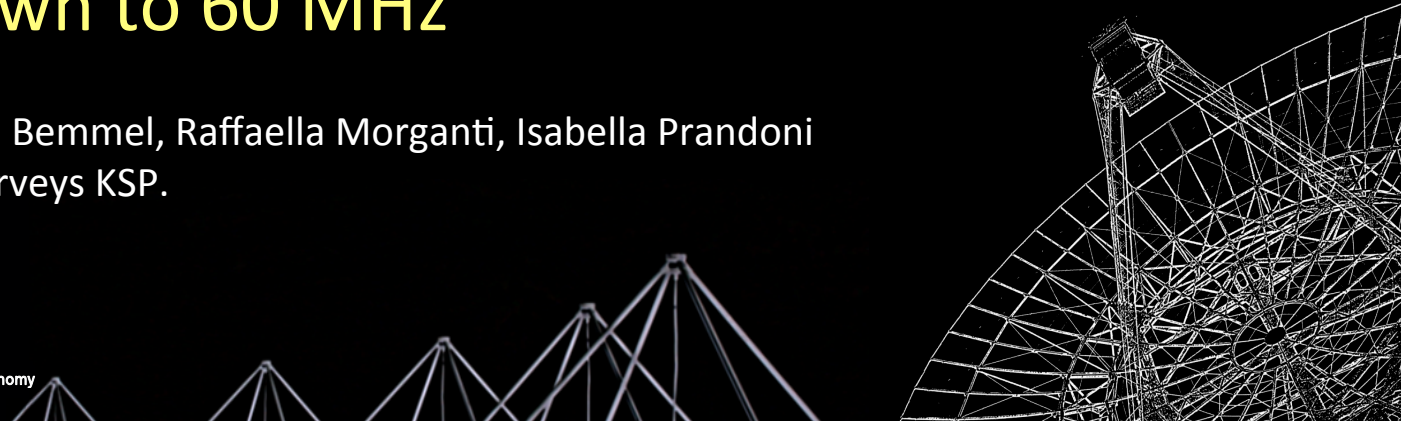


# The Lockman Hole with LOFAR: a Multi-frequency Study of the Faint Radio Population down to 60 MHz

Elizabeth Mahony, Ilse van Bemmelen, Raffaella Morganti, Isabella Prandoni  
and many others in the Surveys KSP.

**ASTRON**

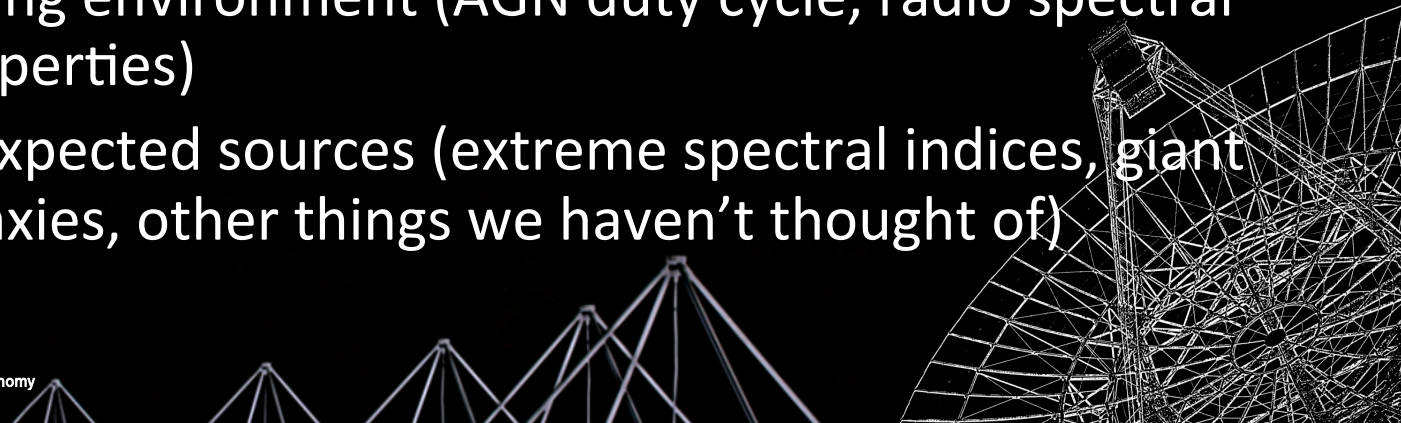
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# Blank Fields – science goals

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- Target well-known fields to study large samples of AGN (PI: Philip Best)
  - Nature of the sub-mJy source population (i.e. AGN vs. SF contribution)
  - The cosmic accretion history of black holes
  - Evolution of AGN and it's connection to the host galaxy (what role do low-luminosity radio sources play?)
  - Evolution of radio sources and the interaction with the surrounding environment (AGN duty cycle, radio spectral index properties)
  - Rare/unexpected sources (extreme spectral indices, giant radio galaxies, other things we haven't thought of)

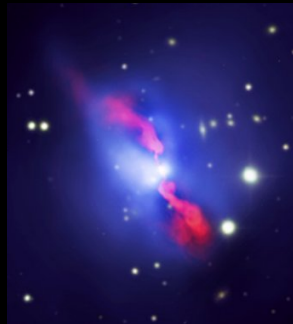


# The cosmic accretion history of black holes

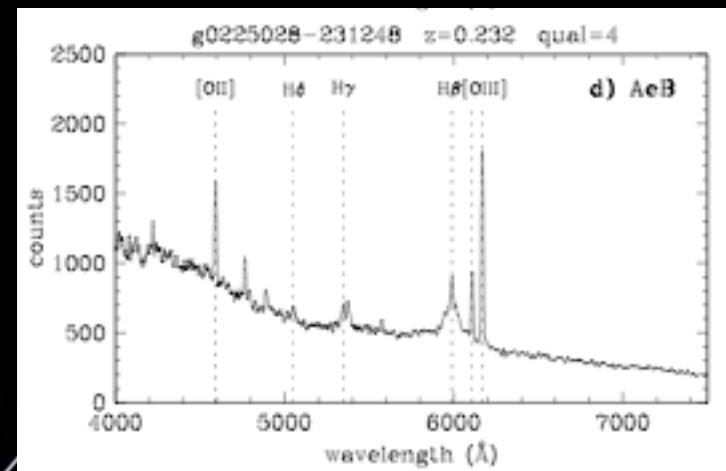
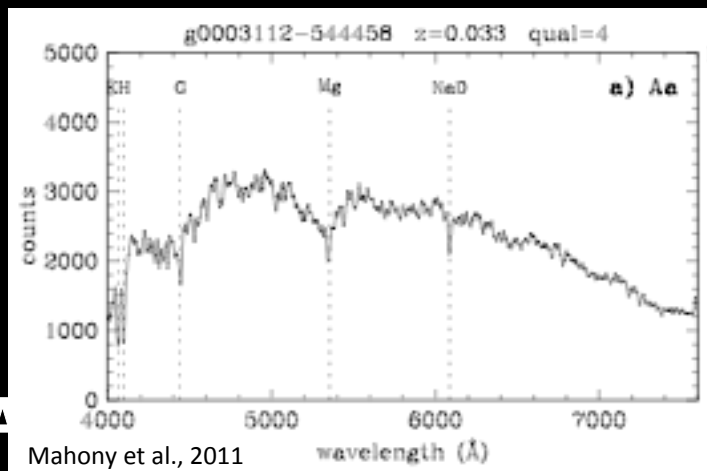
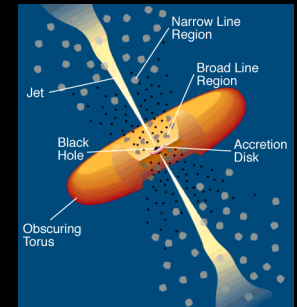
## • Jet-mode (LERG) vs. Radiative mode (HERG)

(e.g. Best 05, Croton 06, Hardcastle 07, Best & Heckman 12, Heckman & Best 14)

