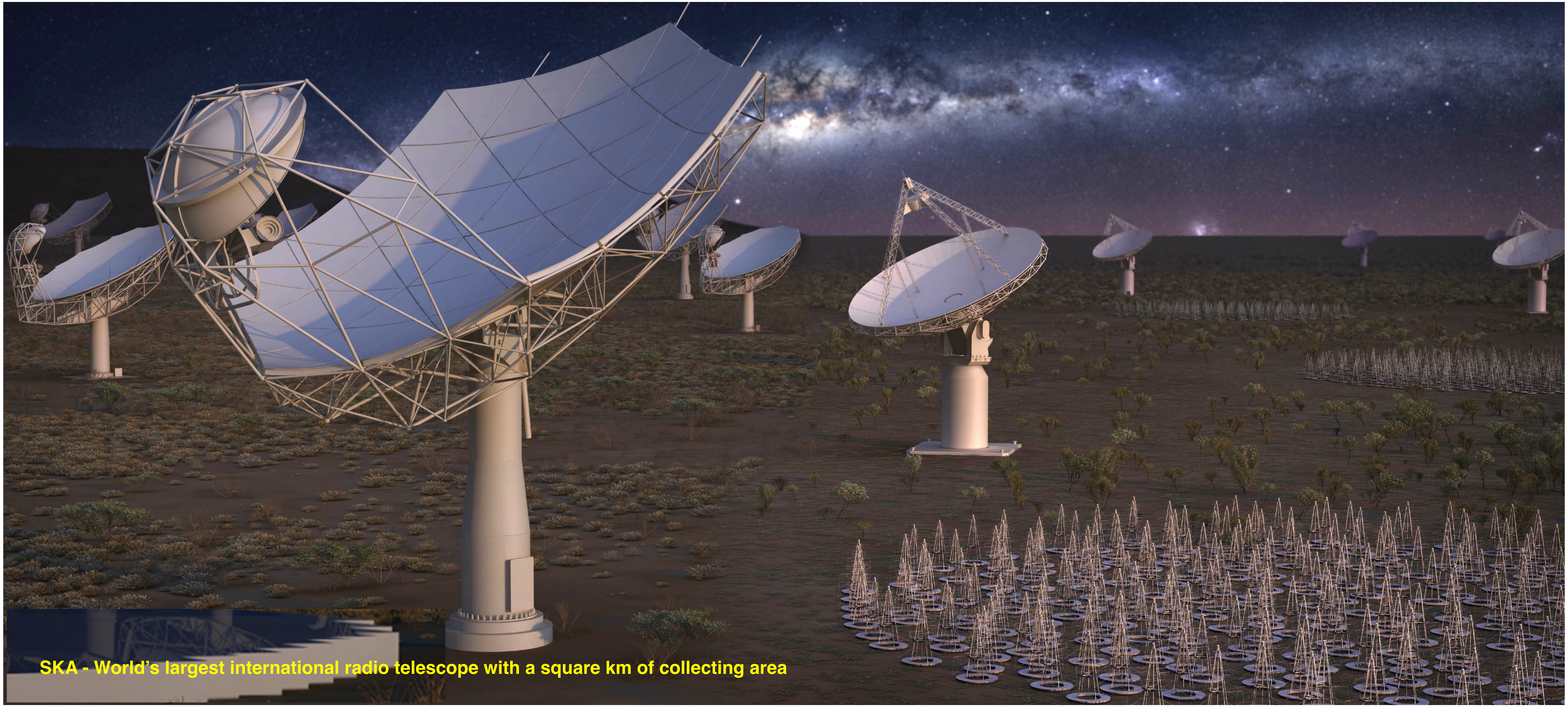
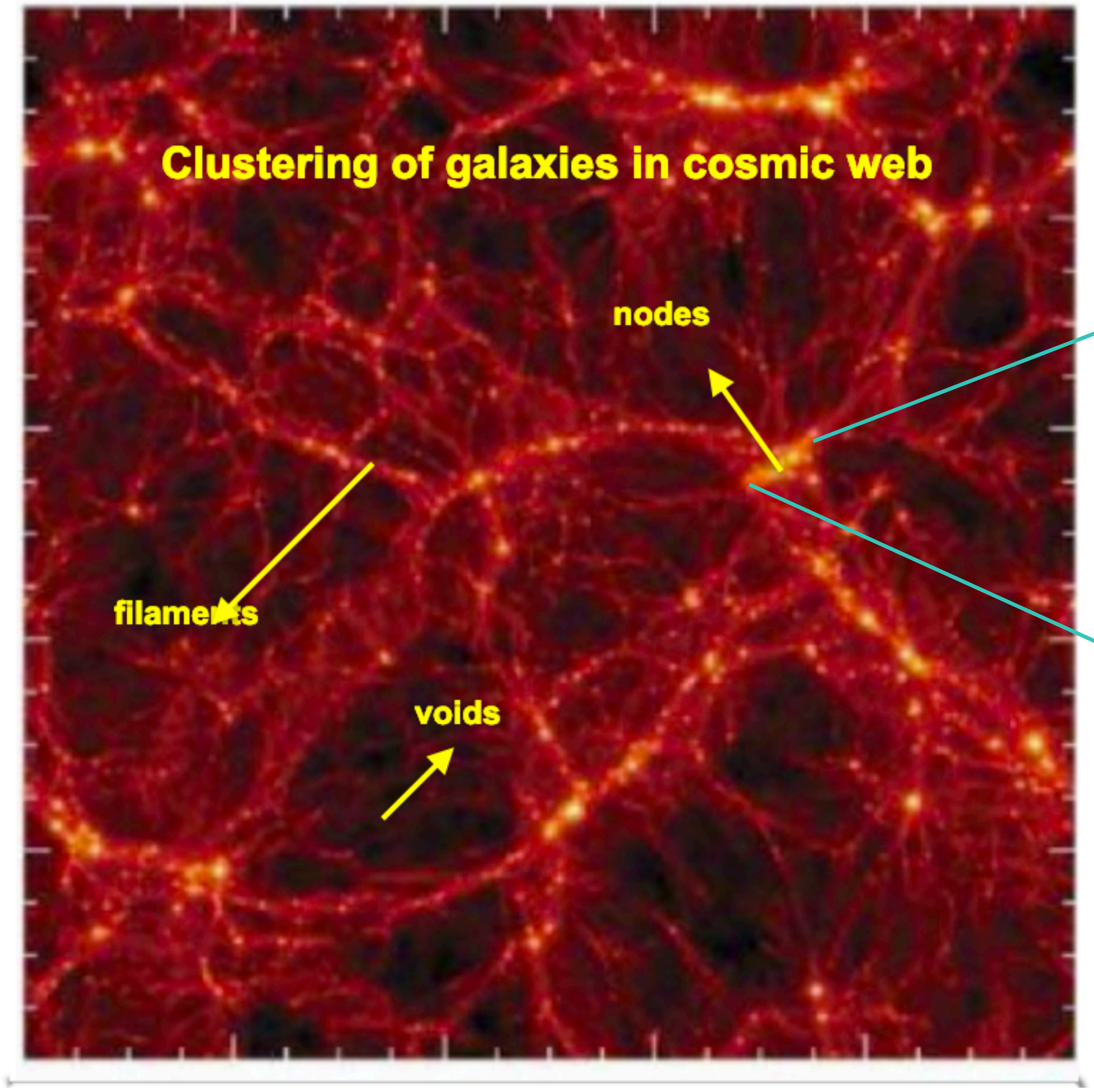
Distant Universe with Gravitational Lensing in the SKA Era



