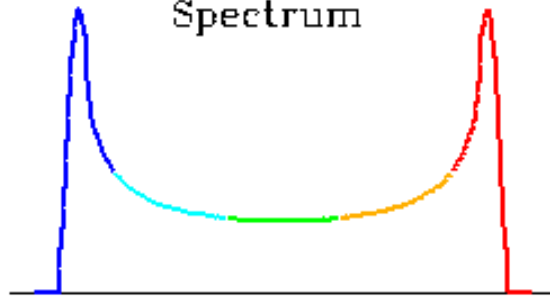


3C196

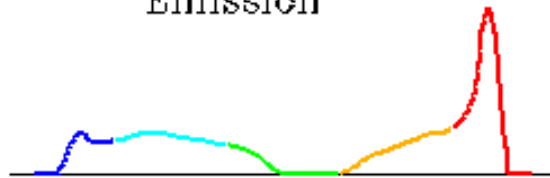
Mapping
intervening
protogalaxies
in 21cm absorption



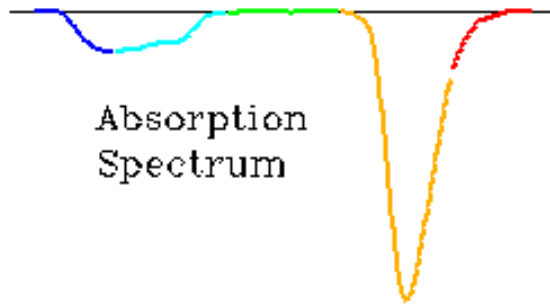
Emission
Spectrum



Restricted
Emission




Absorption
Spectrum



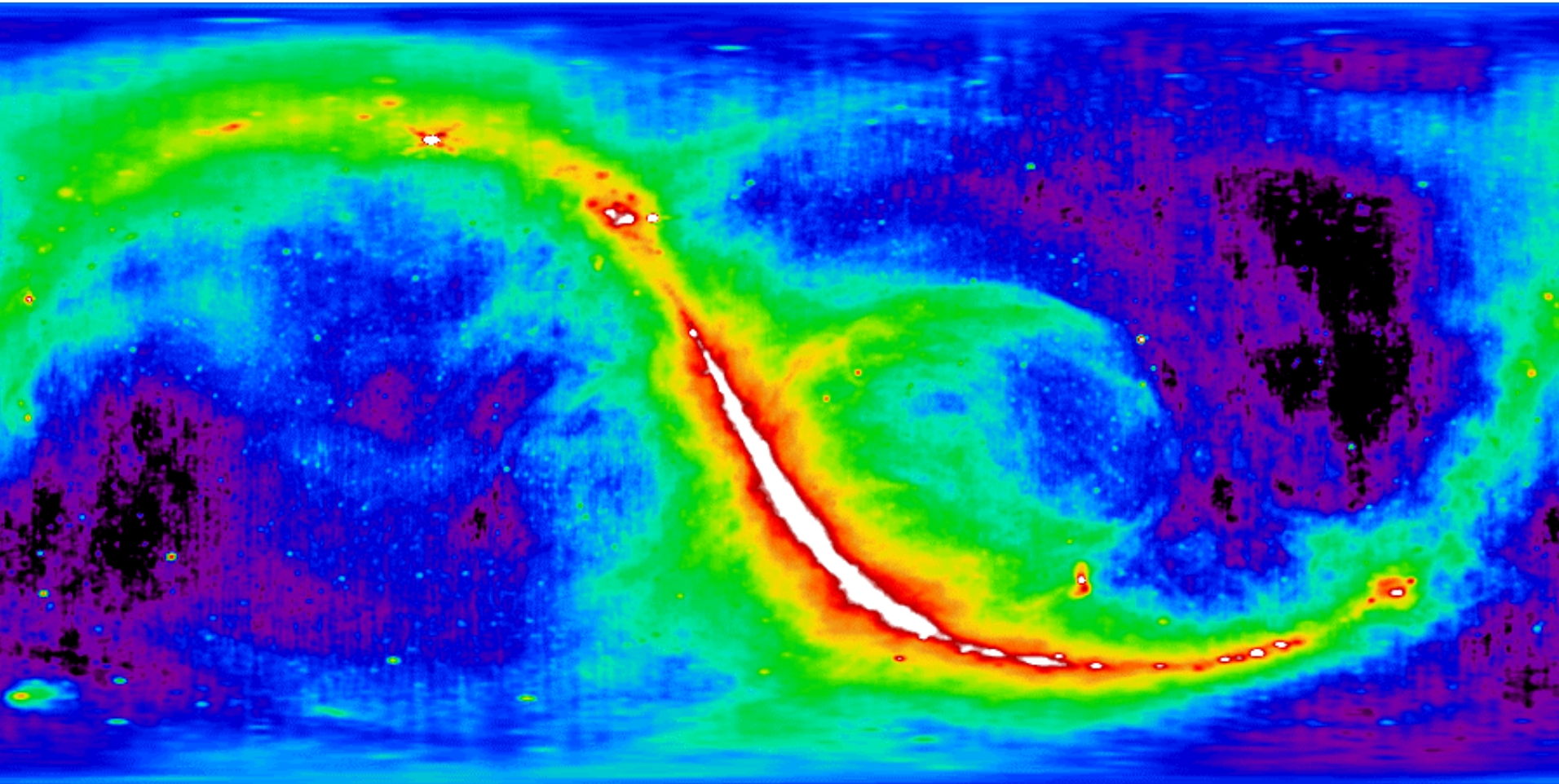
SKAMP-III
compatible !

Top 4 LOFAR astronomical science drivers

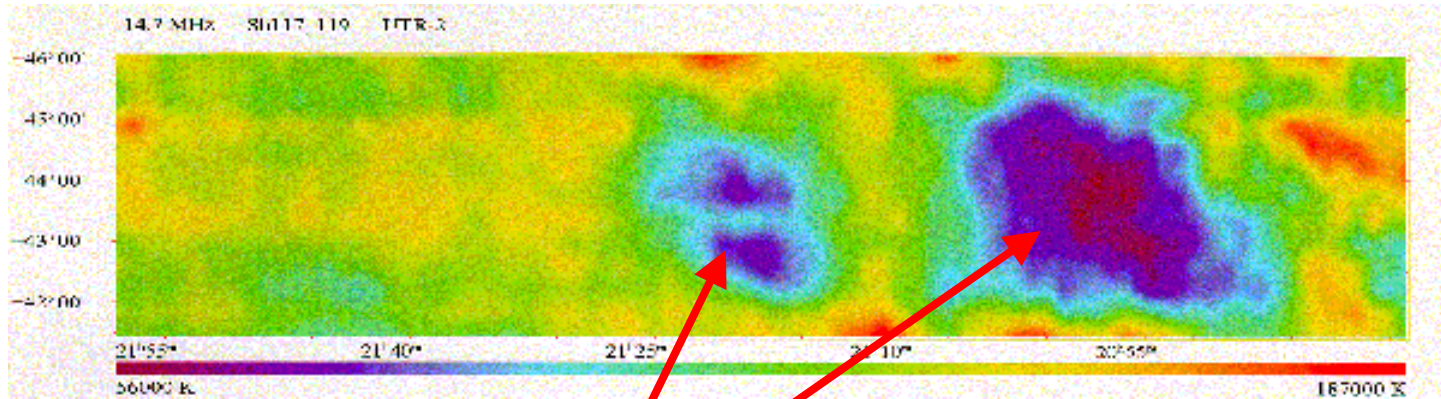
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 - \Rightarrow catalog of background radio sources for intervening HI absorption
-  • 3-D mapping of the Galactic non-thermal emission
 - uses free-free absorption by known extended thermal sources
 - will determine the origin of the Galactic cosmic ray flux

Radio sky in 408 MHz continuum (Haslam et al)

(Dominated by synchrotron emission from relativistic electrons)

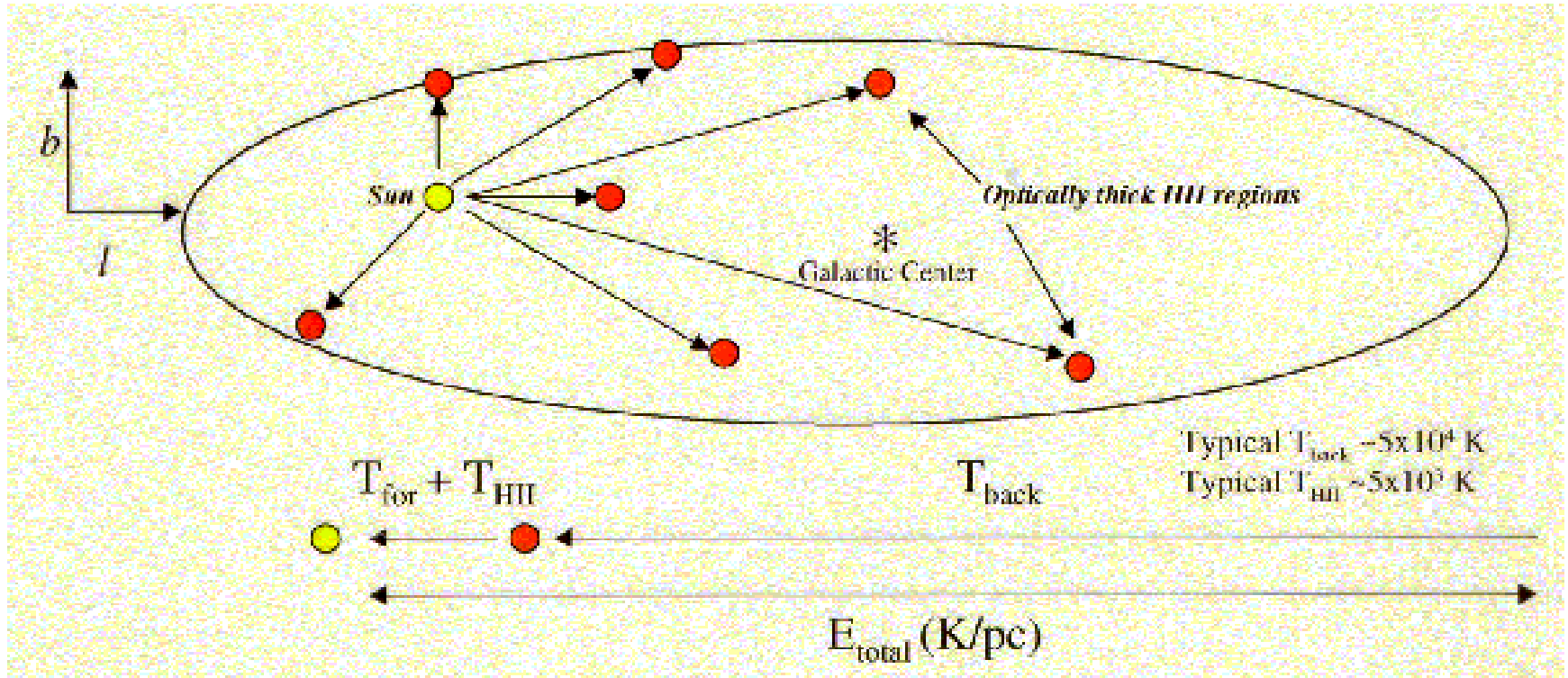


holes in the Galactic radio sky...

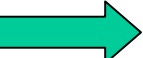


**Optically thick thermal plasma
... HII regions**

mapping the synchrotron emission in front of ... and behind the opaque thermal sources

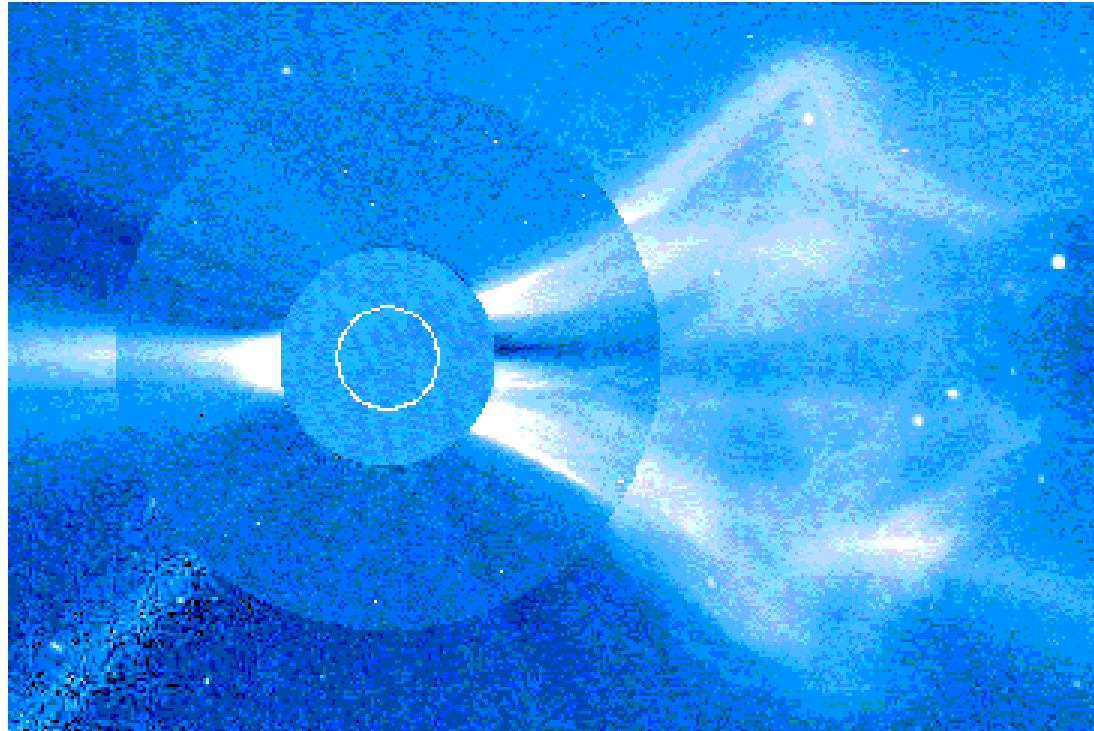


Top 4 LOFAR astronomical science drivers

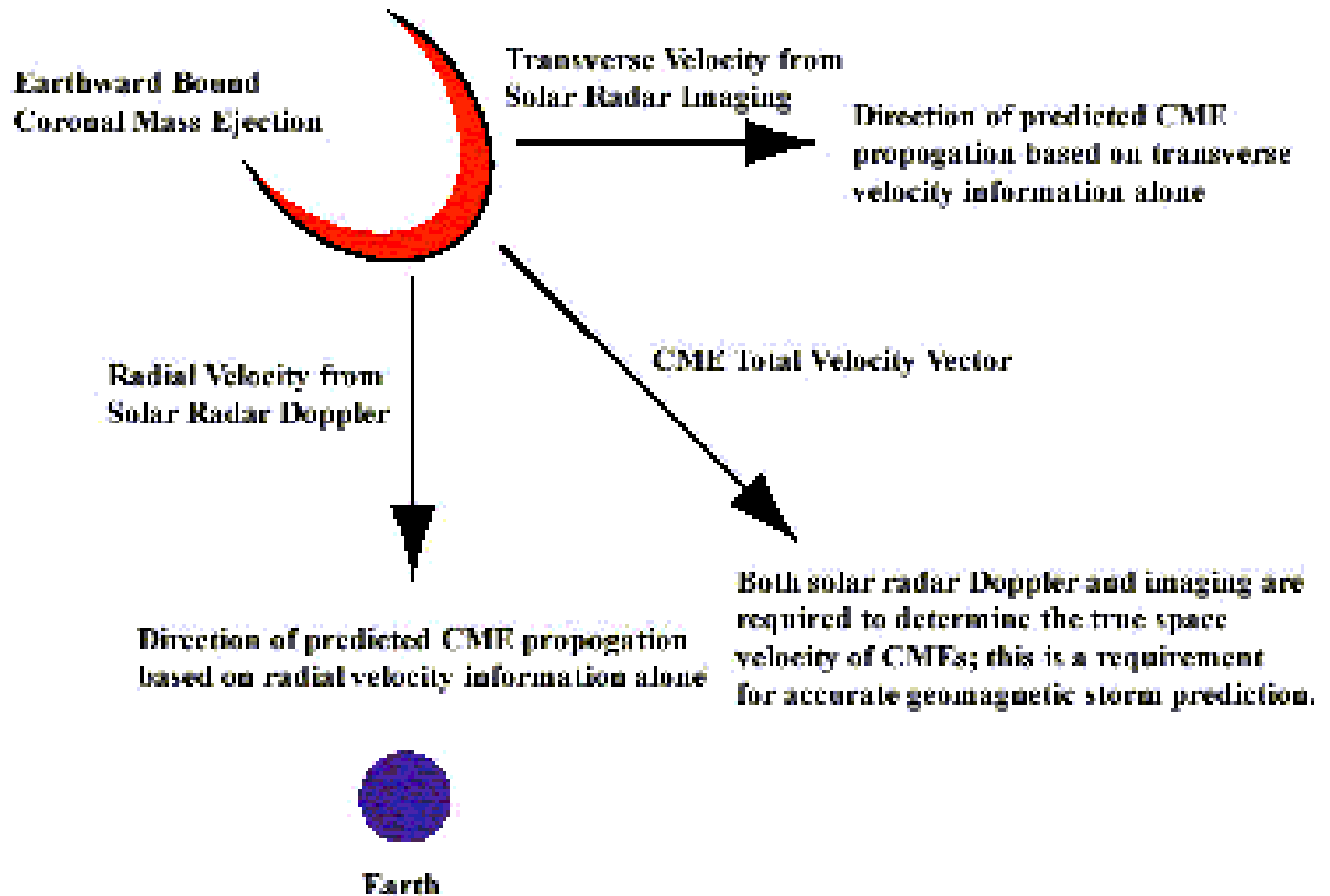
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 - will determine the origin of the Galactic cosmic ray flux
-  Transient and bursting sources
- no moving parts \Rightarrow nearly instantaneous response to trigger events
 - central core is an all-sky (hemisphere) monitor
 - sensitive to non-thermal, coherent emission events, should they exist(?)

The SUN

Coronal Mass Ejections, CMEs



CME Velocities from Long Wavelength Solar Radar



Frank's 3 favorites

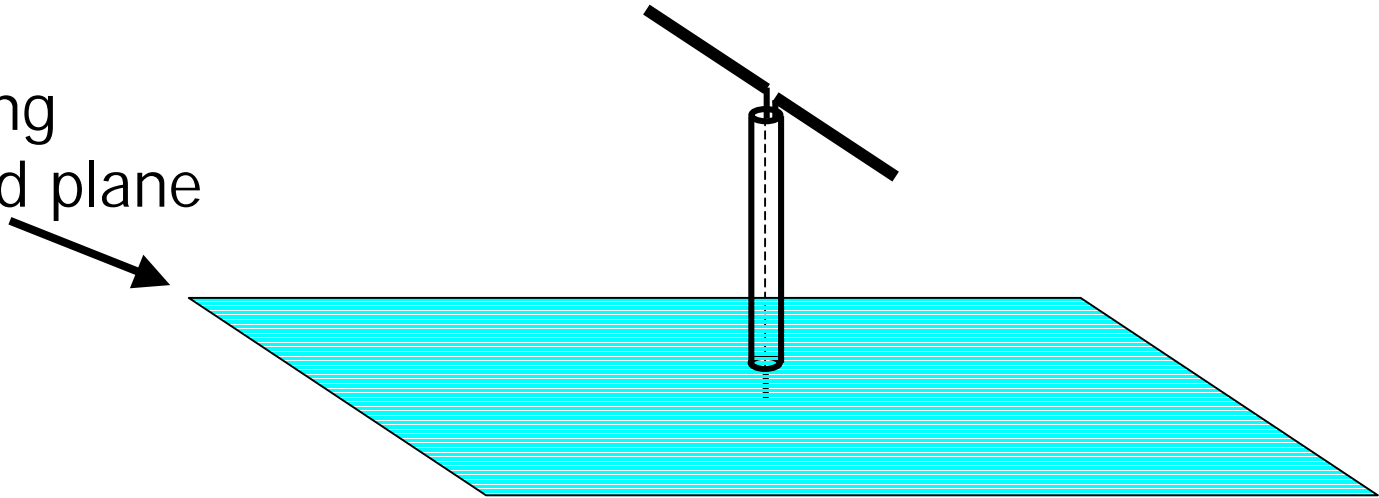
LOFAR astronomical science drivers

- Highest redshift radio sources
 - Steep spectrum selection ($\alpha < -2$) \Rightarrow 1 source per sample of 10,000
 - \Rightarrow catalog of background radio sources for intervening HI absorption #3
- 21cm emission/absorption from Epoch of Reionisation #1
 - very tough to achieve sensitivity: high risk / high gain
- 3-D mapping of the Galactic non-thermal emission
 - uses free-free absorption by known extended thermal sources
 - will determine the origin of the Galactic cosmic ray flux
- Transient and bursting sources #2
 - no moving parts \Rightarrow nearly instantaneous response to trigger events
 - central core is an all-sky (hemisphere) monitor
 - sensitive to non-thermal, coherent emission events, should they exist(?)

