Quasar Absorption System

Current status of QALs (1)

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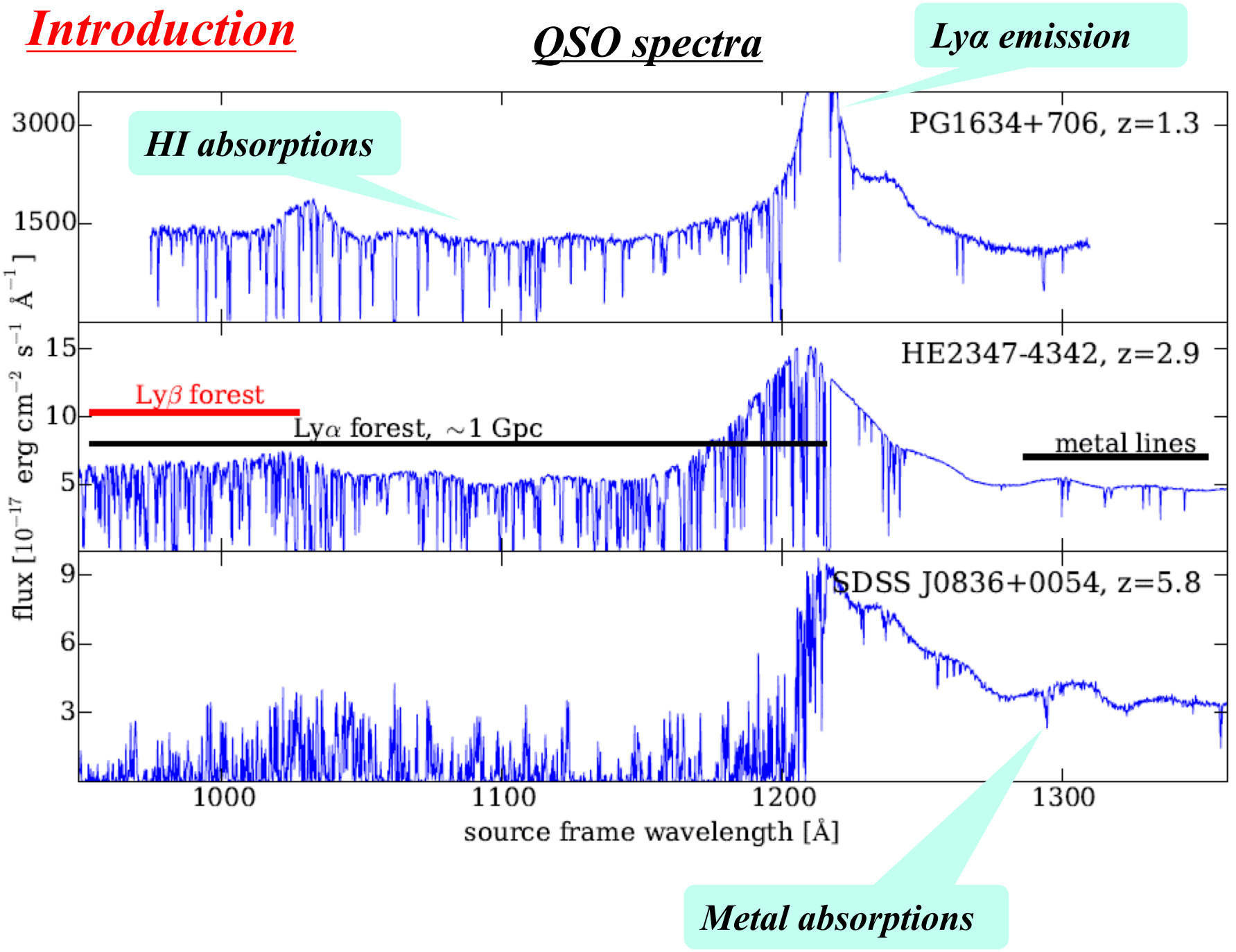
Introduction

QSO spectra



Classification

- **HI absorption Systems**

  Photo-ionization: "Ionized" system ?

  Cross section $\sigma(\nu) = \sigma_1(\nu_1/\nu)^3 \quad \nu_1(1s \rightarrow np)(\Rightarrow \lambda_1 = 912\mathring{A})$

  $$\sigma_1 = 7.9 \times 10^{-18} \quad \mathrm{cm}^2$$

  $$N_{th} = \sigma_1^{-1} = 1.3 \times 10^{17} \quad \mathrm{cm}^{-2}$$

- **Metal absorption Systems**

  Elements: C, Mg, Fe, Na, Zn, etc.. :

  Constraints on SF, SN feedback process

Why we focus on absorption systems ?

- **Physical properties of *Intergalactic Medium*（IGM)**

  Dominant process in IGM

  ⇒ ***Photo-ionization: UV background radiation at e=13.6 eV***

Photon vs Baryon

$$H + \gamma \rightleftharpoons p + e^{-}$$

UV background radiation at e=13.6 eV

- ***Number densities of Radiation sources***

  QSOs, young galaxies, …

- ***Proximity Effect:***

  Decrease Lyα Forest in the vicinity of QSOs

Ionization state of IGM

Ionization rate per hydrogen atom

$$\Gamma = \int_{\nu_1}^{\infty} 4\pi \frac{J_\nu}{h\nu} \sigma(\nu) d\nu \sim 4 \times 10^{-12} J_{21} \ \ \mathrm{sec}^{-1}$$

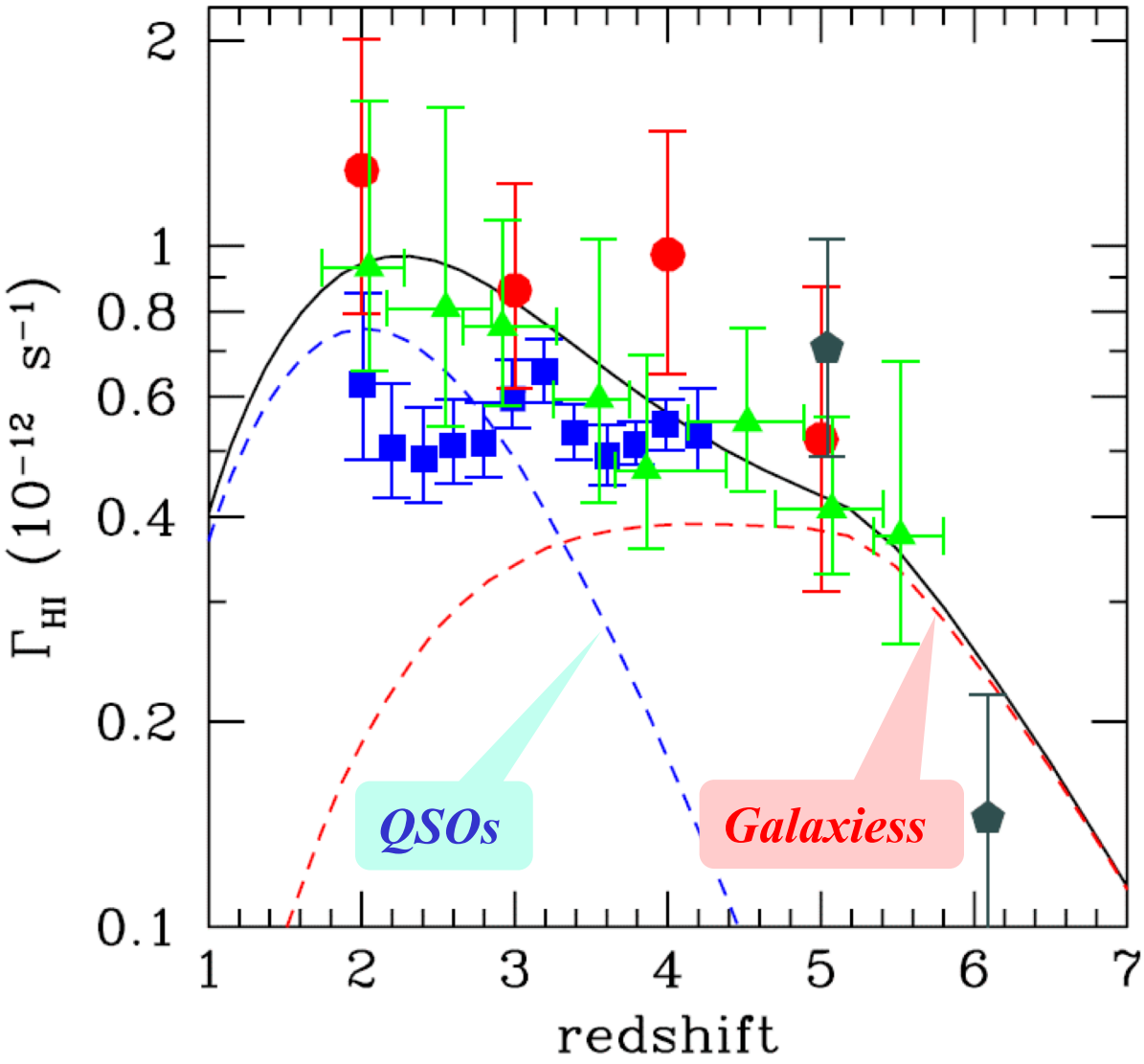
Photo-ionization timescale

$$t_{pi} = \Gamma^{-1} \sim 8 \times 10^3 J_{21}^{-1} \ \ \mathrm{yr}$$

Recombination timescale

(+ Timescales of physical & chemical processes gravitational instability, etc)

Hydrogen photoionization rate



Haadt & Madau 2012

Photon vs Baryon

Observed photon is enough to ionize the intergalactic medium?

$$H + \gamma \quad \rightleftharpoons \quad p + e^{-}$$

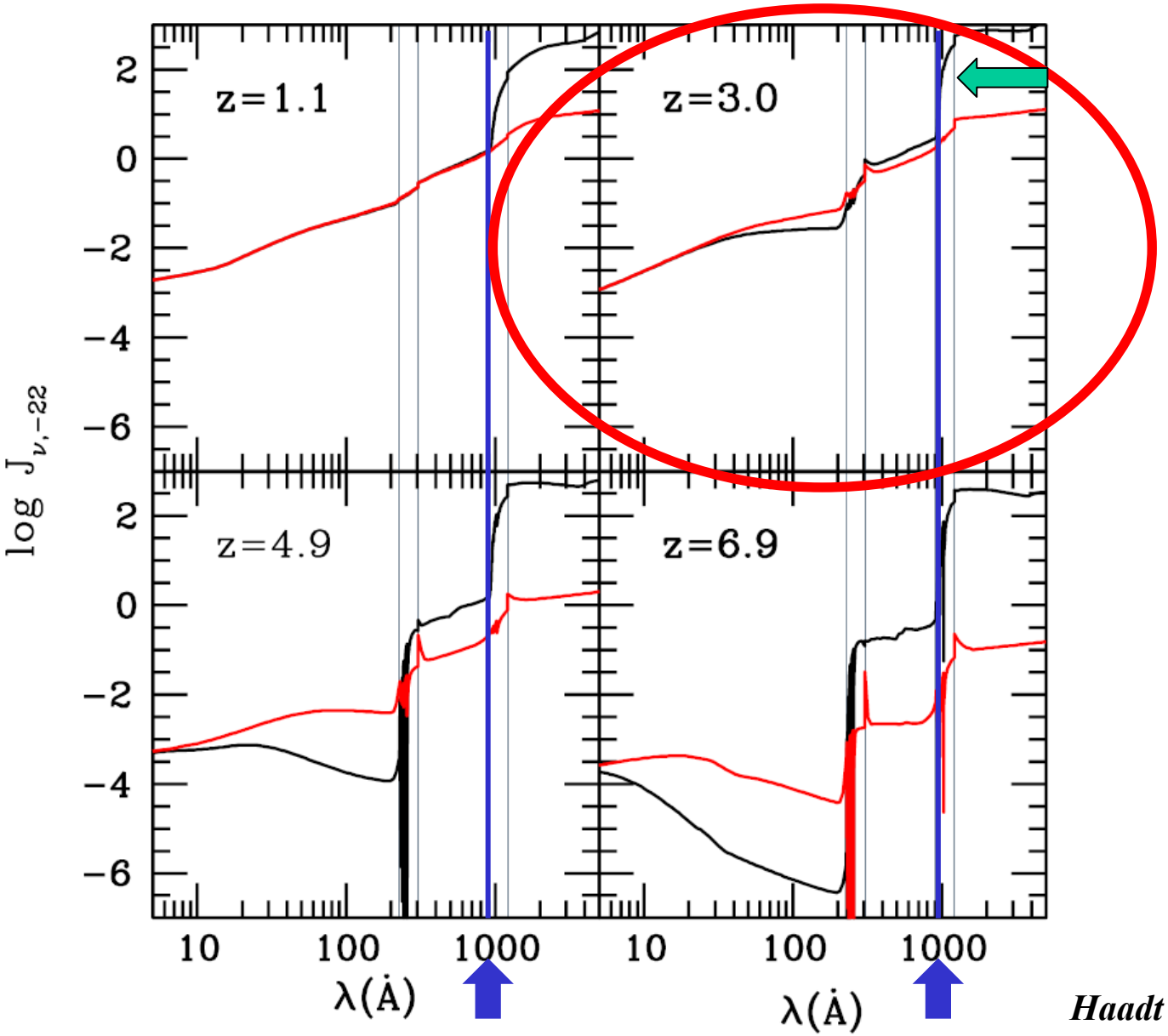
Photon number density n_γ vs Baryon number density n_B

$$\frac{n_\gamma}{n_B} = \frac{J_\nu \cdot \frac{1}{h\nu} \cdot \frac{\nu}{c} \cdot 4\pi}{\frac{1}{m_p} \cdot \frac{3\Omega_B H^2}{8\pi G}} \sim \frac{6 \times 10^{-5} J_{21} (\nu_{\rm LL}/\nu)}{0.9 \times 10^{-5} \Omega_B h_{70}^2 \, E(z)^2}$$

$$\sim \frac{0.3 J_{21}}{\Omega_B h_{70}^2} \qquad \textit{at } z=3$$

Ionizing radiation intensity at 912 Å

$$J_{912,-22} \equiv J_{912}/10^{-22}\ \mathrm{erg\,cm^{-2}\,s^{-1}\,Hz^{-1}\,sr^{-1}}$$