- Host galaxy accretes 'hot' gas ( $T > 10^5$  K)
- Forms an inefficient accretion disk
- Very weak, or no emission lines in the optical spectrum

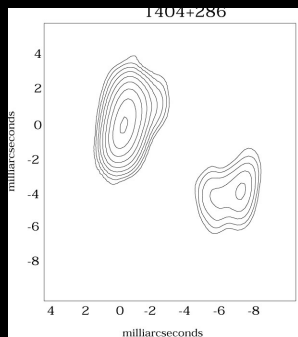


- Host galaxy accretes 'cold' gas
- Forms an efficient accretion disk
- Strong emission lines in the optical spectrum

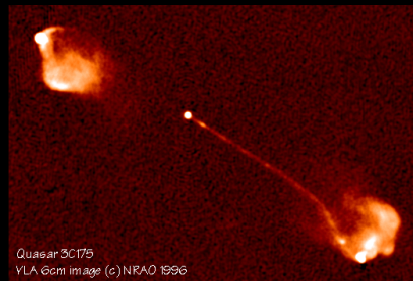
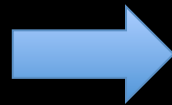


# Spectral index properties of low frequency radio sources

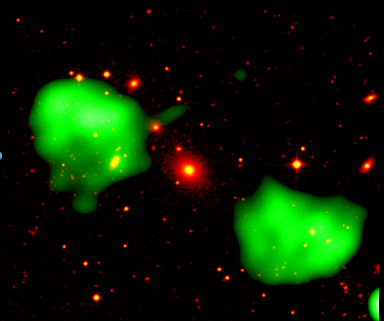
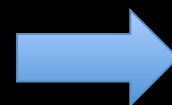
- Study the evolution of radio sources



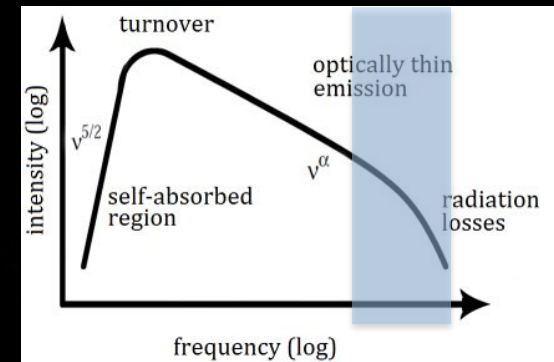
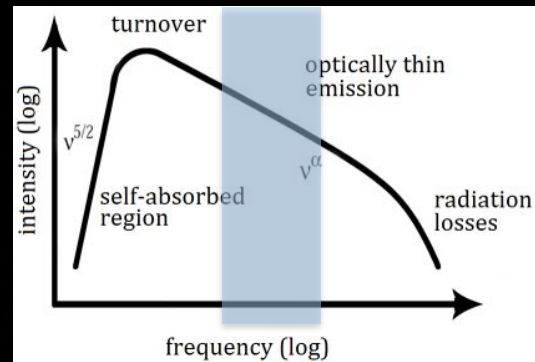
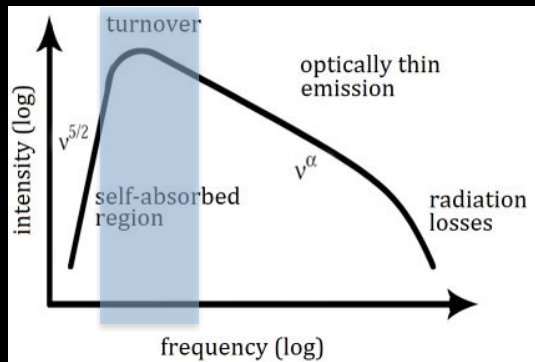
GPS/CSS



FRI/FRII



relics  
(restarted?)



# Cycle 0 Blank Fields

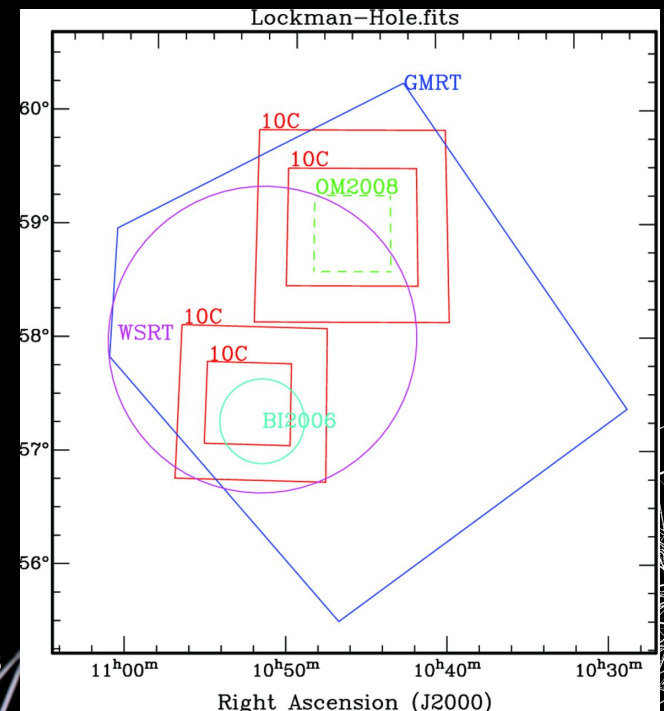
- Initial fields chosen to have lots of ancillary data

**Table 1:** Details of the 25 proposed blank-fields for the Tier 2 of the LOFAR Surveys, and a description of associated multi-wavelength data in these fields over degree-scale areas.

Field	RA	Dec	Multi-wavelength datasets
XMM-LSS	02 25 00	-04 30 00	SuprimeCam, CFHT-deep, CFHT-wide, PanSTARRS, UKIDSS, VIDEO, SERVS, SWIRE, HerMES, SCUBA2, Galex, GMRT, VLA
COSMOS	10 00 00	+02 12 00	HST/ACS, CFHT, SuprimeCam, PanSTARRS, Ultra-VISTA, Spitzer, HerMES, SCUBA-2, Galex, XMM, Chandra, zCOSMOS, VLA, GMRT
Lockman Hole	10 47 00	+58 05 00	PanSTARRS, UKIDSS, SERVS, SWIRE, HerMES, VLA, GMRT, WSRT, X-ray, SCUBA, SCUBA-2, Galex
Groth Strip	14 17 00	+52 30 00	PanSTARRS, CFHTLS, DEEP2 spectra, Galex, XMM, Chandra, GMRT
XMM/Chand 13h	13 35 00	+37 55 00	SuprimeCam, XMM, Chandra
Boötes	14 32 00	+34 30 00	NOAO NDWFS, Spitzer, HerMES, Chandra, GMRT
Elais N1	16 11 00	+54 57 00	PanSTARRS, UKIDSS, SERVS, SWIRE, HerMES, GMRT, Galex
NEP	18 00 00	+66 33 00	CFHT, Subaru, Deep Akari
SA22	22 15 00	+00 17 00	PanSTARRS, UKIDSS, Galex, VVDS spectra
Herschel-ATLAS (*8)	13 20 00	29 00 00	Herschel, SDSS, UKIDSS
HETDEX (*8)	11 to 15hrs	+58 00 00	HETDEX spectroscopy, SDSS, UKIDSS

# The Lockman Hole

- Extensive multiwavelength data:
  - PanSTARRS, UKIDSS, SERVS, SWIRE, HerMES, VLA, GMRT, WSRT, Chandra, SCUBA, SCUBA-2, Galex
- Multiwavelength radio data covering a wide range in frequency:
  - WSRT: 1.4 GHz, 7 deg<sup>2</sup>, 11  $\mu$ Jy
  - WSRT: 350 MHz, 0.7 mJy
  - GMRT: 610 MHz, 5 deg<sup>2</sup>, 60  $\mu$ Jy
  - VLA: 1.4 GHz, 1 deg<sup>2</sup>, 6  $\mu$ Jy
  - 10C: 15 GHz, 4.5 deg<sup>2</sup>, 0.1 mJy