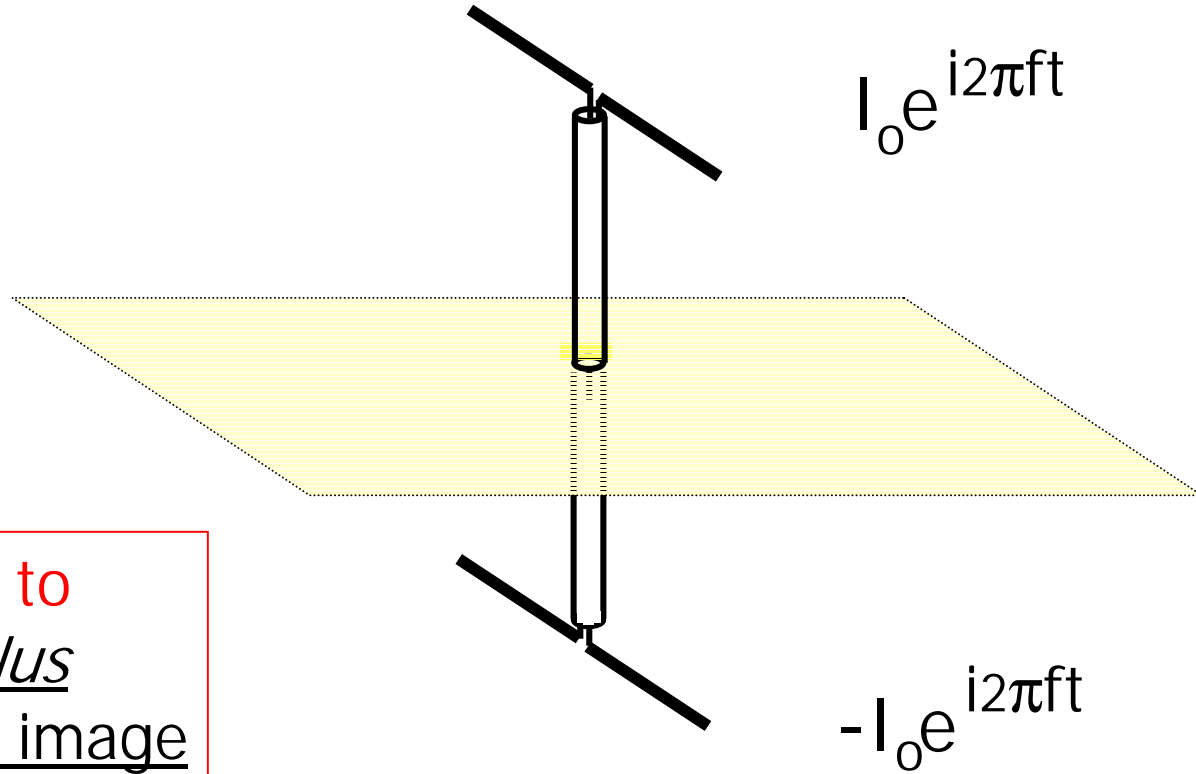


Dipole + ground plane

conducting
ground plane

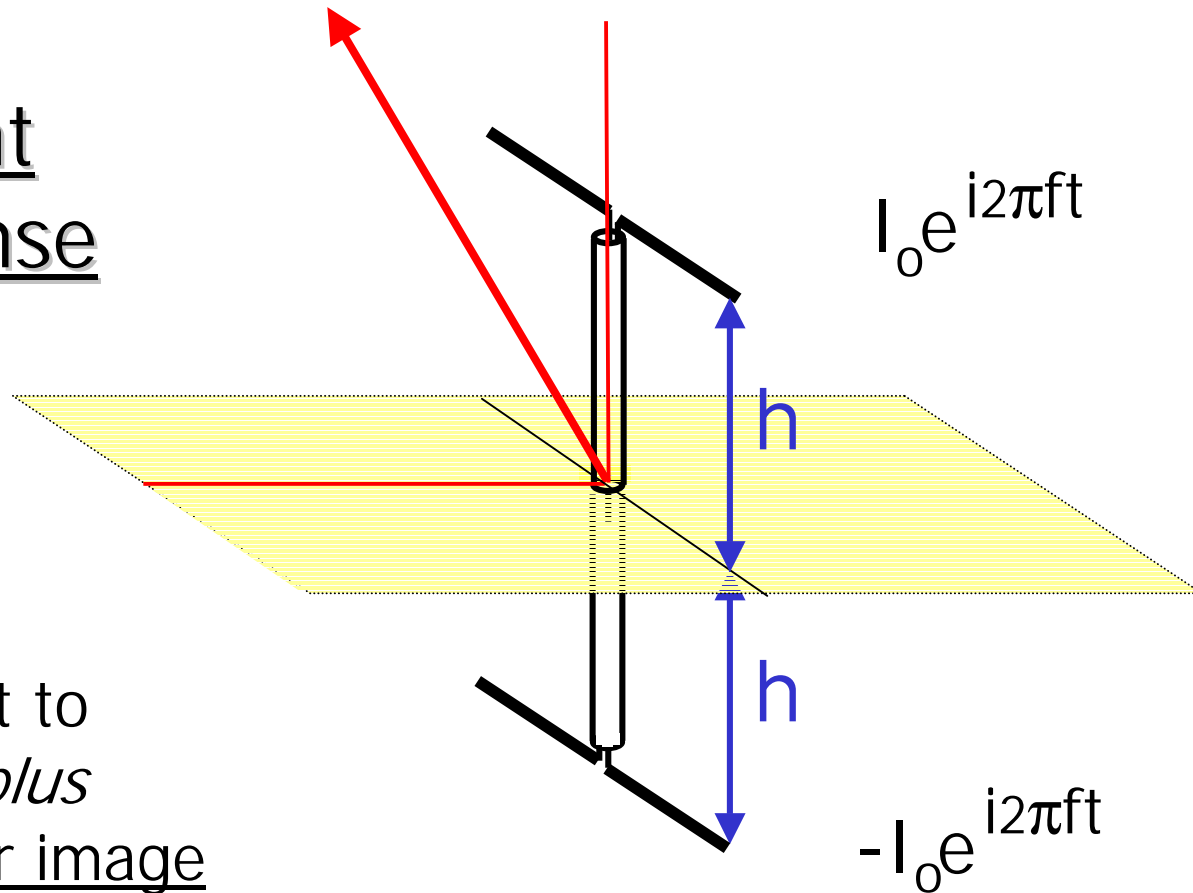


Dipole + ground plane



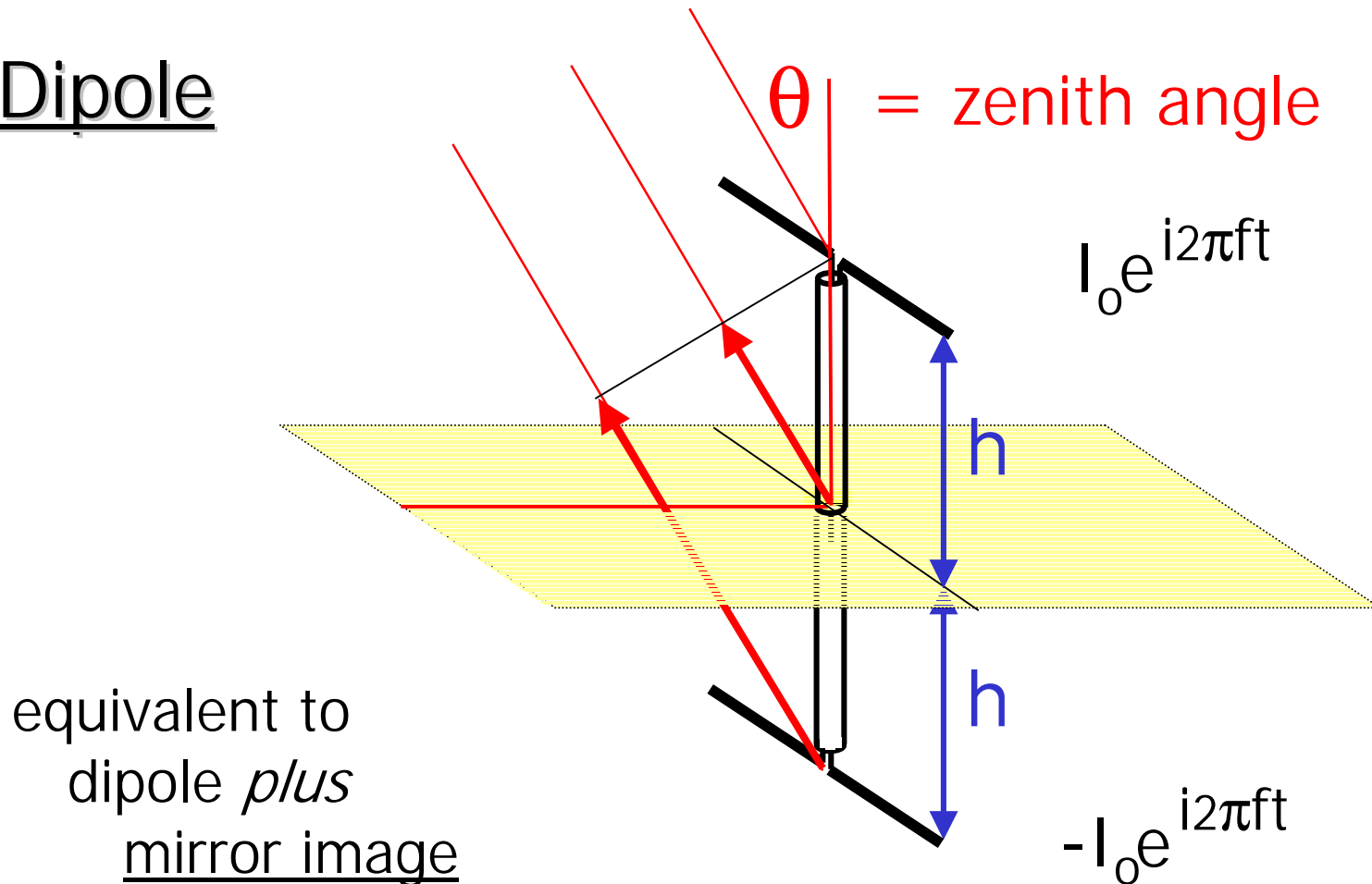
equivalent to
dipole *plus*
mirror image

Dipole
element
response



equivalent to
dipole *plus*
mirror image

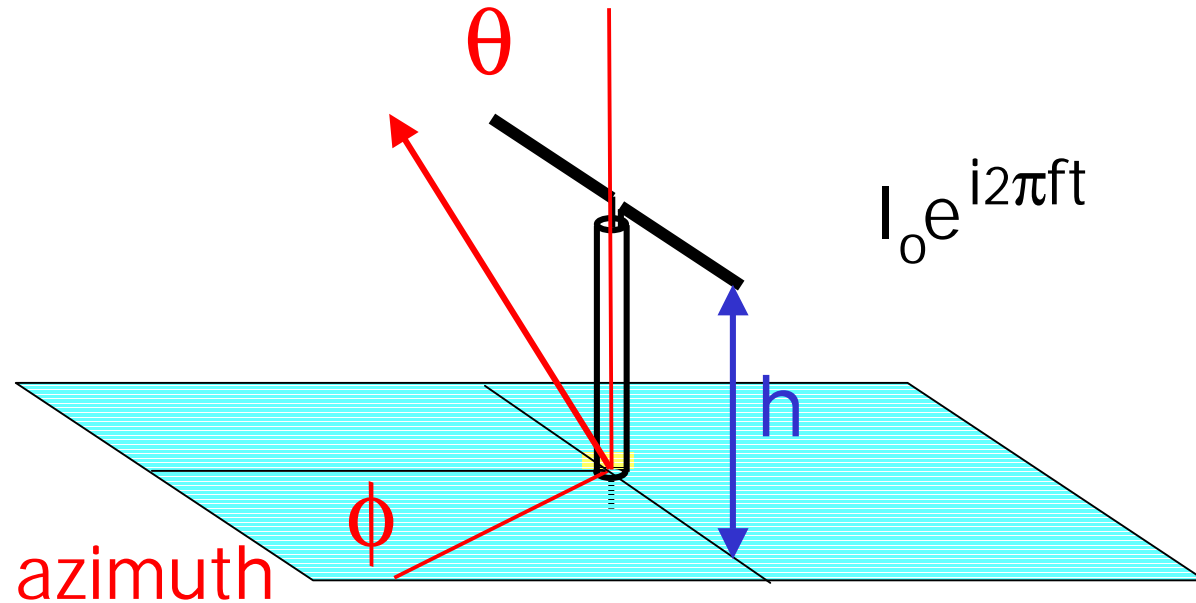
Dipole



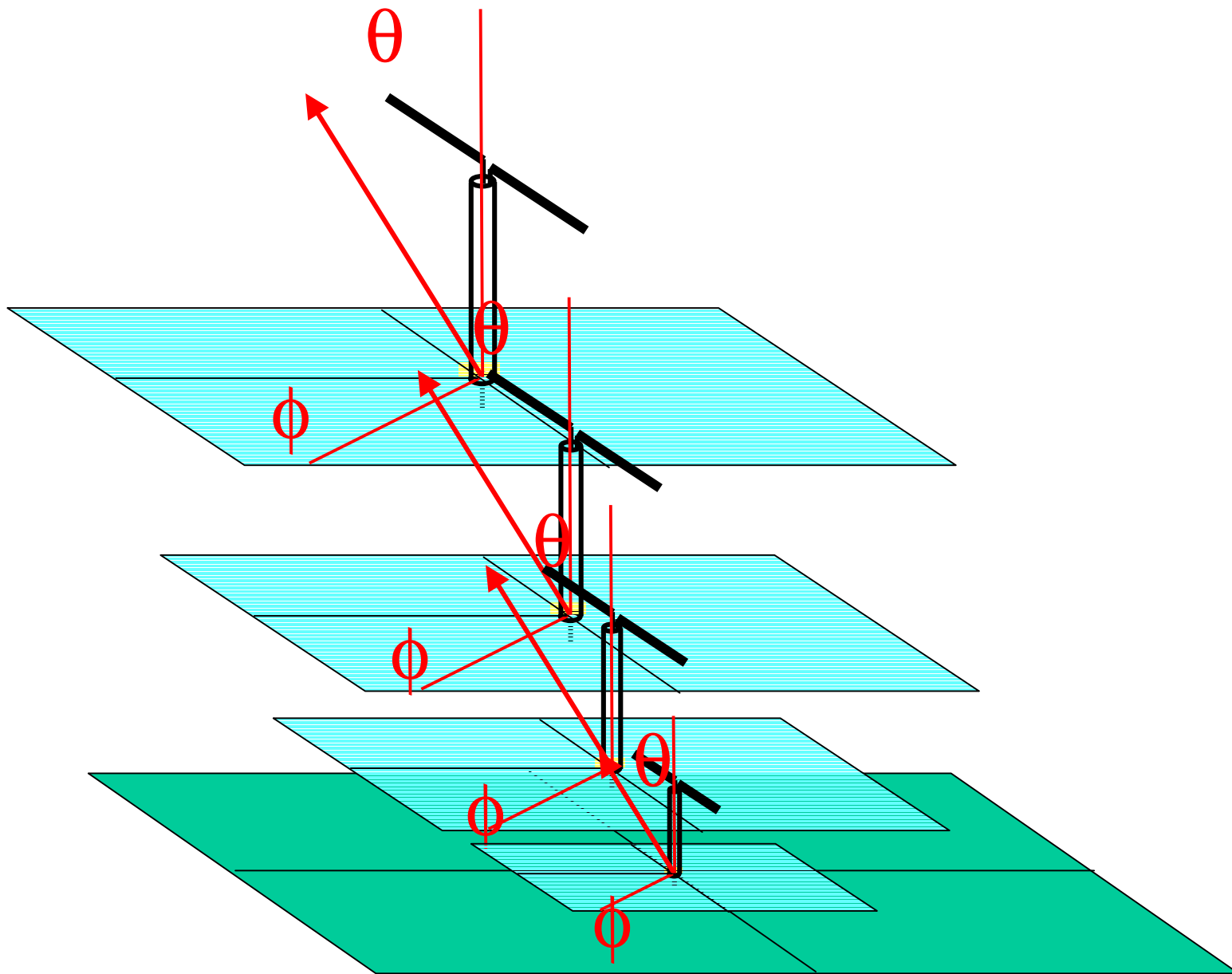
$$P(\theta) \sim \sin^2 [2\pi h \cos(\theta) / \lambda]$$

(maximize response at $\theta=0$ if $h=\lambda/4$)

Dipole

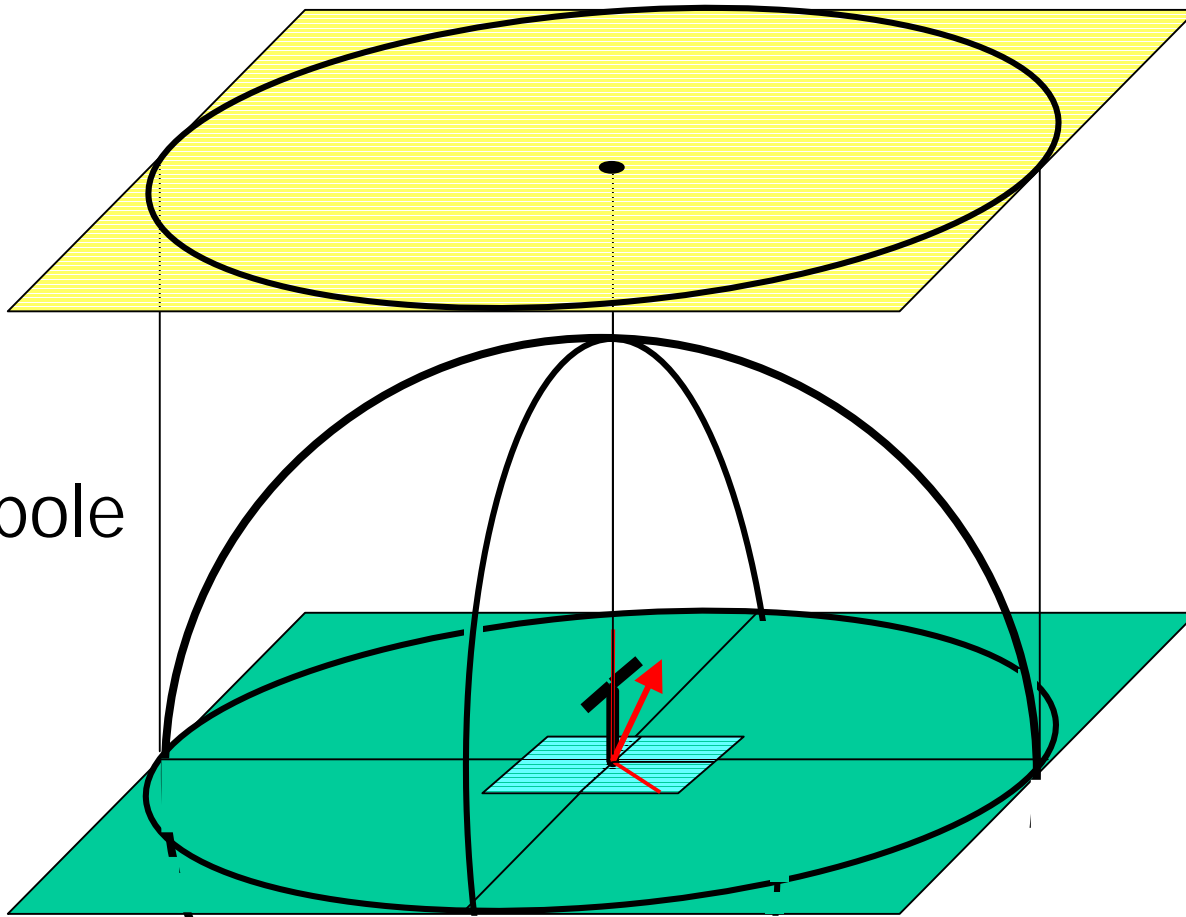


$$P(\theta) \sim \sin^2[2\pi h \cos(\theta)/\lambda] \{1 - \sin^2\theta \sin^2\phi\}$$

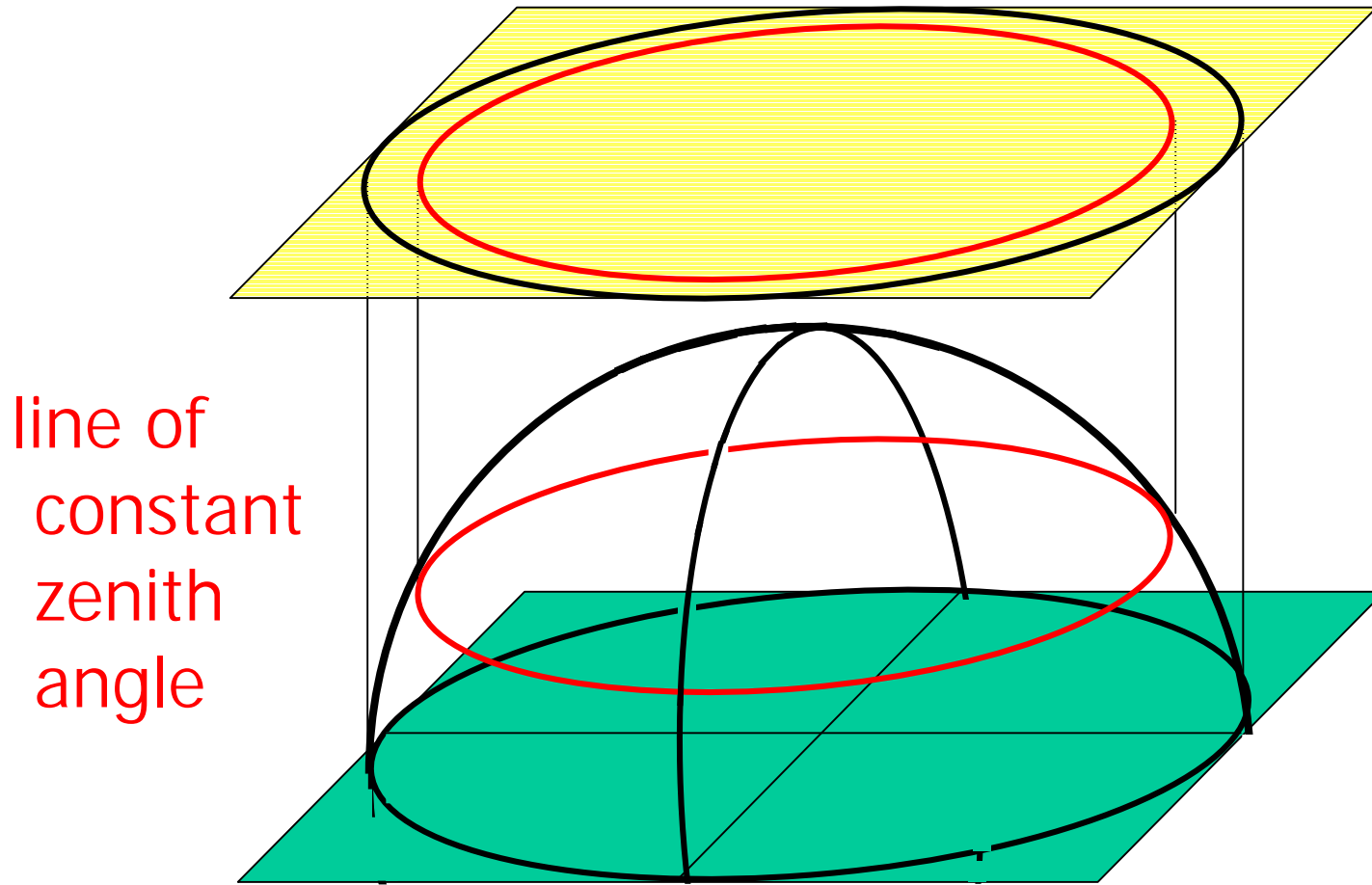


The 'sin projection' of hemisphere onto a plane:

