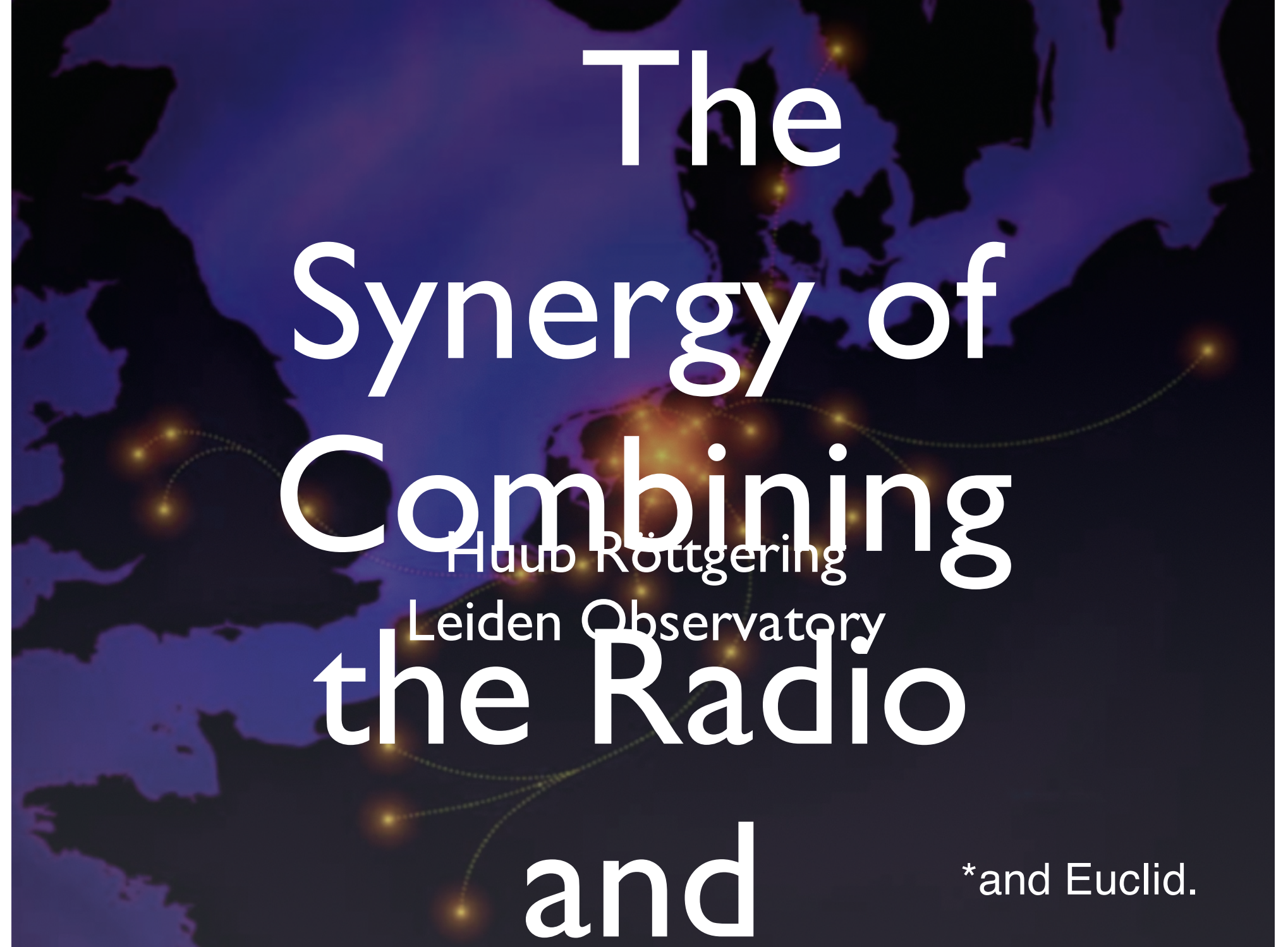



Huub Röttgering
Leiden Observatory

# Overview

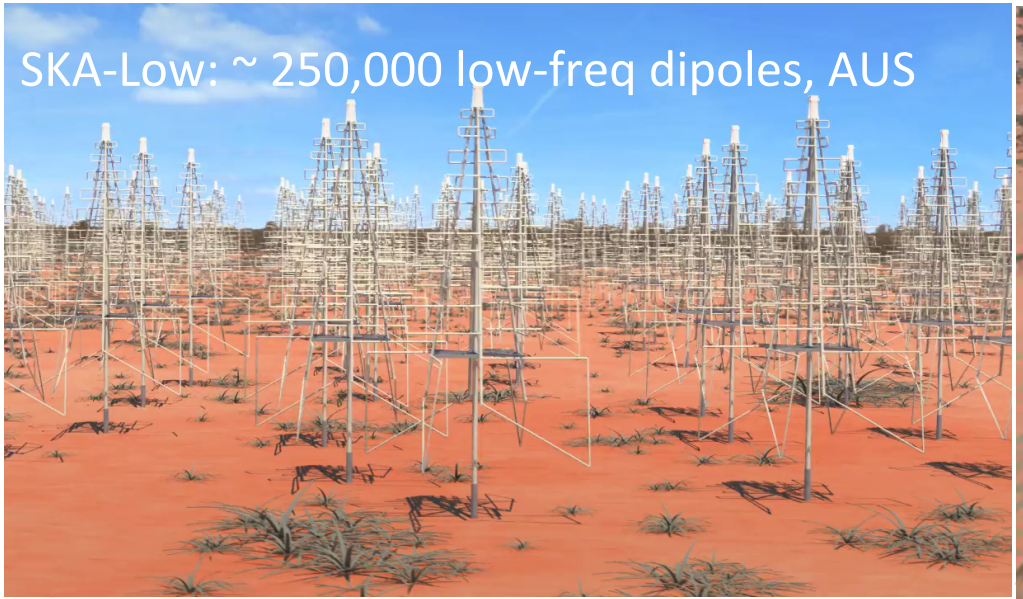
- Radio telescopes
  - LOFAR
- Radio surveys
- Cosmology
- Legacy science

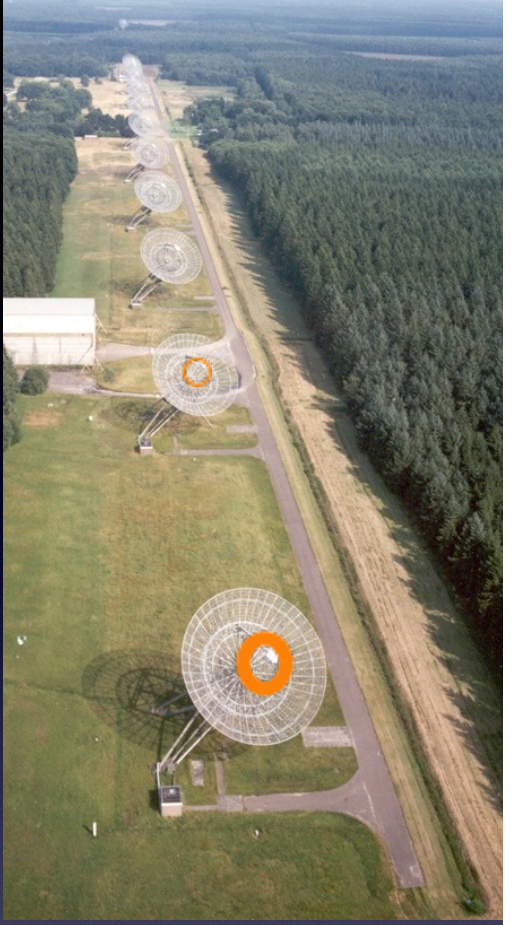
**Advancing Astrophysics with the Square Kilometre Array**
8 – 13 June, 2014, Giardini Naxos, Italy

# SKA Phase 1

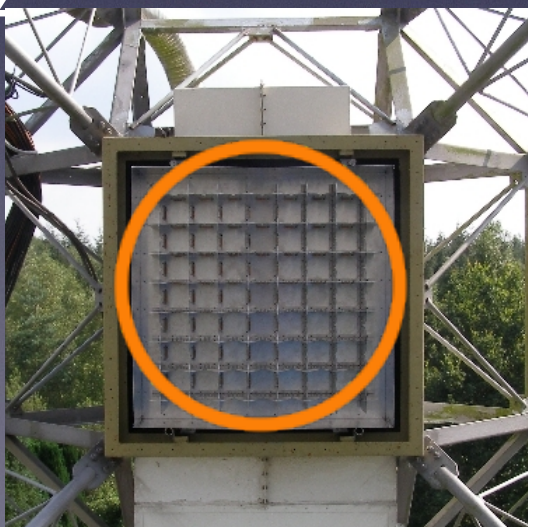
2 sites (South Africa, Australia);
3 telescopes; one Observatory
Frequency range SKA1: 50 MHz – 3 GHz

Cost-cap: €650M
Construction: 2017 – 2023
Early science: 2020
Phase 2 SKA: 2023 - 2030

- ASKAP: 36 x 12m x 36 pixels @ 1.4 GHz
- WSRT/APERTIF: 10 x 25m x 37 @ 1.4 GHz
- Meerkat: 64 x13m x 1 pixel @ 0.6-15 GHz

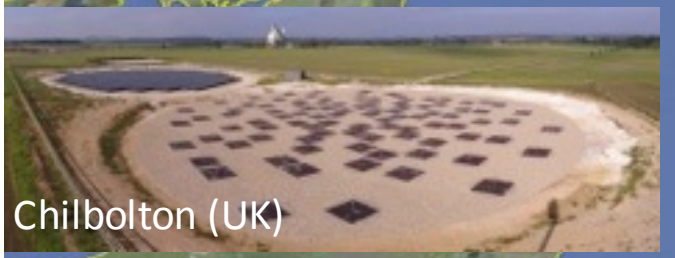



LOFAR
10-80 MHz
120-240 MHz


36 LOFAR stations
baselines 100 km

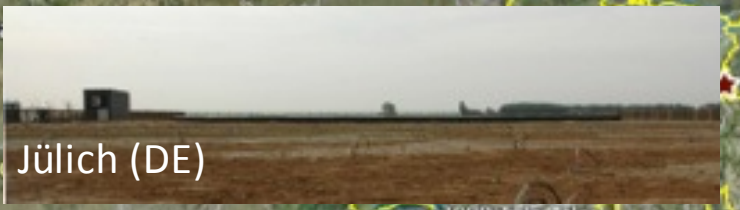
# LOFAR Stations Across Europe + three polish stations coming!





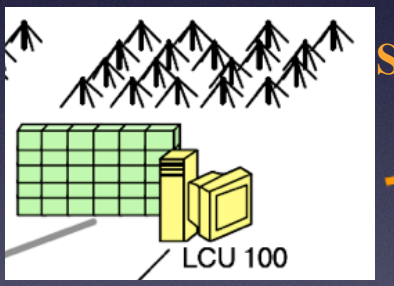




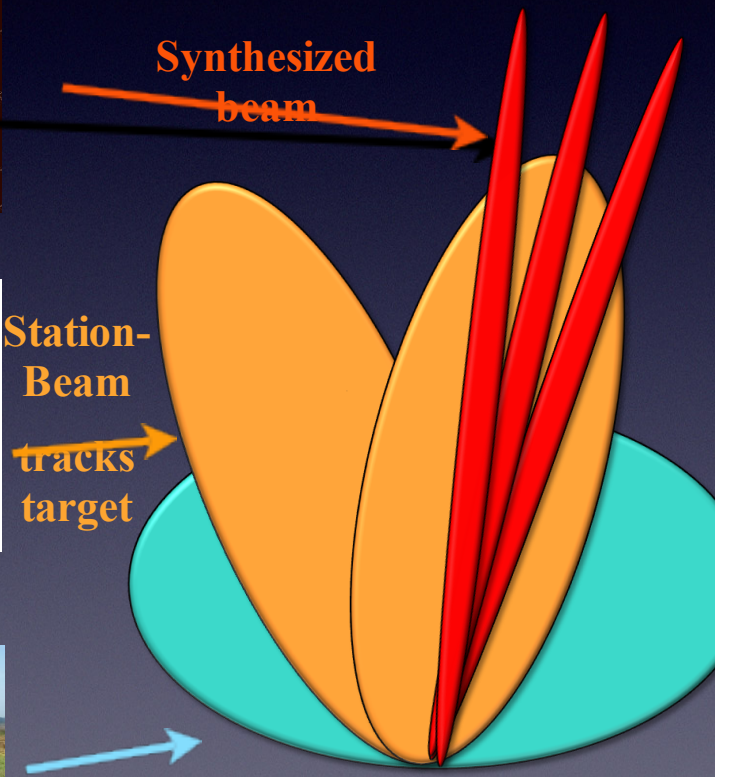



# Challenges

- Data rates of up to a Tb/s
- Radio interference
- Removal of strong sources: Cygnus A, Tau A, ….
- Timing of the stations clocks
- Ionosphere
  - ``seeing'

