Radiative Transfer Projects in RECAP Collaboration

Seok-Jun Chang

MPA

RECAP erc synergy grant

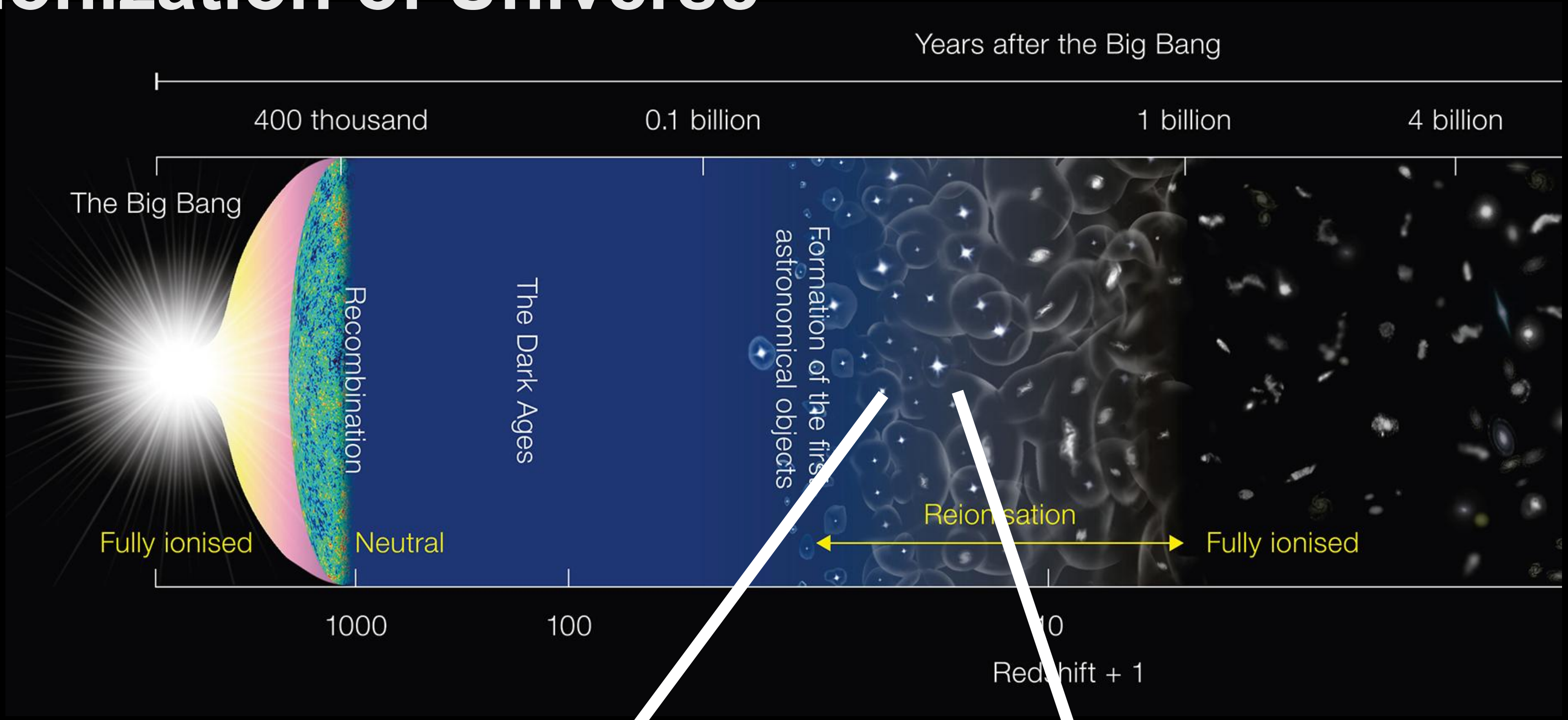
MAX-PLANCK-INSTITUT FÜR ASTROPHYSIK

Funded by the European Union

European Research Council Established by the European Commission

30 March 2026, 3rd RECAP Online Meeting

Reionization of Universe



Reionization Source

- O/B stars in **SFG**
- **AGN**

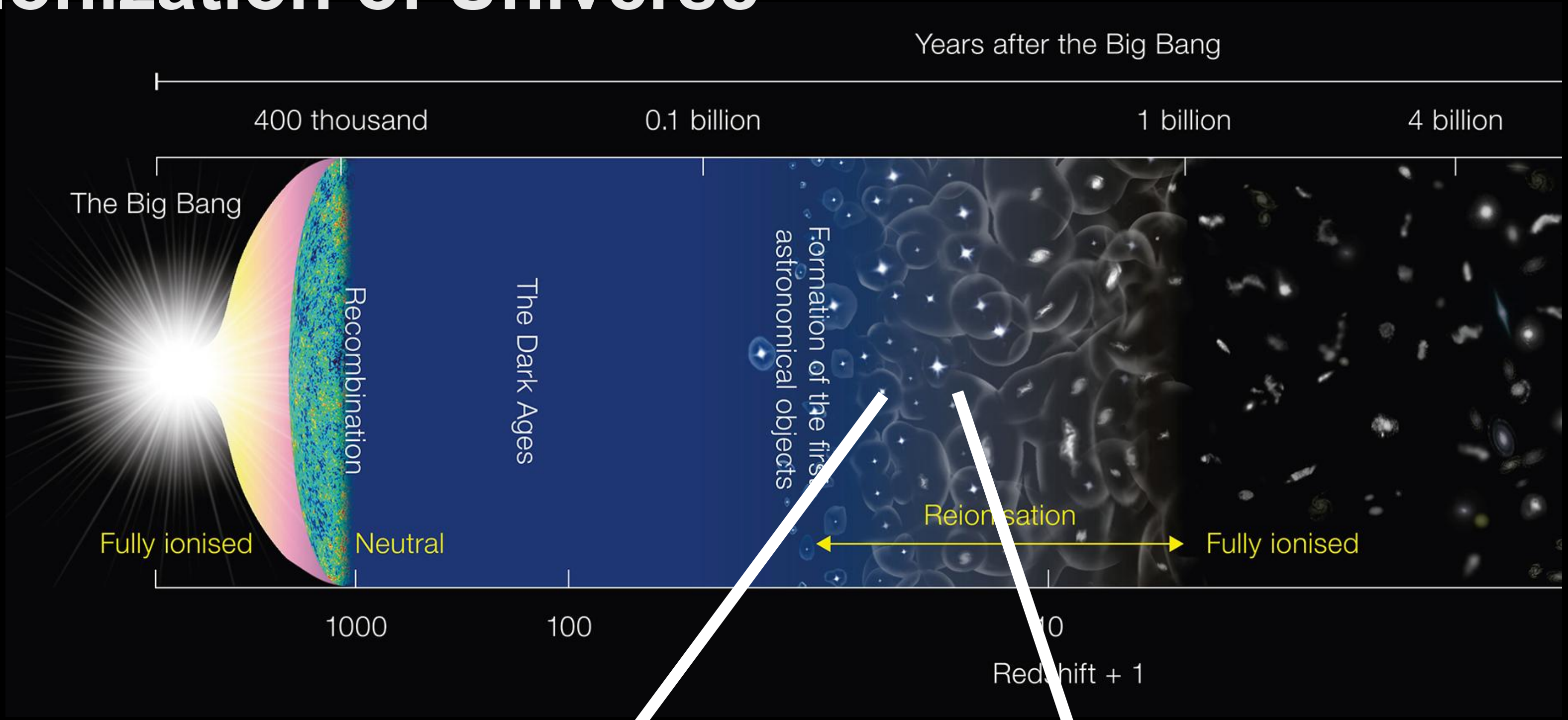
UV & X-ray

$$\dot{n}_{\mathrm{Ionization}} = n_{HI} \int_{\nu>\nu_{\mathrm{HI}}}^{\infty} \frac{4\pi J_\nu}{h\nu} \sigma_{\mathrm{HI}}(\nu) d\nu$$