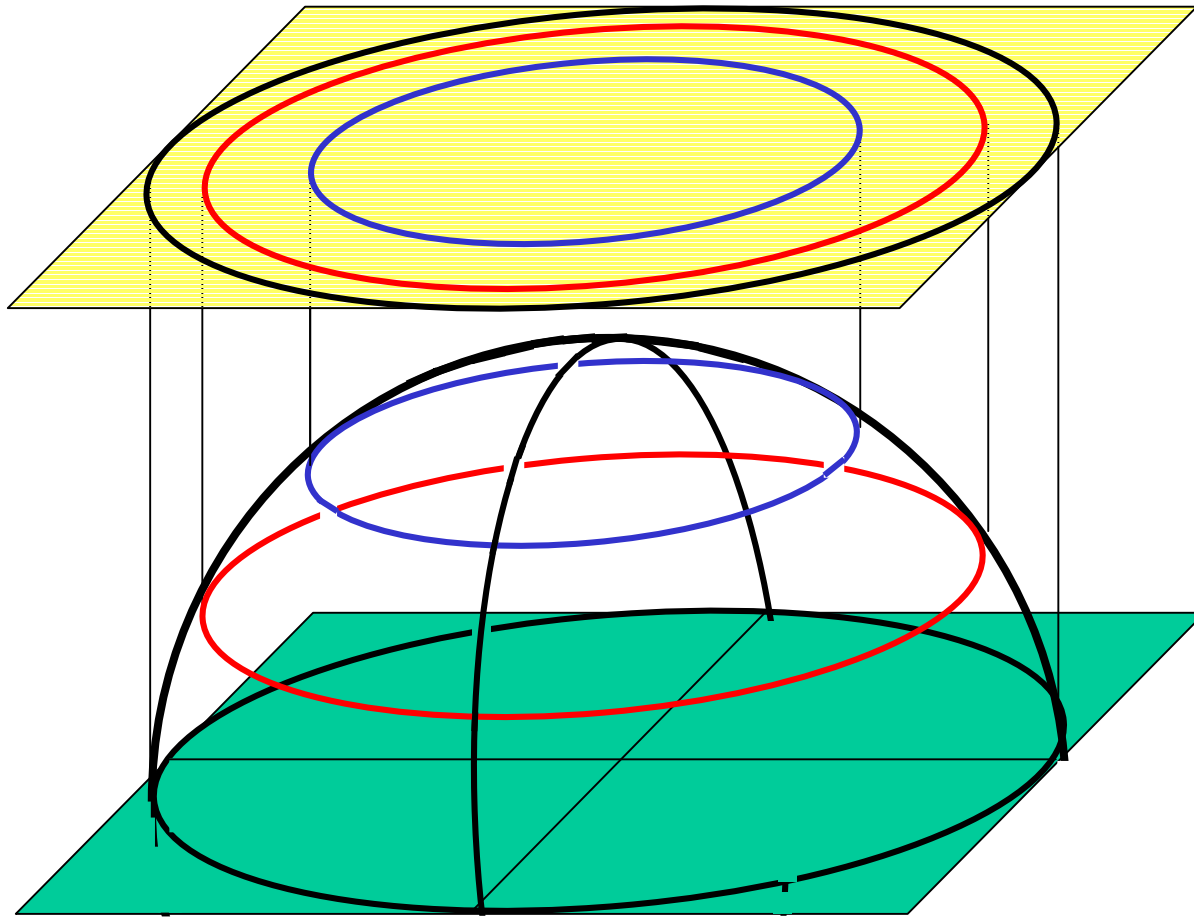
The Sky
above dipole



'sin projection'

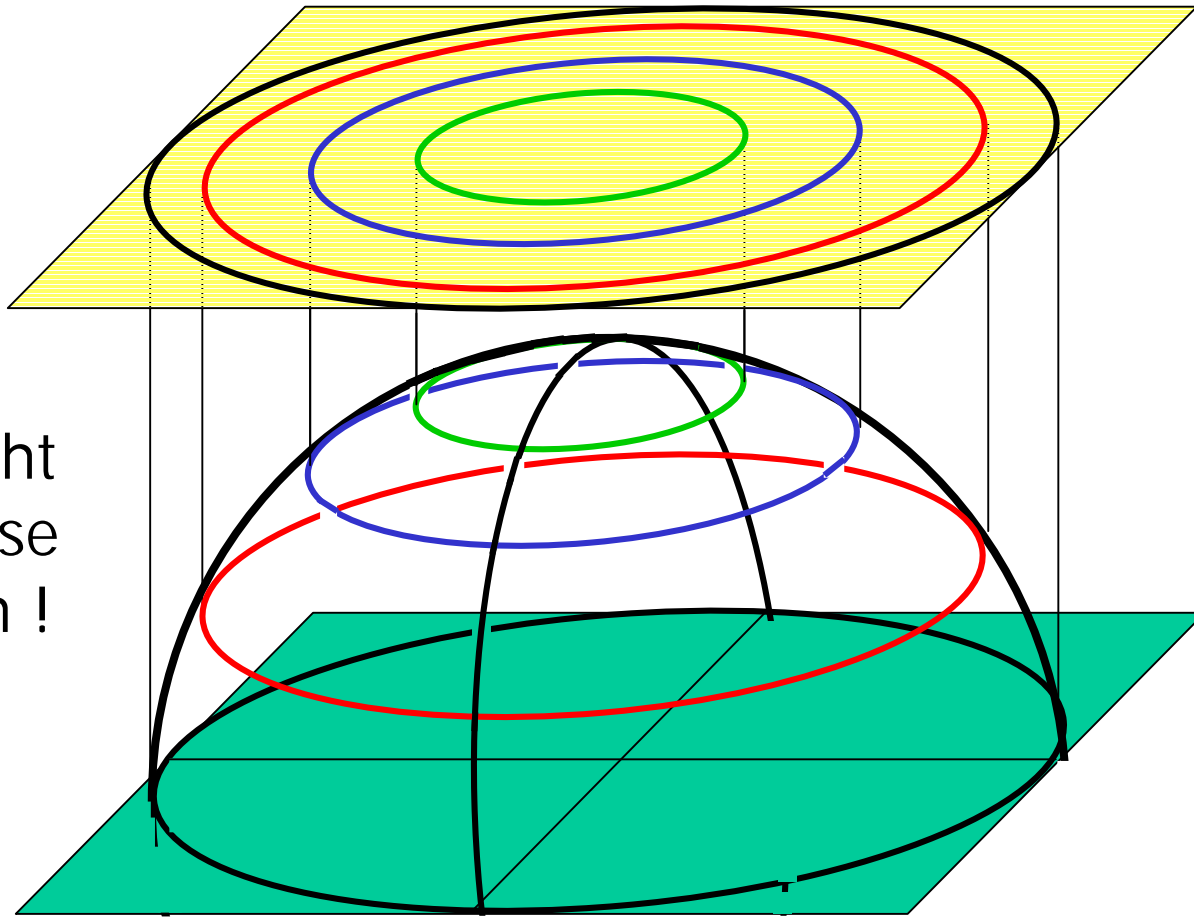


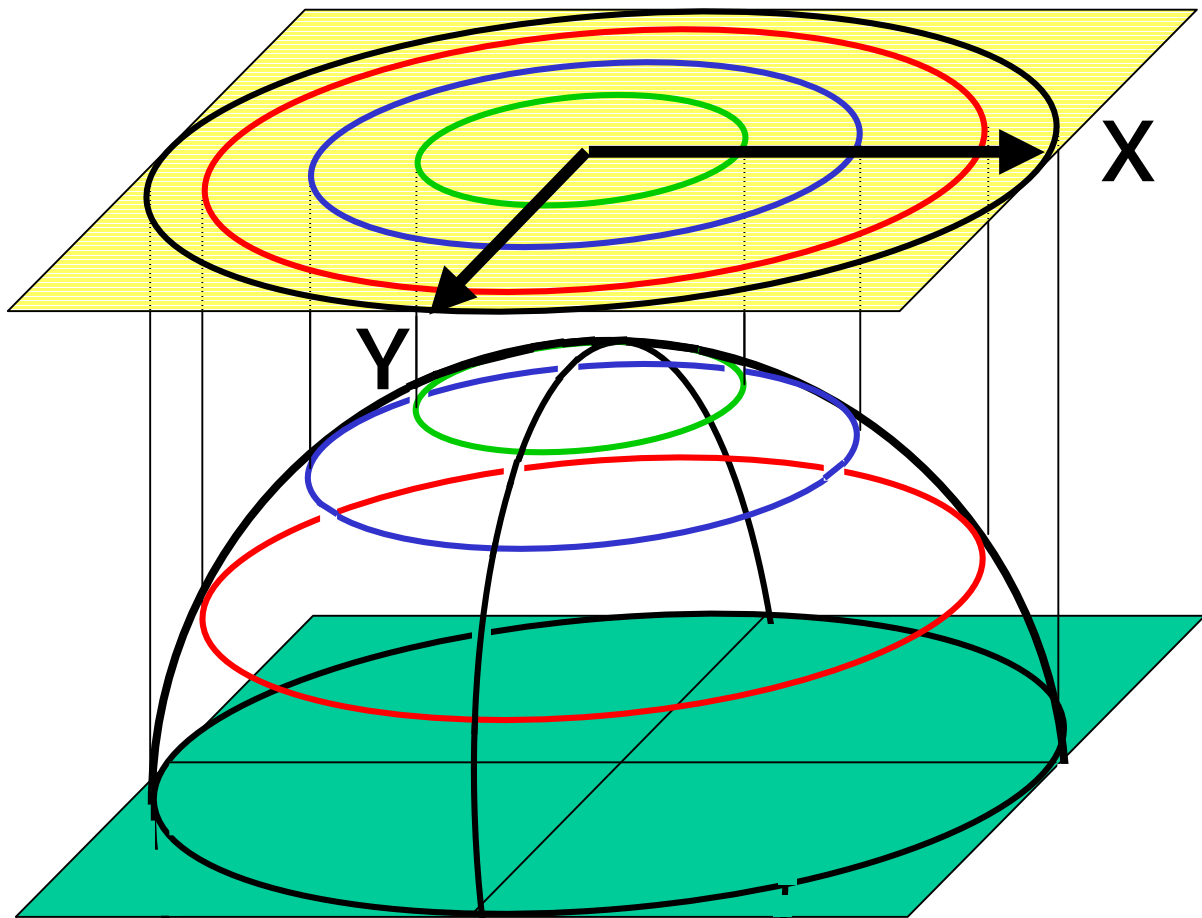
'sin projection'

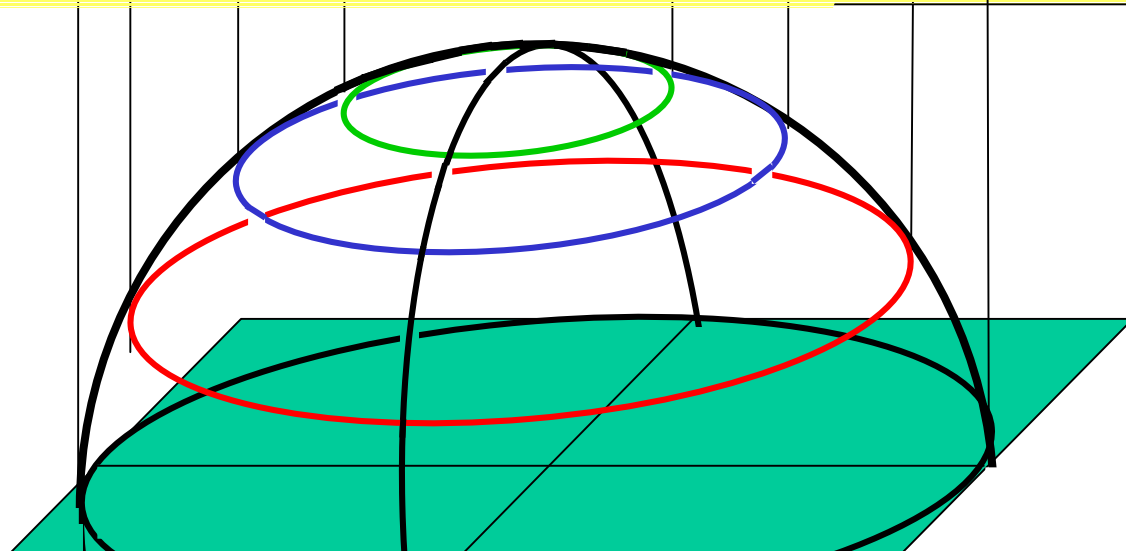
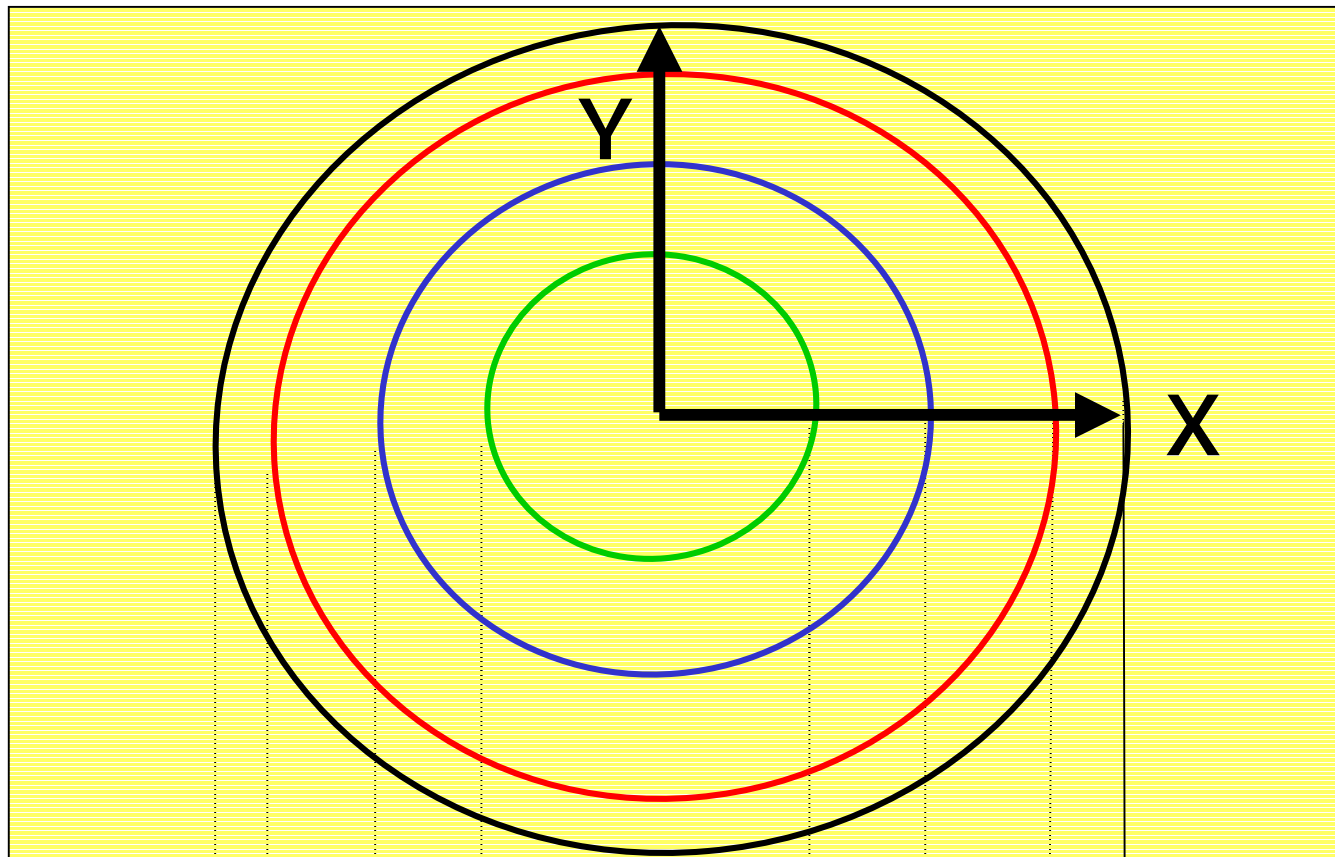


'sin projection'

gives
little weight
to sky close
to horizon !



