CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON

Lya emission from simulated high-z galaxies and their circum-galactic medium

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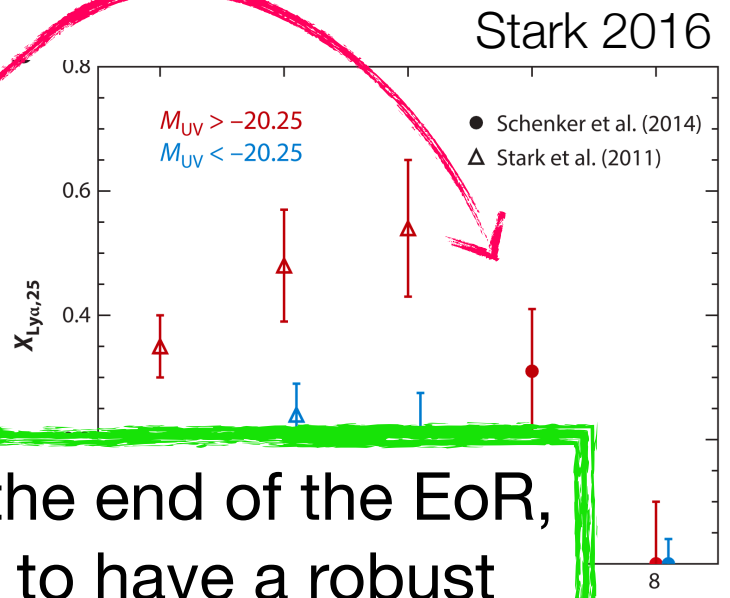
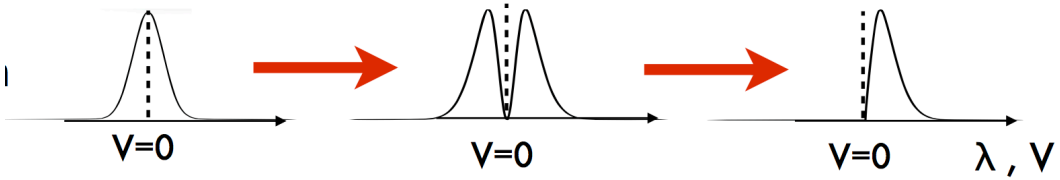
LAEs as probes of reionisation

A partially neutral IGM will reduce the visibility of LAEs

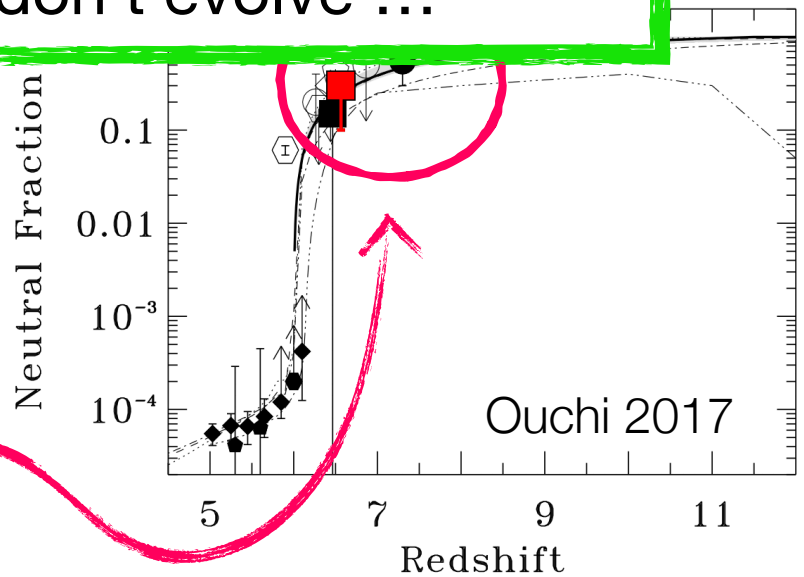
Intrinsic emission → ISM → IGM → observer



LAEs may tell us something about the end of the EoR, but it would be more comfortable to have a robust theory telling us how they don't evolve …

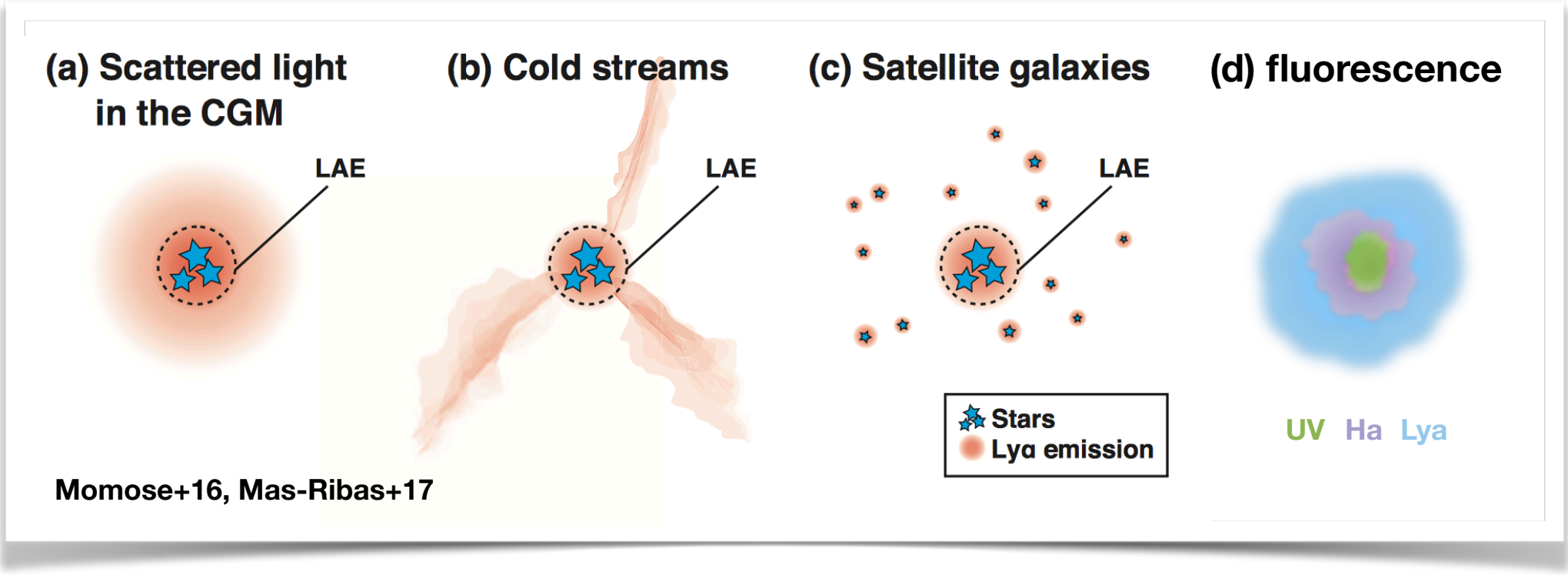


A partially neutral IGM will boost the clustering signal of LAEs



(see also Garel+12,15,16)

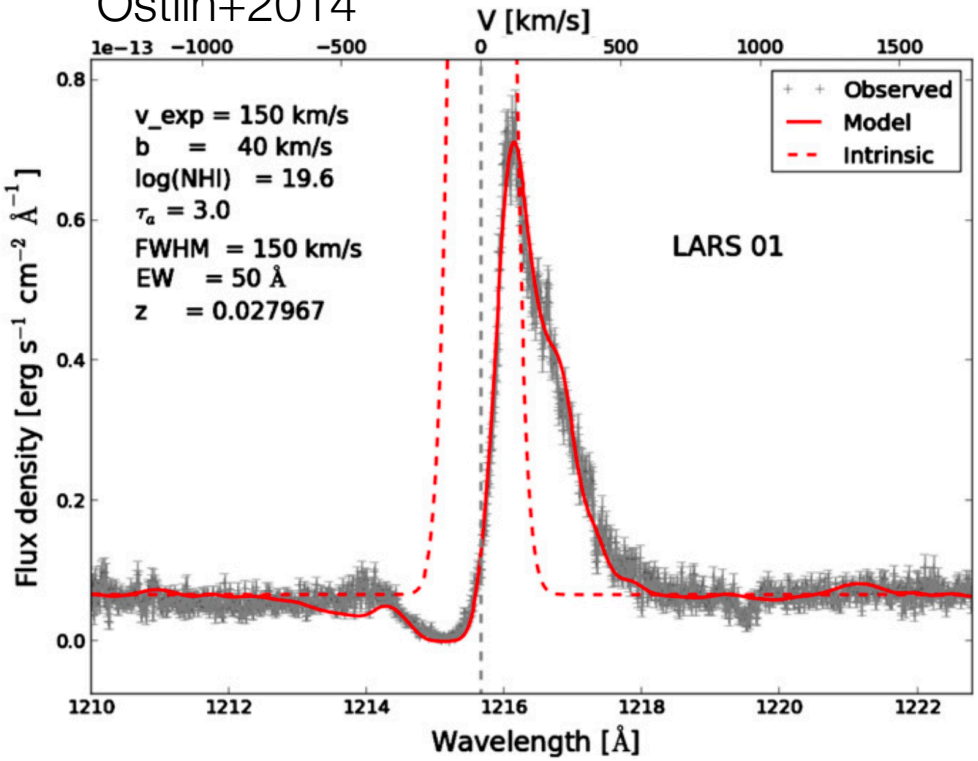
Extended Lya halos around (high-z) galaxies: Can we use that to learn about SN feedback ?



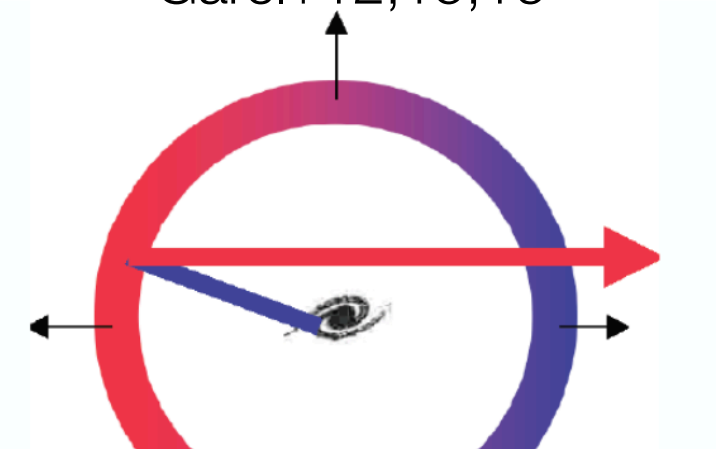
We need to build a quantitative theory for *all* these scenarios, which relates detailed Lya observables to physical properties of galaxies and their CGM. This would allow us to set direct constraints on SN feedback.

Can simulations help us understand idealised models ?

Östlin+2014



Verhamme+8, Schaerer+11, Garel+12,15,16



Most observed Lya lines seem to be marked by outflows

What do all these successful idealised models relate to ?

