Laboratoire d'Études Spatiales et d'Instrumentation en Astrophysique

NenuFAR & VO standards usage

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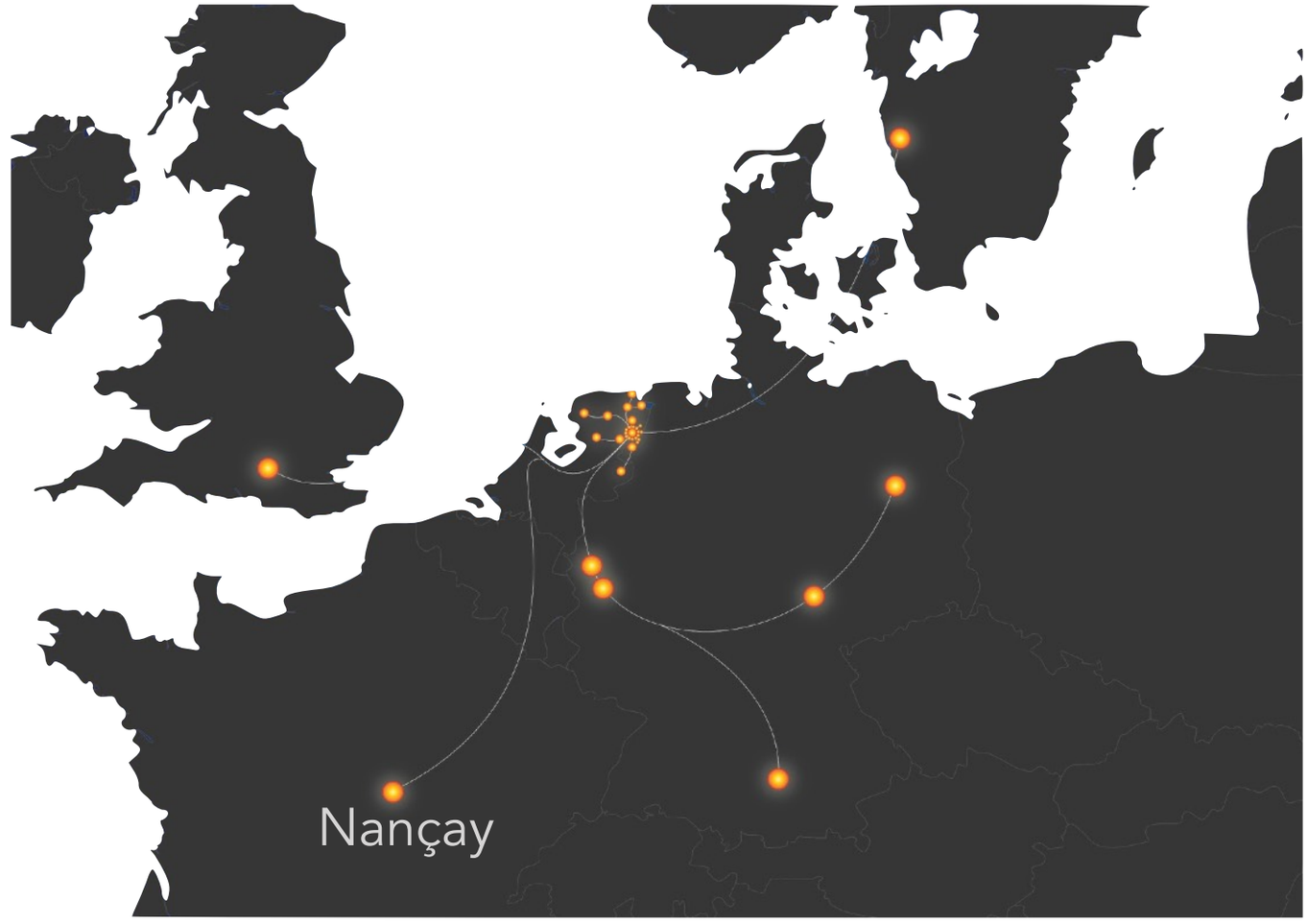
LOFAR 'SuperStation'

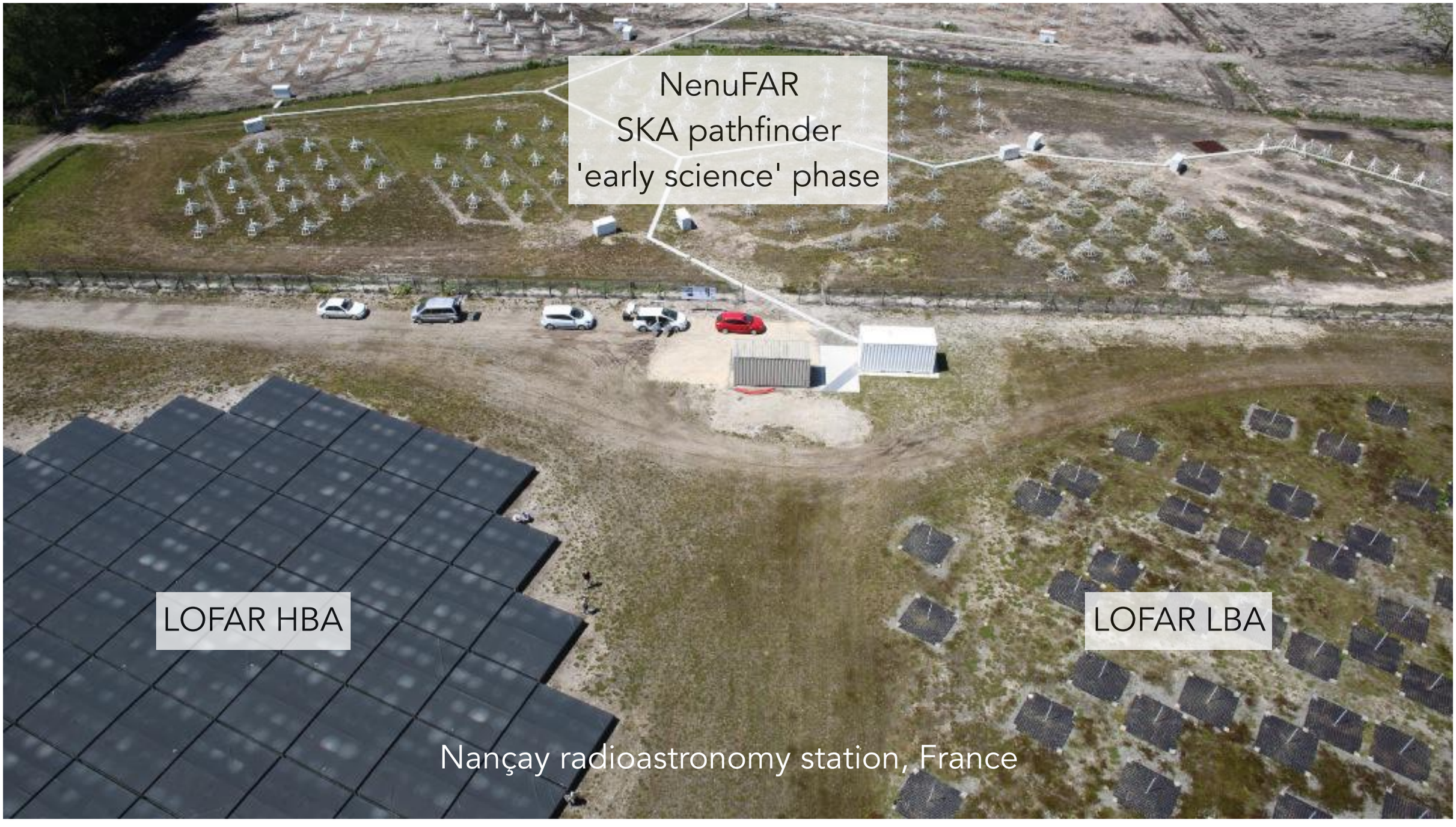
- **LOFAR** (*Low-Frequency Array*), large radio arrays pathfinder: ~50 antenna arrays ('stations') throughout Europe.
  - LBA: 30 - 80 MHz
  - HBA 110 - 250 MHz
- One LOFAR station in *Station de Radioastronomie de Nançay* FR606 with HBA, LBA and LBL data stream inputs.
- Make use of the **96 unused LBL entries** to build a *LOFAR SuperStation.*