$$\dot{n}_{\mathrm{Recombination}} = n_e n_{\mathrm{HII}} \alpha(T)$$

Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Reionization of Universe



Reionization Source

- O/B stars in **SFG**
- **AGN**

He ionization
Anisotropic Radiation
Impact on CGM

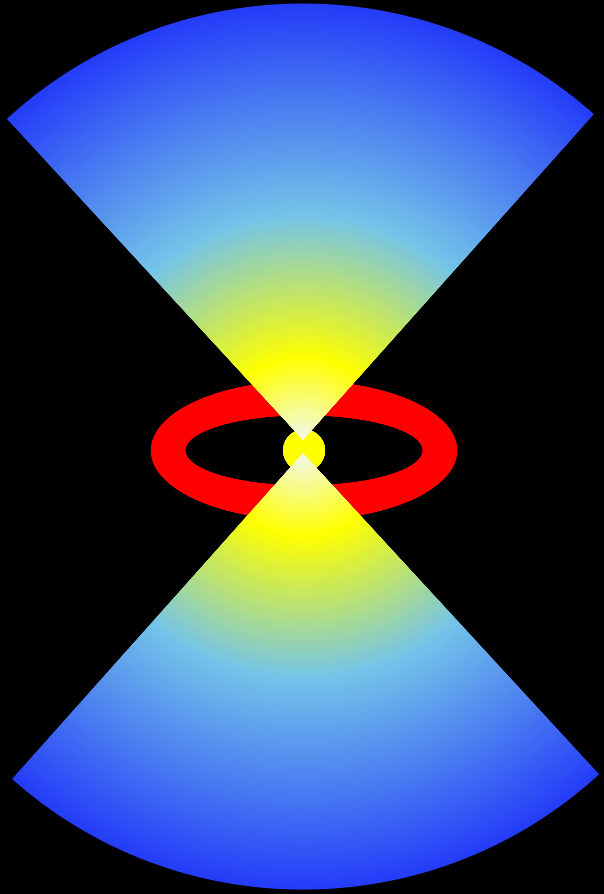
UV & X-ray

$$\dot{n}_{\mathrm{Ionization}} = n_{HI} \int_{\nu>\nu_{\mathrm{HI}}}^{\infty} \frac{4\pi J_\nu}{h\nu} \sigma_{\mathrm{HI}}(\nu) d\nu$$

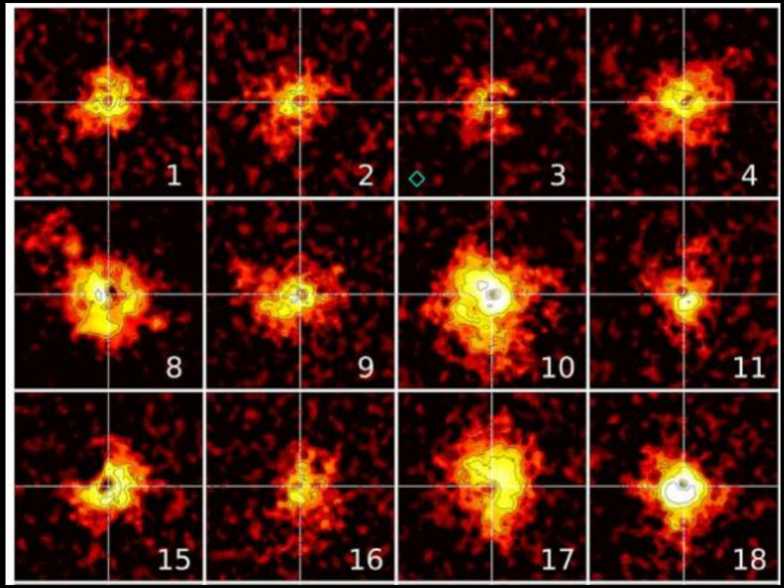
$$\dot{n}_{\mathrm{Recombination}} = n_e n_{\mathrm{HII}} \alpha(T)$$