I. Numerical challenges in predicting Lya from simulations.

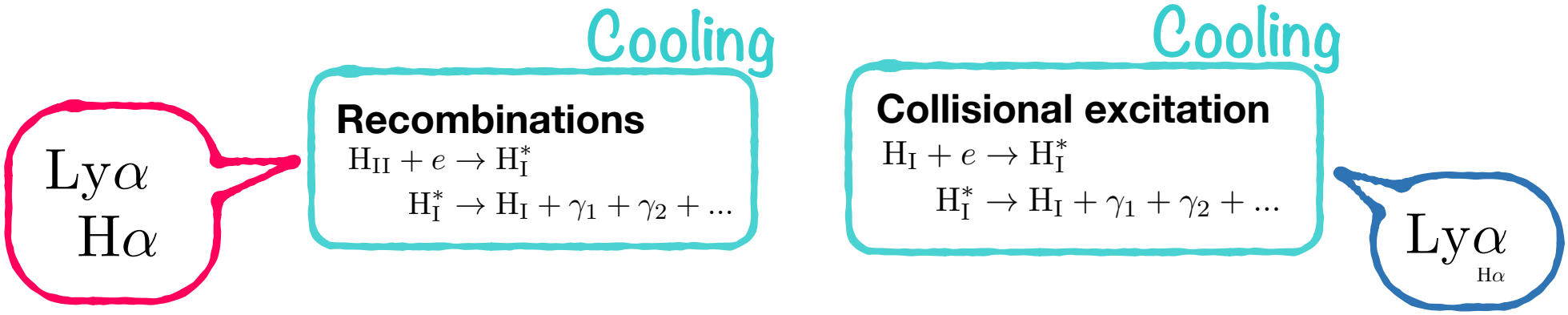
II. Lya budget & extended emission

III. Angular and time variations

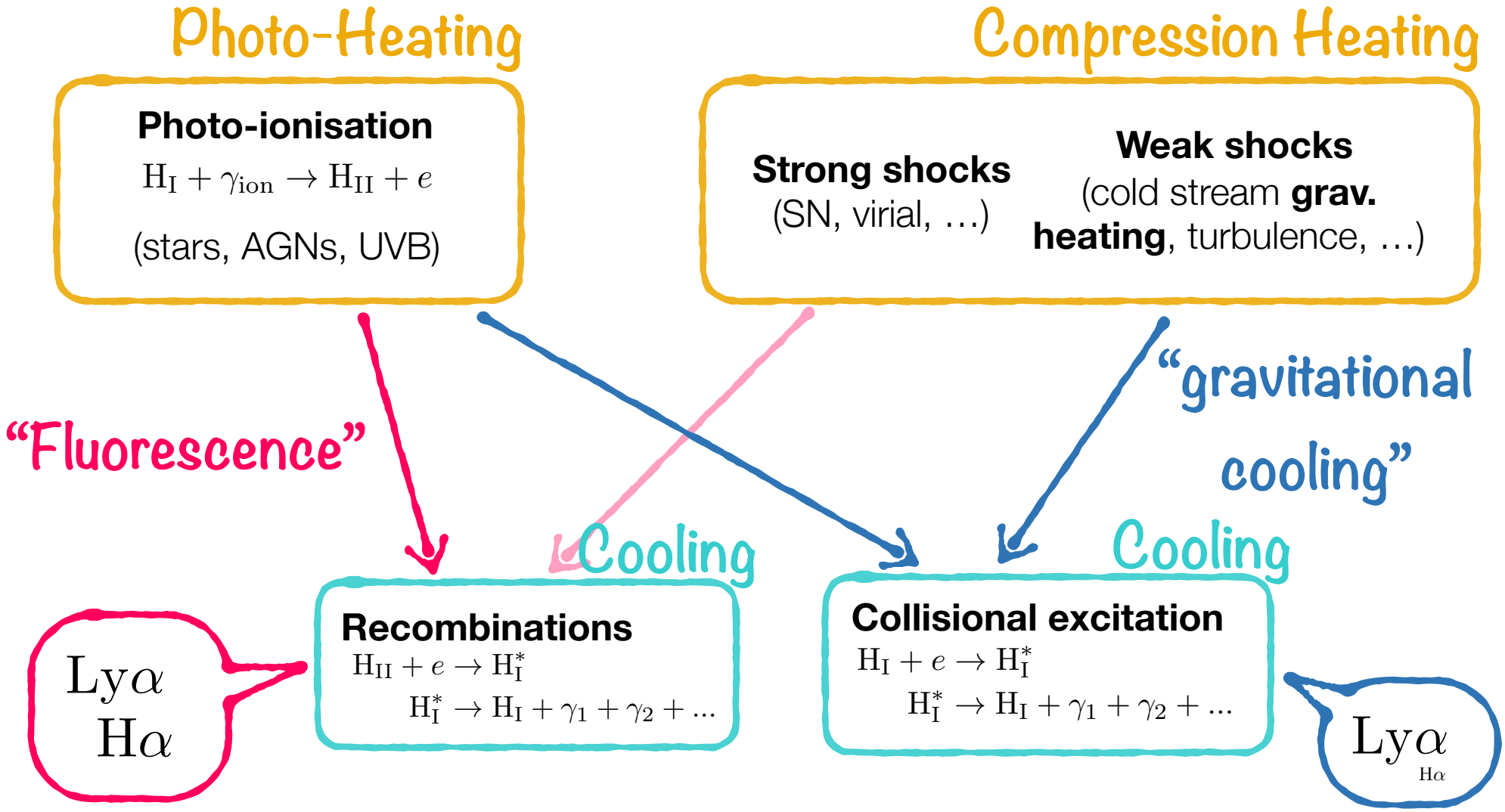
IV. Future directions

I. Numerical challenges in predicting Lya from simulations

Predicting Lya emission from simulated galaxies



Predicting Lya emission from simulated galaxies



Predicting Lya emis

Fluorescent Lya emission can be robustly computed with ionising RT in post-processing of regular simulations ("Hydro + RT") (see e.g. Cantalupo+05, Laursen+09a, Kollmeier+10, Zheng+10,11, Yajima's talk,

Photo-Heating

Photo-ionisation

$\mathrm{H_I} + \gamma_{\mathrm{ion}} \rightarrow \mathrm{H_{II}} + e$

(stars, AGNs, UVB)

"Fluorescence" & HII regions

Cooling

Cooling

gravitational cooling"

Recombinations

$\mathrm{H_{II}} + e \rightarrow \mathrm{H_I^*}$

$\mathrm{H_I^*} \rightarrow \mathrm{H_I} + \gamma_1 + \gamma_2 + ...$

Lyα

Hα

Collisional excitation

$\mathrm{H_I} + e \rightarrow \mathrm{H_I^*}$

$\mathrm{H_I^*} \rightarrow \mathrm{H_I} + \gamma_1 + \gamma_2 + ...$

Lyα Hα

Predicting Lya emissio

Photo-heating from the UVB requires some on-the-fly self-shielding approximation (see Furlanetto+03, Goerdt+10 vs. Faucher-Giguère+10, Rosdahl+12).

Photo-Heating

Photo-ionisation

$\mathrm{H_I} + \gamma_{\mathrm{ion}} \rightarrow \mathrm{H_{II}} + e$

(stars, AGNs, UVB)

"Fluorescence" & HII regions

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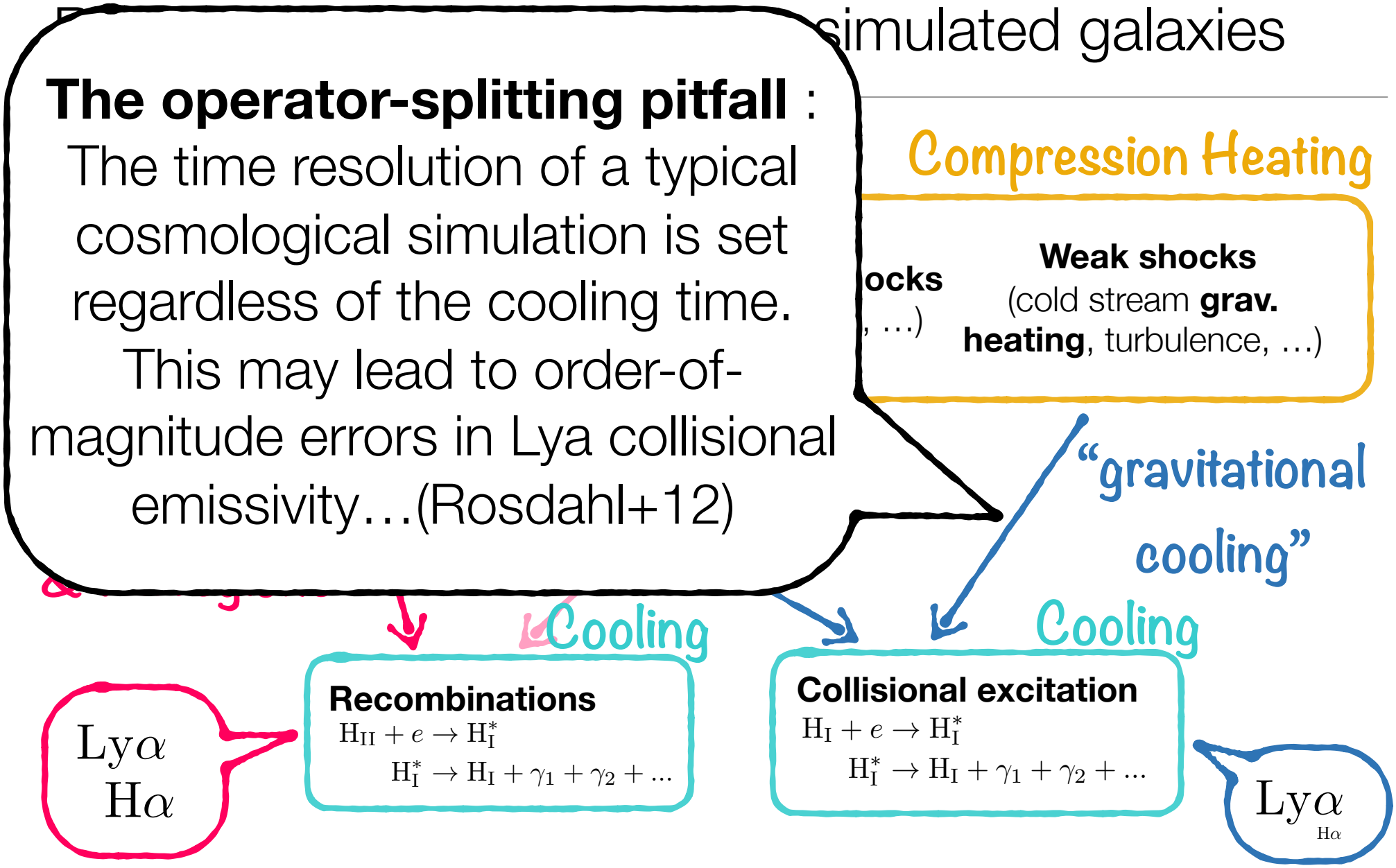
$\mathrm{H_I^*} \rightarrow \mathrm{H_I} + \gamma_1 + \gamma_2 + \ldots$

$\mathrm{Ly}\alpha$ $\mathrm{H}\alpha$

Photo-heating from local sources requires full RHD (e.g. Tasitsiomi 2006, Rosdahl+15)

