The evolution of radio luminosity function of star forming galaxies and AGNs up to $z \sim 5.5$

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1. Introduction

✓ Cosmological evolution of physical properties of galaxy

2. Data

✓ VLA-COSMOS 3GHz large survey (Smolčić et al. 2017)

3. Method

✓ C^- method

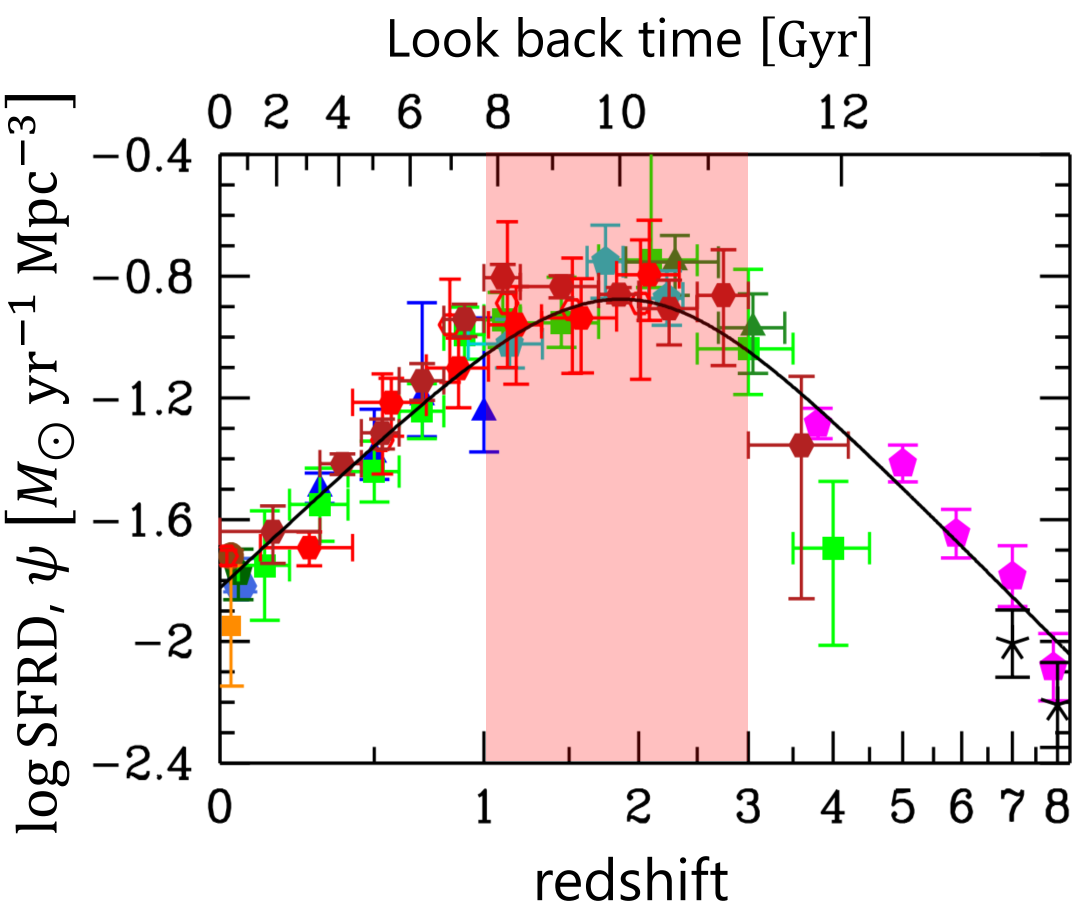
4. Result

5. Discussion

✓ The differential number counts, redshift distribution, SFRD evolution, NC+GL

Introduction: galaxy evolution

The physical properties of galaxies evolves through cosmic time (e.g., star formation rate density (SFRD), SMBH accretion rate).



Madau & Dickinson (2014)

The Cosmic Noon

The peak of galaxy interaction and star forming activity (Hopkins et al. 2008, Popping et al. 2017).

The mass accretion rate onto SMBH is also the highest (Caplar et al. 2018).

Introduction: galaxy evolution

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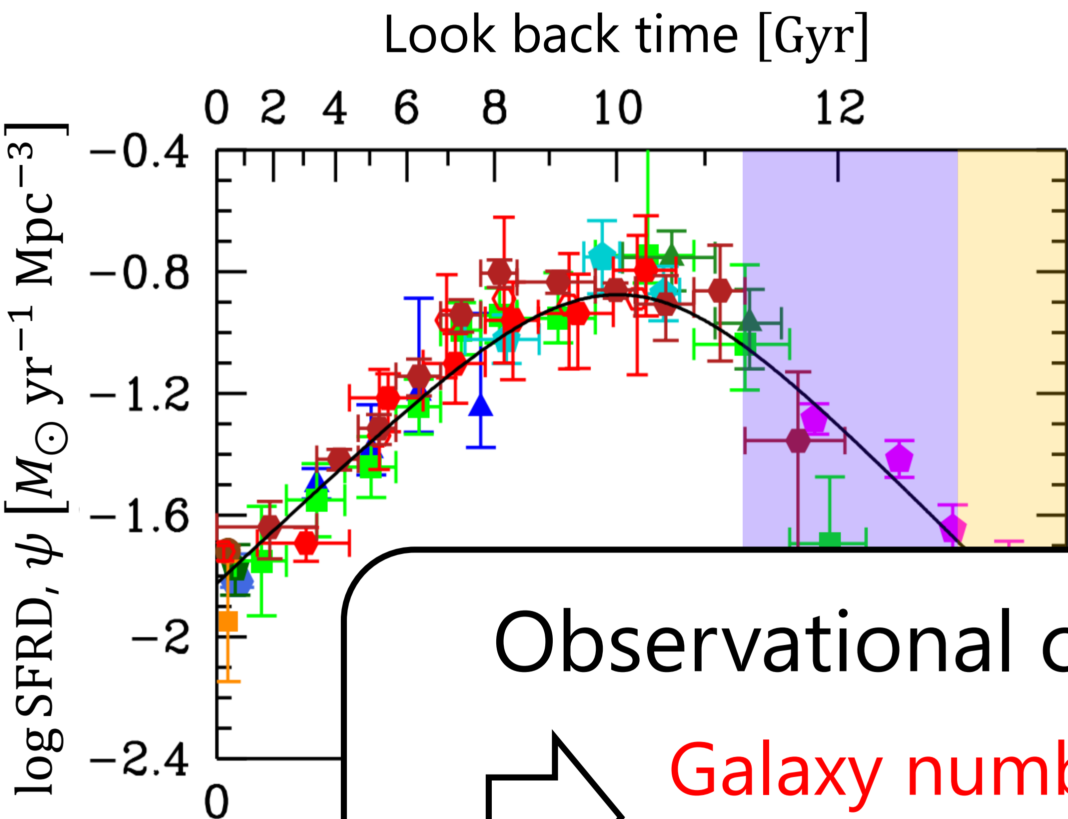


Madau & Dickinson (2014)

The Cosmic Dawn

Active galaxy formation.