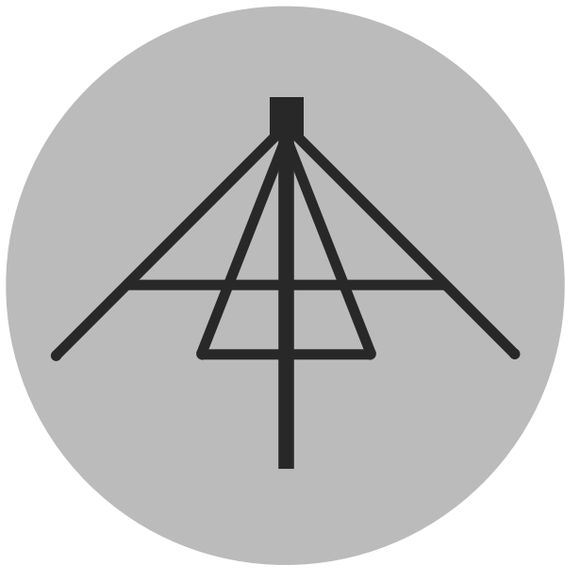
- **NenuFAR** *New Extension in Nançay upgrading LOFAR*:

LOFAR SuperStation	**Standalone Imager**	**Standalone Beamformer**
PSF < 1 arcsec	PSF ~10 arcmin	Up to 768 beams
Increase short bsl. sensitivity	96 + 6 distant Mini-Arrays	Pulsar & SETI modes

NenuFAR & LOFAR



NenuFAR



Antenna

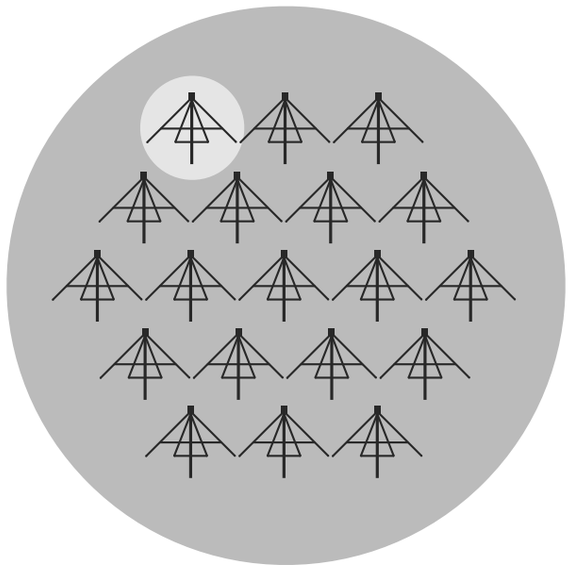
1938 LWA-like radiator antennas

Dual-polarizations inverted V shape elements

Low-Noise Amplifier

~**All-sky** field of view

Broadband response at **10-85 MHz**



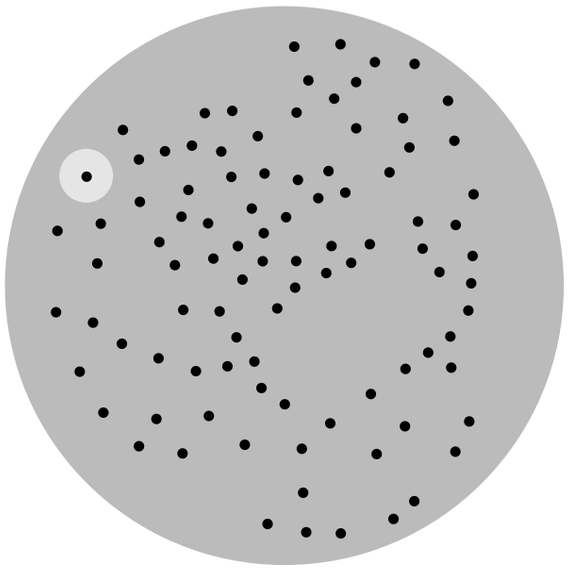
Mini-Array

Hexagon tile of **19 antennas**

Analog beamforming with delay lines

16384 pointable directions on the sky

Beam width: 46° at 15 MHz, 8° at 85 MHz



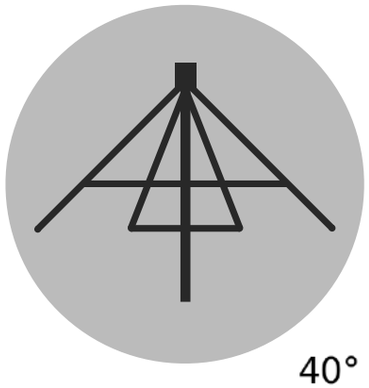
Core

96 mini-arrays (400m core) + 6 remote (up to 3km)