Whittam et al., 2013

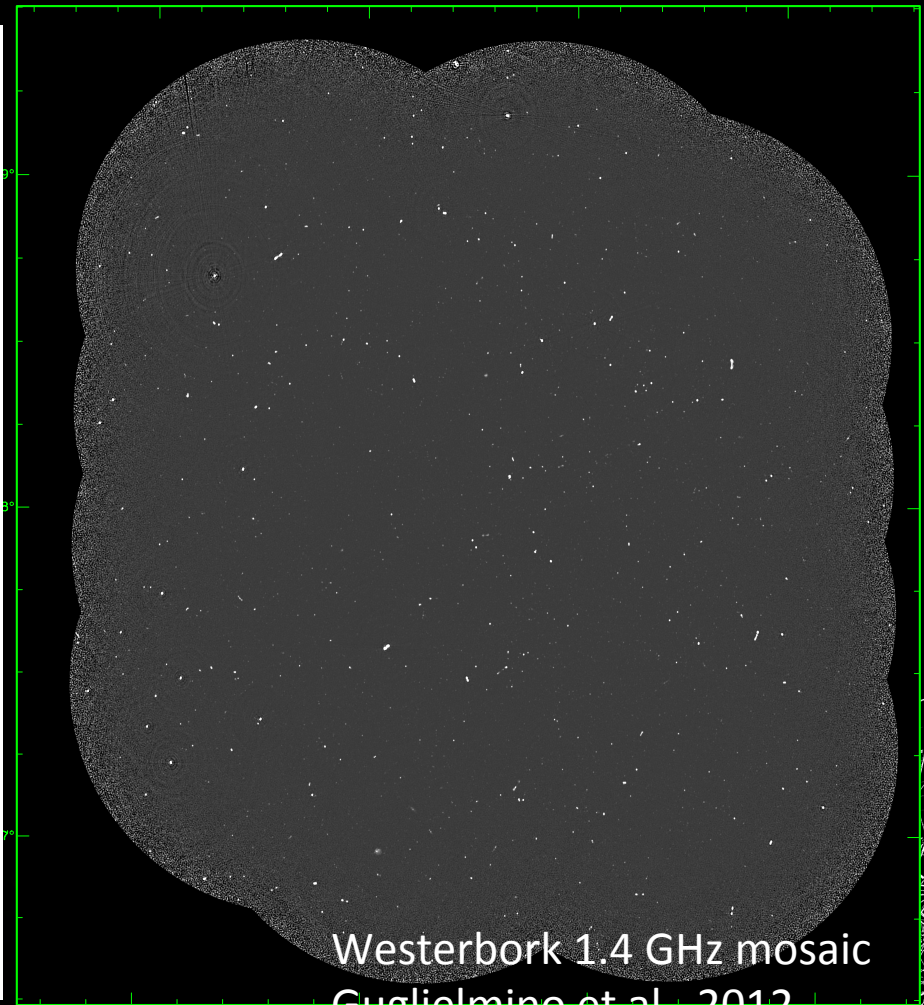
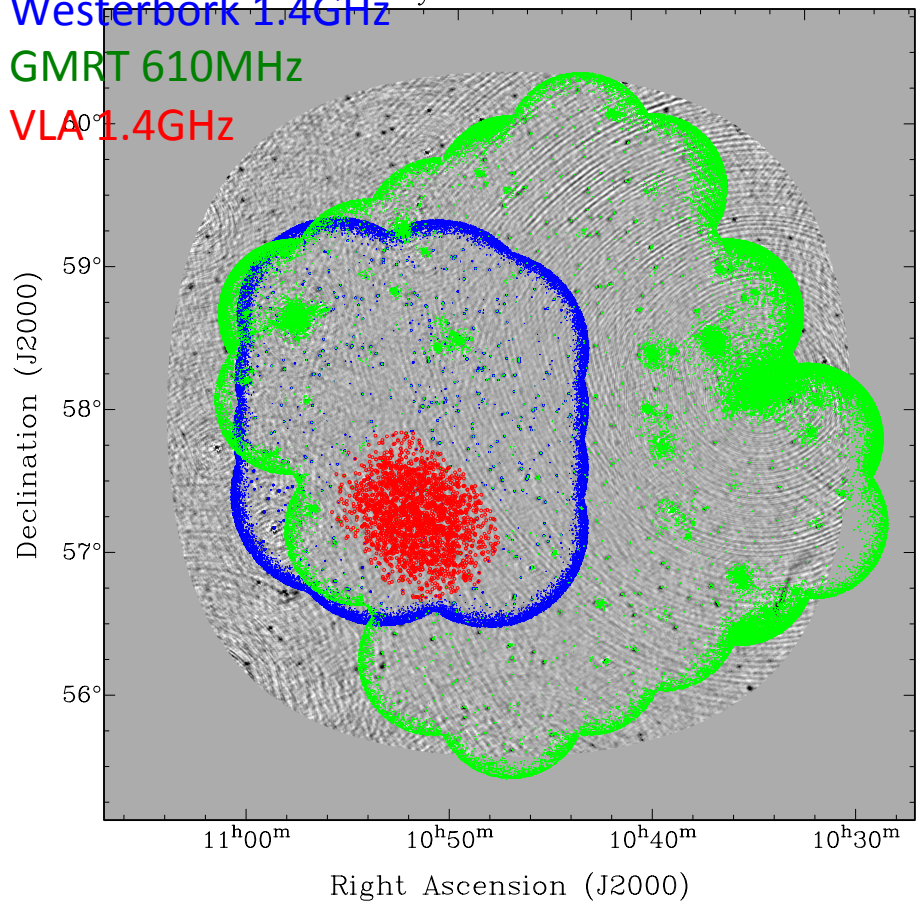
# The Lockman Hole

Radio Surveys of the Lockman Hole

Westerbork 1.4GHz

GMRT 610MHz

VLA 1.4GHz



Westerbork 1.4 GHz mosaic  
Guglielmino et al. 2012

# LOFAR Observations

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- Cycle 0: 10 hrs HBA + 10 hrs LBA
- HBA:
  - Calibrator: 122 subbands (4C59.16)
  - Lockman Hole: 366 subbands
  - 3C196 + 3C295 observed for 10 mins at beginning and end
- Data reduction:
  - Preprocessing (RFI flagging/averaging – 5sec, 1 channel per SB)
  - Solve for amplitude solns on primary calibrator (3C295)
  - Transfer solutions to Lockman Hole
  - Combine SBs into groups of 10
  - Solve for phase-only solutions on Lockman Hole field
  - Image



