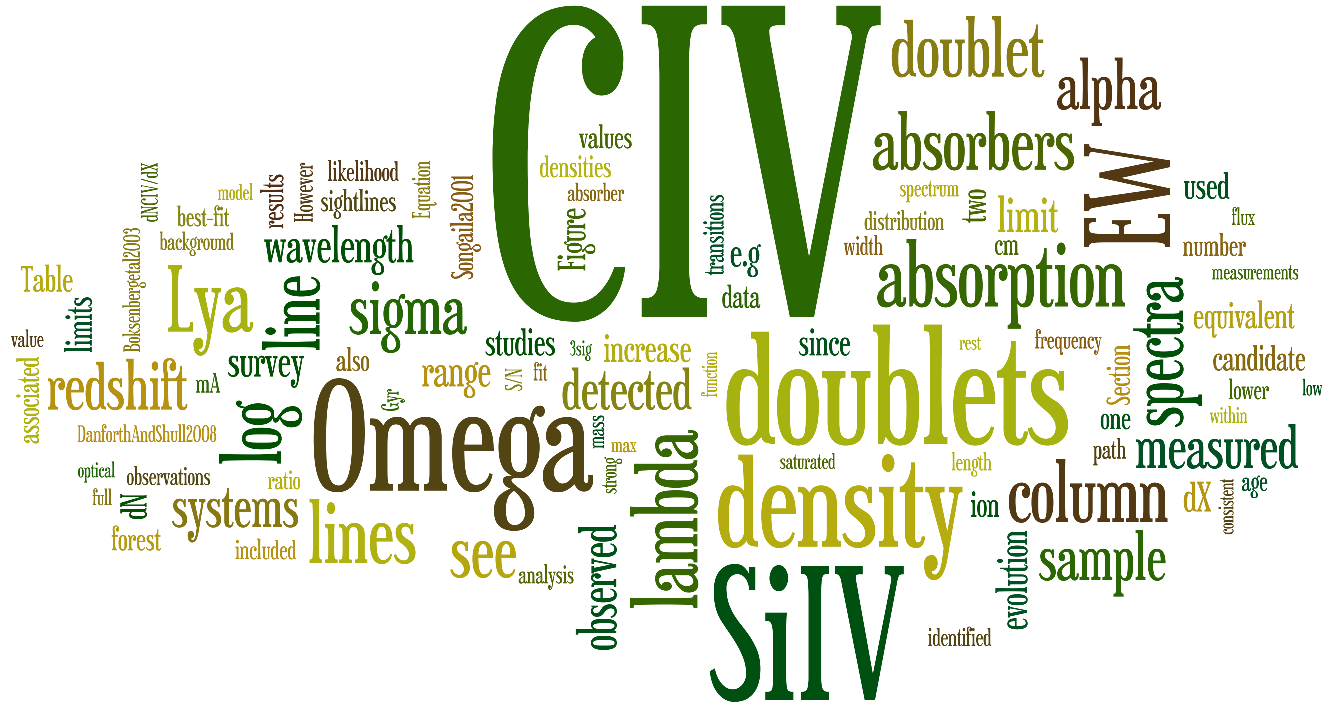

The Last Eight-Billion Years of Intergalactic CIV and SiIV Evolution

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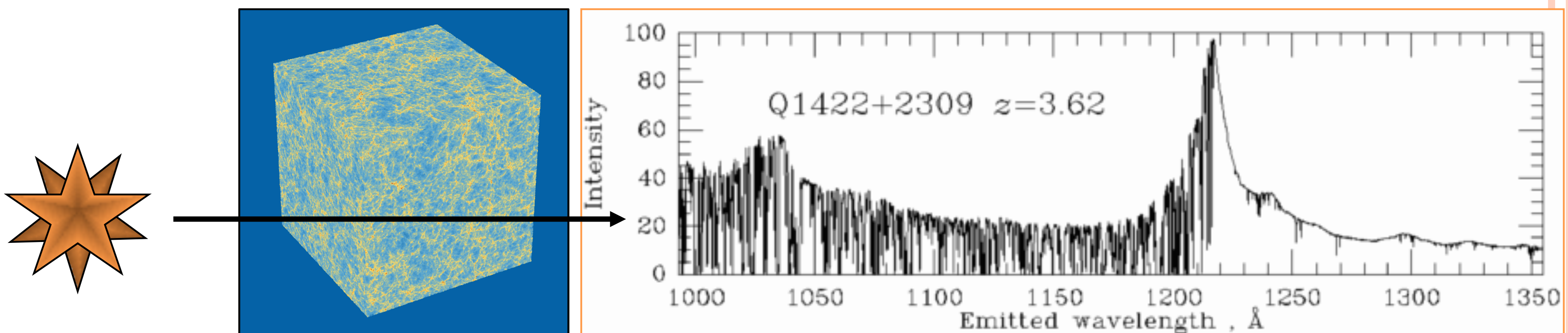
Collaborators: Xavier Prochaska (UCSC); Chris Thom (STScI); Hsiao-Wen Chen (Chicago); Rob Simcoe (MIT); Joop Schaye & Co. (Leiden)

WHY CIV AND SIIV ABSORBERS?

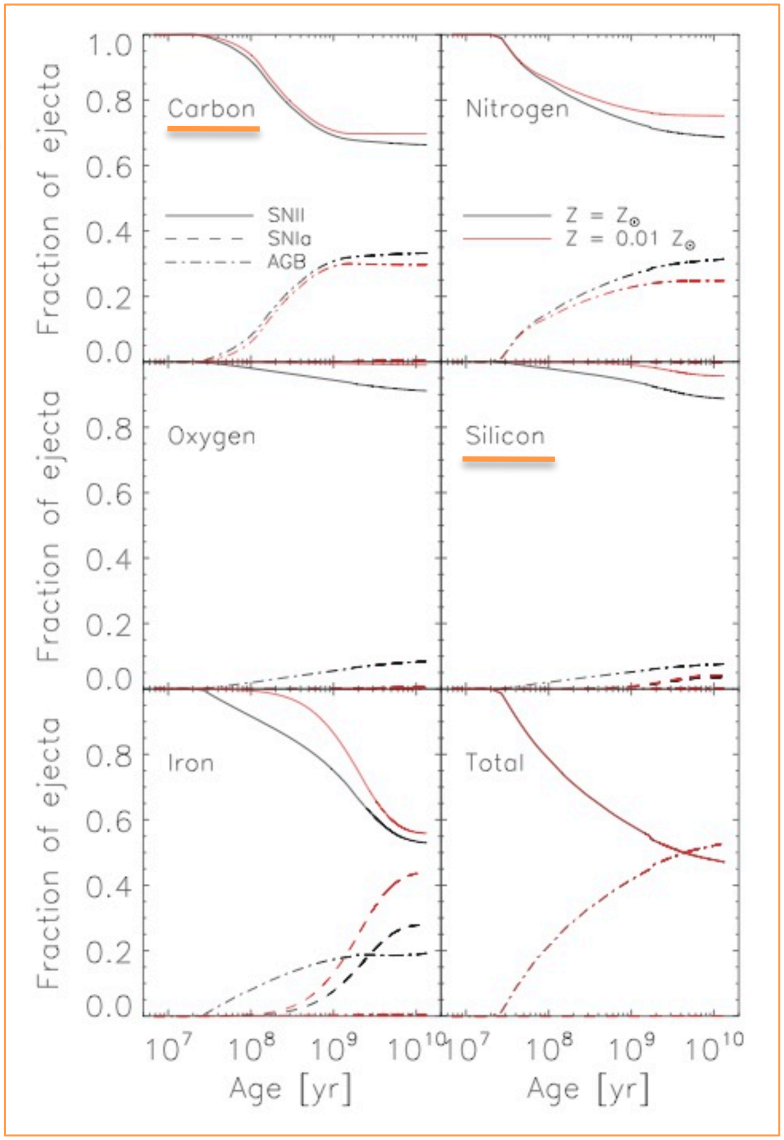
- Trace cosmic enrichment cycle with common metals
  - And Si may trace O, which is most common
- Well-studied with optical telescopes for $1.5 \leq z \leq 5.5$
- Resonant absorption-line doublets
  - Characteristic wavelength separation and rest equivalent width ratio
- Rest wavelengths red-ward of Lyα 1215 (i.e., outside forest, unlike OVI)