Epoch of reionization: $z = 6 - (15 - 20)$

Observational constraint

⇨ Galaxy number counts & Luminosity function

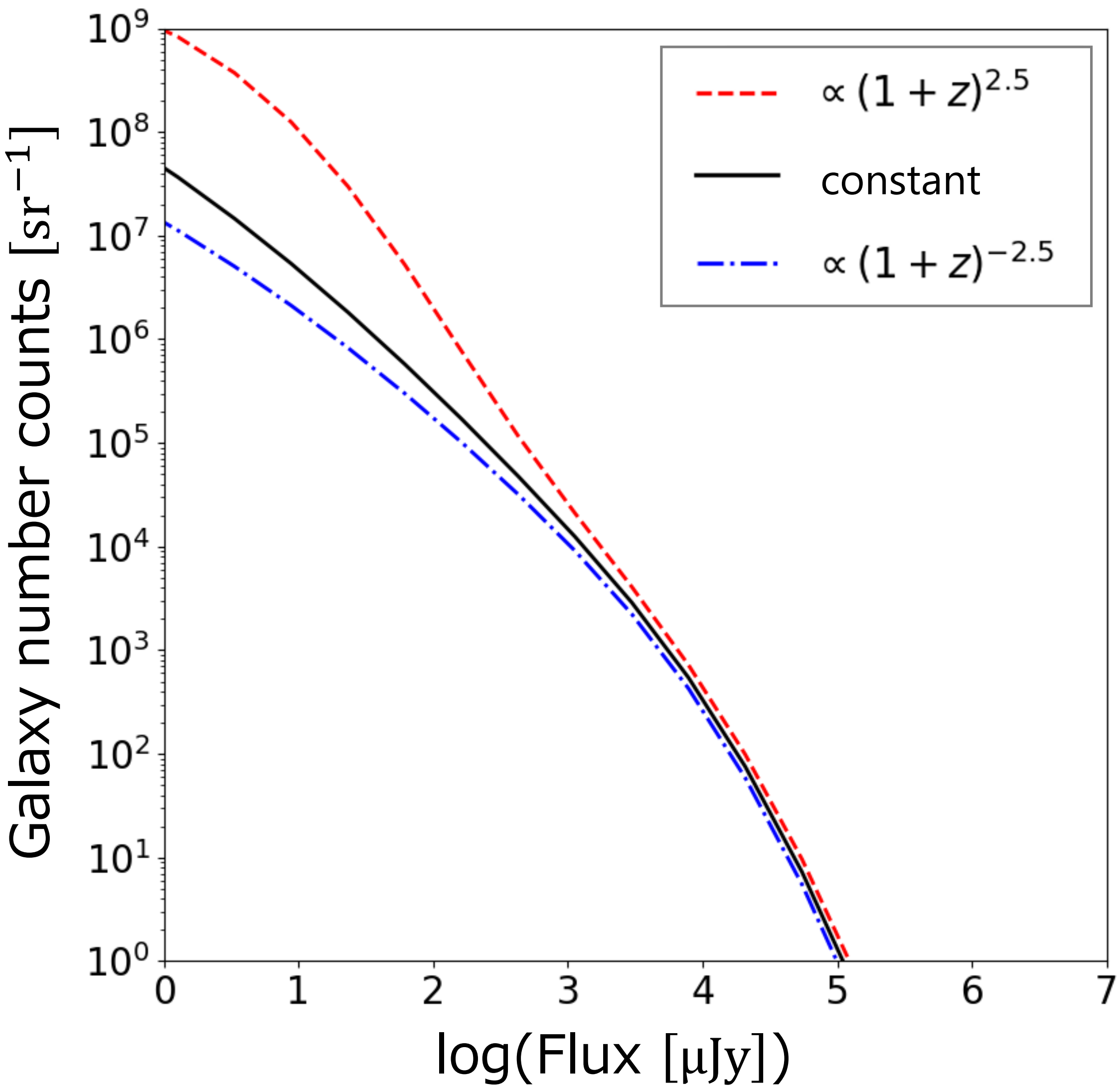
The aim of this study

Assess the parameter of luminosity function for each redshift ranges

↓

Construct a evolution model on star forming galaxy (SFG) and active galactic nuclei (AGN)

Introduction: empirical constrains on galaxy evolution through number counts (NC)



In the past, the luminosity of galaxy is...