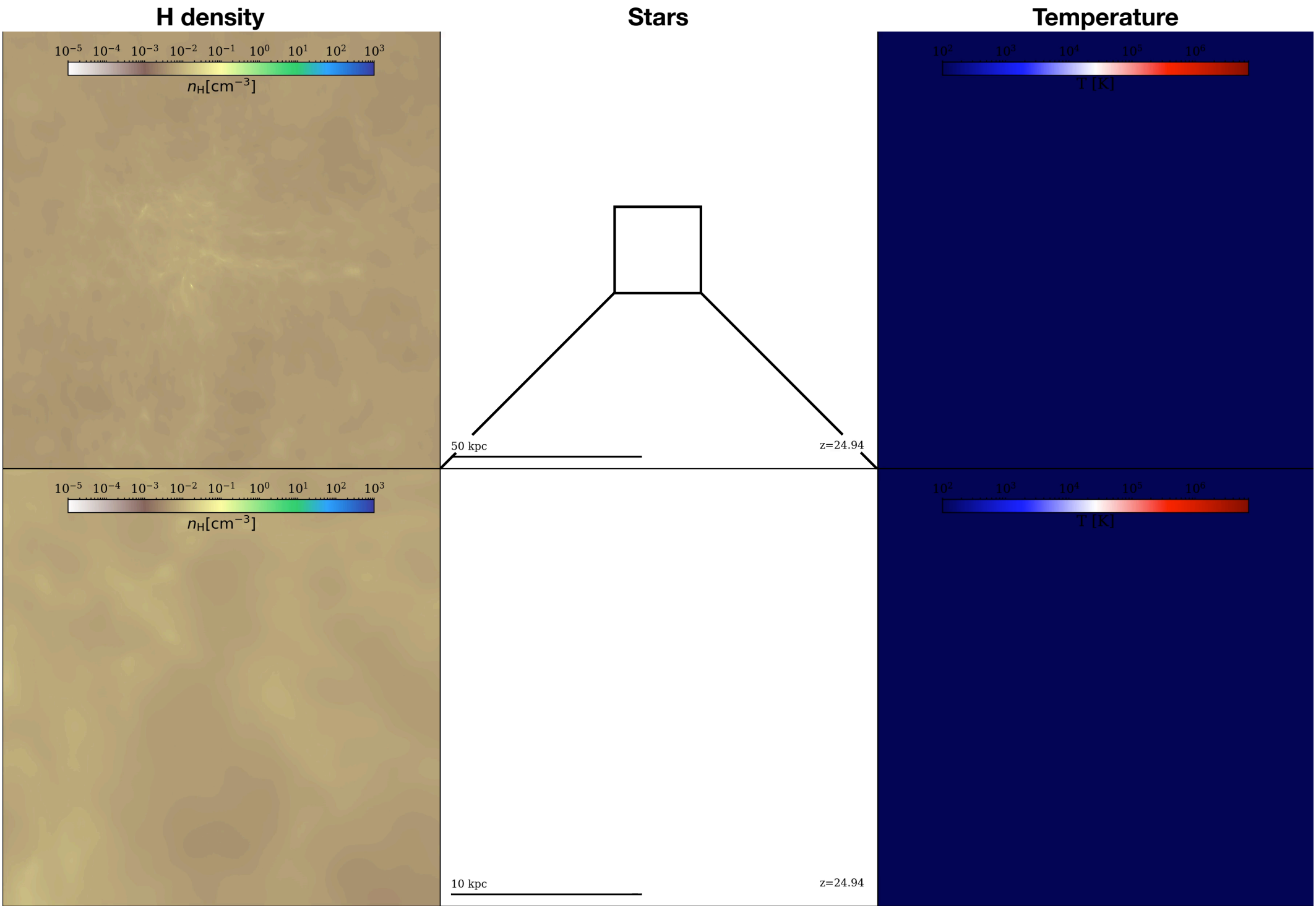

simulated galaxies
The operator-splitting pitfall :
The time resolution of a typical cosmological simulation is set regardless of the cooling time.
This may lead to order-of-magnitude errors in Lya collisional emissivity…(Rosdahl+12)
Compression Heating
ocks
, …)
Weak shocks
(cold stream grav. heating, turbulence, …)
"gravitational cooling"
Cooling
Cooling
Lyα
Hα
Recombinations
$H_{II} + e \rightarrow H_I^*$
$H_I^* \rightarrow H_I + \gamma_1 + \gamma_2 + ...$
Collisional excitation
$H_I + e \rightarrow H_I^*$
$H_I^* \rightarrow H_I + \gamma_1 + \gamma_2 + ...$
Lyα
Hα

Predicting Lya emission from simulated galaxies

- **Full Radiation-hydrodynamics** : on-the-fly self-shielding from UVB is OK for the CGM but misses an important photo-heating term in the ISM.
- **High resolution** : resolve everywhere the cooling time + resolve small-scale ISM structure (see *Verhamme+12 & Behrens & Braun 14, + Kimm and Smith's talks*).
- **Dust model** : e.g. from metallicity & HI distributions (***Laursen+09***)
- **Lya RT** : this is a problem solved (although solution may become more efficient see *Smith+17*)

Example simulation used in this talk

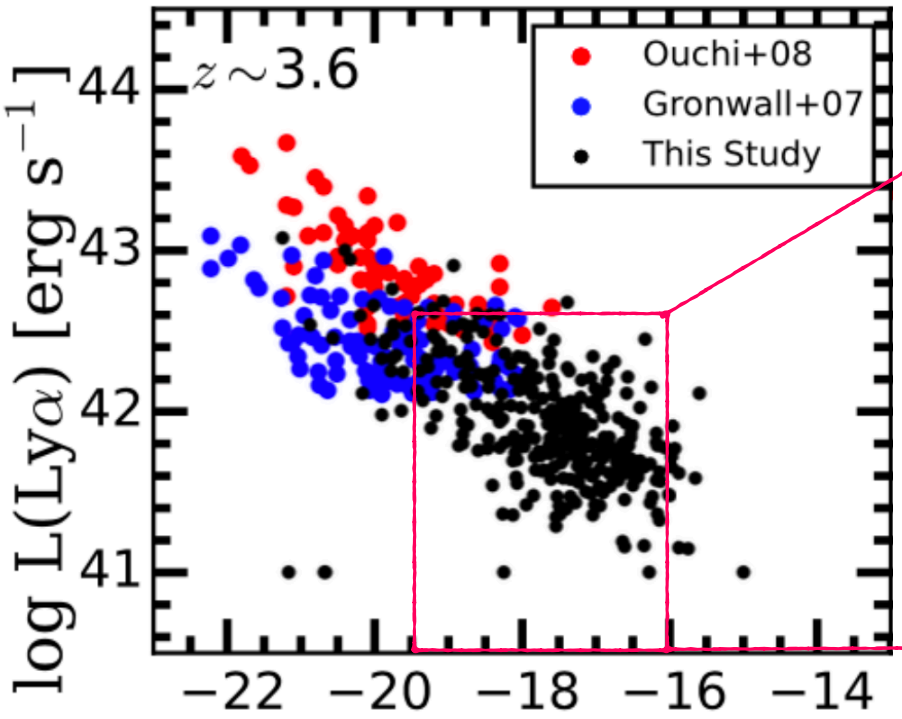
- Zoom-in **RHD simulation** (RAMSES-RT): gas is evolved together with ionising radiation emitted by star particles.
- **Star formation** is triggered where the turbulent Jeans length becomes unresolved. Stars are formed on a free-fall timescale, with a high (local) efficiency. [Kimm+17, Trebitsch+17].
- No polytropic EoS.
- **SN feedback** is Kimm+15's mechanical feedback, which injects momentum so as to reproduce all phases of the Sedov explosion. [see also Rosdahl+16]
- We use an on-the-fly self-shielding approximation, in which the **UVB** is damped exponentially at nH > 0.01 / cm3.
- **Mock observations** (Lya, broad bands) are computed with radiative transfer in post-processing (RASCAS, Michel-Dansac+18, in prep.)



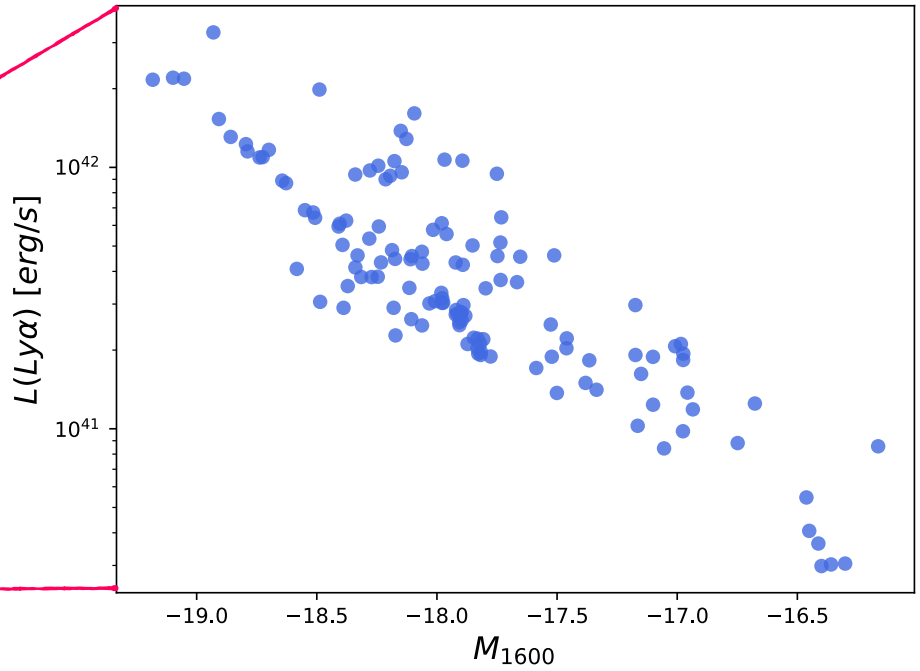
M_{halo} = 5.5 10^{10} M_{sun}, DM particles ~10^4 M_{sun}, star particles ~10^3 M_{sun}, dx ~15pc

Our simulated galaxy is a typical LAE as observed by Wisotzki+16 and Leclercq+18

Hashimoto+18



This simulation



From z = 6 and z = 3,

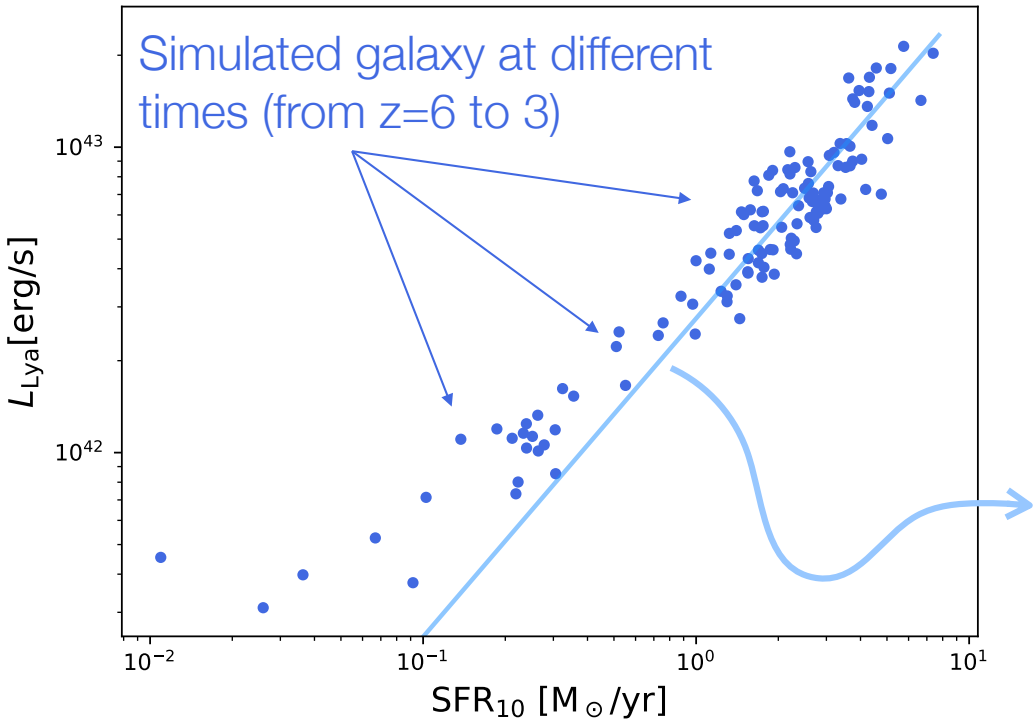
Stellar mass goes from ~$10^8 M_{sun}$ to ~$10^9 M_{sun}$

SFR grows from ~0.1 to ~10 Msun/yr

II. Lya budget & extended emission

How much is **emitted**, how much **escapes**, how much **scatters** ?
Where is it **emitted**, from where does it **escape**, where does it **scatter** ?