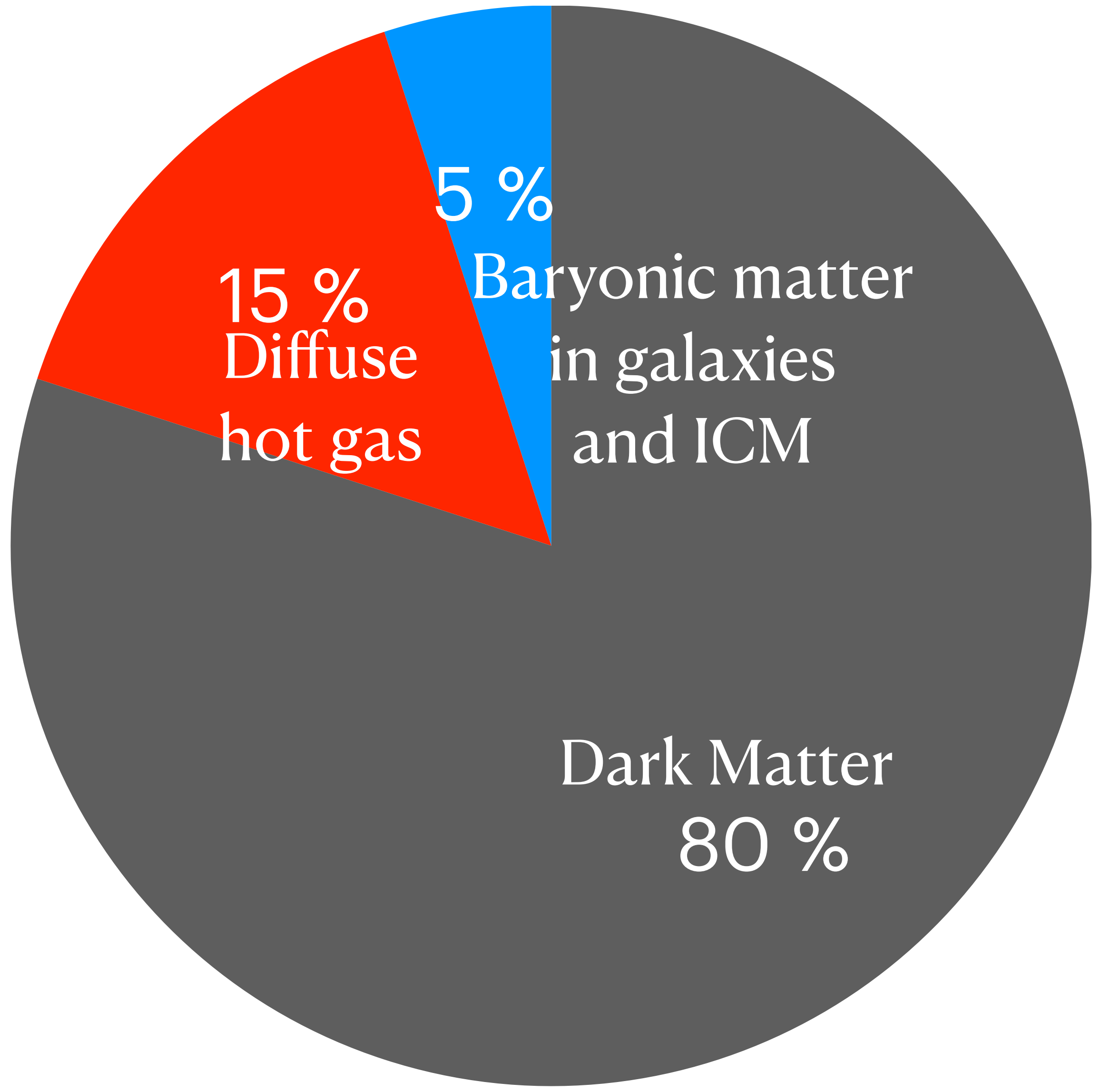
Mamta Pommier

University Catholic of Lyon - University of Lyon

Brunetti & Jones 2014



Galaxy clusters

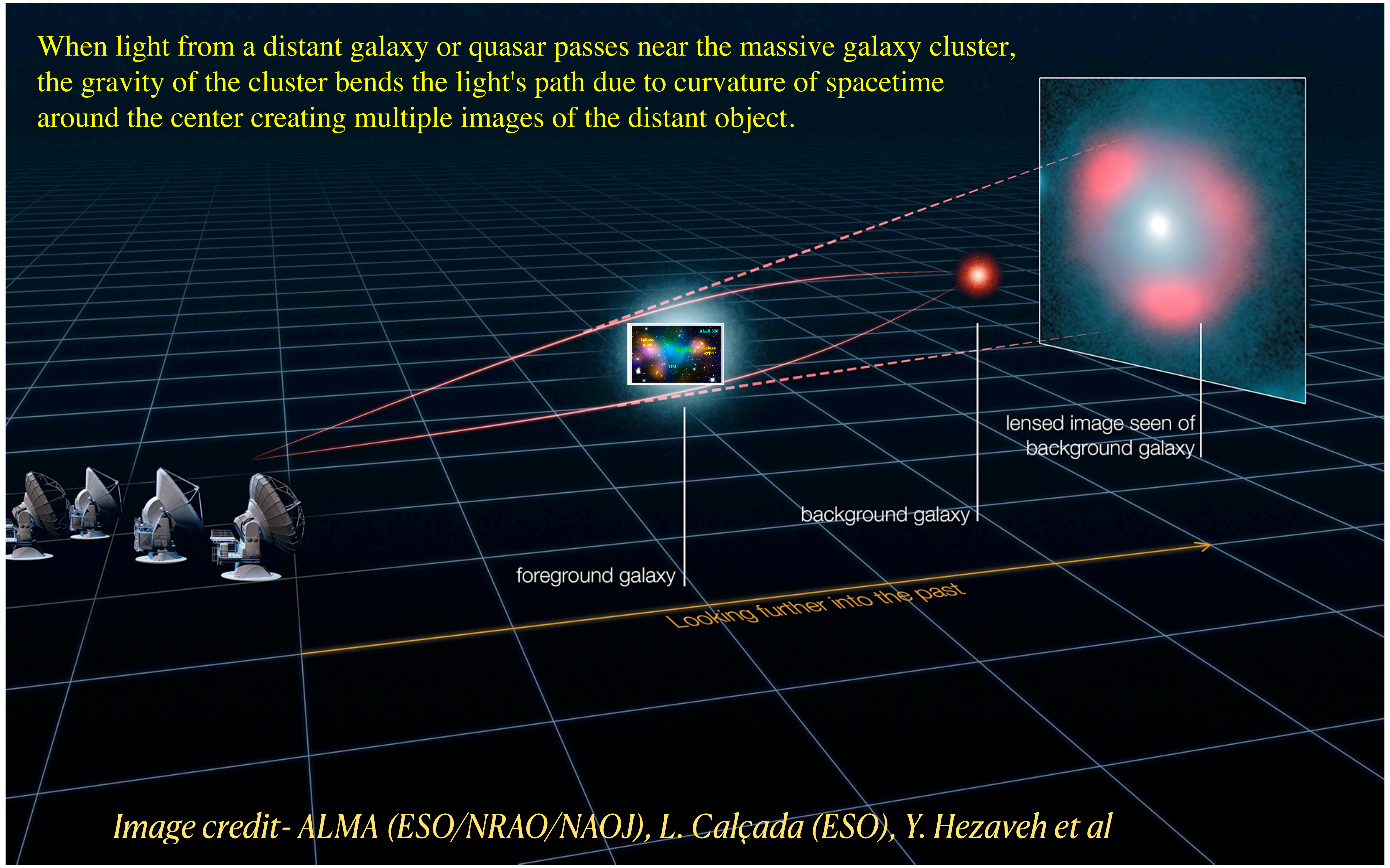


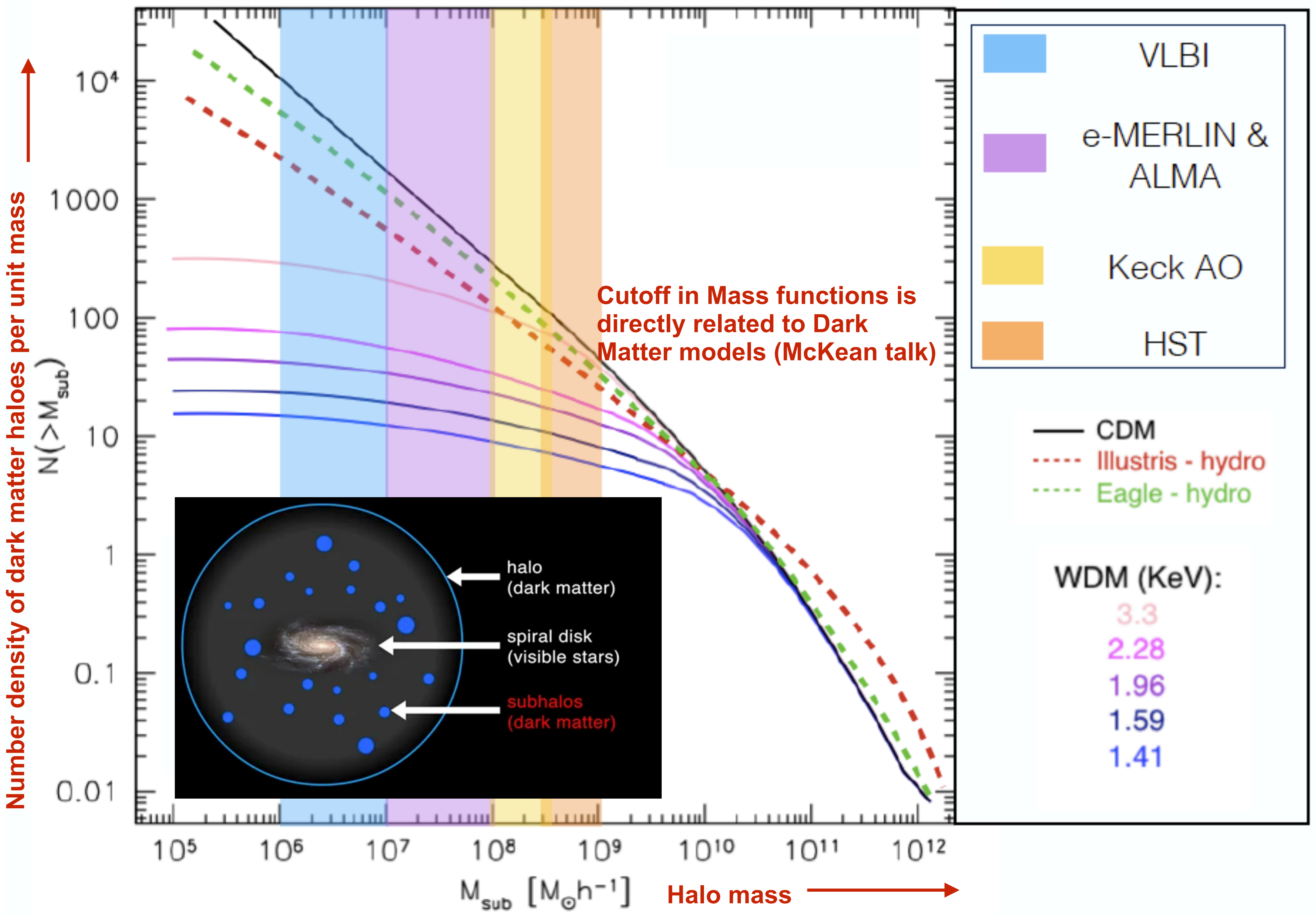
-Galaxy groups come together, fall in the higher density (50% of galaxies reside in clusters or groups) regions experiencing lot of turbulent activities, where galaxies loose their gas through ram pressure stripping and fall in the hot ICM.

-Extreme cluster environment plays a crucial role in the evolution of cluster dynamics and galaxies within the cluster environment. Galaxies undergo a morphological transformation from spiral to SO-type, ellipticals.

Strong Gravitational lensing with galaxy clusters

Walsh et al. 1979, Biggs et al. 2004; Estrada et al. 2007; Gladders et al. 2002; Hewitt, J. et al. 1988; Hennawi et al. 2008; Scarpine et al. 2006

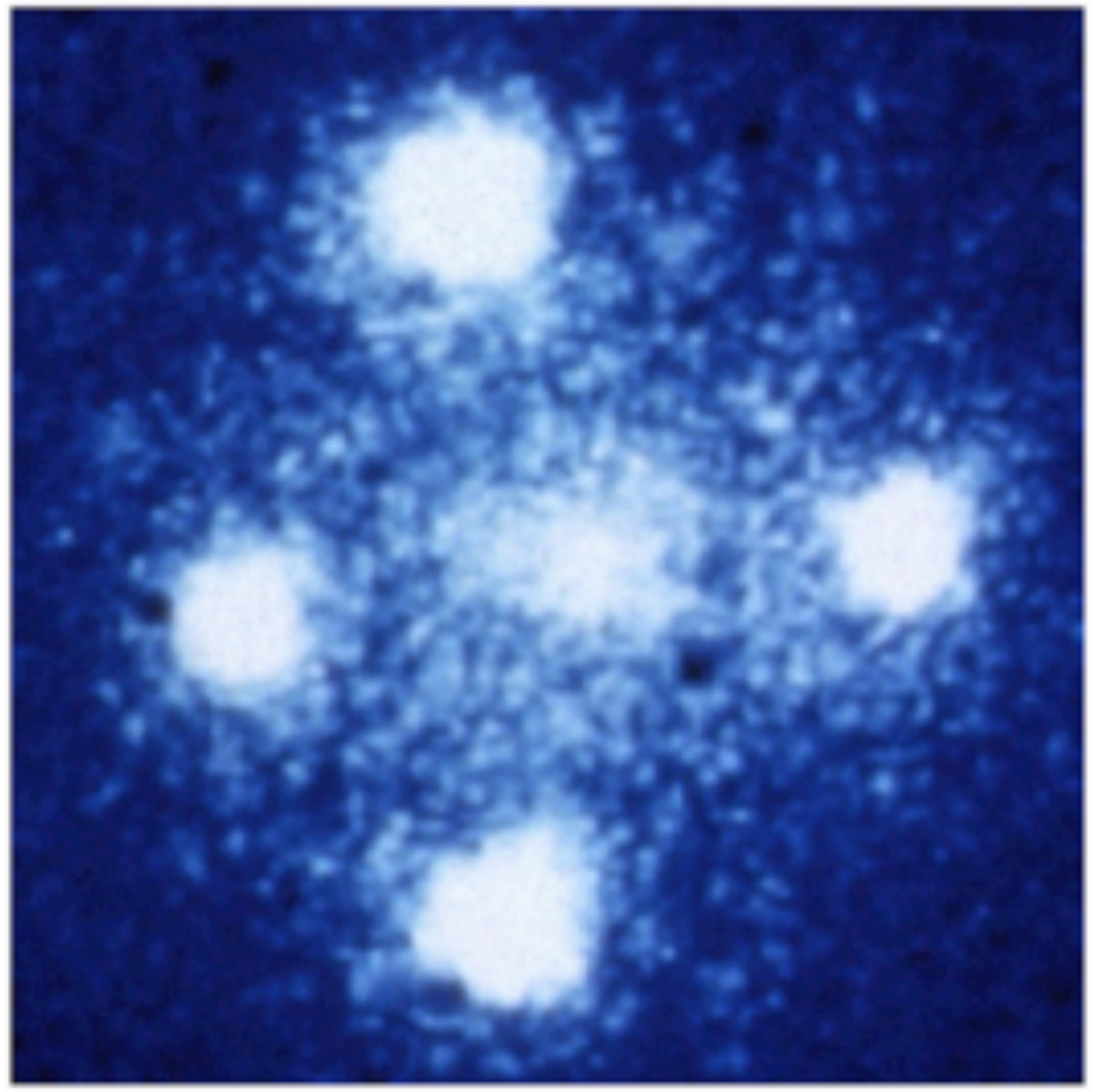




Walsh et al. 1979, Biggs et al. 2004; Estrada et al. 2007; Gladders et al. 2002; Hewitt, J. et al. 1988; Hennawi et al. 2008; Scarpine et al. 2006, McKean et al. 2015

Based upon lensing system and lensed galaxy alignment + mass distribution in the lensing system

ESA/Hubble & NASA



NASA, ESA, and STScI

NASA, ESA, Hubble SM4 ERO Team, ST-ECF

Merging and cool core clusters:

Survey: **GMRT/LOFAR/VLA/NRT/IRAM/MUSE/HST survey on cluster of galaxies** (Ebeling et a. 2001)