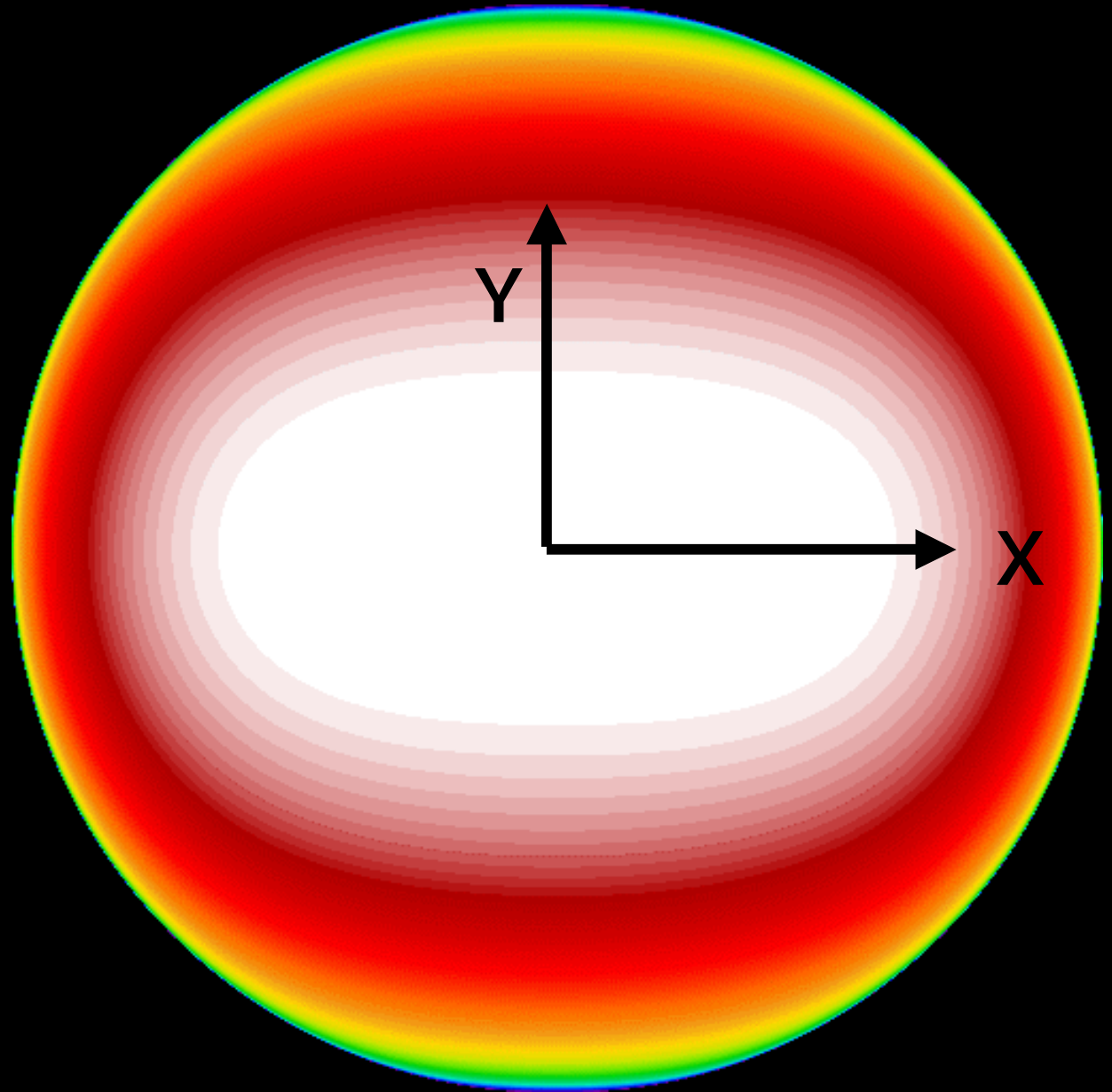




Dipole

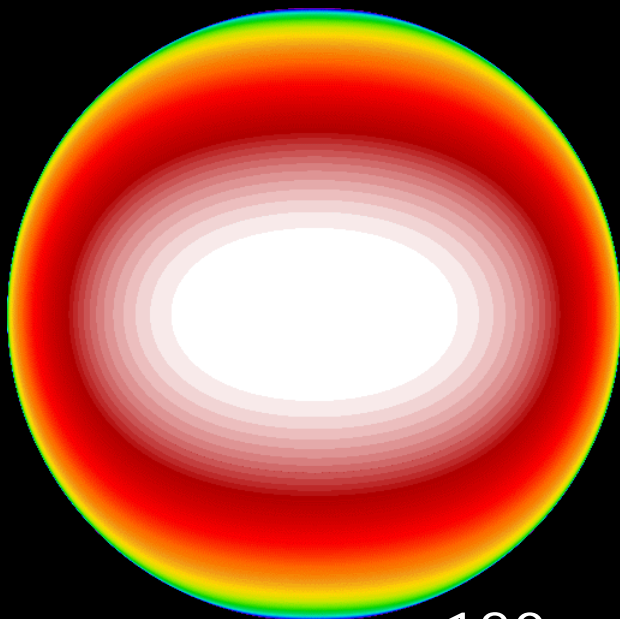
over ground
plane

Tuned for
150 MHz

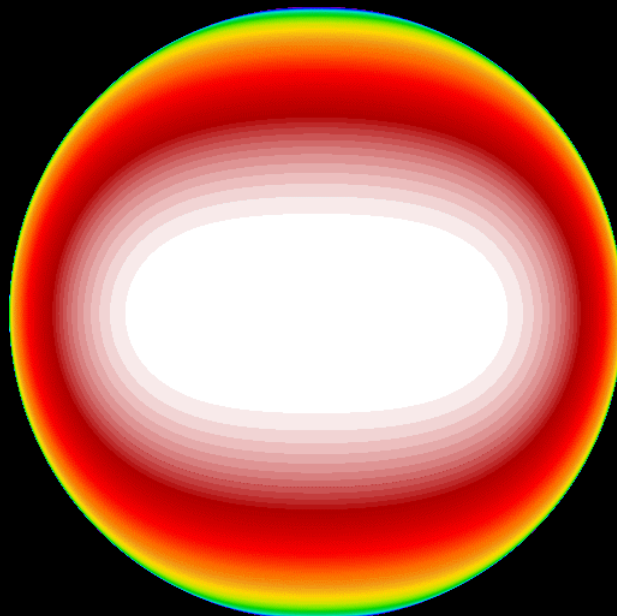


Dipole

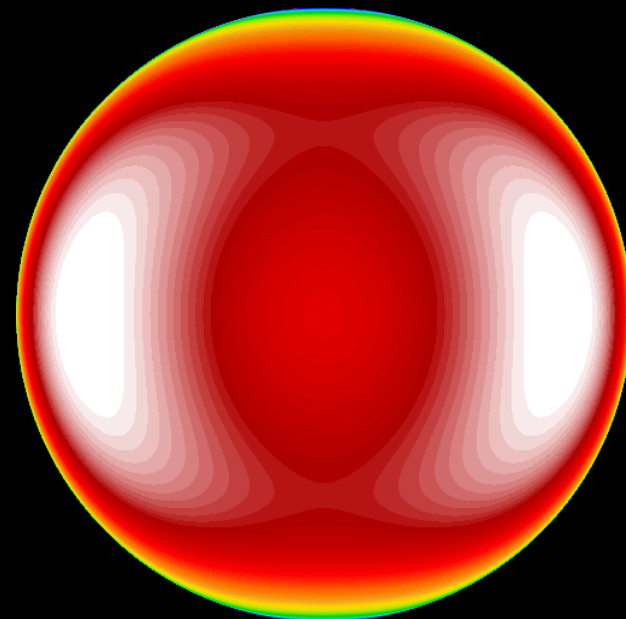
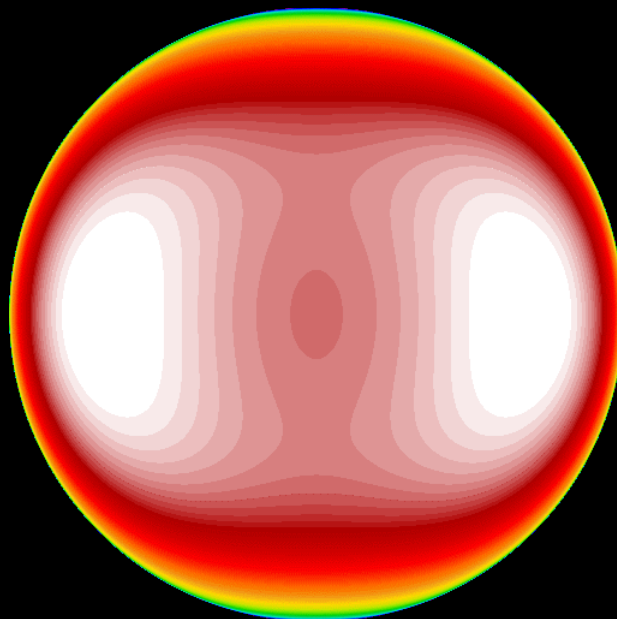
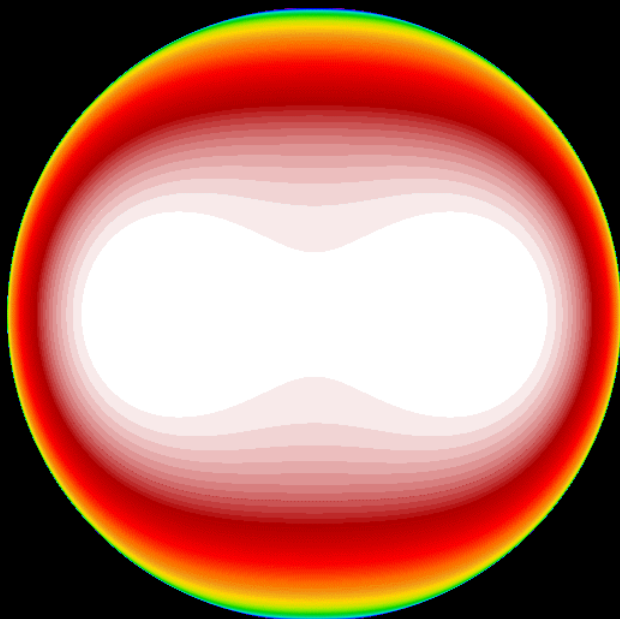
Tuned for
150 MHz



120
180



150
210 MHz



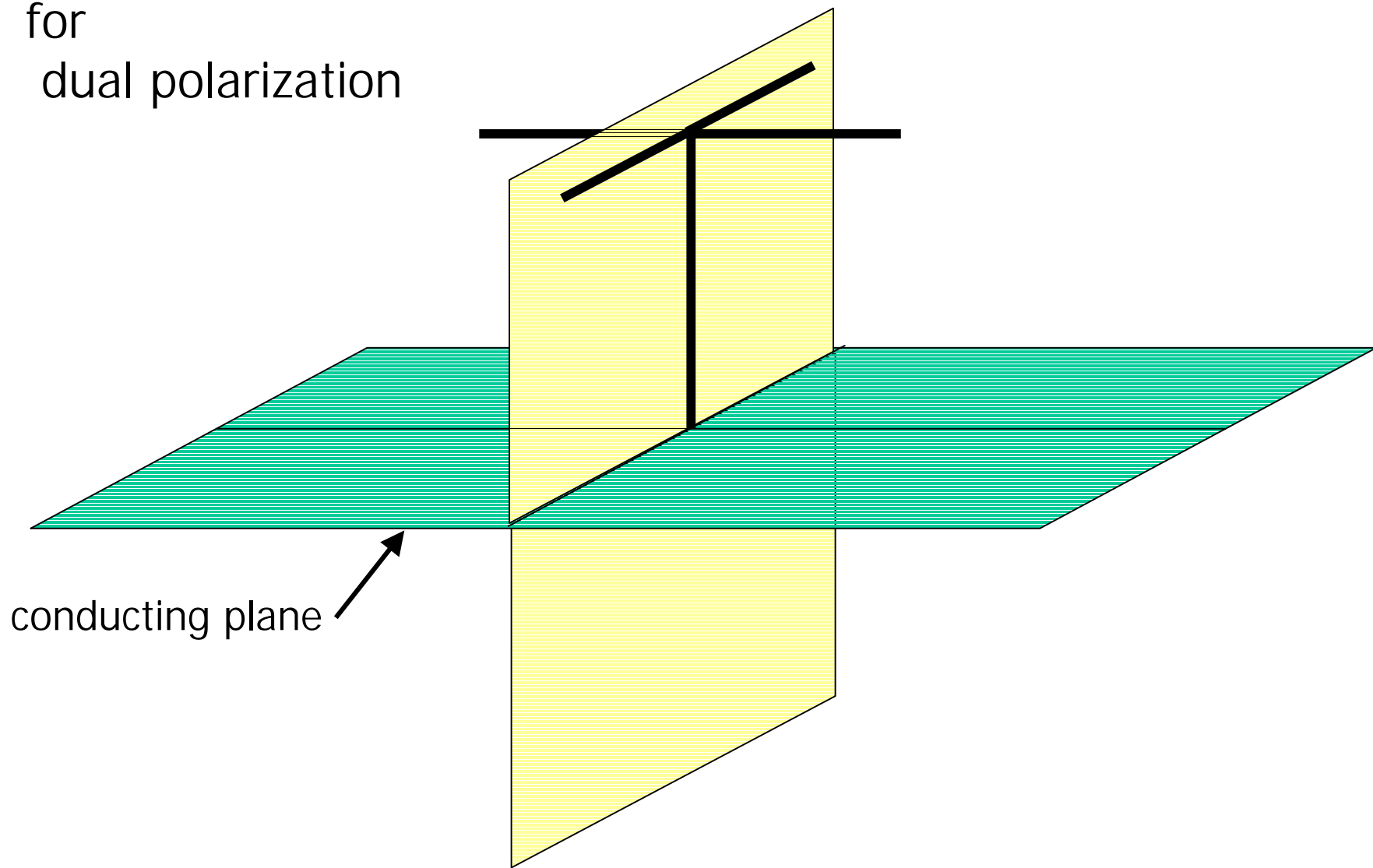
240 MHz

What are these things?



Crossed Dipoles

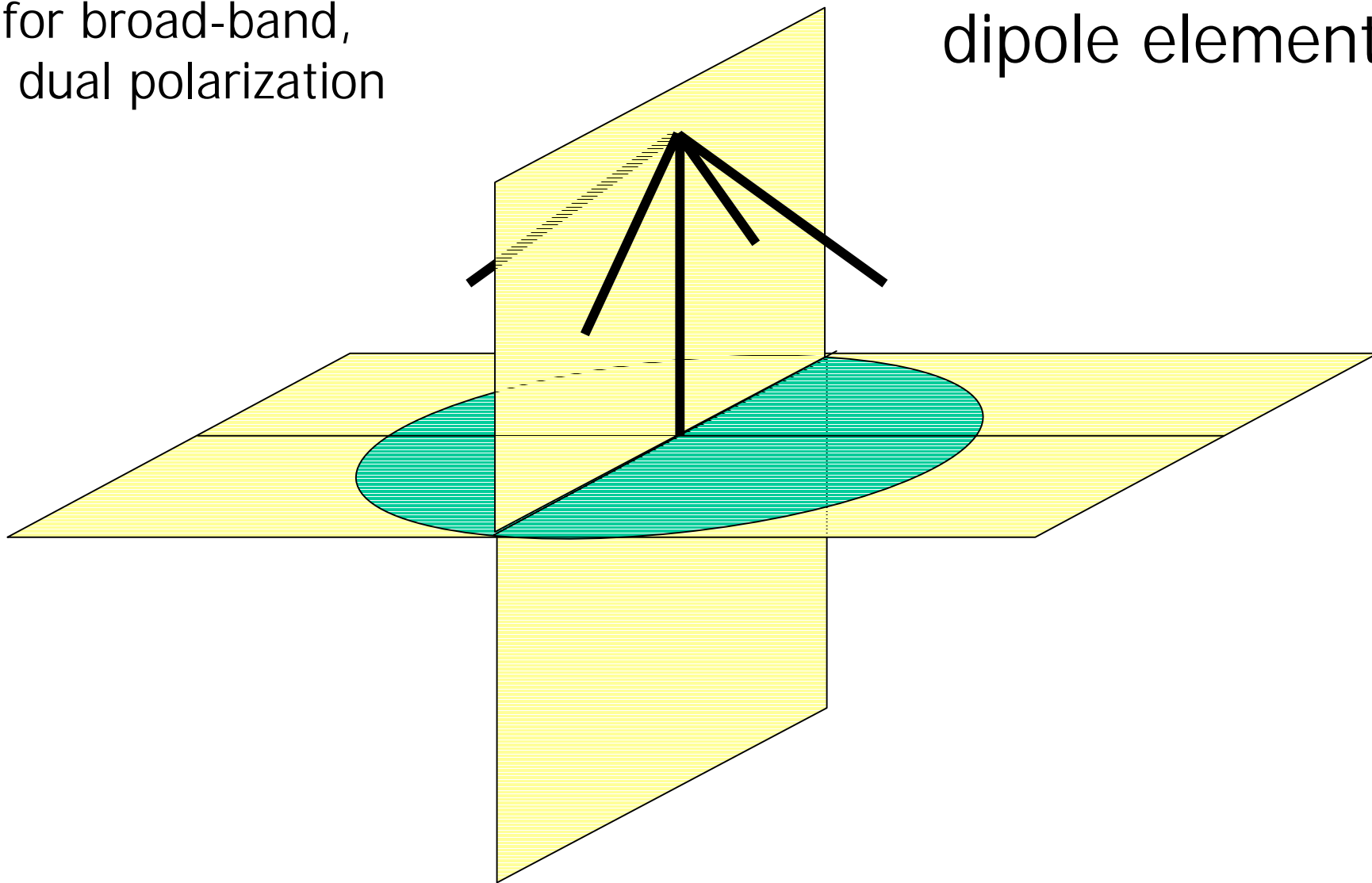
for
dual polarization



Droopy Dipoles

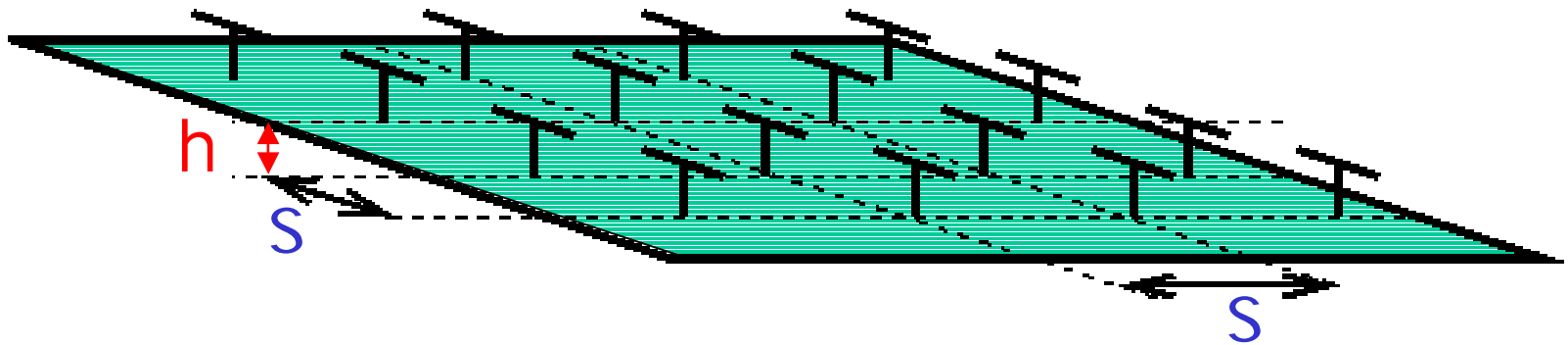
for broad-band,
dual polarization

LOFAR-Low Band
dipole element



4x4 array of dipoles on ground plane

- the 'LOFAR-High band' element

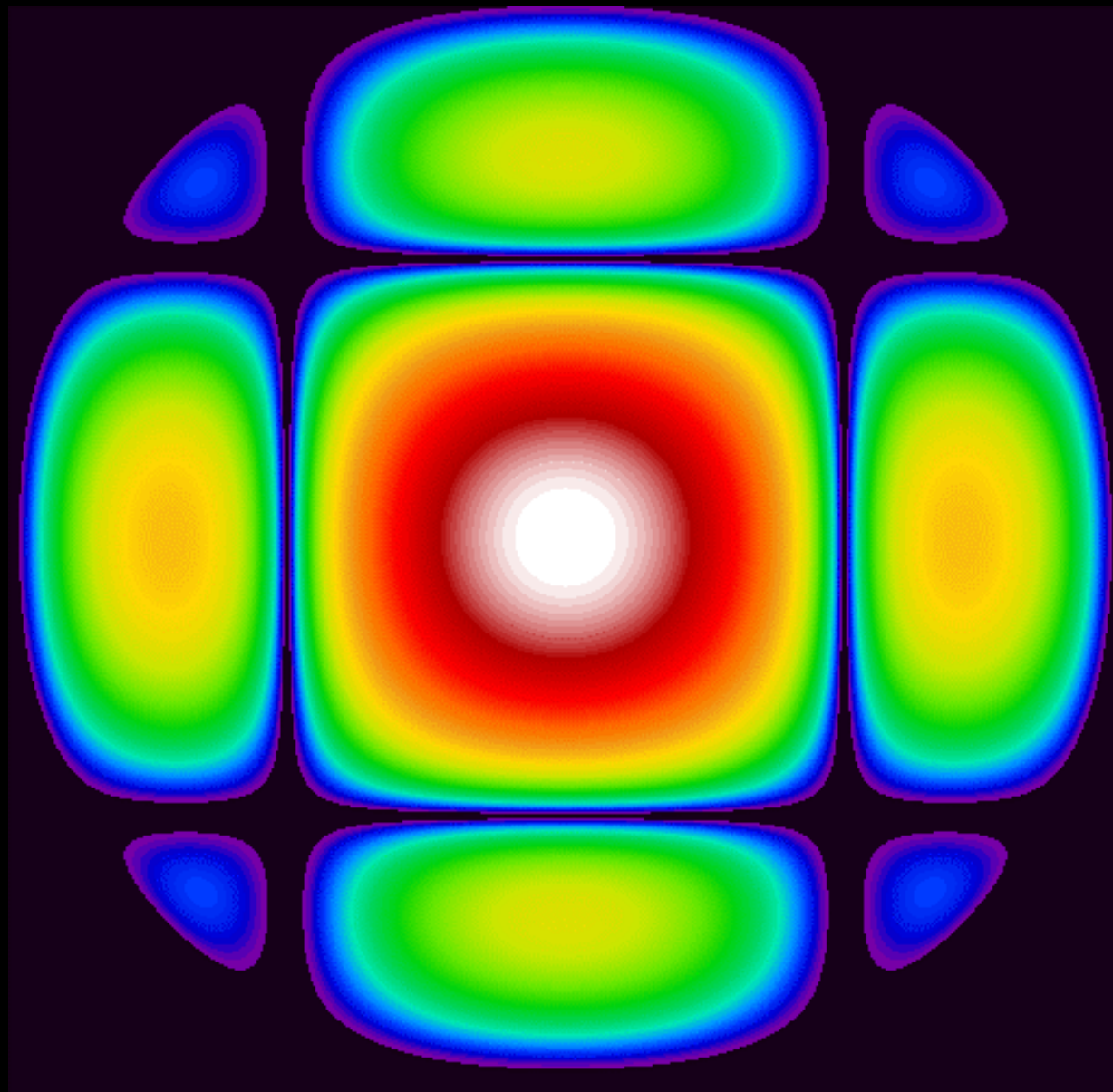


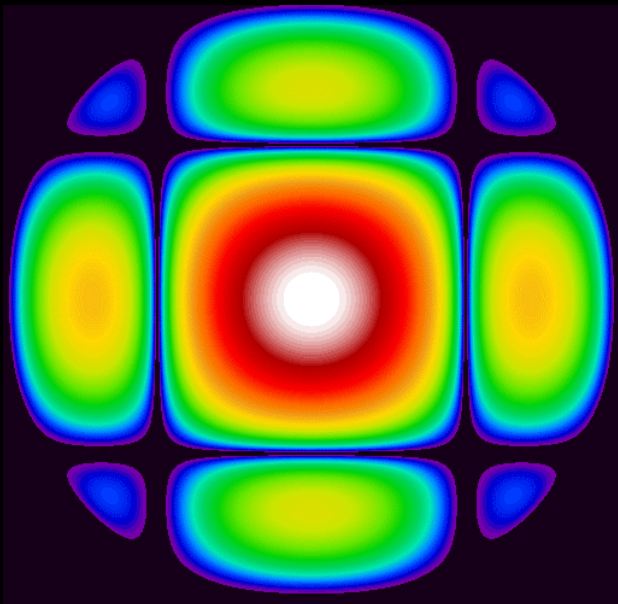
(many analogies to gratings for optical wavelengths)