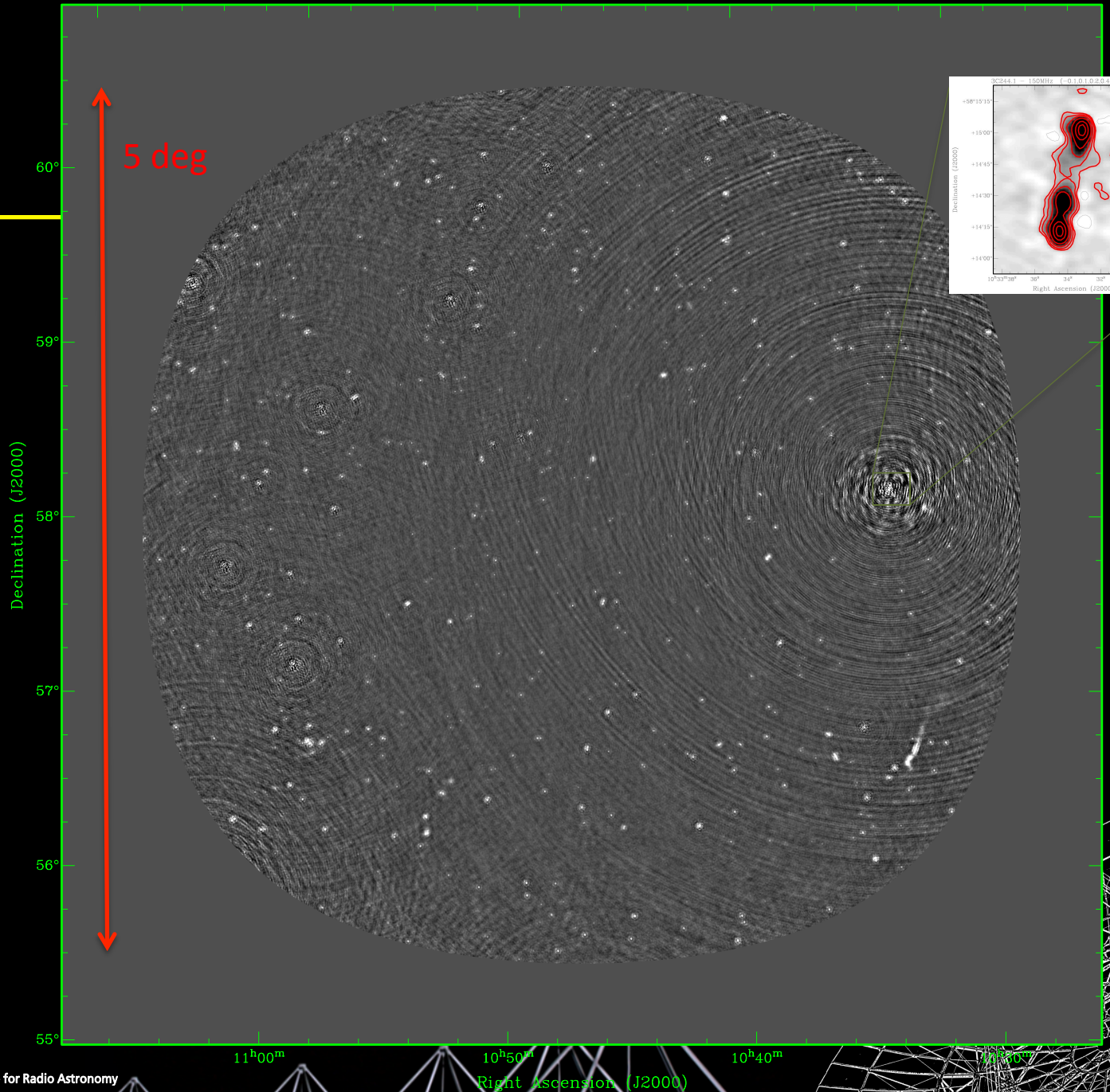
10 subbands

150 MHz

Resolution:

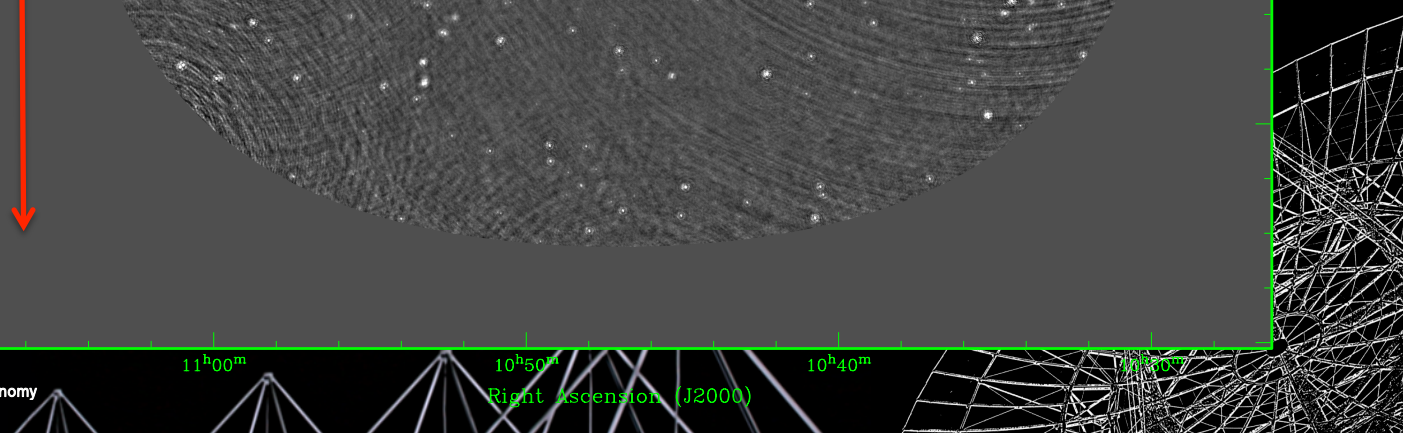
15x9 arcsec

Noise: 2mJy/  
bm



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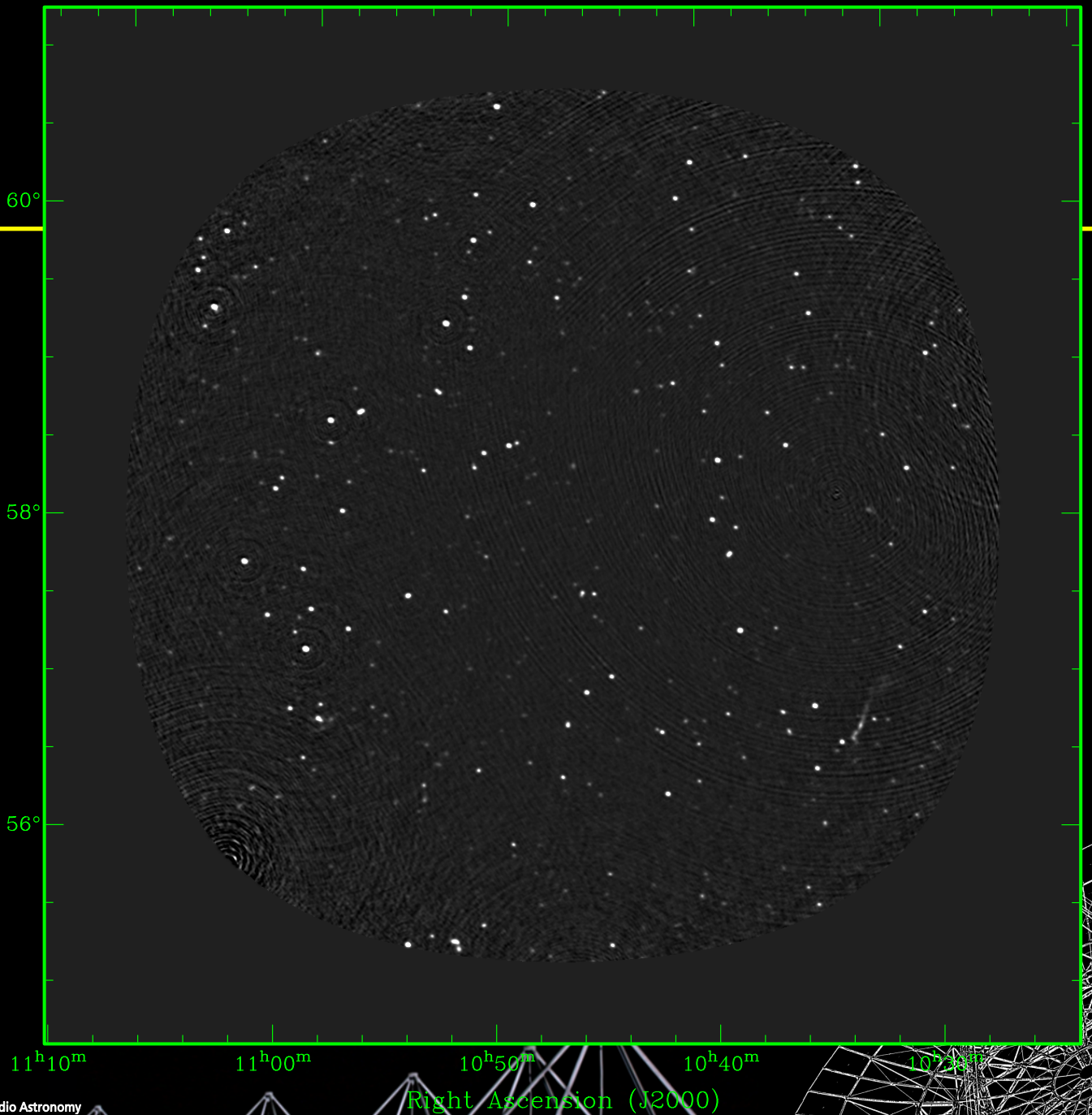
10 subbands  
150 MHz