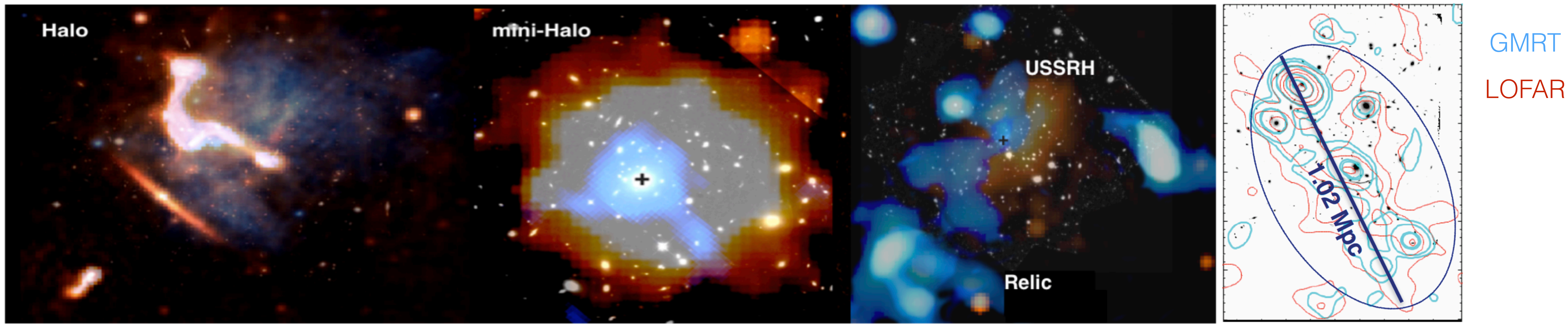
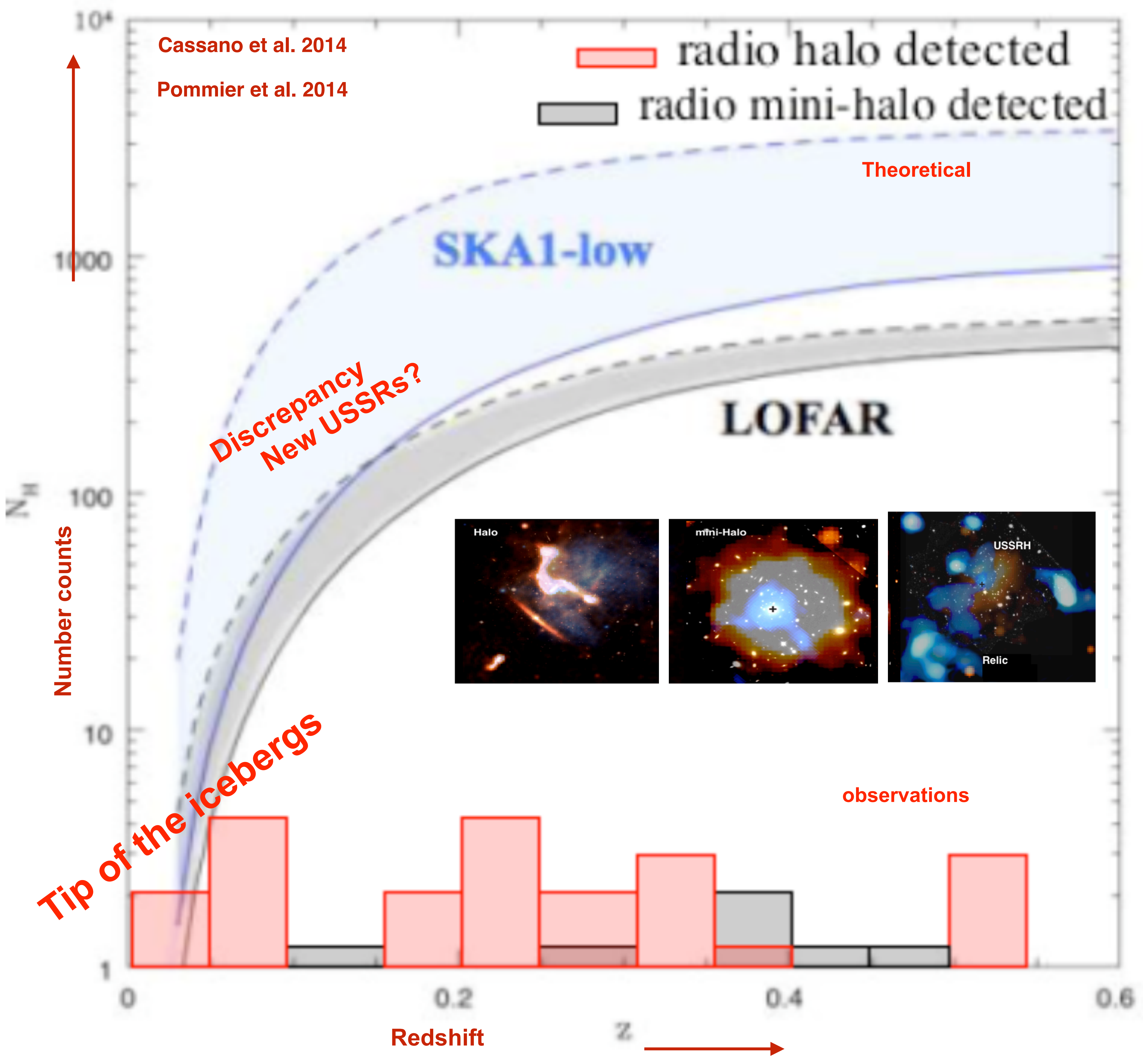


Fig. Non thermal emission in Galaxy clusters at low frequencies with the GMRT/LOFAR

Diffuse emission new contribution with the GMRT & LOFAR !

1. Non-thermal emission in clusters pose fundamental question about their origin, interaction between thermal and non-thermal gas components and insights on the cluster dynamical state and its evolution.
2. Radio emission measured in the ICM of ≥120 clusters (GMRT/LOFAR), however the detection rate still remains at the tip of the ice-bergs (Cassano et al. 2015) with few 100s expected at LOFAR sensitivity and 1000s for the SKA.
3. Ultra steep spectrum radio haloes are new population yet be discovered with the SKA!

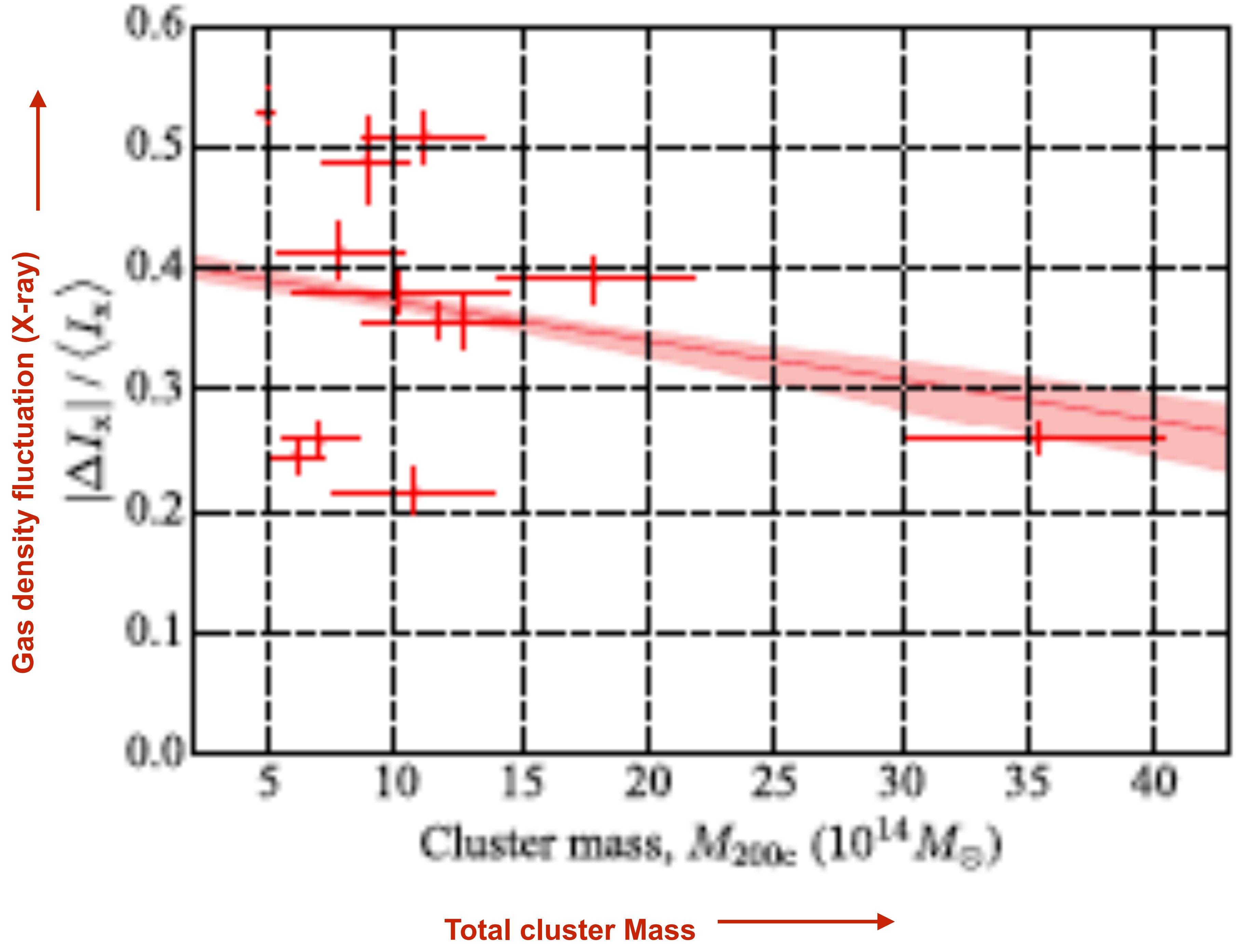
Results- Cluster of galaxies- Discovery of rare low frequency radio (GMRT/LOFAR < 240 MHz) emission from the ICM M.Pommier et al. 2013, 2014, 2015, 2016, 2017, 2019

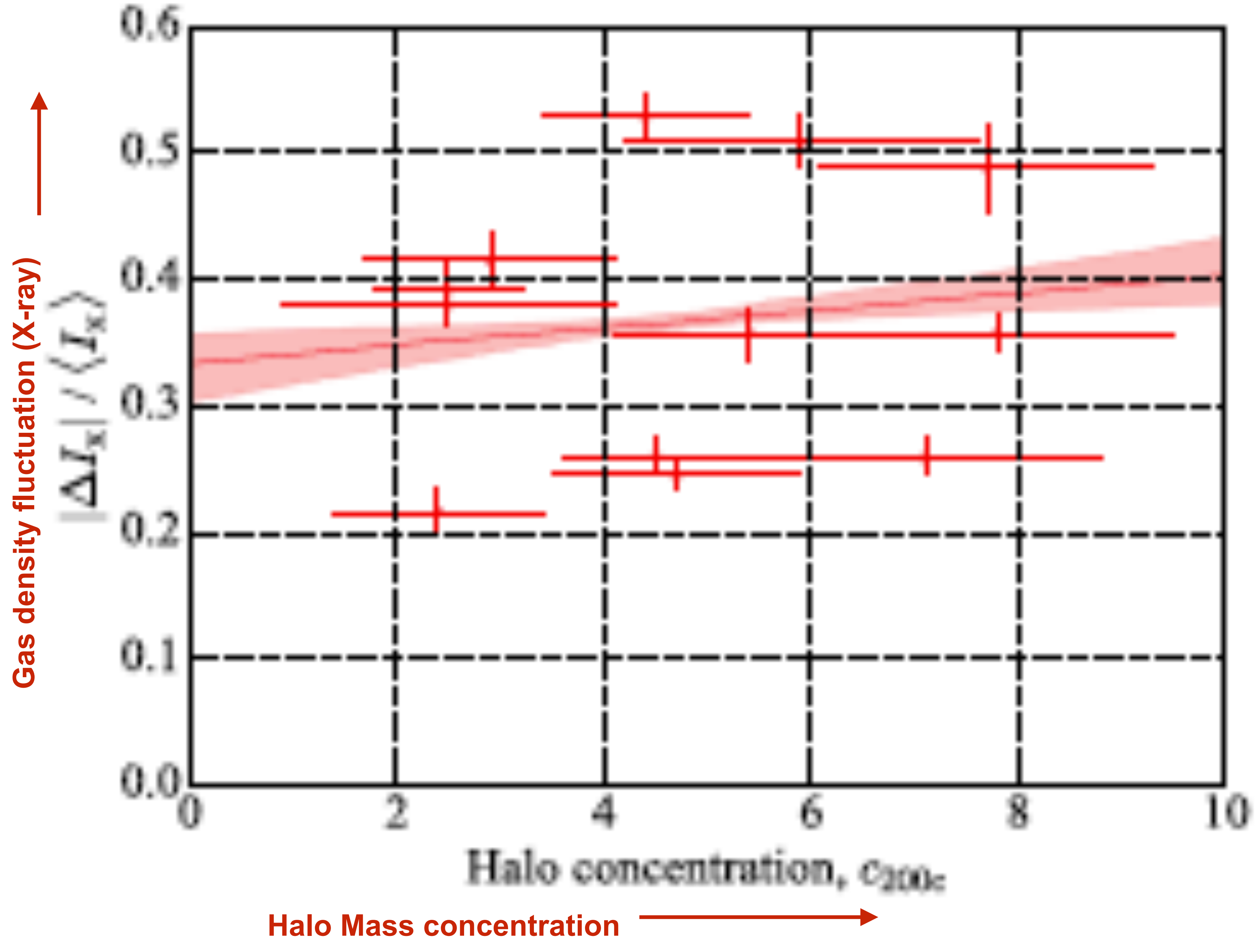


Results:

- Non-thermal radio emission (Halos, Relics, Phoenix, USSRHs- Mpc scale) in 84% NCCs, Mini-halos (few kpc) in 75% CCs
- Different stages of mergers (Pre- and Post-) identified in clusters using spectral information and multi wavelength data
- SKA-MID users case to discover more radio haloes and mini-haloes.