4x4

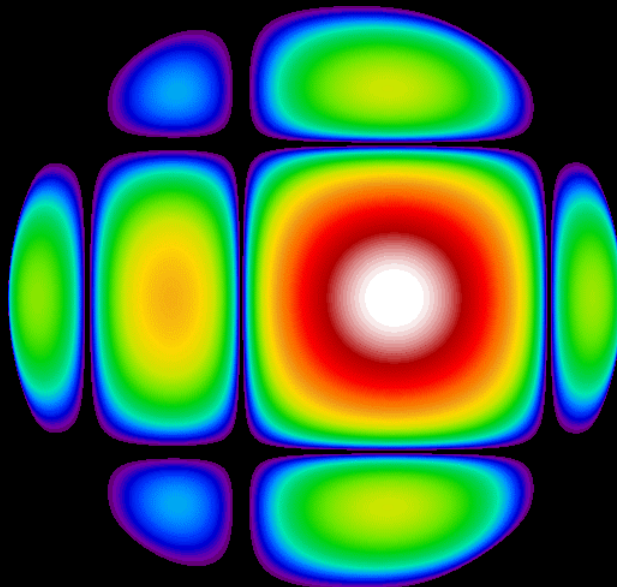
Tuned for
150 MHz

sin projection

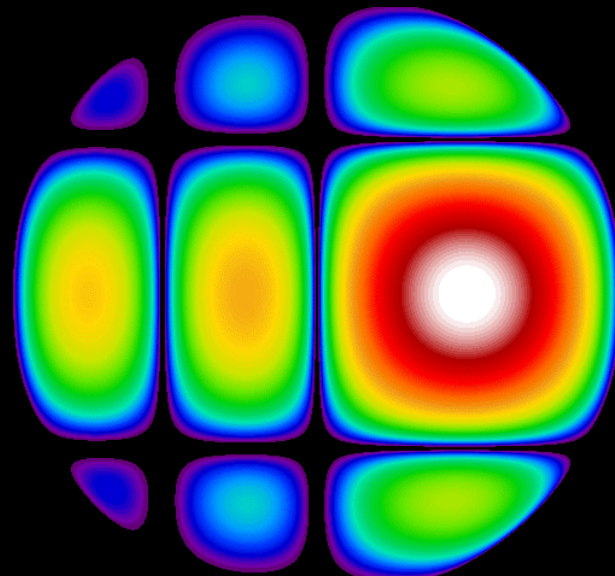




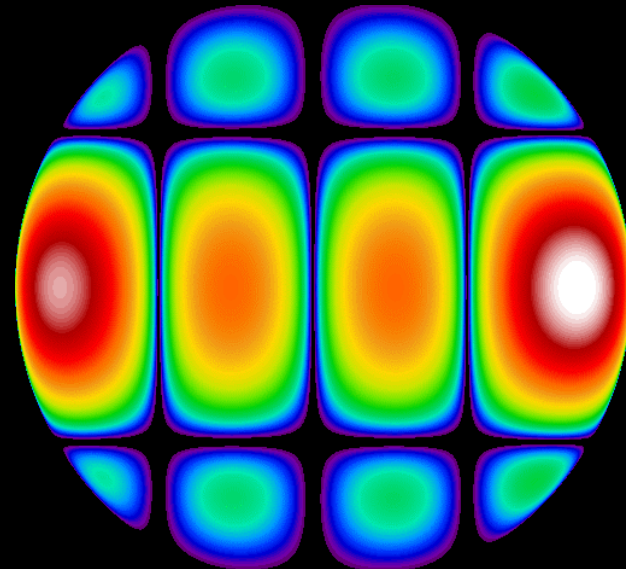
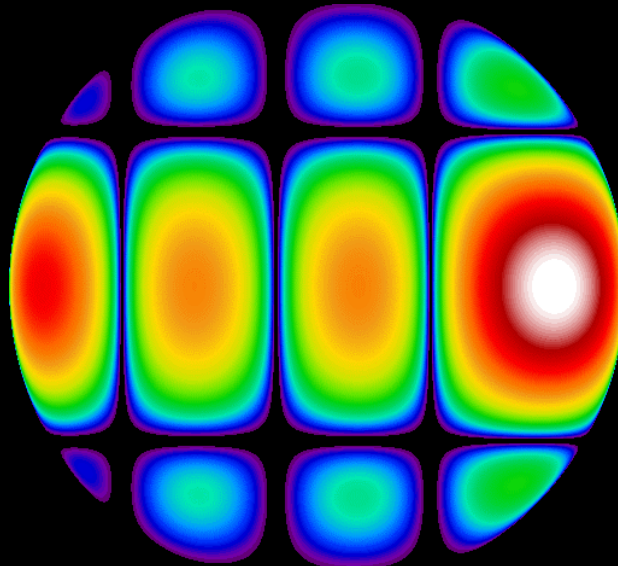
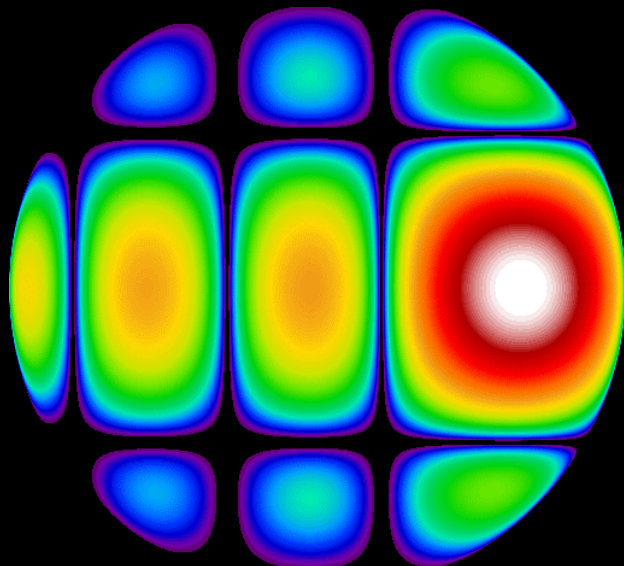
ZA = 0 deg
45



15
60



30
75

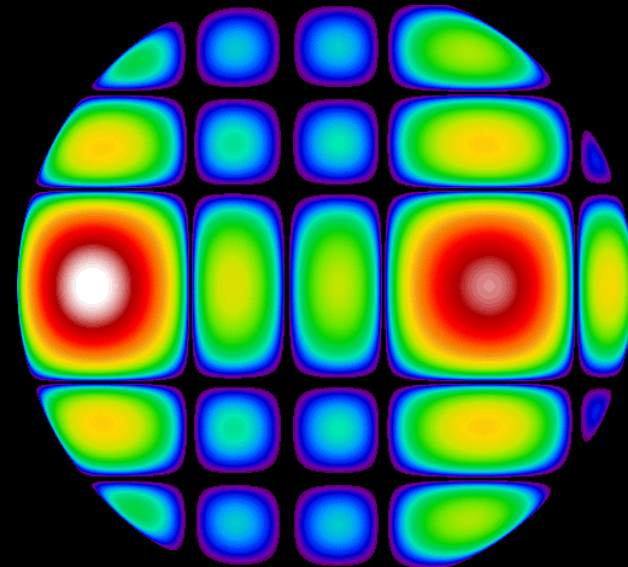
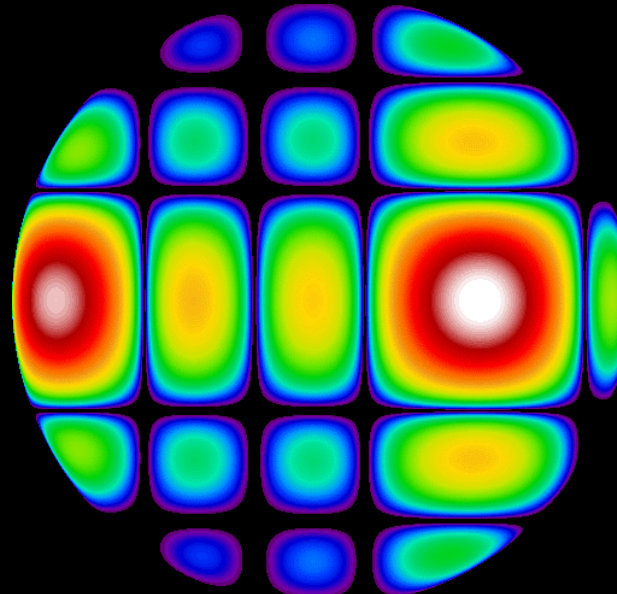
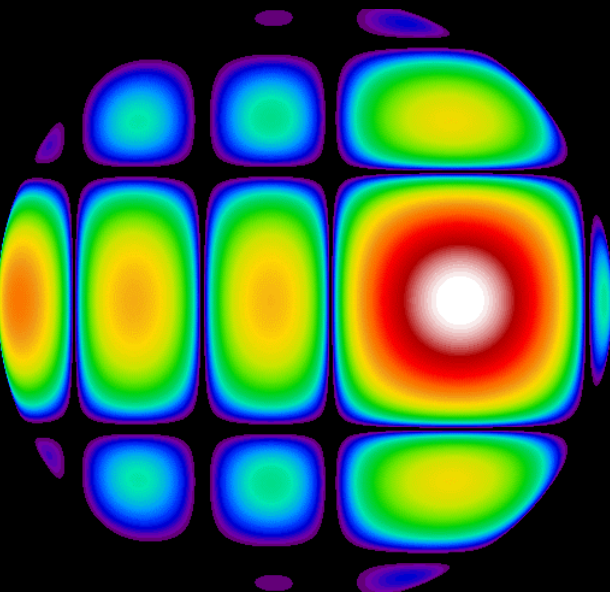
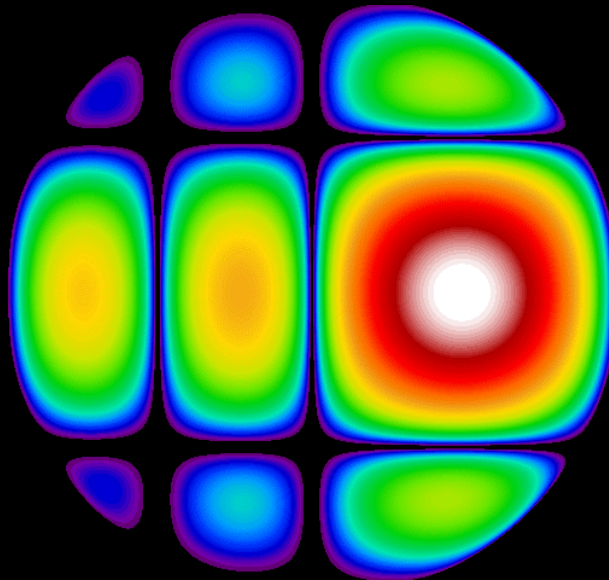
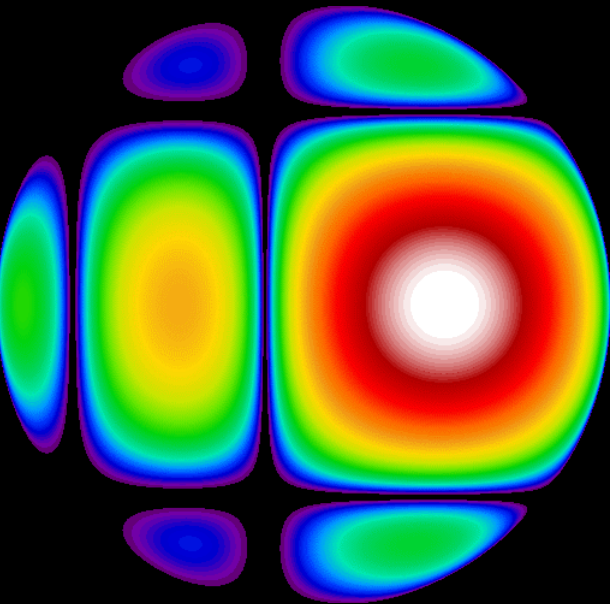


4x4 Patterns

- ZA = 30 deg
- tuned for 150 MHz

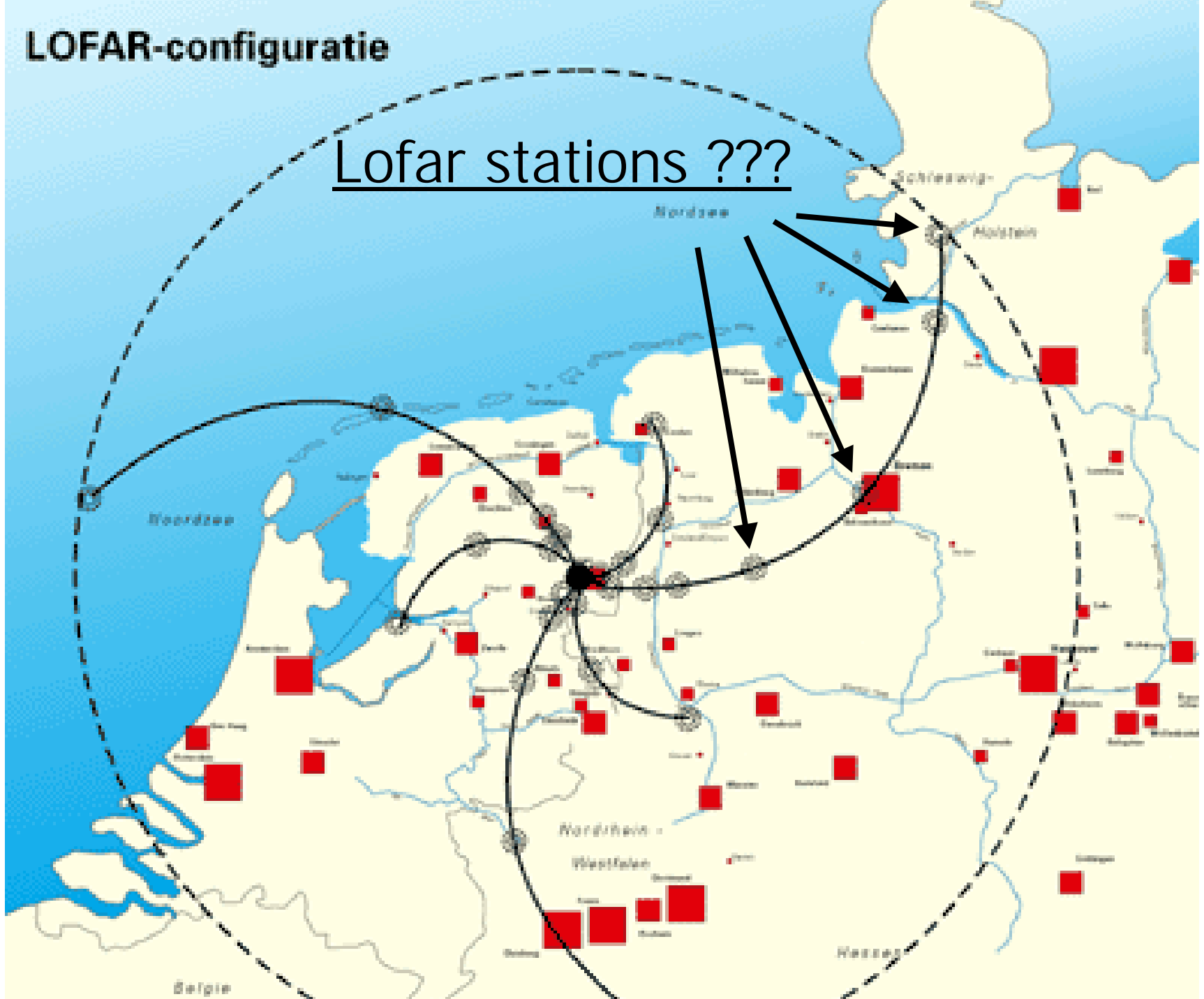
120 150

180 210 240



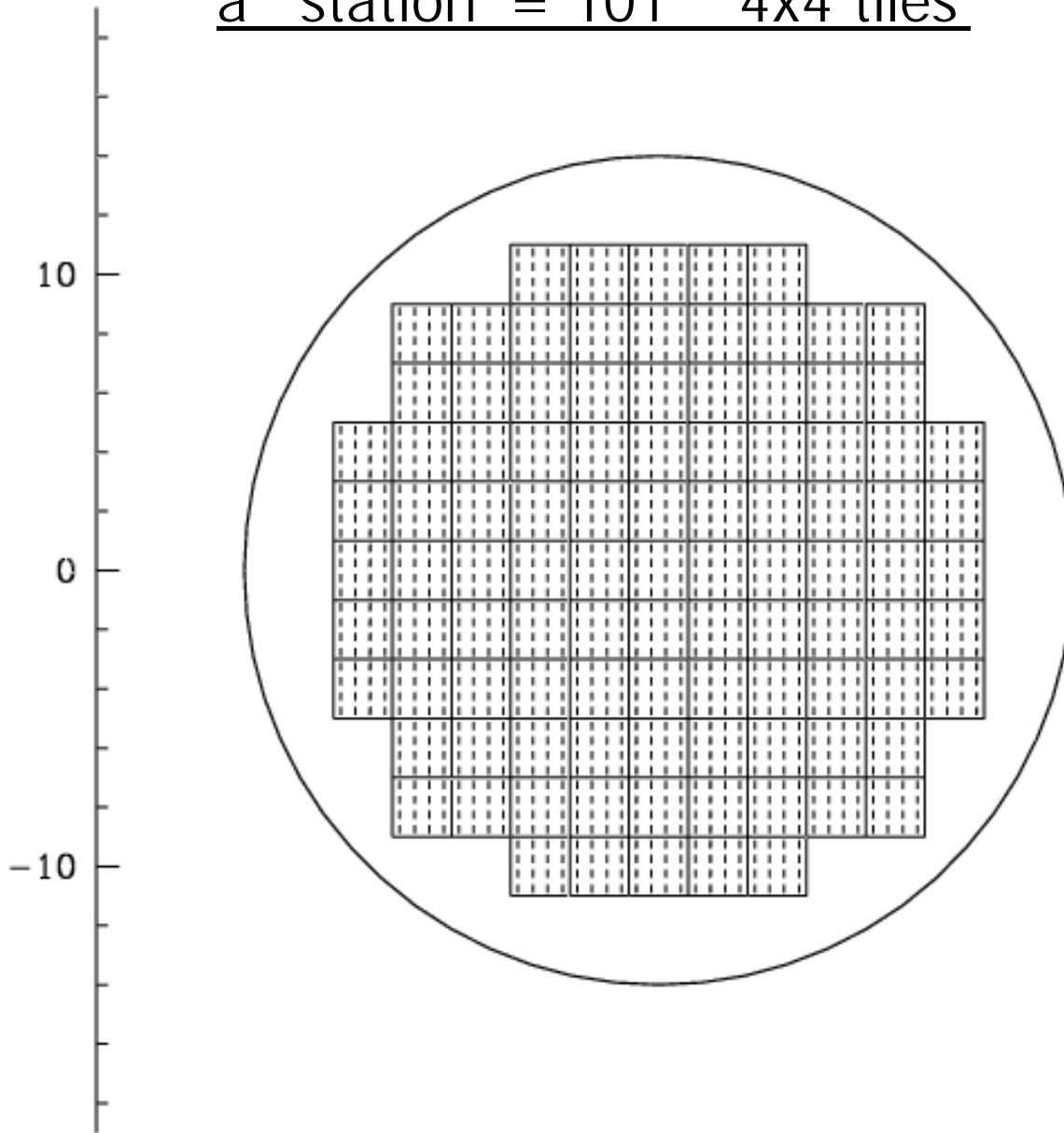
LOFAR-configuratie

Lofar stations ???

