SKA時代の21cm観測による AGN光度関数への制限

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Constraining the luminosity function of active galactic nuclei through the reionization observations in the SKA era

arXiv:2104.05212

Introduction

SMBH growth (Seeds→SMBH)

The growth history of SMBH can be constrained from AGN observation at high redshift.
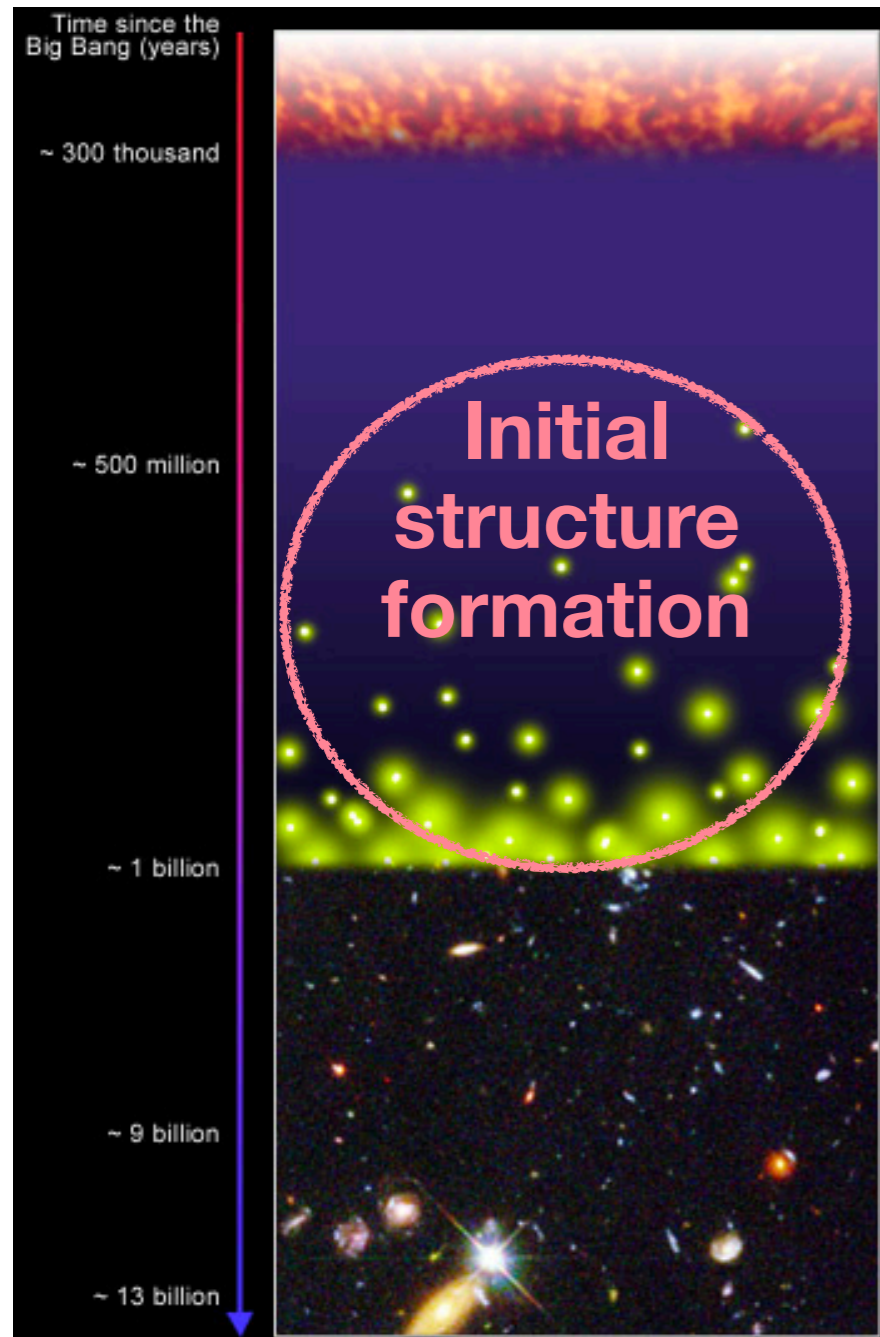
- ✓ IGM ionization property

- ✓ Ionizing source : emission from AGN

SKAO

Can we investigate the evolution of AGN from 21cm line emission from IGM via SKA observation?

