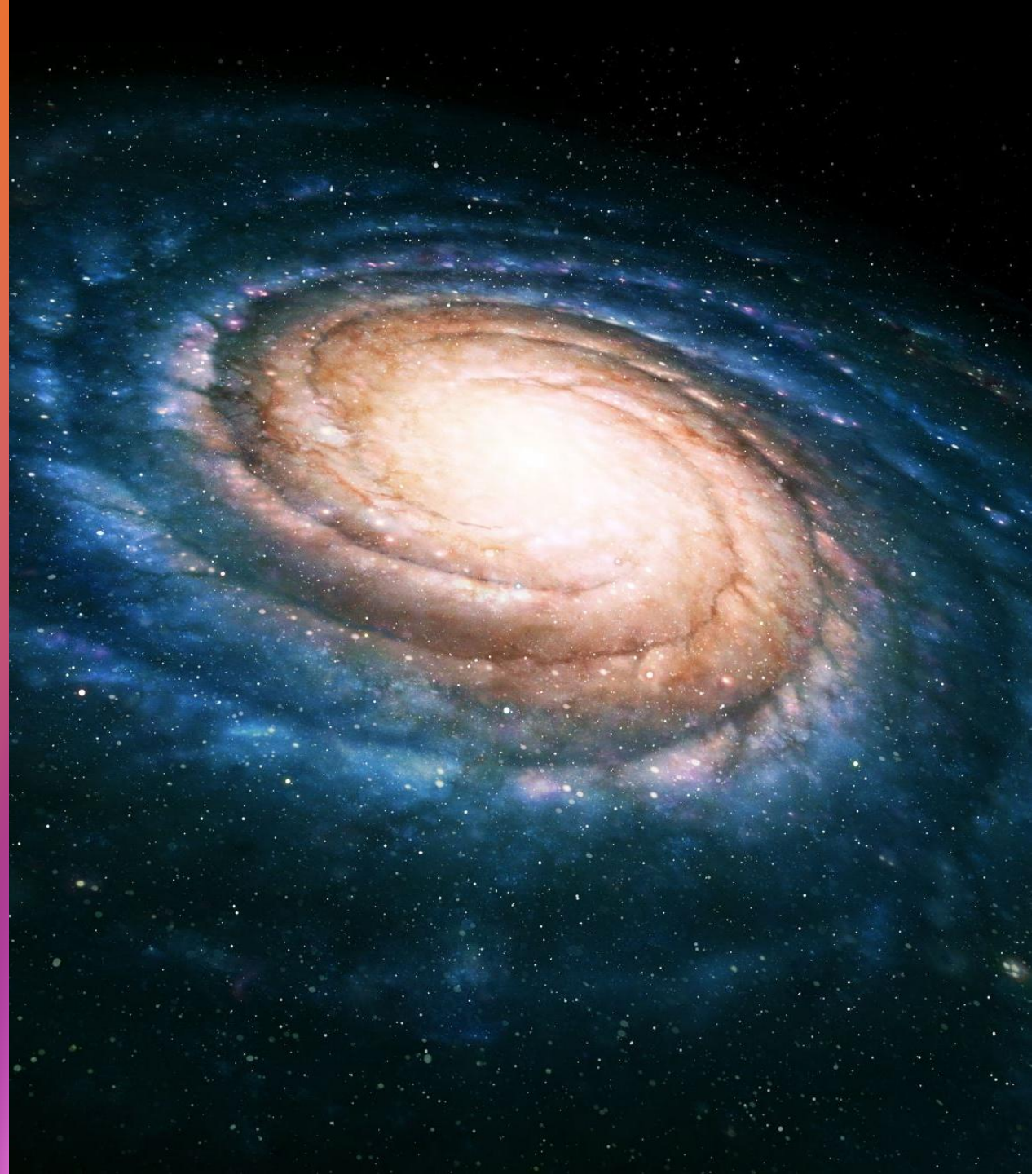
Estimation of cosmological parameters using the 21cm line at the cosmic dawn