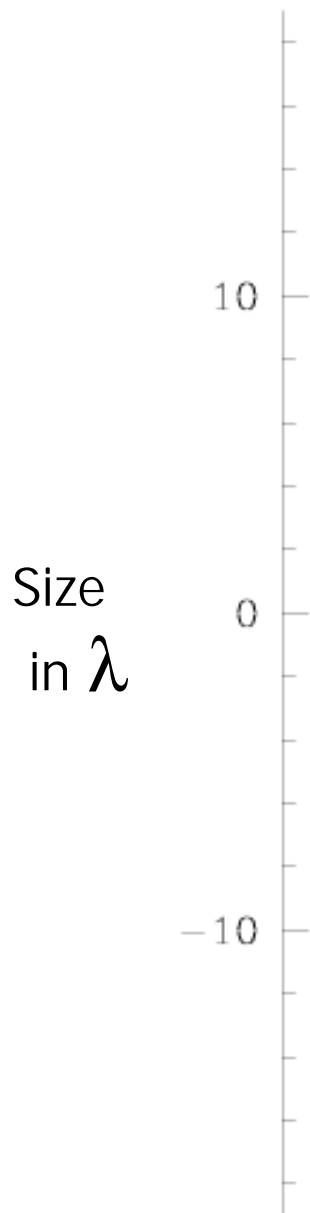


a 'station' = 101 '4x4 tiles'

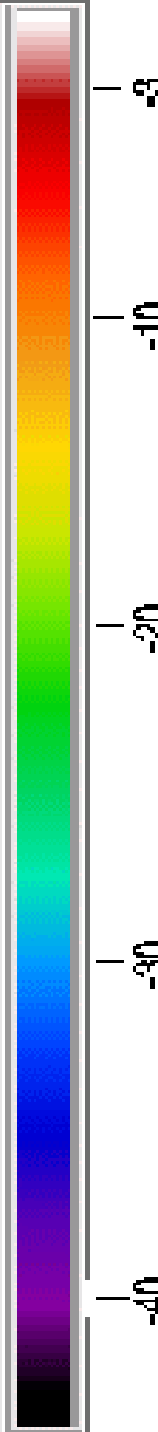
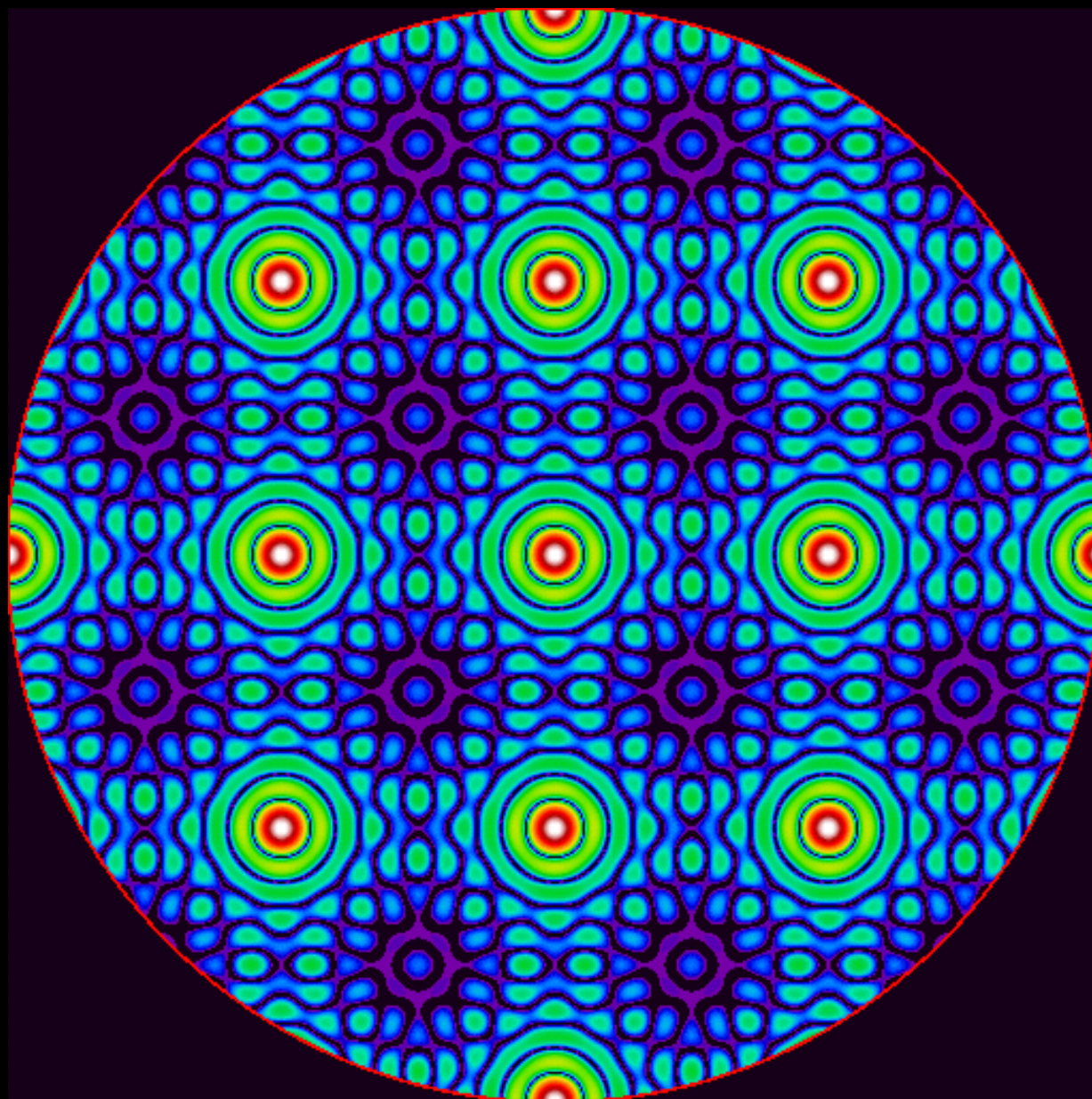
Size
in λ



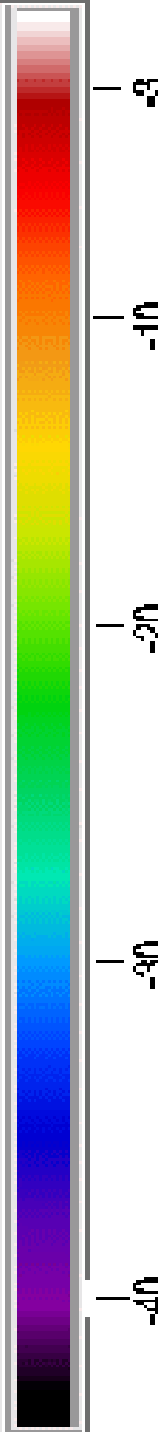
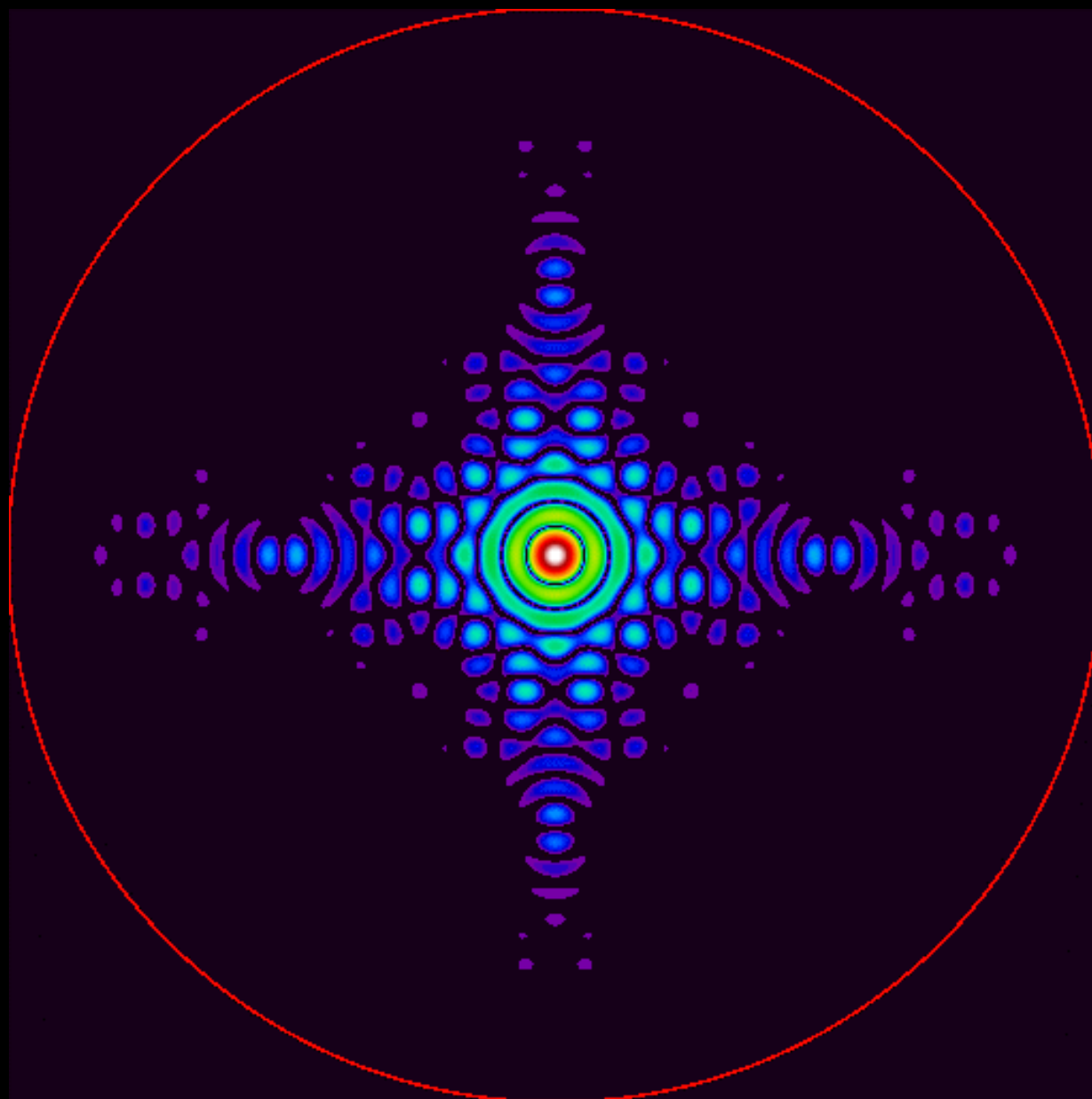
a 'station' as 101 omni-directional elements



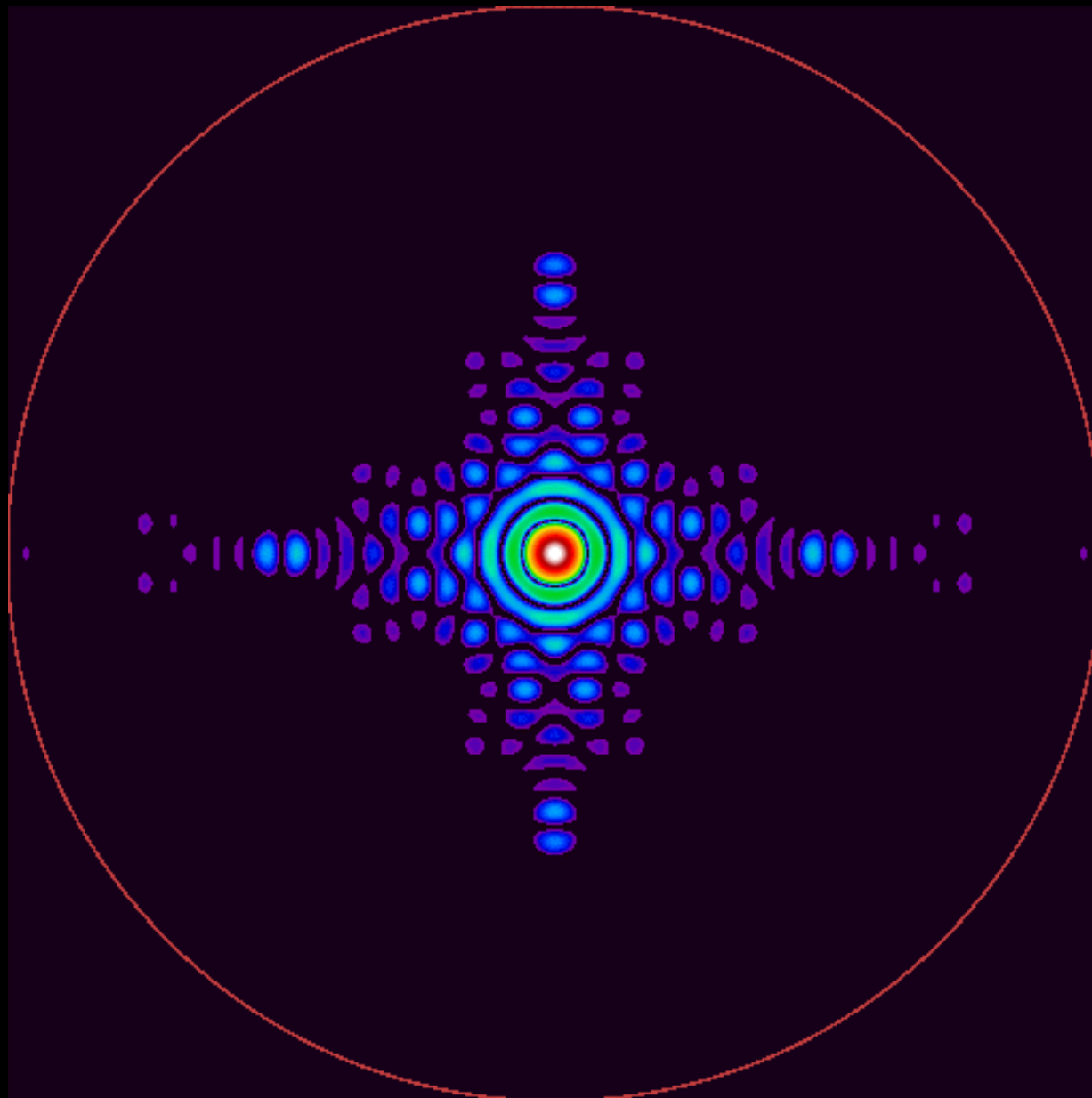
Station Beam: no 4x4 envelope



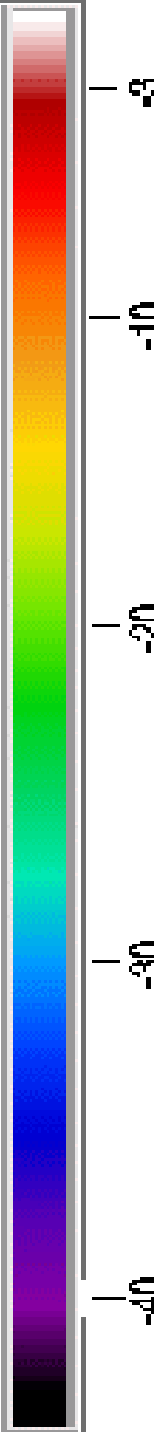
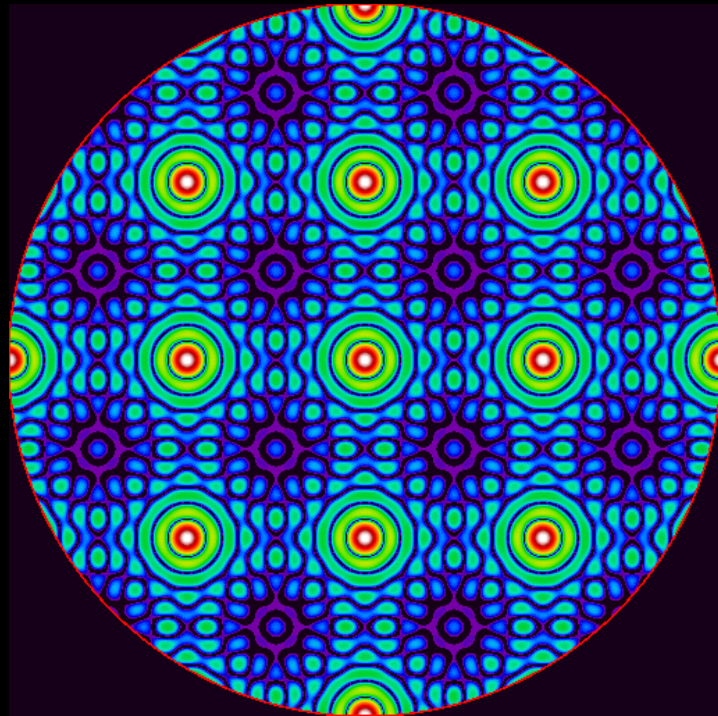
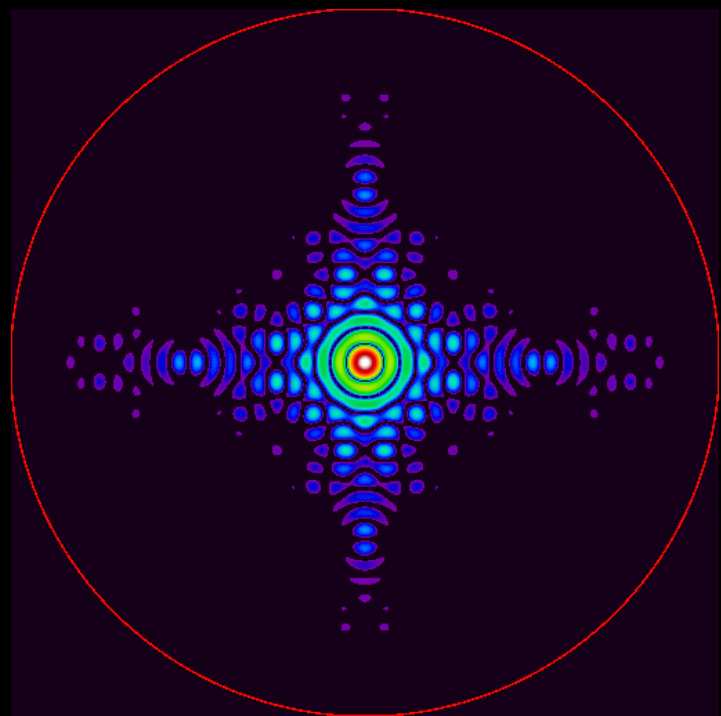
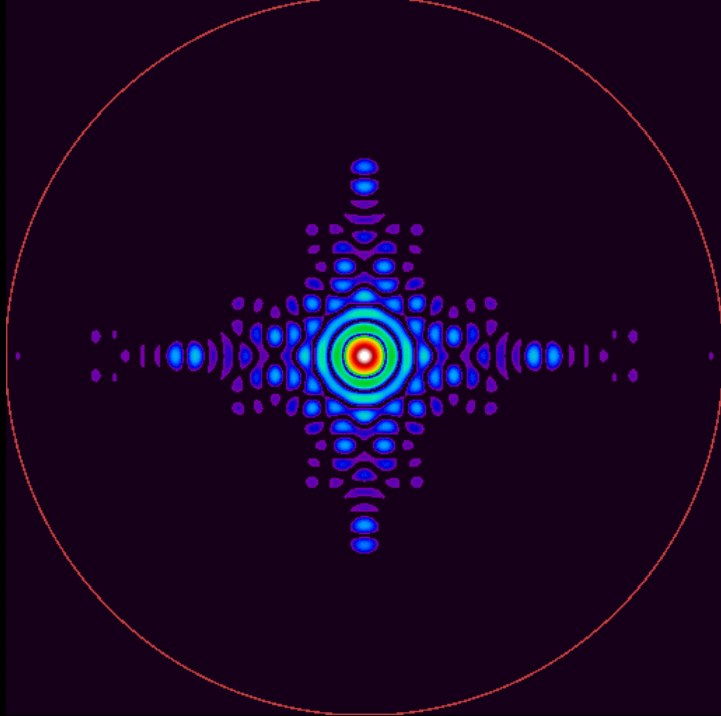
Station Beam: using 4x4 envelope