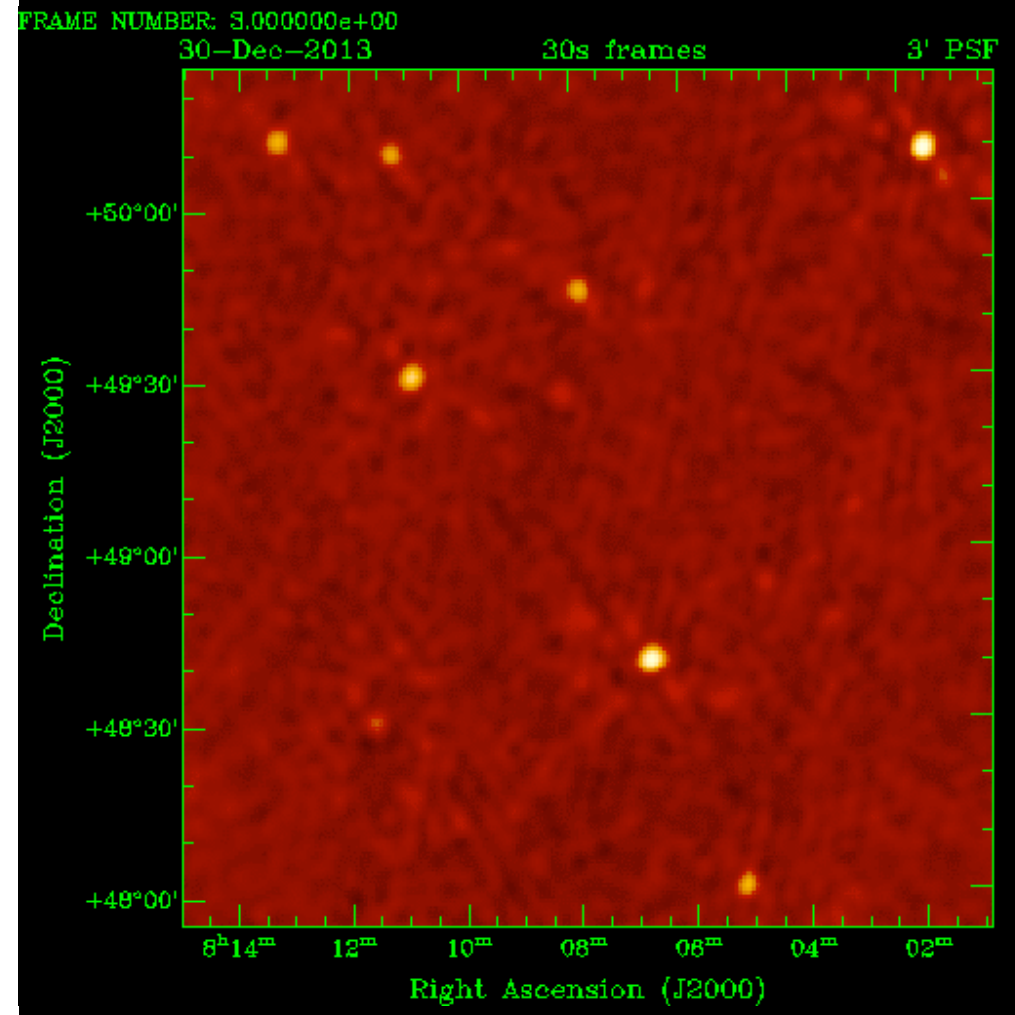


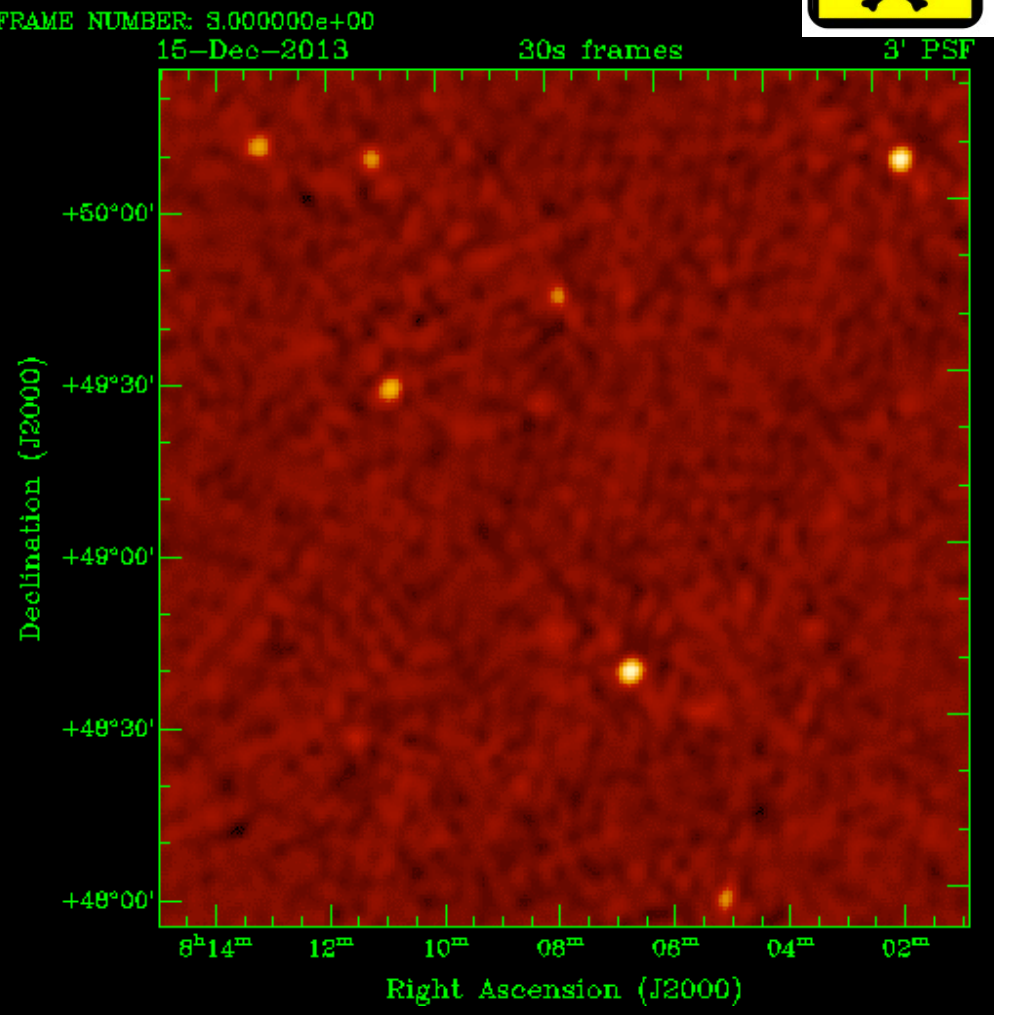

## Three Beams



quiet ionosphere

wild ionosphere

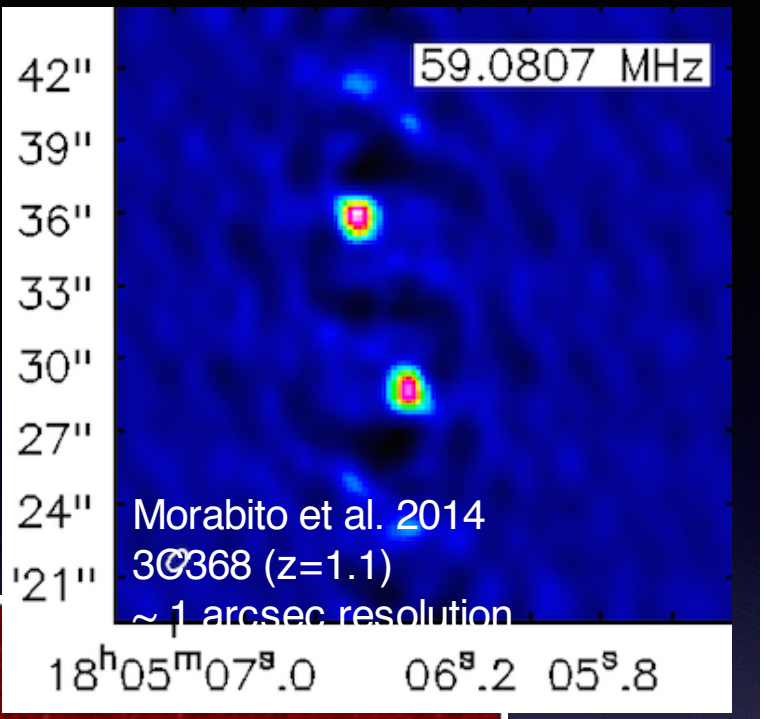


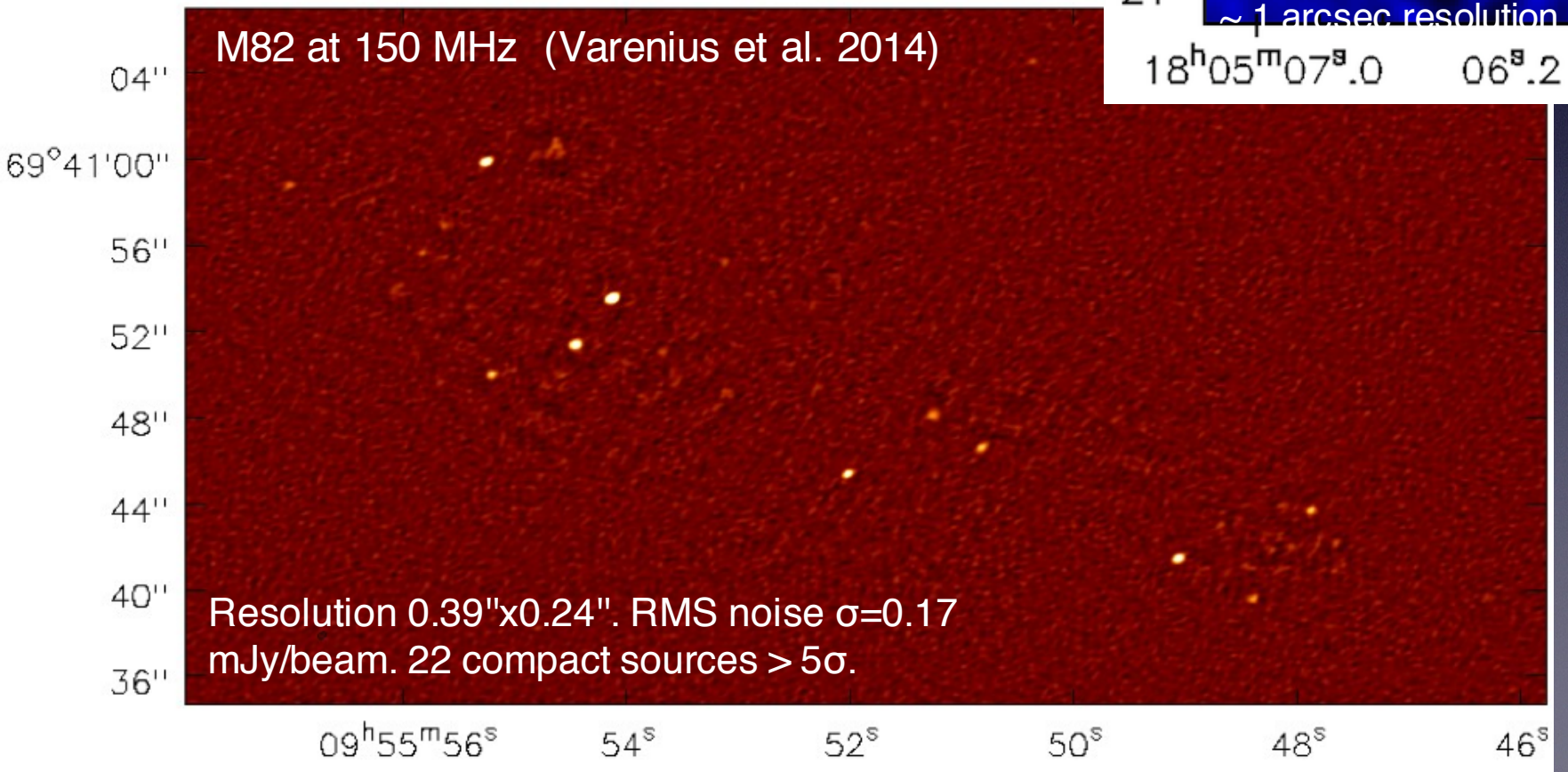




Note: these images have only 3 arcmin resolution, the NL array has 5 acres resolution…