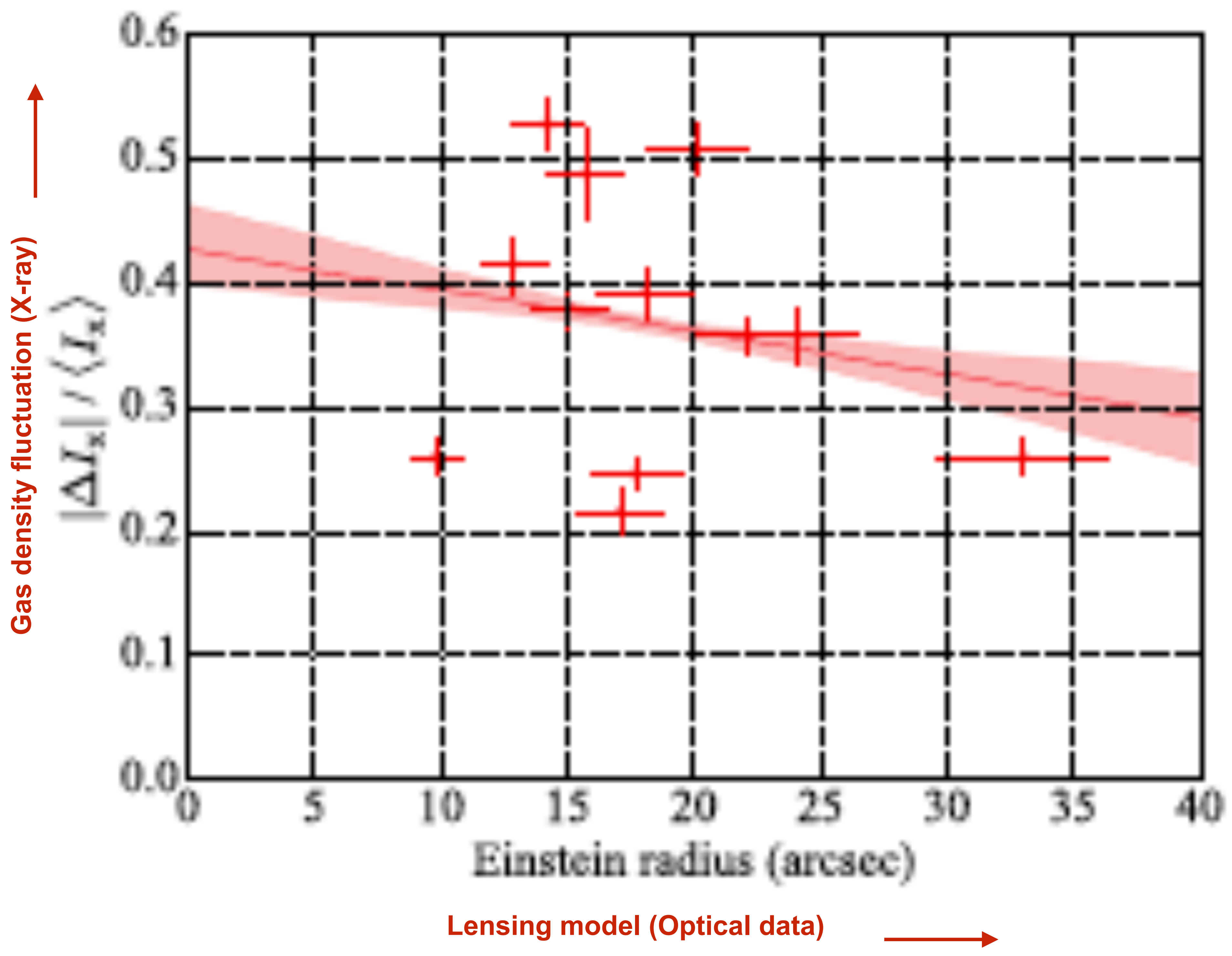
Ueda et al. 2019, Umetsu et al 2016, 2018, Zitrin et al. 2015

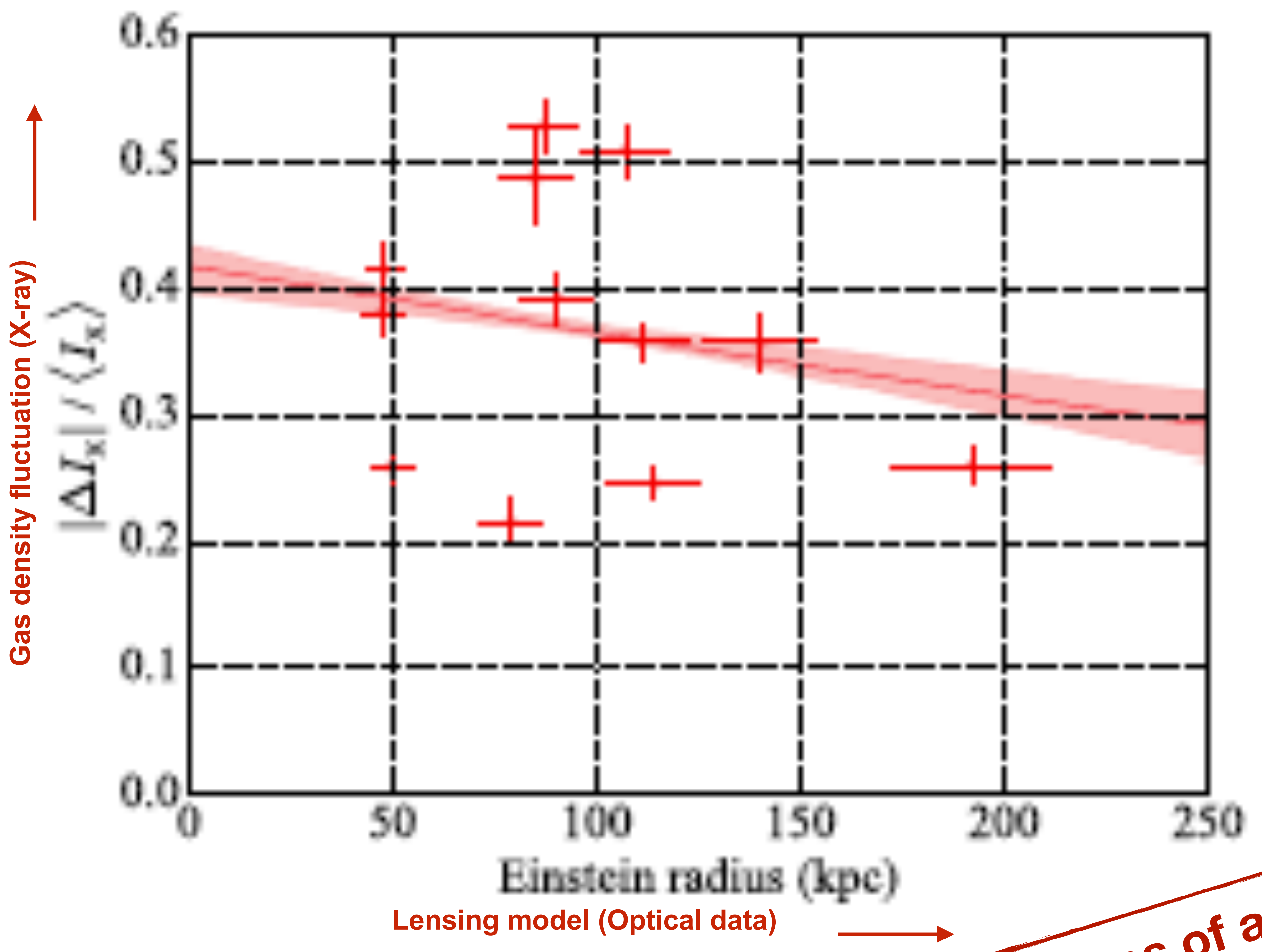




Several mini-haloes of a few 100s of kpc scale detected at radio wavelengths in lensing clusters

Ueda et al. 2019, Umetsu et al 2016, 2018, Zitrin et al. 2015





Several mini-haloes of a few 100s of kpc scale detected at radio wavelengths in lensing clusters