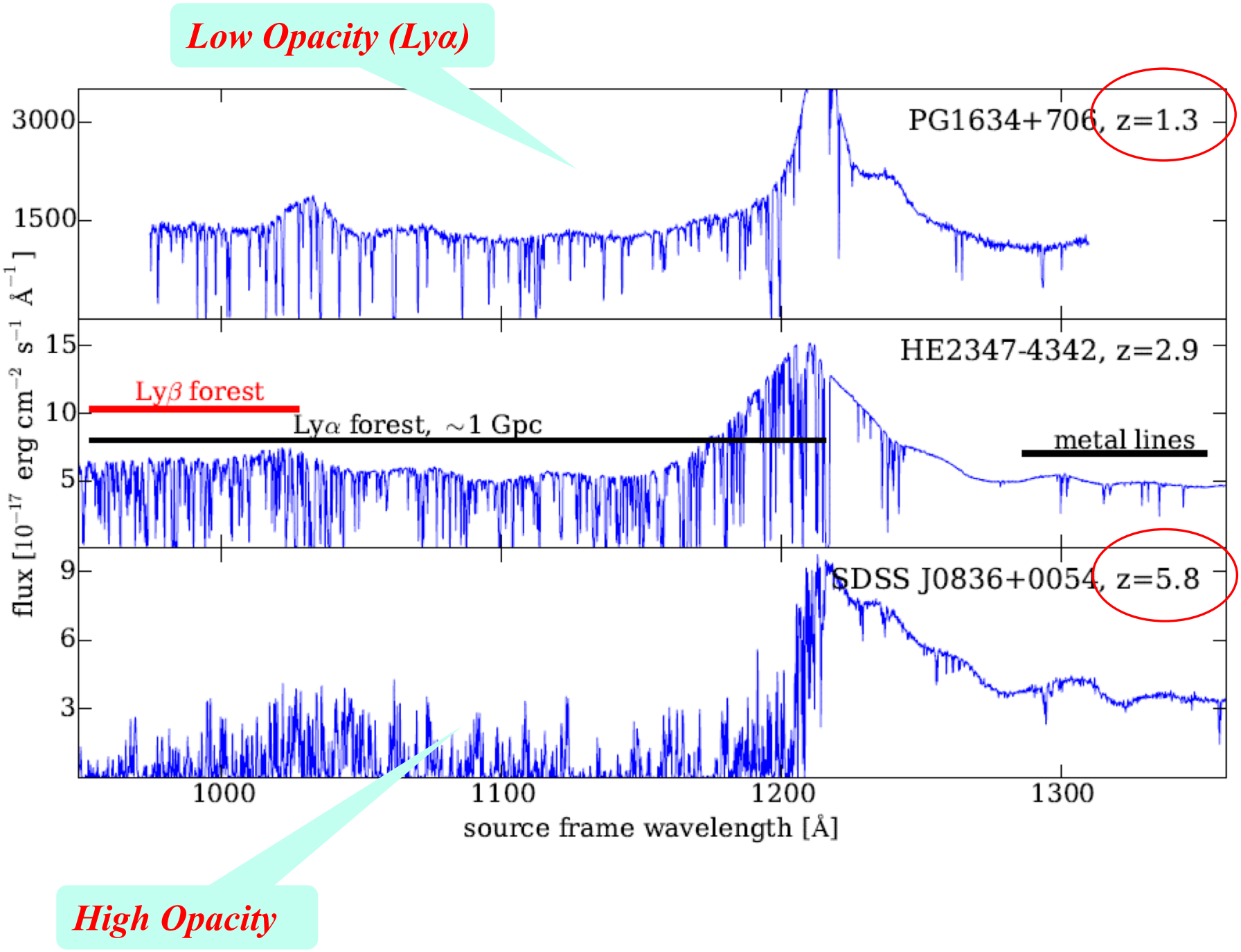
Haadt & Madau 2012

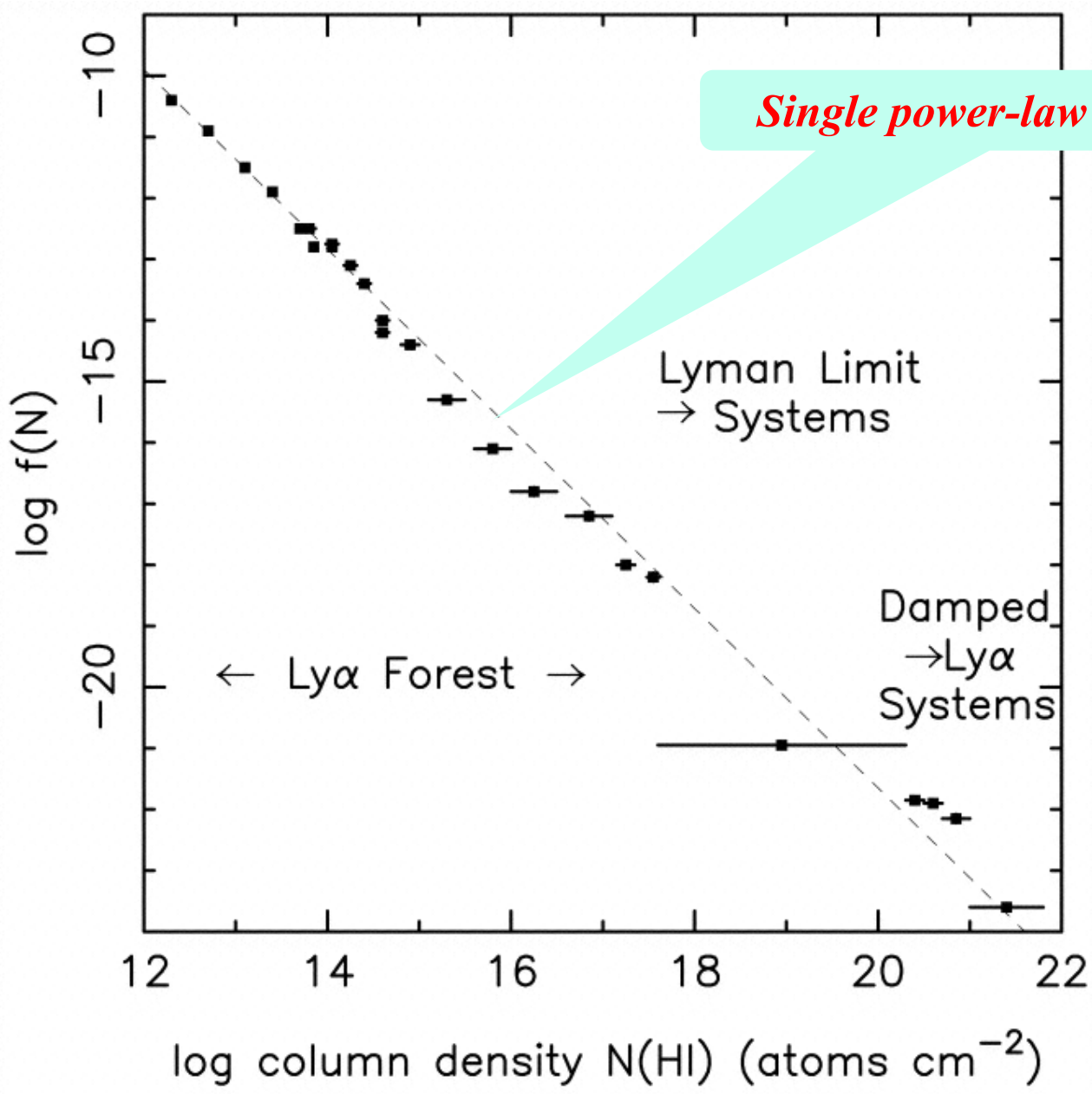
Photo-ionization: UV background radiation at e=13.6 eV

Specific Intensity

$$J_\nu(\epsilon \sim 13.6\mathrm{eV}) \sim 10^{-21}\ \mathrm{erg\ cm^{-2}\ s^{-1}\ Hz^{-1}\ str^{-1}} (= J_{21})$$

at z~2-3


Low Opacity (Lyα)
PG1634+706, z=1.3
HE2347-4342, z=2.9
Lyβ forest
Lyα forest, ~1 Gpc
metal lines
SDSS J0836+0054, z=5.8
High Opacity
flux [10^-17 erg cm^-2 s^-1 Å^-1]
source frame wavelength [Å]
3000
1500
15
10
5
9
6
3
1000
1100
1200
1300


Single power-law ($\propto N(HI)^{-\beta}$)
Lyman Limit
→ Systems
Damped
→Lyα
Systems
← Lyα Forest →
log f(N)
−10
−15
−20
12
14
16
18
20
22
log column density N(HI) (atoms cm^{-2})

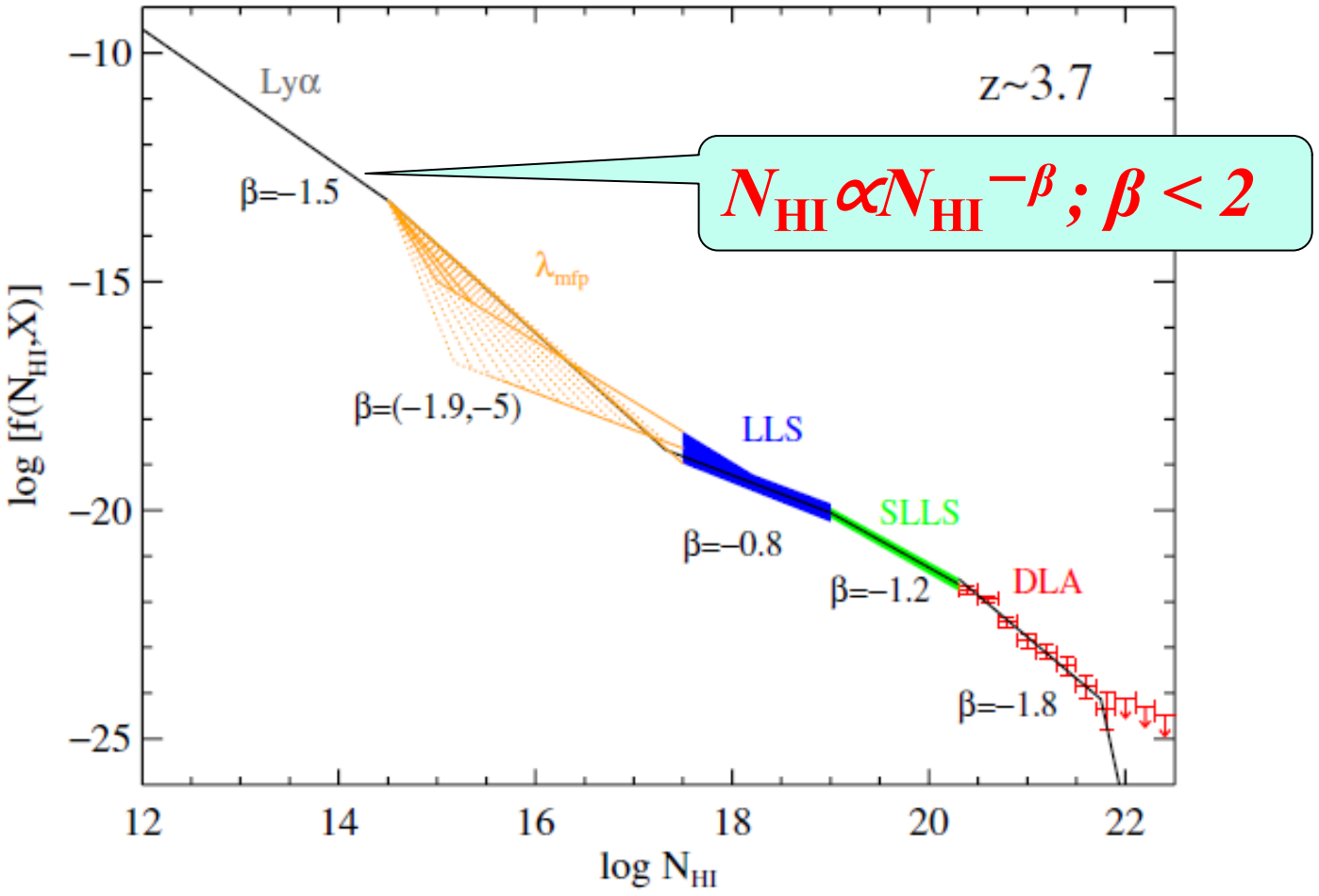


Figure 14. Solid black curve shows our estimation of $f(N_{\rm H\,I}, X)$ at $z \approx 3.7$ as a series of six power laws that intersect at $N_{\rm H\,I} =$

Prochaska et al. 2010

HI gas reservoir

DLA contains a *significant fraction of the HI gas* in the universe!