Name : Yusuke Tomiyasu

Collaborator : Tomo Takahashi
Fumiya Okamatsu



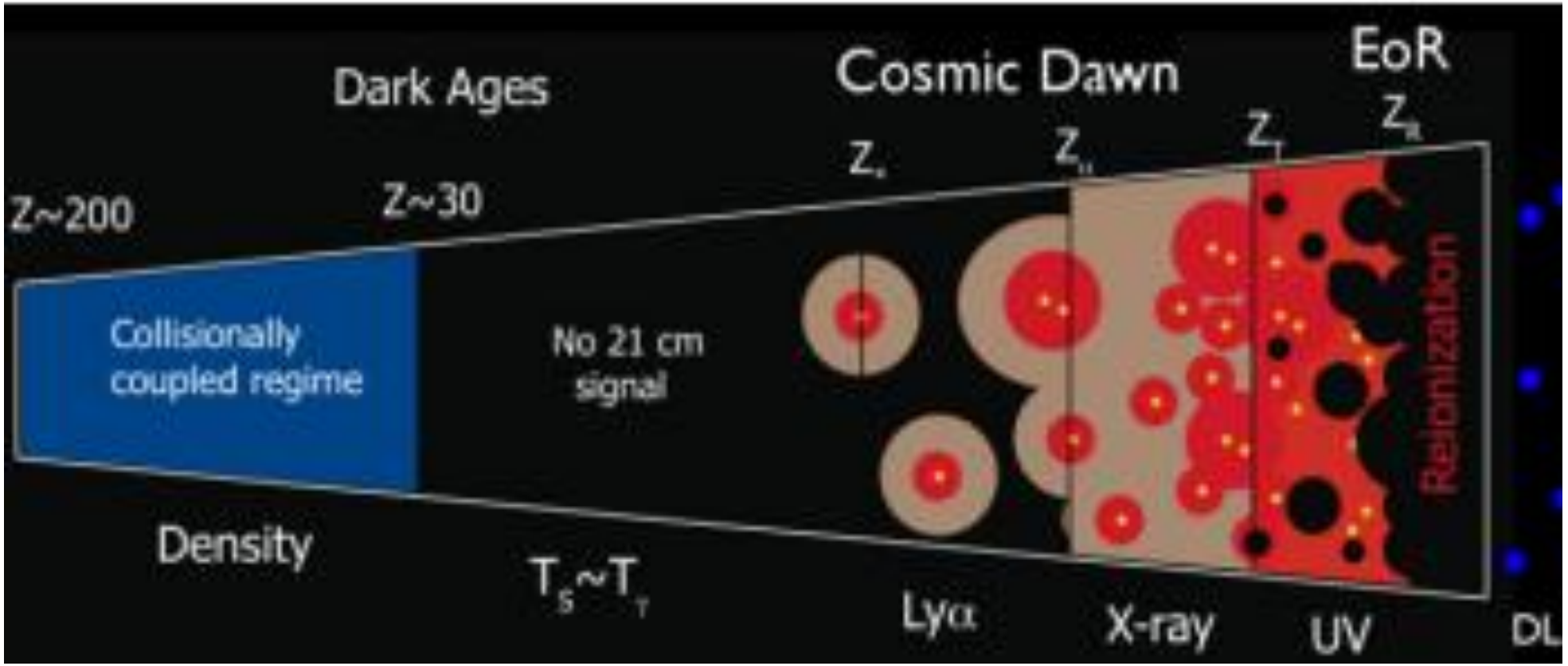
purpose

- We can probe cosmological and astrophysical parameters by using the 21cm line signal from the cosmic dawn era

- We investigate how astrophysical parameters affect constraints on cosmological ones

About the time of the universe studied

- What is the Cosmic Dawn?