Peeled 3C244.1

Resolution:  
~70 arcsec

Noise: ~8 mJy/  
bm

Declination (J2000)



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Right Ascension (J2000)

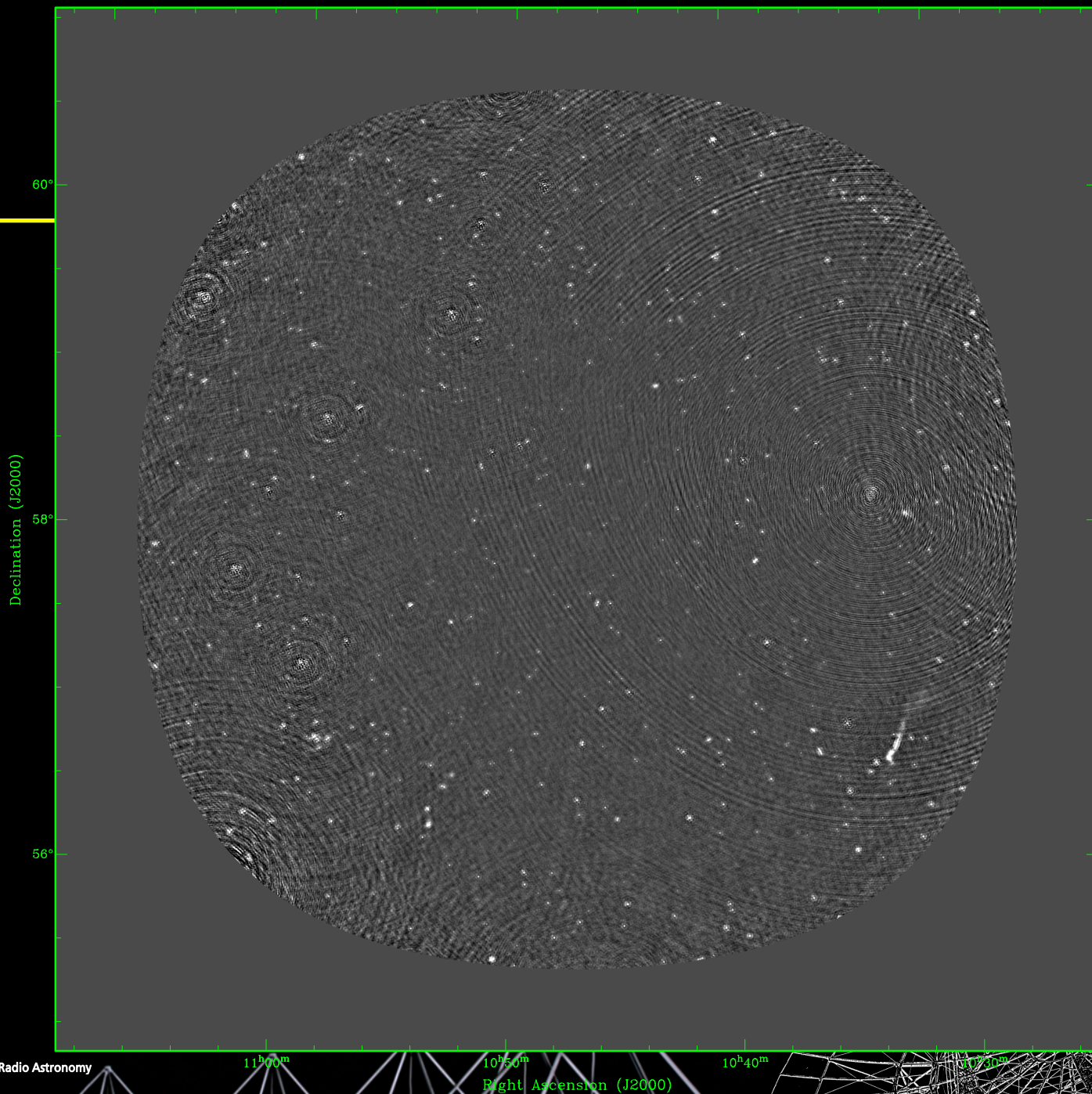
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10 subbands  
150 MHz