Goal

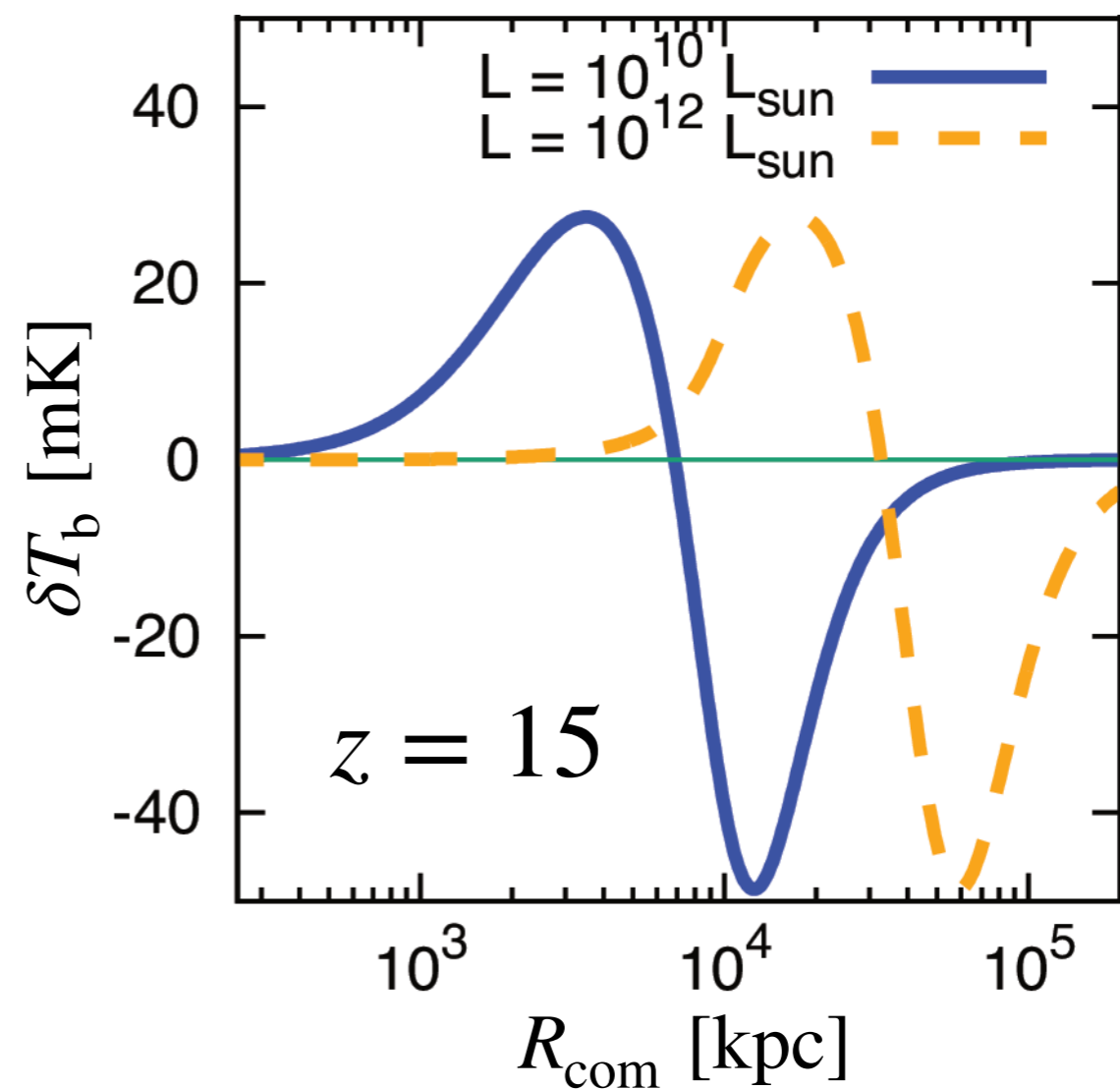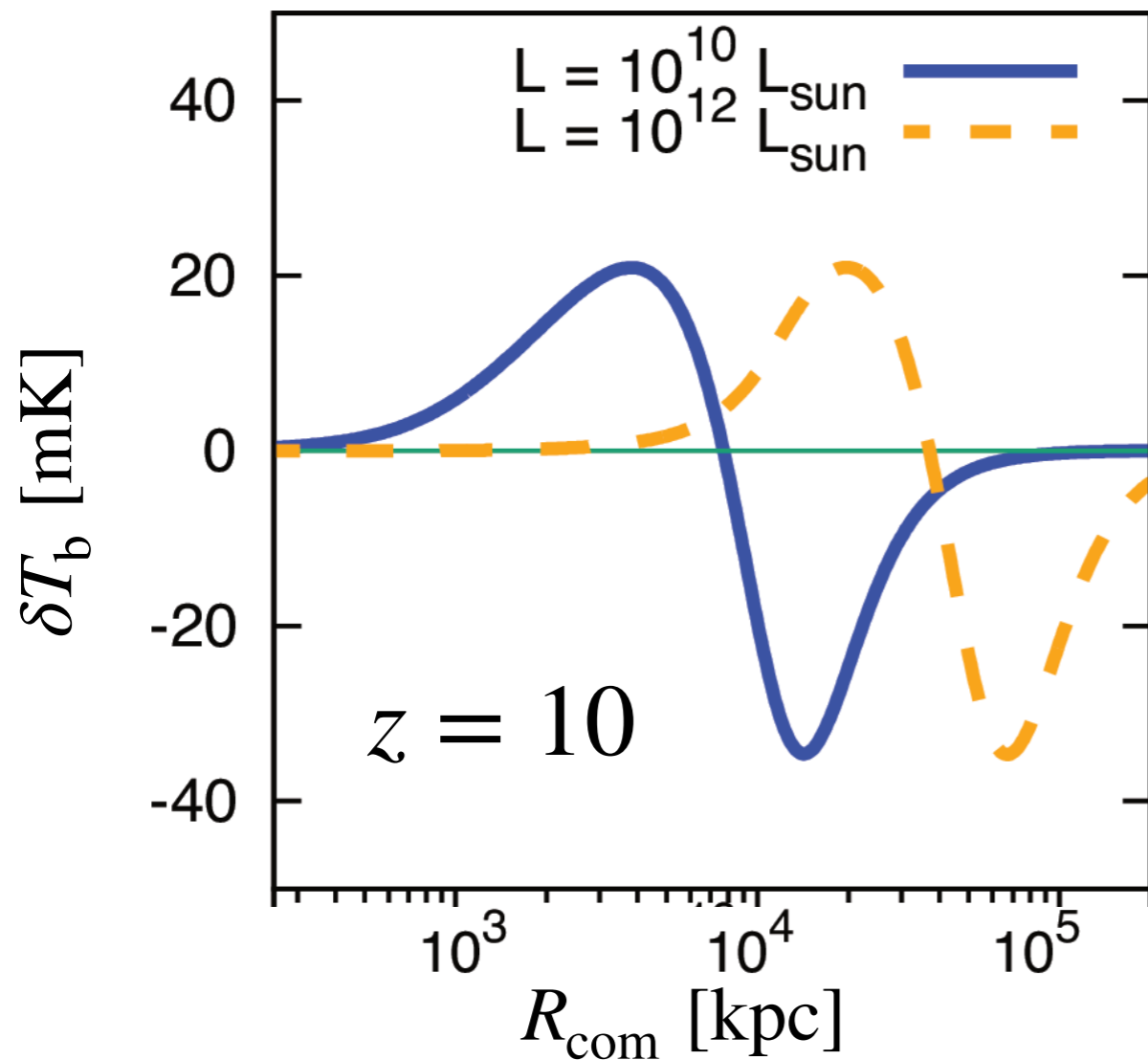Constraints on the AGN luminosity function and its evolution throughout the reionization era with IGM ionization model.