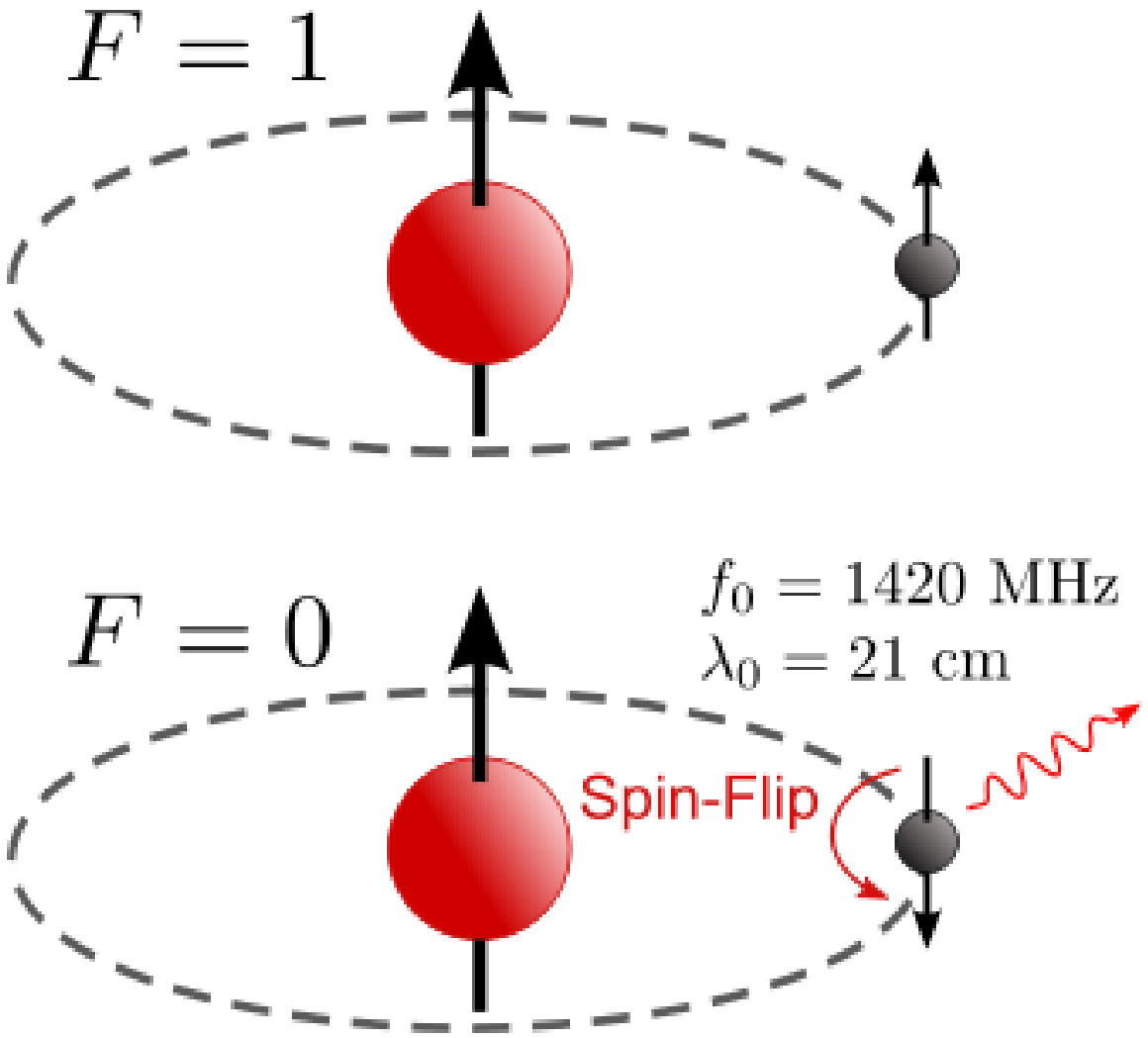
https://astronomy.fas.harvard.edu/files/astronomy/files/loeb_2012_rep._prog._phys._75_086901.pdf

About 21cm signal

- What is 21cm line?