Ω(HI) ~10^{-3} at 0 < z < 4

$$\Omega_{\rm DLA} \propto \int N_{\rm HI} \frac{\partial^2 N}{\partial N_{\rm HI} \partial z} dN_{\rm HI}$$

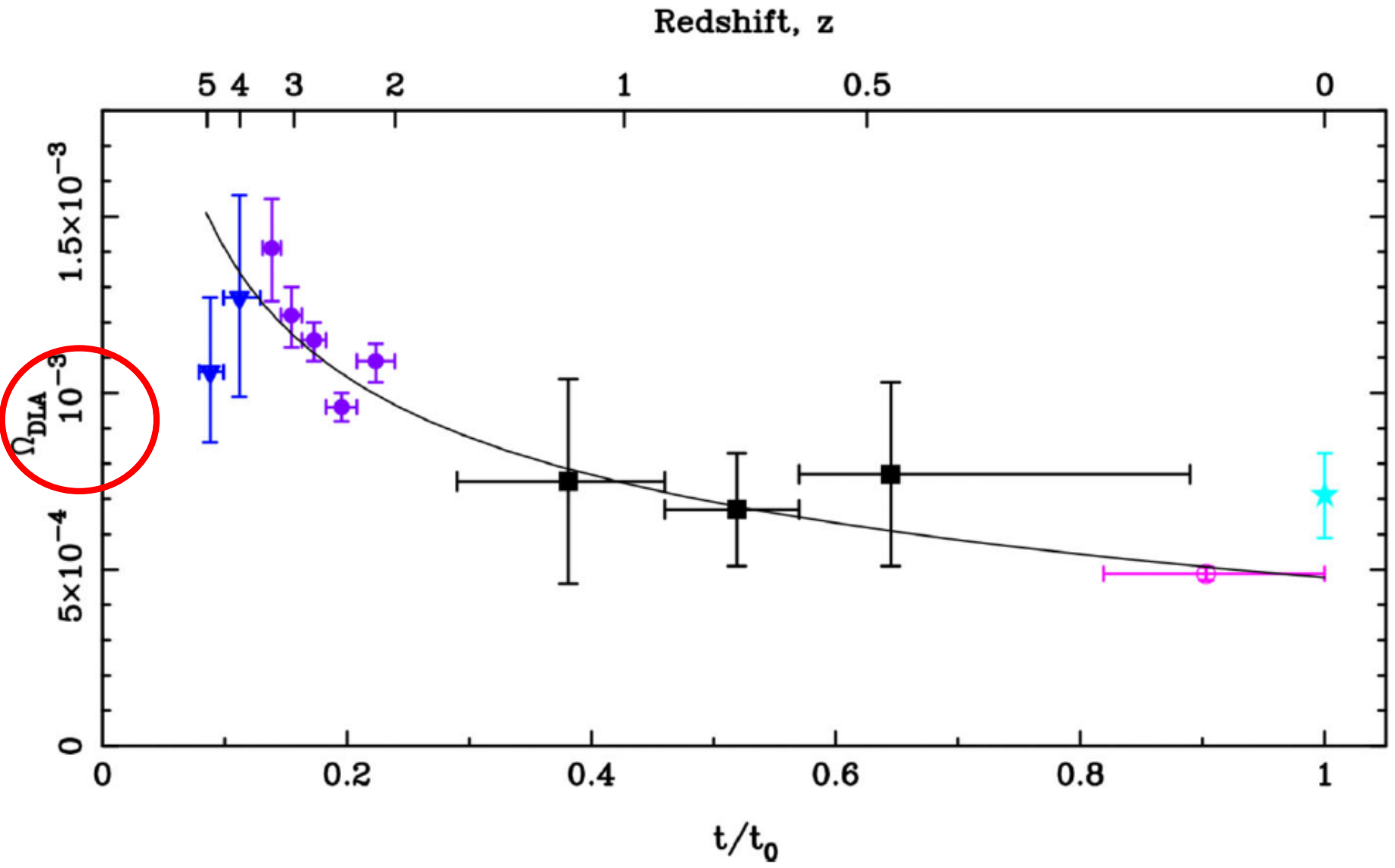
$$\frac{dN}{dN_{\rm HI}} \propto N_{\rm HI}^{-\beta}$$

$$\Omega_{\rm DLA} \propto \int N_{\rm HI} N_{\rm HI}^{-\beta} dN_{\rm HI} \propto \int N_{\rm HI}^{1-\beta} dN_{\rm HI}$$

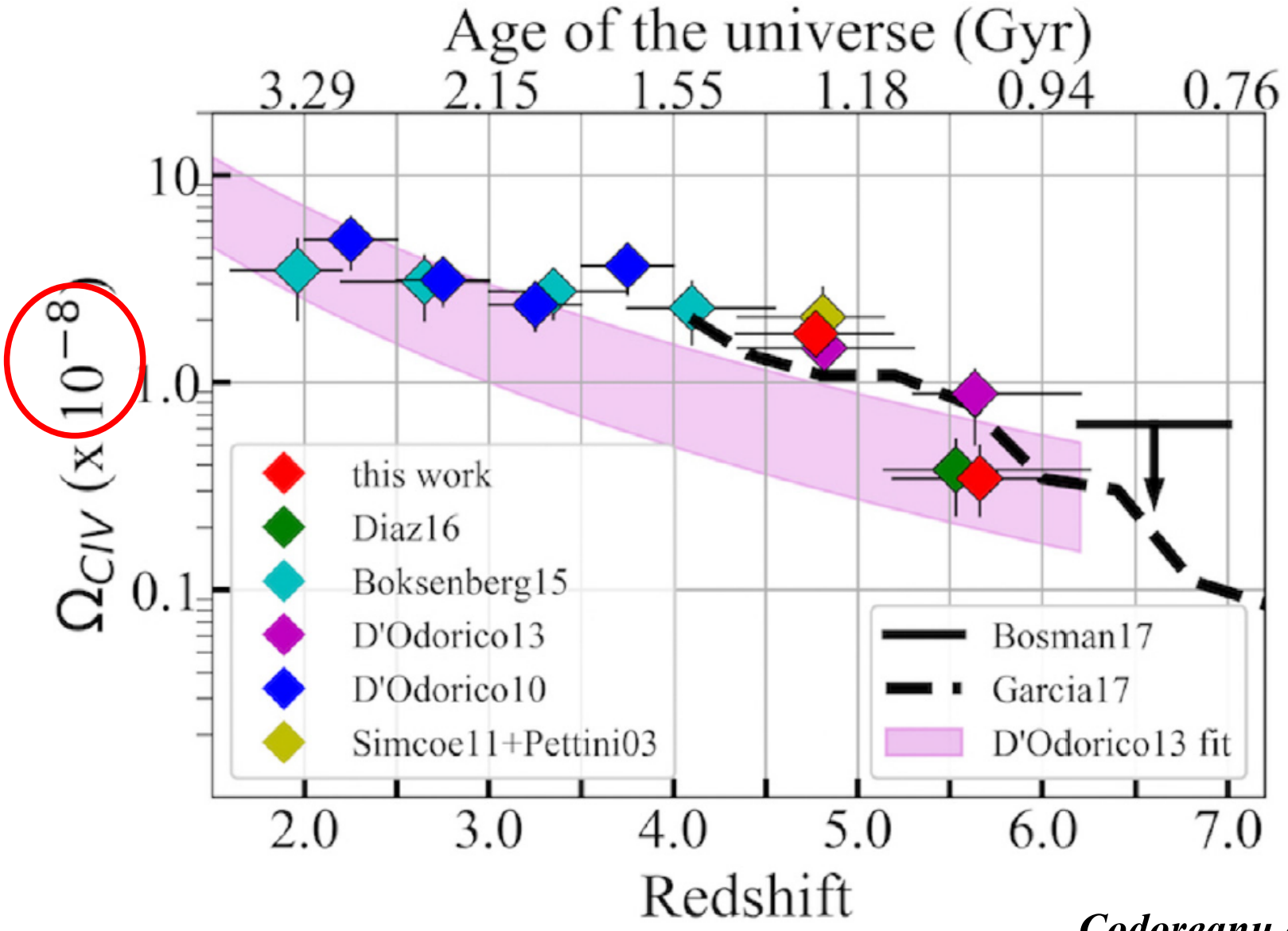
$$\propto \left[N_{\rm HI}^{2-\beta}\right]^{N_{\rm HI}(max)} \sim N_{\rm HI}(max)^{2-\beta}$$