brighter

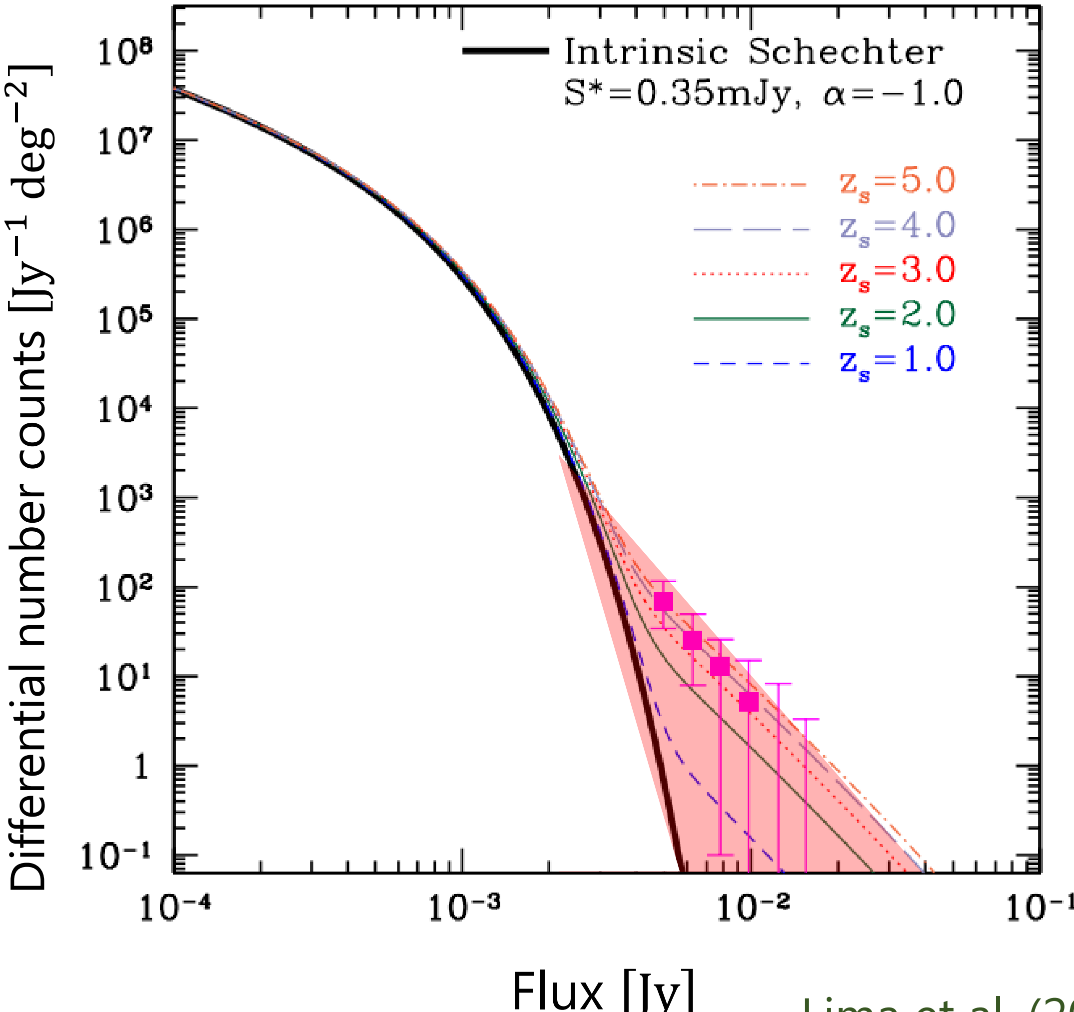
➡ The NC increases

fainter

➡ The NC decreases

Introduction: gravitational lensing (GL)

Bias on number counts: gravitational lensing



Lima et al. (2010)

Increase of NC due to the effect of GL.

In submillimeter band, approximately 60% of NC shows effect of GL at maximum.

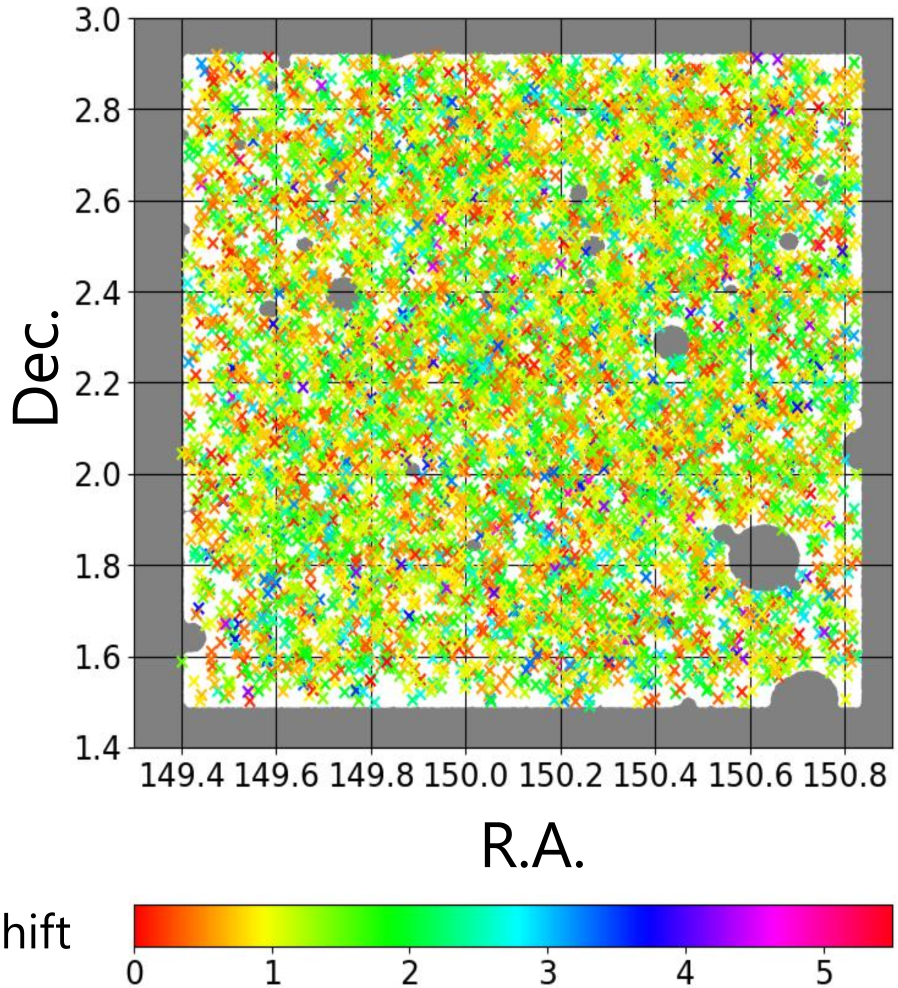
Data: VLA-COSMOS 3GHz Large Project

Region	VLA-COSMOS field ($1.77\mathrm{deg}^2$)
Number of sample	10,830 ($S/N > 5$)
Feature	The deepest radio survey $S_{\mathrm{lim}} = 11.0(\mu\mathrm{Jy}), z < 5.5$
Reference	Smolčić et al. (2017)

Karl G. Jansky Very large array (VLA)

www.vla.nrao.edu/

$1.4\mathrm{deg} \times 1.4\mathrm{deg}$



Data: selection

Color (Ilbert et al. 2010)

Blue & Green: $M_{\mathrm{NUV}} - M_r < 3.5$

Radio excess; 3σ (Delvecchio et al. 2017)

$$\log\left(\frac{L_{1.4\mathrm{GHz}}}{\mathrm{SFR}_{\mathrm{IR}}}\right) > 21.984(1+z)^{0.013}$$