Time since the
Big Bang (years)

~ 300 thousand

~ 500 million

Initial structure formation

~ 1 billion

~ 9 billion

~ 13 billion

Diorgovski et al.

Radial profile of brightness temperature

Brightness temperature : $\delta T_{\rm b}$

$$\delta T_{\rm b} = \frac{T_{\rm spin}(T_{\rm k}) - T_{\rm CMB}}{1+z}(1 - e^{-\tau_{\nu_0}(x_{\rm HI})})$$

- Broader distribution with brighter central luminosity up to 1 [arcmin]
- Signal gets brighter with larger $n_{\rm H}$, $T_{\rm gas}$ in high redshift

Minimum AGN luminosity SKA

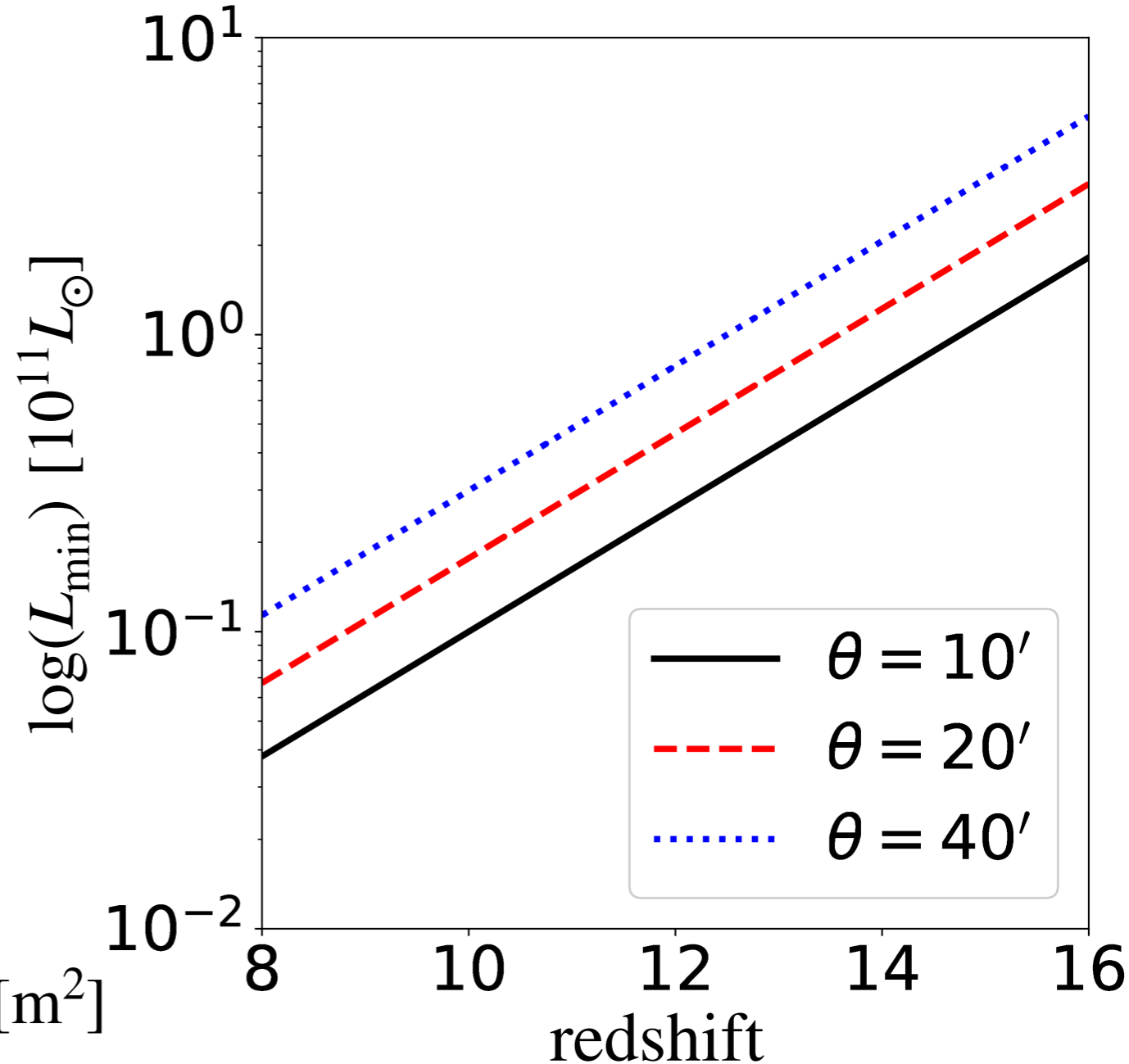✓ Conversion from brightness temperature to 2D profile $\delta T_{\mathrm{b}}^{\mathrm{2D}}$