β = 1.4-1.7

➡ ***HI gas resides in DLAs !***



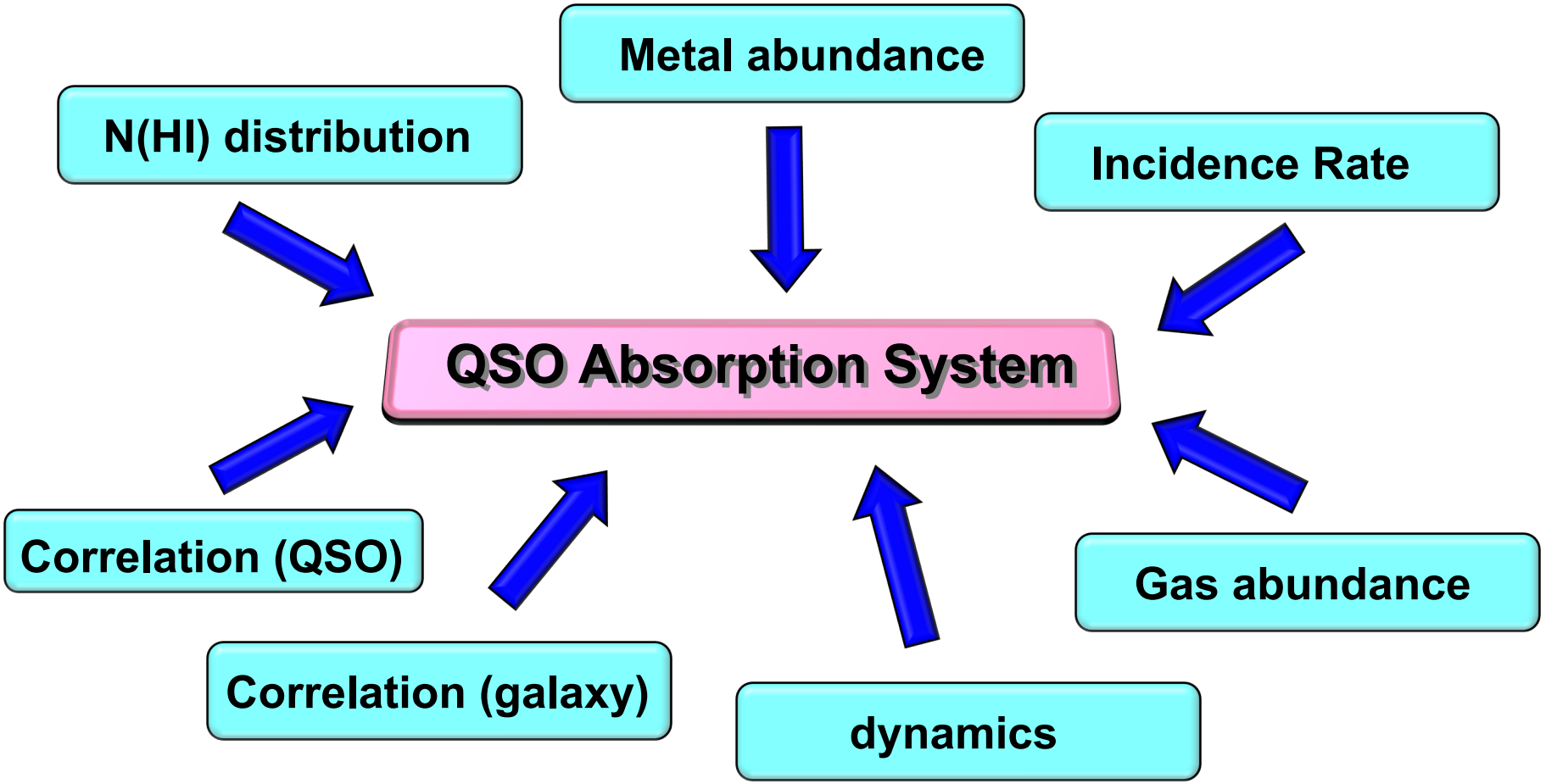
Rao et al. 2017



Codoreanu et al. 2018

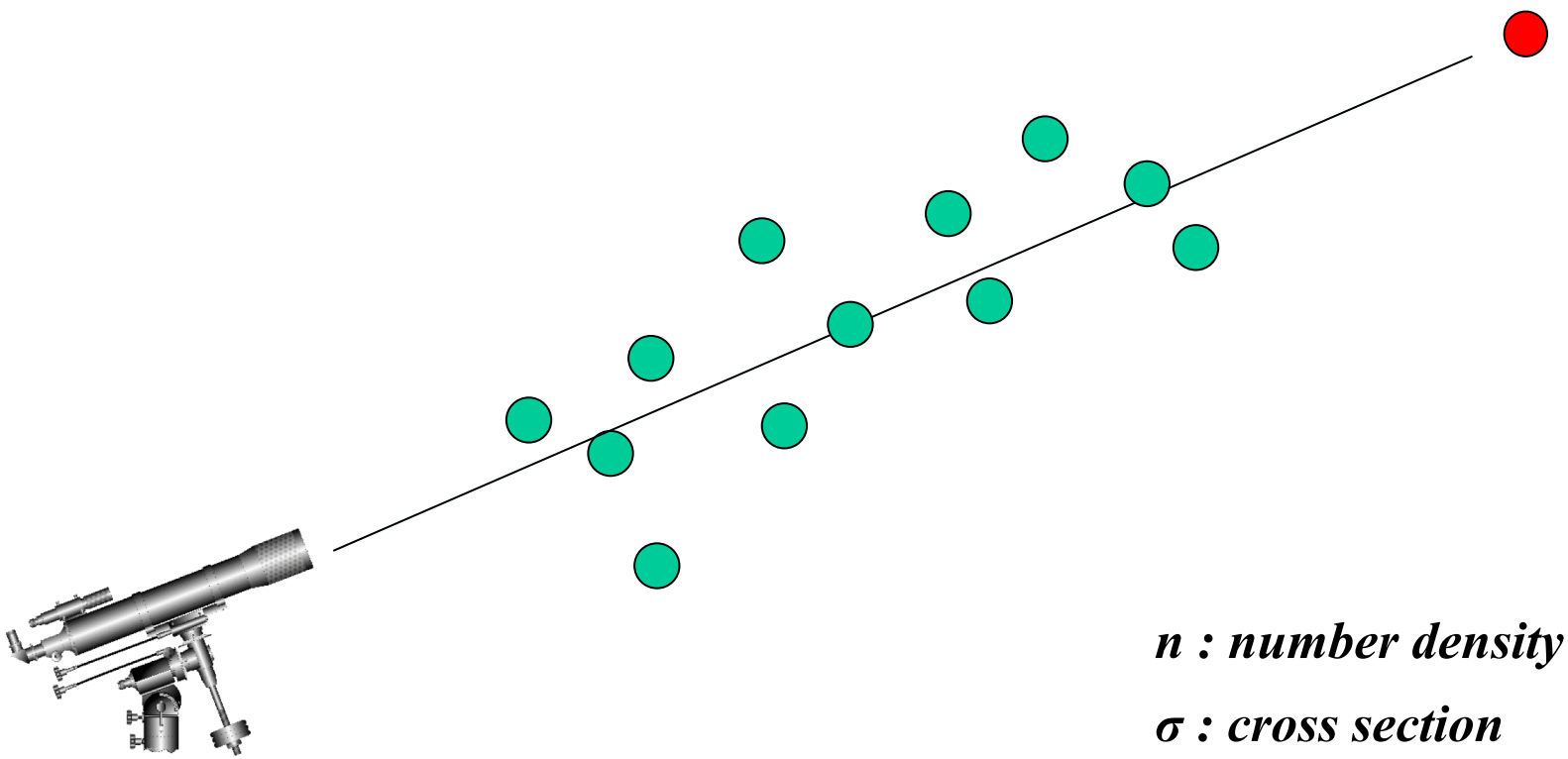
QSO Absorption Systems

Types	Log N(HI)	dN/dz	Origin
Lyα Forest	13-16.5	~30 (z<2) ~100 (z=3)	Intergalactic density fluctuations
LLS	17-19	~0.6(z~1) ~1-3 (z=3)	Cool CGM (10^4 K) (?)
Sub-DLA	19-20	~0.6 (z=3)	Extended halo gas, outflows (?)
DLA	20-22	~0.1 (z=1) ~0.2 (z=3)	Galactic disk, Extended halo gas, outflows, inflows, tidal gas, etc…
C IV	~ Lyα Forest (?)	~10 (z~0) <10 (z>3)	halo hot gas (10^5 K) IGM
Mg II	15-20	~1 (z~1) <5 (z>3)	halo warm gas (10^3 K) Gas out/inflow
O VI	~ LLS(?)	~1-10 (z~0) ~30 (z~2)	Warm-hot CGM (?)


Metal abundance
N(HI) distribution
Incidence Rate
QSO Absorption System
Correlation (QSO)
Gas abundance
Correlation (galaxy)
dynamics

Incidence rate

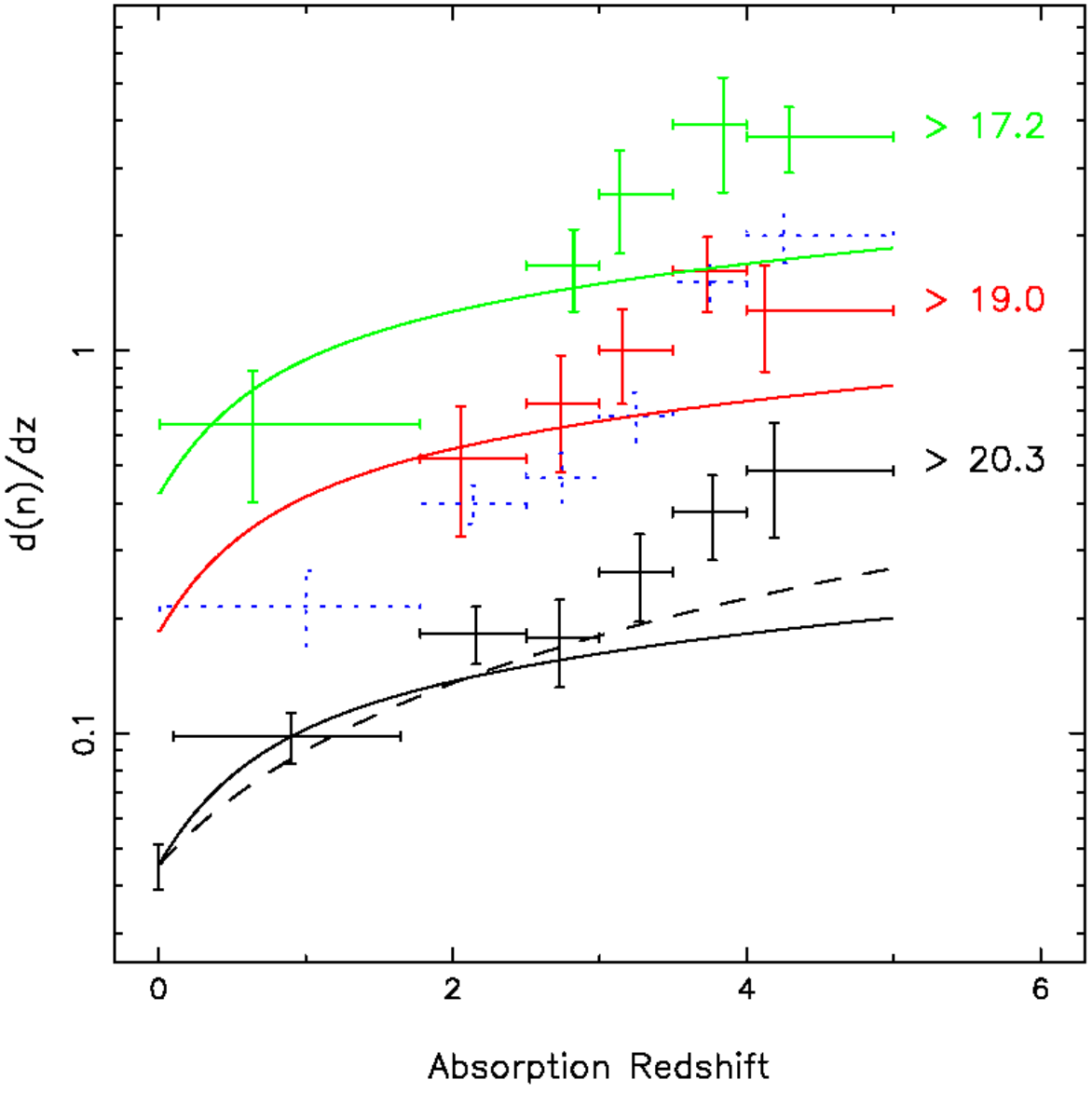
$$\left(\frac{dN}{dz}\right) = n\sigma \frac{c}{H(z)(1+z)}$$



n : number density

σ : cross section

Redshift Distributions (Incidence Rates) of DLA, sub-DLA &LLS

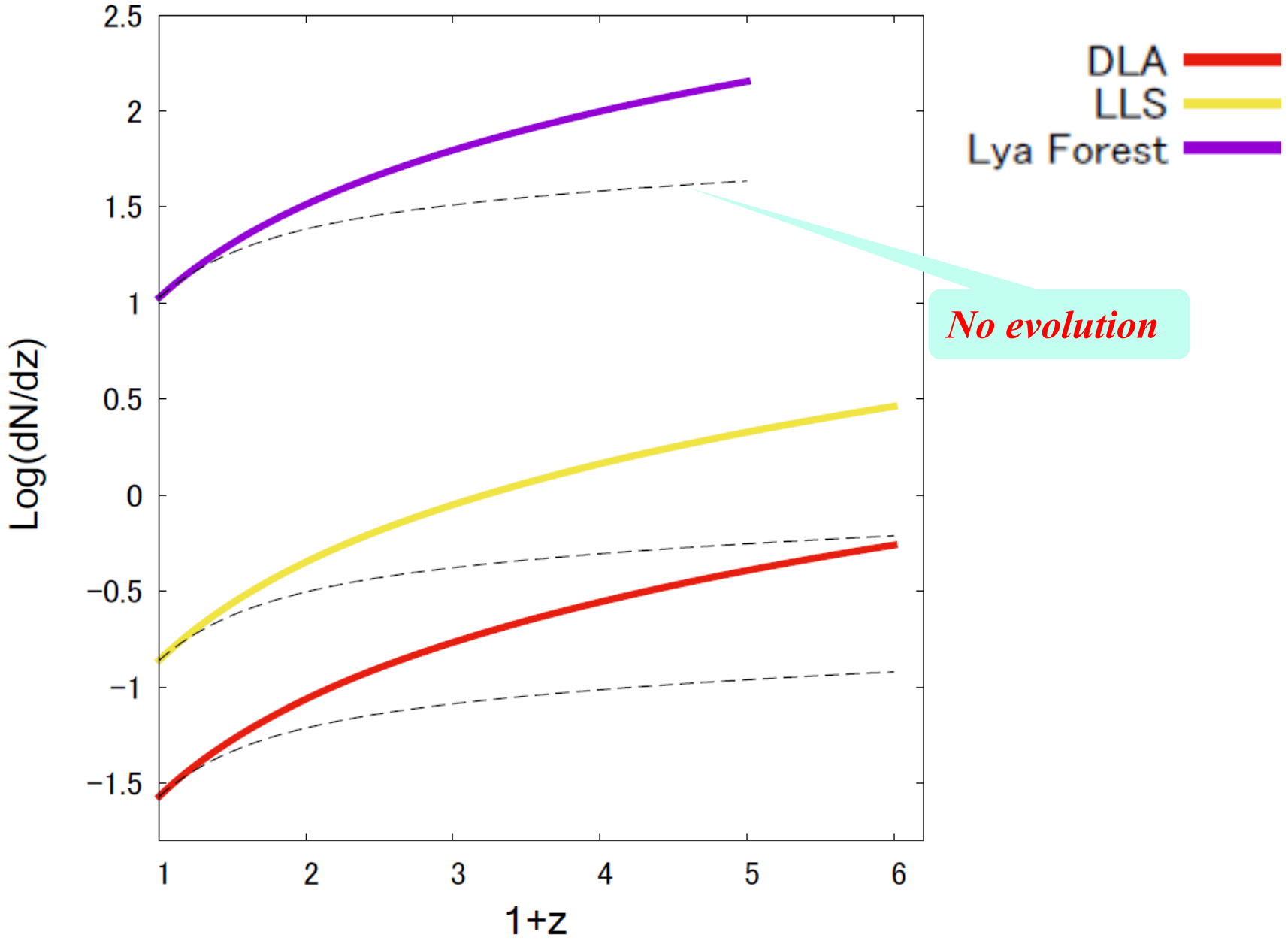


LLS
(17.2<Log$N(HI)$/cm^{-2}<19.0)