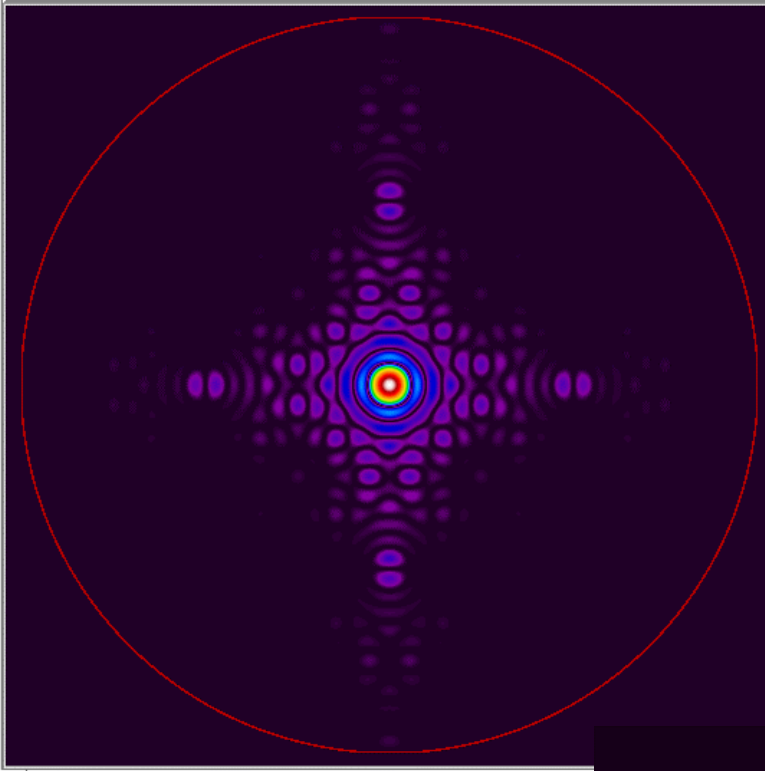


Station Beam: 4x4 envelope and taper

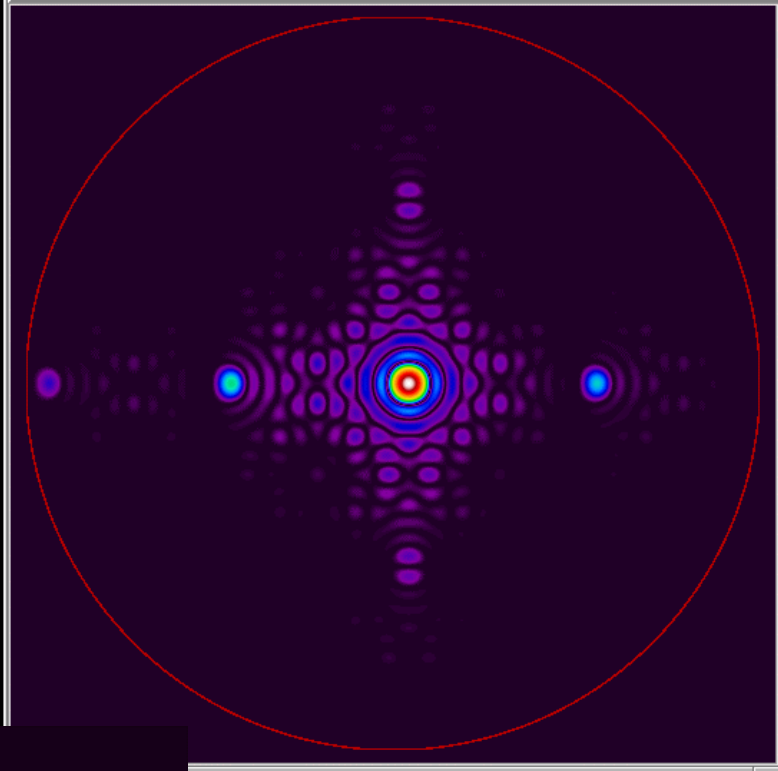


Station Beam

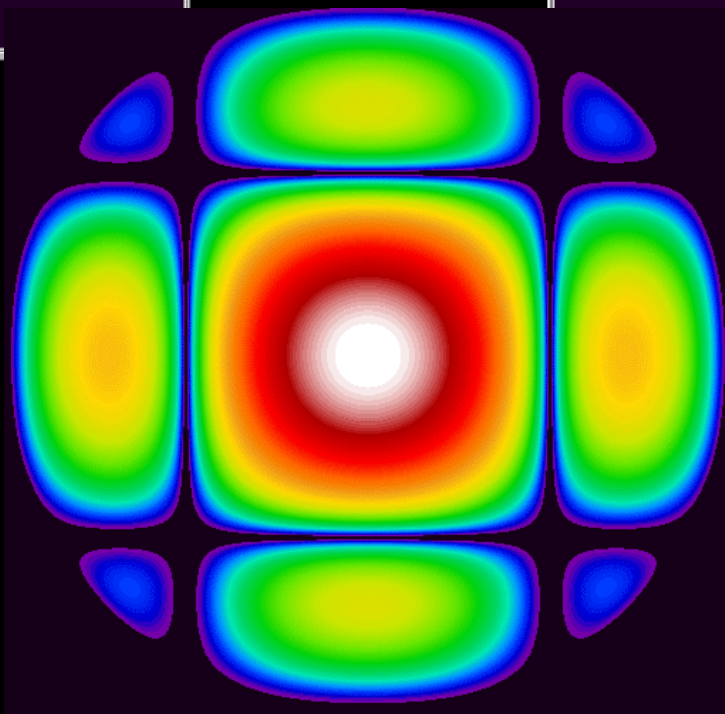




Offset
Station
Beam



Centered
station
beam



inside the
4x4 beam

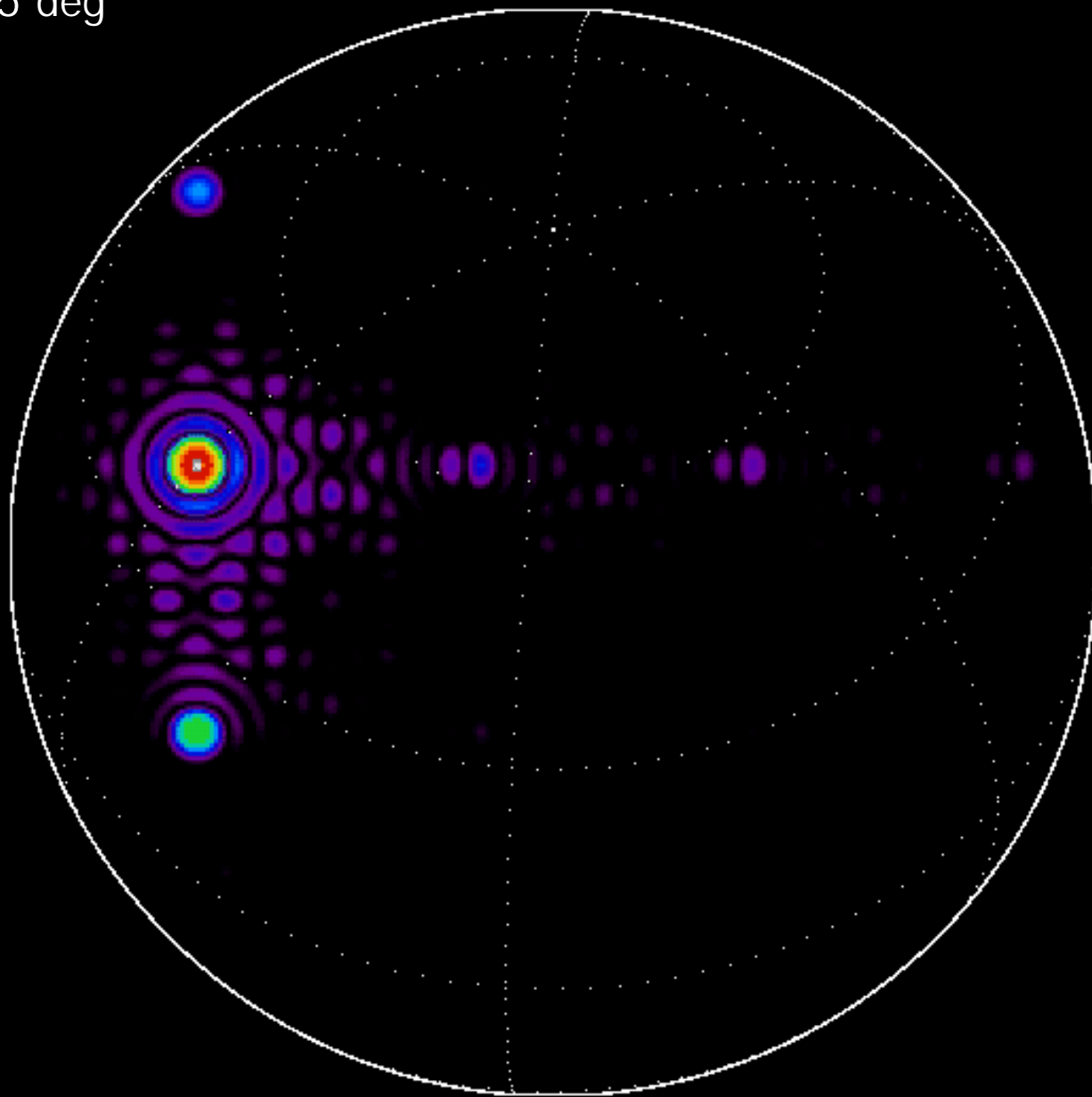


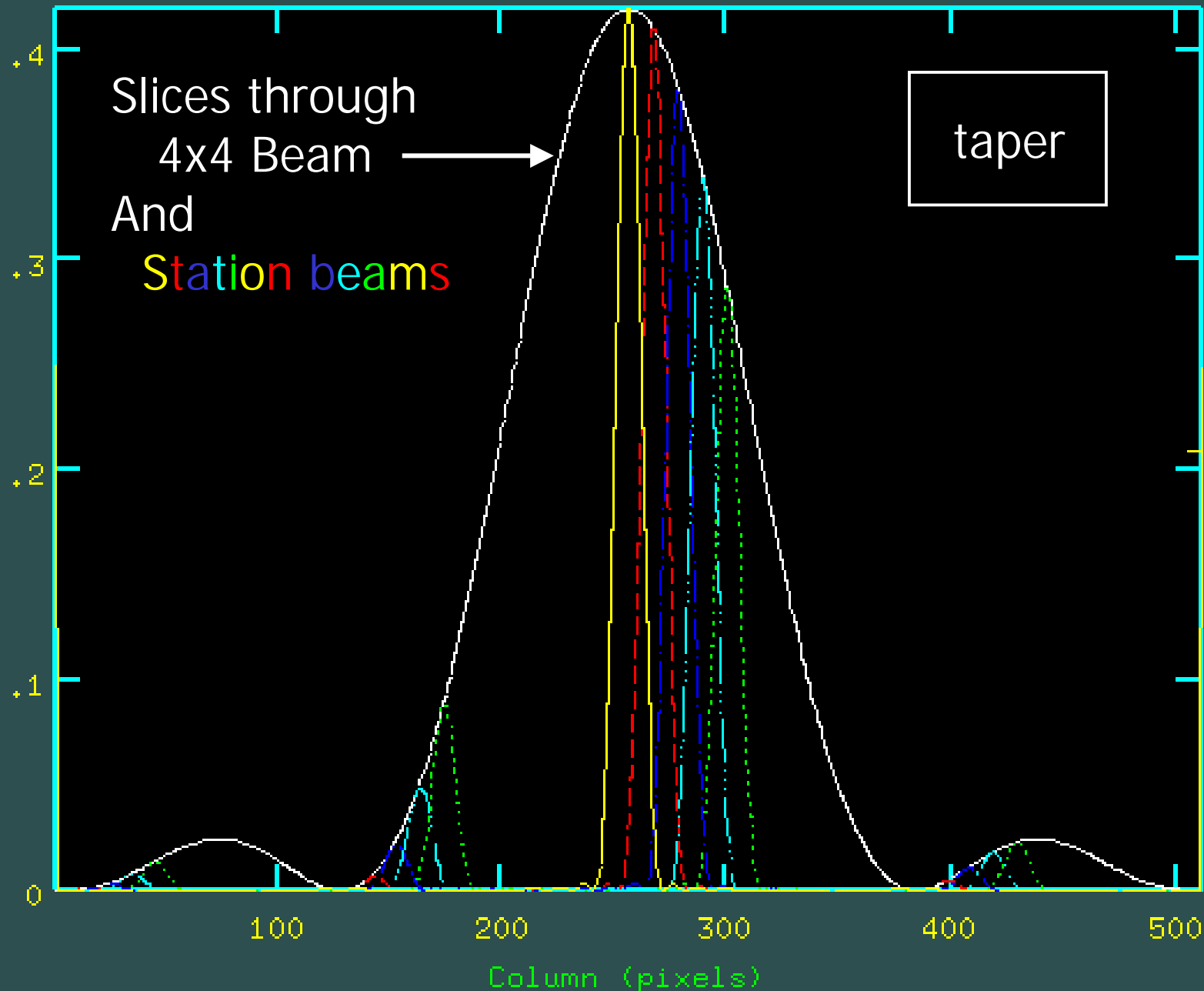
Latitude: +53.5 deg

Decl 4x4: 45

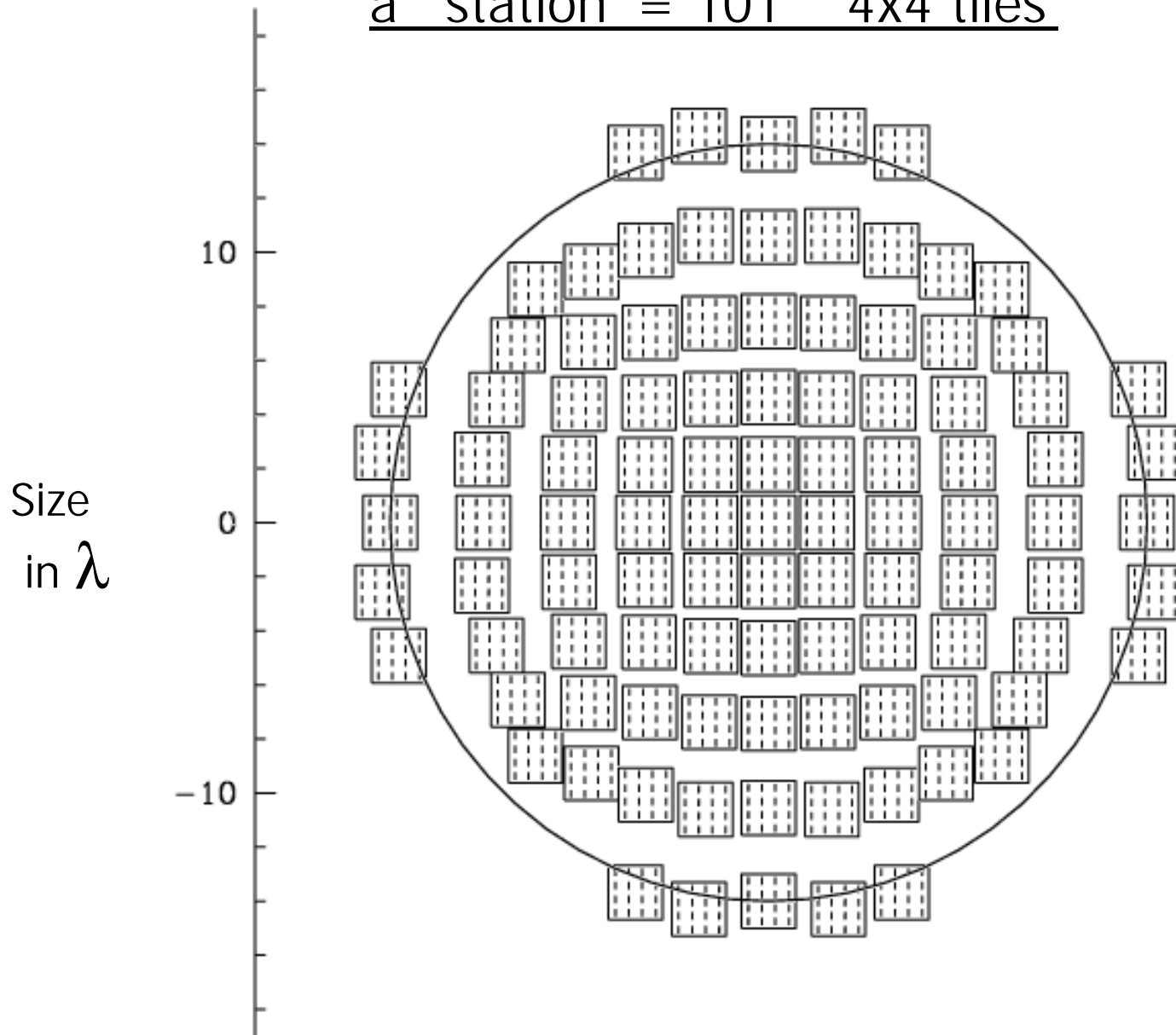
Offset: 5

@ p.a. 45

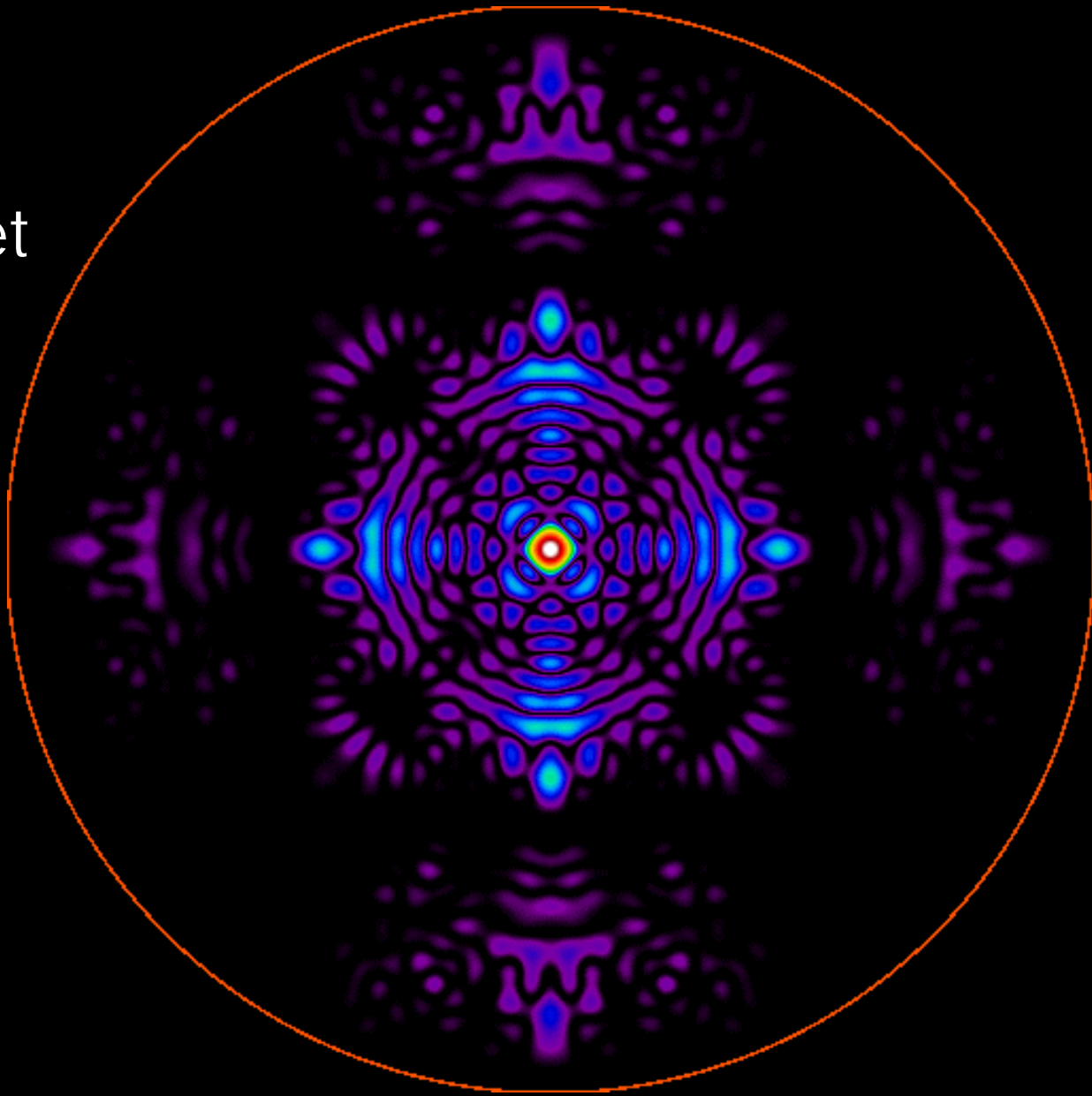




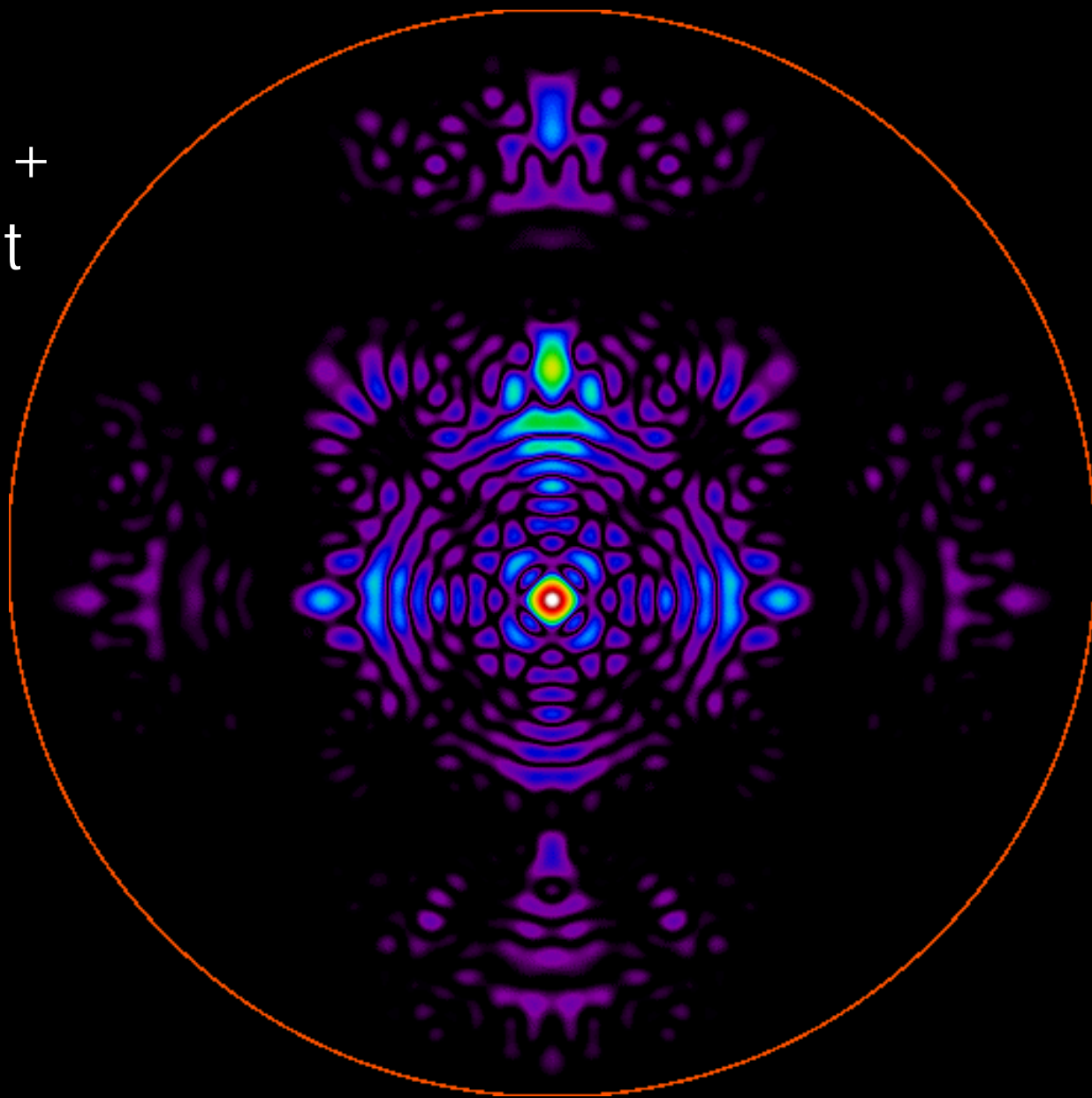
a 'station' = 101 '4x4 tiles'