Optimal uv plane coverage for snapshots

Relative **MA rotations**: dampen grating lobes

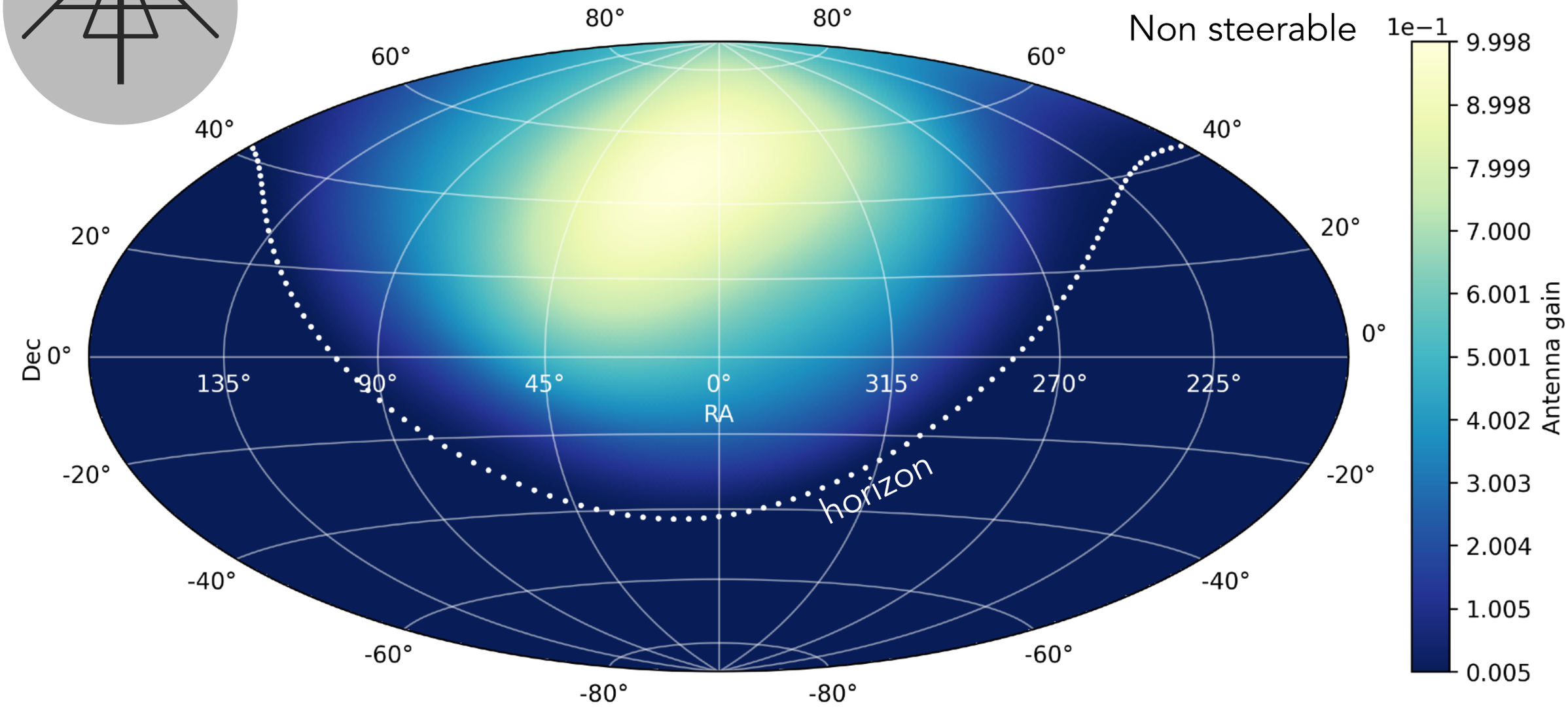
NenuFAR Antenna response



~All-(visible)-sky field of view, two polarizations

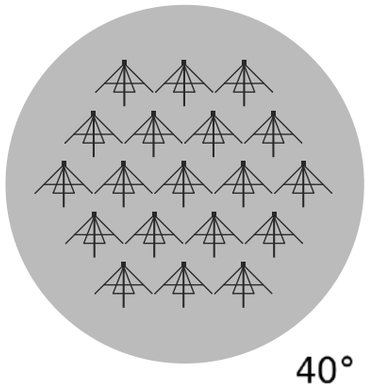
Local **zenith maximal sensitivity**

Non steerable



Model of antenna response with NEC (*Numerical Electromagnetics Code*) simulation (D. Charrier)