Peeled 3C244.1

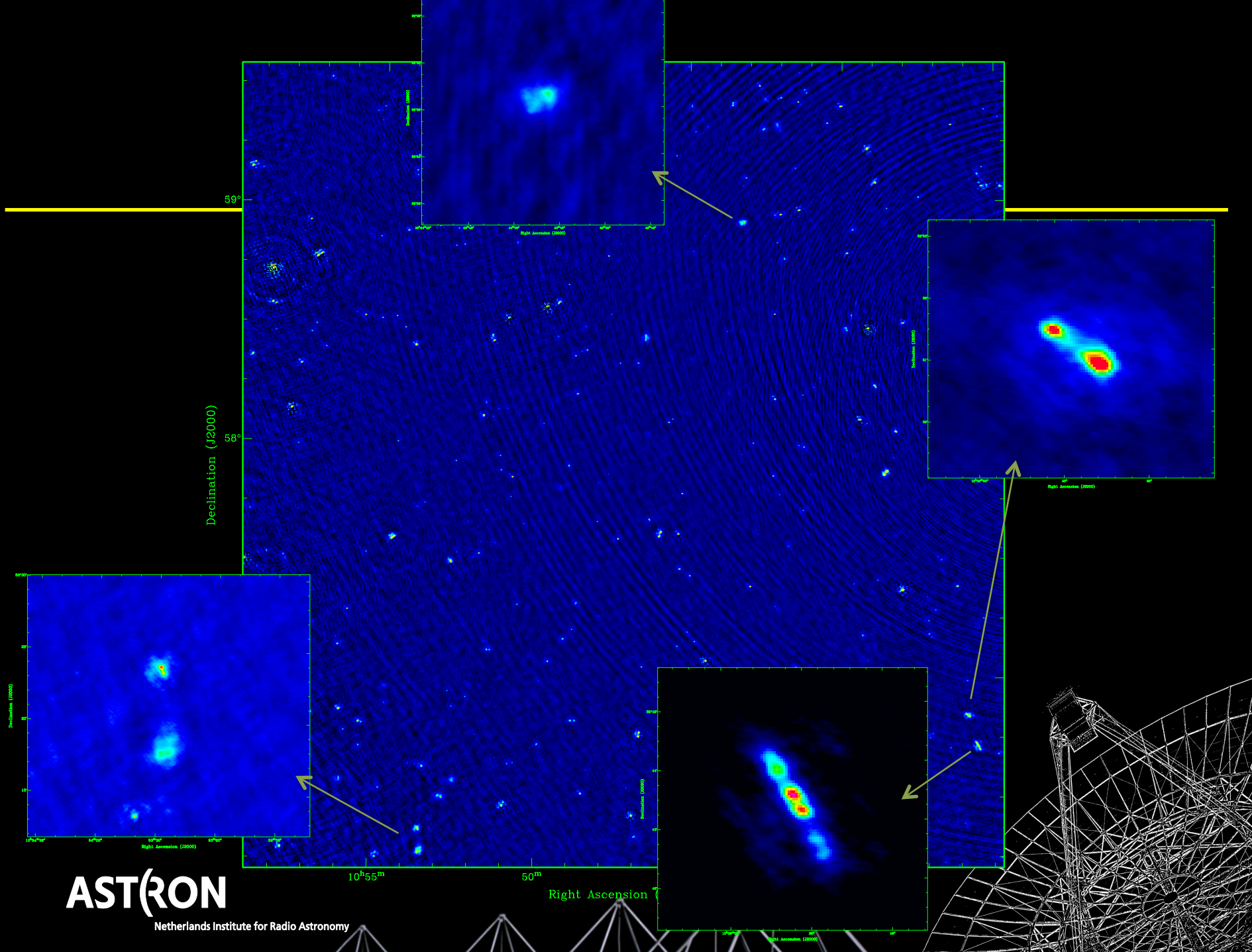
Resolution:  
15x9 arcsec

Noise: 1.5 mJy/  
bm



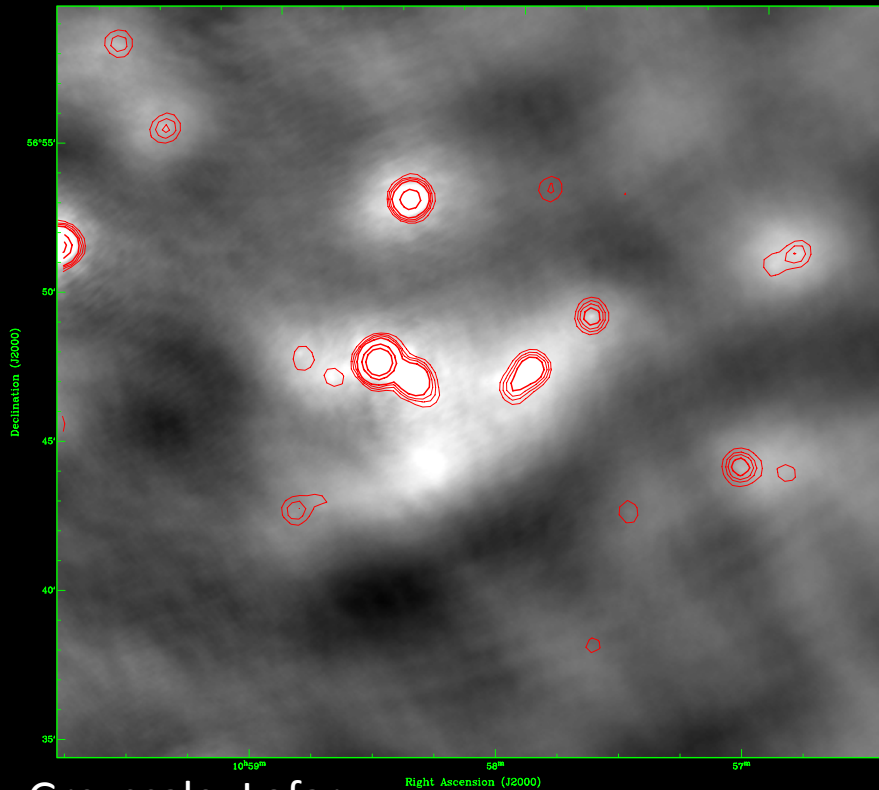
**ASTRON**

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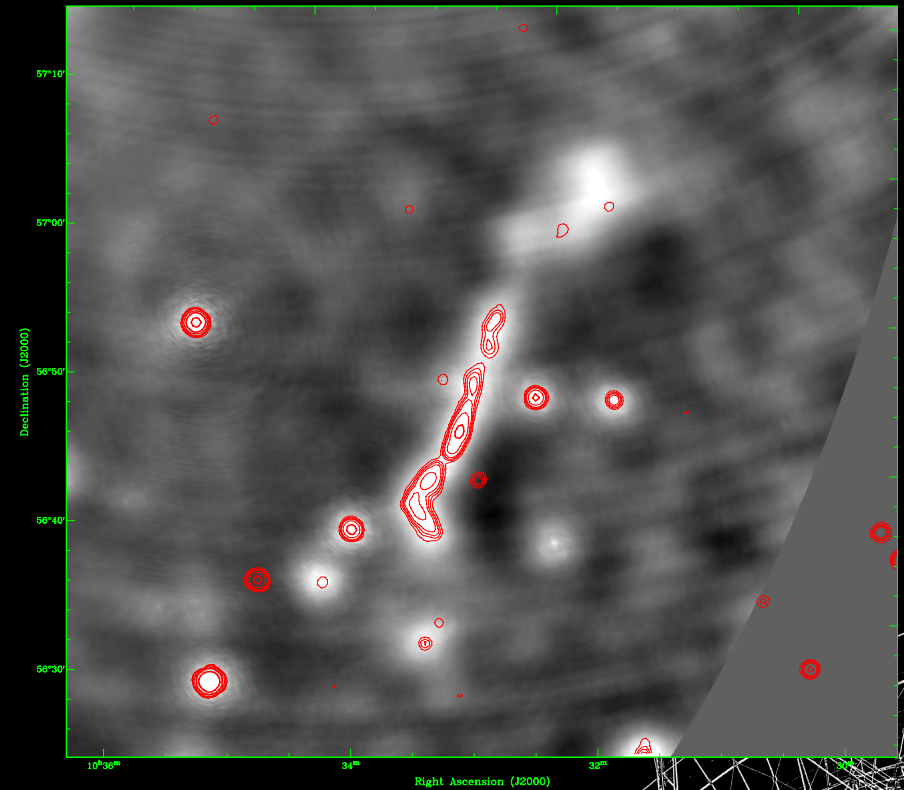