Seok-Jun Chang, sjchang@mpa-garching.mpg.de

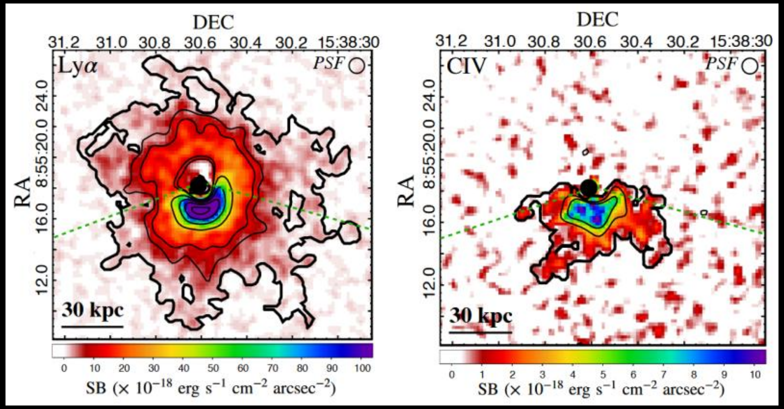
AGN and its Impact on CGM



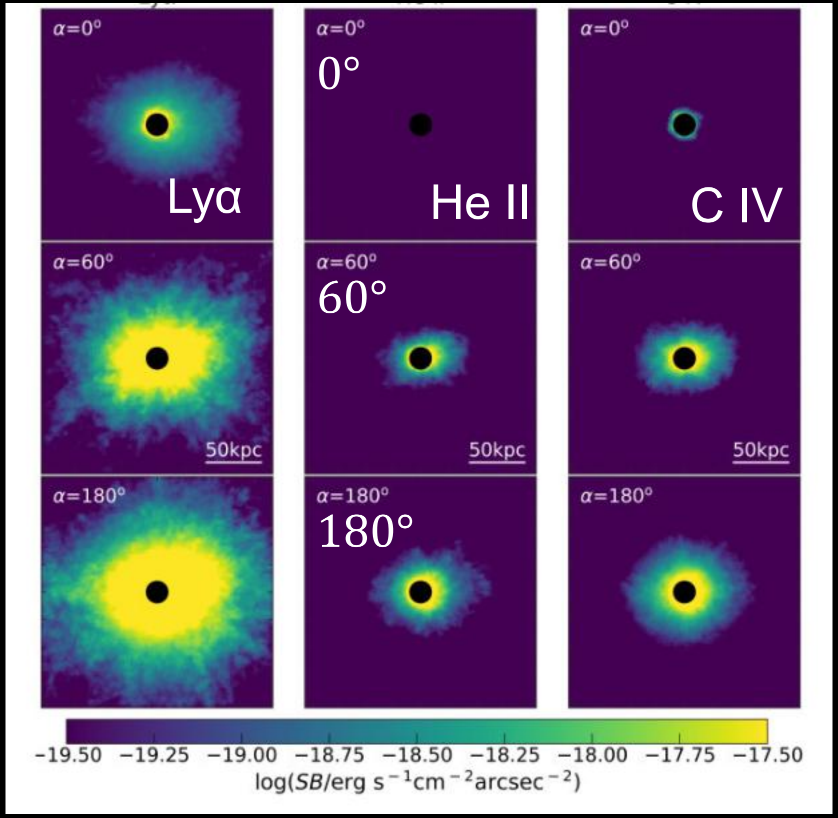
Arrigoni Battaia et al. 2019



Travascio et al. 2020



Obreja et al. 2024

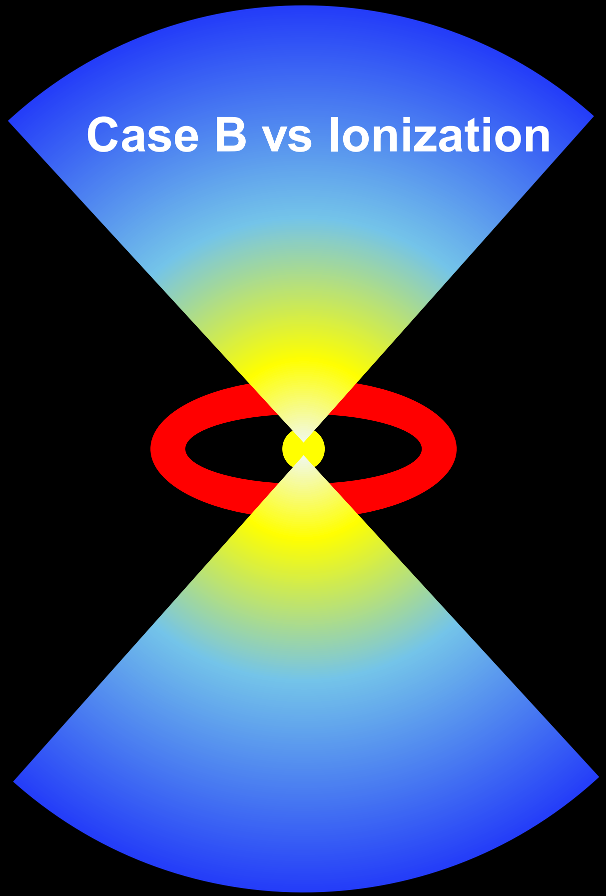


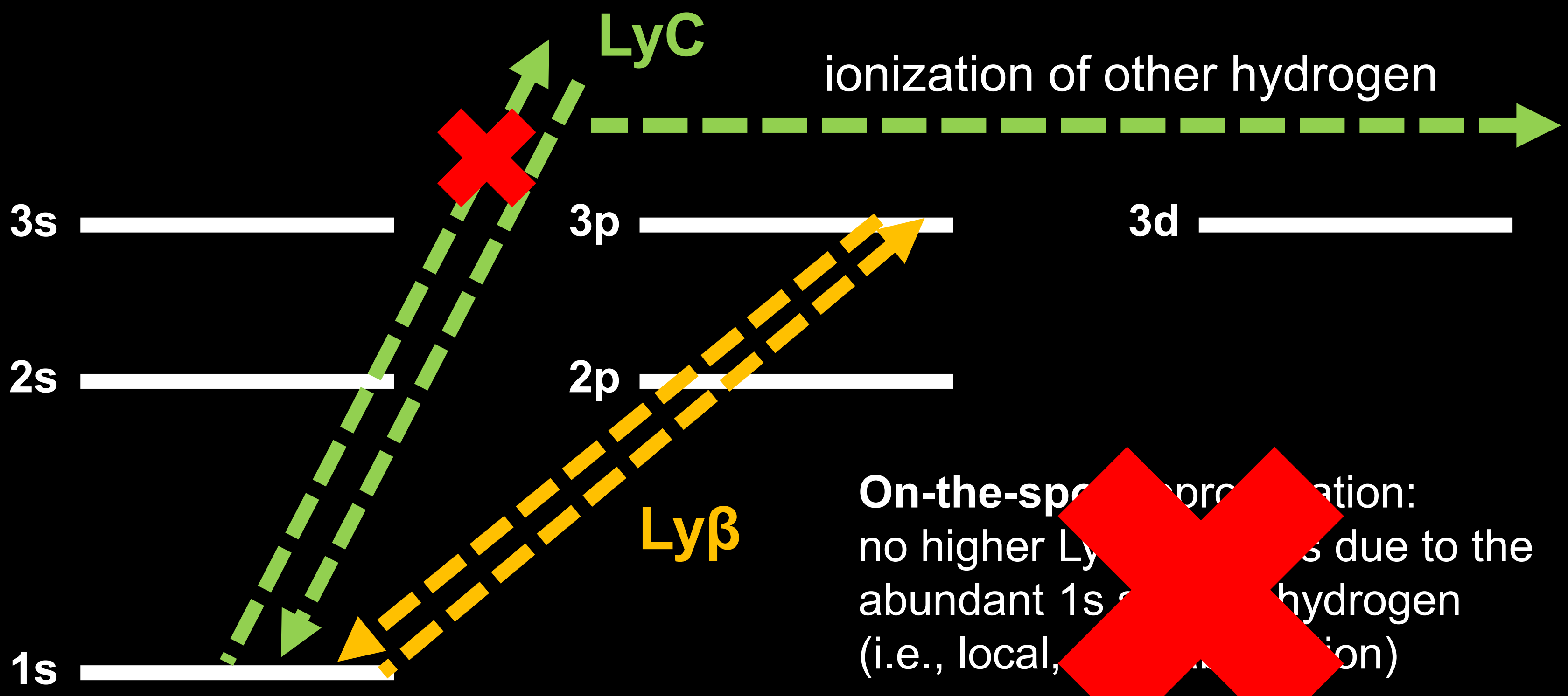
Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Anisotropic Radiation of AGN

$$\dot{n}_{\mathbf{Ioniz}} = \dot{n}_{\mathbf{Case\ B\ Rec}}$$

Case B recombination does not include recombination to the 1s state (a free-bound transition), which emits LyC photons.