Global Lya budget #1
Intrinsic emission vs. SFR



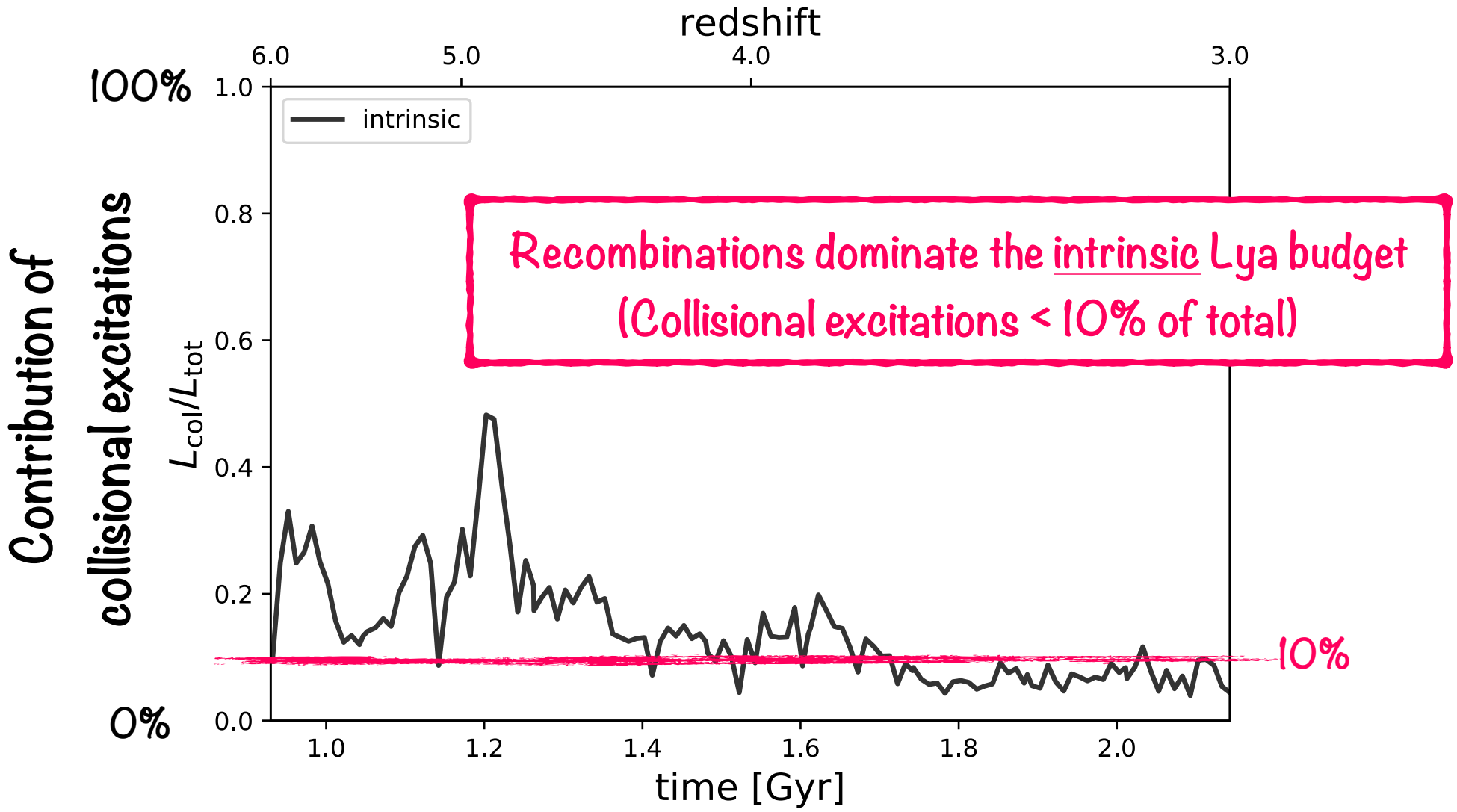
The total Lya luminosity ("fluorescence + cooling") scales linearly with SFR

$$L_{\rm Lya} \sim 3\ 10^{42} \left(\frac{\rm SFR}{1\ {\rm M}_\odot/{\rm yr}} \right) {\rm erg/s}$$

What drives the luminosity : fluorescence or "cooling"

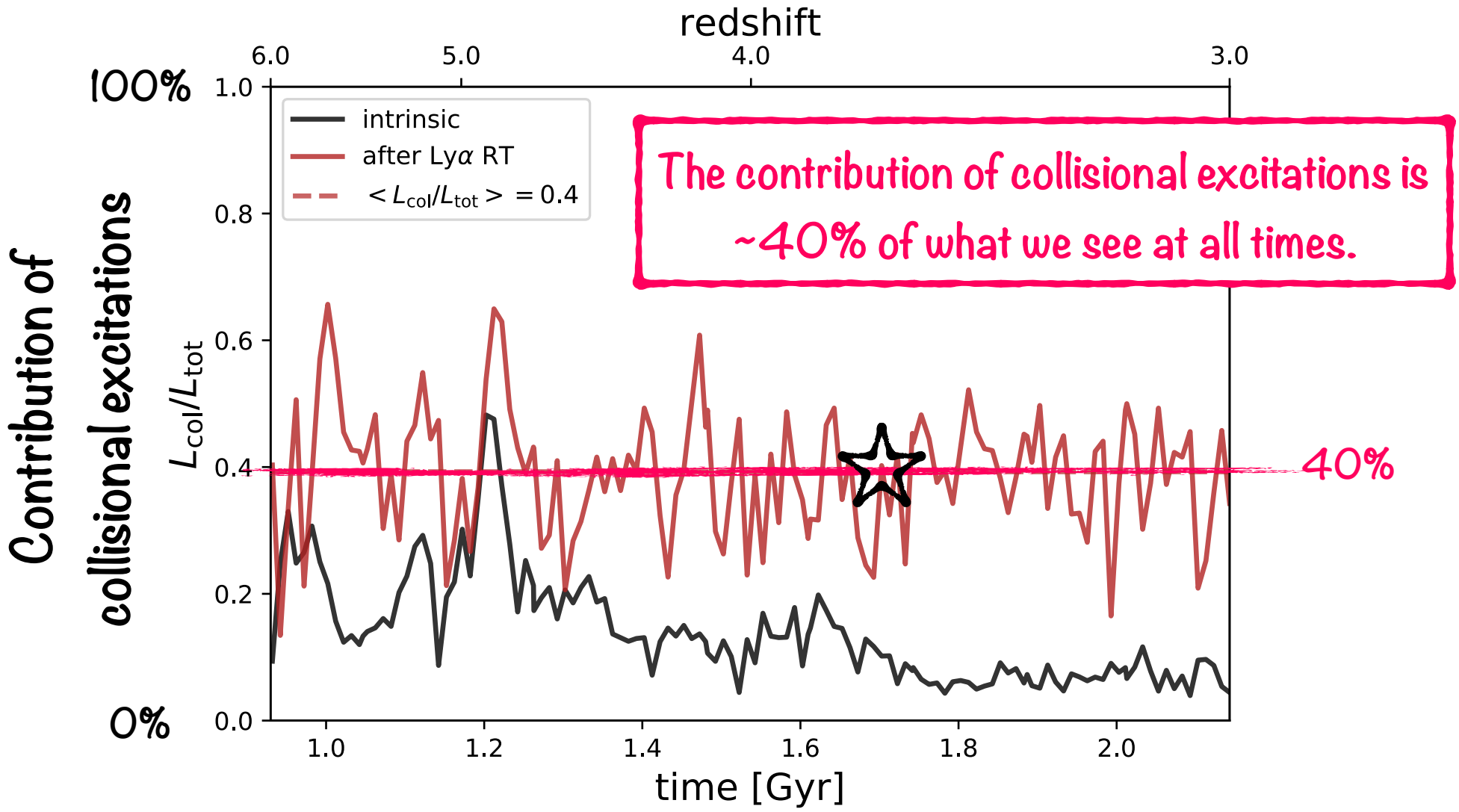
- Expectations from *Tasitsiomi 2006*, *Laursen+07,09a,09b*: **Recombinations dominate** (>90%) total emission, and **collisions are negligible** (< 10%).
- *Yajima+12* : Collisions dominate (~90% at z=10) down to z=3 (~50%). Strong redshift evolution.

Global Lya budget #2
What is *emitted* from (simulated) galaxies



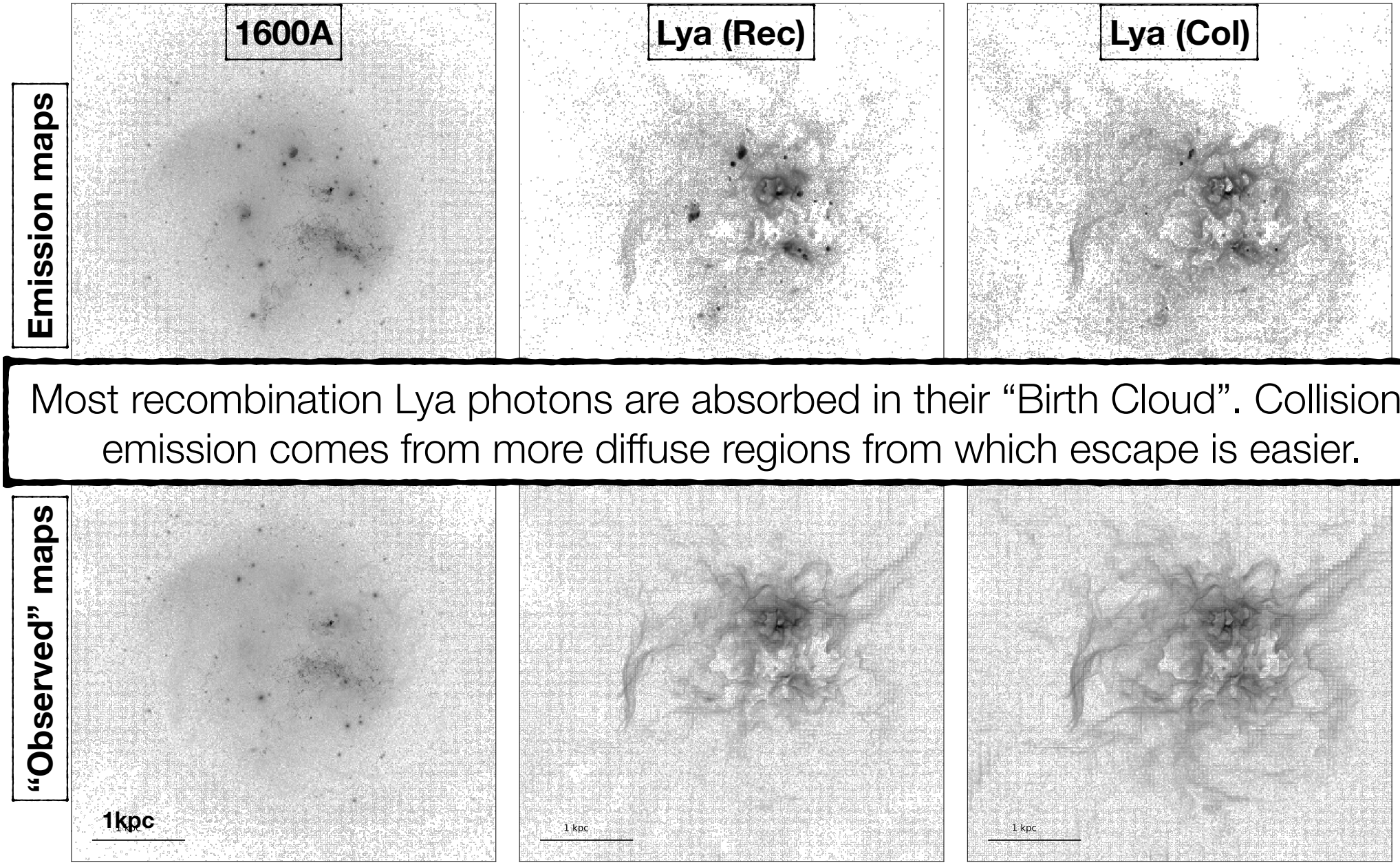
We find a weak trend with redshift: coll. excitations contribute more at higher z's