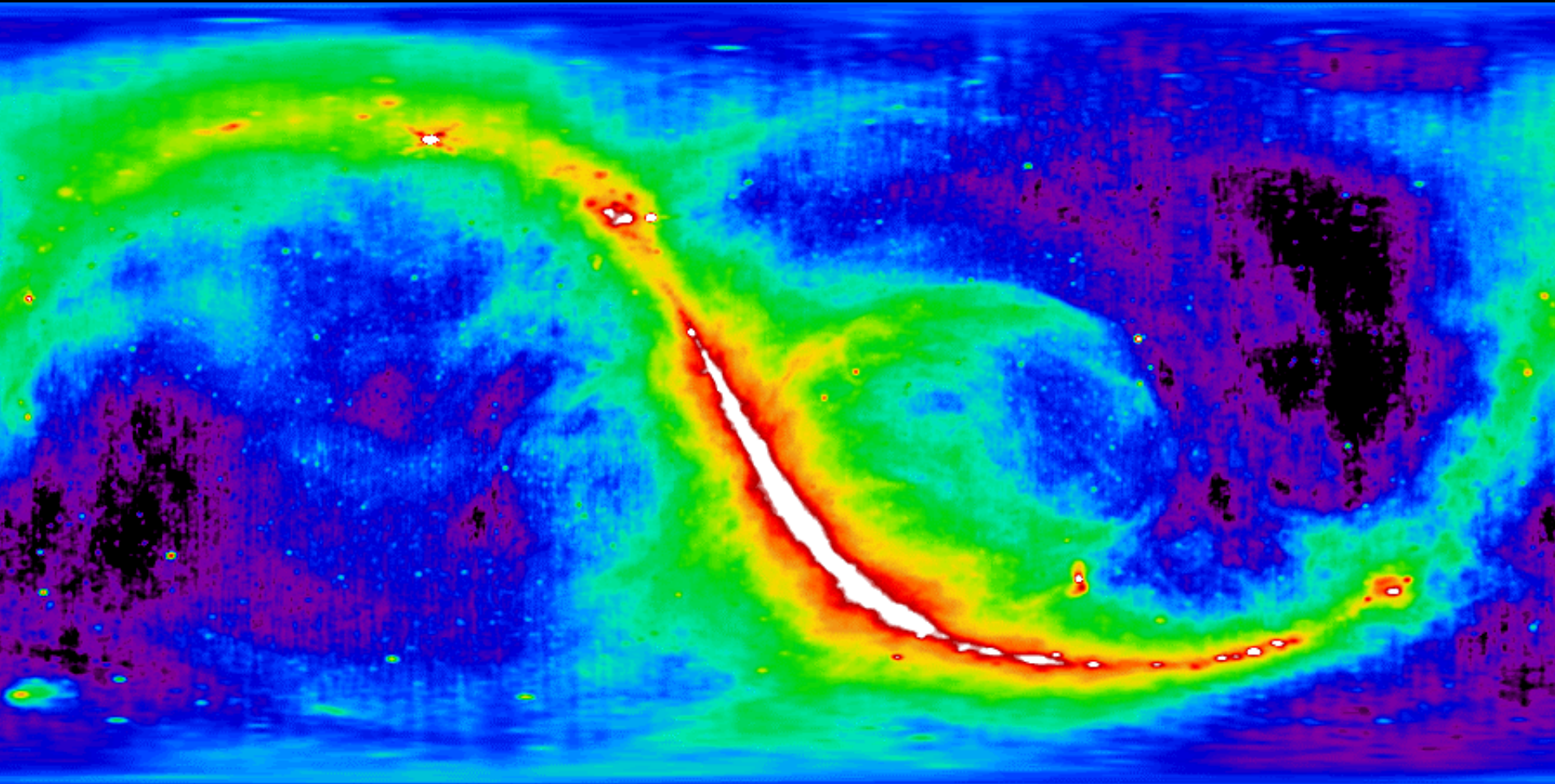
Zenith
no offset



Zenith +
5° offset



Radio sky in 408 MHz continuum (Haslam et al)



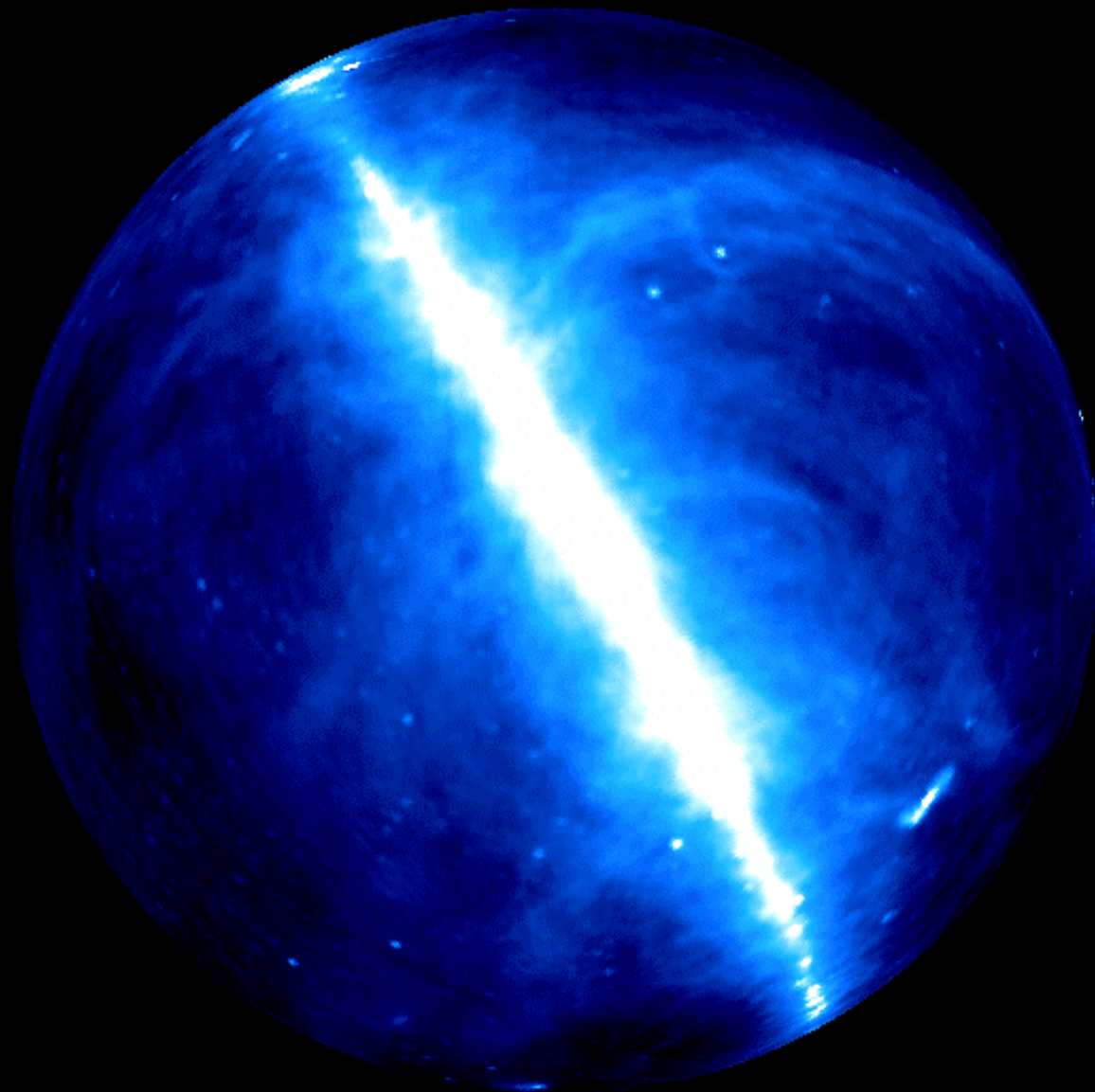
-30 deg

north

east

west

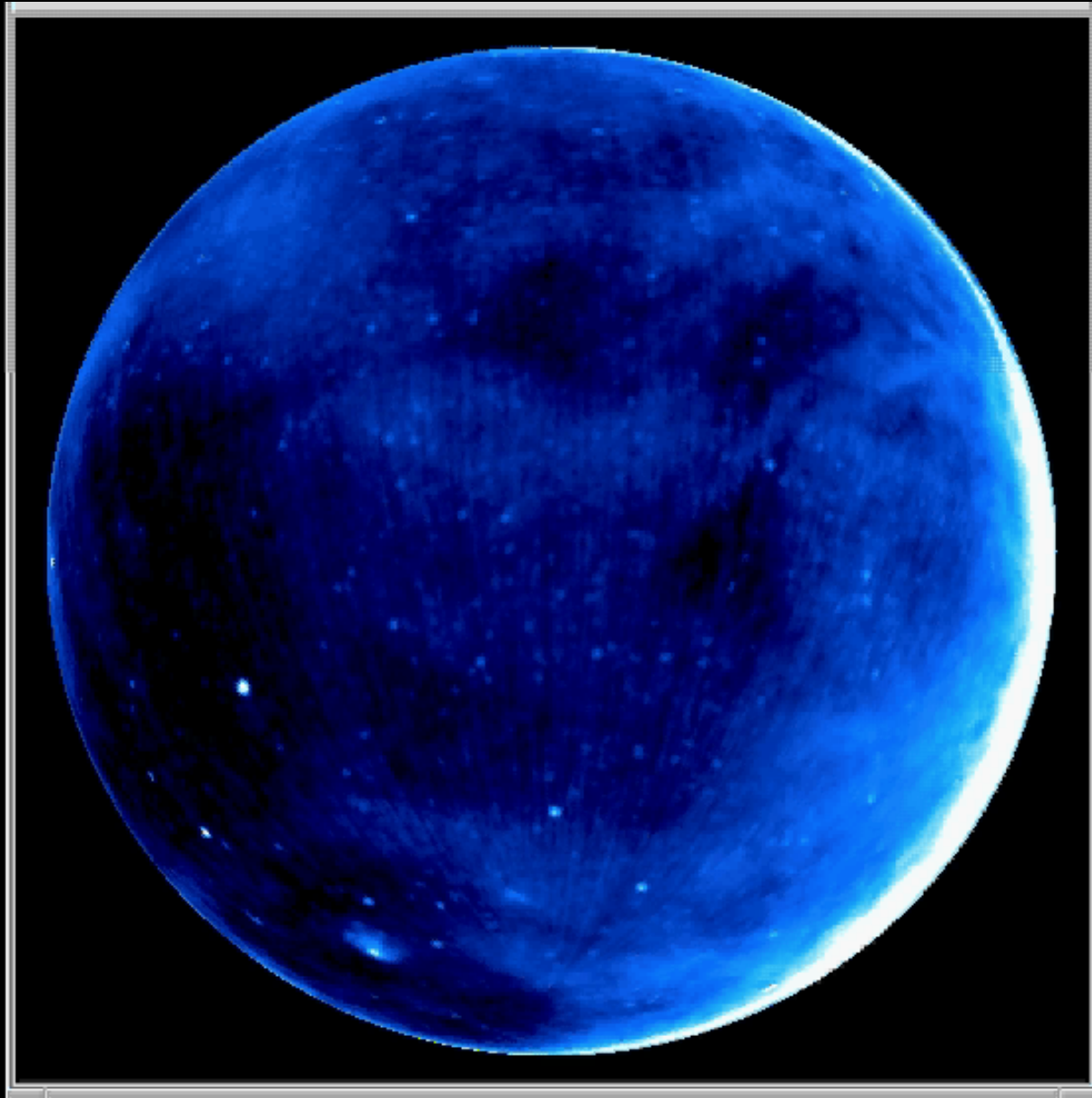
south



North

Latitude
-30

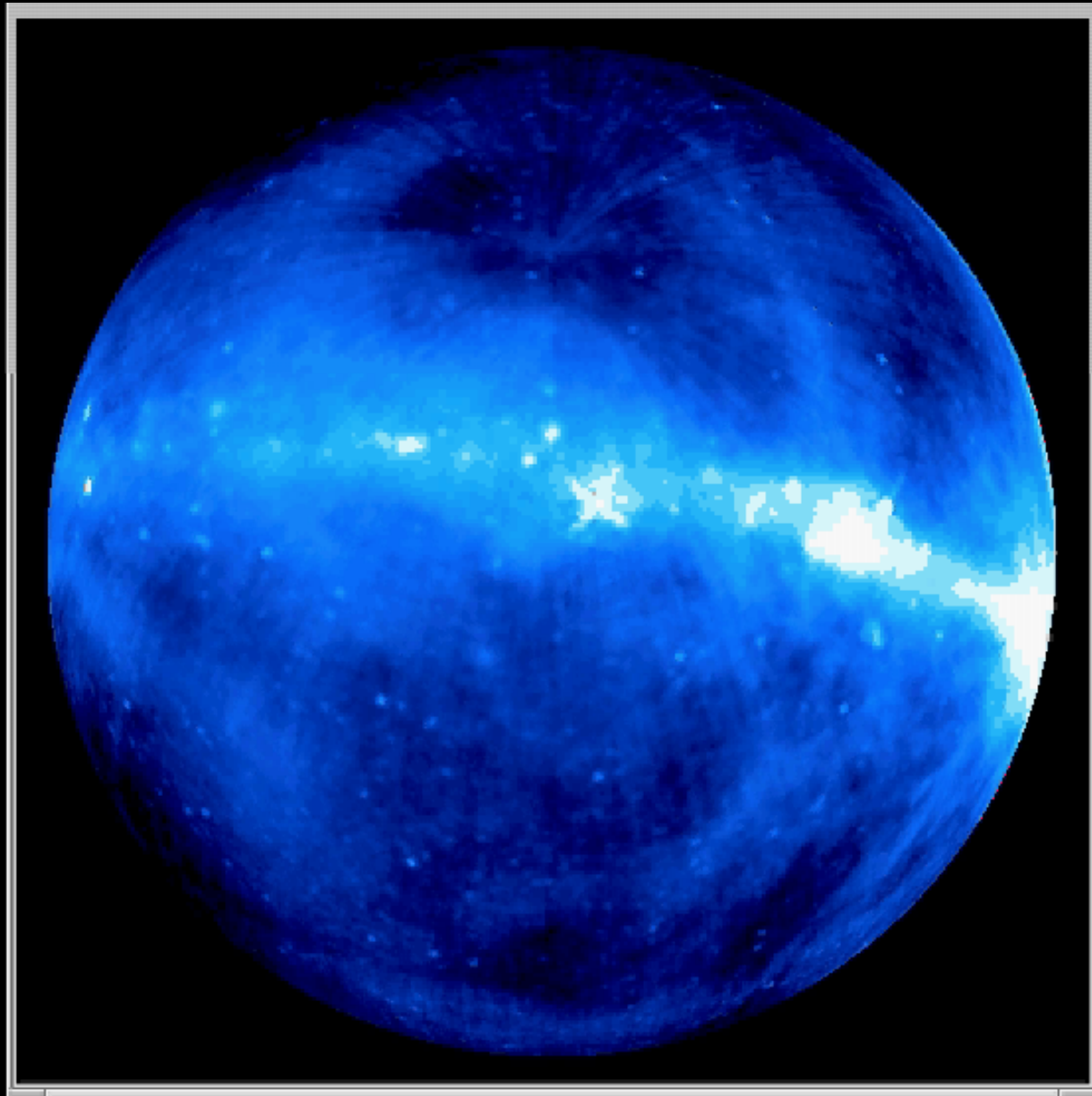
East



North

Latitude
+53.5

East



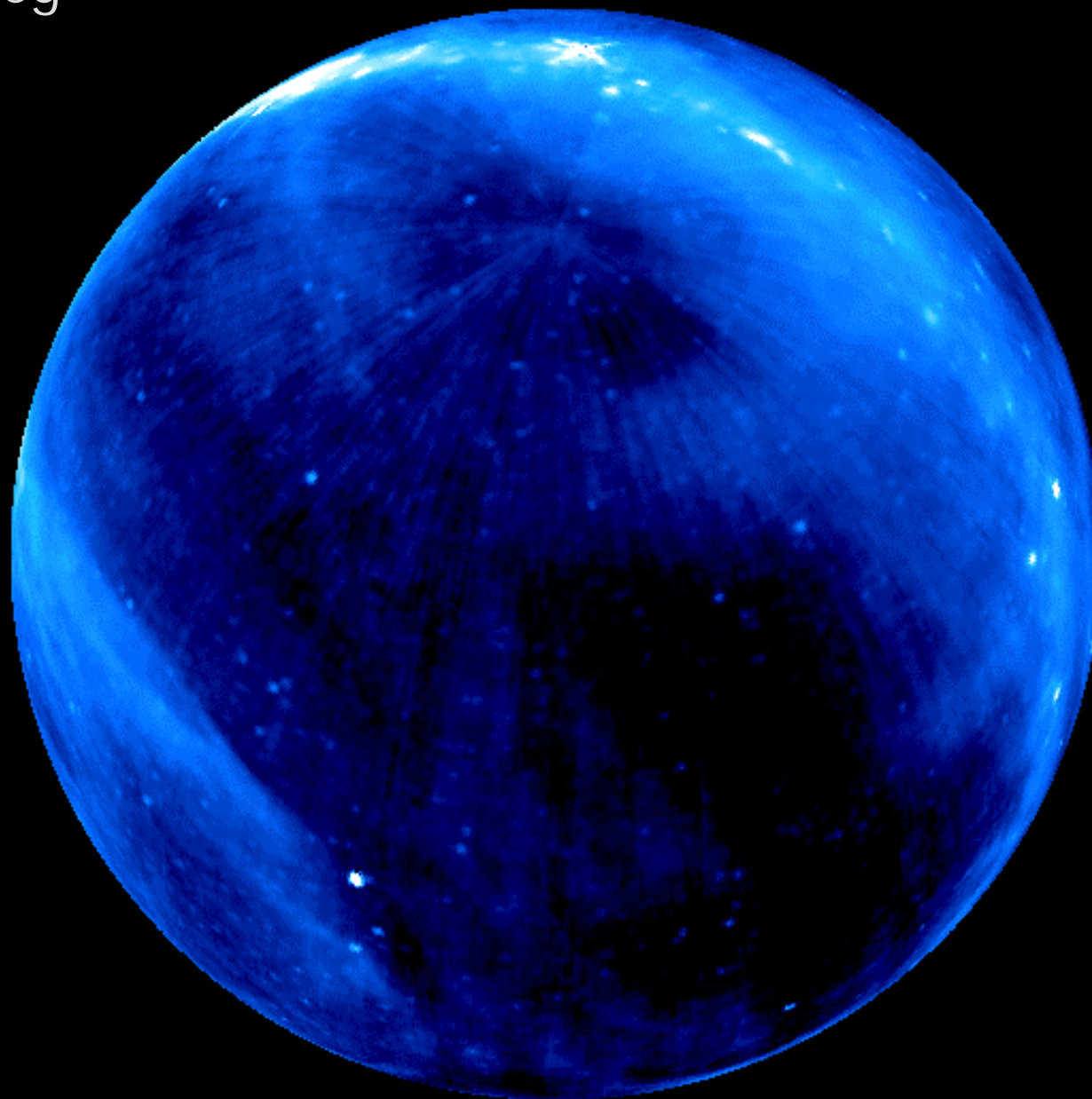
+53.5 deg

north

east

west

south



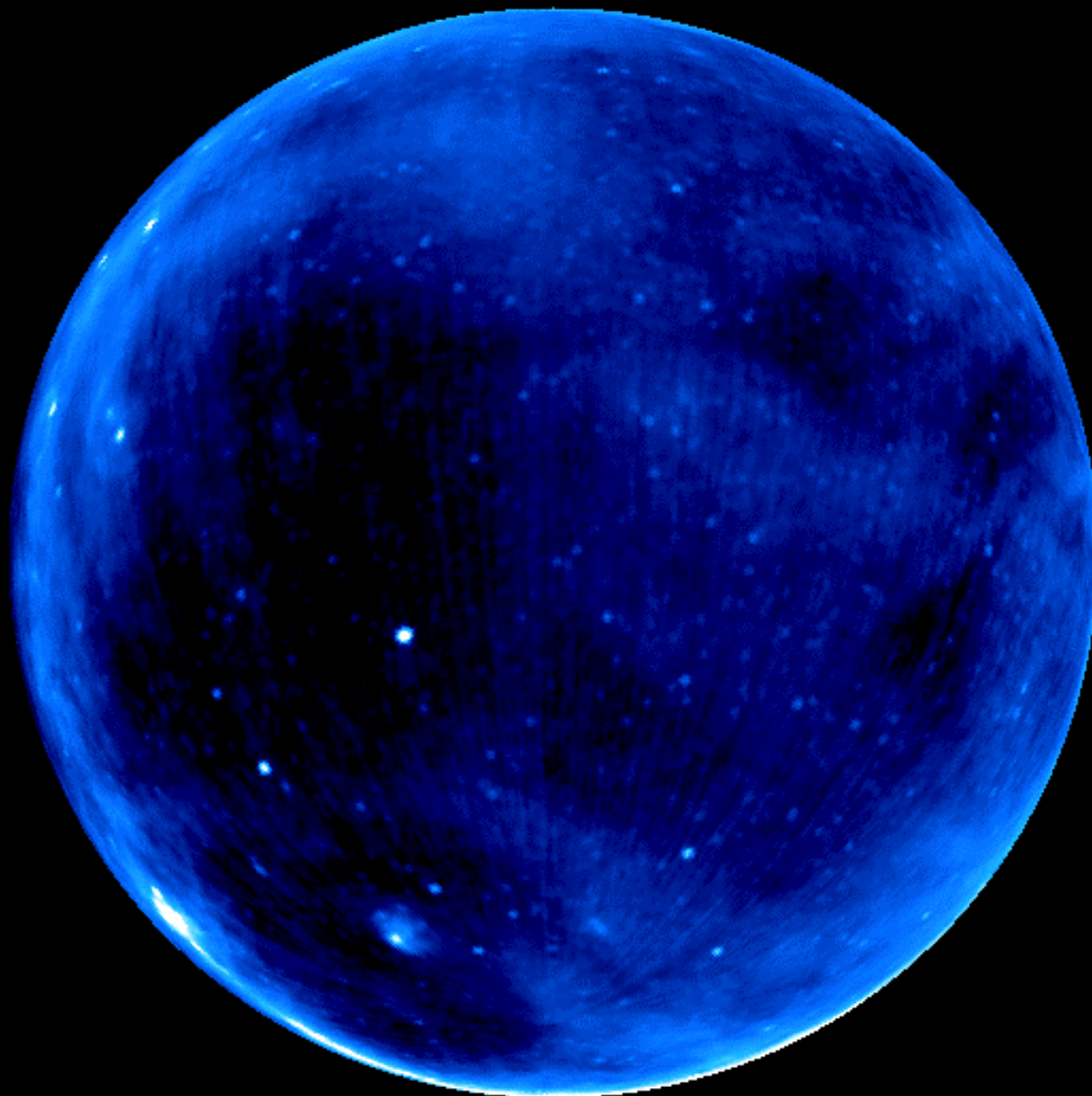
-30 deg

north

east

west

south





Top 4 LOFAR astronomical science drivers

- 21cm emission/absorption from Epoch of Reionisation
- Highest redshift radio sources
[=> catalog of background radio sources for intervening HI absorption]
- 3-D mapping of the Galactic non-thermal emission
- Transient and bursting sources

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Effect of moving
station beam
w.r.t. 4x4 beam

ZA = 30 deg
for 4x4
5 deg Offset for
station beam