F=1 : triplet state

F=0 : singlet state



https://en.wikipedia.org/wiki/Hydrogen_line

Base 21cm physics

- Basic equation of radiative transfer

$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu$$

α_ν : coefficients for absorption,

j_ν : coefficients for emission

- Rayleigh-Jeans limit

$$I_\nu = 2k_B T\nu^2/c^2$$

T : $brightness\ temperature$

- Brightness temperature along a line of sight through the intermediate medium observed

$$T_b = T_s(1 - e^{-\tau_\nu}) + T_\gamma(\nu)e^{-\tau_\nu}$$

T_s : *spin temperature*

T_γ : *background radio source of brightness temperature* $(T_\gamma = T_{CMB})$

τ_ν : *optical depth*

- *The optical depth of a cloud of hydrogen*

$$\tau_\nu = \int ds \left[1 - \exp\left(-\frac{E_{10}}{k_B T_s}\right)\right] \sigma_0 \Phi(\nu) n_0$$

E_{10} : *Energy difference between triplet state and singletstate*

$$\sigma_0 = \frac{n_H}{4}$$

n_H : *hydrogen density*

21cm cross-section : $\sigma(\nu) \equiv \Phi(\nu)\sigma_0$

$$\sigma_0 = \frac{3c^2 A_{10}}{8\pi\nu^2}$$

A_{10} : *spontaneous decay rate of spin − flip transition*

- differential brightness temperature :

$$\delta T_b = \frac{T_b - T_\gamma}{1+z} = \frac{T_s - T_\gamma}{1+z}(1 - e^{-\tau_\nu})$$

$$\approx \frac{T_s - T_\gamma}{1+z}\tau_\nu$$

$$\approx 27 x_{HI}(1+\delta_b)\left(\frac{\Omega_b h^2}{0.023}\right)\left(\frac{0.15}{\Omega_m h^2}\frac{1+z}{10}\right)^{\frac{1}{2}}\left(\frac{T_S - T_\gamma}{T_S}\right)\left[\frac{\partial_r v_r}{(1+z)H(z)}\right] mK$$

δ_b : $fractional\ over\ density\ in\ baryons$

x_{HI}: $neutral\ fraction\ of\ hydrogen$

$\partial_r v_r$: $specific\ velocity\ of\ hydrogen\ gas$

$T_s > T_\gamma$ $\quad \delta T_b$: $emission\ line$

$T_s < T_\gamma$ $\quad \delta T_b$: $absorption\ line$

- Spin temperature

$$T_s^{-1} = \frac{T_\gamma^{-1} + x_\alpha T_\alpha^{-1} + x_c T_K^{-1}}{1 + x_\alpha + x_c}$$

$$x_{tot} \equiv x_\alpha + x_c$$

$$T_\alpha : color\ temperature\ of\ the\ Ly\alpha\ radiation\ field (T_\alpha = T_K)$$

$$T_K : gas\ kinetic\ temperature$$

$$x_\alpha , x_c : Coupling\ coefficients\ for\ collisions\ and\ Ly\alpha$$

$$x_{tot} \geq 1 : T_s \approx T_K$$

$$x_{tot} \ll 1 : T_s \approx T_\gamma$$

21cm line at cosmic dawn

1,Cosmic dawn : $T_s < T_{CMB}$

21cm signal is observed as absorption line

2,Emission of $Ly\alpha$ photons from first astrophysical objects affect the spin temperature

Global signal

- Parameter dependence of brightness temperature

$$T_b = T_b(\Omega_b h^2 , \Omega_c h^2 , \epsilon_* \ldots)$$

The Other parameters

$$\Omega_b : Baryon\ enegy\ density$$
$$\Omega_c : Energy\ density\ of\ cold\ dark\ matter$$
$$\epsilon_* : star\ formation\ rate$$