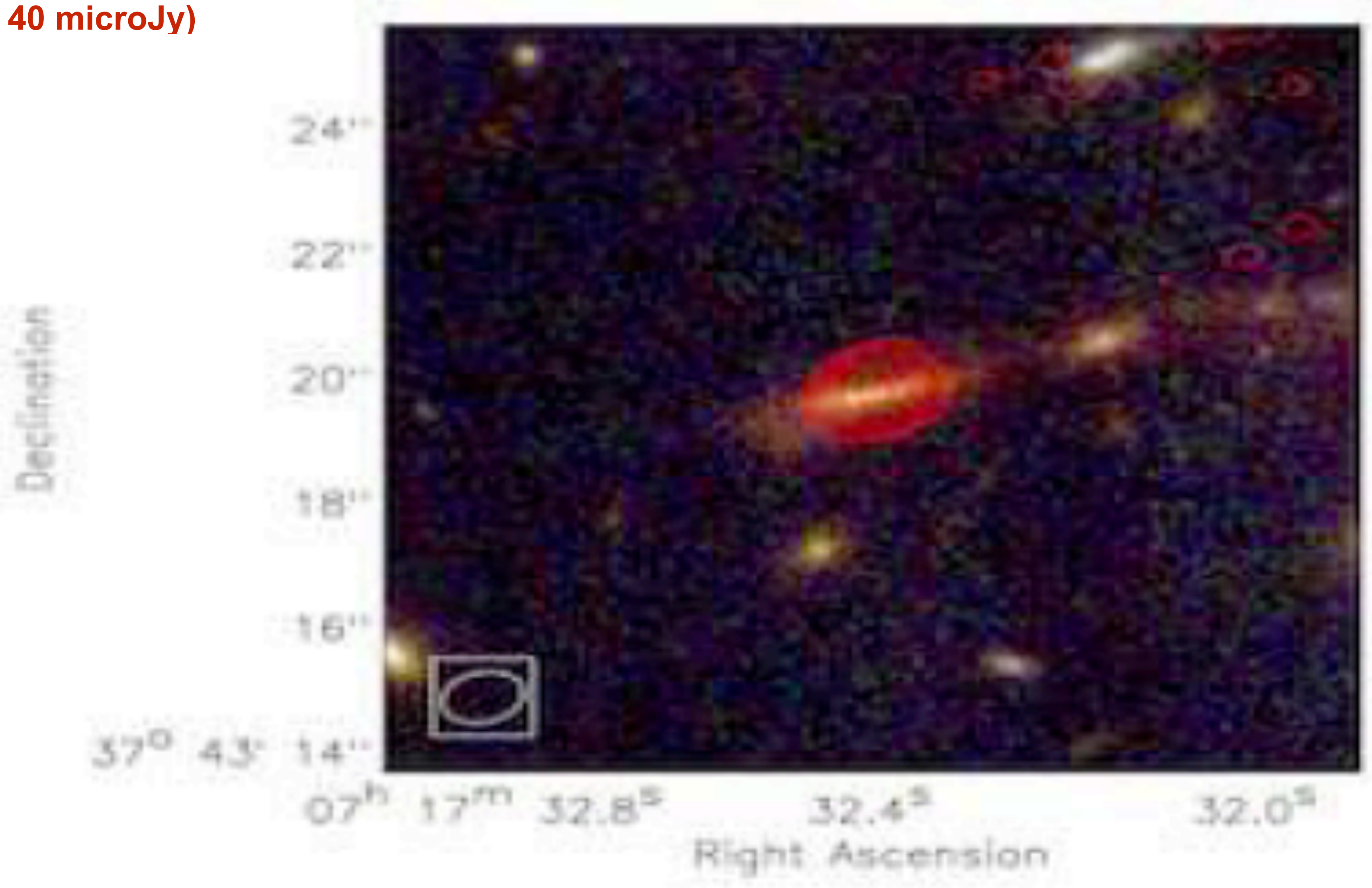
Background Lensed galaxies

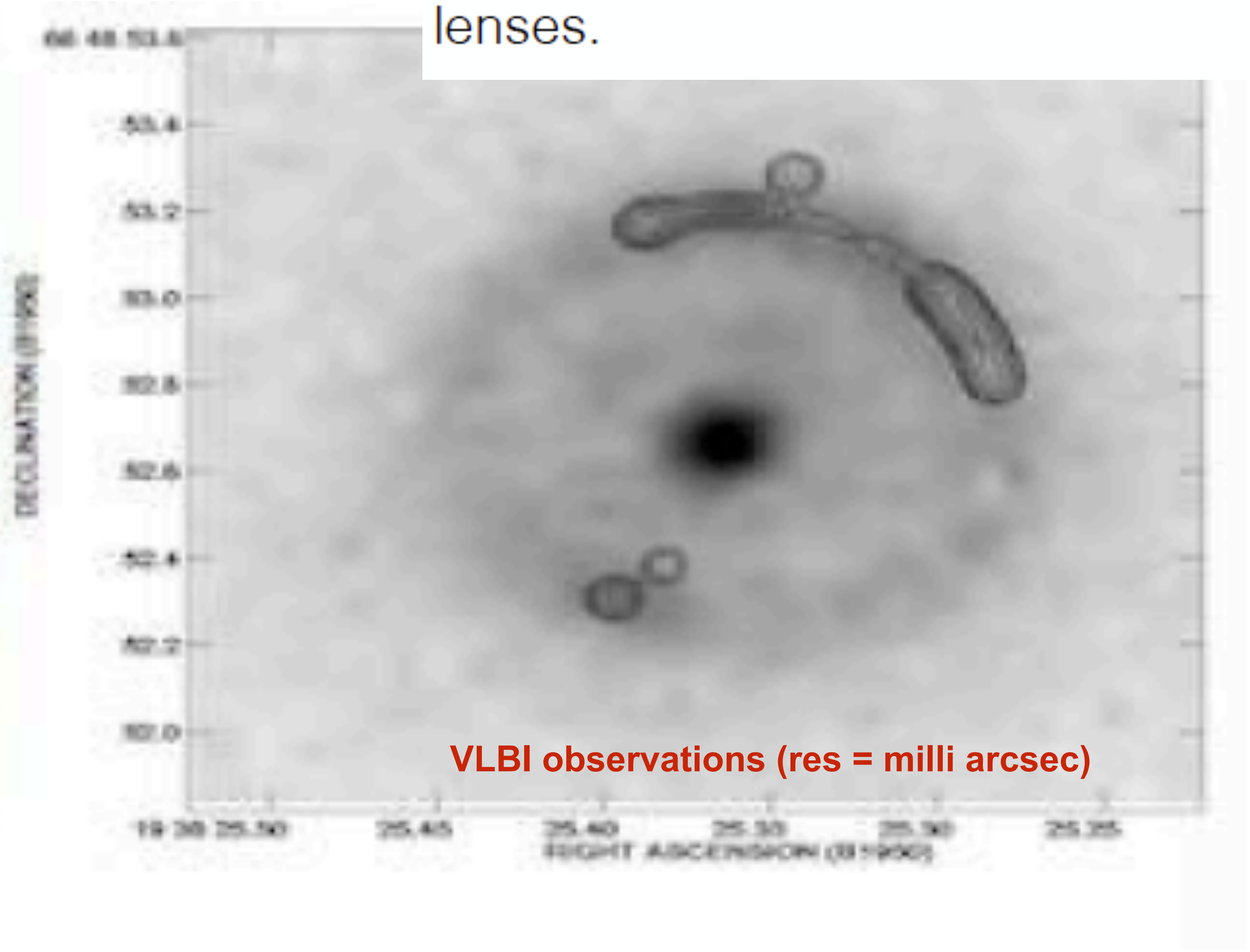
Walsh et al. 1979, Biggs et al. 2004; Estrada et al. 2007; Gladders et al. 2002; Hewitt, J. et al. 1988; Hennawi et al. 2008; Scarpine et al. 2006, McKean et al. 2015, Pommier et al. 2018

A couple of additions with the GMRT/LOFAR observations (600- 110 MHz range, res = arcsec, 40 microJy)

VLA based systematic surveys have found **~36** radio-loud gravitational lenses.

VLBI observations (1GHz-1THz, res = milli arcsec, 10 microJy)





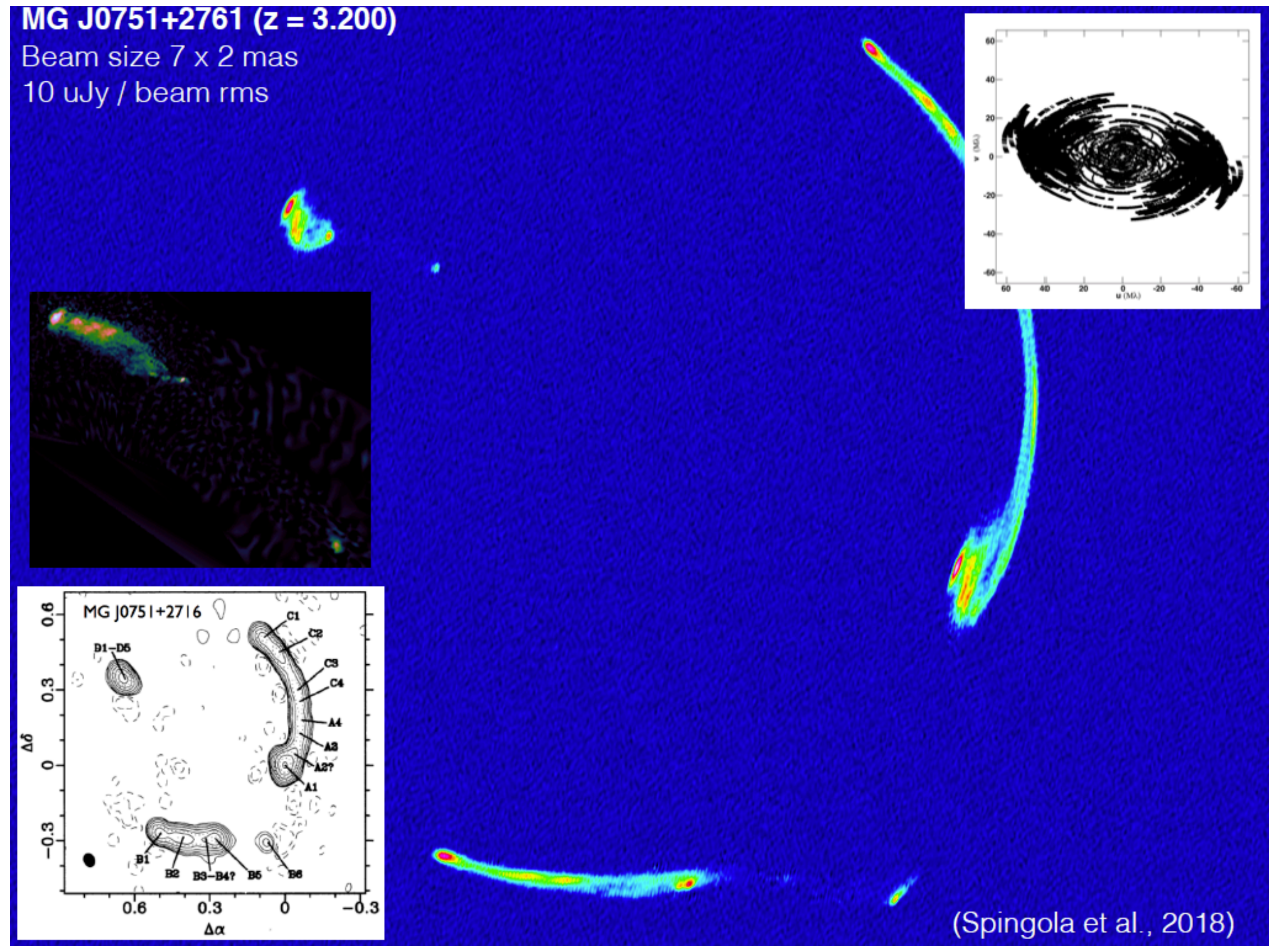
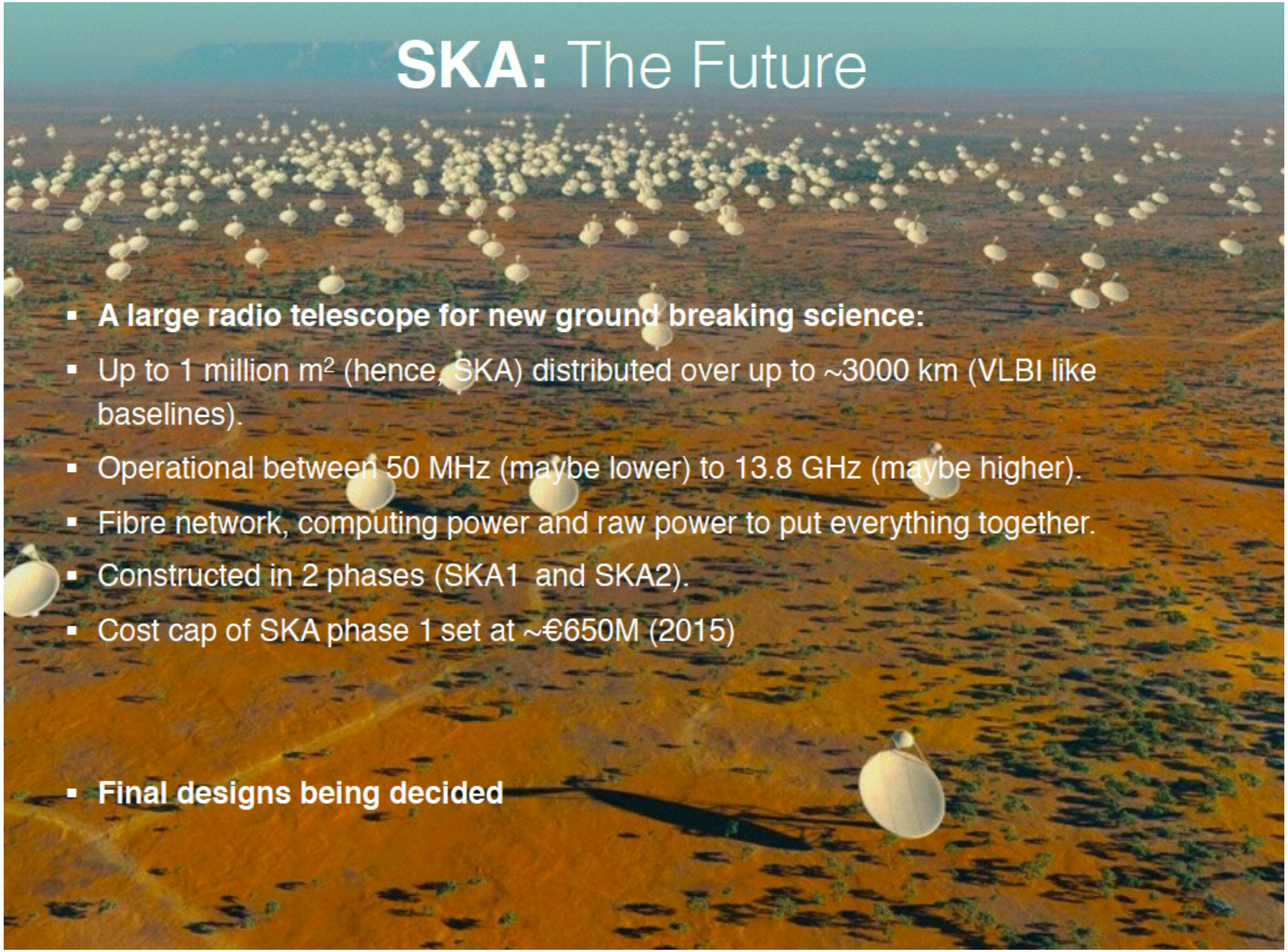
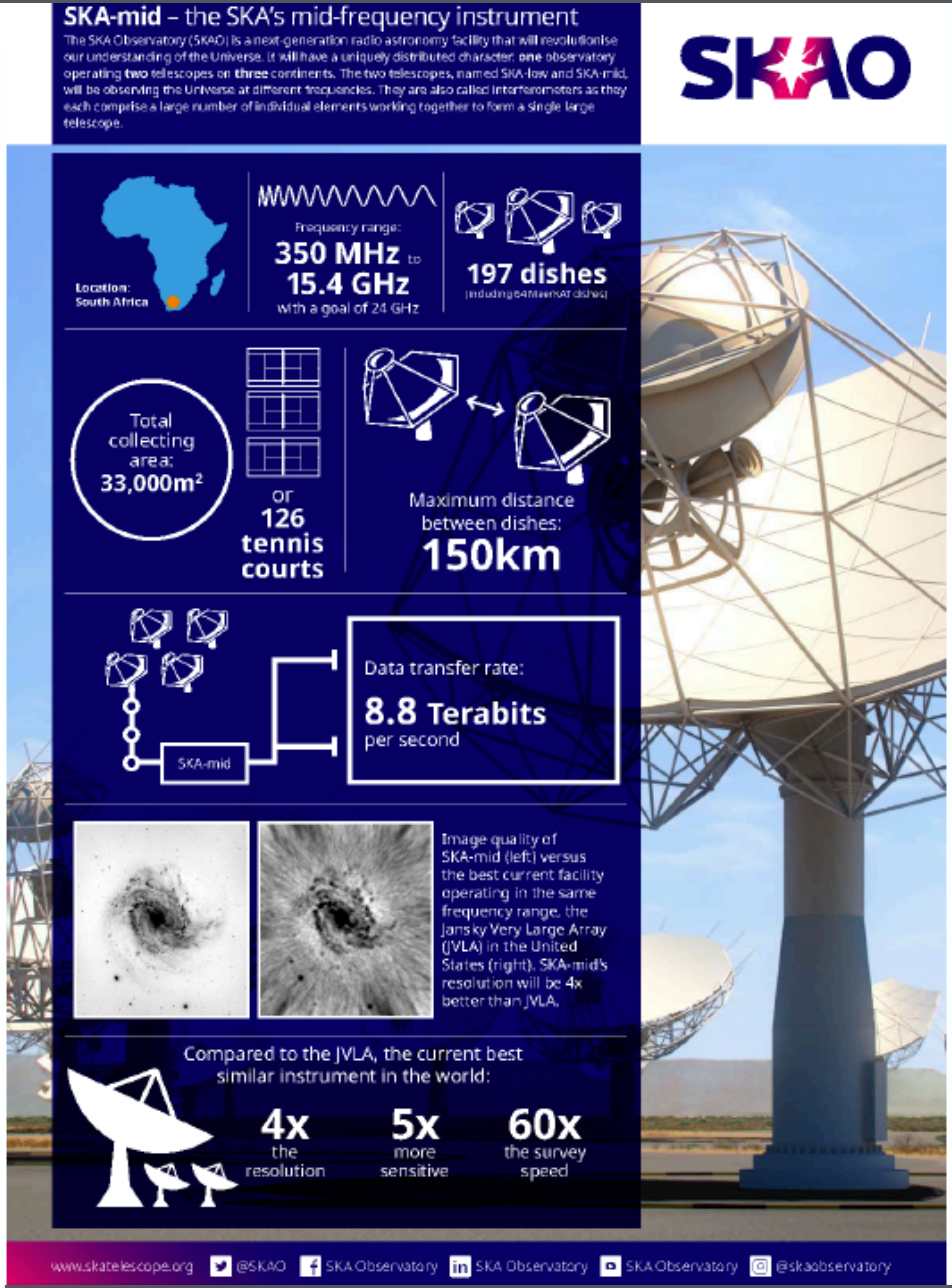