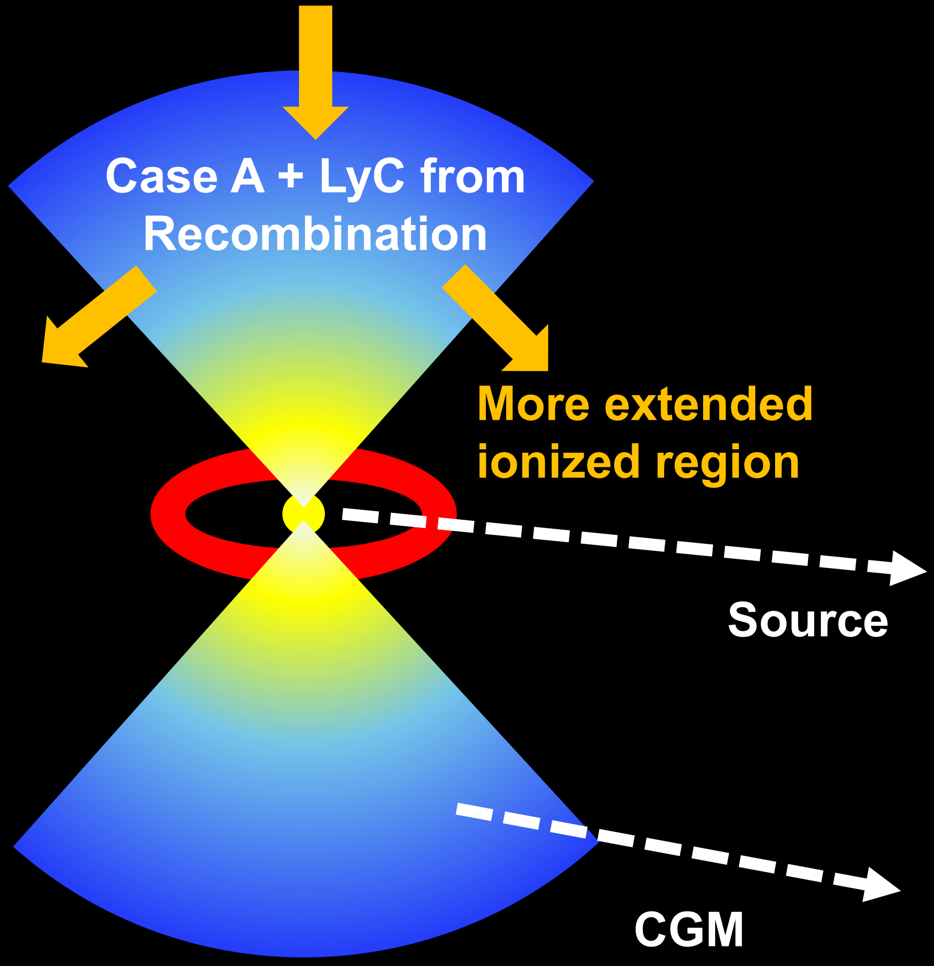


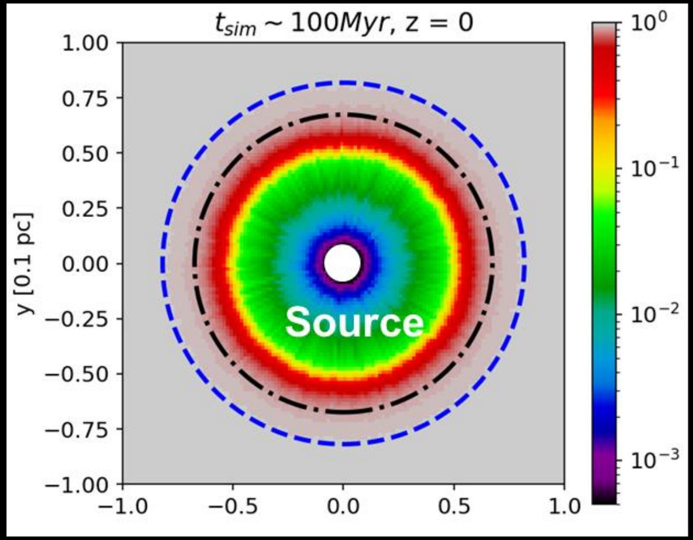


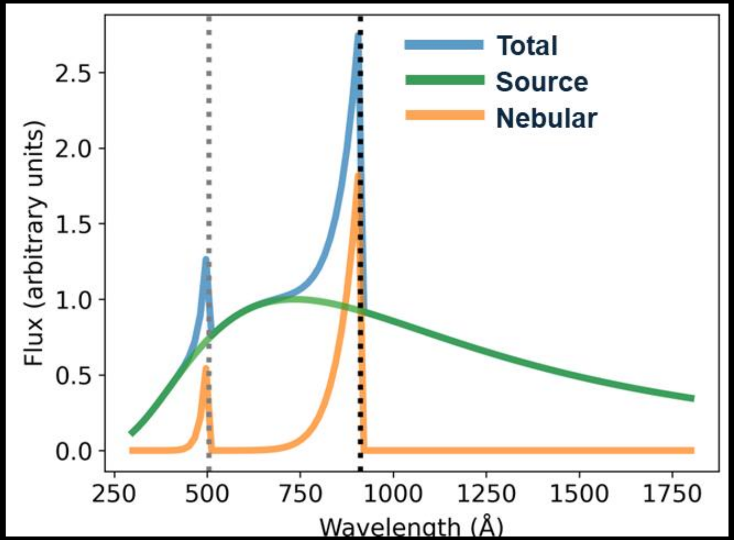
On-the-spo … pro … ation:
no higher Ly … s due to the
abundant 1s … hydrogen
(i.e., local, … ion)

Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Anisotropic Radiation of AGN







- Different Power-law for UV & X-ray continuum
- Various opening angles

+ Post-processing of hydro sims

- Uniform density
- Exponential or power-law profile
- Clumpy cold gas (sub-grid geometry)

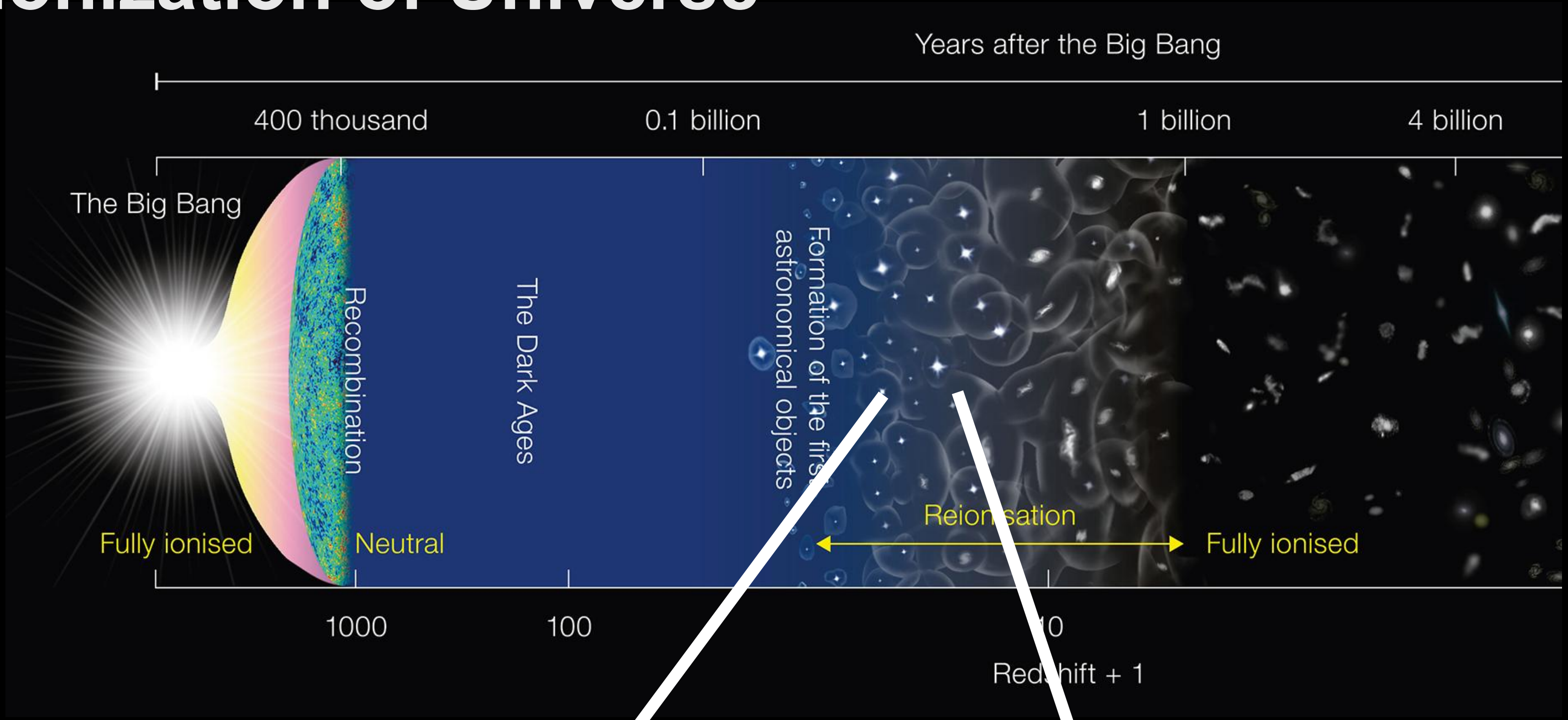
Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Objectives & Plans