Red: $M_{\mathrm{NUV}} - M_r > 3.5$

Herschel detection

Non Herschel detection

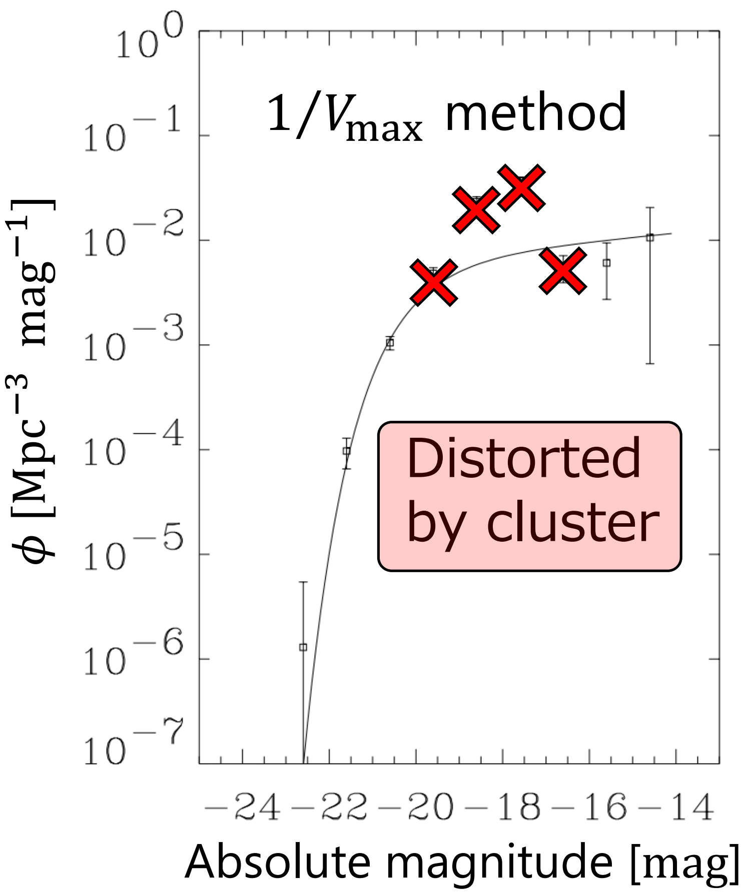
SFG (4,647)

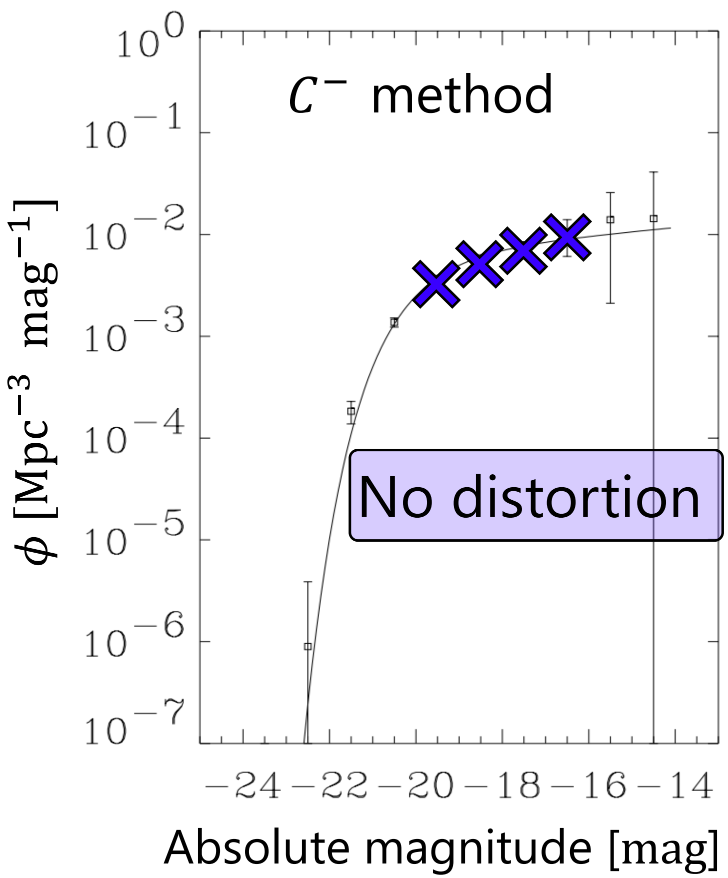
AGN (1,814)

C^- method (Lynden-Bell 1971)

✓ C^- method is not affected by cosmic variance.

Luminosity function inferred from mock sample with a cluster.