How to estimate cosmological parameters

- Purpose

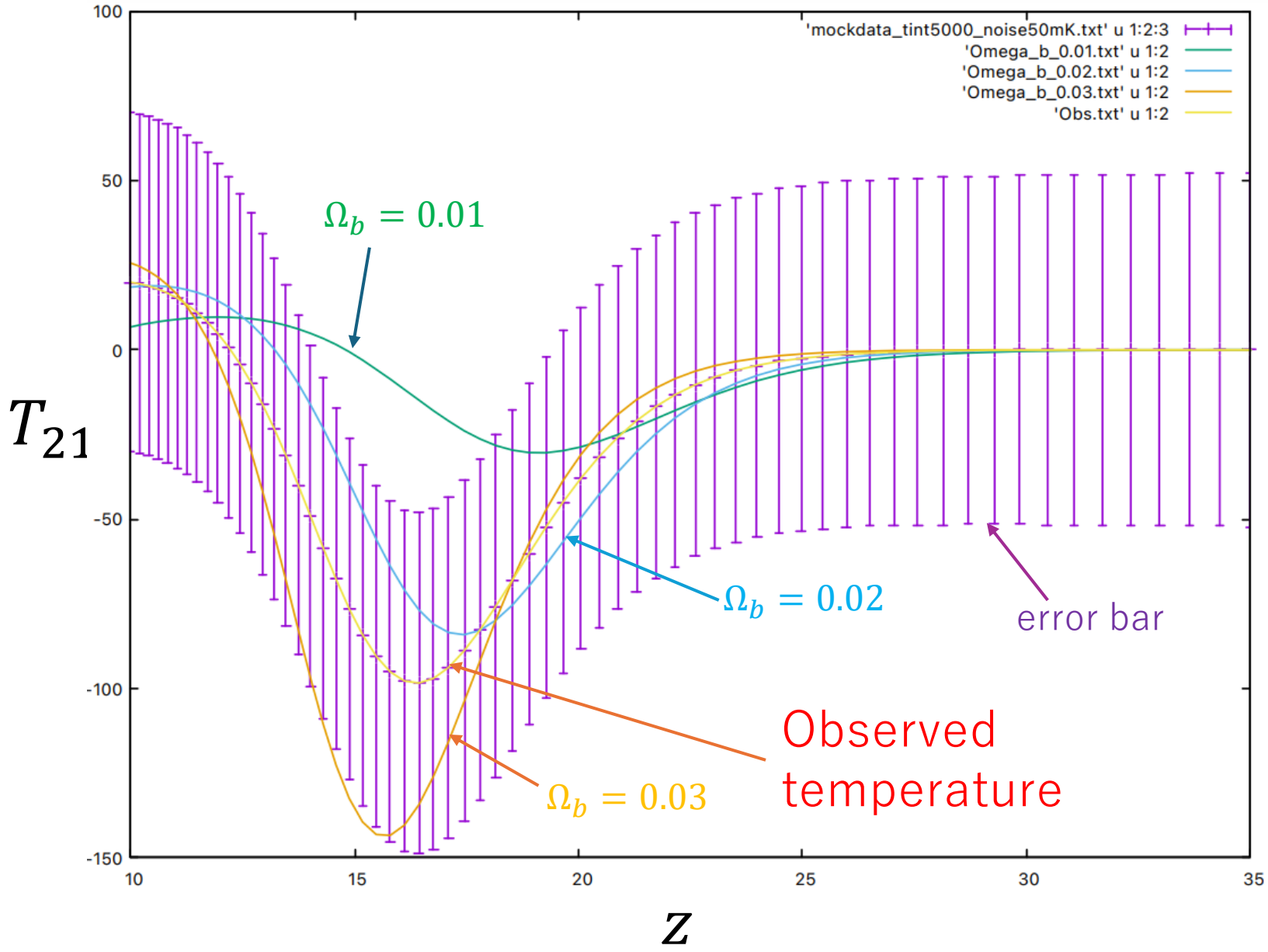
The purpose is to investigate expected constraints from future observations of 21cm cosmic dawn signal

In particular, we study the effects of astrophysical parameters on constraints on cosmological