1. Quantify the impact of anisotropic AGN radiation
    - Determine how anisotropic emission modifies the spatial and angular structure of CGM ionization compared to isotropic models.
2. Assess the validity of the Case B
    - Compare Case B mode with Case A + LyC from recombination
    - Identify regimes where Case B fails, particularly in how much anisotropy of radiation is required.
3. Characterize the ionization front structure
    - Measure the sharpness and thickness of the ionization front
    - Evaluate how diffuse recombination radiation broadens fronts and fills shadowed regions.
4. Determine directional LyC escape fractions
    - Compute angle-dependent escape fractions of LyC & X-ray (to IGM)
    - Quantify how CGM processing modifies the angular distribution and hardness of escape SED

Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Reionization of Universe



Reionization Source

- **O/B stars in SFG**
- AGN

Lyα emission by JWST

UV & X-ray

$\dot{n}_{\mathrm{Ionization}}$

$\dot{n}_{\mathrm{Recombination}}$

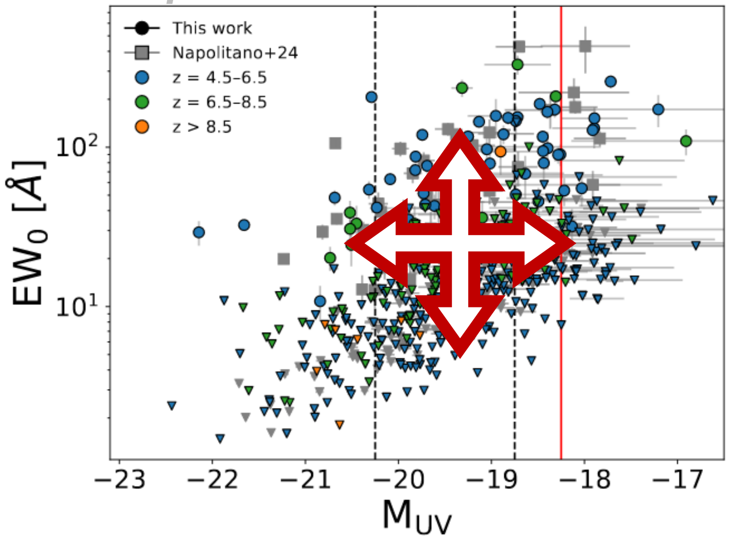
$$\dot{n}_{\mathrm{Ionization}} = n_{HI} \int_{\nu > \nu_{\mathrm{HI}}}^{\infty} \frac{4\pi J_\nu}{h\nu} \sigma_{\mathrm{HI}}(\nu) d\nu$$

$$\dot{n}_{\mathrm{Recombination}} = n_e n_{\mathrm{HII}} \alpha(T)$$

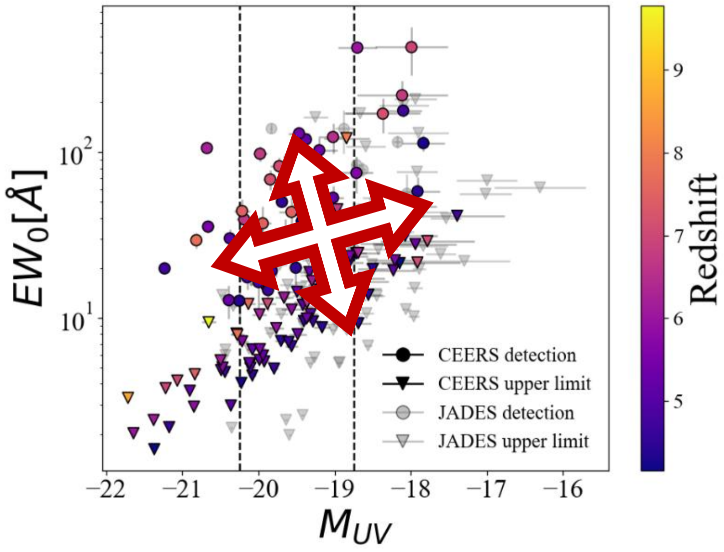
Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Observations of Lyα and non-resonance lines, Hβ & [O III]