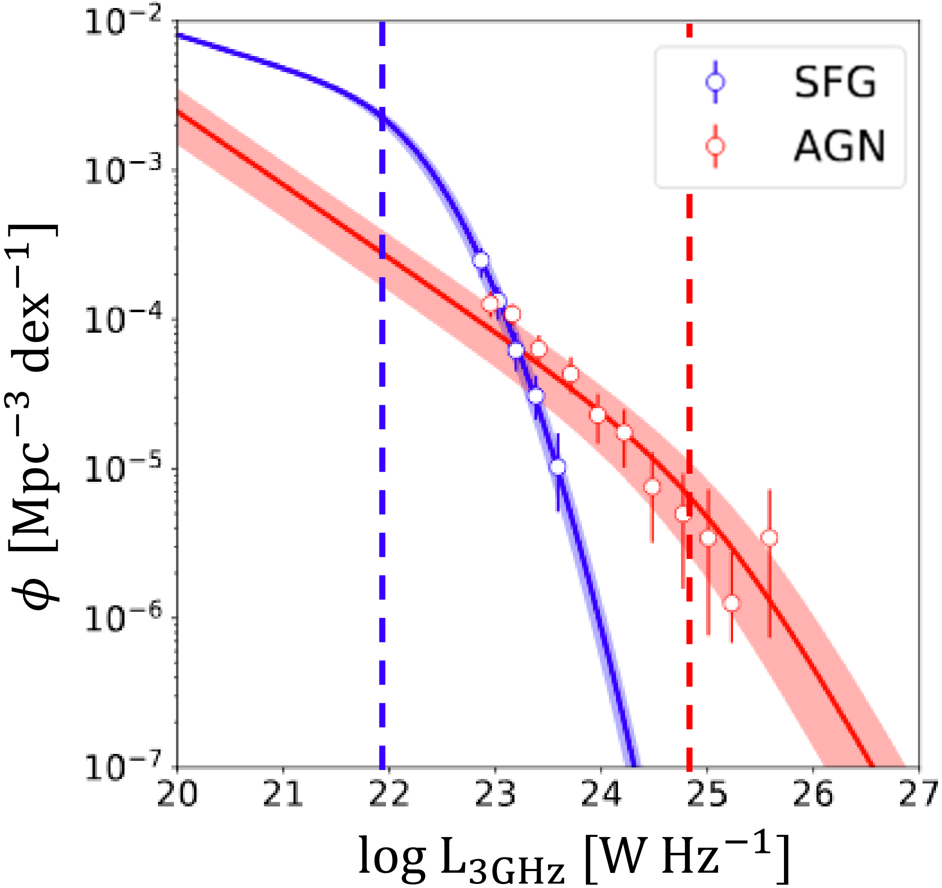


Takeuchi et al. (2000)

Results: 3GHz luminosity function

The bright end of luminosity function is dominated by AGN and the faint end is dominated by SFG for all nine redshift ranges.

$z = 0.7 - 1.0$



We assumed pure luminosity evolution model (PLE) and the redshift dependency of parameter L_* is modeled as below.

$$L_*(z) = L_{*,0}(1+z)^{Q(z)}$$

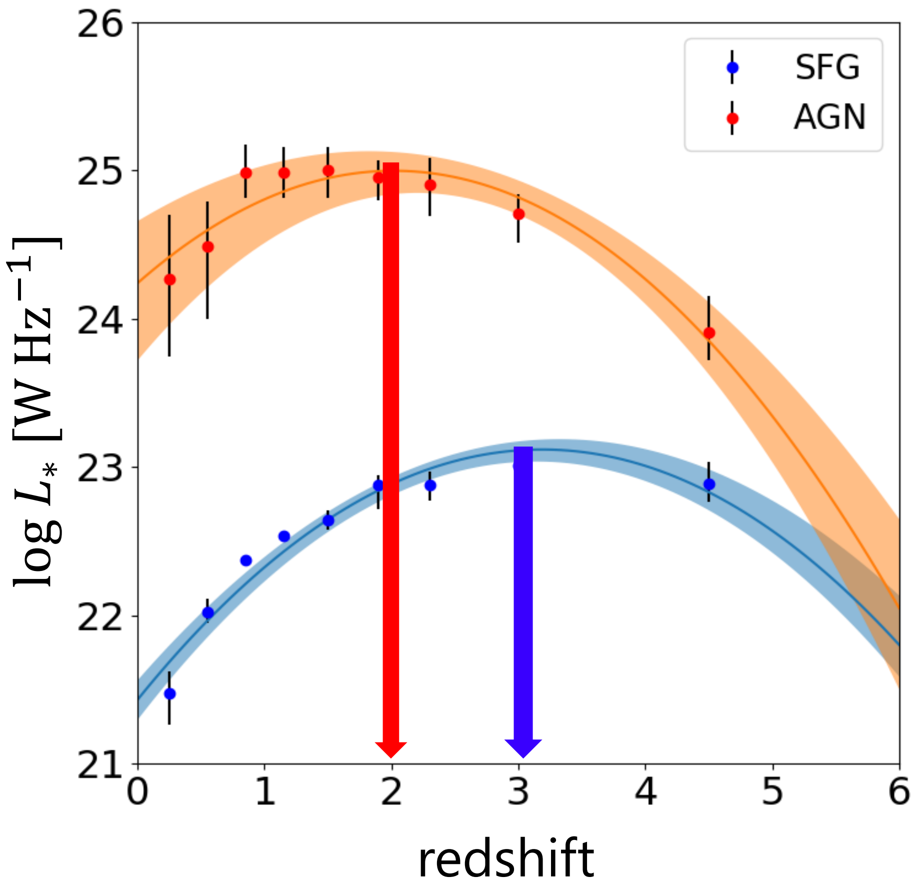
with $Q(z) = \alpha_1 + \alpha_2 z$

(The error shows 95% confidence interval estimated with bootstrap method)

Results: redshift dependency of L_*

The SFG has a peak at $z \sim 3$ ($t_{\cos} \sim 2.2$ Gyr) and AGN have a peak at z ~ 2 ($t_{\cos} \sim 3.3$ Gyr).

The time lag is $\Delta t_{\cos} \sim 1$Gyr.



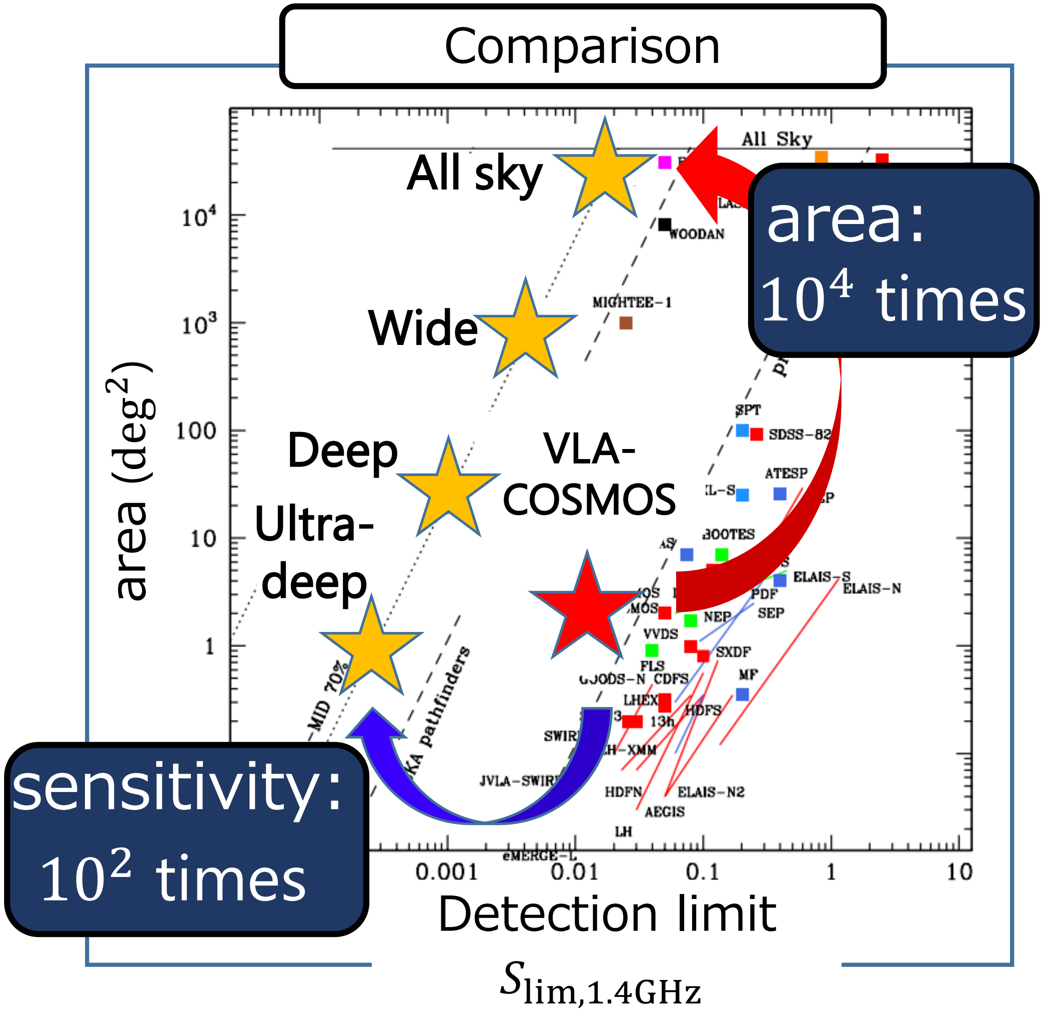
Star formation triggered by galaxy merger.