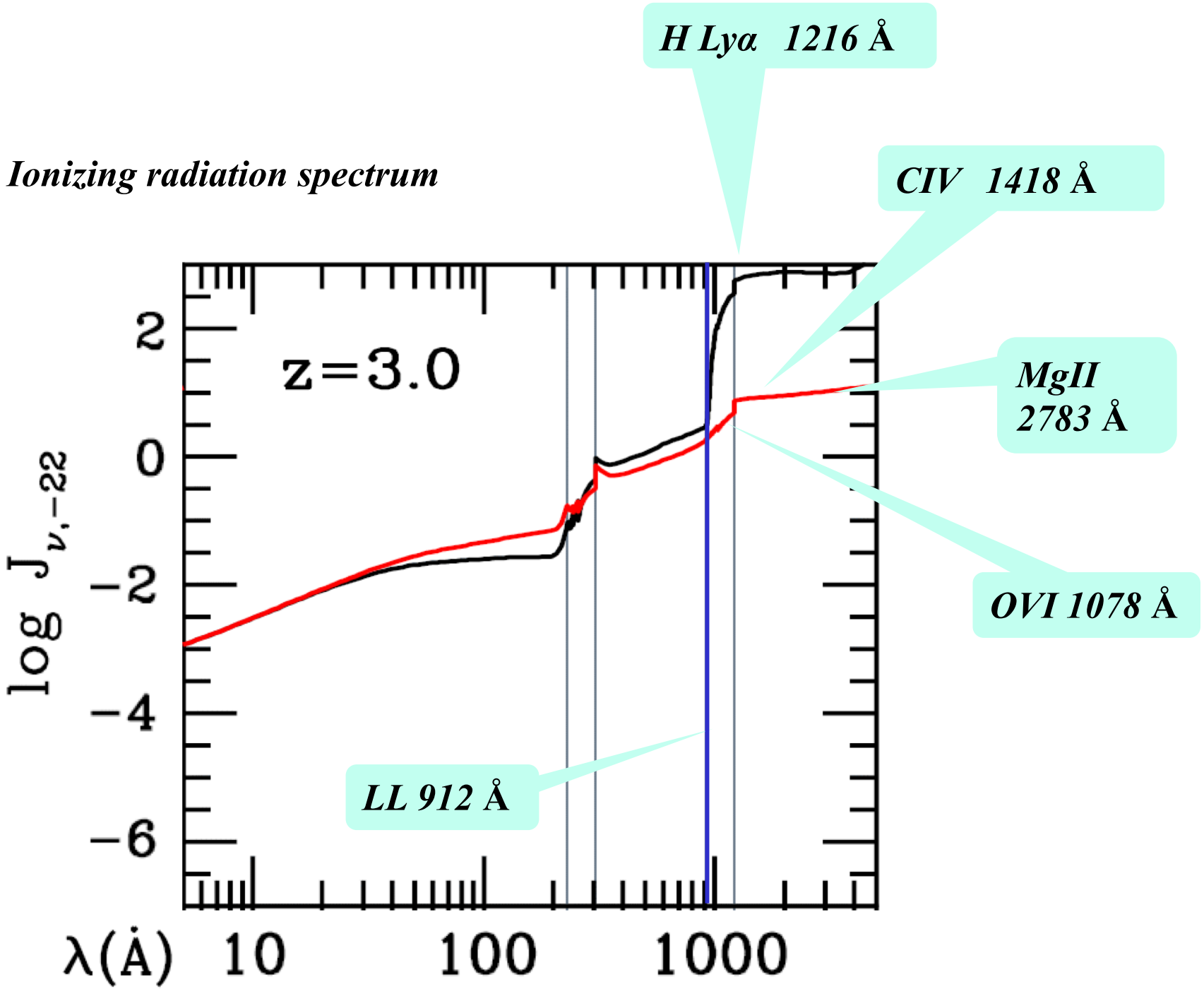
Sub-DLA
(19.0<Log$N(HI)$/cm^{-2}<20.3)

DLA **(Log$N(HI)$/cm^{-2}>*20.3)***

HI absorption systems



Ionizing radiation spectrum



Low ionization system

Mg II, Si II, Al II, O I, etc

IP/eV = 15.0, 16.3, 18.8, 13.6, ..

→ ***Low-temperature/high-density regions***

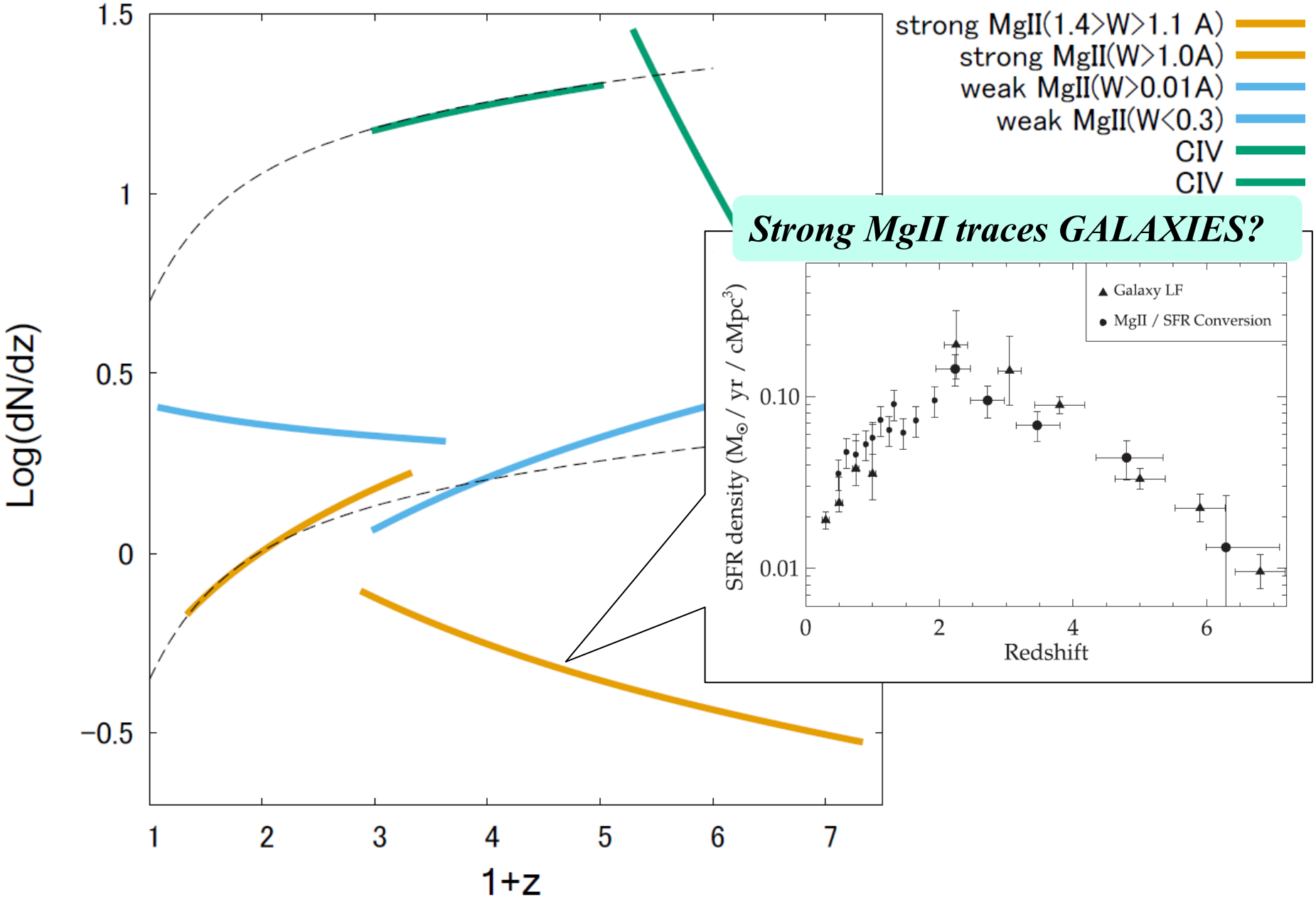
High ionization system

C IV, Si IV, O IV, etc

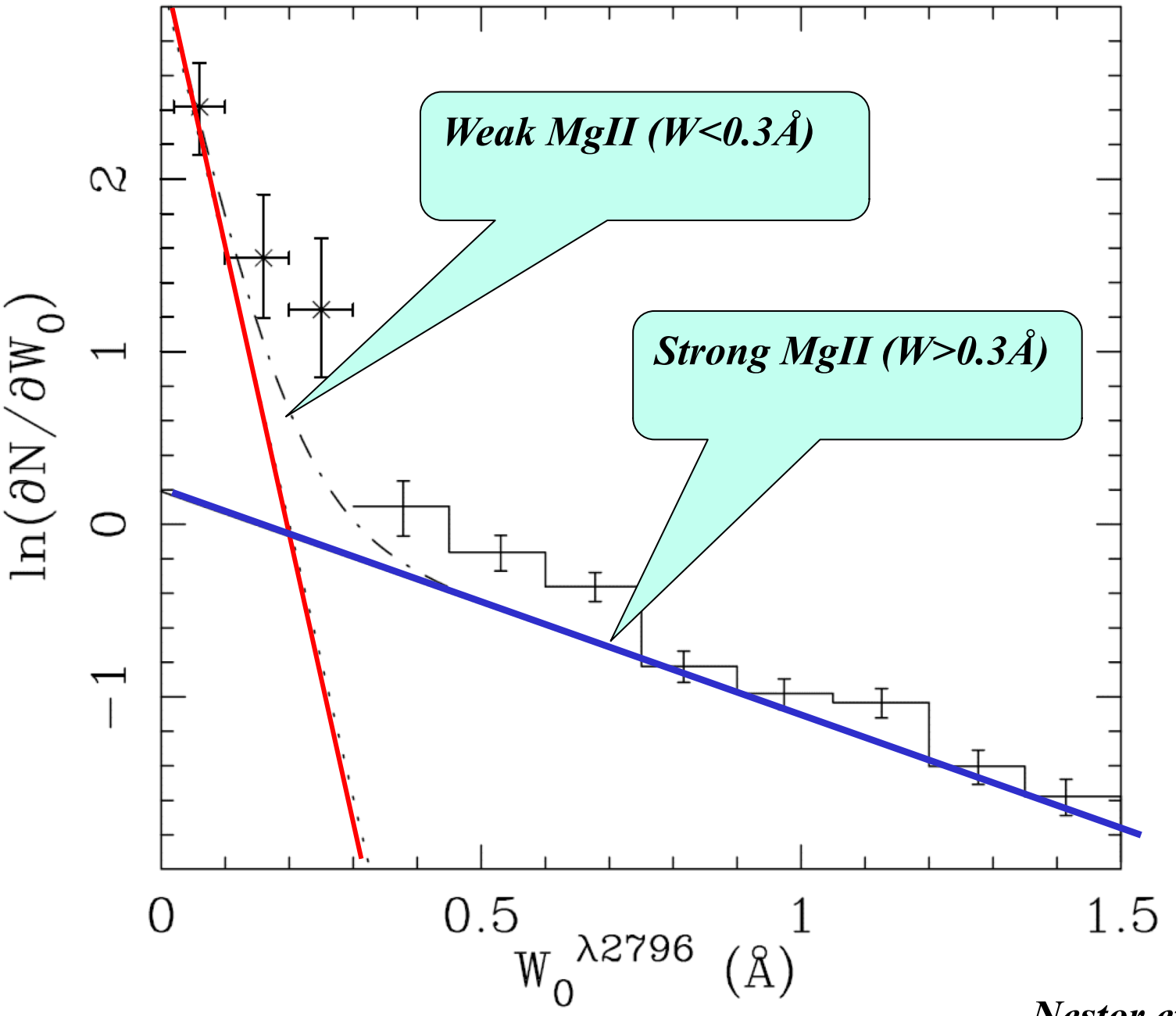
IP/eV = 64.4, 45.1, 136.1, ..