Napolitano et al. 2025

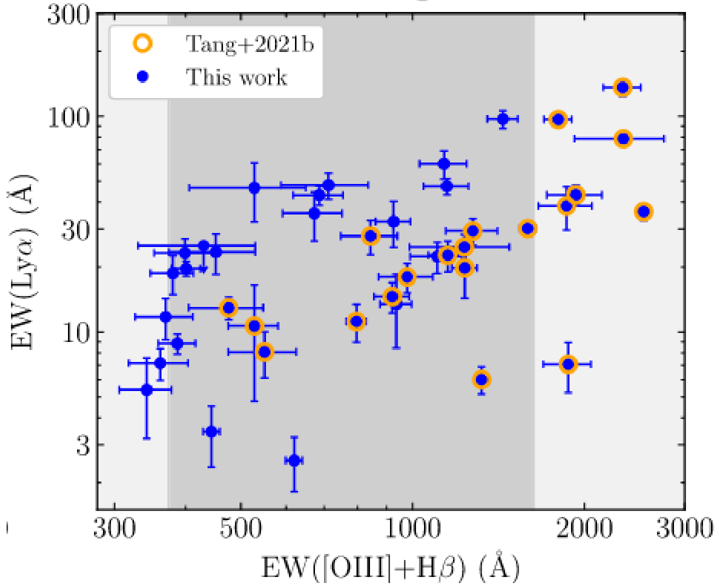


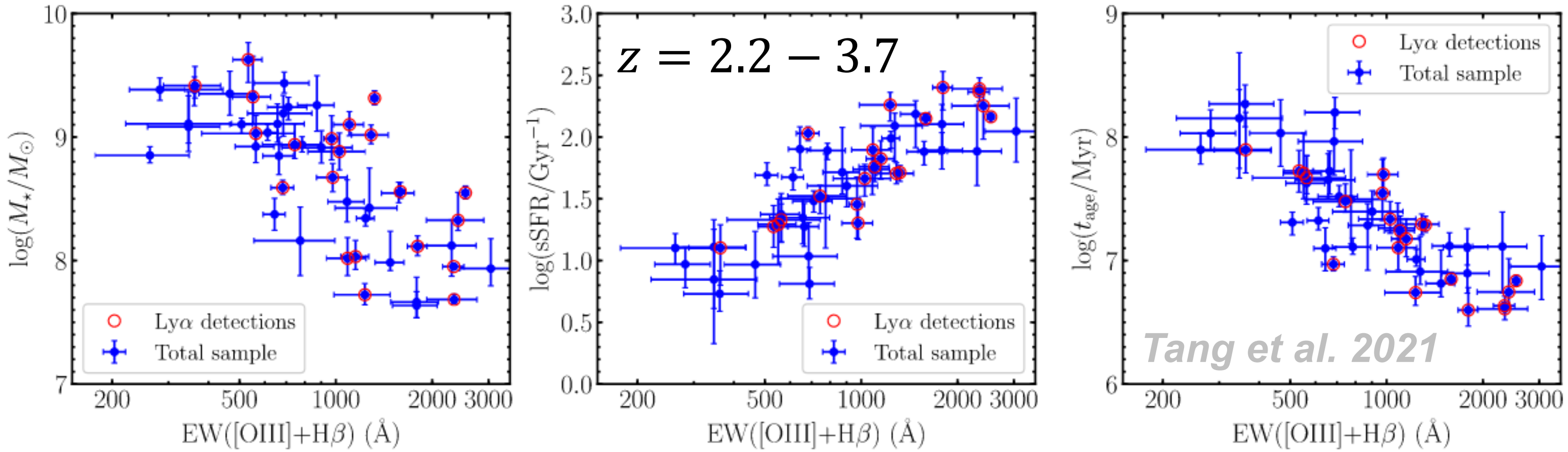
Napolitano et al. 2024



- **Radiative Transfer**
- **Line of sight dependence**
- **Ionized bubble size**