NenuFAR Single Mini-Array Beam

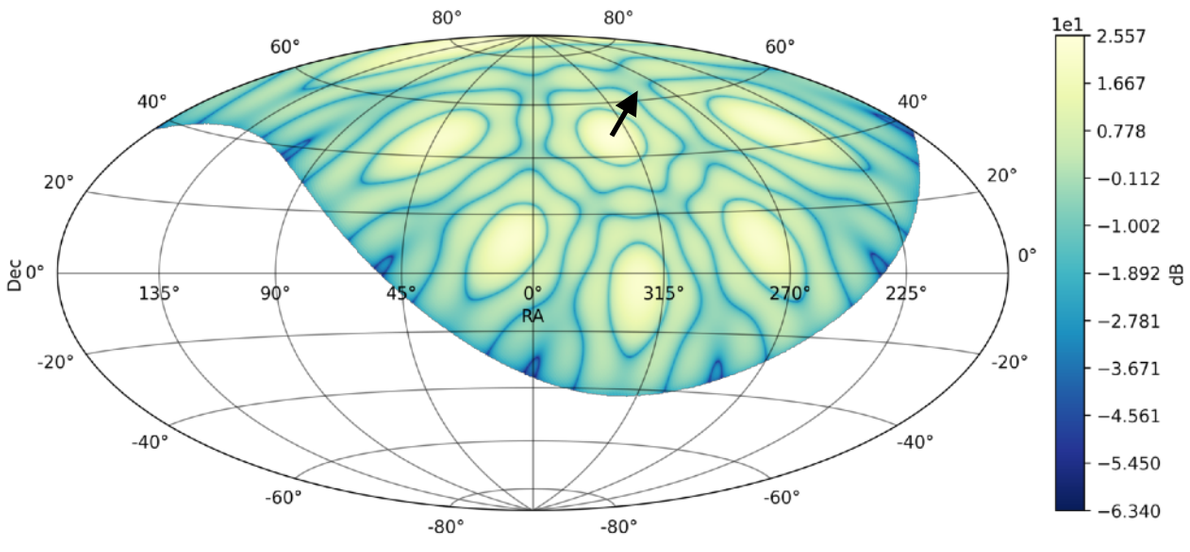


80 MHz MA beam
zenith pointing

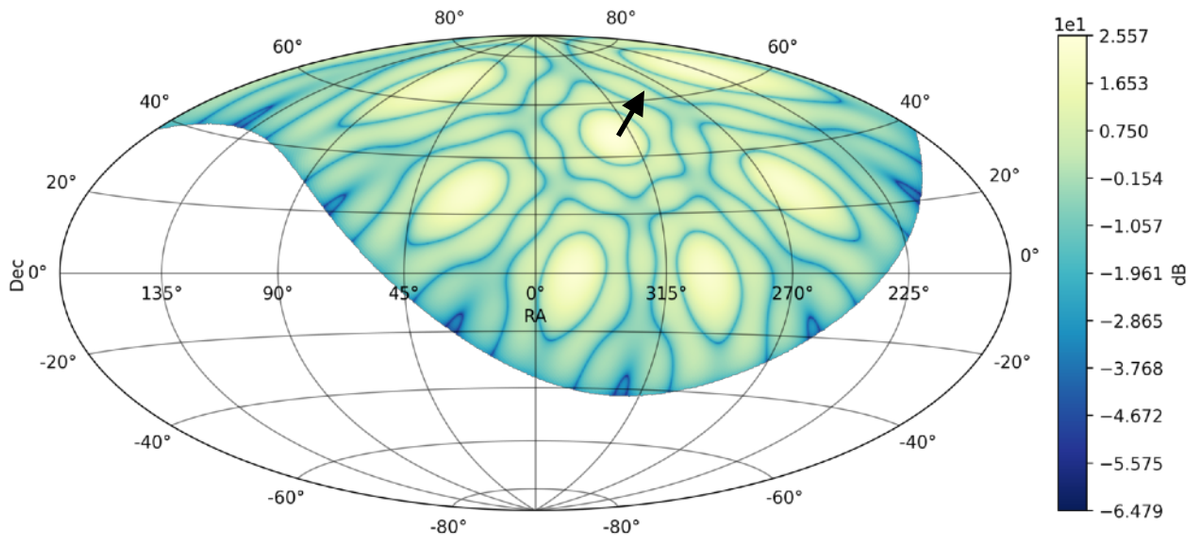
Always there (even if zenithal pointing) for $\lambda \leq d$, i.e. $f \geq 54.5$ MHz
Depends on pointing for $\lambda \geq d \geq \lambda/2$, i.e. 27.3 MHz $\leq f \leq 54.5$ MHz
None for $d \leq \lambda/2$, i.e. $f \leq 27.3$ MHz

NenuFAR Mini-Array Rotations

MA 00 (0°)



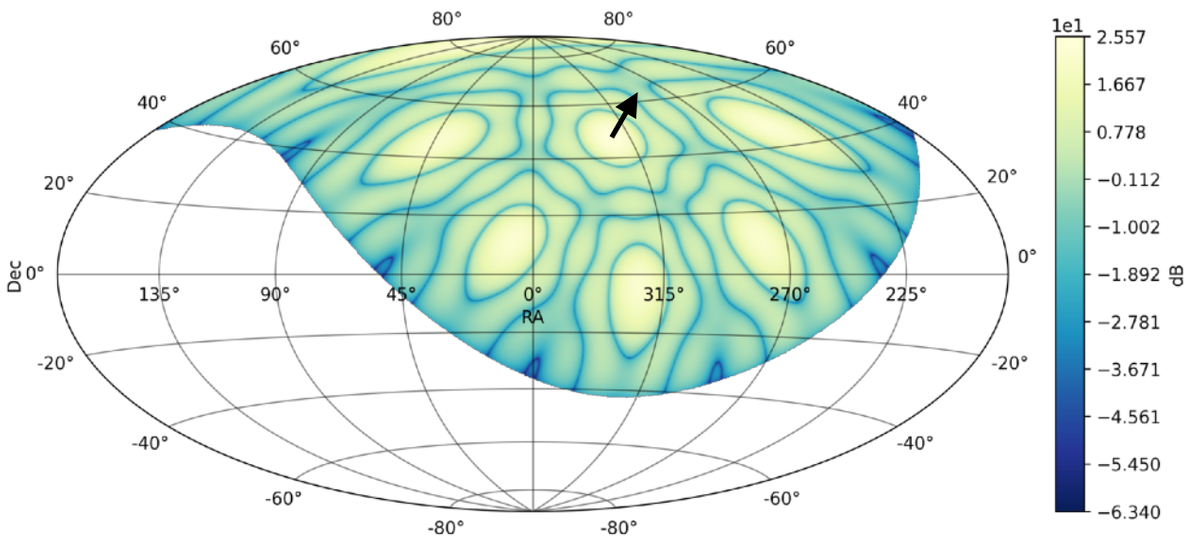
MA 01 (30°)



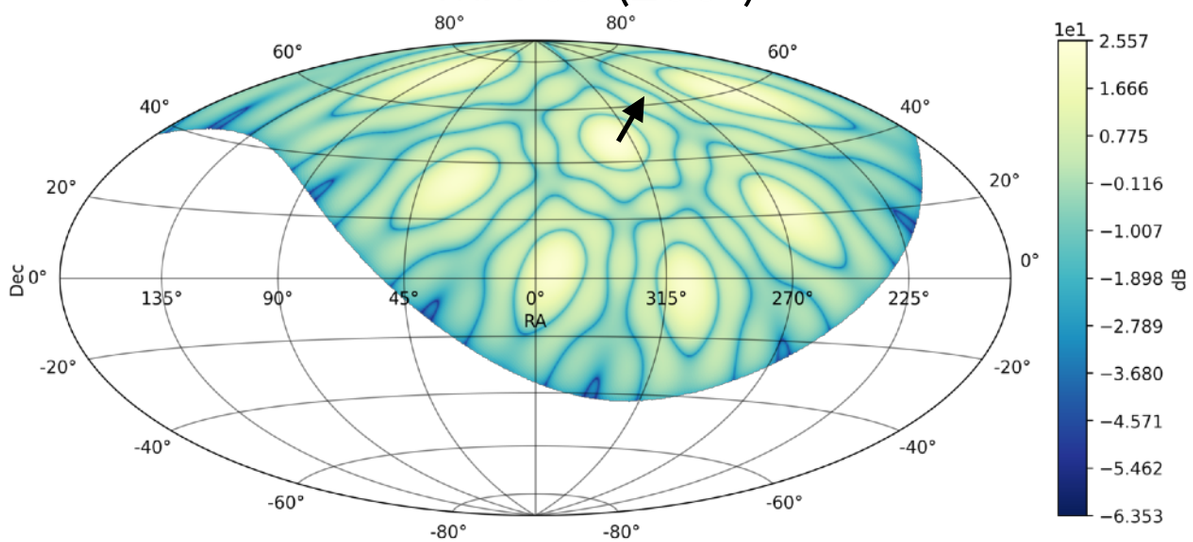
Same pattern
300° = 0° + 5x60°
(hexagon symmetry)

MAs are rotated by angles multiple of 10°
to reduce grating lobe contribution once summed