→ ***High-temperature/low-density regions***

Metal absorption systems

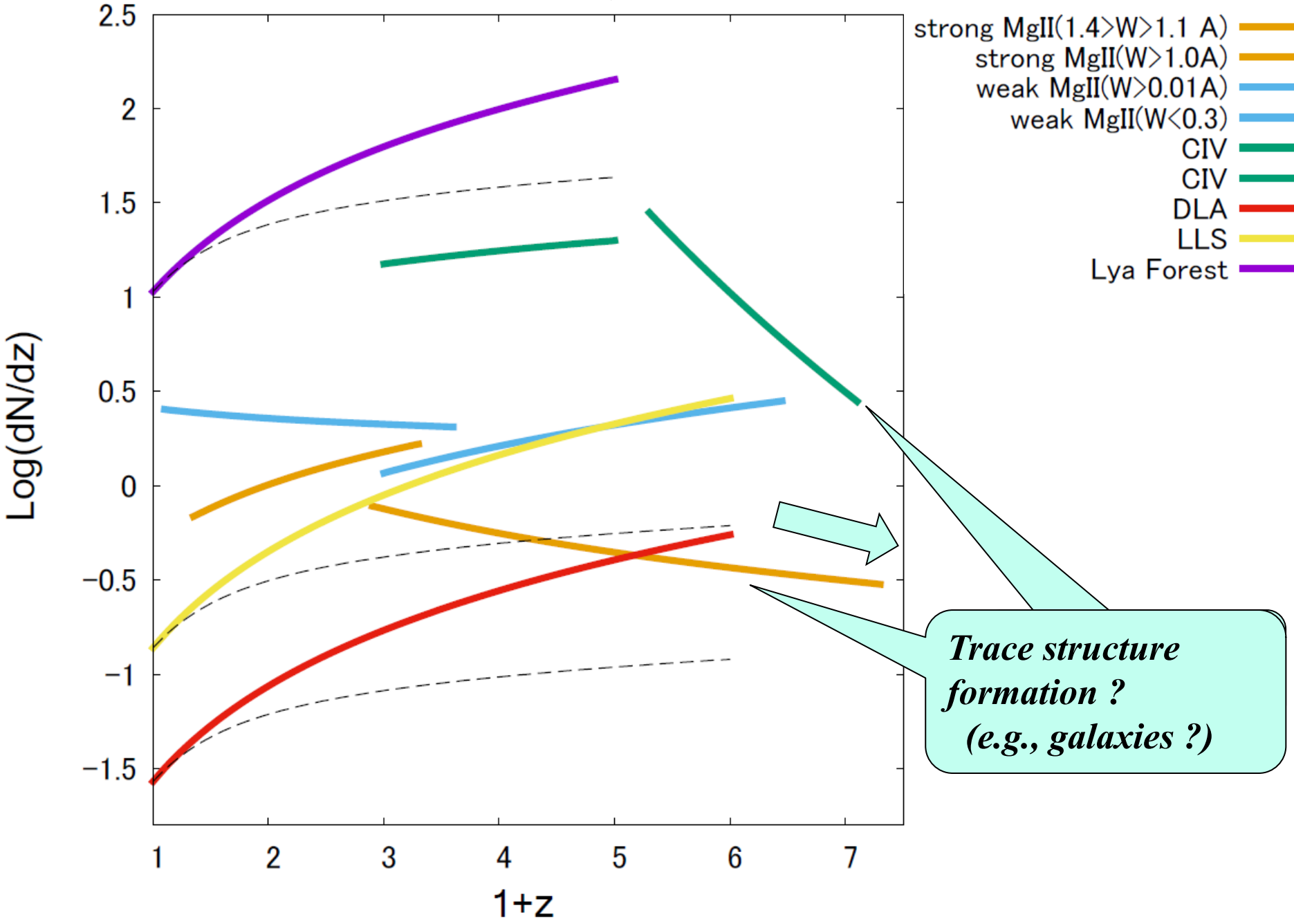


Strong MgII traces GALAXIES?