$\tau = 0.5 - 1$ Gyr

Mancuso et al. (2016)

SF suppression due to AGN feedback.

Square Kilometre Array: SKA



Prandoni & Seymour (2015)

High angular resolution,
High sensitivity,
Large observation area

Constraints on high redshift universe physics.

Discussion

Redshift dependency of $L_*(z)$

- Redshift distribution, SFRD history
- Estimation of number counts in the SKA surveys

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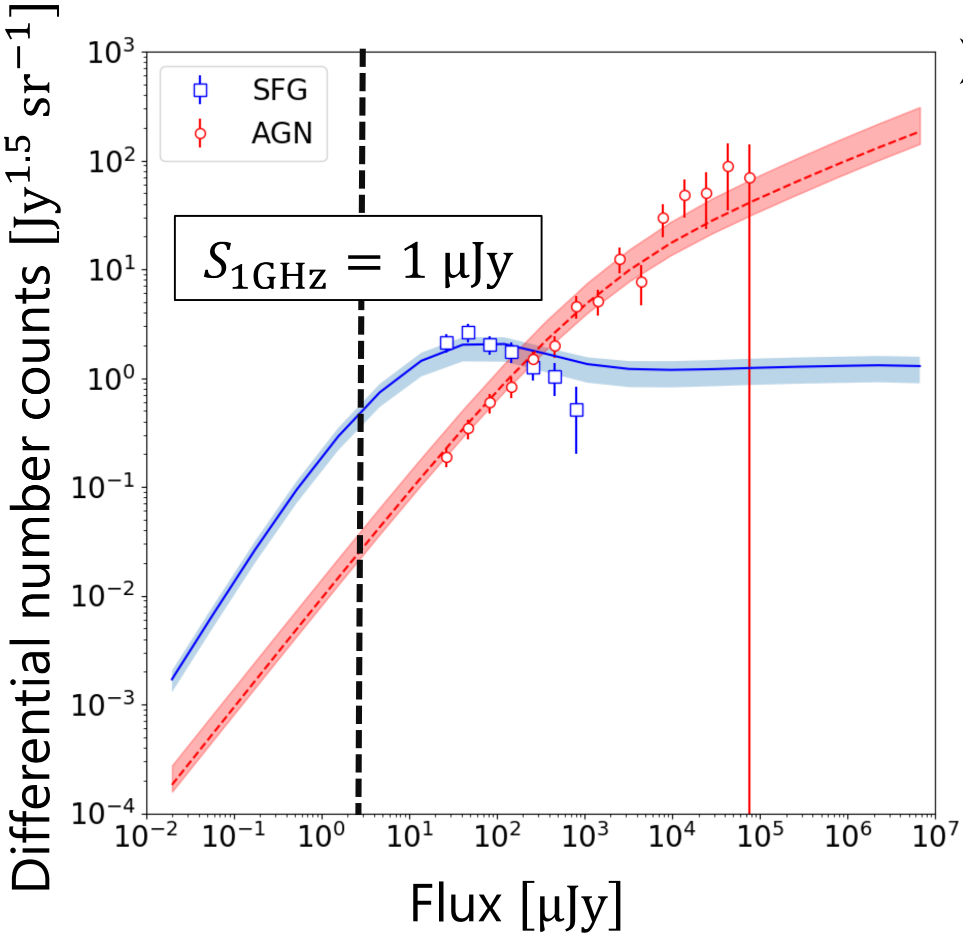
Assessment of the effect of gravitational lensing on galaxy number counts.

Discussion: galaxy number counts

The comparison of Euclid normalized differential galaxy number counts between the model and observation.



- Bright end ($S_{3\mathrm{GHz}} > 1$ mJy)