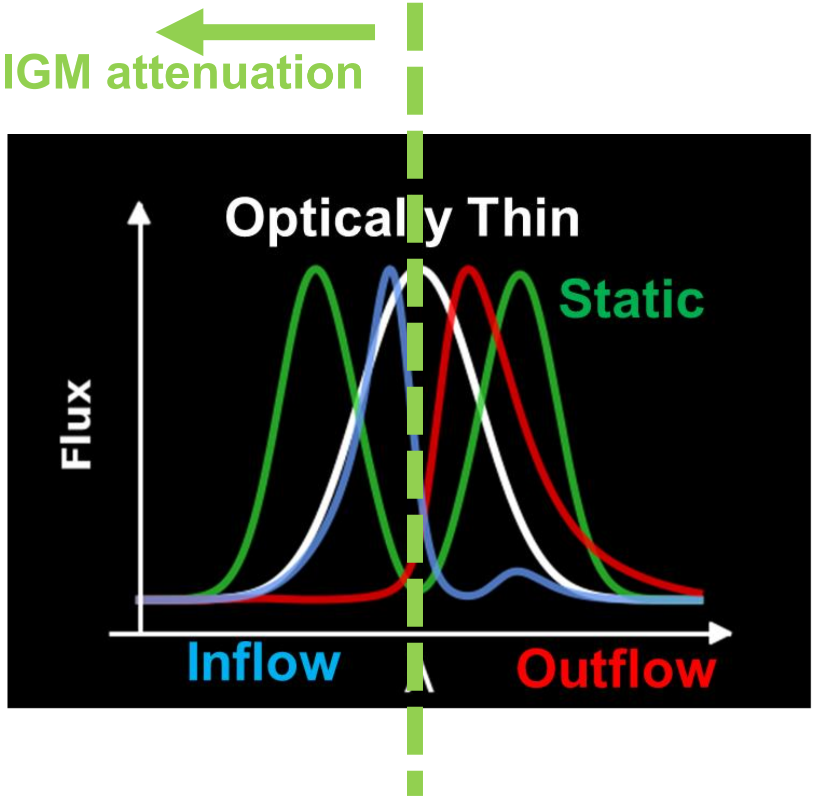
Tang et al. 2024

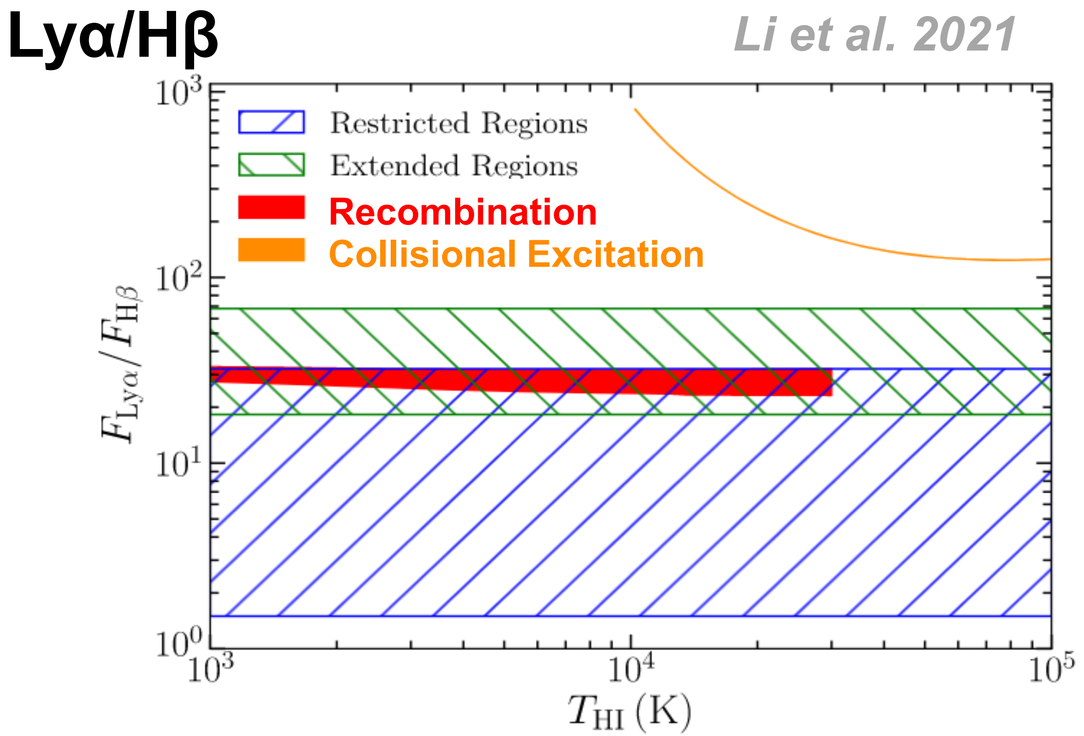




Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Radiative Transfer of Lyα and Hβ & [O III]





$j_{\mathrm{H\beta}} \propto n_e n_p \alpha_B(T_e),\ \alpha_B \propto T_e^{-0.7}$ Recombination

$j_{\mathrm{[O\,III]}} \propto n_e n_{\mathrm{OIII}} \frac{\Omega}{T_e^{1/2}} e^{-\frac{\Delta E}{kT}}$ Collisional Excitation

$$\frac{j_{\mathrm{[O\,III]}}}{j_{\mathrm{H\beta}}} \propto \frac{n_{\mathrm{OIII}}}{n_p} T_e^{0.2} e^{-\frac{\Delta E}{kT}}$$

Seok-Jun Chang, sjchang@mpa-garching.mpg.de

Objectives & Plans

MPA RECAP team

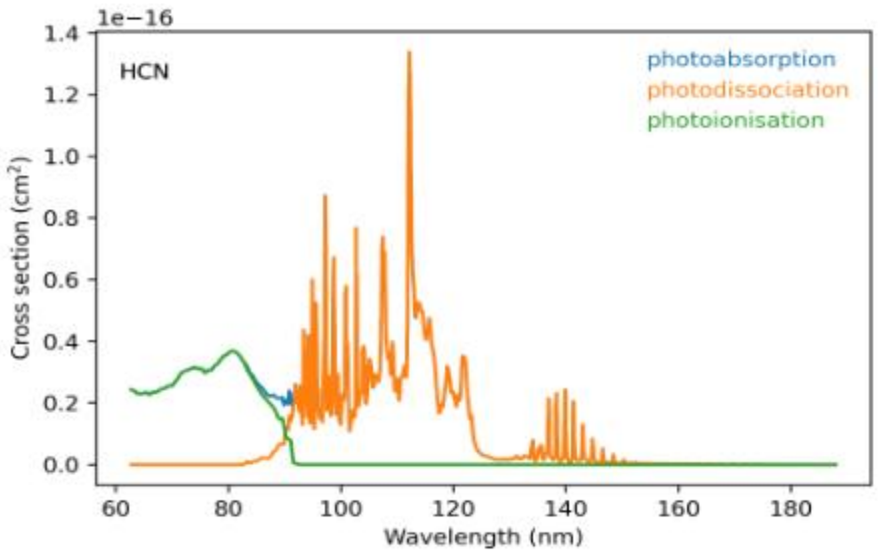
1. Quantify the distribution of Lyα observables based on [O III]+Hβ properties with post-processing of SPICE.
   - Lyα emission, including radiative transfer effects (Elie)
   - [O III] and Hβ emission lines (Benny)