- Interest in systems with both doublets for e.g., ionizing background studies

METAL ABSORPTION LINES AFFECTED BY…

- Metallicity and relative abundances
- Ionizing background
  - Changes ionization balance
- Physical distribution
  - Function of density and physical size



(Wiersma+ 2009)

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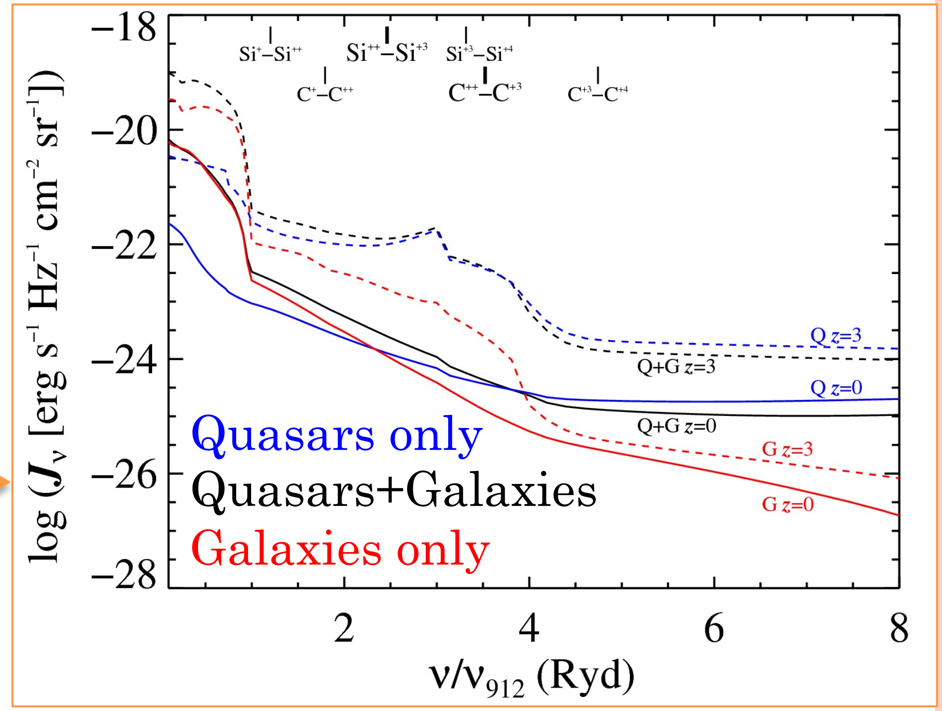

(Haardt & Madau 1996, 2005)

Local sources (e.g., stellar radiation field) softens background.

At $z \approx 3$, HeII reionization affects UVB around 4 Ryd.

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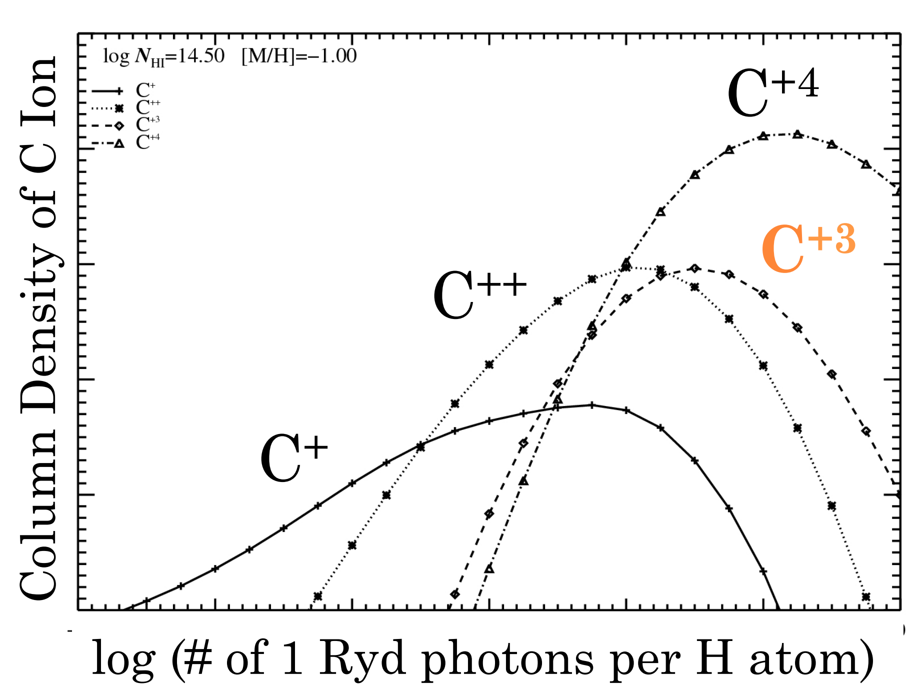

(Haardt & Madau 1996, 2005)

Local sources (e.g., stellar radiation field) softens background.

At $z \approx 3$, HeII reionization affects UVB around 4 Ryd.

C^{+3} not necessarily dominate C ion but best tracer observationally.

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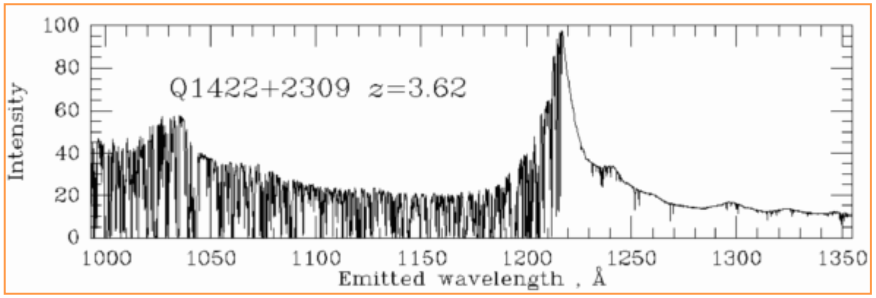
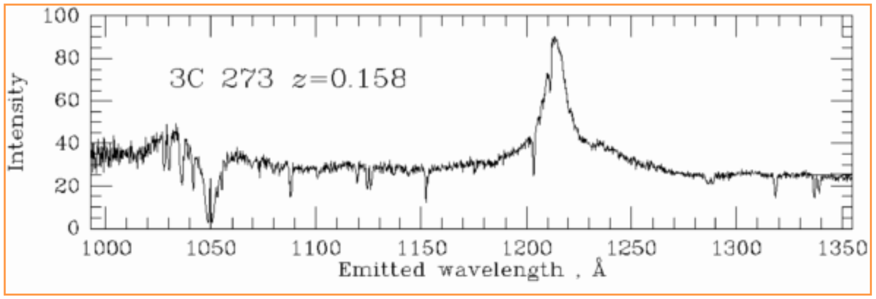




$$\frac{d\mathcal{N}}{dX} = \frac{c}{H_0} n_{co\text{-}m} \sigma_{phys}$$

Absorber line density ~ co-moving number density × physical cross section of absorber