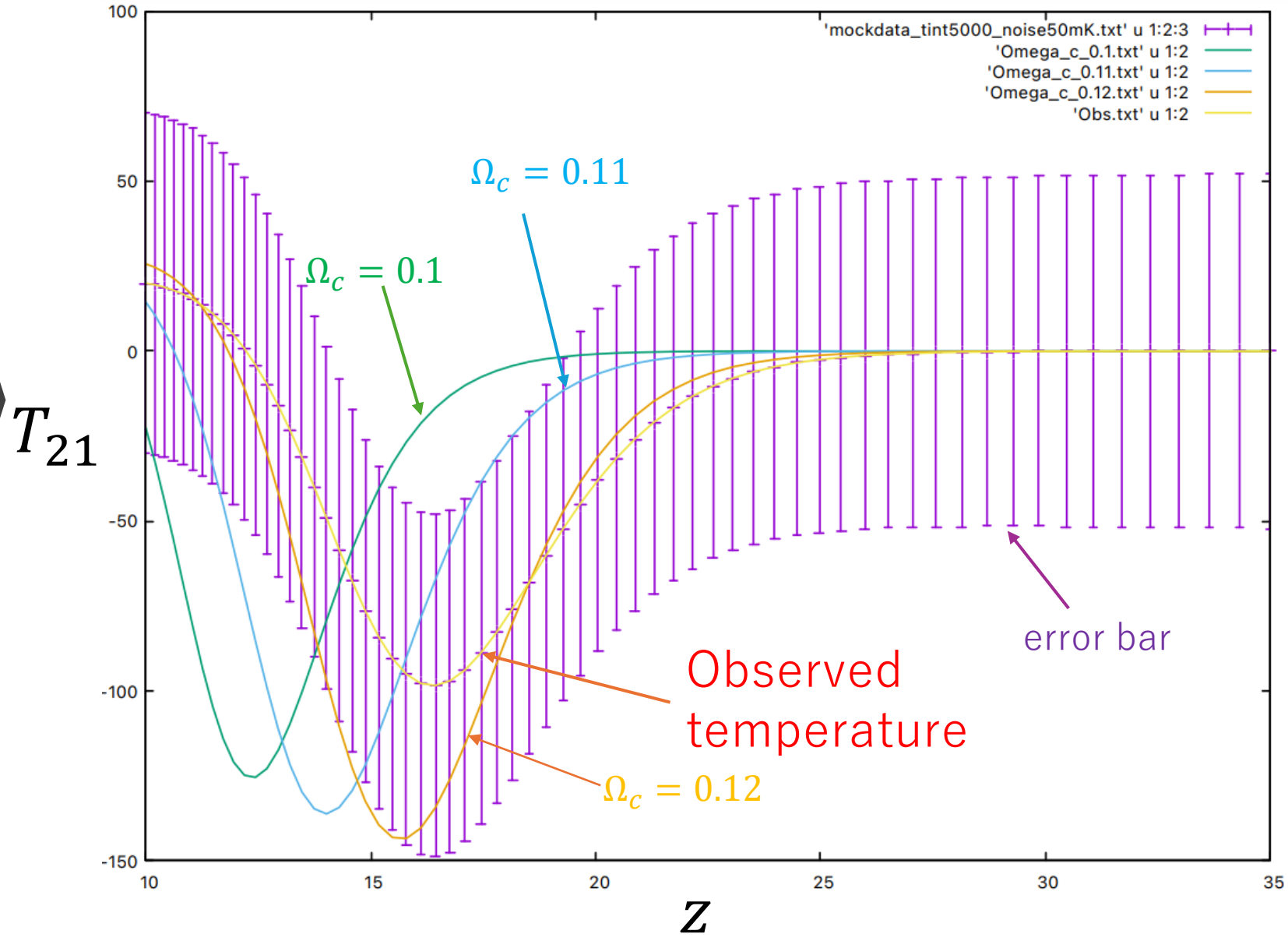
- Way

By using a mock data obtainable in future observations, we constrain cosmological parameter