Global Lya budget #3
What is *observed* from (simulated) galaxies



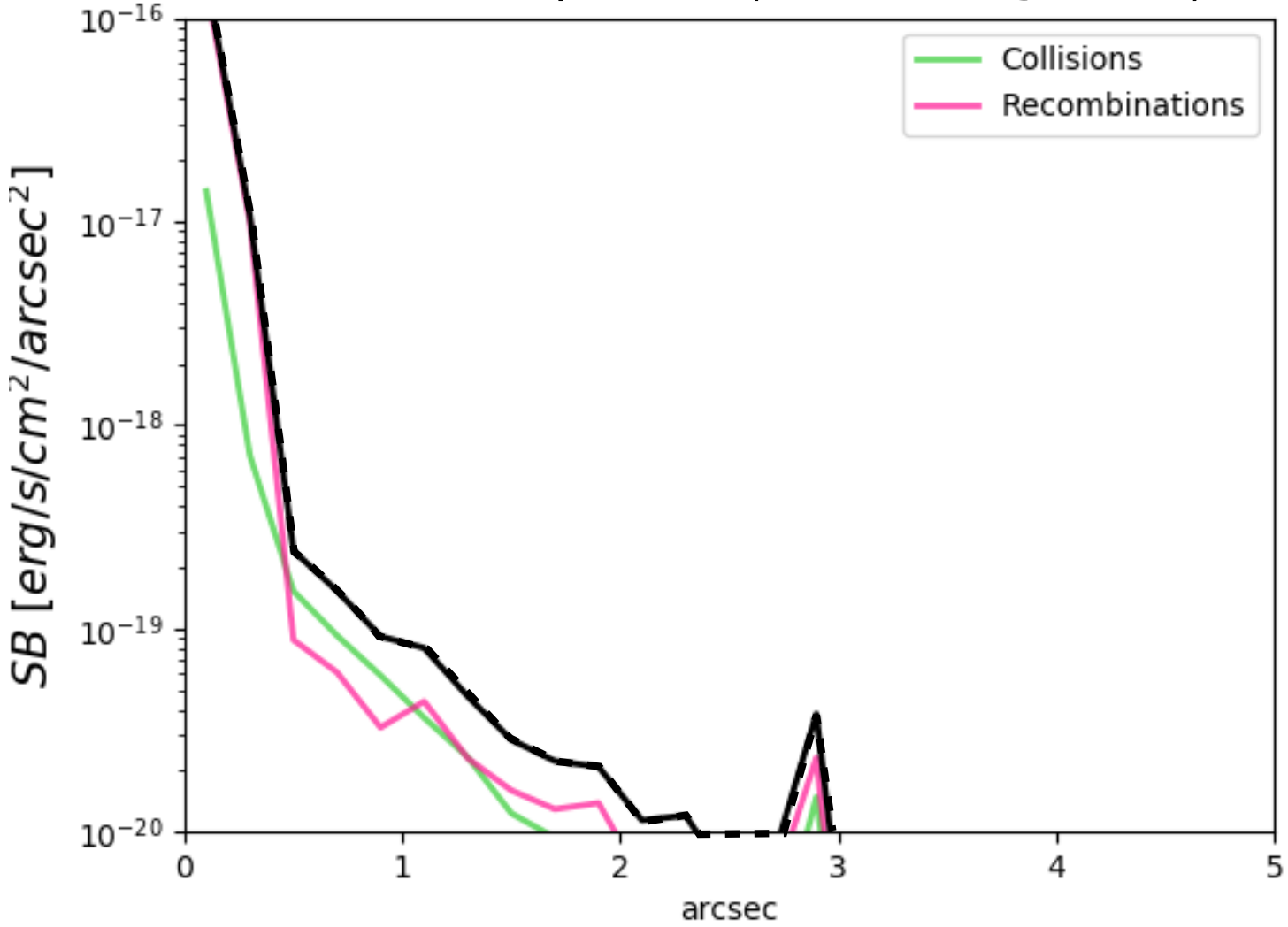
(see Laursen+9b)

Where are photons emitted and absorbed

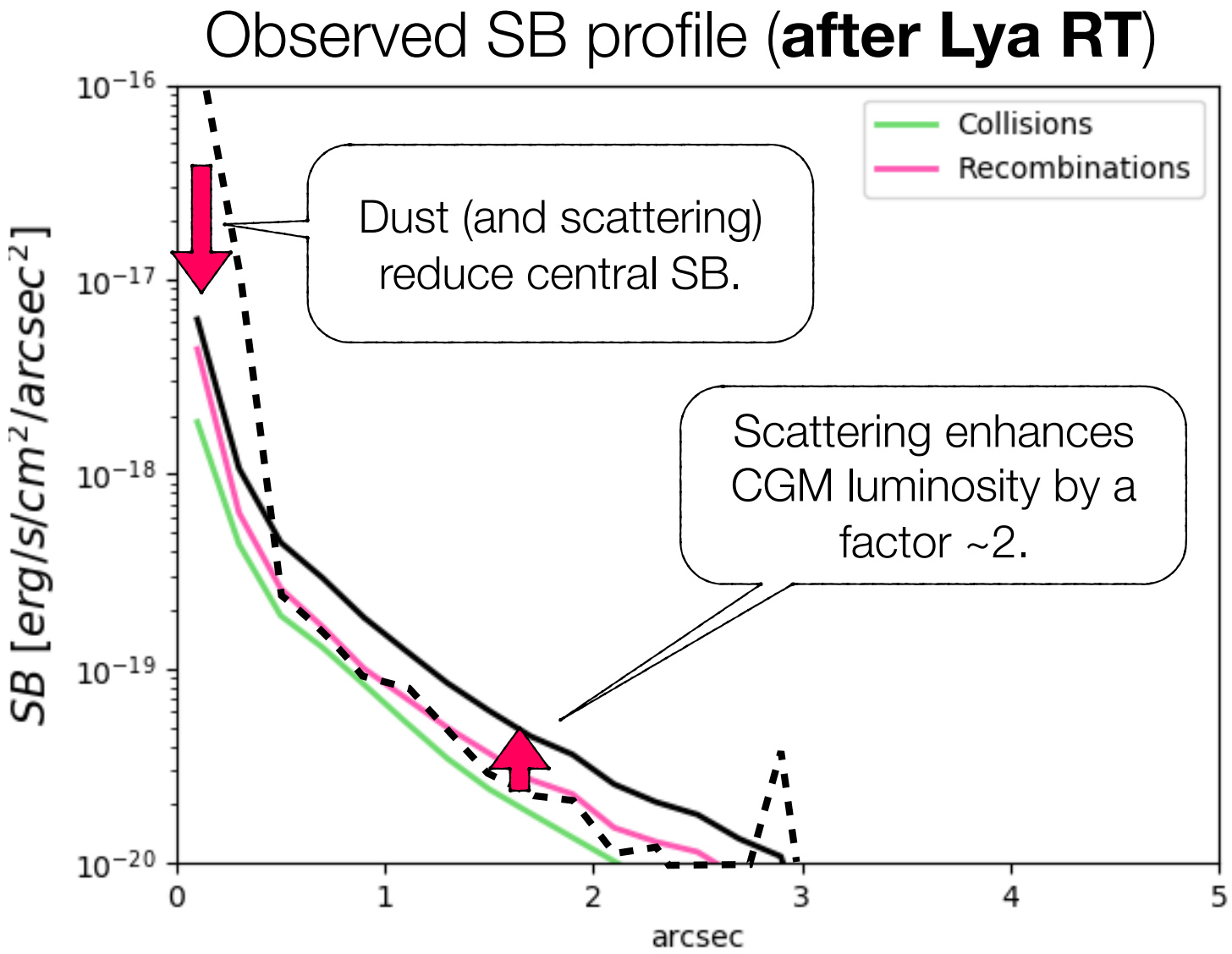


Extended emission
Impact of scattering and dust

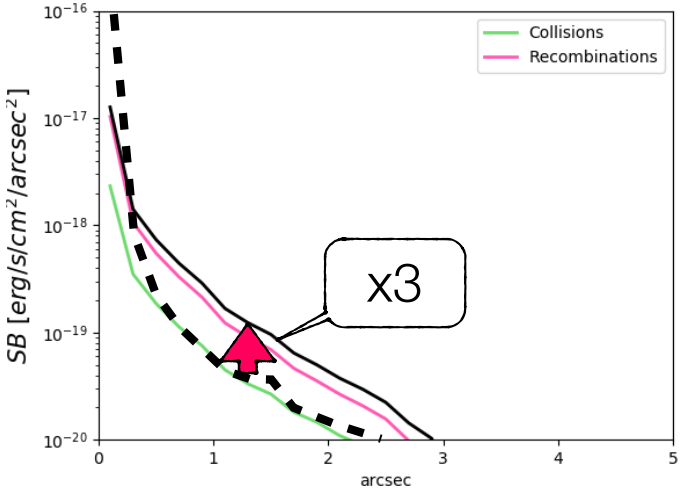
Intrinsic SB profile (**before Lya RT**)