$$\delta T_{\mathrm{b}}^{\mathrm{2D}} = 2 \int_{r_{\min}(z)}^{r_{\max}(z)} dr_z \delta T_{\mathrm{b}}(R)$$

- Noise in terms of brightness temperature
$$\delta T_{\mathrm{N}}(\lambda_{\mathrm{obs}}) = \frac{\lambda_{\mathrm{obs}}^2}{\Delta\theta^2 A_{\mathrm{eff}}} \frac{T_{\mathrm{sys}}}{\sqrt{\Delta\nu t_{\mathrm{obs}}}}$$

✓ Assumption

- 100 hrs observation with SKA

- Effective collecting are : $A_{\mathrm{eff}} = 10^4$ [m^2]

- Only $\delta T_{\mathrm{b}}^{\mathrm{2D}}$ region three times brighter than δT_{N},

→ Detect!

Fisher analysis

1. Number of galaxies in (i, j)-th bin : $N_{i,j}$

$$N_{i,j} = 4\pi f_{\text{sky}} \int_{z_{i,\text{min}}}^{z_{i,\text{max}}} dz \int_{L_{\text{min},j}} dL \; \frac{dV}{dz}\frac{dn}{dL}(L, z)$$
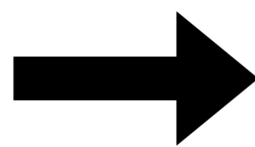
2. Element of Fisher matrix : $F_{\mu\nu}$

$$F_{\mu\nu} = \sum_{i,j} \frac{1}{\sigma_{i,j}^2} \frac{\partial N_{i,j}}{\partial \theta_\mu} \frac{\partial N_{i,j}}{\partial \theta_\nu}$$