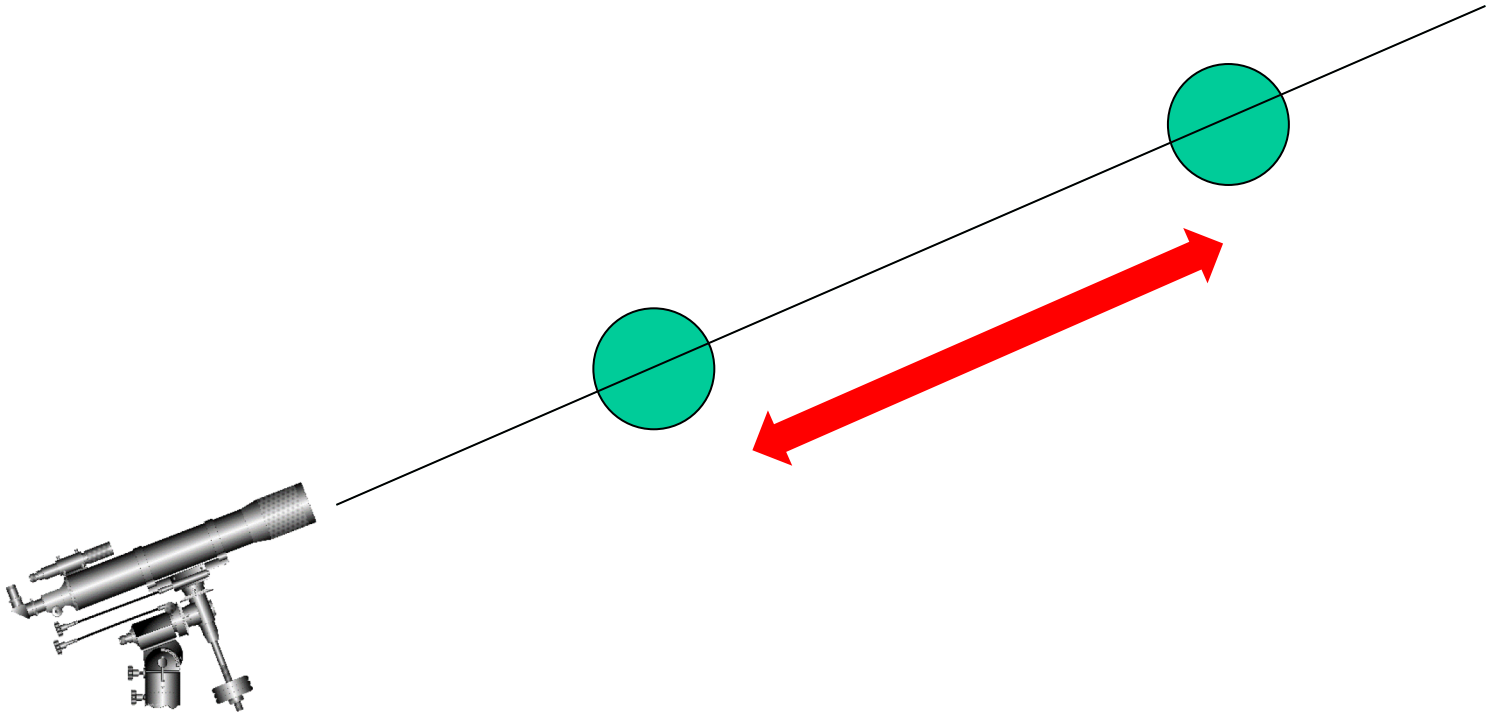
Nestor et al. 2005

HI & Metal absorption systems

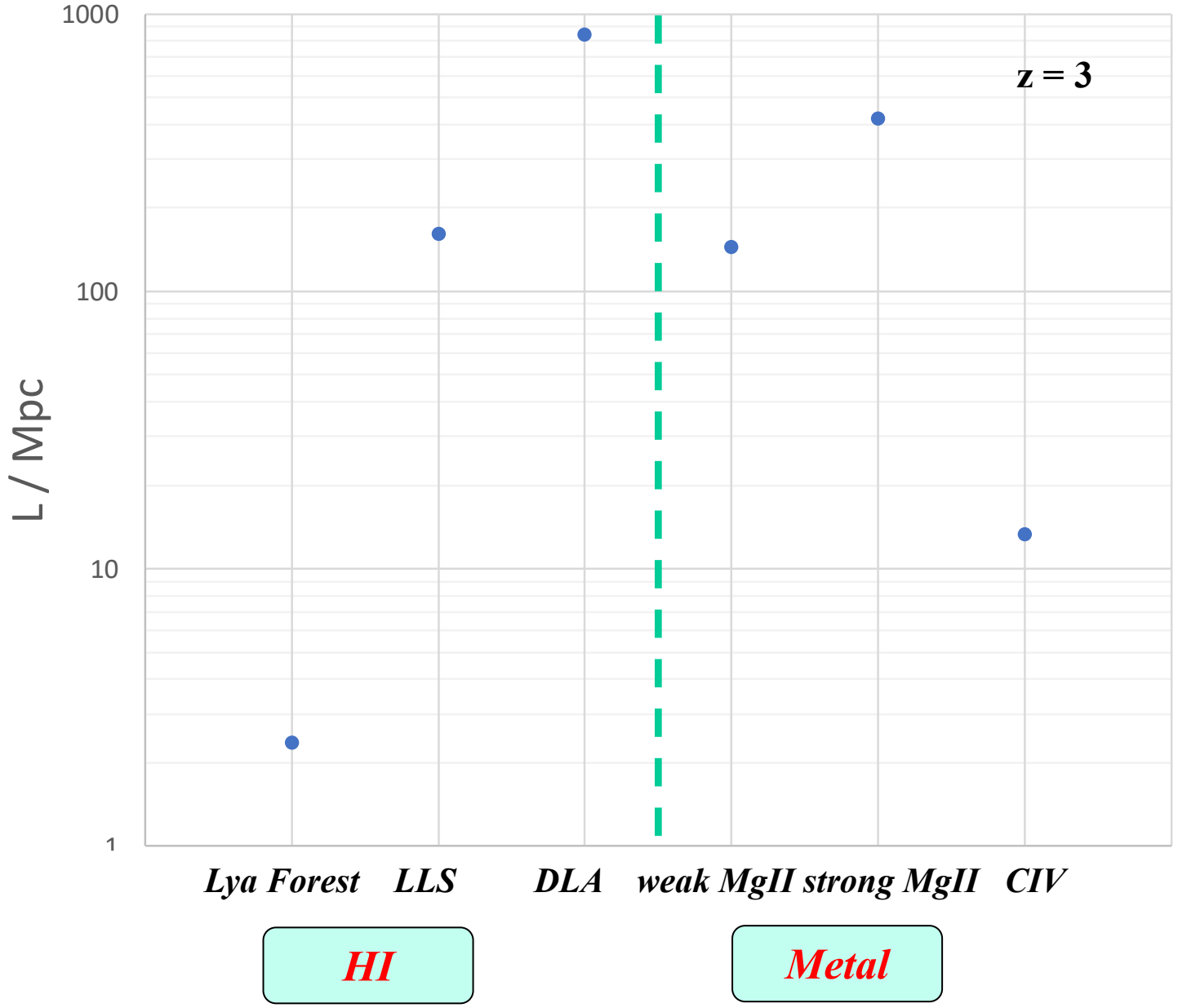


Mean proper distance along the line of sight

$$L = \frac{c}{H(z)(1+z)} \left(\frac{dN}{dz} \right)^{-1}$$

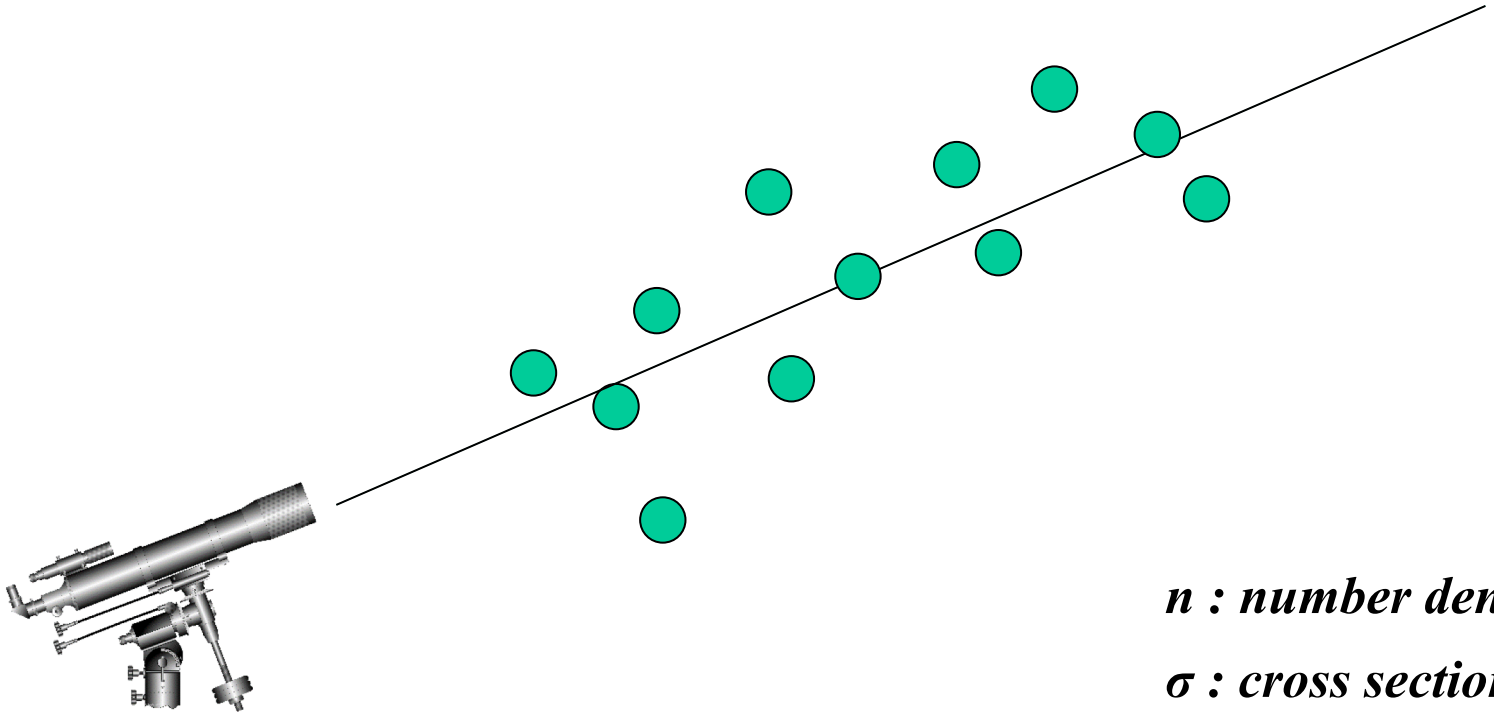


Mean proper distrance between systems along the line of sight



Incidence rate

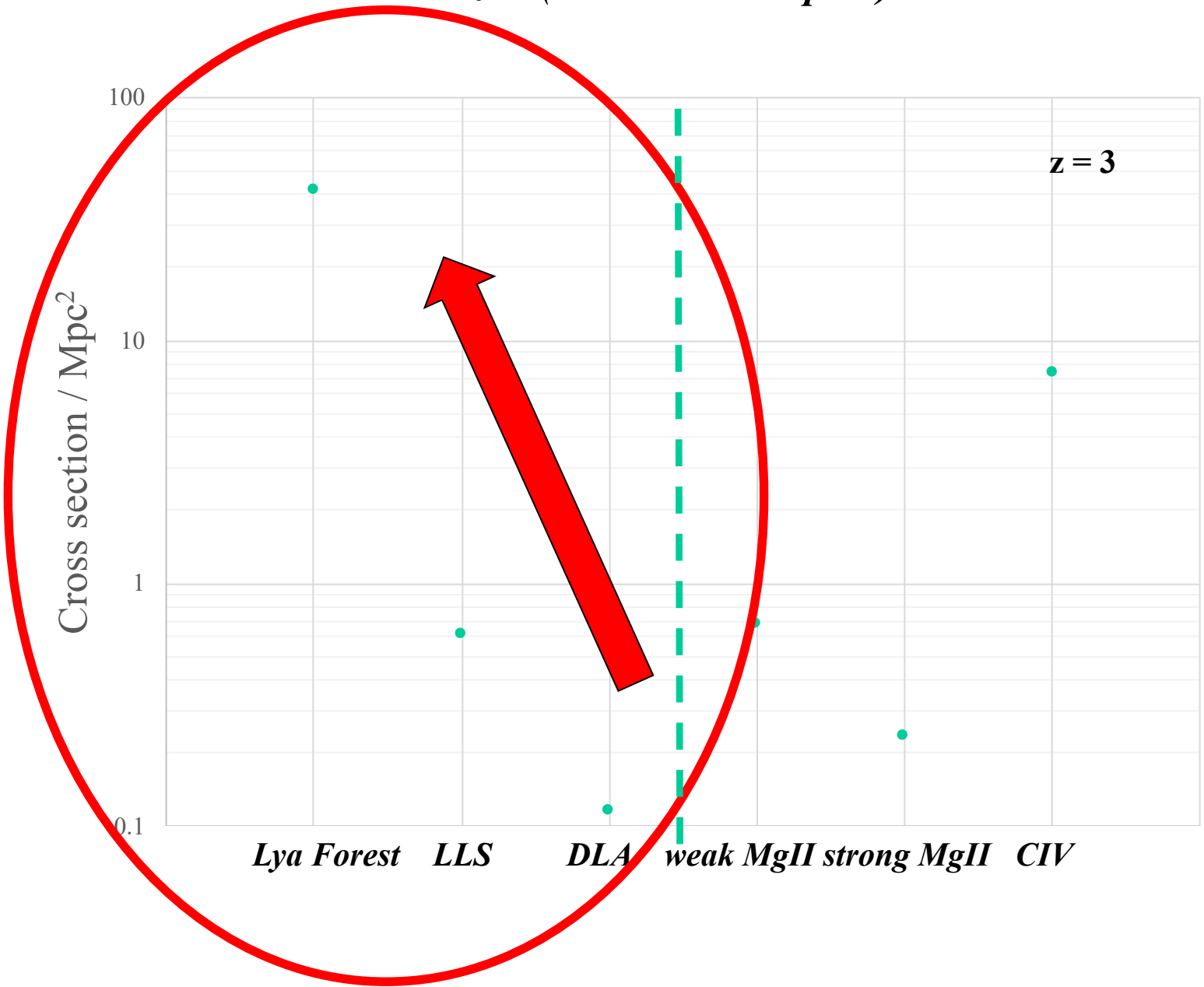
$$\left(\frac{dN}{dz}\right) = n\sigma\frac{c}{H(z)(1+z)}$$



n : number density

σ : cross section

Total cross sections σ at z=3 (n=1.0×10^{-3} Mpc^{-3})



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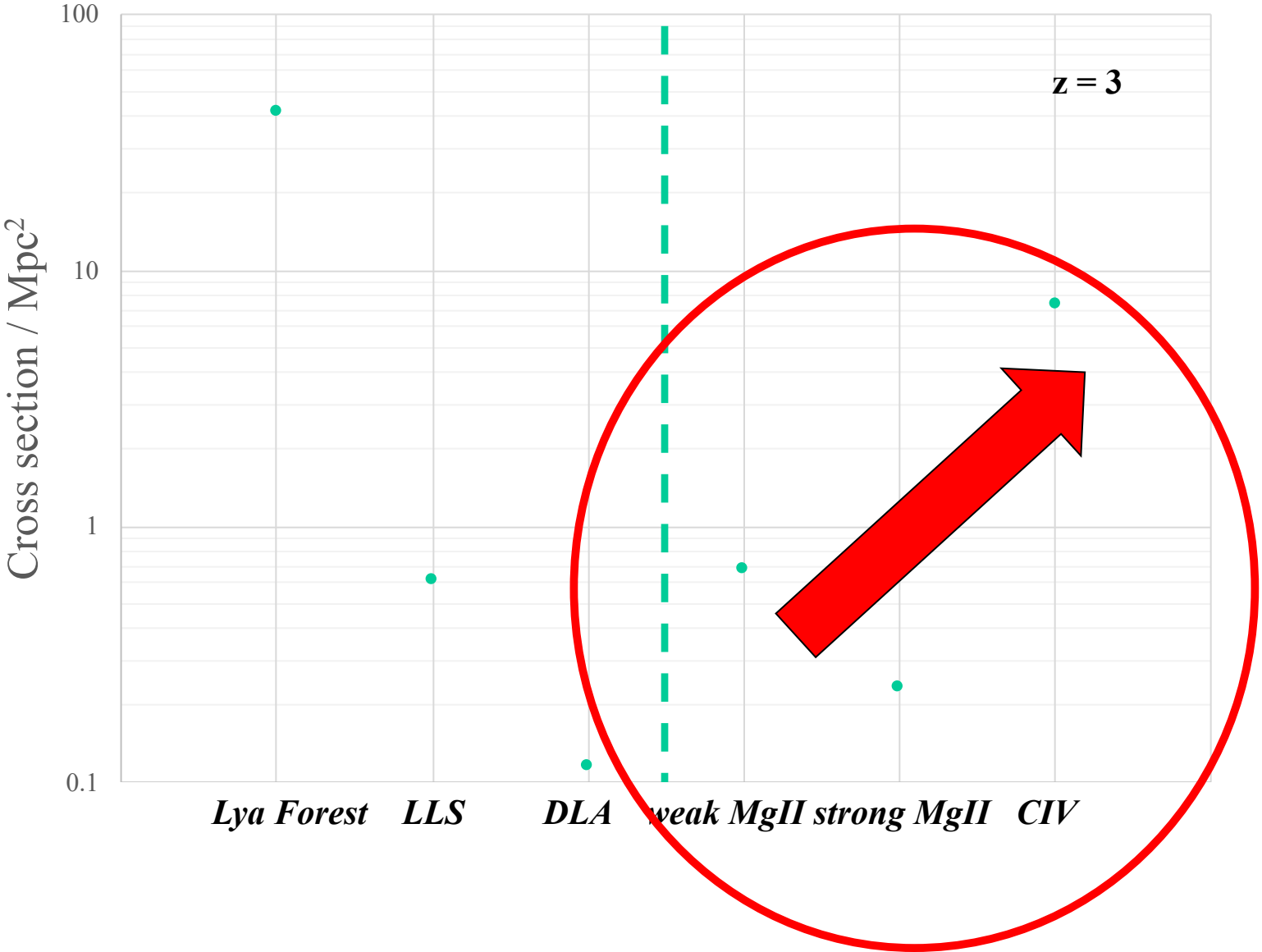