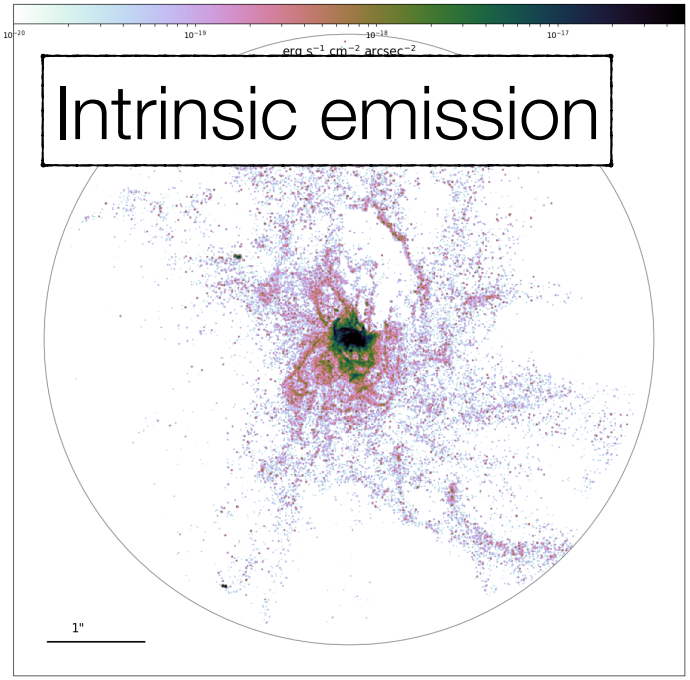


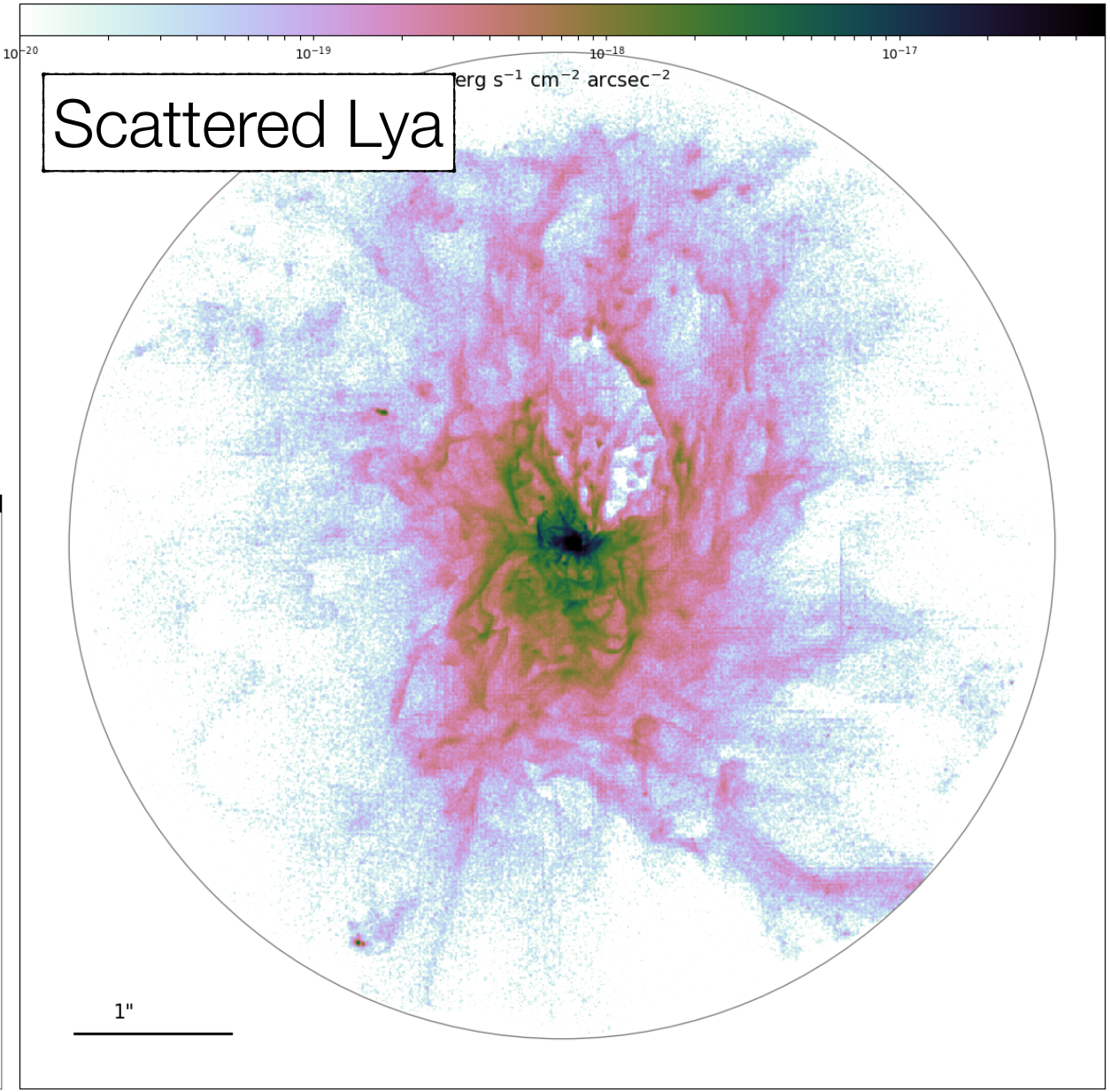
Extended emission
Impact of scattering and dust



Extended emission
Impact of scattering and dust



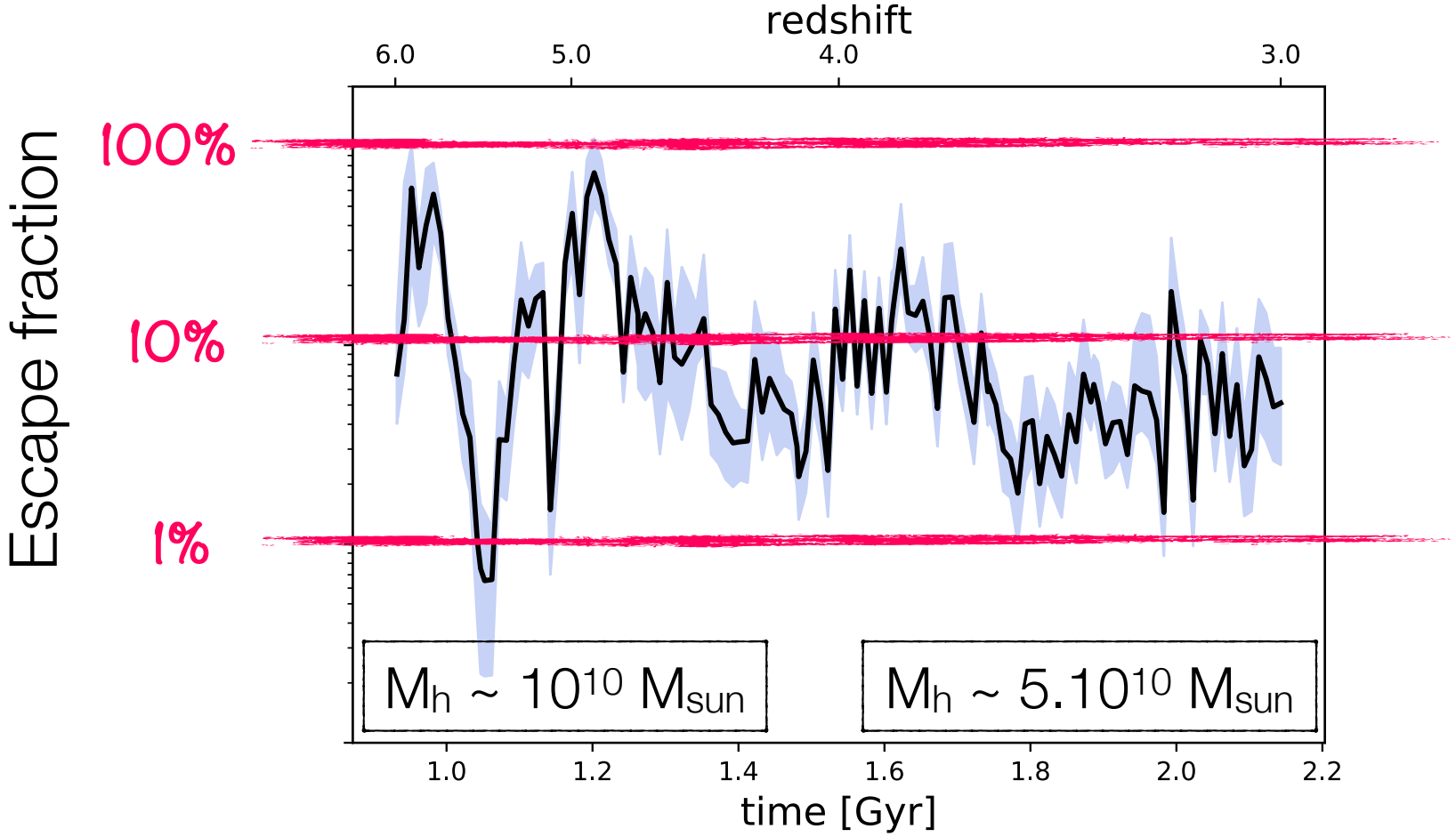




III. Angular and time variations

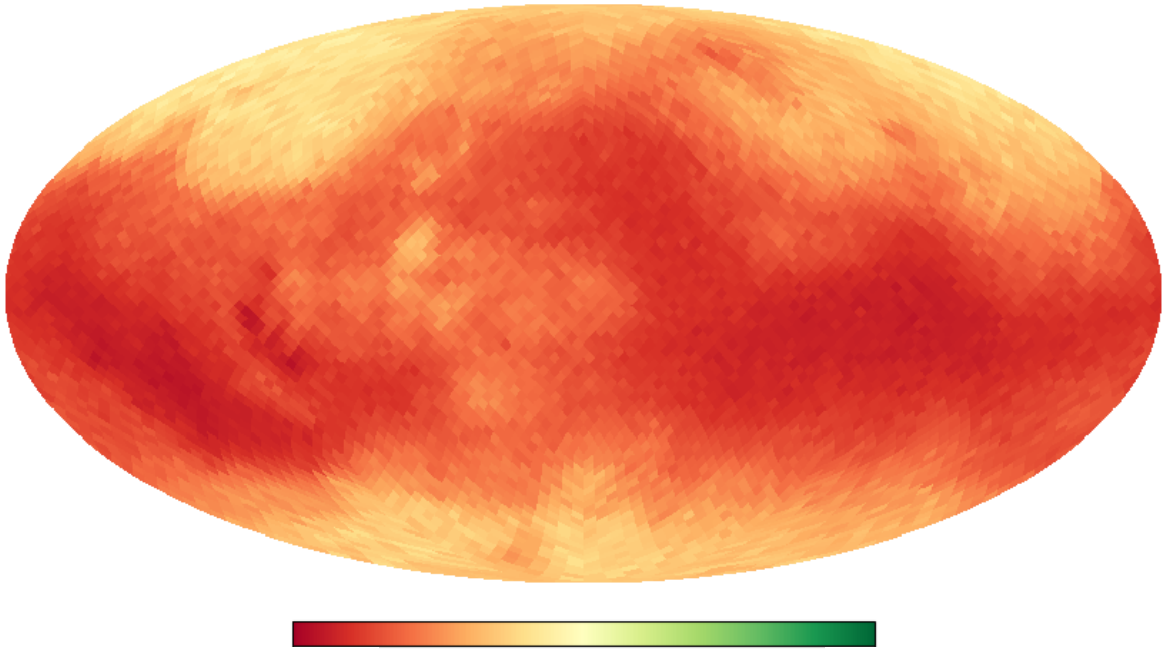
Similar galaxies have very different line properties … What if we could observe a single galaxy along many lines of sight or at different times ?