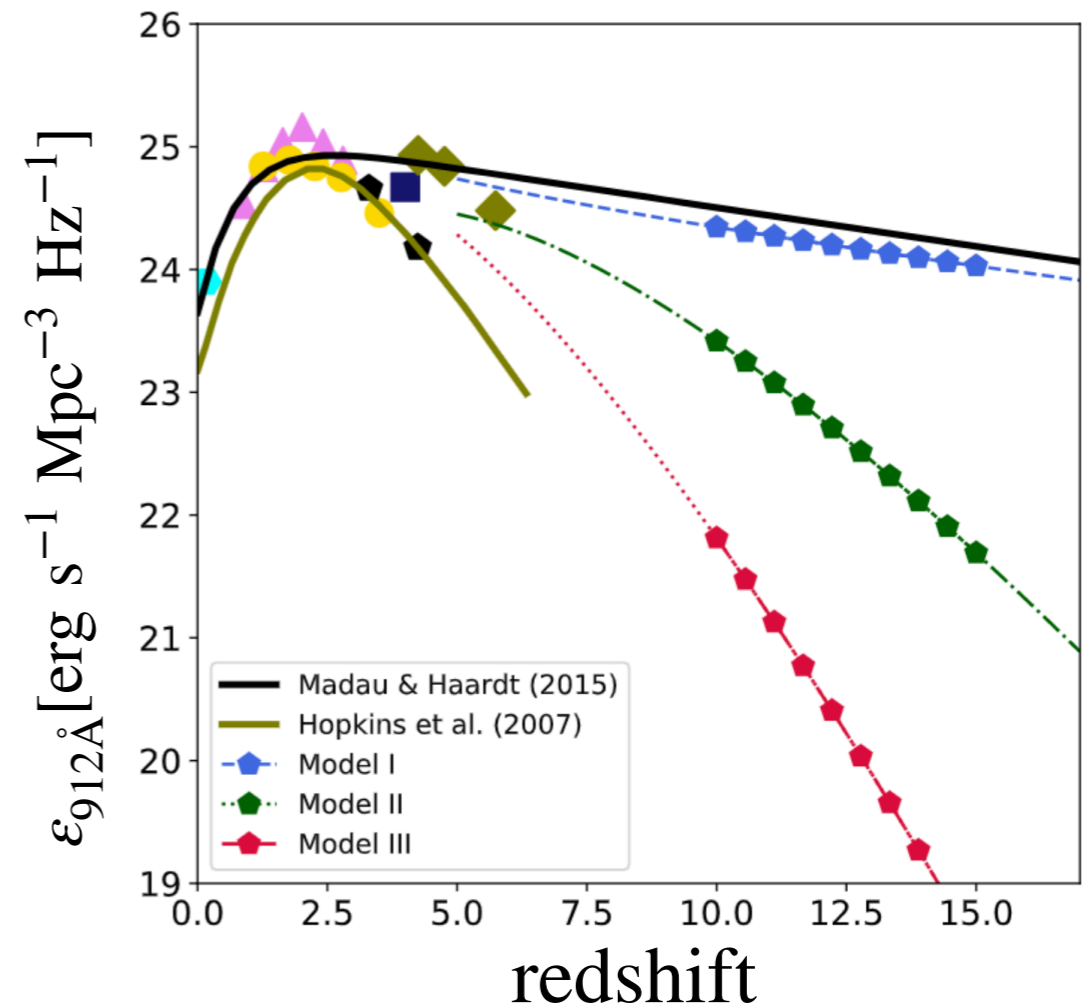$$(\mu, \nu) = (A, \gamma_1, \gamma_2, \beta_1, \beta_2, L_*)$$