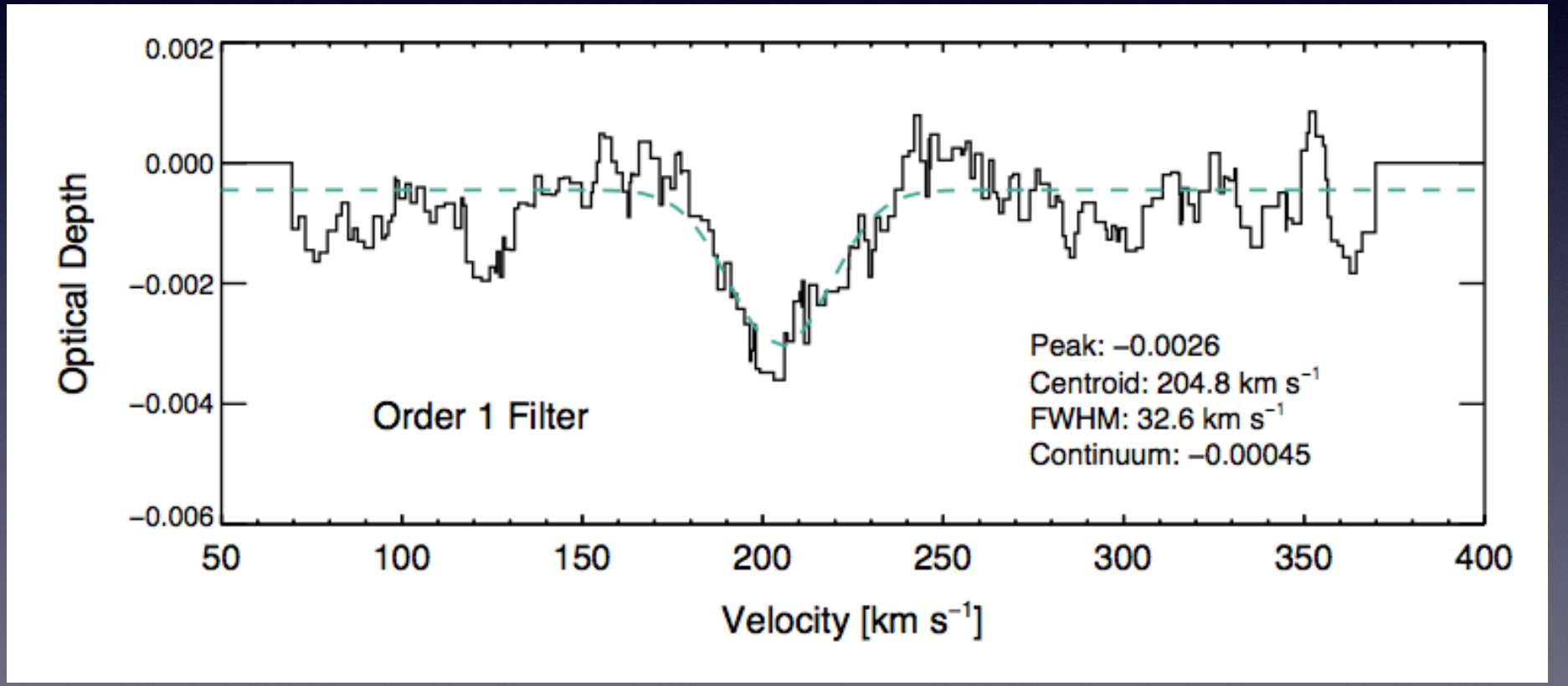
Ger de Bruyn & LOFAR EoR team

# European baselines



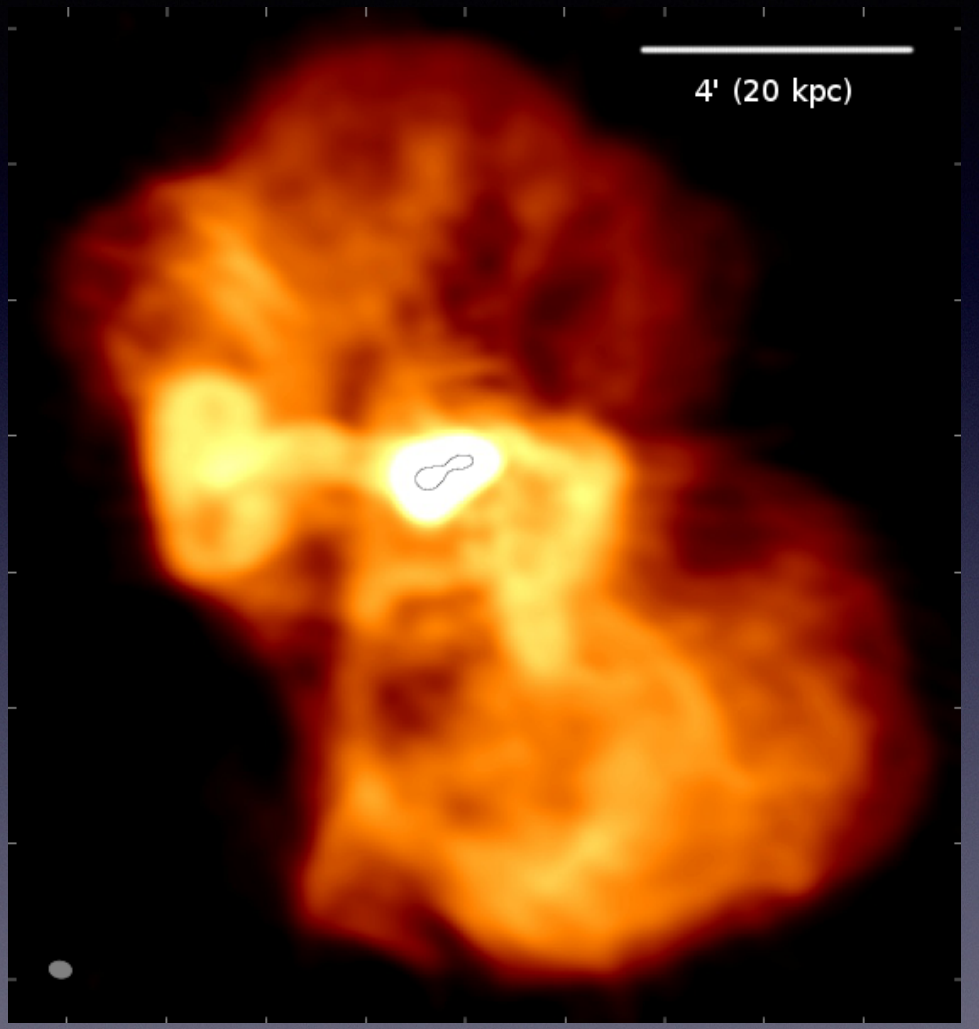



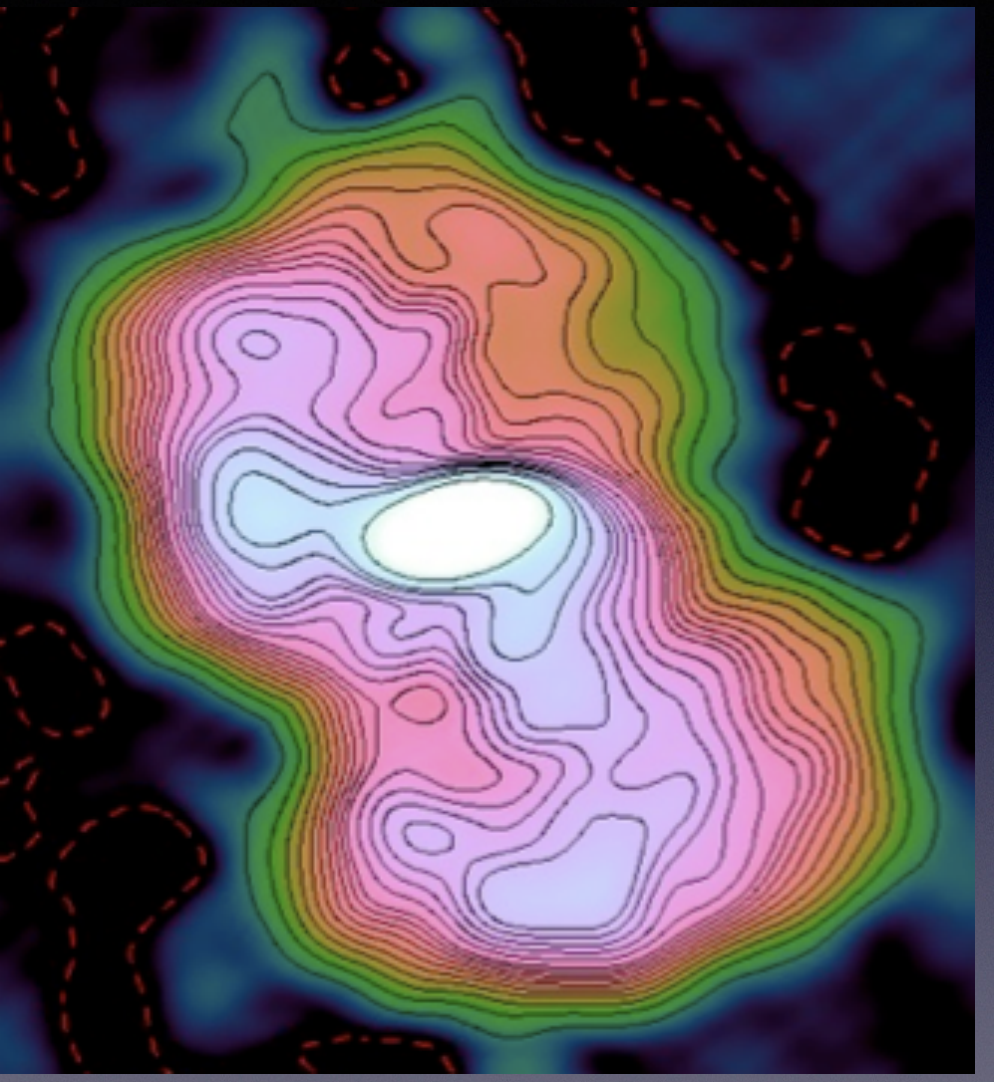
# M82:
# First detection
# Carbon radio recombination