# A couple of interesting sources....

Abell 1132



1029+570

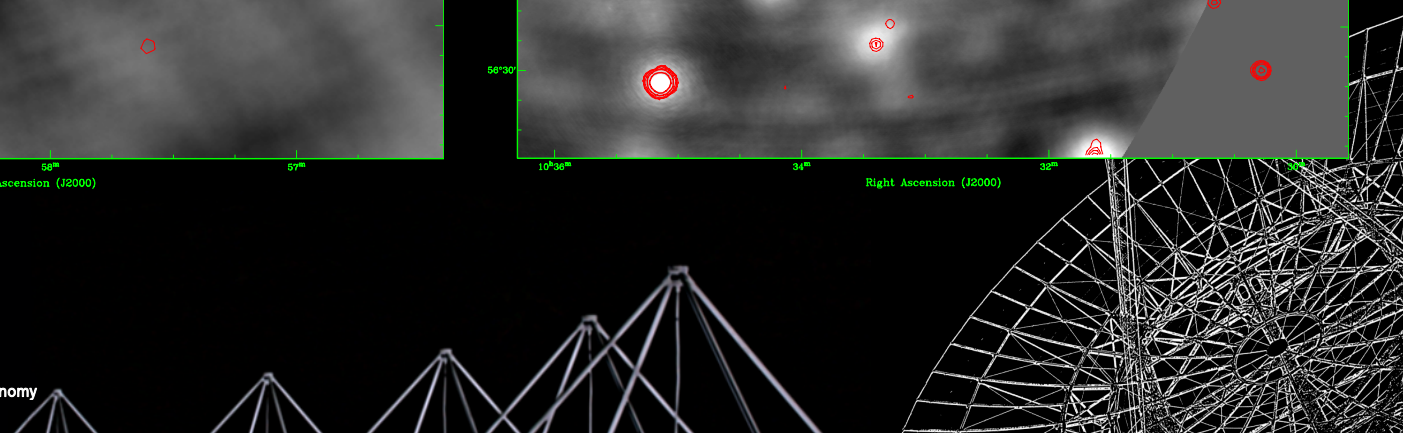


Greyscale: Lofar

Contours: NVSS

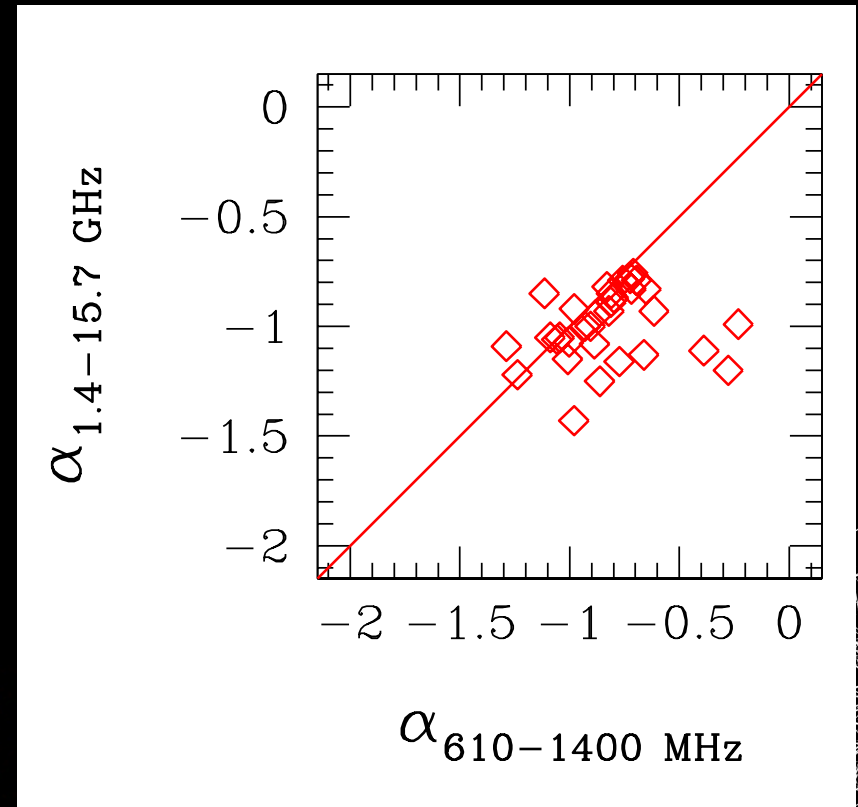
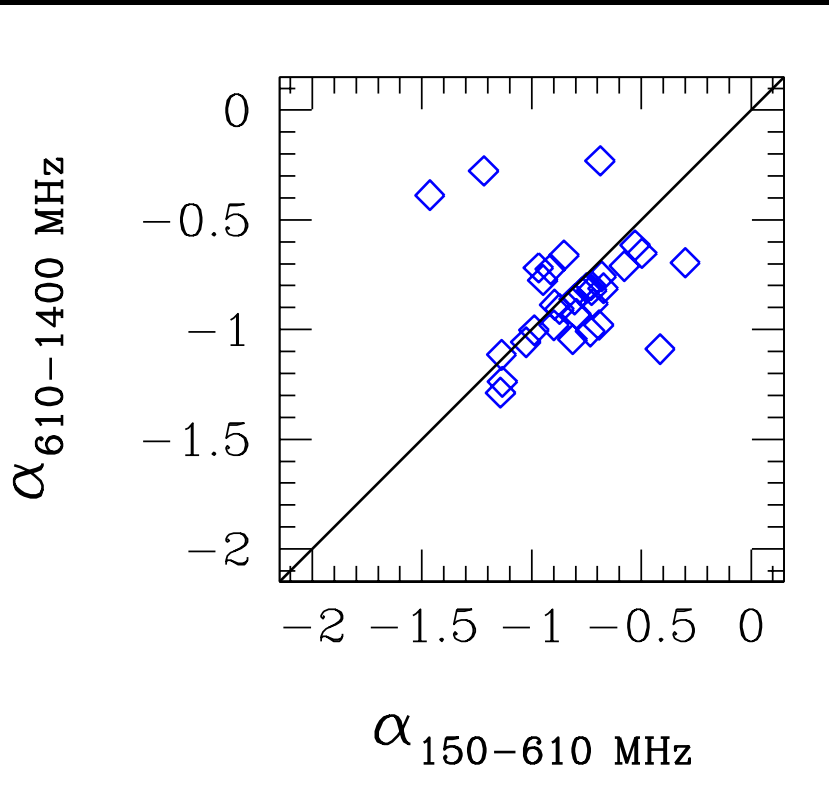
**ASTRON**

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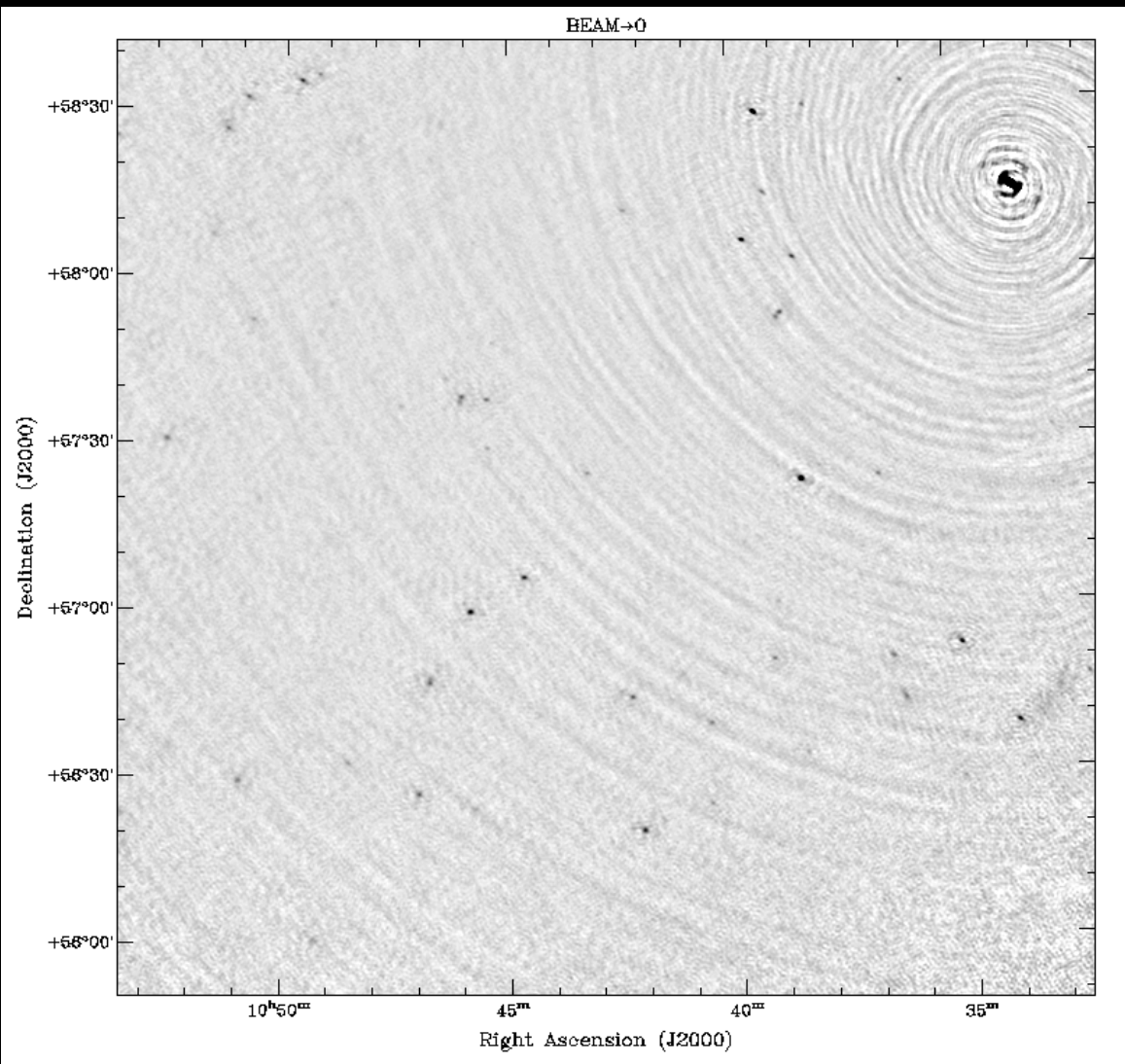


# Spectral indices

- Spectral flattening towards lower frequencies??