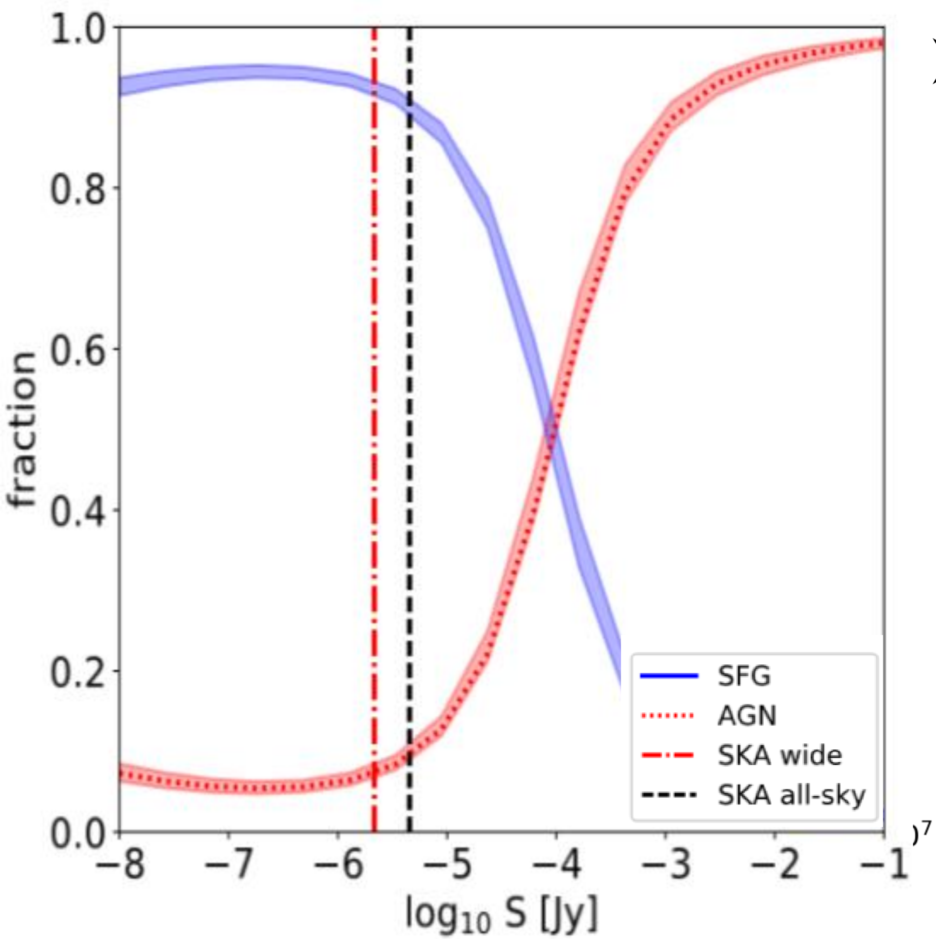
  About 90% of NC is dominated by AGN.

- Faint end ($S_{3\mathrm{GHz}} < 10\ \mu\mathrm{Jy}$)

  With SKA-wide survey detection limit, about 90% of NC is dominated by SFG.

Discussion: galaxy number counts

The comparison of Euclid normalized differential galaxy number counts between the model and observation.



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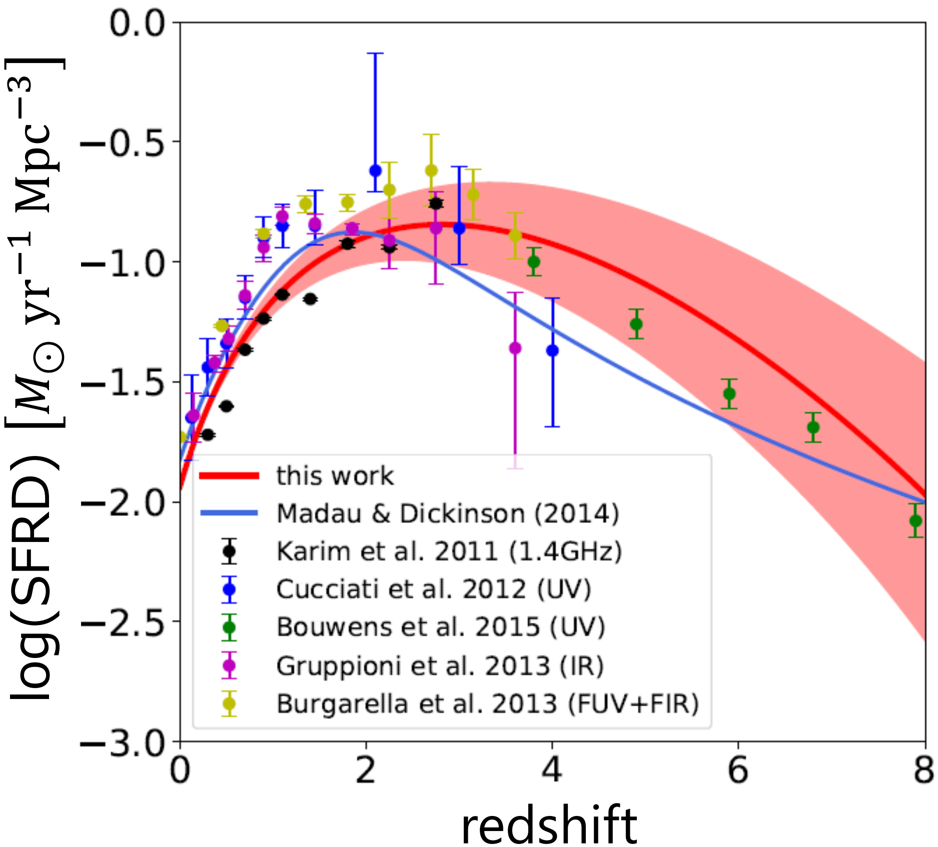
Discussion: redshift dependency of SFRD

- SFR estimation from 3GHz radio data



3GHz

$q = 2.34$ (Dale & Helou 2002)

FIR

$L_{\mathrm{IR}} = 1.91 L_{\mathrm{FIR}}$ (Magnelli et al. 2015)