Morabito et al

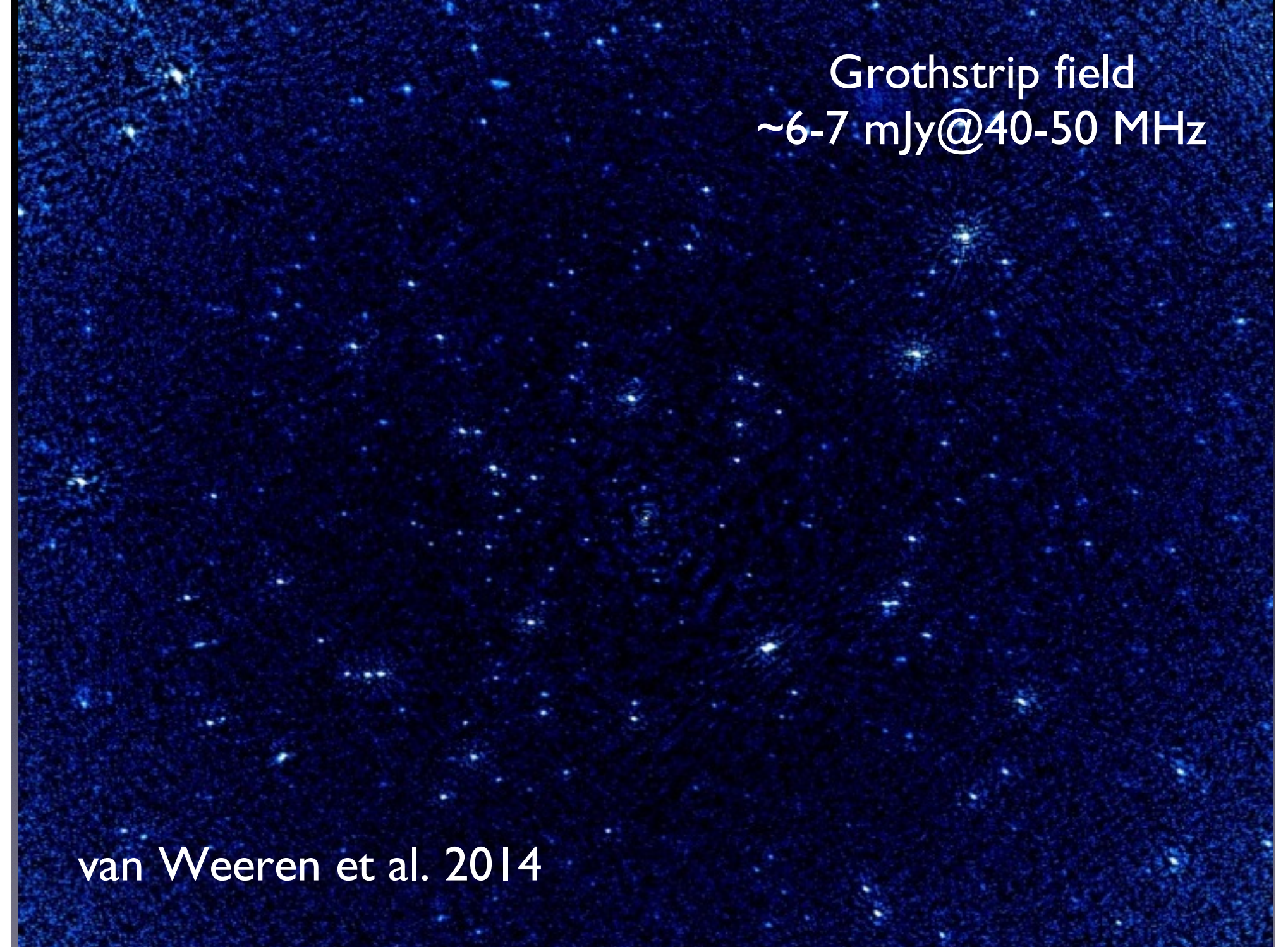
# M87 - de Gasparin

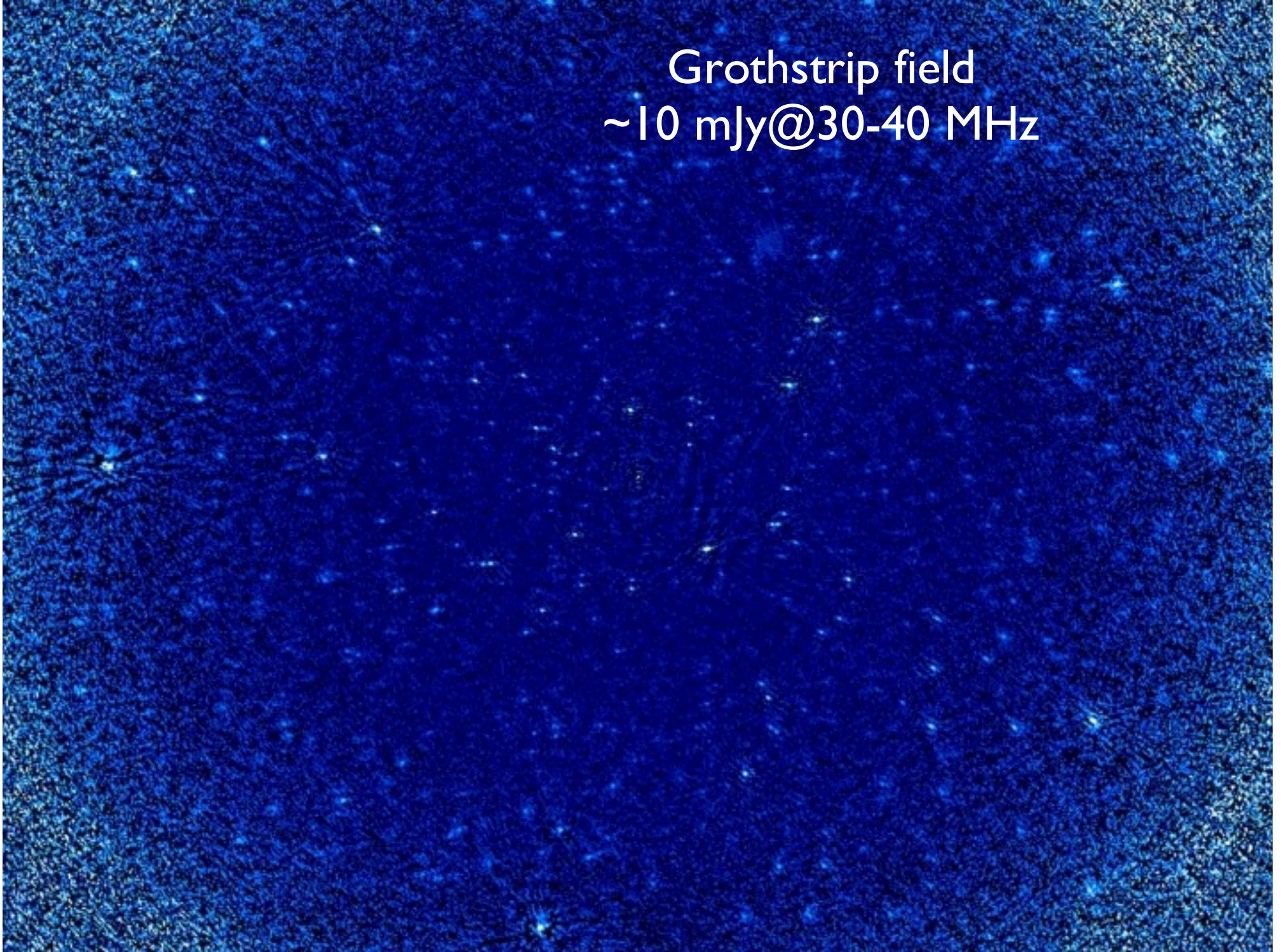


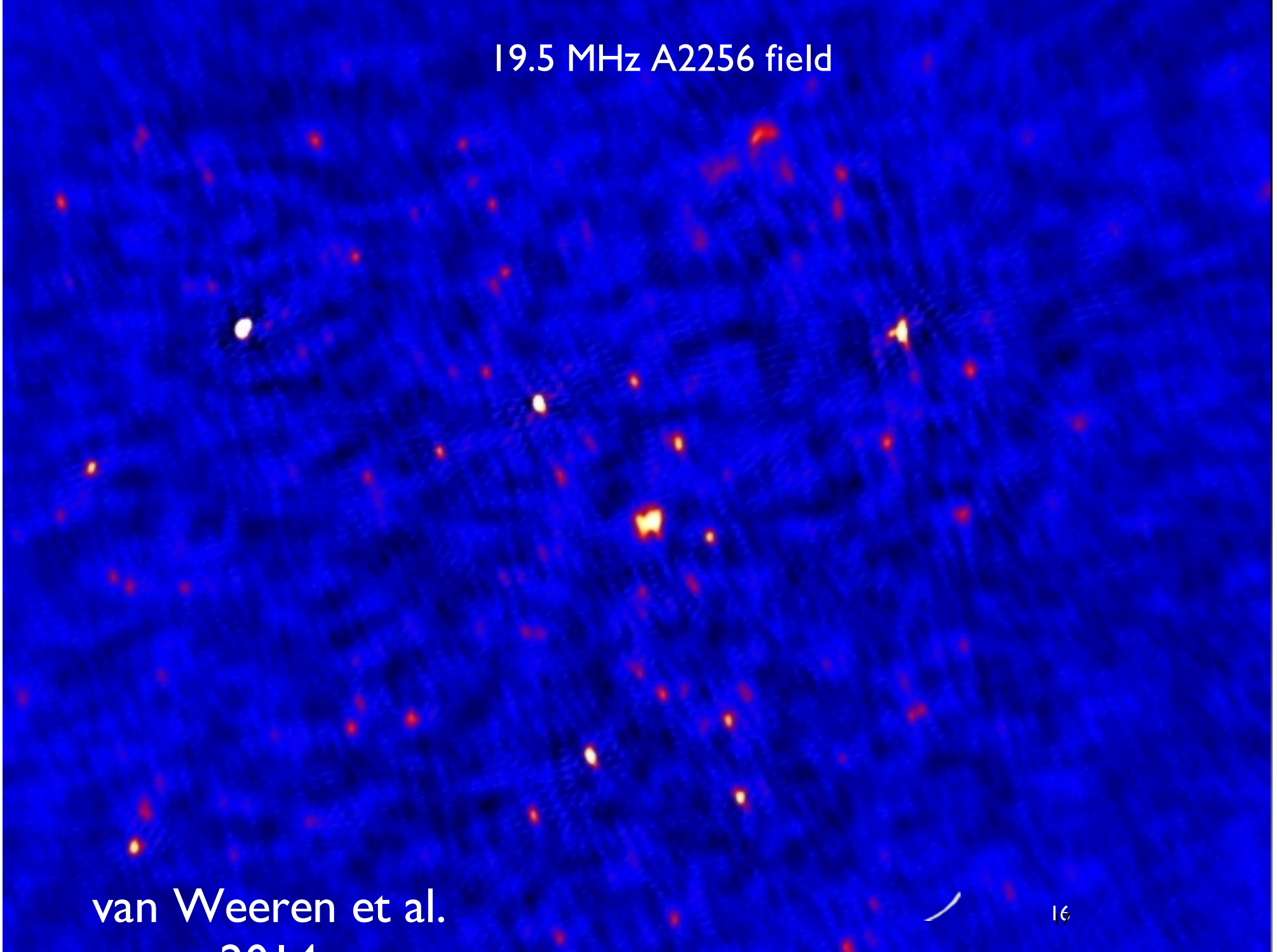



140 MHz, rms 6 mJy/19”x14”

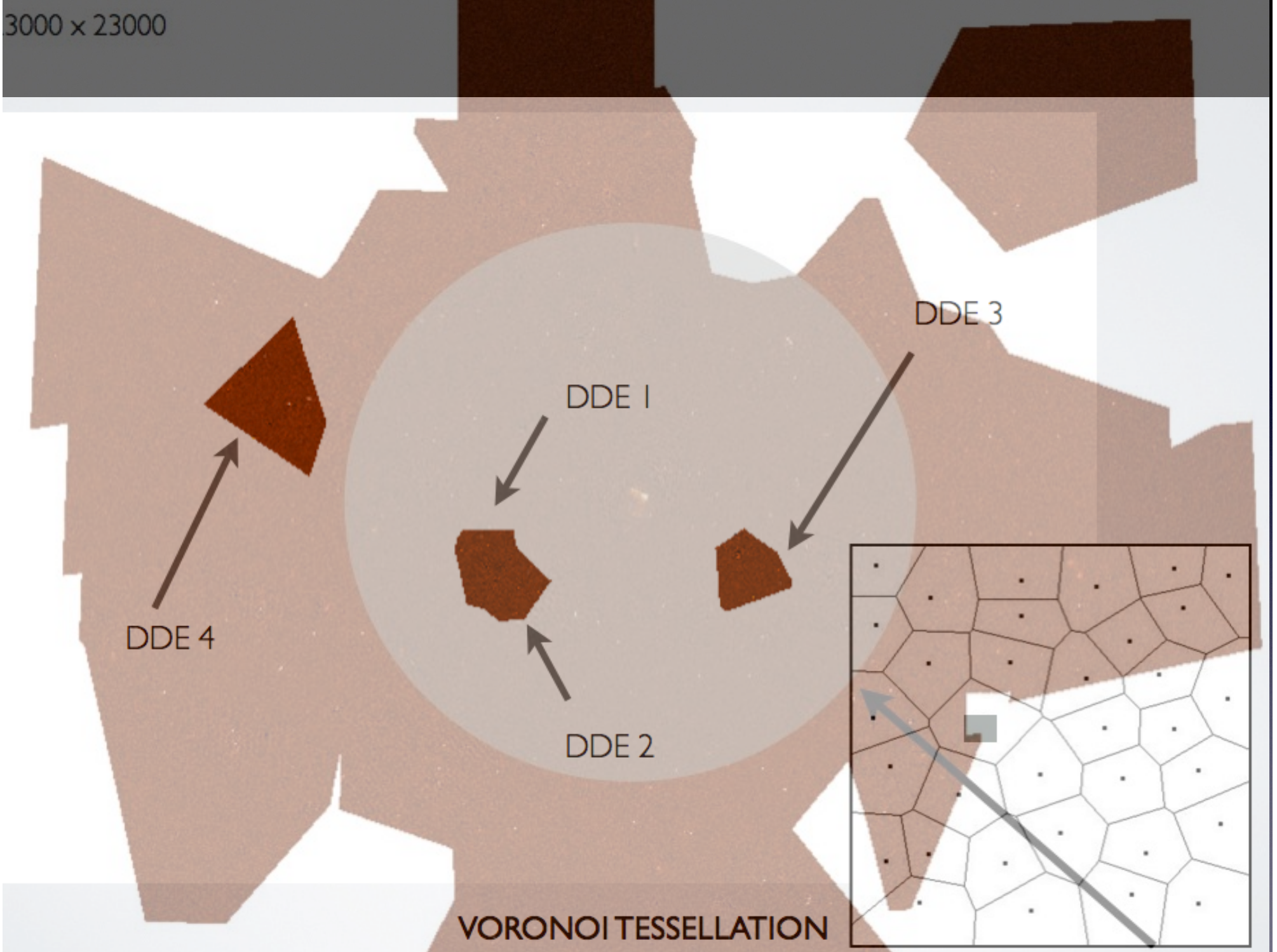
25 MHz, rms 0.6 Jy/85” x 44”