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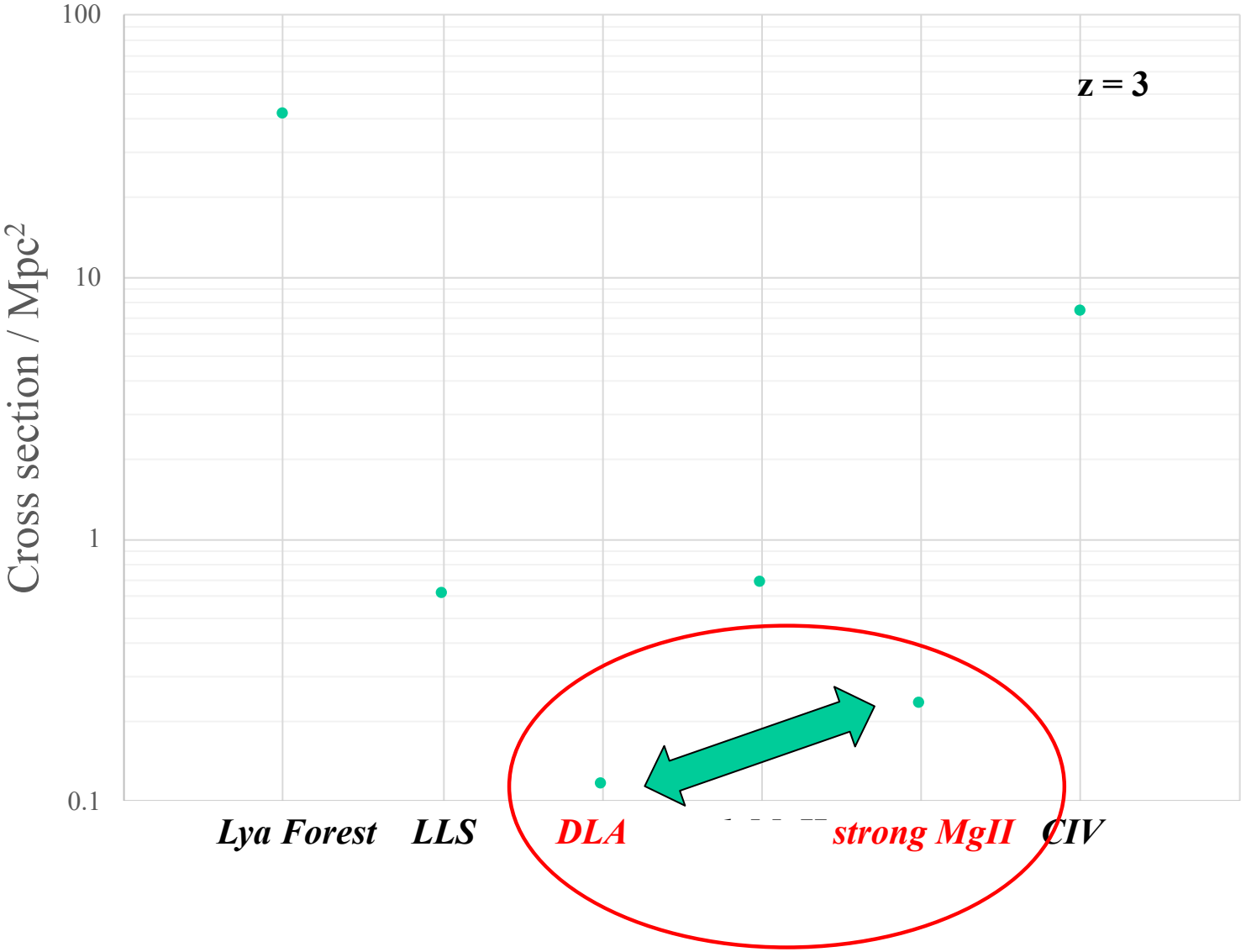
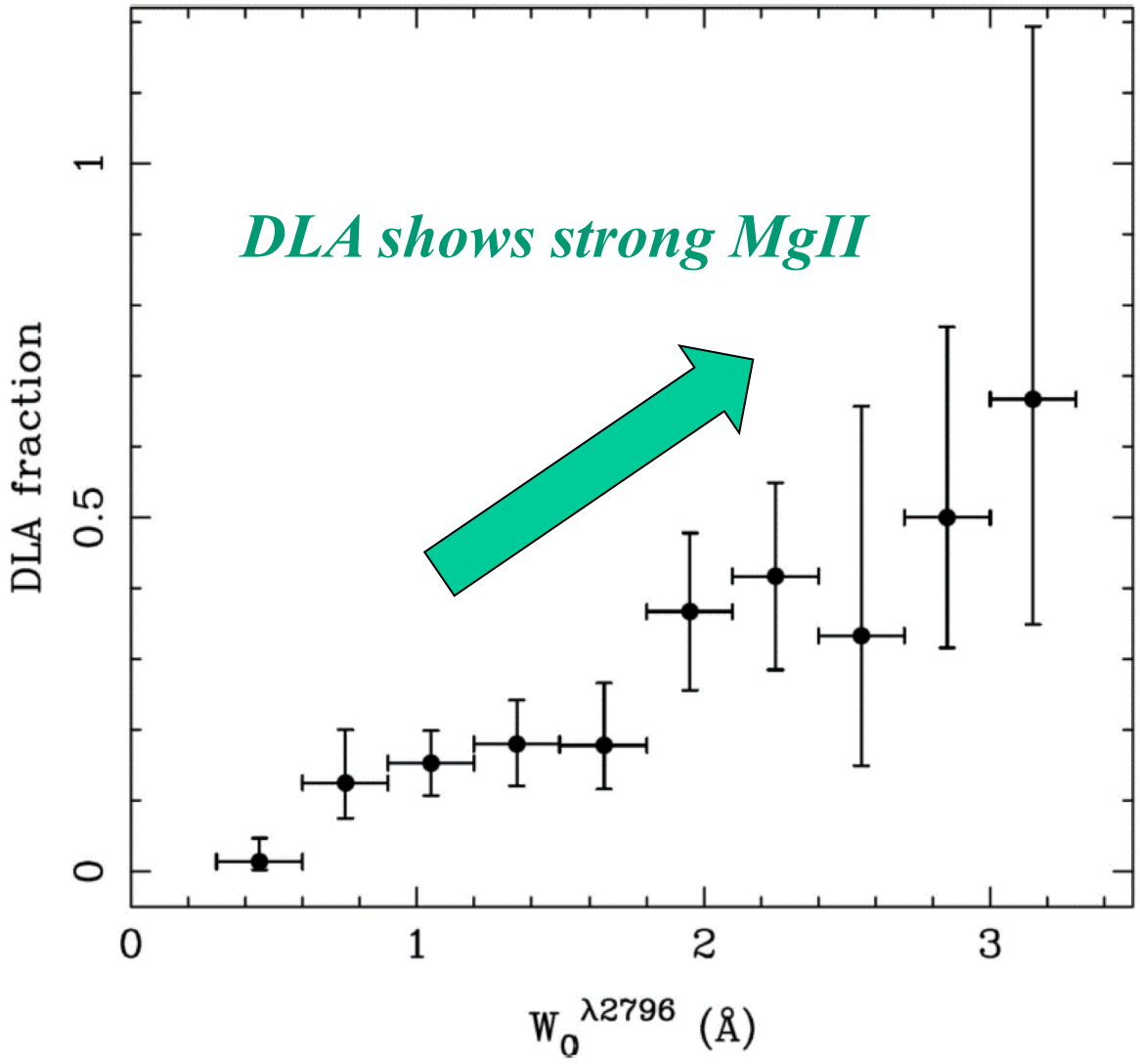
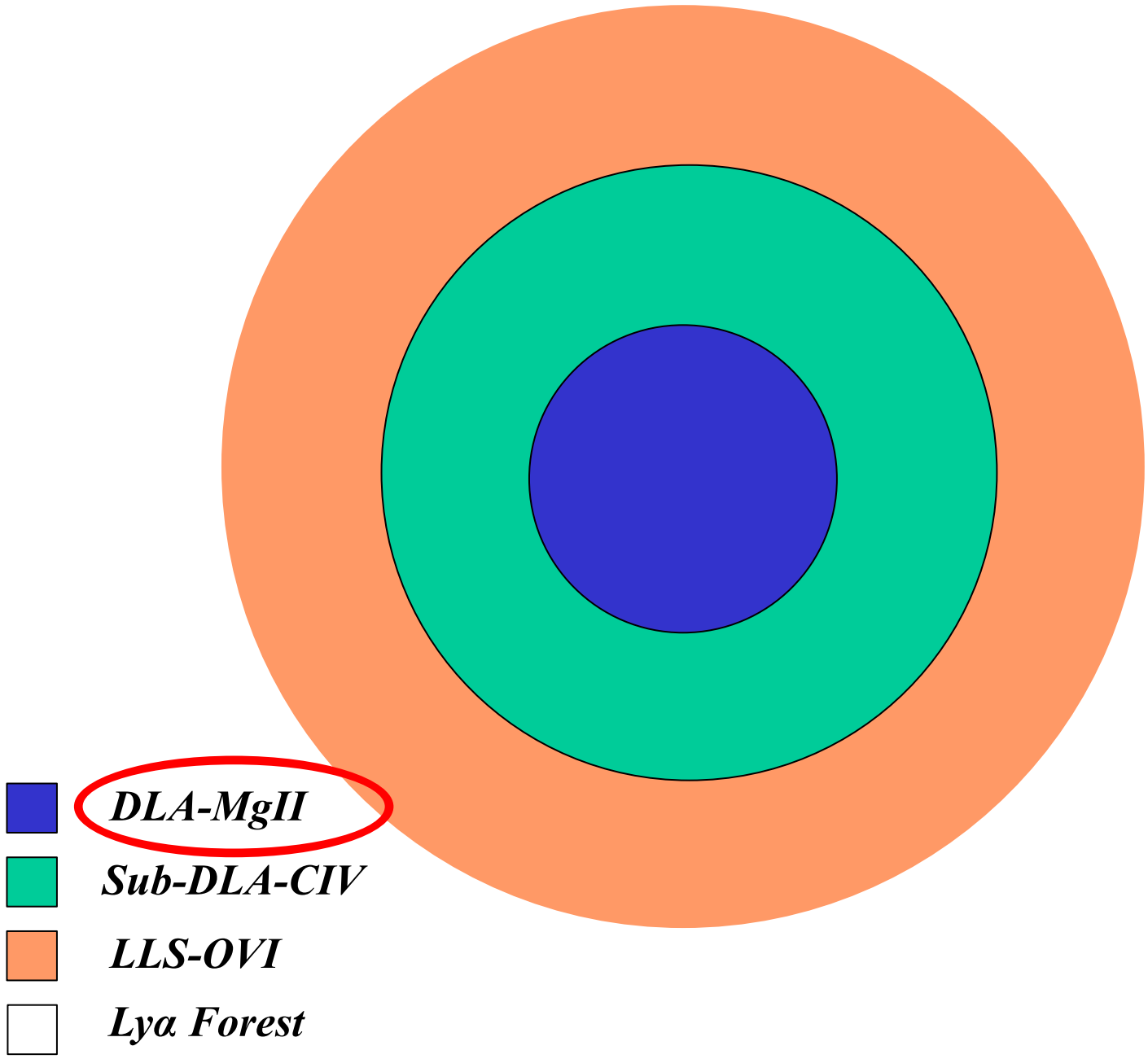


Strong MgII and DLA



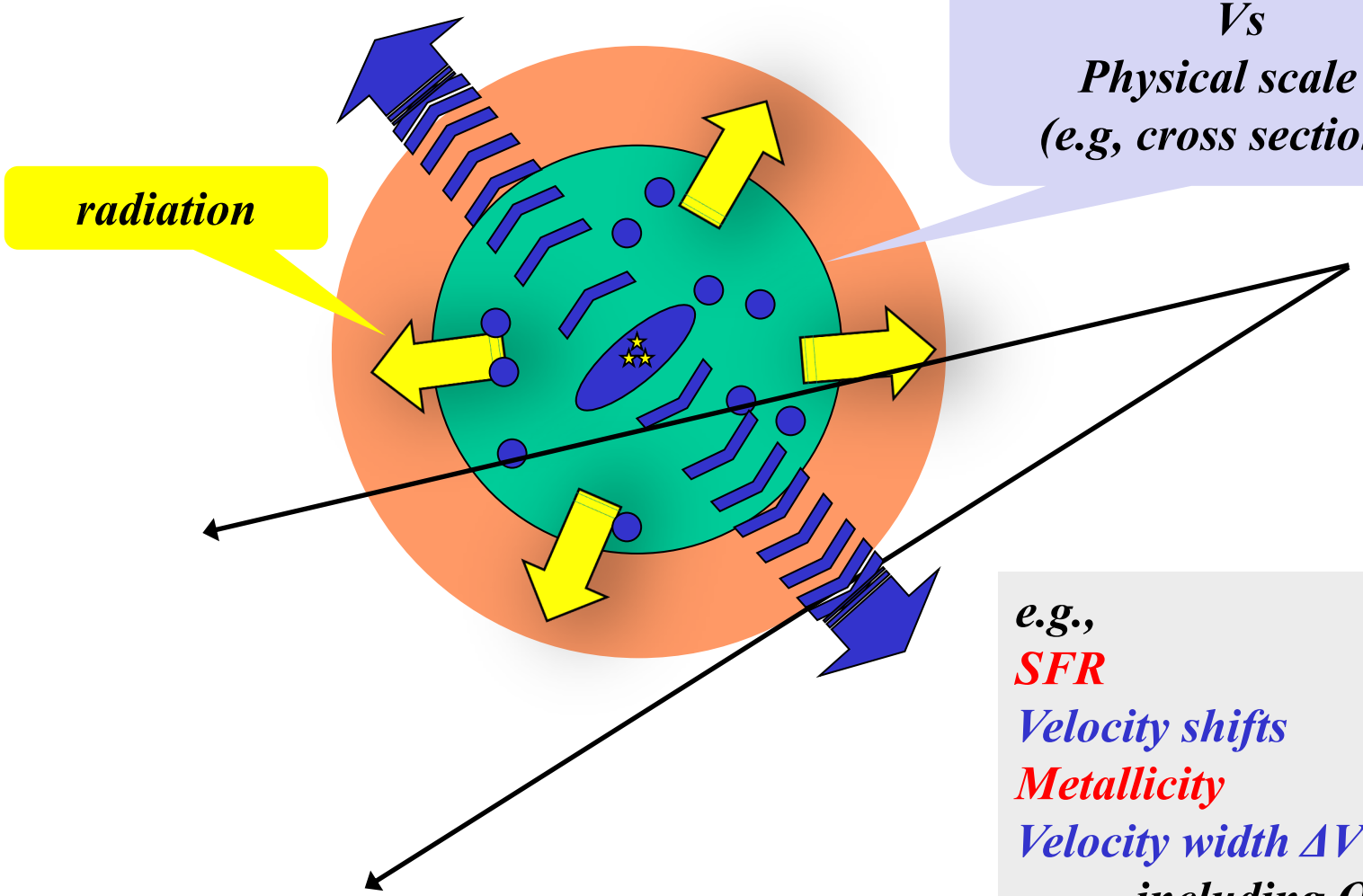
MgII Absorption width

Rao et al. 2017


DLA-MgII
Sub-DLA-CIV
LLS-OVI
Lyα Forest

Absorbers as a probe of SF in galactic halos

SF in galaxctic halos
Vs
Physical scale R
(e.g, cross section σ)



e.g.,
SFR
Velocity shifts
Metallicity
Velocity width ΔV_{90}
including Outflow

DLA
Sub-DLA
LLS

Summary

- QSO Absorption System

  HI, Metal absorption system & IGM

- **Incident rates *dN/dz* (+ Total cross-section)**

  DLA < LLS < Lyα forest

  ***strong* MgII < weak MgII < CIV ~ OVI**

  ⟷ Galaxy < Halo (virial radius) < CGM < LSS (filaments, voids)

- A probe of galaxy, galactic halo, CGM and IGM

  Galaxy ⟵ ***DLA* and *strong MgII***

  Halo (cloud in/outflow) & CGM ⟵ ***DLA~LLS*, *MgII***

  IGM ⟵ ***Lya-forest* , *CIV***