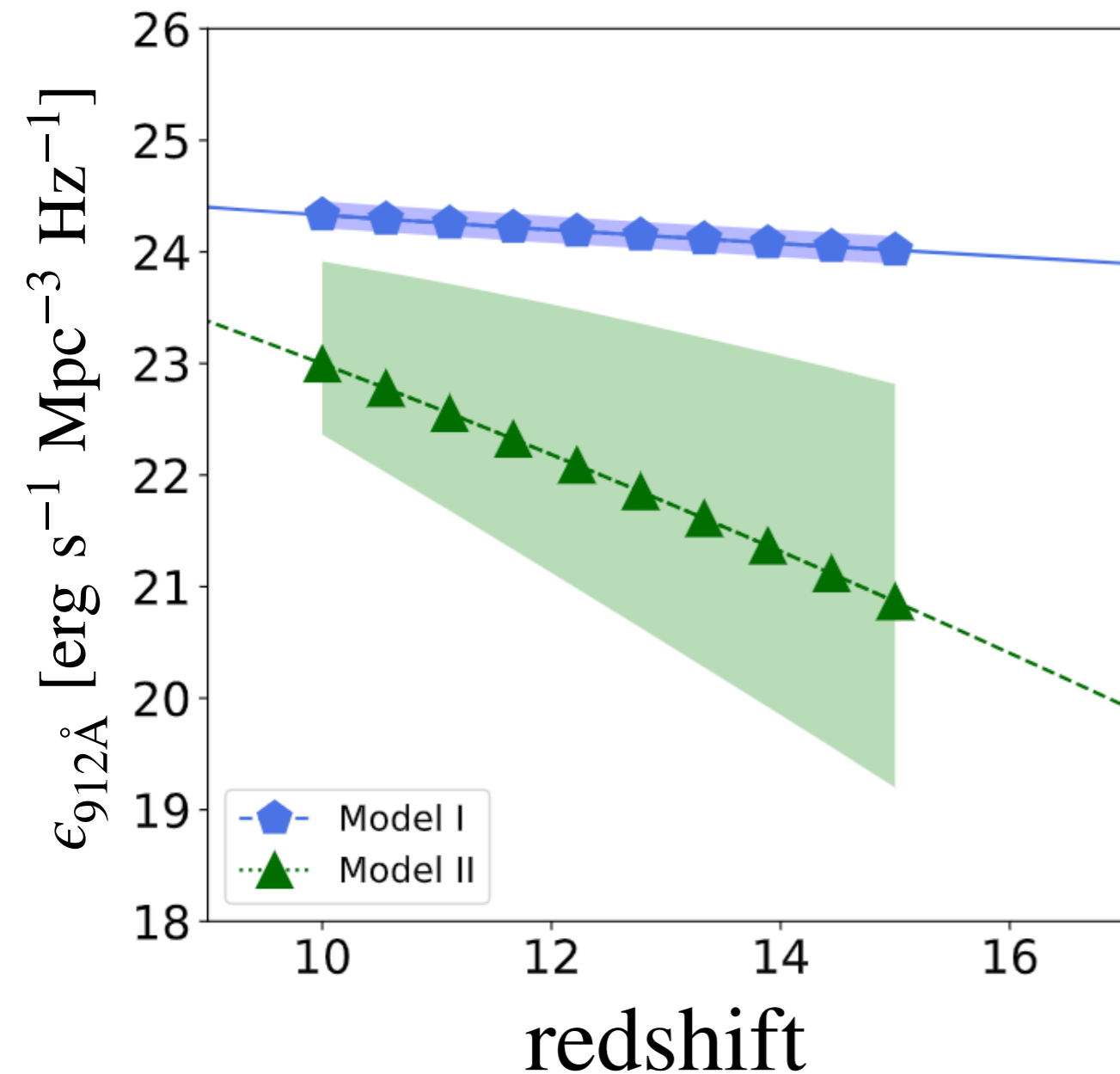3. Variance-covariance matrix : C

$$[C] = [F]^{-1}$$

⟶ Constrains of C for three fiducial galaxy evolution models

Ionization photon emissivity with fiducial models

Madau & Haardt (2015)
Hopkins et al. (2007)
Model I
Model II
Model III

Emissivity of ionization photon

of bin = (20,20)

- Model I and II are distinguishable with 1σ error with (20×20) bins.

- Since luminosity in Model III is too dim, the number of detected galaxies is order $\mathcal{O}(1)$ at $z \sim 10$.

➡ It is impossible to achieve reasonable constrains.

Emissivity of ionization photon

of bin = (20,20)

with $L_{\mathrm{lim}} = 1/10 L_{\mathrm{lim},0}$

- Model I and II are distinguishable with 1σ error with (20×20) bins.