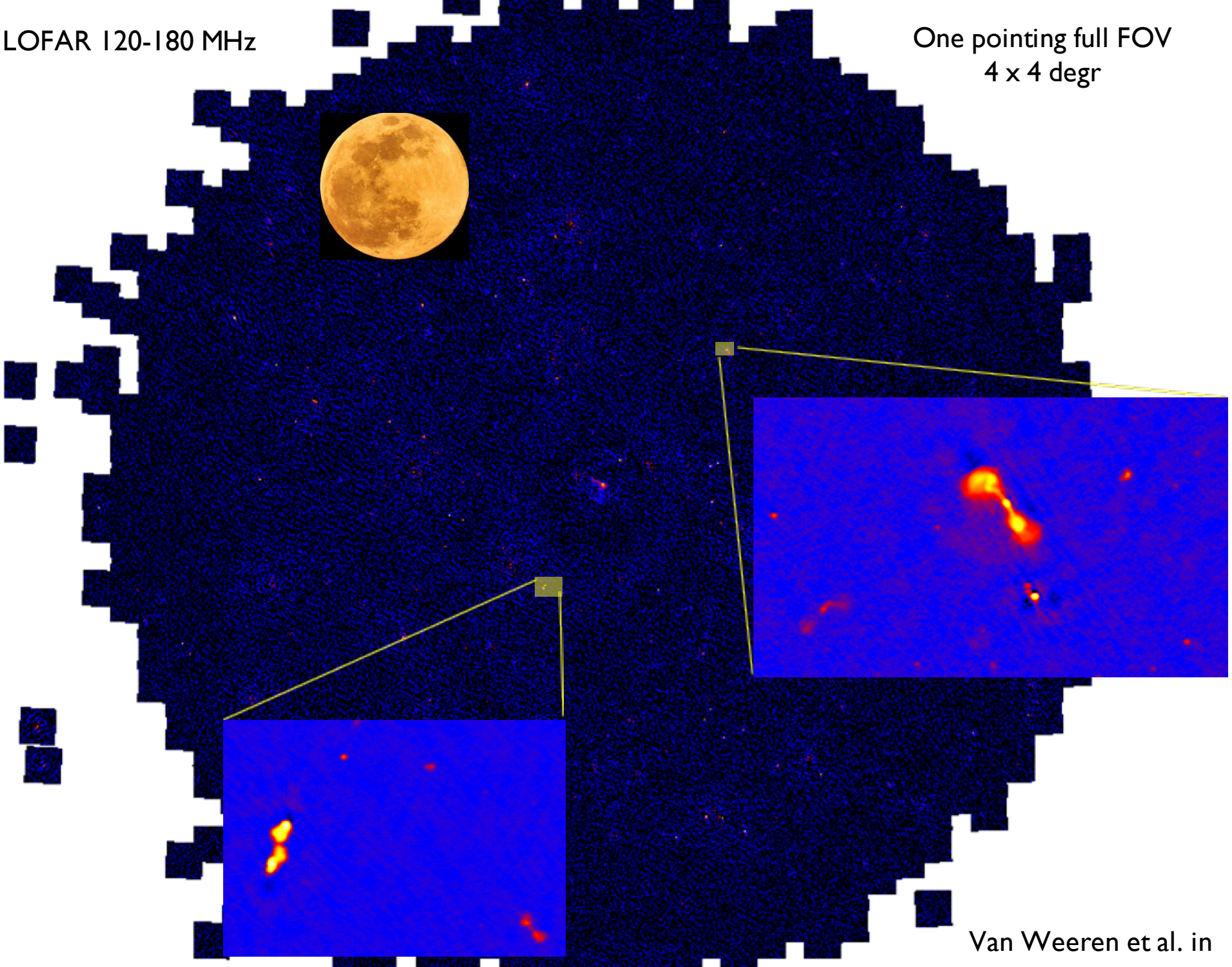

Grothstrip field
~6-7 mJy@40-50 MHz
van Weeren et al. 2014


Grothstrip field
~10 mJy@30-40 MHz




van Weeren et al.
2014


3000 x 23000
DDE 3
DDE 1
DDE 4
DDE 2
VORONOI TESSELLATION

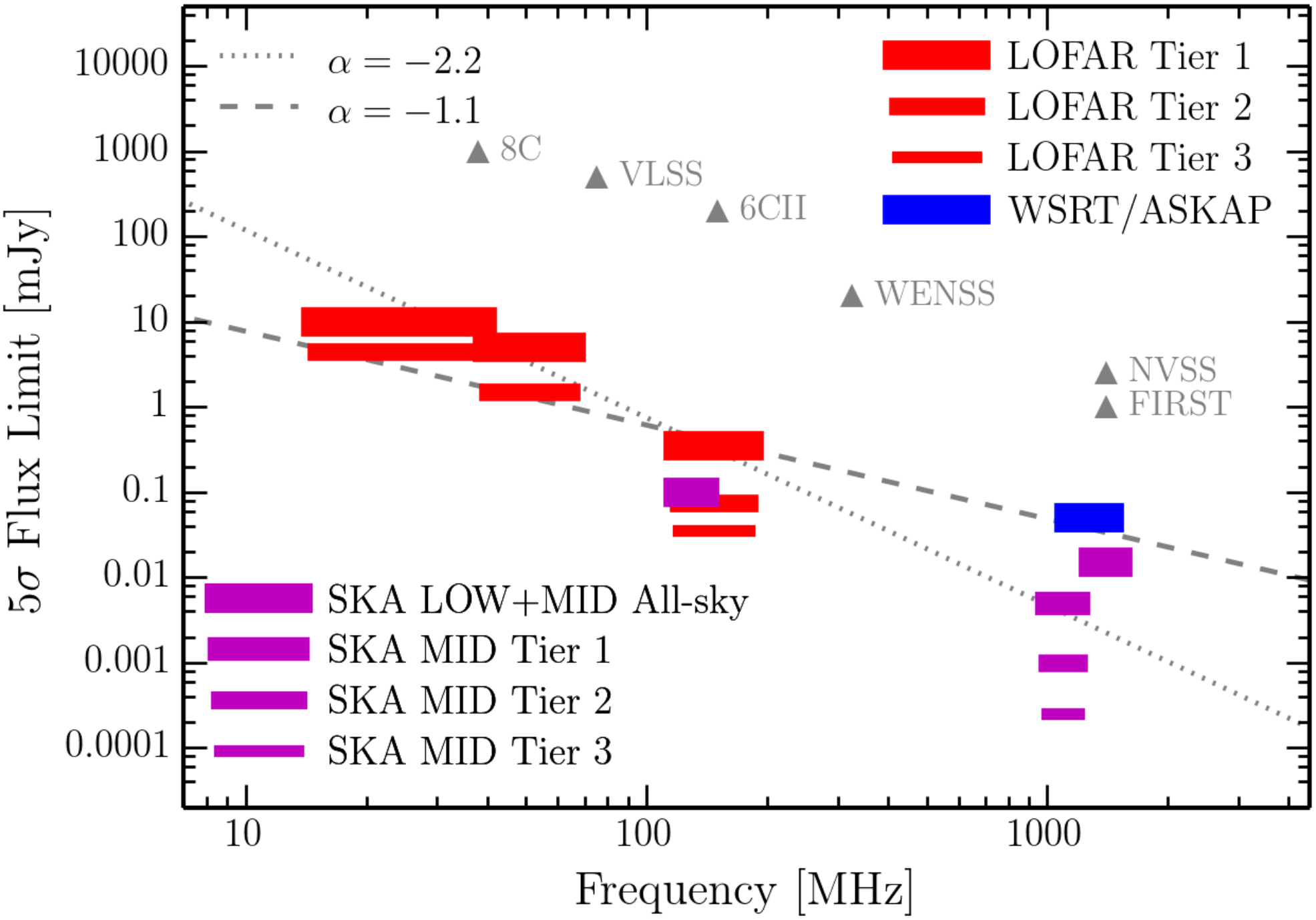

LOFAR 120-180 MHz
One pointing full FOV
4 x 4 degr
Van Weeren et al. in

# Overview

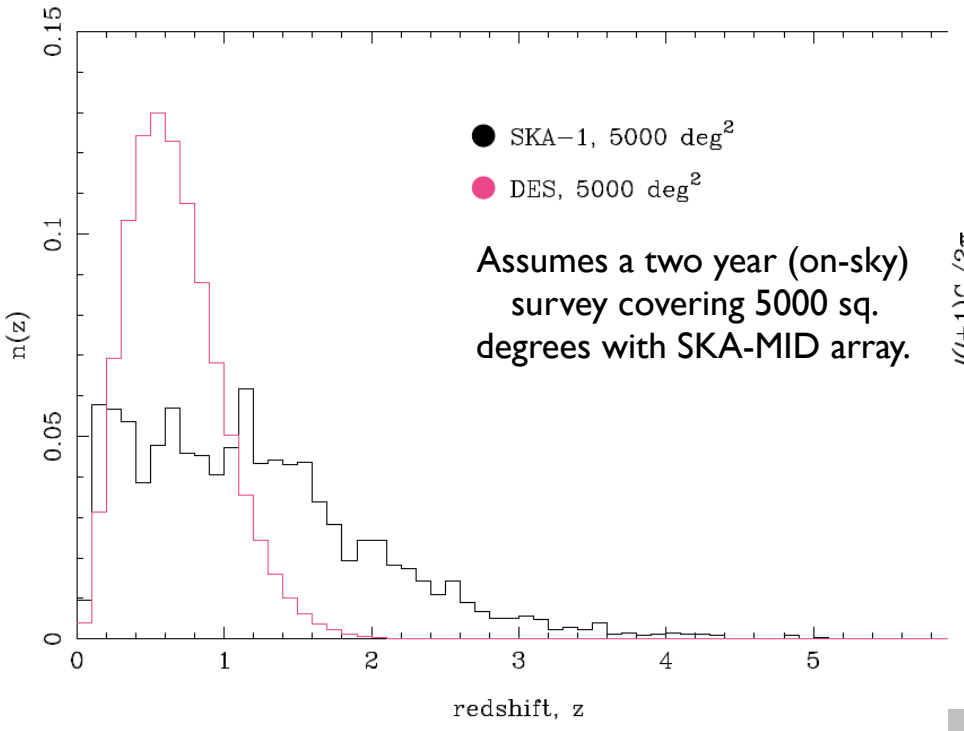
- Radio telescopes
  - LOFAR
- **Radio surveys**
- **Cosmology**
  - Main probes:
    - Weak Lensing – Michael Brown
    - Baryon Acoustic Oscillations – Phil Bull
    - Redshift Space Distortions – Alvise Raccanelli

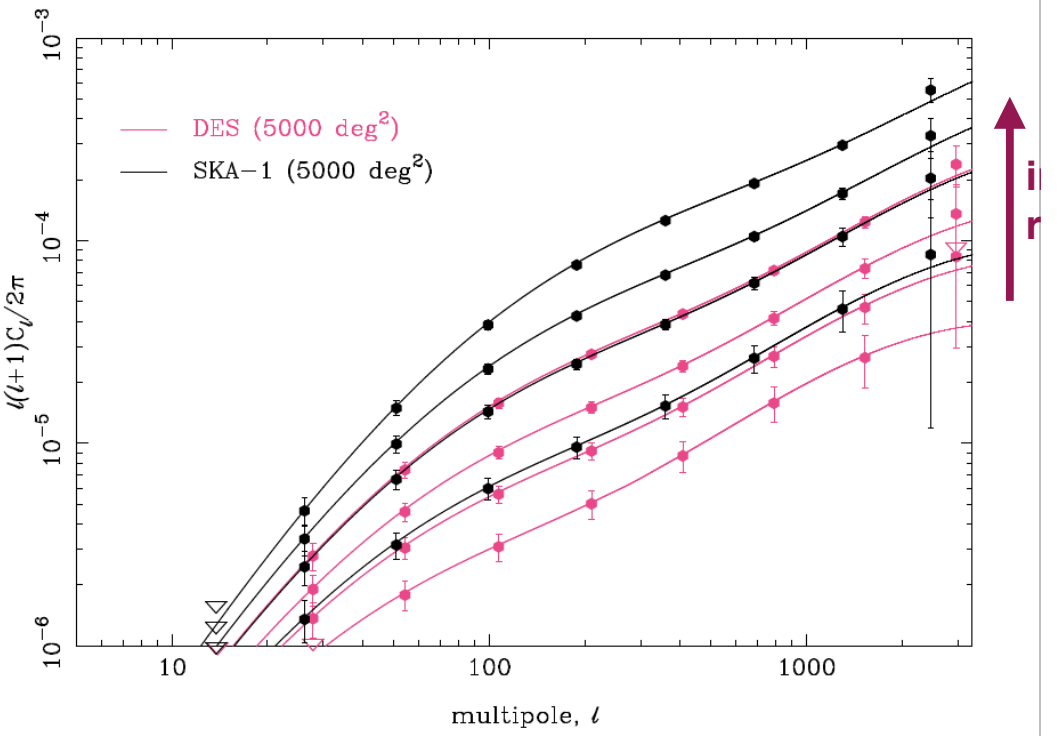
Selling points

- Large volumes
- different systematics
- different redshift distributions


$\alpha = -2.2$
$\alpha = -1.1$
8C
VLSS
6CII
WENSS
NVSS
FIRST
LOFAR Tier 1
LOFAR Tier 2
LOFAR Tier 3
WSRT/ASKAP
SKA LOW+MID All-sky
SKA MID Tier 1
SKA MID Tier 2
SKA MID Tier 3
10000
1000
100
10
1
0.1
0.01
0.001
0.0001
10
100
1000
$5\sigma$ Flux Limit [mJy]
Frequency [MHz]

# SKA-1: Weak lensing 5000 sq deg with SKA mid




Brown et al. (2014)

Different systematics and redshift range

# Large scale SKA surveys offer exciting and unique opportunities for weak lensing analyses

⋆ rejects spurious instrumental systematic effects:

- In general, the observed ellipticity is composed of the lensing-induced ellipticity, the galaxy's intrinsic shape and instrumental systematics:

$$\tilde{\gamma} = \gamma + \gamma^{s}$$

- Cross-correlating optical and radio-based shear estimates:

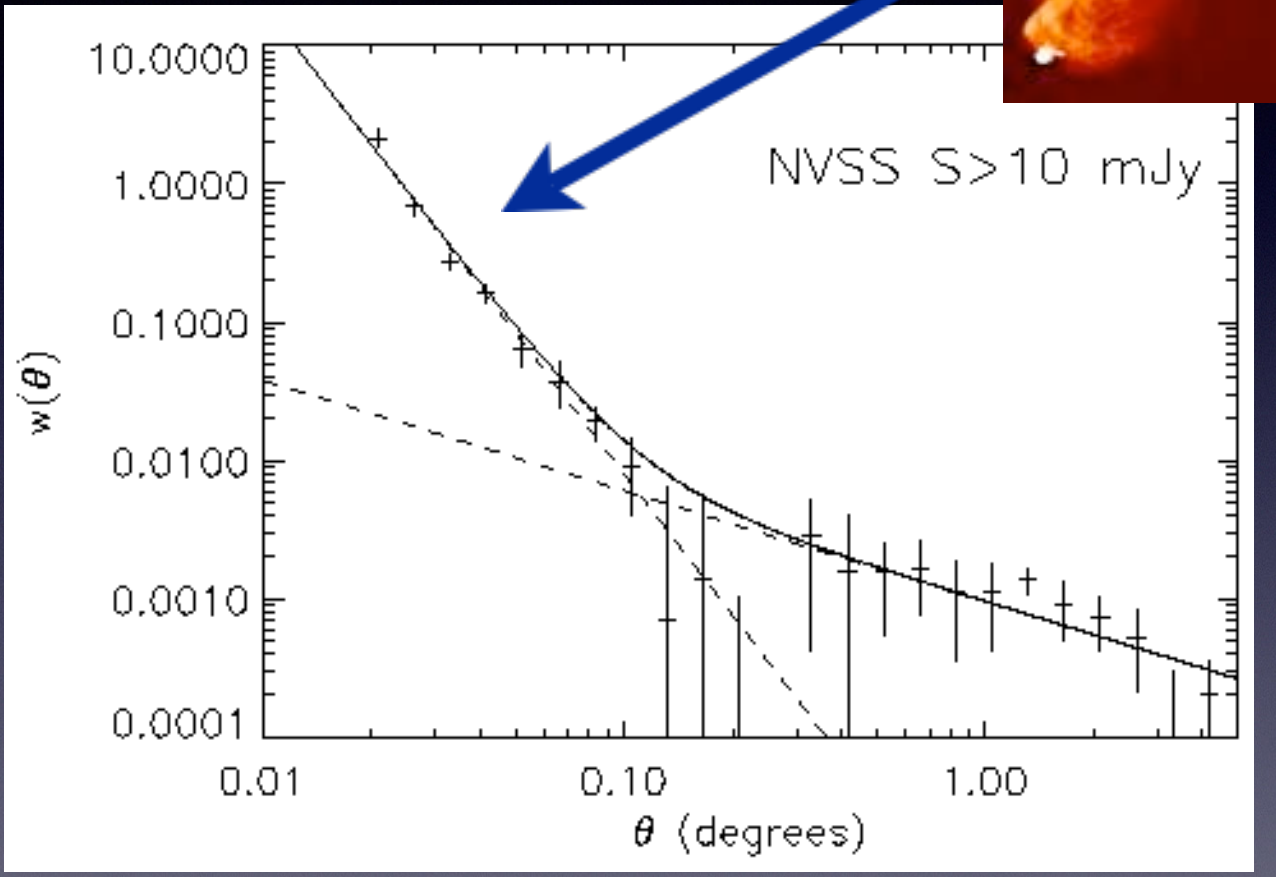
$$\langle \tilde{\gamma}_o \tilde{\gamma}_r \rangle = \langle \gamma\gamma \rangle + \langle \gamma\gamma_o^s \rangle + \langle \gamma\gamma_r^s \rangle + \langle \gamma_o^s \gamma_r^s \rangle$$

Cosmic shear signal

Systematics will be uncorrelated for optical and radio telescopes

Jarvis & Jain (2008); Patel et al. (2010)

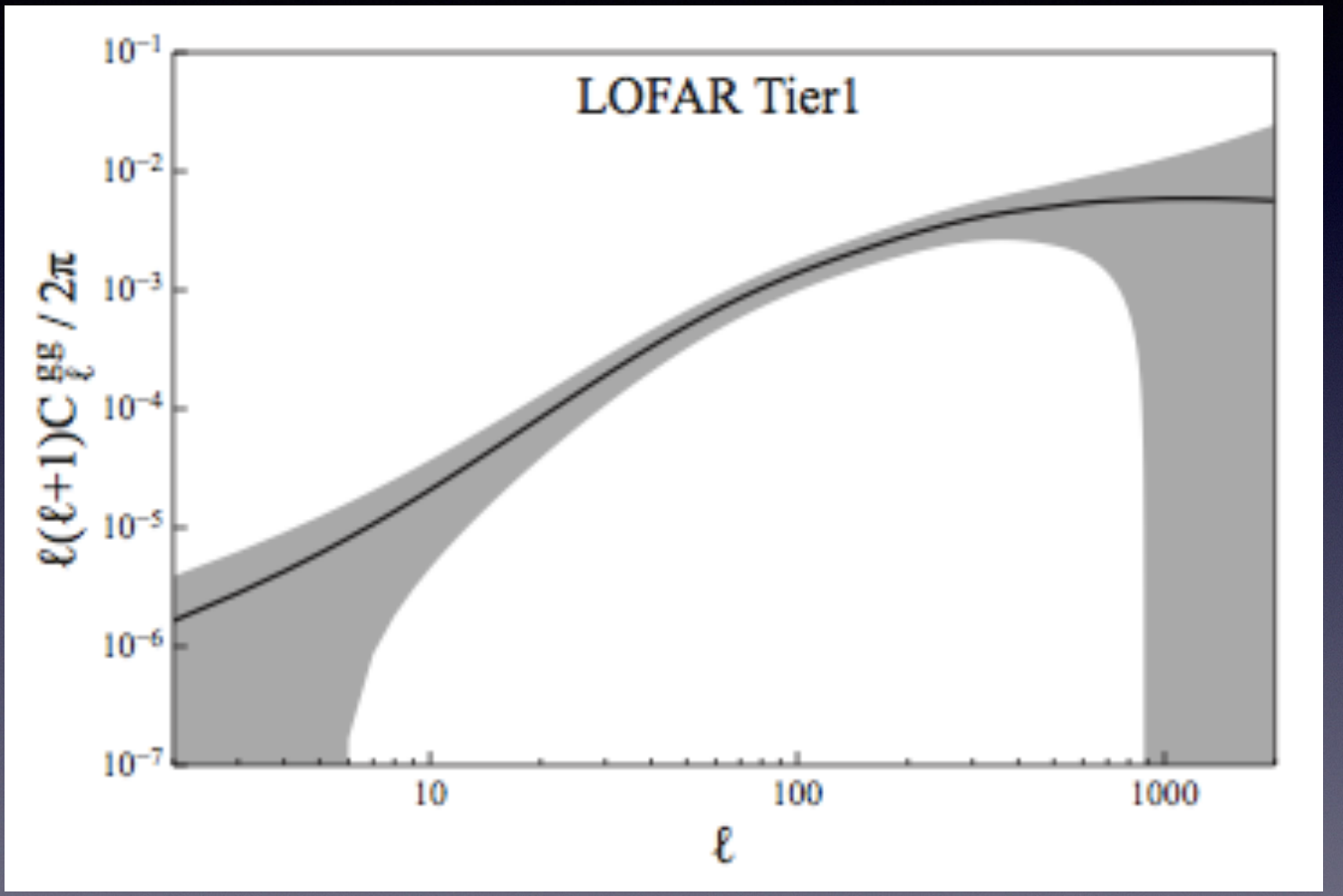
Source power spectrum: fluctuation of sources counts on various scales



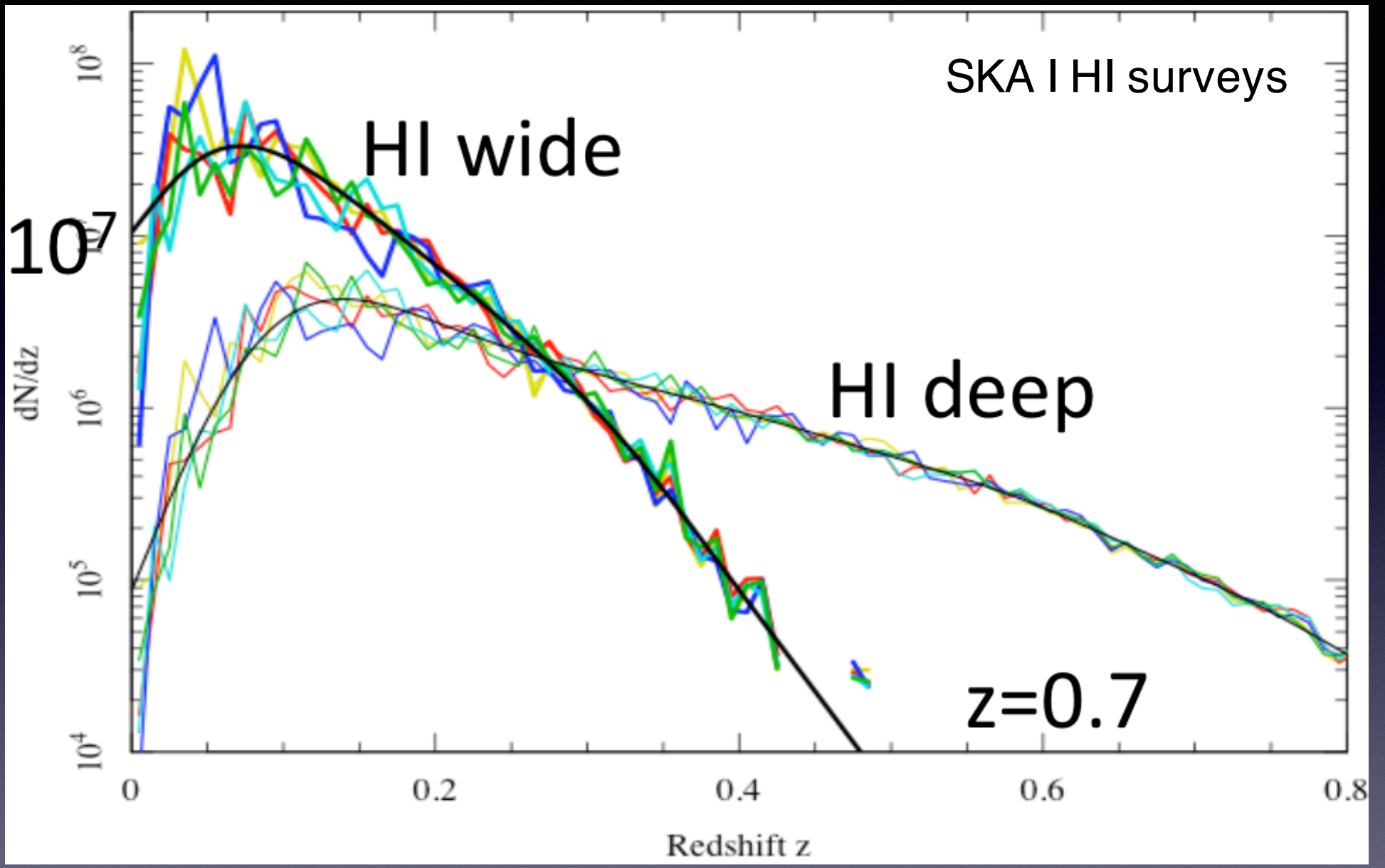

Different systematics: indeed
Overzier, HR, etal. 2003

Source power spectrum:

probing non-gaussianity



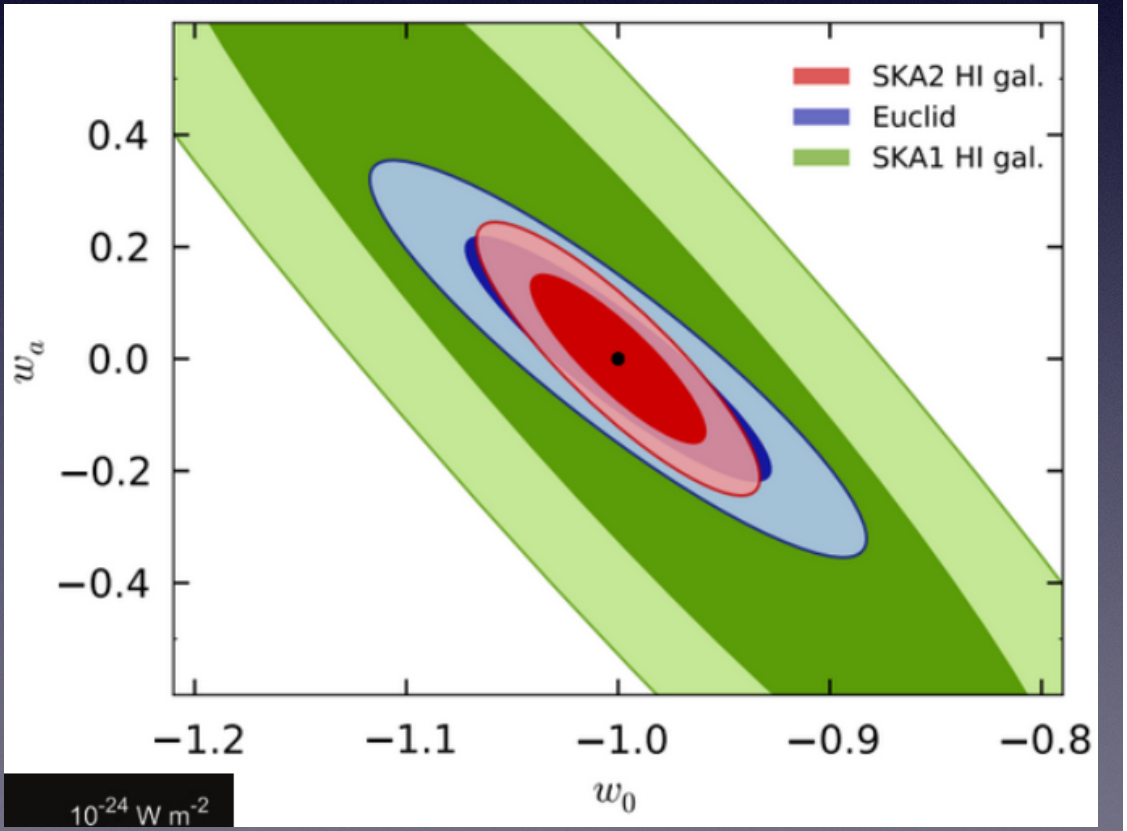

Raccanelli et al. 2011



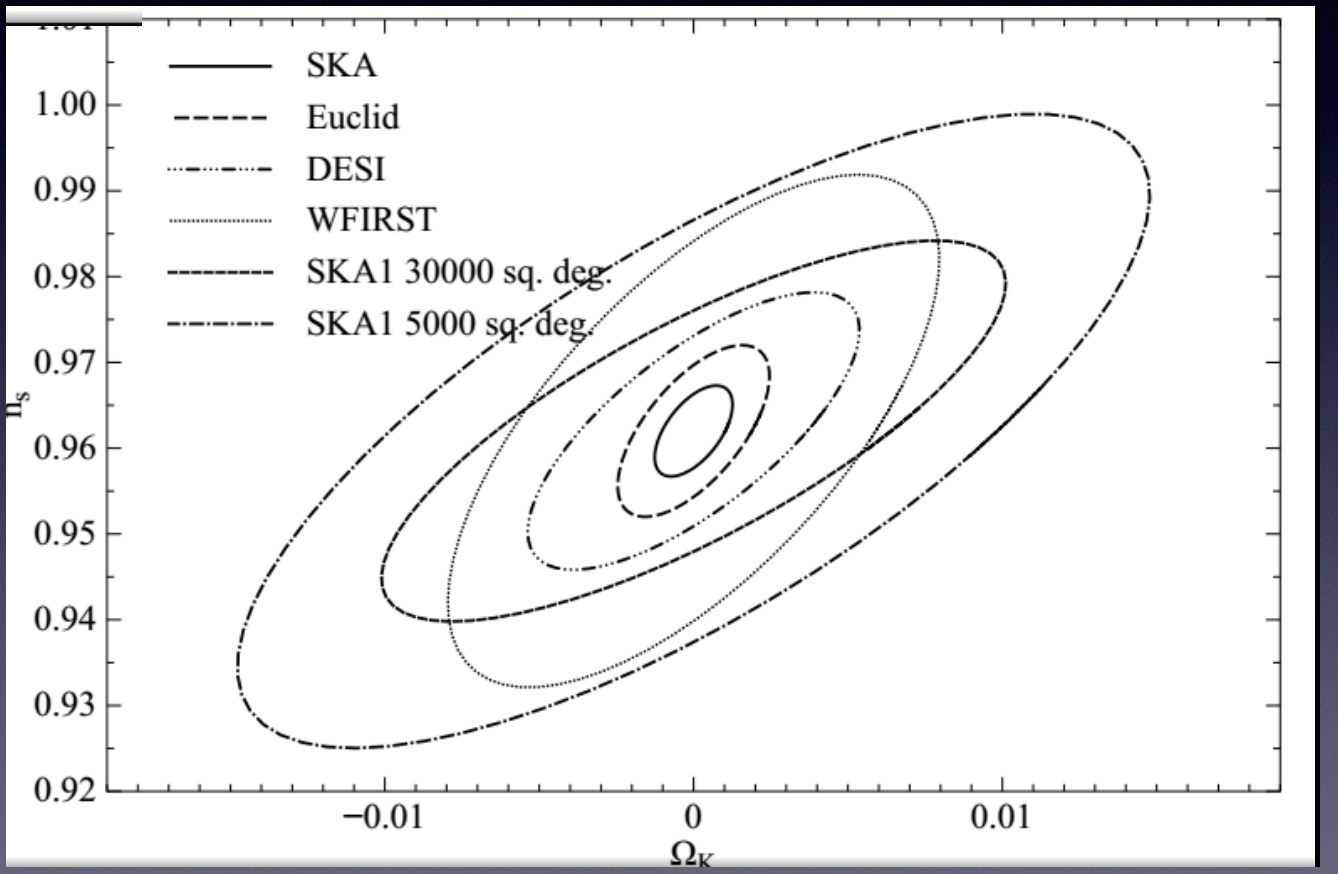

SKA I: 10^7 galaxies, SKA II: 10^9 galaxies

# HI - BAO

- SKA-I galaxy survey (10^7 gal) – prepares for Phase II 10^9 gal.



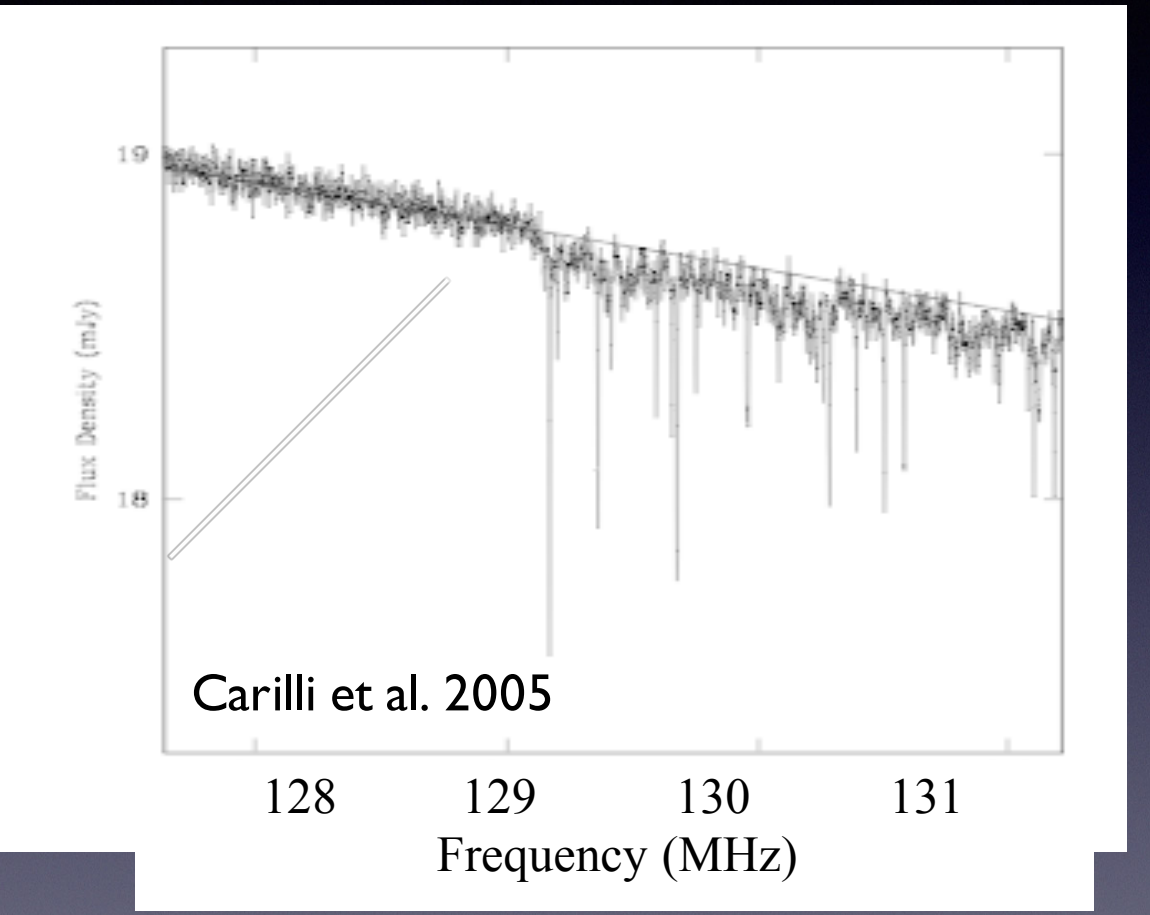
# HI - redshift space distortions



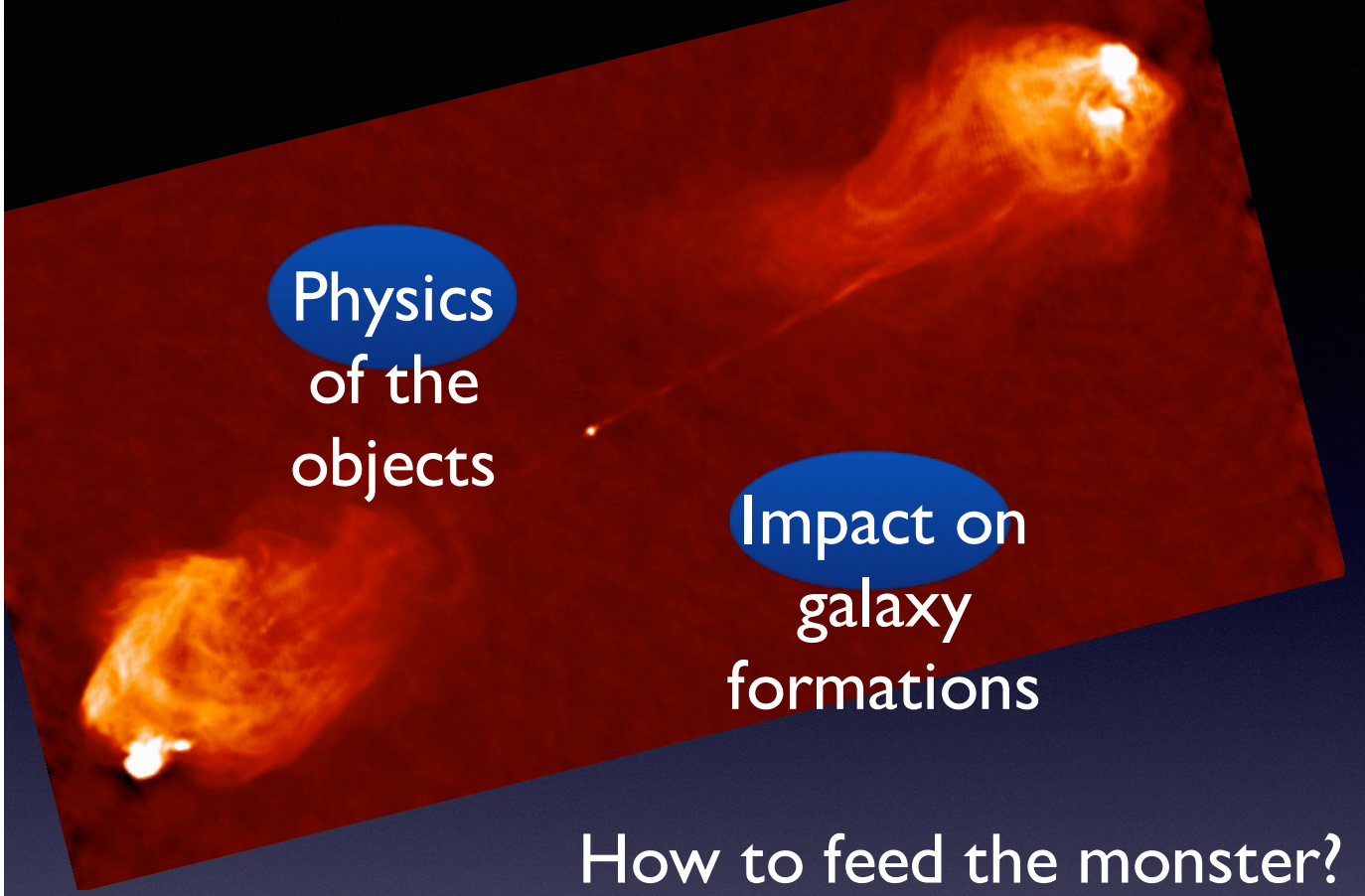
# Overview

- Radio telescopes
  - LOFAR
- Radio surveys
- Cosmology
- **Legacy science**

# 21 cm forest spectrum
# EoR on pc/kpc scales




Fan: WFIRST: ~100 z~8 quasars
10% radio loud?