Figure 14: Lensing effect - *Left*: cluster-galaxy lensing: lensed galaxy at z=2.32 seen in merging cluster MACSJ0717.5 + 3745 with radio contours (red) overlaid on HST optical background image (adapted from van Weeren et al. 2016). *Right*: galaxy-galaxy lensing: Einstein's ring seen in JVAS B1938+666 with radio contours (black) overlaid on HST image (adapted from King et al. 1997).

Lensed galaxies are rare and faint in nature


SKA: The Future
A large radio telescope for new ground breaking science:
Up to 1 million m² (hence, SKA) distributed over up to ~3000 km (VLBI like baselines).
Operational between 50 MHz (maybe lower) to 13.8 GHz (maybe higher).
Fibre network, computing power and raw power to put everything together.
Constructed in 2 phases (SKA1 and SKA2).
Cost cap of SKA phase 1 set at ~€650M (2015)
Final designs being decided



1. Large dishes of 15m diameter

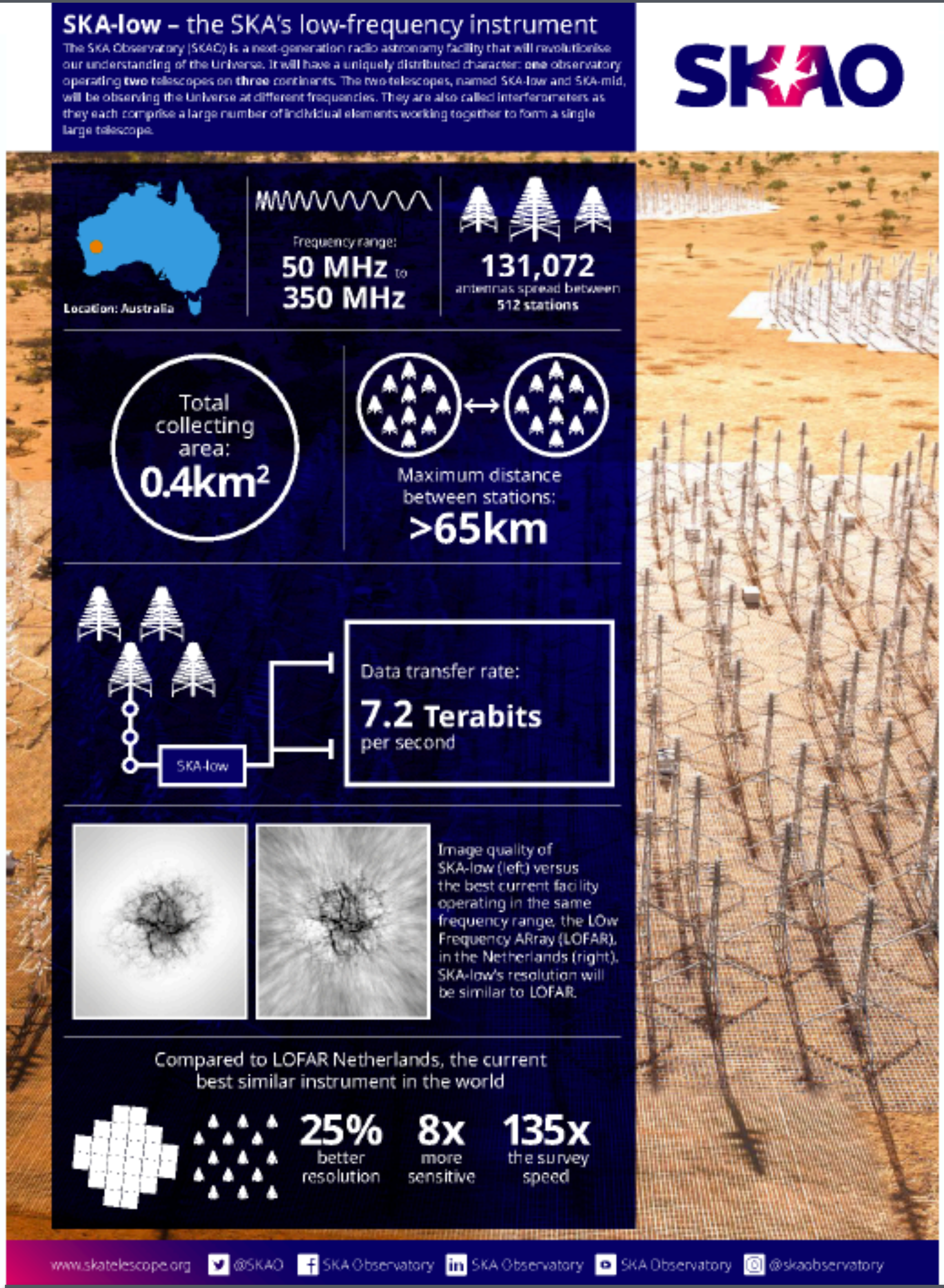
2. Wide Frequency coverage (GHz range) and built at MeerKAT site

3. Best for HI surveys, extragalactic spectral line studies, etc.

4. GMRT@ 1.4 GHz, 2 arcsec, 30 microJy/beam for 1 hr

5. SKA-Mid@ 1.4 GHz, 0.4 arcsec, 2 microJy/beam for 1 hr

5 x better resolution & 15 x better sensitivity



1.Dipole based aperture array with a quarter of a million wide bandwidth close-packed antennas of a single design within a 2 km diameter core and three spiral arms, extending out to a radius of 50 km and enabling higher spatial resolution observations.

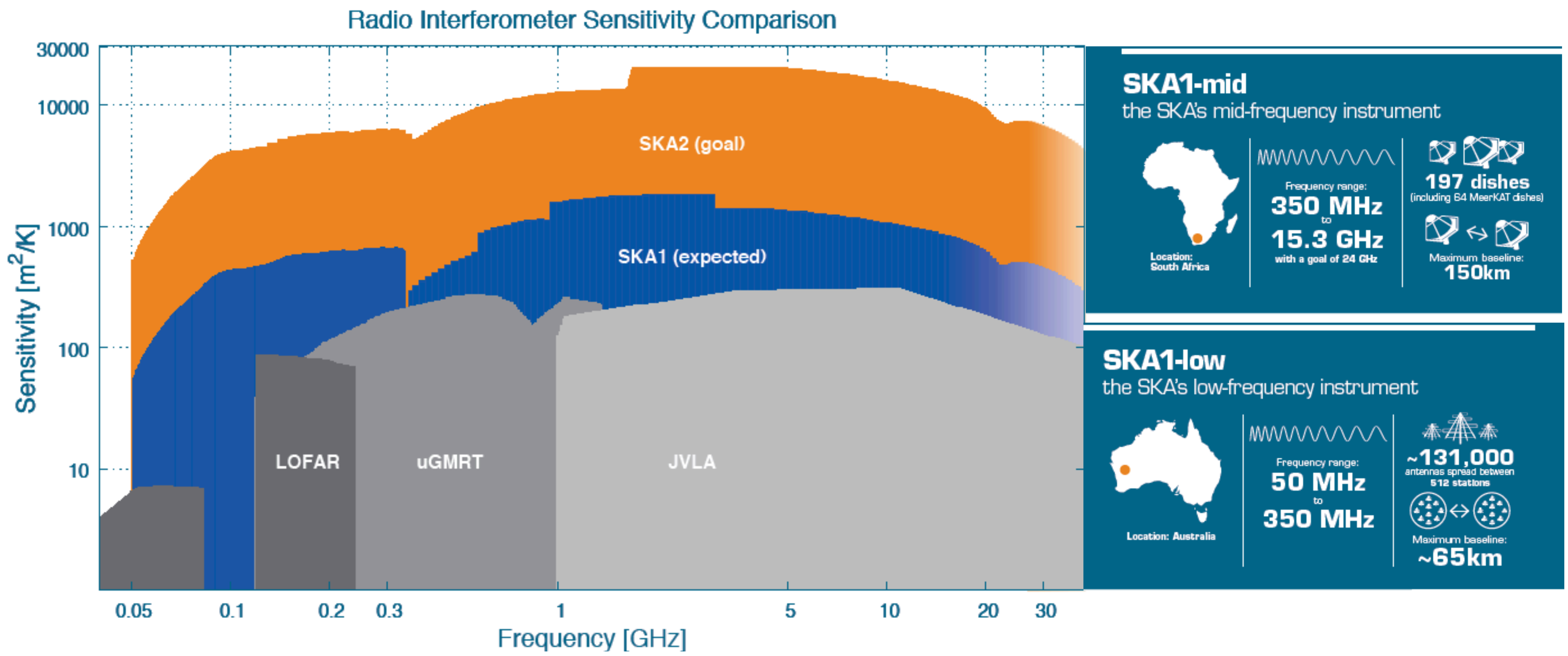
2.Wide Frequency coverage (MHz range), built at MWA site