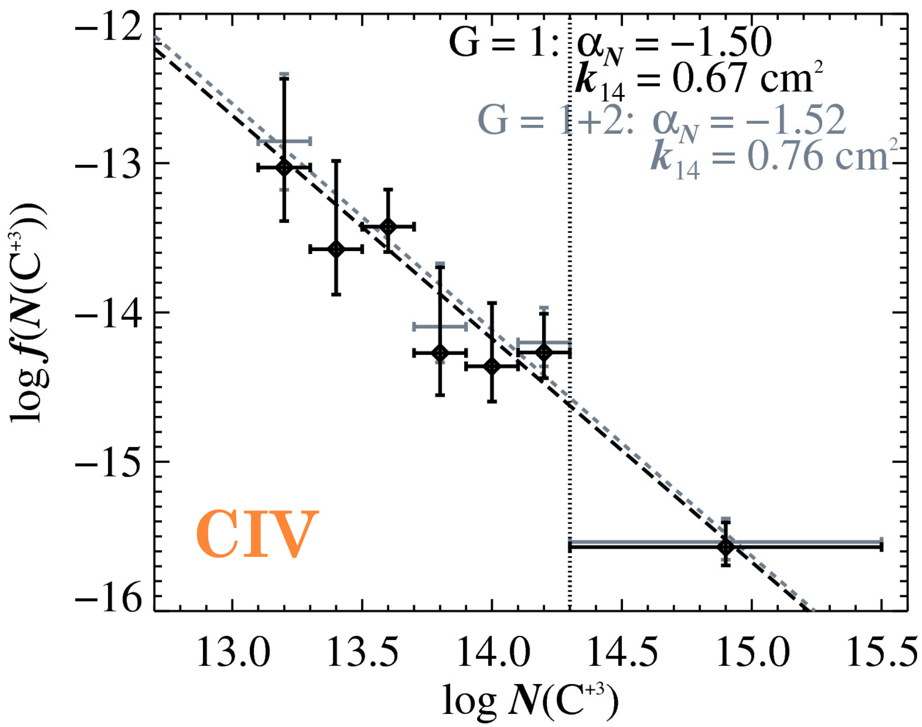
$N(C^{+3})$ and $N(Si^{+3})$ Frequency Distributions

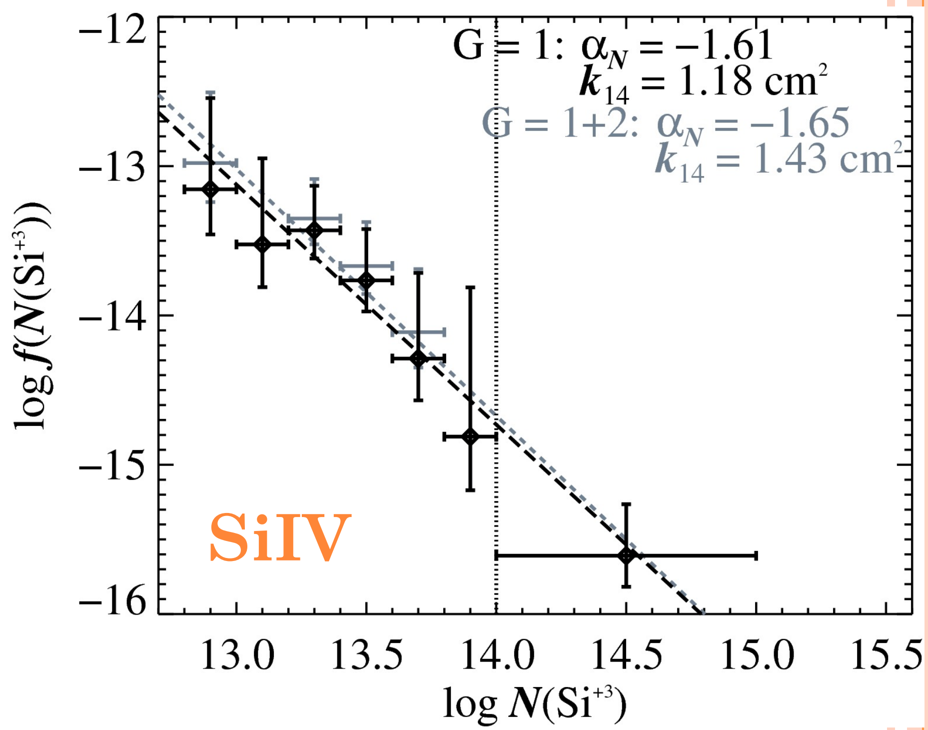
Definition:

$$f(N(C^{+3})) \equiv \frac{\Delta\mathcal{N}}{\Delta N(C^{+3})\,\Delta X(N(C^{+3}))}$$

Power-law model:

$$f(N(C^{+3})) = k\left(\frac{N(C^{+3})}{N_0}\right)^{\alpha}$$





No observed break in $f(N)$.

Defining and Measuring C^{+3} Mass Density

- Relative to critical density of Universe:

$$\Omega_{C^{+3}} = \frac{H_0 m_C}{c\rho_{c,0}} \int_{N_{min}}^{N_{max}} f(N(C^{+3}))N(C^{+3})dN(C^{+3})$$

- *Could* sum column densities:

$$\Omega_{C^{+3}} = \frac{H_0 m_C}{c\rho_{c,0}} \sum_{\mathcal{N}} \frac{N(C^{+3})}{\Delta X(N(C^{+3}))}$$

- *Actually* assume power-law formulism and integrate:

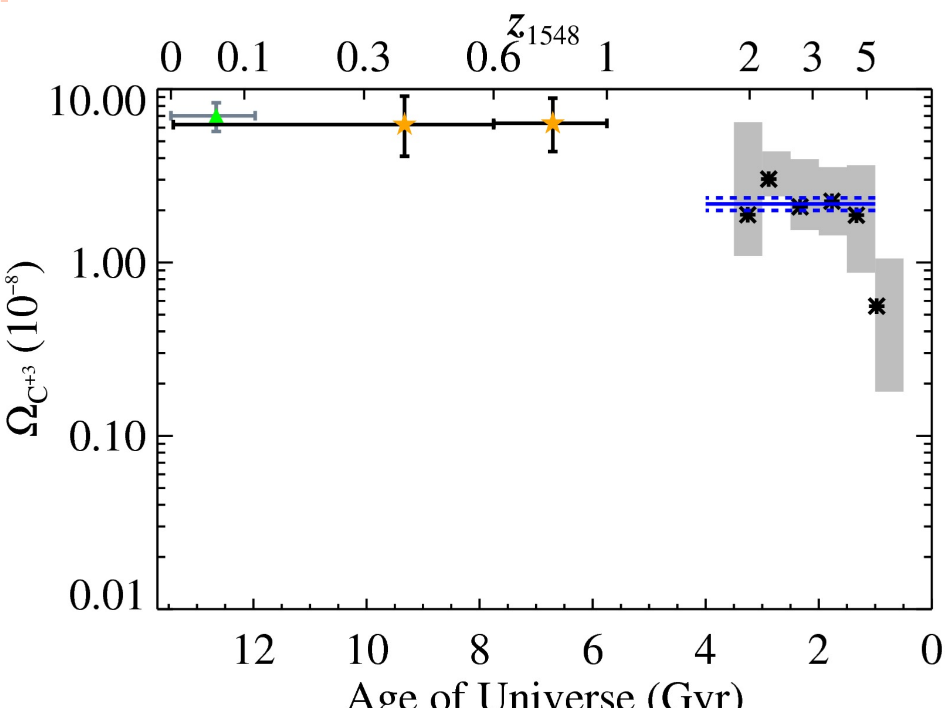
$$\Omega_{C^{+3}} = \frac{H_0 m_C}{c\rho_{c,0}} \frac{k}{2+\alpha} \left(\frac{N_{max}^{2+\alpha} - N_{min}^{2+\alpha}}{N_0^{\alpha}} \right)$$

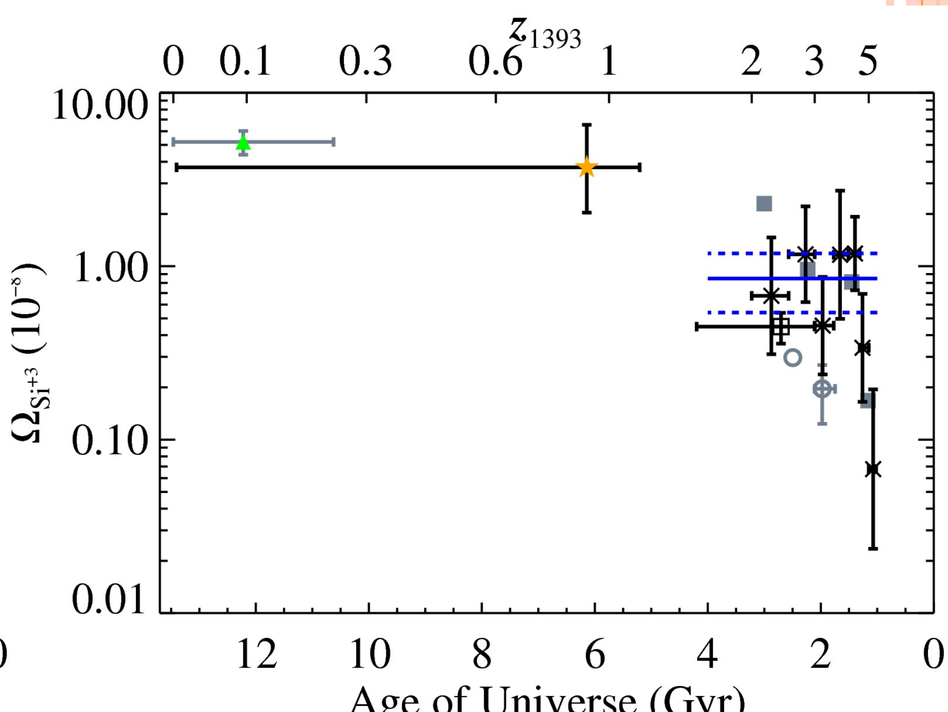
  - Define finite bounds: $13 \leq \log N \leq 15$

Mass Densities Over Age of Universe

C^{+3}: Increases by 4±0.5 over high-*z* variance-weighted mean.
Rate: (0.51±0.16) × 10^{-8} Gyr^{-1}

Si^{+3}: Increases by 4+3/-1.9 over high-*z* unweighted median.
Rate: (0.61±0.13) × 10^{-8} Gyr^{-1}