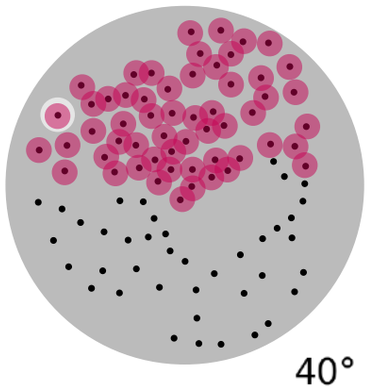
MA 02 (300°)



MA 03 (200°)



NenuFAR Beam with 56 Mini-Arrays



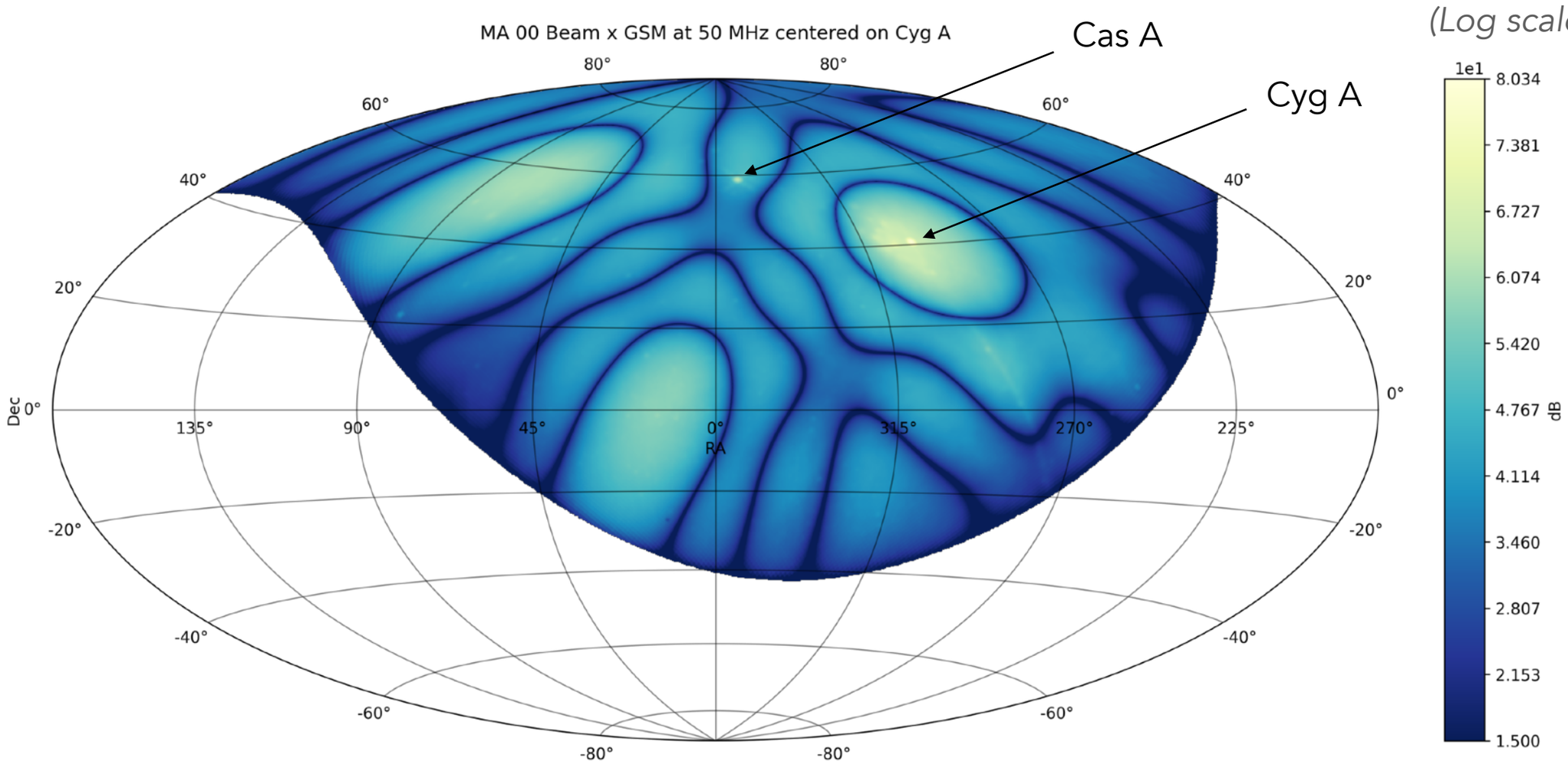
Finer beam pencil (coherent summation of 56 Mini-Arrays)

Mini-Array 'main lobe'

Grating lobe 'annulus'
(addition of rotated grating lobes)

Bright source contribution

- Depending on the **frequency** and **observation time:**
  - A bright source can fall in a MA primary beam / Grating lobe annulus
  - Beamforming: sky position information lost
  - Imaging: demix/source peeling possible, but better avoid that for low SNR observations