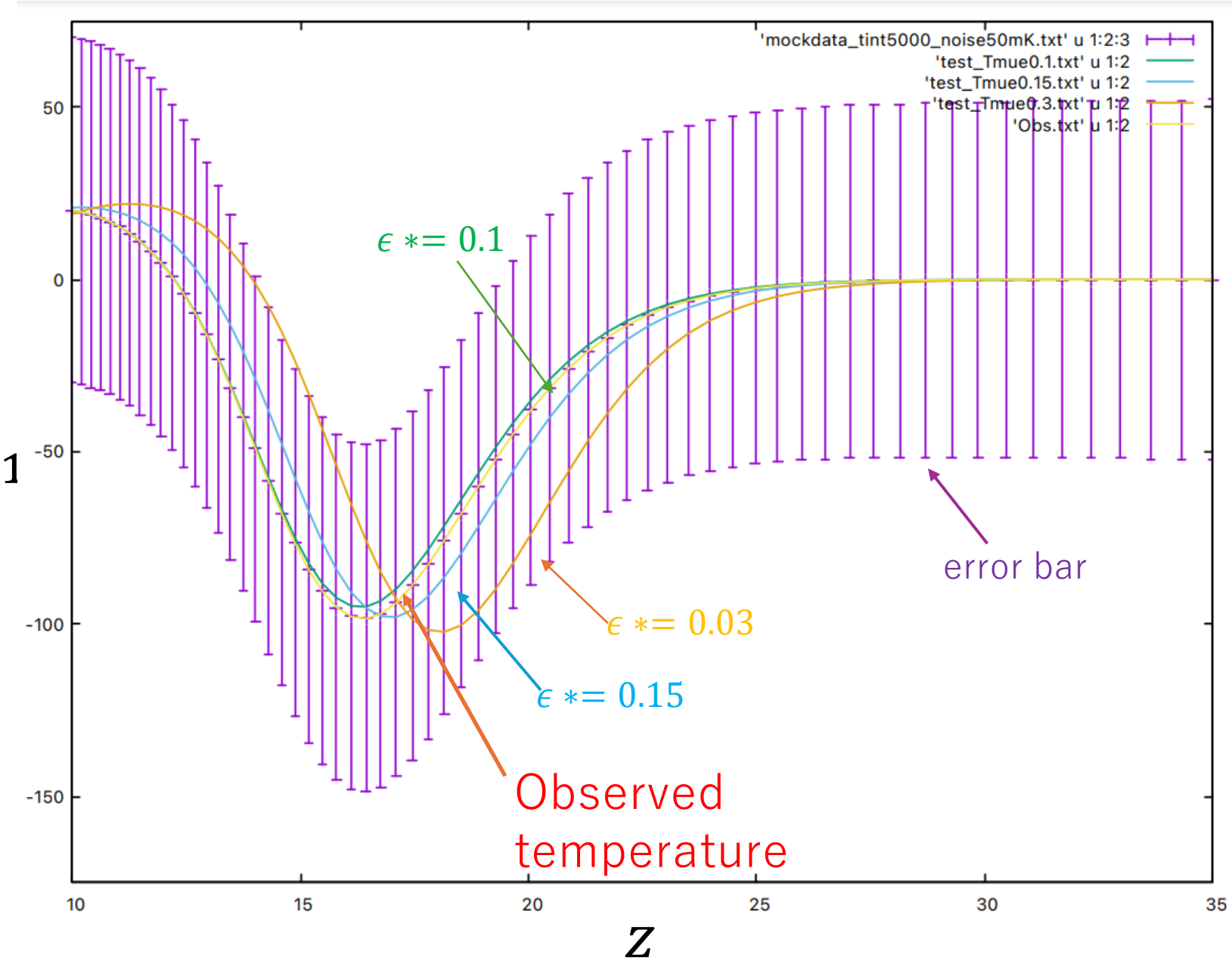
Changes in global signal when changing Ω_b