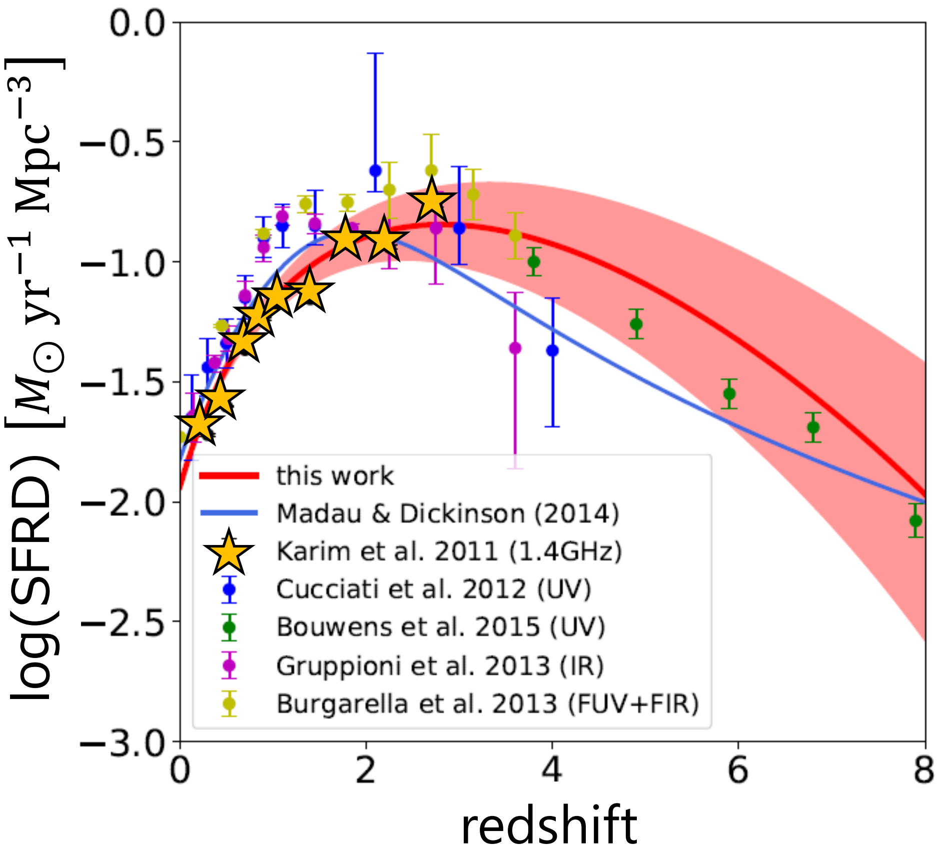
IR

$$\mathrm{SFR}\ [M_\odot\ \mathrm{yr}^{-1}] = \frac{L_{\mathrm{IR}}[L_\odot]}{5.8 \times 10^9}$$

(Kennicutt 1998)

SFR

Discussion: redshift dependency of SFRD



For $z < 2$:

The SFRD is consistent with the value estimated from UV and IR observations.

For $z > 2$:

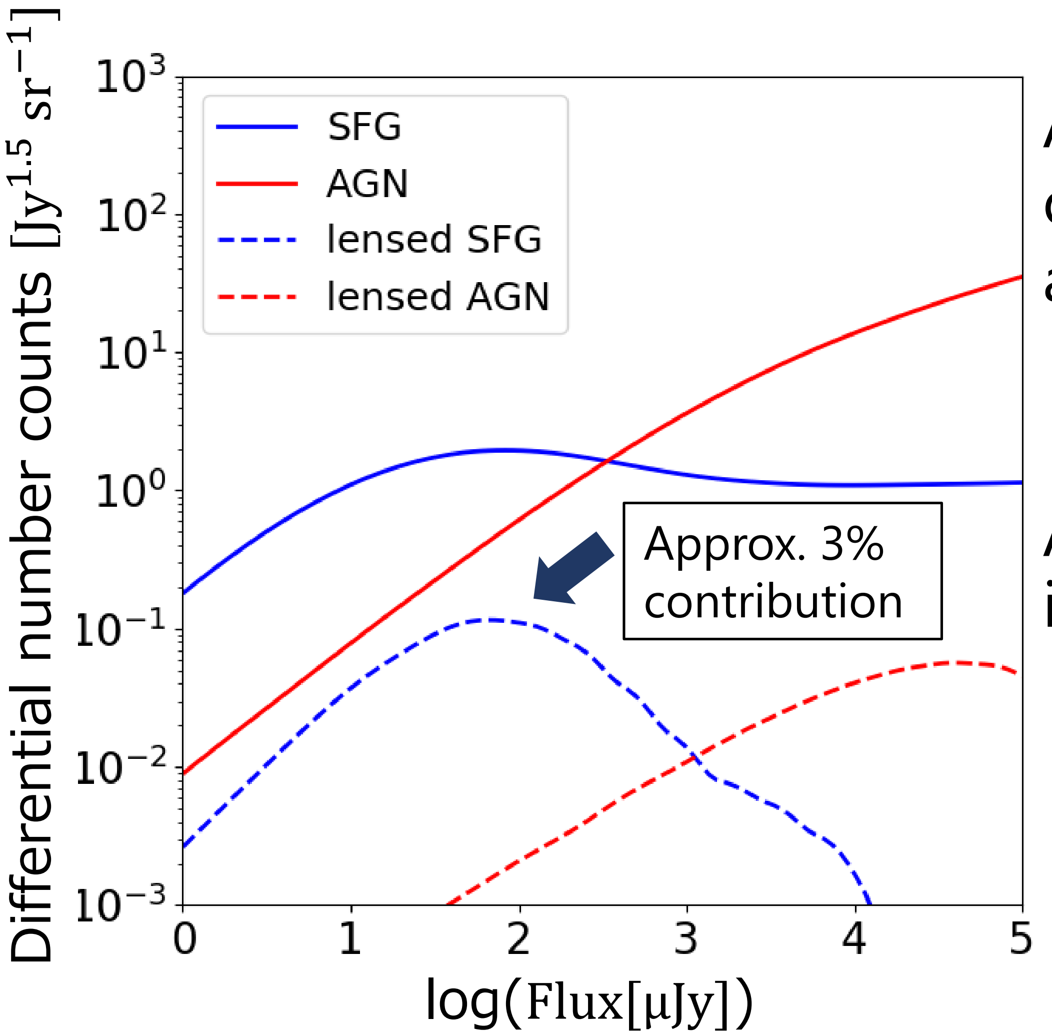
The SFRD is larger by factor 2-3.

The results with radio observation (Karim et al. 2014, $z < 3$) is consistent with this model.

This result indicates the q value (or IR-radio ratio) has lower value at high redshift (c.f., Magnelli et al. 2015).

Discussion: NC + GL

The assessment of the effect of lensing magnification on galaxy number counts.



As for SFG, the contribution of lensed galaxies is up to 3% at $S_{3GHz} \sim 100$ μJy.

As for AGN, the contribution is less than 0.5%.

Conclusions

1. We assessed the $3\mathrm{GHz}$ luminosity function for samples $z < 5.5$ with C^- method and constructed the evolution model of galaxies.

2. SFRD history indicates the non-constancy of the radio-FIR relation at $z > 2$.

3. The effect of gravitational lensing on the differential number counts is about 3% at $S_{3\mathrm{GHz}} \sim 100\ \mu\mathrm{Jy}$ for SFGs at most.