# LBA data

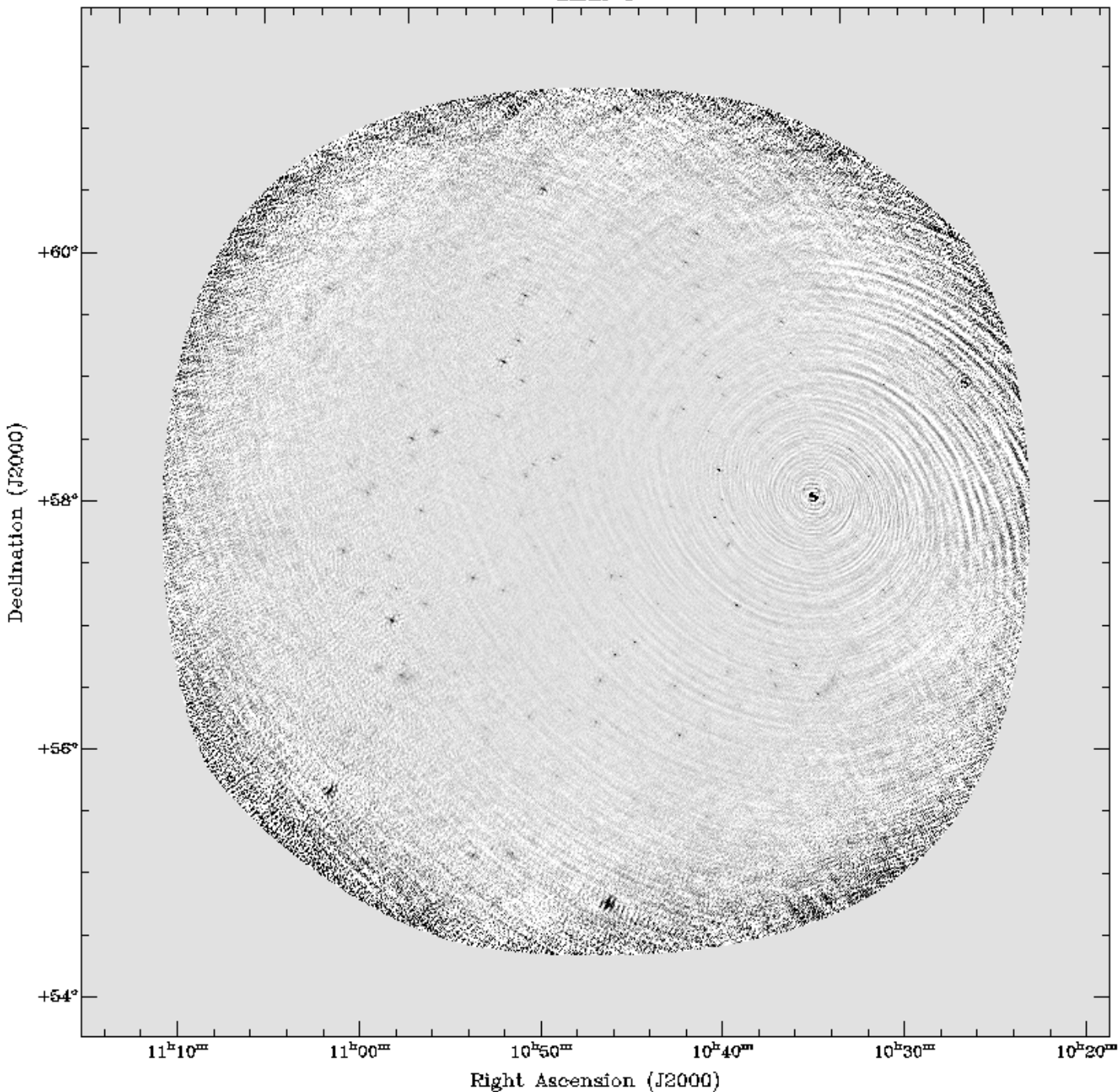


## Lockman Hole LBA

- 4 hour run
- 60MHz frequency
- 2MHz bandwidth (10 SBs)
- 40 channels
- Amplitude from 3C196
- Skymodel from HBA
- $uv < 5 \lambda$
- beam  $\sim 30$  arcsec
- $\sim 3 \times 3$  degrees zoom

Slide courtesy of J. van Bemmelen

BEAM→0

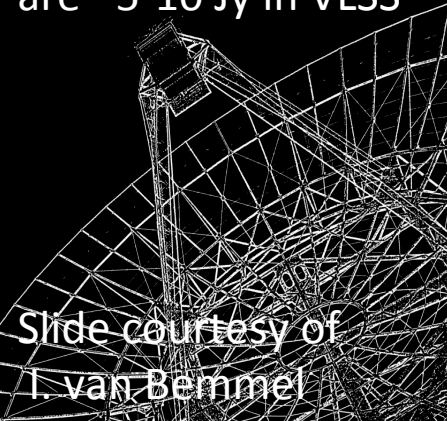


Entire field of view  
Beam  $\sim 30$  arcsec  
Cleaning artifacts  
(plus-shaped sources)

$\sim 120$  sources  
detected

rms  $\sim 15$  mJy/bm

The bright sources at  
the edge of the field  
are  $\sim 5$ - $10$  Jy in VLSS



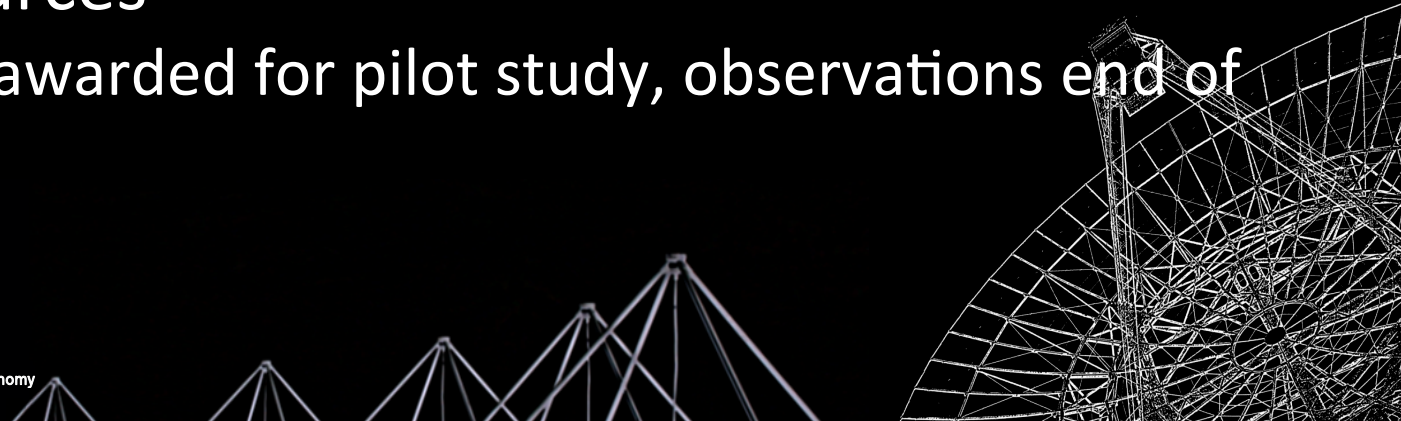
Slide courtesy of  
I. van Bemmel



# Next steps

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- Update skymodel
  - better peeling
- Reduce the other 350 subbands
- Cycle 1 observations – 6 nights observed in late March/early April
- WHT proposal – get optical spectroscopy of LOFAR sources
  - 3 nights awarded for pilot study, observations end of May





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