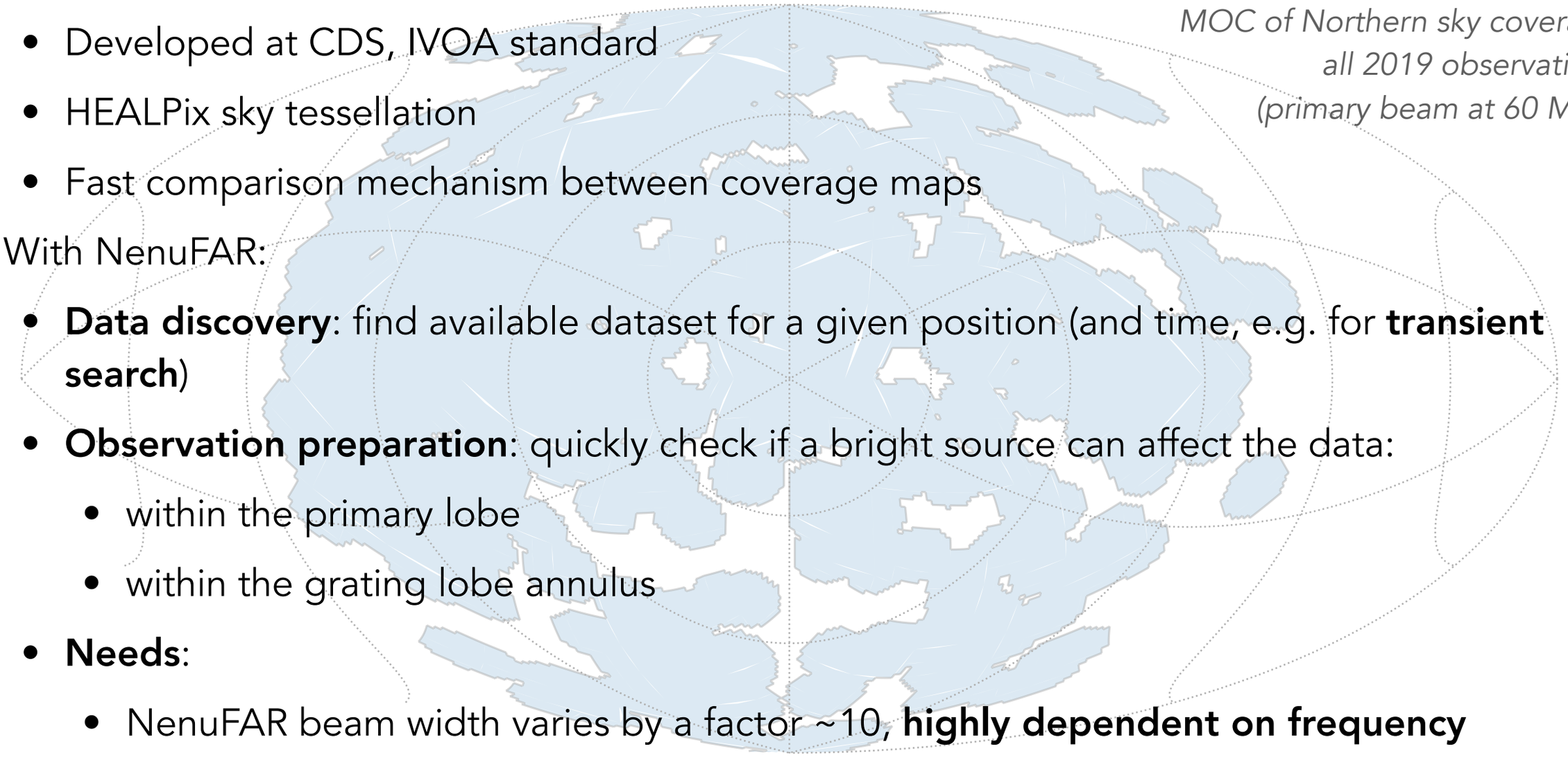


ST(e)MOC

- **Space Time HEALPix Multi-Order Coverage map**
  - Developed at CDS, IVOA standard
  - HEALPix sky tessellation
  - Fast comparison mechanism between coverage maps
- With NenuFAR:
  - **Data discovery**: find available dataset for a given position (and time, e.g. for **transient search**)
- **Observation preparation**: quickly check if a bright source can affect the data:
  - within the primary lobe
  - within the grating lobe annulus
- **Needs**:
  - NenuFAR beam width varies by a factor ~10, **highly dependent on frequency**
  - addition of frequency/wavelength/energy 'E' axis to STMOC
  - (already presented at OV France meeting in March 2020)

Background:

MOC of Northern sky coverage
all 2019 observations
(primary beam at 60 MHz)



NenuFAR observation database

- Each NenuFAR observation generates a low resolution FITS file with all necessary **metadata**
- NenuFAR observation database: **TAP service** on ObsCore table *(B. Cecconi)*
- Currently gather obs. from 2019-01-01 to 2019-11-05
- Queries with **pyvo**
- Already in use within the main NenuFAR Python package: **nenupy**
- **ToDo:**
  - Auto add new entry
  - EPNcore table (solar system data)

Name	Table Head	Description	Unit	UCD
accref	Product key	Access key for the data	N/A	N/A
owner	Owner	Owner of the data	N/A	N/A
embargo	Embargo ends	Date the data will become/became public	a	N/A
mime	Type	MIME type of the file served	N/A	meta.code.mime
accsize	File size	Size of the data in bytes	byte	VOX:Image_FileSize
dataproduct_type	Dataproduct_type	High level scientific classification of the data product, taken from an enumeration	N/A	meta.id
dataproduct_subtype	Dataproduct_subtype	Data product specific type	N/A	meta.id
calib_level	Calib_level	Amount of data processing that has been applied to the data [Note calib]	N/A	meta.code;obs.calib
obs_collection	Obs_collection	Name of a data collection (e.g., project name) this data belongs to	N/A	meta.id
obs_id	Obs_id	Unique identifier for an observation	N/A	meta.id
obs_title	Obs_title	Free-from title of the data set	N/A	meta.title;obs
obs_publisher_did	Obs_publisher_did	Dataset identifier assigned by the publisher.	N/A	meta.ref.uri;meta.curation
obs_creator_did	Obs_creator_did	Dataset identifier assigned by the creator.	N/A	meta.id
access_url	Access_url	The URL at which to obtain the data set.	N/A	meta.ref.url
access_format	Access_format	MIME type of the resource at access_url	N/A	meta.code.mime
access_estsize	Access_estsize	Estimated size of data product	kbyte	phys.size;meta.file
target_name	Target_name	Object a targeted observation targeted	N/A	meta.id;src
target_class	Target_class	Class of the target object (star, QSO, ...)	N/A	src.class
s_ra	S_ra	RA of (center of) observation, ICRS	deg	pos.eq.ra
s_dec	S_dec	Dec of (center of) observation, ICRS	deg	pos.eq.dec
s_fov	S_fov	Approximate spatial extent for the region covered by the observation	deg	phys.angSize;instr.fov
s_region	S_region	Region covered by the observation, as a polygon	N/A	pos.outline;obs.field
s_resolution	S_resolution	Best spatial resolution within the data set	arcsec	pos.angResolution
t_min	T_min	Lower bound of times represented in the data set, as MJD	d	time.start;obs.exposure
t_max	T_max	Upper bound of times represented in the data set, as MJD	d	time.end;obs.exposure
t_exptime	T_exptime	Total exposure time	s	time.duration;obs.exposure
t_resolution	T_resolution	Minimal significant time interval along the time axis	s	time.resolution
em_min	Em_min	Minimal wavelength represented within the data set	m	em.wl;stat.min
em_max	Em_max	Maximal wavelength represented within the data set	m	em.wl;stat.max
em_res_power	Em_res_power	Spectral resolving power delta lambda/lamda	N/A	spect.resolution
o_ucd	O_ucd	UCD for the product's observable	N/A	meta.ucd
pol_states	Pol_states	List of polarization states in the data set	N/A	meta.code;phys.polarization
facility_name	Facility_name	Name of the facility at which data was taken	N/A	meta.id;instr.tel
instrument_name	Instrument_name	Name of the instrument that produced the data	N/A	meta.id;instr
s_xel1	S_xel1	Number of elements (typically pixels) along the first spatial axis.	N/A	meta.number
s_xel2	S_xel2	Number of elements (typically pixels) along the second spatial axis.	N/A	meta.number
t_xel	T_xel	Number of elements (typically pixels) along the time axis.	N/A	meta.number
em_xel	Em_xel	Number of elements (typically pixels) along the spectral axis.	N/A	meta.number
pol_xel	Pol_xel	Number of elements (typically pixels) along the polarization axis.	N/A	meta.number
s_pixel_scale	S_pixel_scale	Sampling period in world coordinate units along the spatial axis	arcsec	phys.angSize;instr.pixel
em_ucd	Em_ucd	Nature of the product's spectral axis	N/A	meta.ucd
preview	Preview	URL of a preview (low-resolution, quick-to-retrieve representation) of the data.	N/A	meta.ref.url;datalink.preview
source_table	Source_table	Name of a TAP-queriable table this data originates from. This source table usually provides more information on the the data than what is given in obscore. See the TAP_SCHEMA of the originating TAP server for details.	N/A	meta.id;meta.table