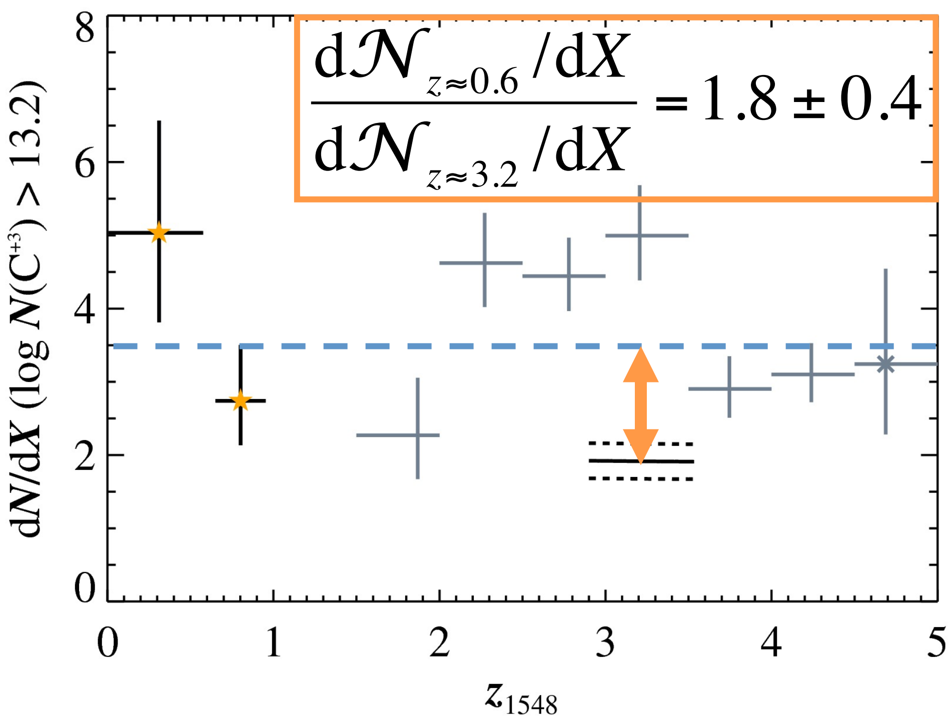


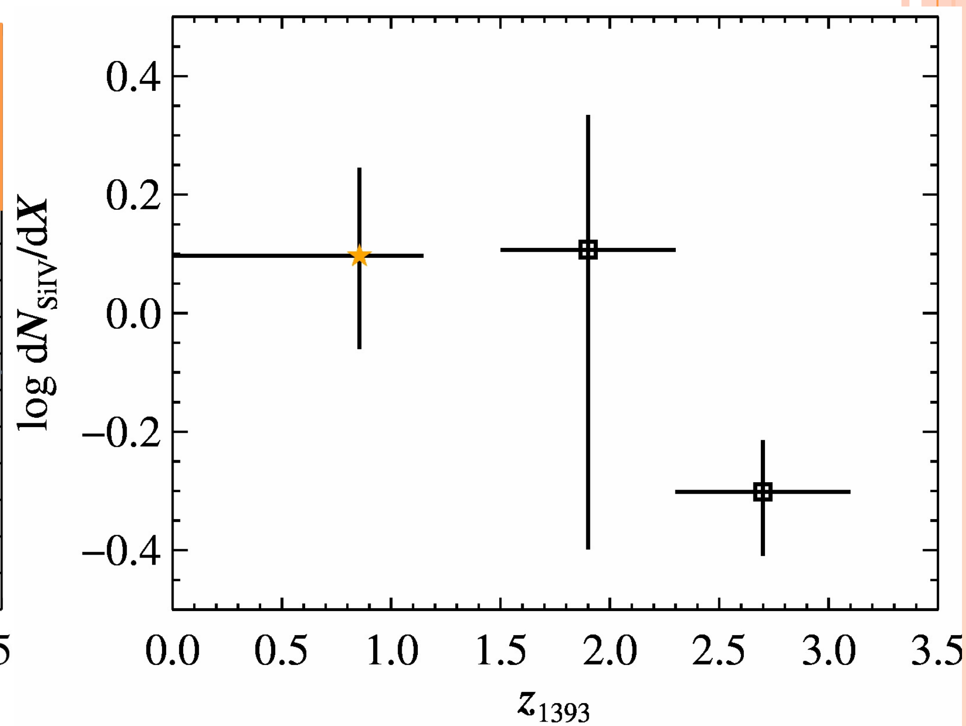
Songaila 1997, 2001, 2005; Pettini+ 2003; Boksenberg+ 2003; Scannapieco+ 2006; Danforth & Shull 2008; Becker+ 2008; Ryan-Weber+ 2009; Cooksey+ 2010, 2011

Absorber Line Density: Evolution?

d$\mathcal{N}_{CIV}$/dX: Yes! But…
not significant, just statistically significant

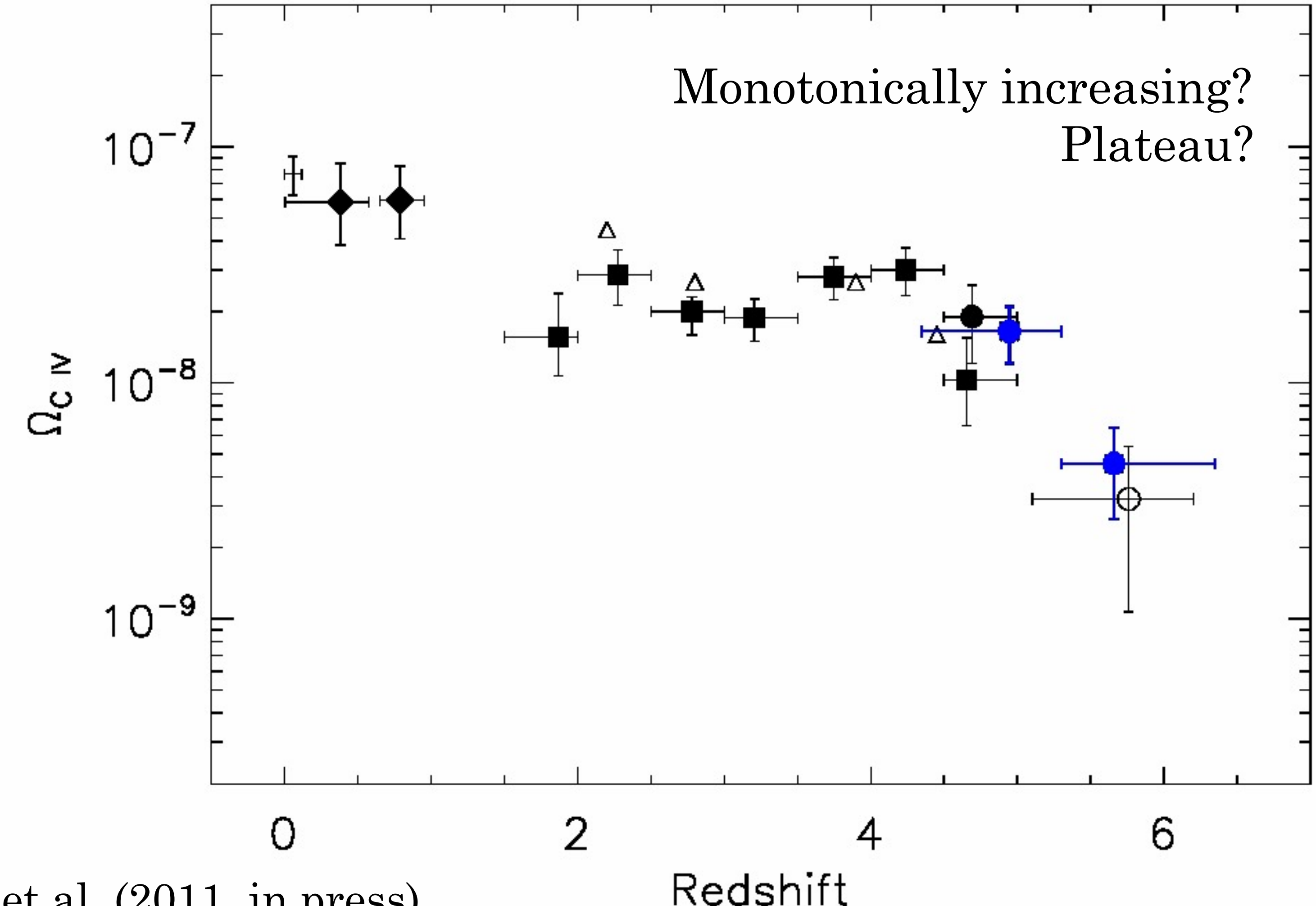
d$\mathcal{N}_{SiIV}$/dX: No! But…
high-redshift studies need to be improved…





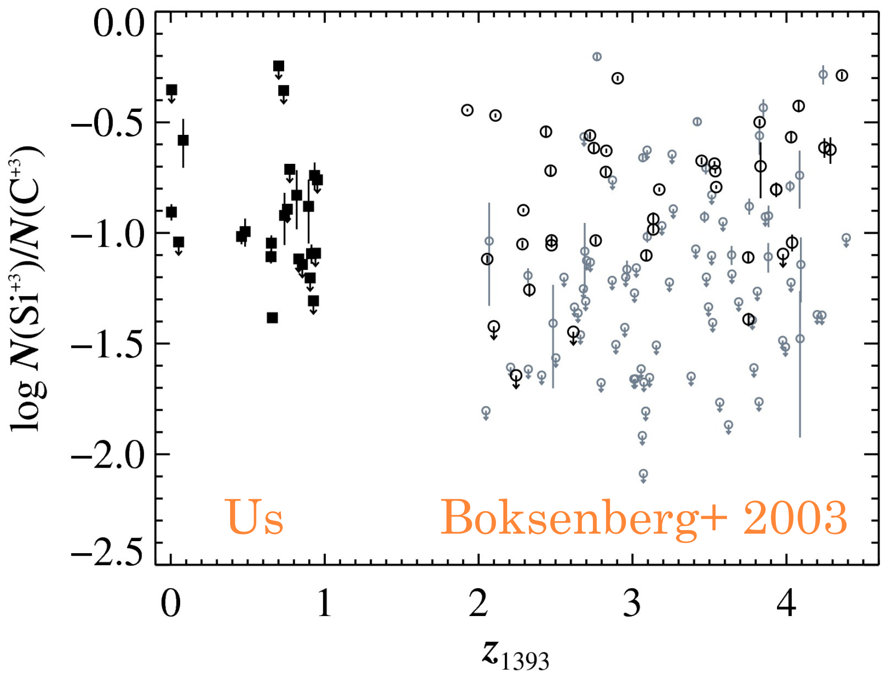
(Songaila 2001, Pettini+ 2003, Boksenberg+ 2003, Scannapieco+ 2006)