- Since luminosity in Model III is too dim, the number of detected galaxies is order $\mathcal{O}(1)$ at $z \sim 10$.
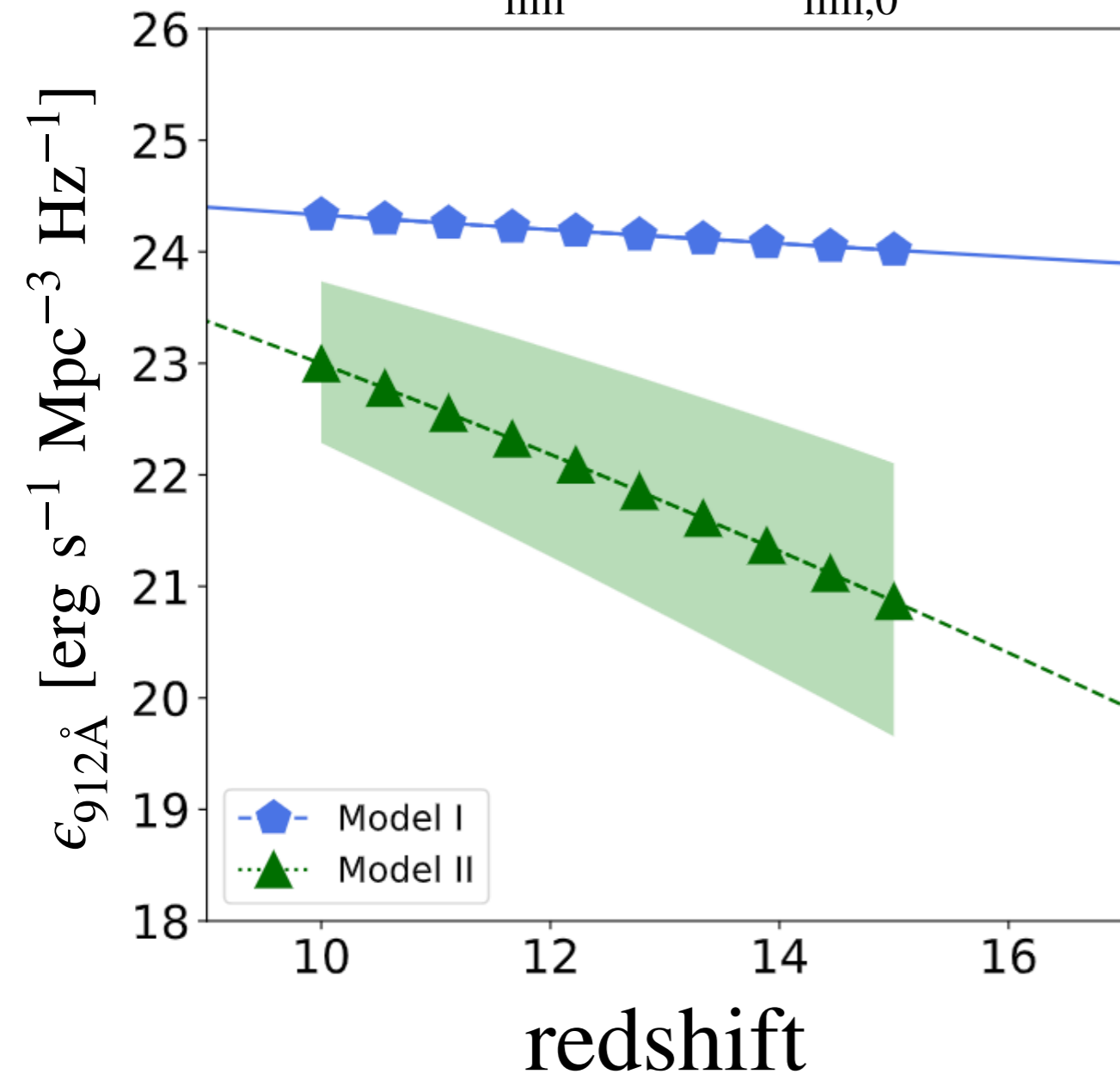
It is impossible to achieve reasonable constrains.

Further analysis with 10 times higher sensitivity

It is still impossible.

Summary

- 21-cm signal from AGN in EoR

- Evaluation of signal detectability with SKA observation

- Constraints of AGN LF parameters and their error with Fisher analysis

Results

✳ AGN in high redshift ($z \geq 10$) can ionize vast IGM region ~ 10 [Mpc]

✳ Some of our models (I and II) predicts the capability of LF parameter constraint with SKA

✳ With # of bin = (20, 20), we can constraint LF in $10 \leq z \leq 15$ even when galaxies are dimmer in order of two than ionization photon emissivity model in Madau & Haardt (2015).