HiPS

- **Hierarchical Progressive Survey**
- NenuFAR Science Key Program #15 **'Large-scale background survey'**
  - **Northern-sky survey**
  - Low-frequency background (structure and components)
    - Model of global cosmic radio emission
- Task is awaiting for the NenuFAR correlator completion (in commissioning)
  - Led by Ukrainian UTR-2 team
  - Combination of UTR-2 survey (10-30 MHz) and NenuFAR (20-80 MHz)
- Radio imaging pipeline: FITS products
- Build and distribute the **NenuFAR HiPS low-frequency survey** as well as **HiPS-progenitor** (keep metadata accessible, including imaging parameters: UV cuts, imaging pipeline, ...)

Supplementary material

NenuFAR Mini-Array Beam

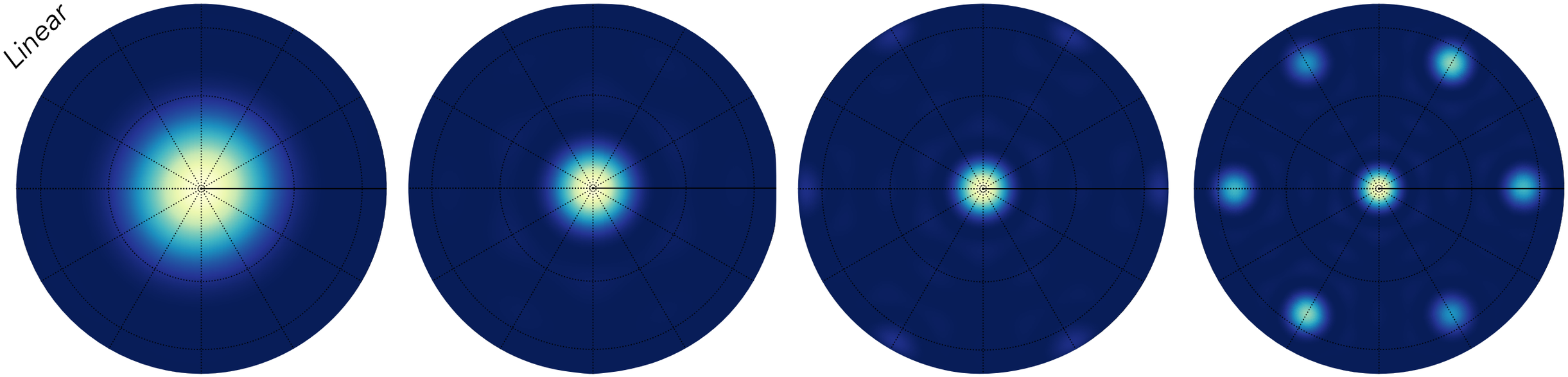
θ~34°

θ~17°

θ~11°

θ~8°

Linear



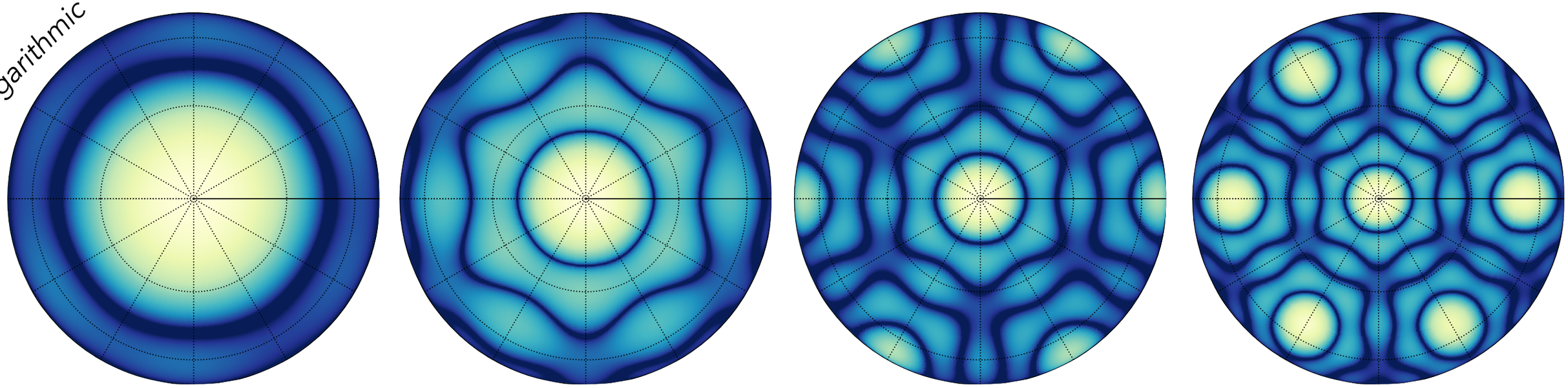
20 MHz

40 MHz

60 MHz

80 MHz

Logarithmic



NenuFAR 56-MAs Beam

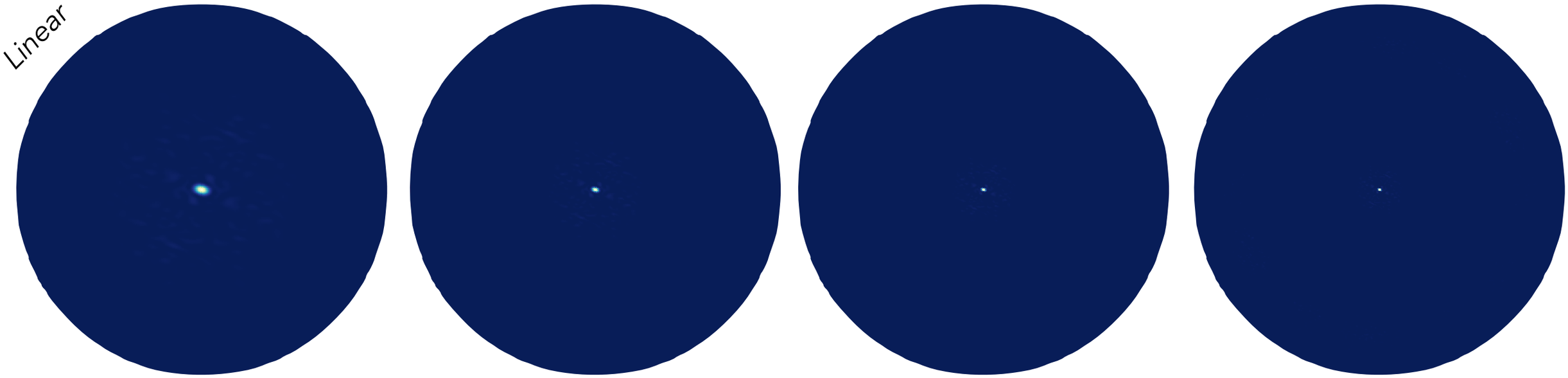
θ~2.0°

θ~1.0°

θ~0.7°

θ~0.5°

Linear



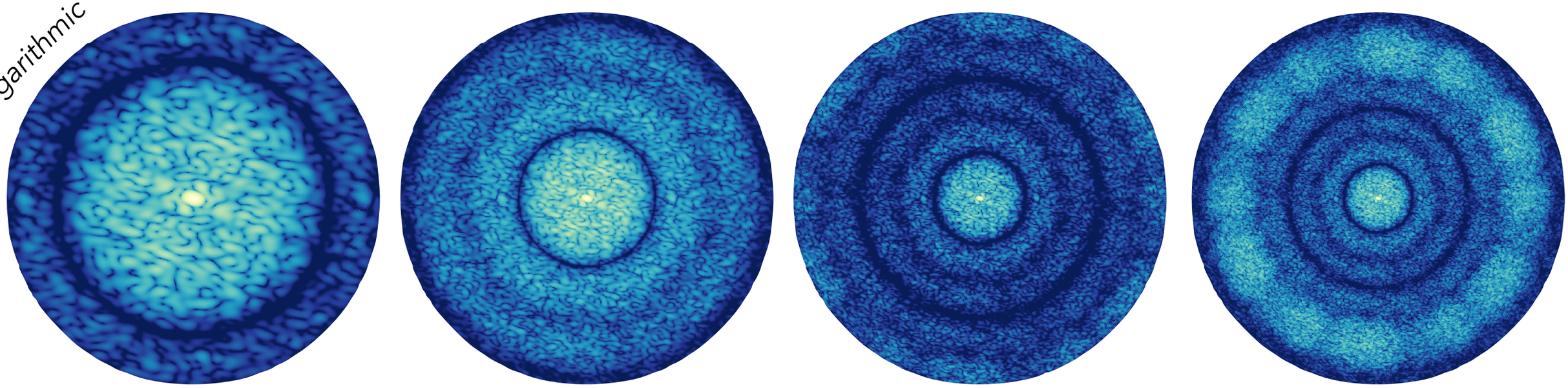
20 MHz

40 MHz

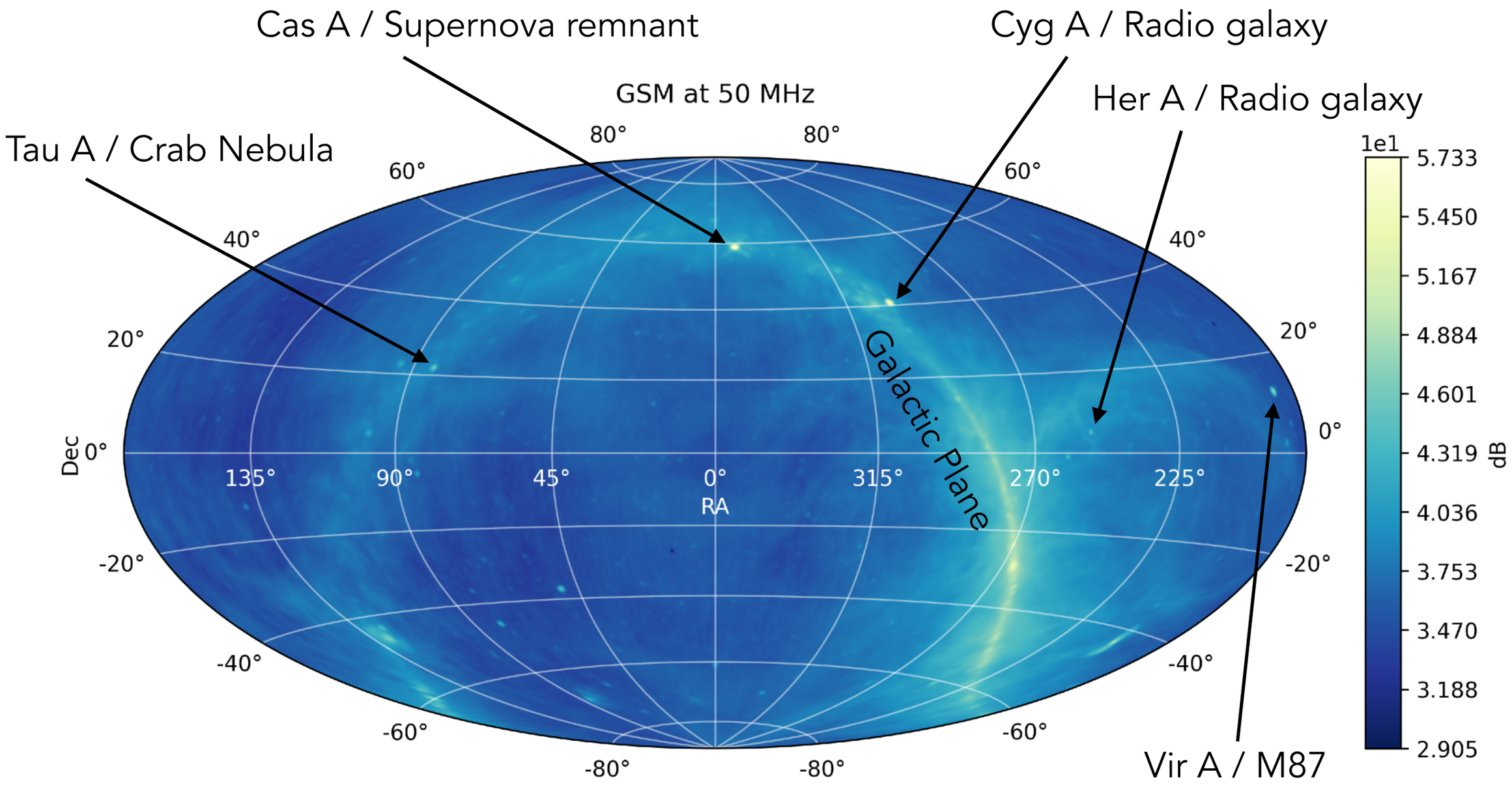
60 MHz

80 MHz

Logarithmic



Low-Frequency Sky



GSM Oliveira-Costa et al., 2008