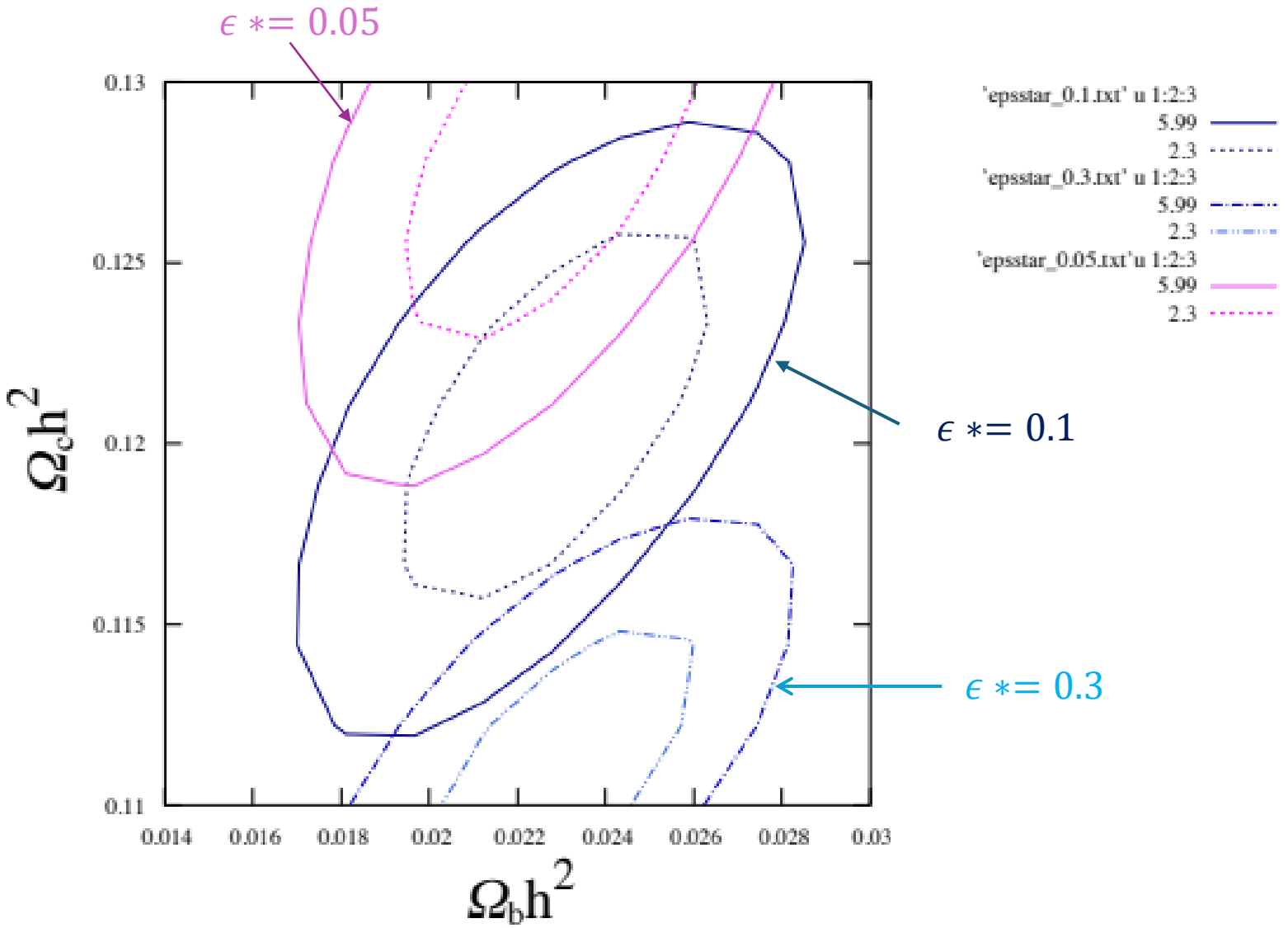
Changes in global signal when changing Ω_c



Change in global signal when changing ε *



Changes in cosmological parameters when changing ∈*



Summary

- We have investigated expected constrains on cosmological parameters from the 21cm signal from the cosmic dawn epoch
- We focused on how the assumption of astrophysical parameters affects constraints on cosmological parameters and found that the effect can be large
- We need to take account of both astrophysical and cosmological parameters properly when studying