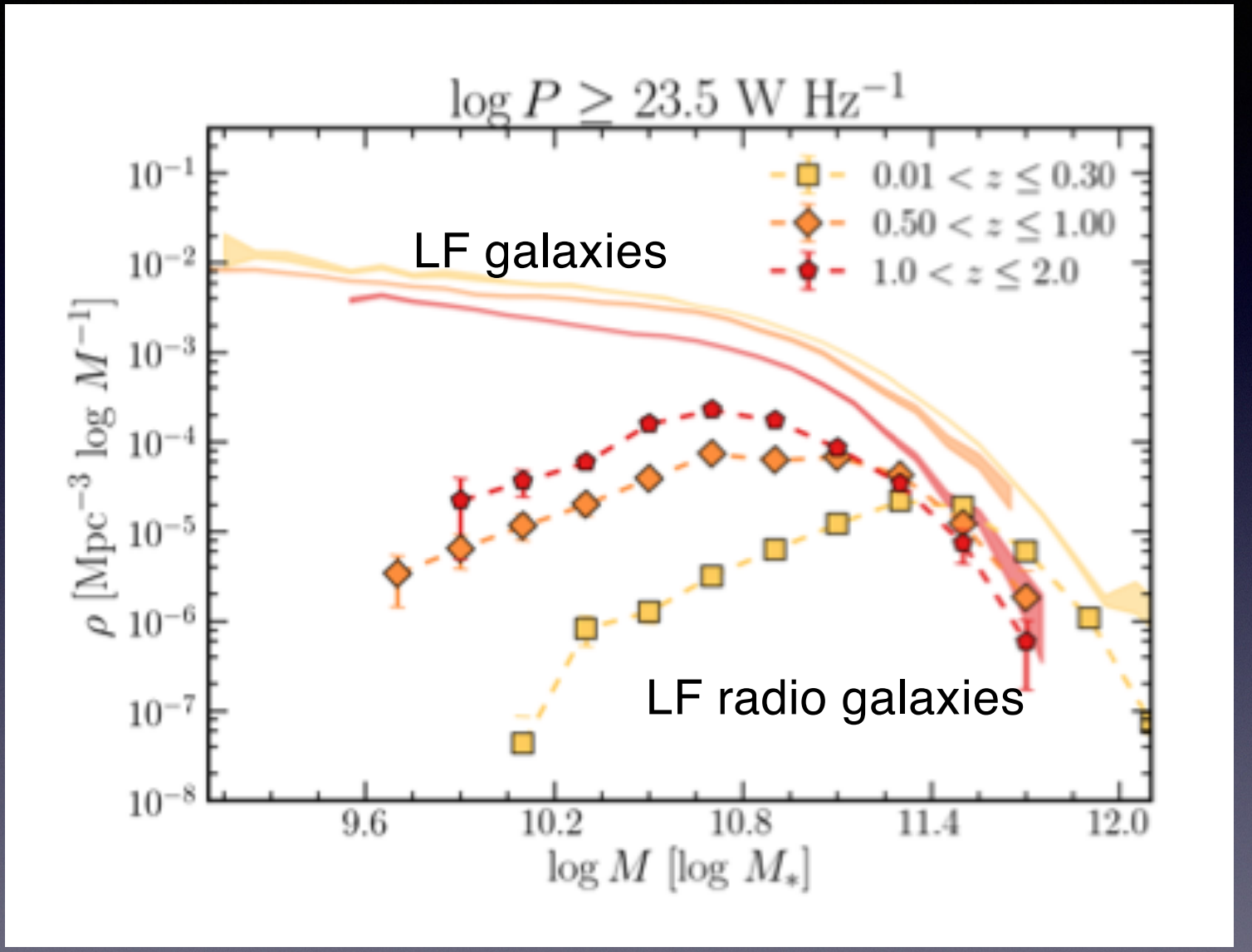



How to feed the monster?

- Cold mode, also named: *quasar mode, radiative mode, fast accretor, high-excitation, strong-lined*
- Hot mode, also named: *radio mode, radiative inefficient, slow accretor, low-excitation, weak-lined*

# "Radio AGN feedback: when the little ones were monsters"

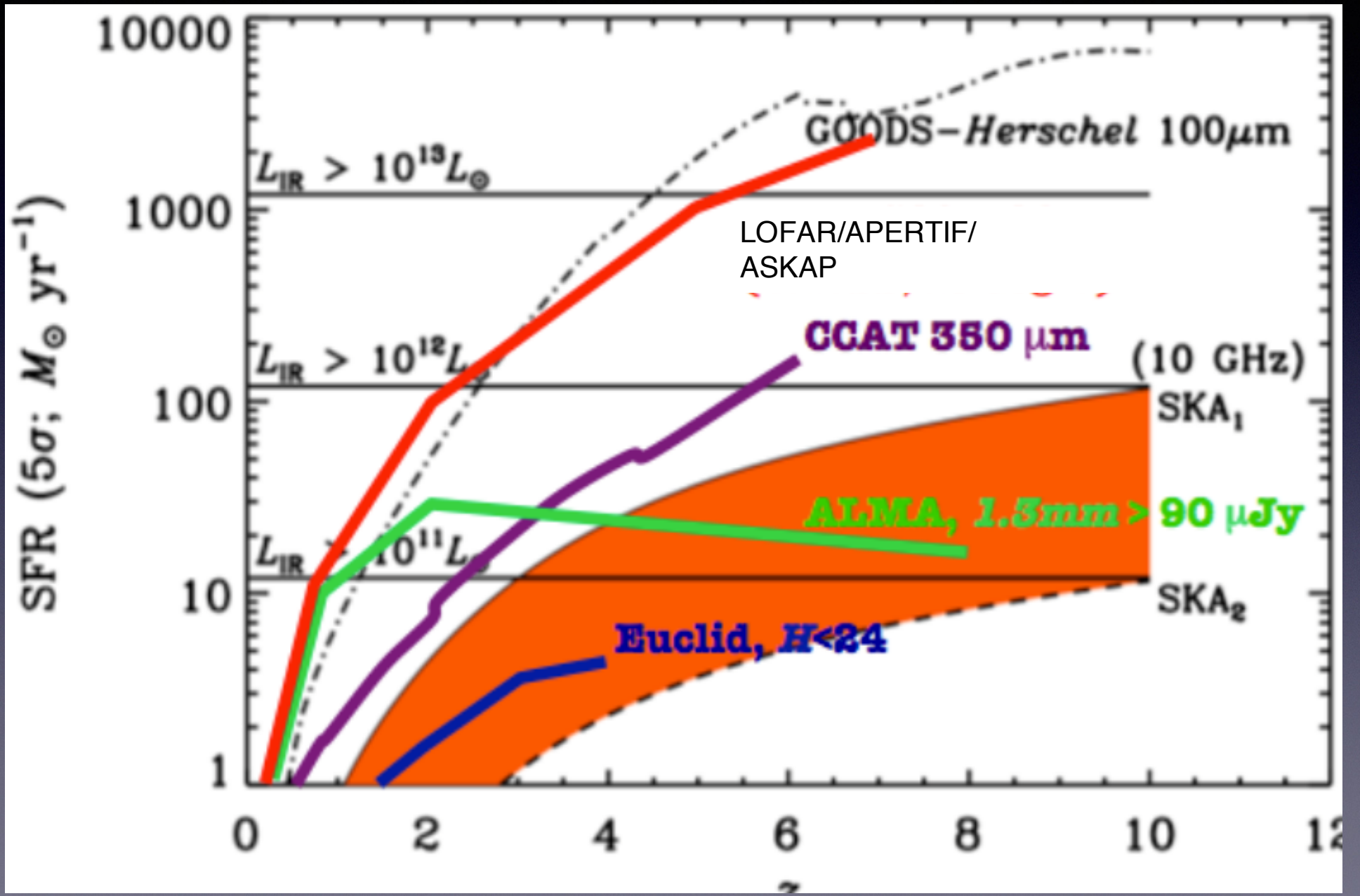
Williams and HR, 2015




Data from cosmos field

How does this depend on the galaxy properties, feeding modes and environment?

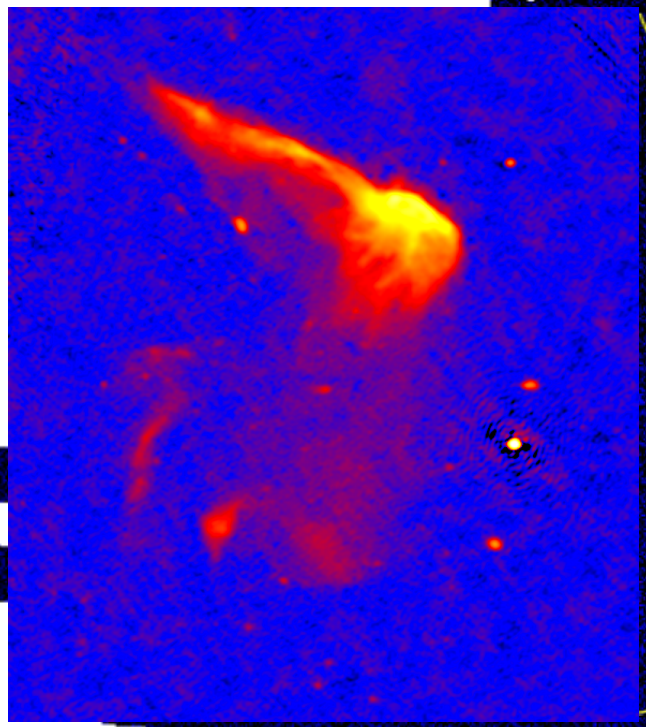
# History of star formation



One pointing full FOV
4 x 4 degr

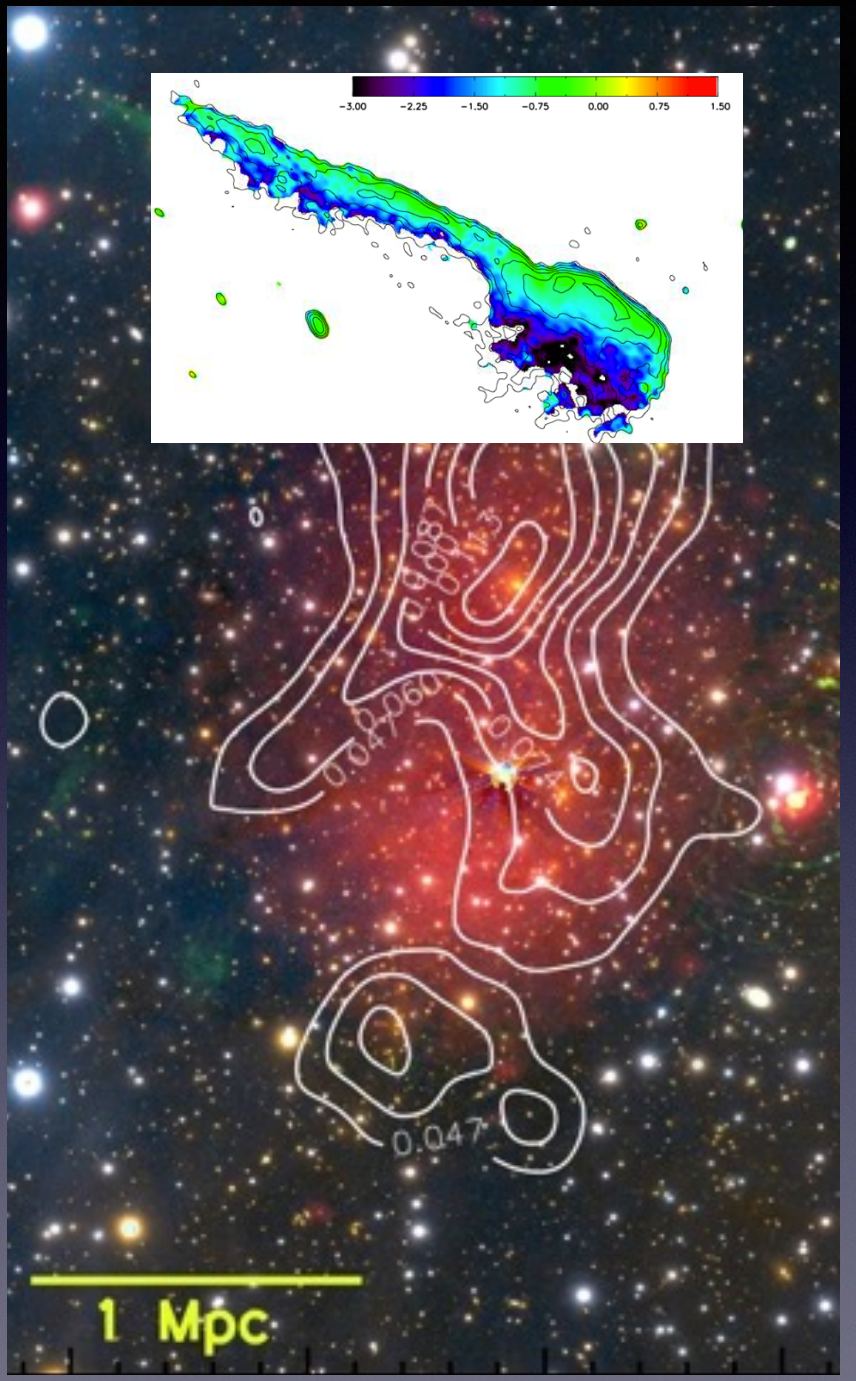
LOFAR 120-180 MHz

Toothbrush cluster
van Weeren et al.



One pointing full FOV
4 x 4 degr

LOFAR 120-180 MHz




Contours Subaru WL map
Dawson, Jee etal.
Mass: 7*10^14 Mo

Red: chandra

Green-blue radio spectral index

2 Mpc shock induced by merging clusters
Shock accelerates particles which then emit synchrotron emission.

Precision cosmology with clusters?

# Conclusion

- Competitive cosmology can be done with radio telescopes
  - different set of systematics
- Combined legacy science is great