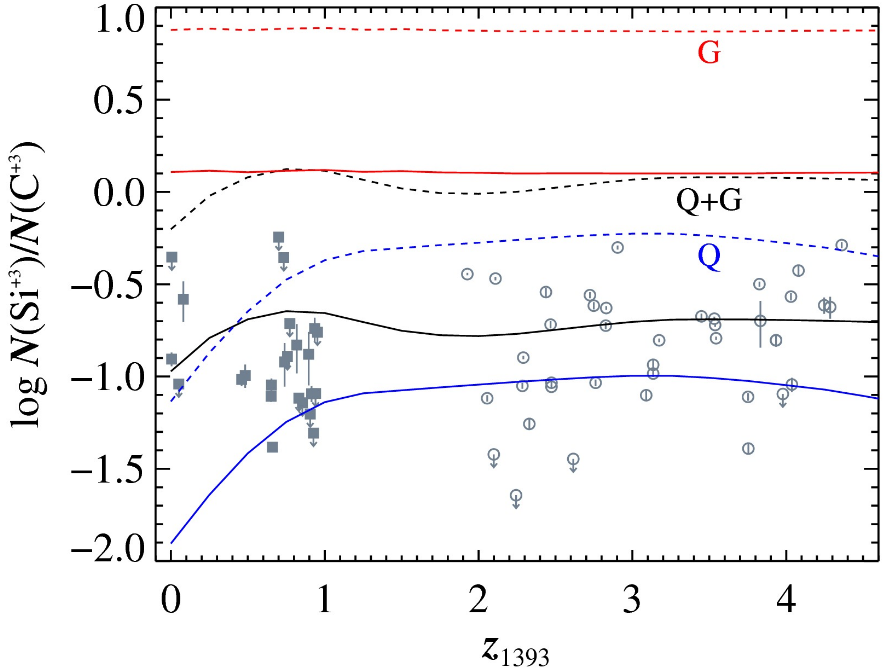
The C+3 Mass Density "Story"… Now Under FIRE



Simcoe et al. (2011, in press)

Ionic Ratio $N(Si^{+3})/N(C^{+3})$





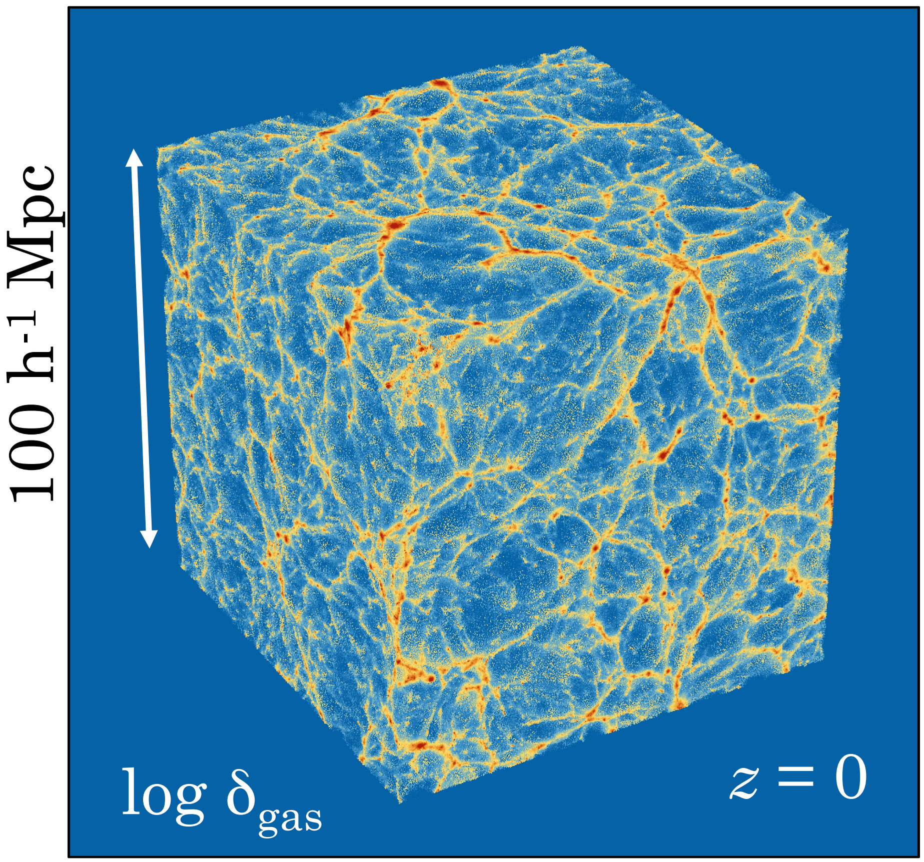
- No evolution with redshift
  - Both samples drawn from same parent population
- $N(Si^{+3})/N(C^{+3}) \approx 0.16$ for 12 Gyr!
  - No signature for HeII reionization at $z \approx 3$
- Balanced interplay of three processes:

$$\frac{N(\mathrm{Si}^{+3})}{N(\mathrm{C}^{+3})} = \left(\frac{L_{\mathrm{Si}}}{L_{\mathrm{C}}}\right)\left(\frac{n_{\mathrm{Si}}}{n_{\mathrm{C}}}\right)\left(\frac{\chi_{\mathrm{Si}}^{\mathrm{Si}^{+3}}}{\chi_{\mathrm{C}}^{\mathrm{C}^{+3}}}\right)$$

- Must turn to simulations…

OVERWHELMINGLY LARGE SIMULATIONS

See Schaye et al. (2010)



(Schaye & Dalla Vecchia 2008; Dalla Vecchia & Schaye 2008; Wiersma et al 2009a, b; Booth & Schaye 2009; and more!)