3.Best for imaging surveys, EOR, pulsars

4.LOFAR@ 50 MHz, 20 arcsec, 7 mJy/beam for 1 Hr

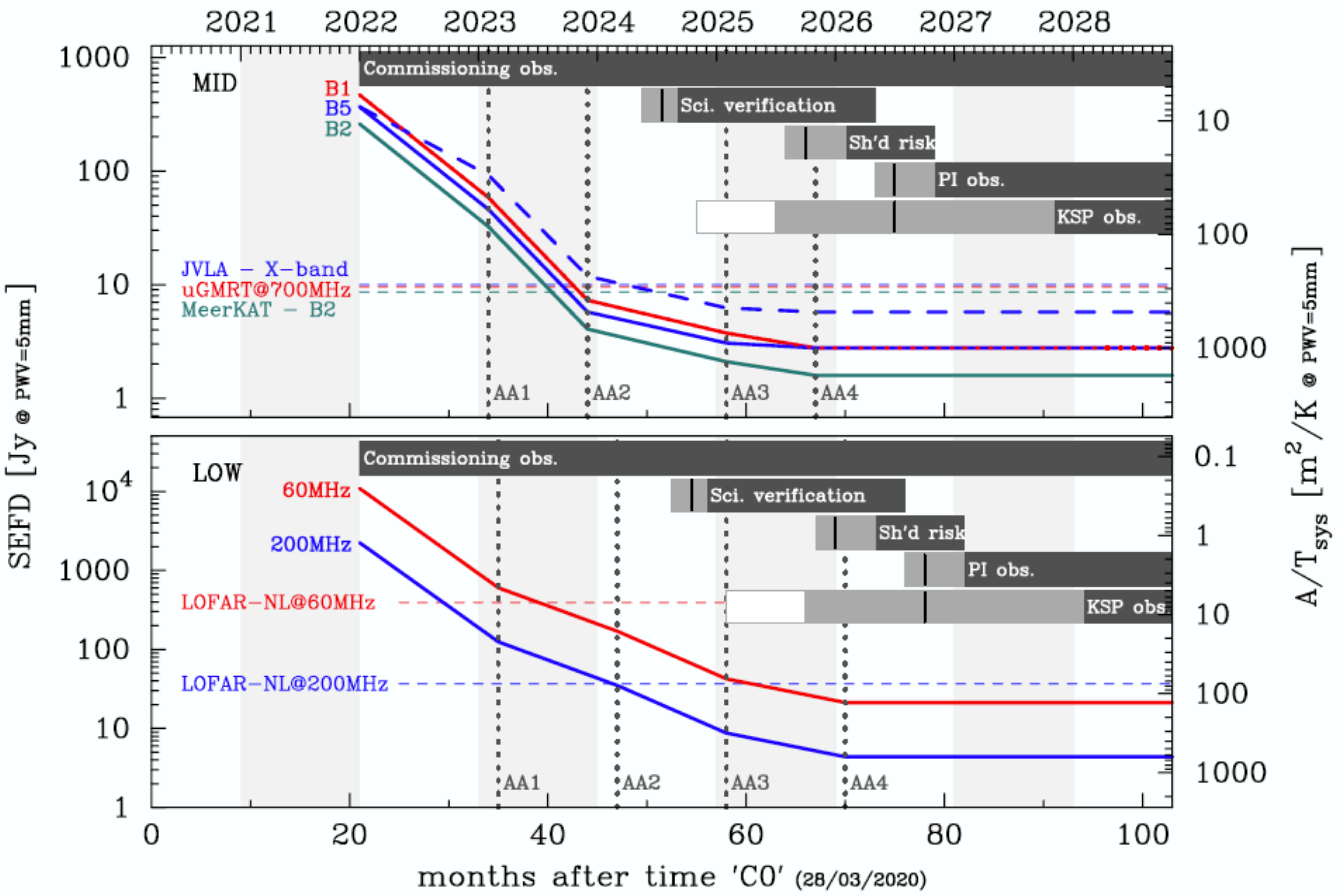
5.SKA-LOW@ 50 MHz, 11 arcsec, 26 microJy/beam for 1 Hr

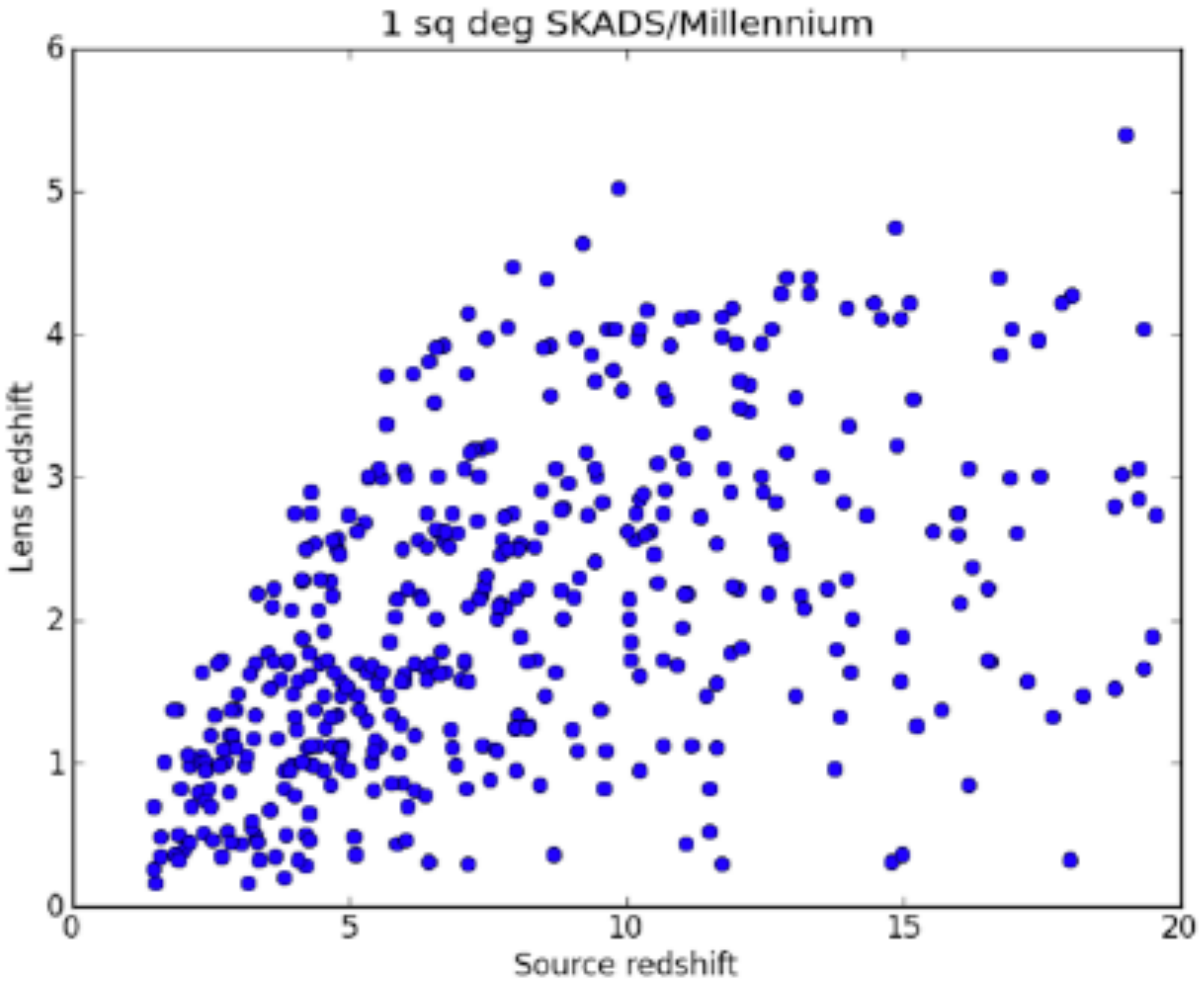
25% better resolution & 8 x better sensitivity

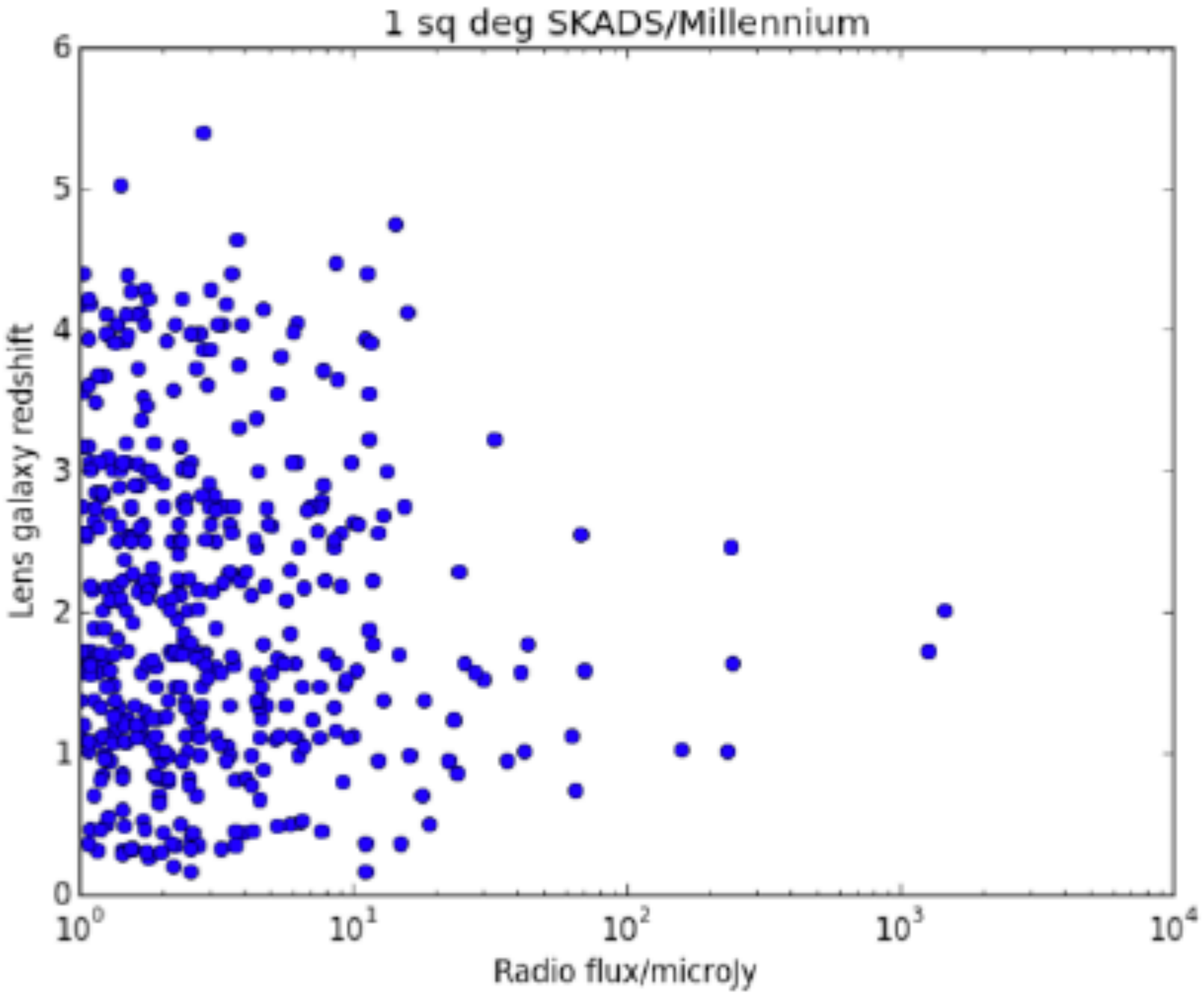


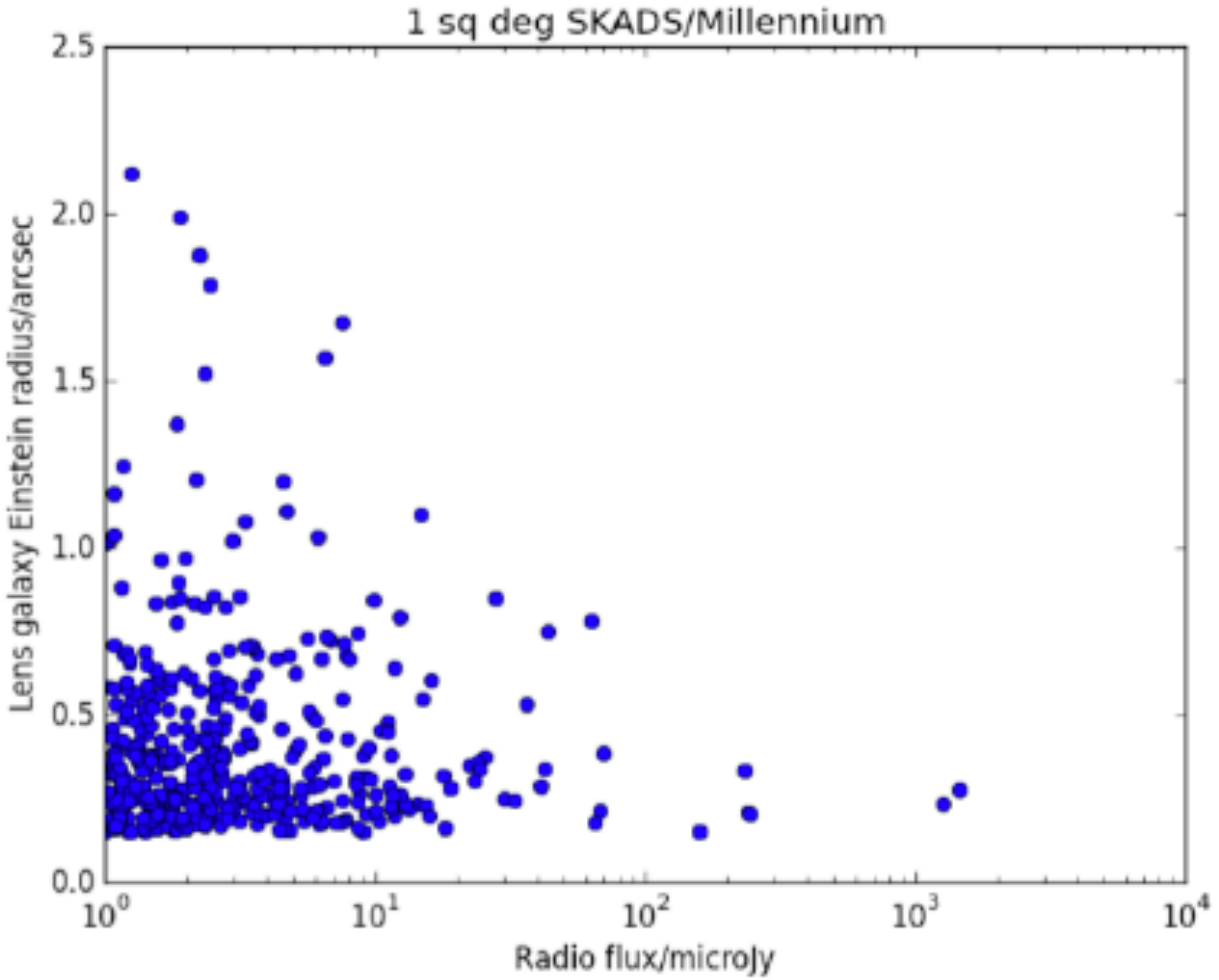
- SKA provides obsrevations at a broad frequency range.
- High sensitivity imaging and spectral data with a possibility to trace extragalactic spectral lines in gas-rich galaxies- like the lensed galaxies.