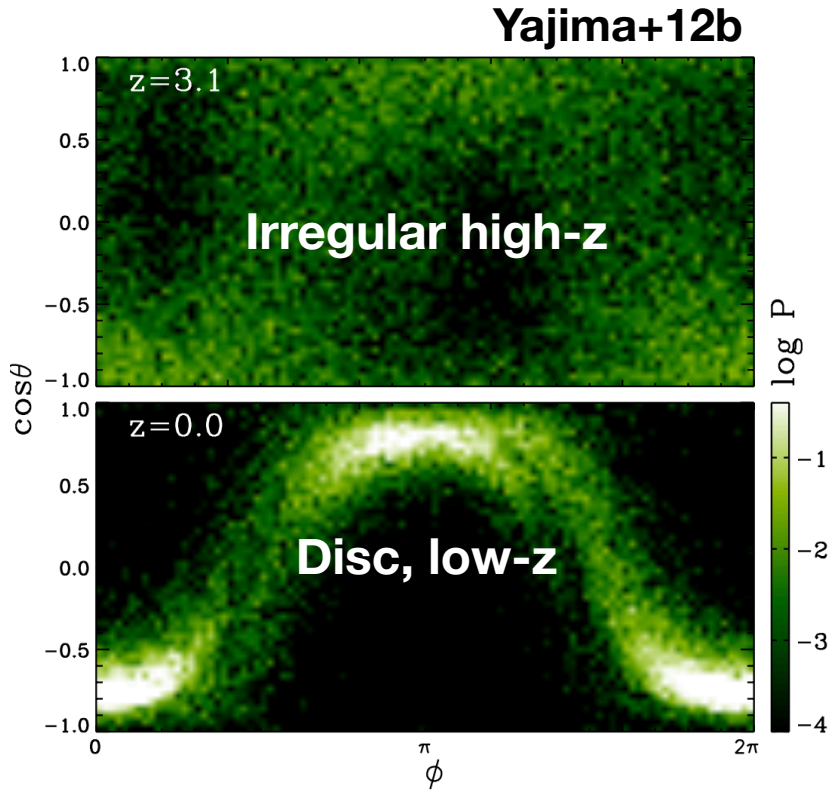
Escape fraction vs. time and mass



Strong & rapid variations are expected due to the small-scale nature of escape regulation (Behrens+14). Some correlation with Halo Mass (see also Laursen+09, *Yajima+12b*).

Escape fraction vs. line-of-sight

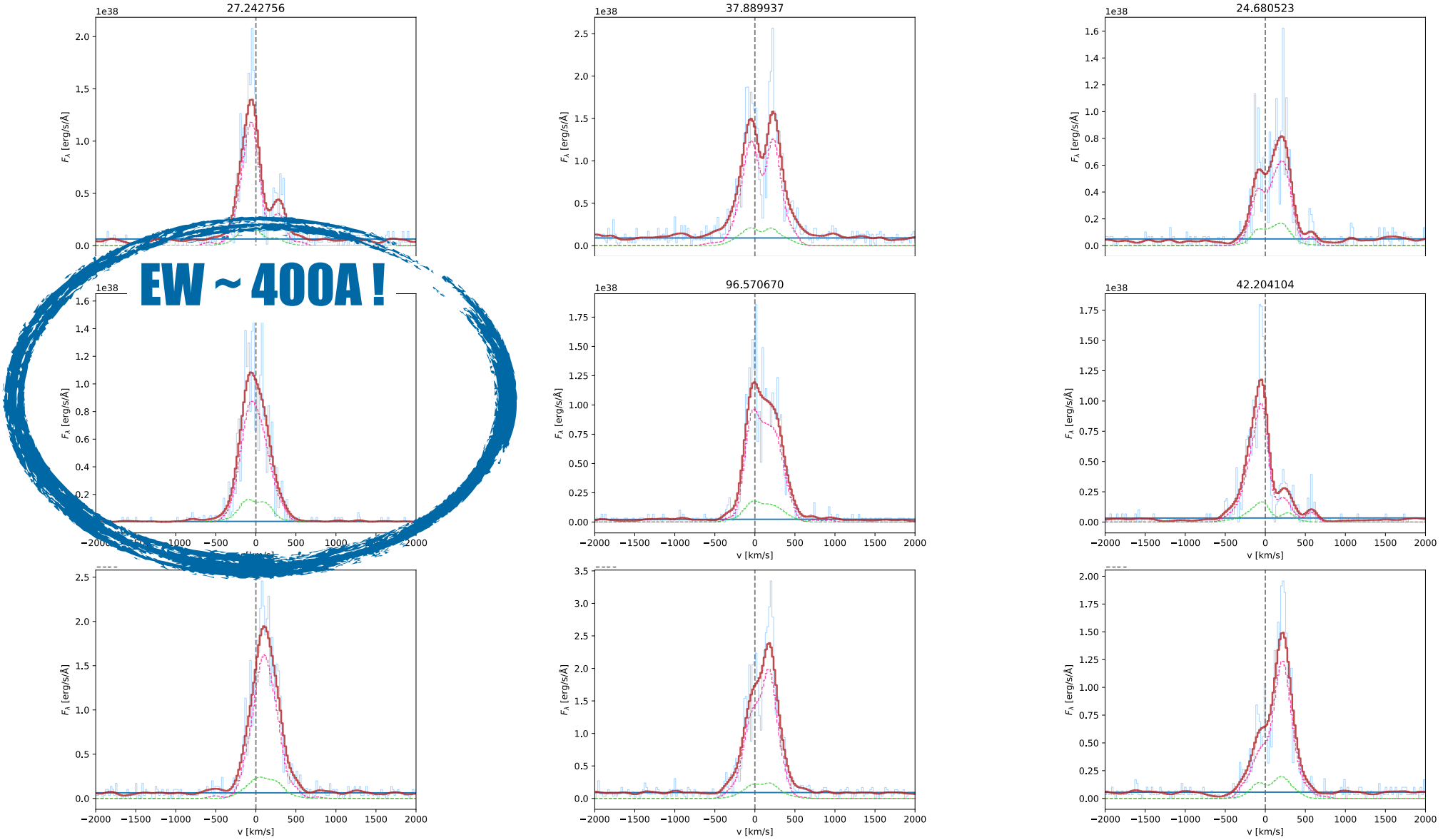




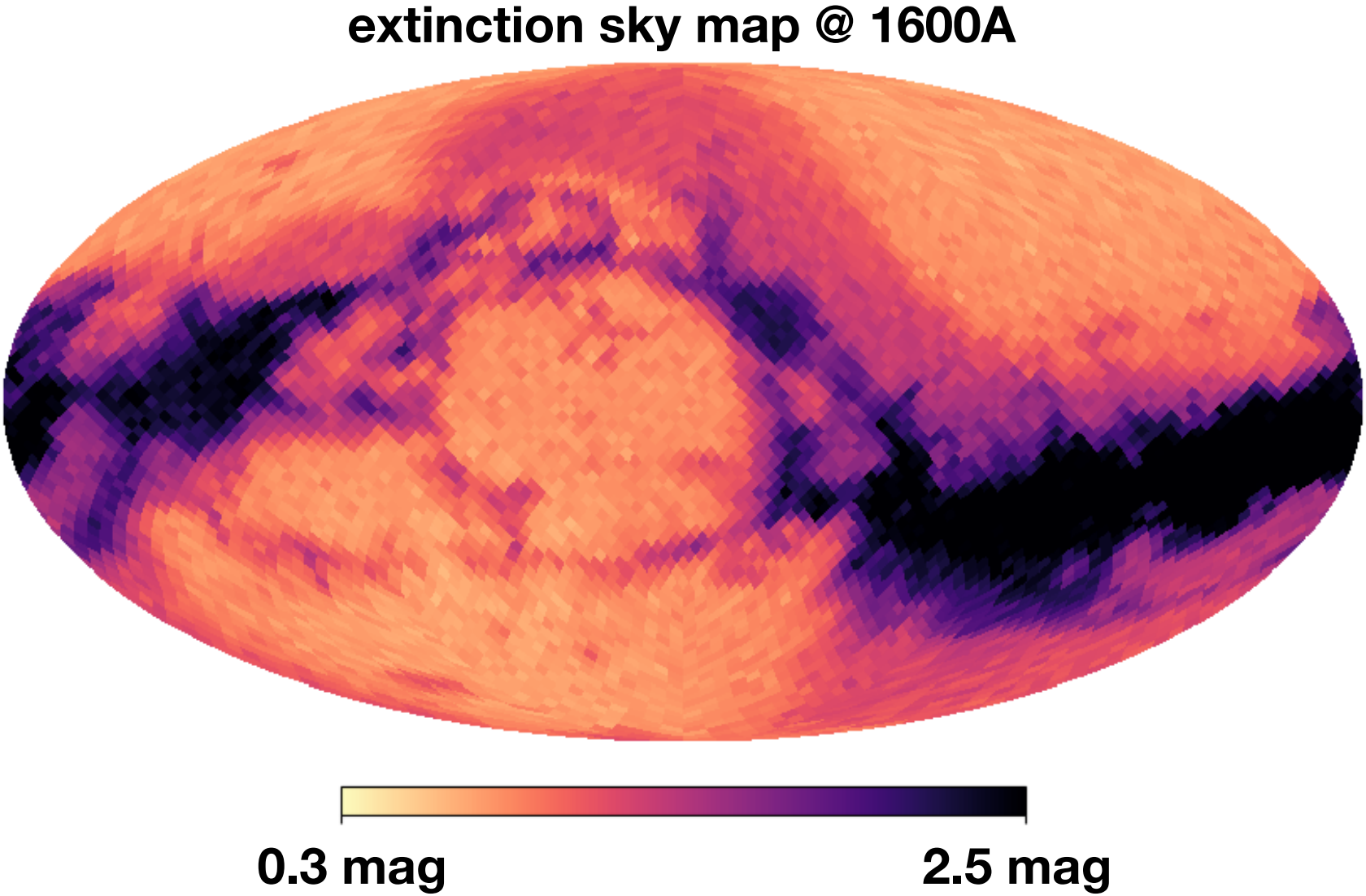
As Laursen+09b & Yajima+12b, we find that **the escape fraction modulates Lya luminosity by a factor less than ~3 in different directions**. This factor is probably larger in disc galaxies (Yajima+12, Verhamme+12, Behrens+14).