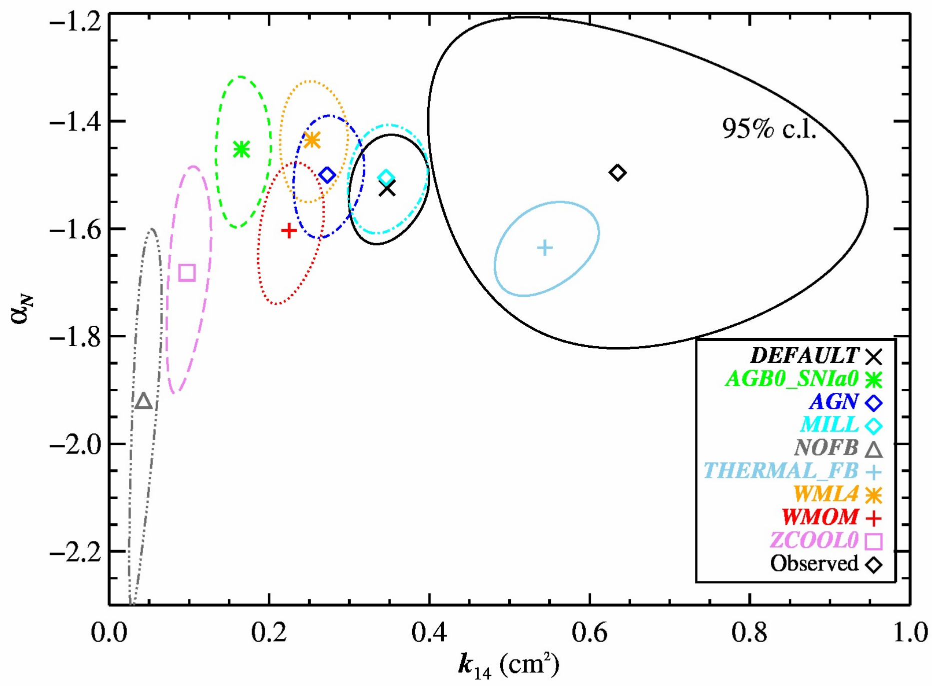
- Hydrodynamic cosmological simulations, $z = 127 \rightarrow 0$
  - Gadget III
  - Periodic boundary conditions
  - 2×512^3 (baryonic+dark matter) particles
  - 100 h^{-1} Mpc on a side
- Chemical evolution physics:
  - Radiative cooling by 11 elements
  - Photoionization by UV background in addition to collisional ionization equilibrium
  - Chemodynamics (production and dispersal of elements)

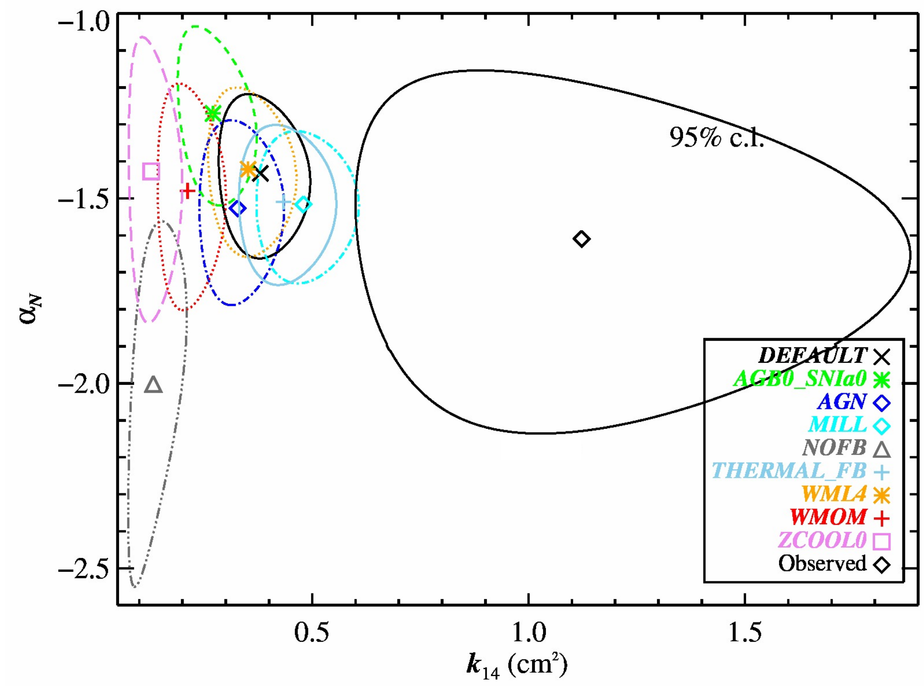
Preliminary

COMPARING SIMULATIONS TO OBSERVATIONS: $N(C^{+3})$ and $N(Si^{+3})$ Frequency Distributions

C^{+3}: Just need feedback and cooling to reproduce shape. Too few CIV absorbers! Except for THERMAL_FB…?

Si^{+3}: Just need feedback to reproduce shape but too few. SiIV observations better reproduced with higher σ_8?

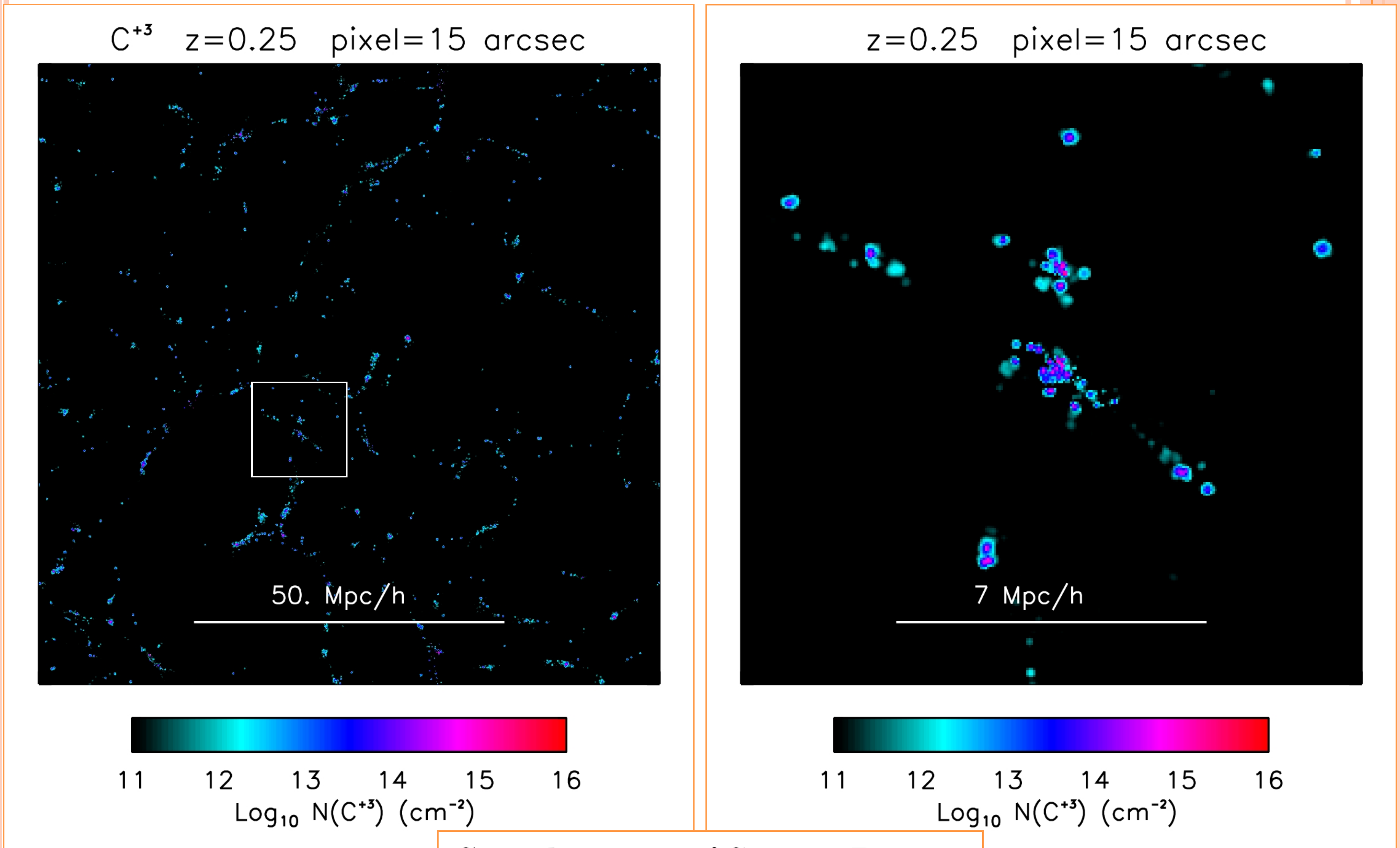




So much more to be explored…!