   - (optional) [C II] emission as cold ISM tracer (Benny)
2. Determine origins of Lyα scatter, including metallicity, dust, H I distribution, and viewing angle.
3. Compare simulated and observed distributions (with Lorenzo & Laura)
4. Evaluate whether Lyα-selected samples are biased relative to selected galaxy populations based on optical emission lines.
5. (optional) + compare with cosmic dawn or local universe?

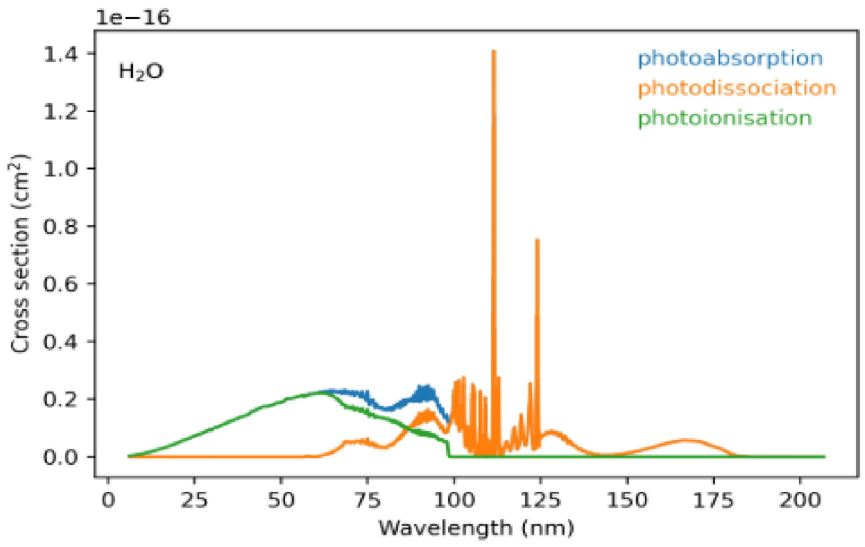
Acknowledgement & Disclaimer

- Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or the European Research Council Executive Agency. Neither the European Union nor the granting authority can be held responsible for them.

- This work is supported by the ERC grant RECAP under grant agreement No 101166930

Seok-Jun Chang, sjchang@mpa-garching.mpg.de





Seok-Jun Chang, sjchang@mpa-garching.mpg.de