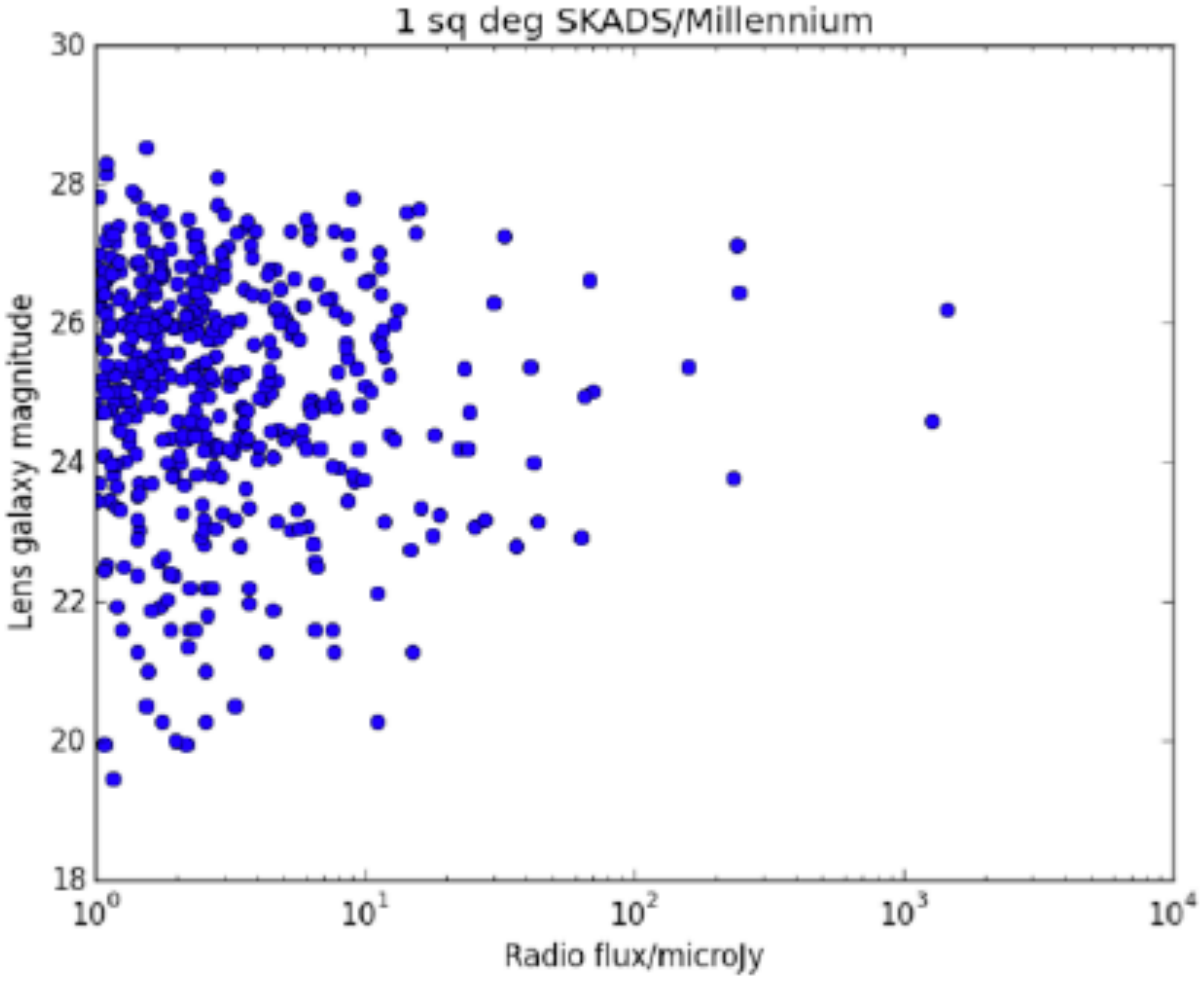
SKA project Timeline



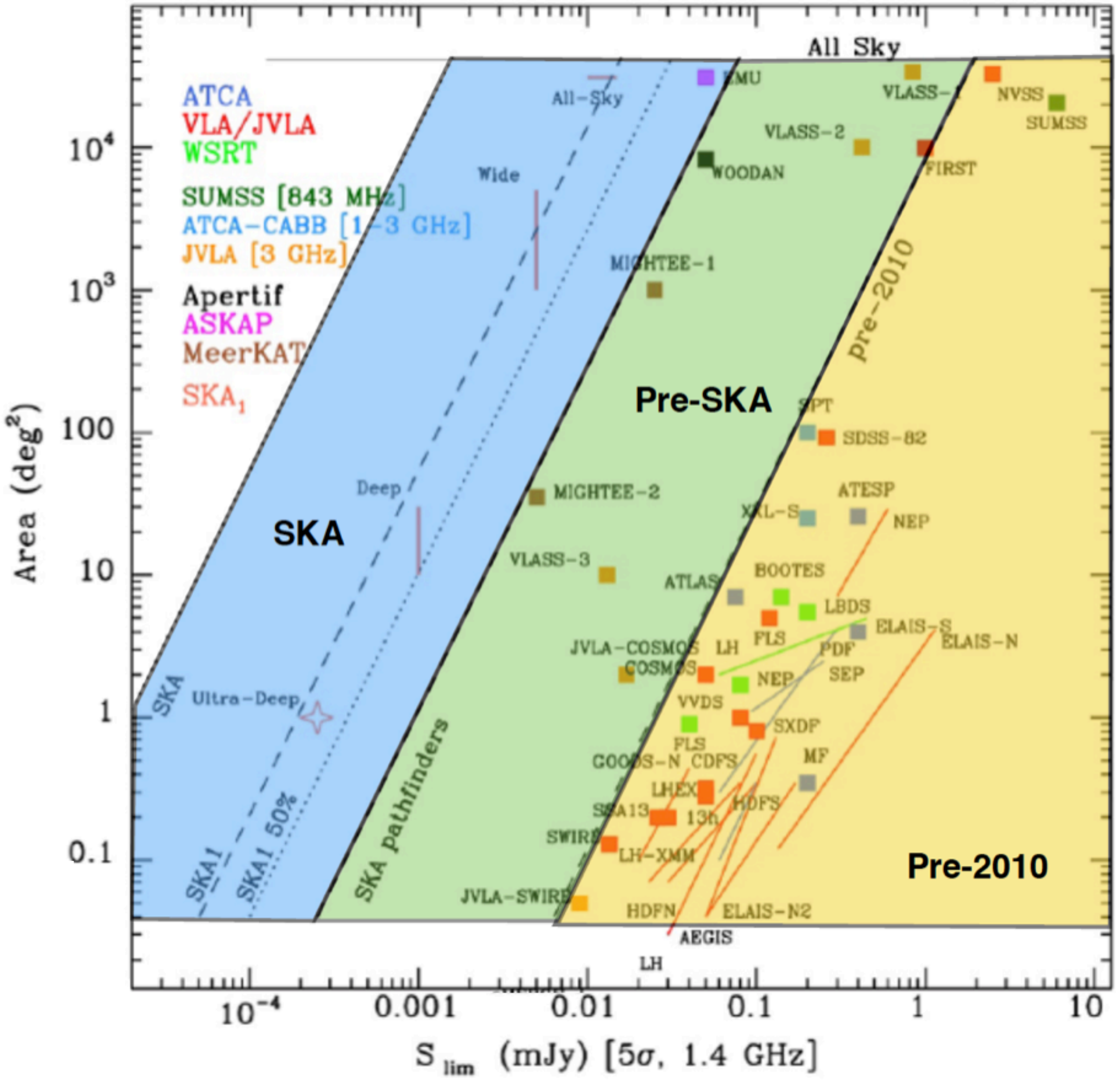

1 sq deg SKADS/Millennium
Lens redshift
Source redshift
0
1
2
3
4
5
6
0
5
10
15
20


1 sq deg SKADS/Millennium
Lens galaxy redshift
Radio flux/microJy
0
1
2
3
4
5
6
10^0
10^1
10^2
10^3
10^4


1 sq deg SKADS/Millennium
Lens galaxy Einstein radius/arcsec
Radio flux/microJy
2.5
2.0
1.5
1.0
0.5
0.0
10^0
10^1
10^2
10^3
10^4


1 sq deg SKADS/Millennium
Lens galaxy magnitude
Radio flux/microJy
30
28
26
24
22
20
18
10^0
10^1
10^2
10^3
10^4

SF galaxies with SKA Prandoni et al. 2014



Previous talks- Galaxy clusters, Commensality (Continuum + several bands+ HI)- Wide area survey- multi-wavelength

COMMENTS ON OBSERVING STRATEGY
Deep observations of 6000 hours at: SKA MID Band 1 (0.35 –1.05 GHz) and 2 (0.95 –1.76 GHz)- imaging (compact array and VLBI mode), Pointed observations of 2000 hours, 1-100 microJy, 0.6-0.28 arsec resolution for compact array and 0.05-0.1 arcsec, ~1 microJy for VLBI mode SKA MID Band 1 (0.35 –1.05 GHz) and 2 (0.95 –1.76 GHz)- spectral line (HI), Pointed observations of 2000 hours, 1-100 microJy, 0.6 arsec resolution for imaging and 0.2 for absorption, Absorption survey frequency resolution 200 MHz-1750 MHz, 10-4 KHz SKA Band 5 (4.6–15.3 GHz)- imaging (1000 hours) and spectral line (1000 hours, extragalactic non-HI eg. CO, HCN, HCO+ lines redshifted to 10-14 GHz range), Pointed observations, 0.3 microJy, 0.05 arsec resolution

Summary:

Gravitational Lensing:

Strong gravitational lenses are crucial for measuring mass distribution of distant galaxies, constraining various dark matter models (CDM, WDM, HDM), providing insights into galaxy formation and evolution.

SKA capabilities:

1. The SKA is expected to discover several new lense systems $>10^5$ (especially CC clusters) that can be used to identify a cutoff on the mass of the clusters hosting lensing properties at radio wavelengths and to measure mass functions and constrain various dark matter models.
2. Majority of known radio gravitational lenses have been found through specific surveys, emphasizing the need for high-sensitivity systematic observations possible with the SKA MID (Resolution- 0.25-0.5 arcsec, Sensitivity- 3 microJy rms, Band 2 (0.95-1.76 GHz)).
3. SKA will significantly increase the number of detected lensed galaxies $>10^3$, probing new classes of objects up to redshift z=5.
4. Deep surveys will uncover sub-μJy level sources, enhancing our understanding of star formation rates (SFR) in high-redshift galaxies and their evolution with z, Are they early-type dark-matter dominated galaxies or quasars?
5. The study of galaxy groups and lensing phenomena provides critical insights into star formation, galaxy evolution, and the nature of dark matter, helping our understanding of structure evolution over cosmic timescales.