Preliminary

C^{+3} Column Density Maps: Galaxies?



Complements of Serena Bertone

Preliminary

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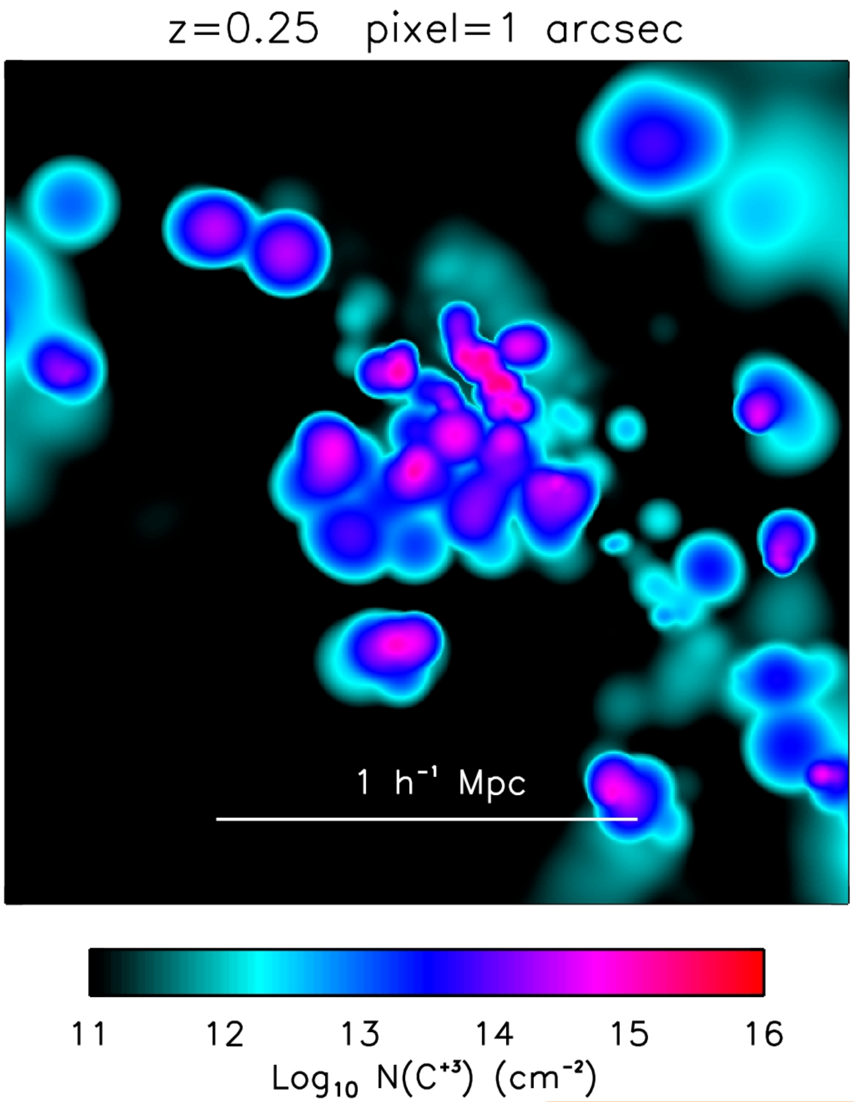

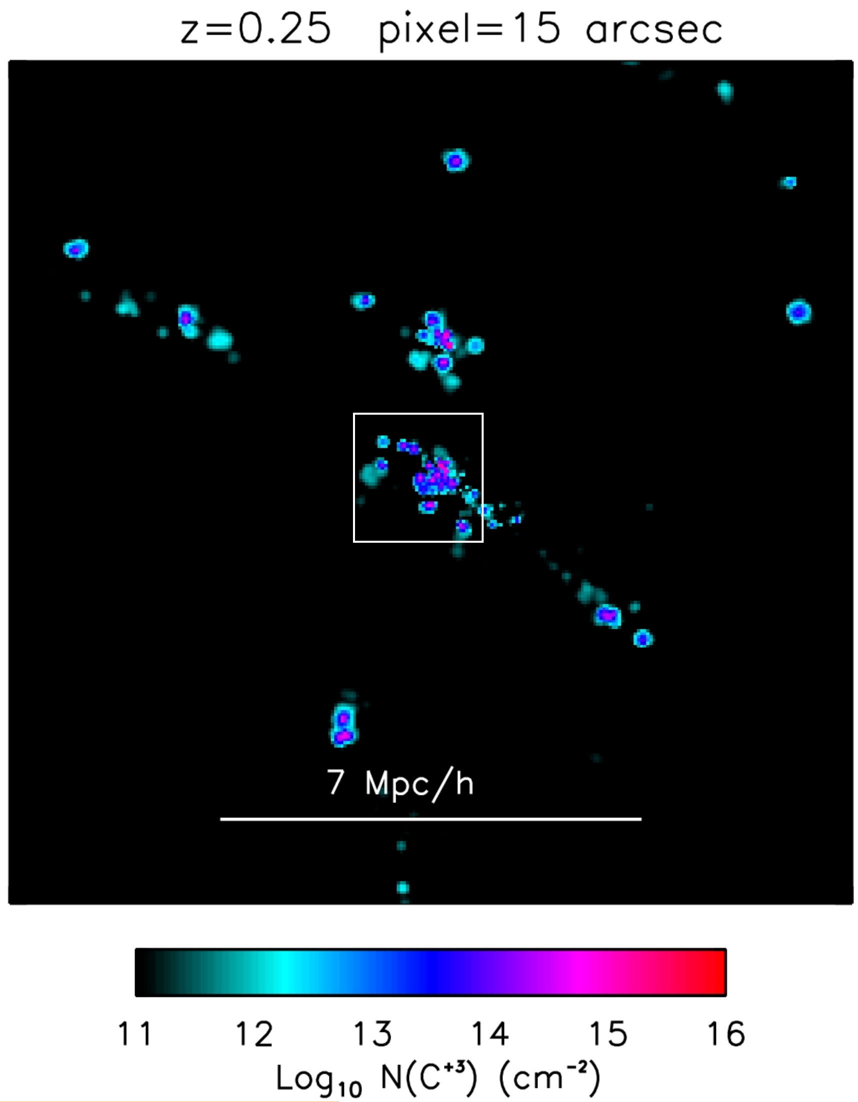

Complements of Serena Bertone

SUMMARY

- $z < 1$ C^{+3} and Si^{+3} mass densities increased compared to $1.5 < z < 5$ mean/median
- Physical distribution of absorbers "work" to keep $d\mathcal{N}/dX$ within factor of two for 12 Gyr
  - Interplay of co-moving number density and cross section
  - CIV and SiIV absorbers likely trace circum-galactic medium more than IGM
    - At low redshift? At all redshifts?!
- Ionic ratio $N(Si^{+3})/N(C^{+3})$ constant for 12 Gyr
  - Processes balance to produce constant ratio…
  - … future work with OWLS to disentangle