Spectra …

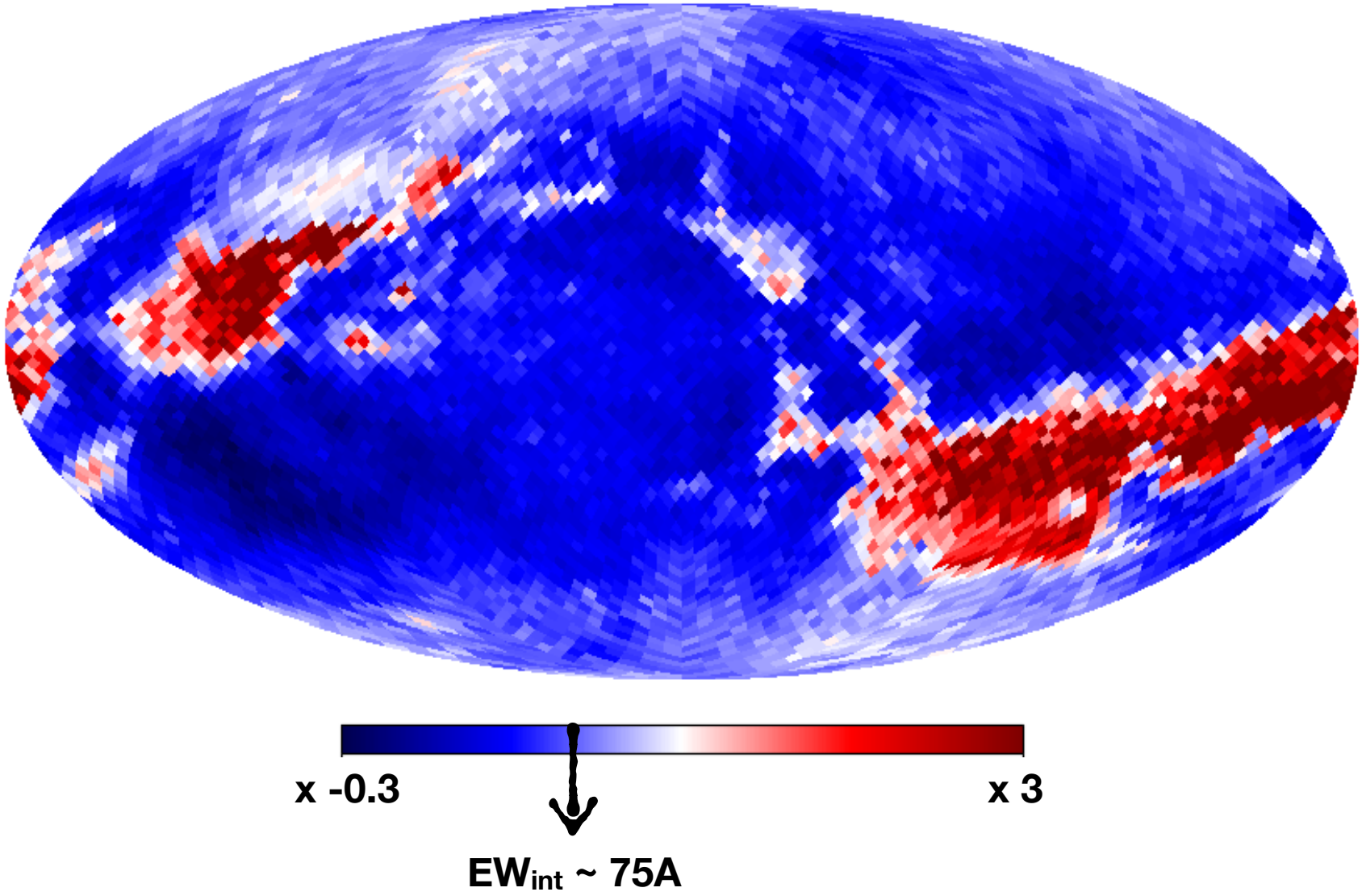
These all come from the same simulated galaxy observed at the same time but in different directions !!



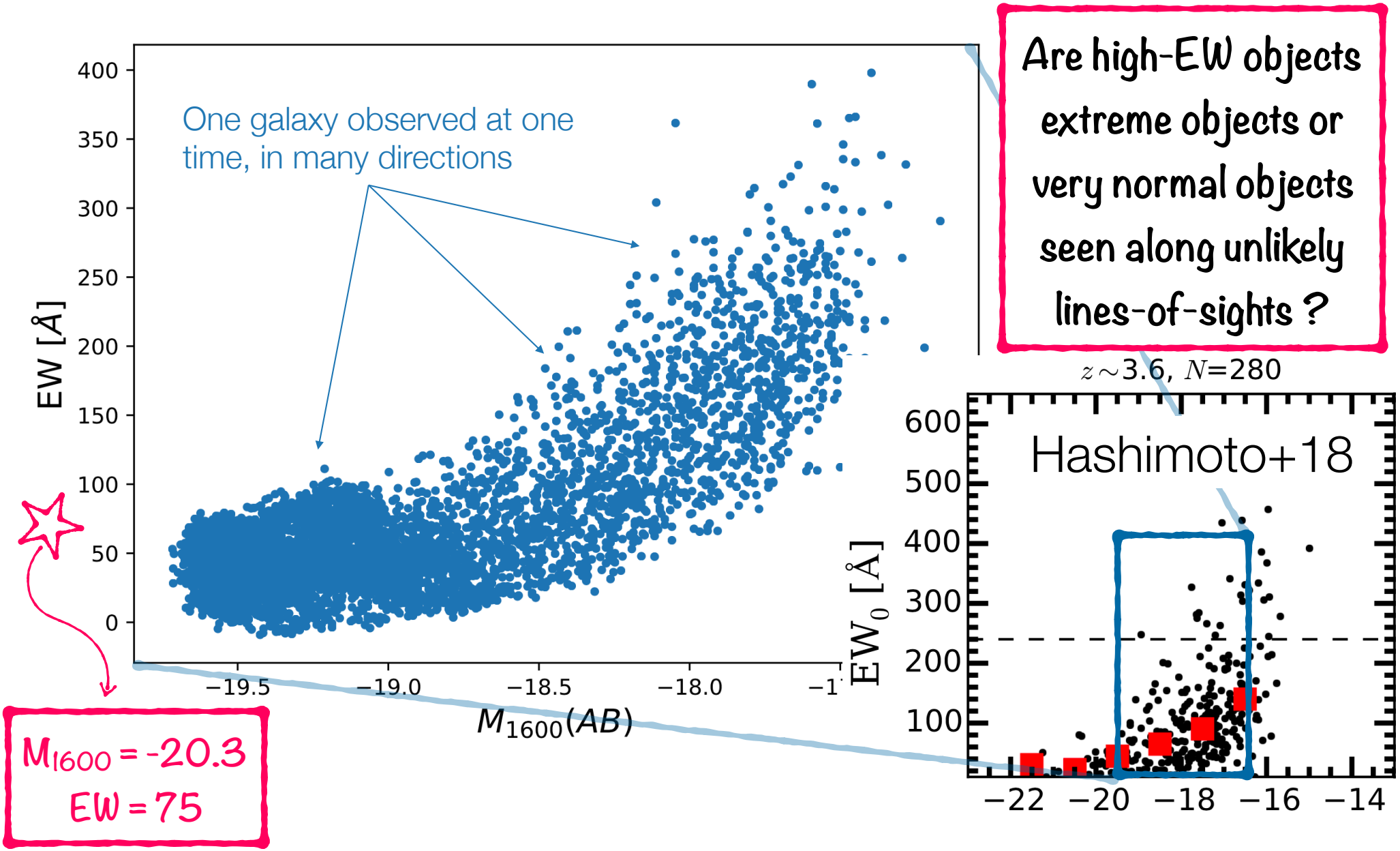
Equivalent width boost



Equivalent width boost

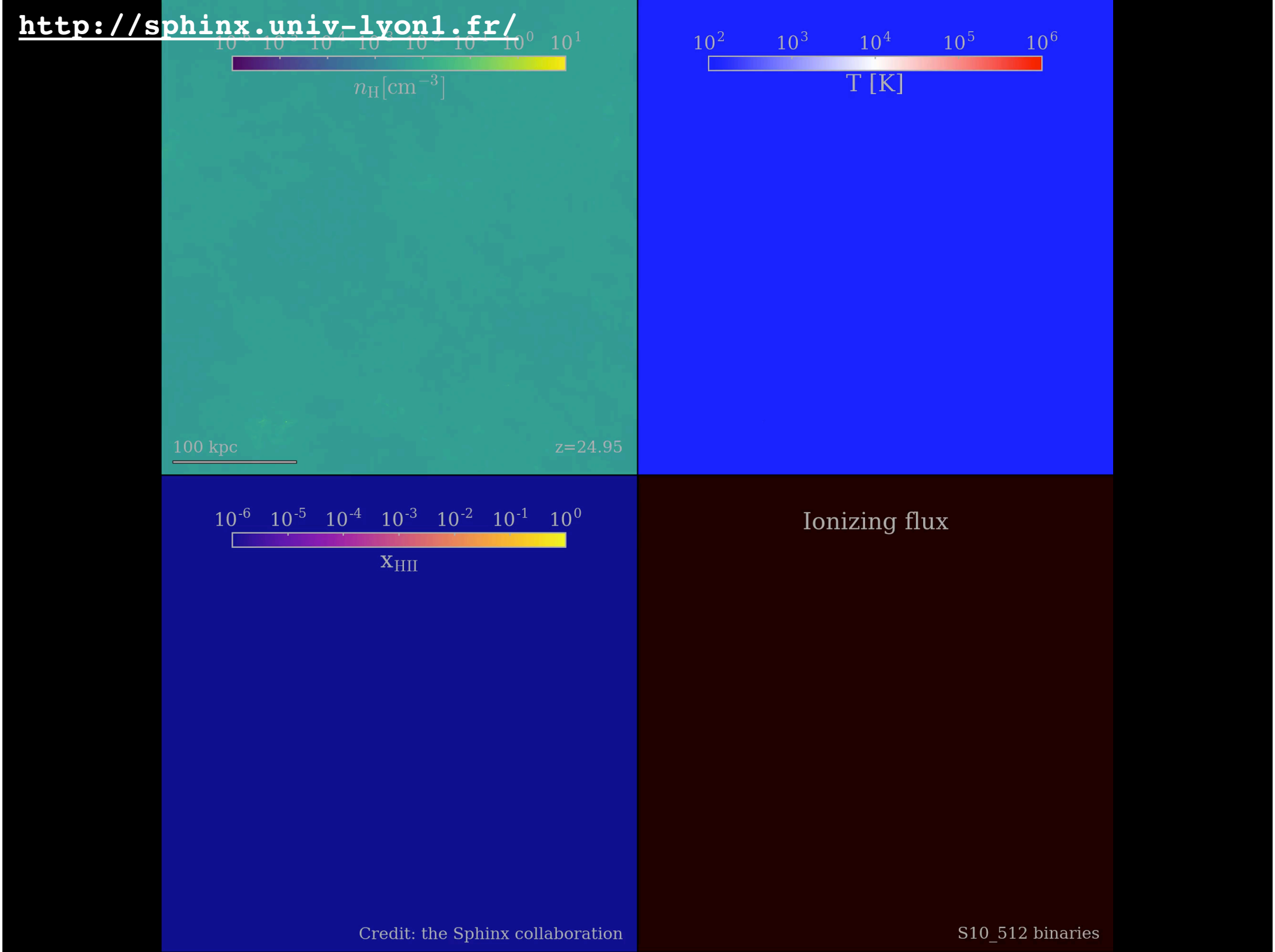


Equivalent width boost and Andō effect



IV. Future directions

Small scales (see talks by Taysun Kimm and Aaron Smith)
SPHINX Project


http://sphinx.univ-lyon1.fr/
10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0} 10^{1}
$n_{\rm H}[{\rm cm}^{-3}]$
100 kpc
z=24.95
10^{2} 10^{3} 10^{4} 10^{5} 10^{6}
T [K]
10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 10^{0}
$x_{\rm HII}$
Ionizing flux
Credit: the Sphinx collaboration
S10_512 binaries

Summary

- Fluorescence largely dominates intrinsic emission, but perhaps not what we see.
- Scattering enhances the CGM SB by a factor ~ 1-3 and produces a halo in reasonable agreement with Leclercq's LAHs.
- The total Lya flux variation with line-of-sight is of limited amplitude (÷/x 2-3).
- The spectral shape of the Lya line varies so much with line-of-sight, one wonders if it may relate to any global properties of the galaxy.
- Differential extinction of Lya wrt. UV continuum produces strong EW where the continuum is strongly absorbed.
- SPHINX is the first simulation ever that will allow us to carry out a fully consistent investigation of LAEs and their visibility through the local IGM during the EoR.