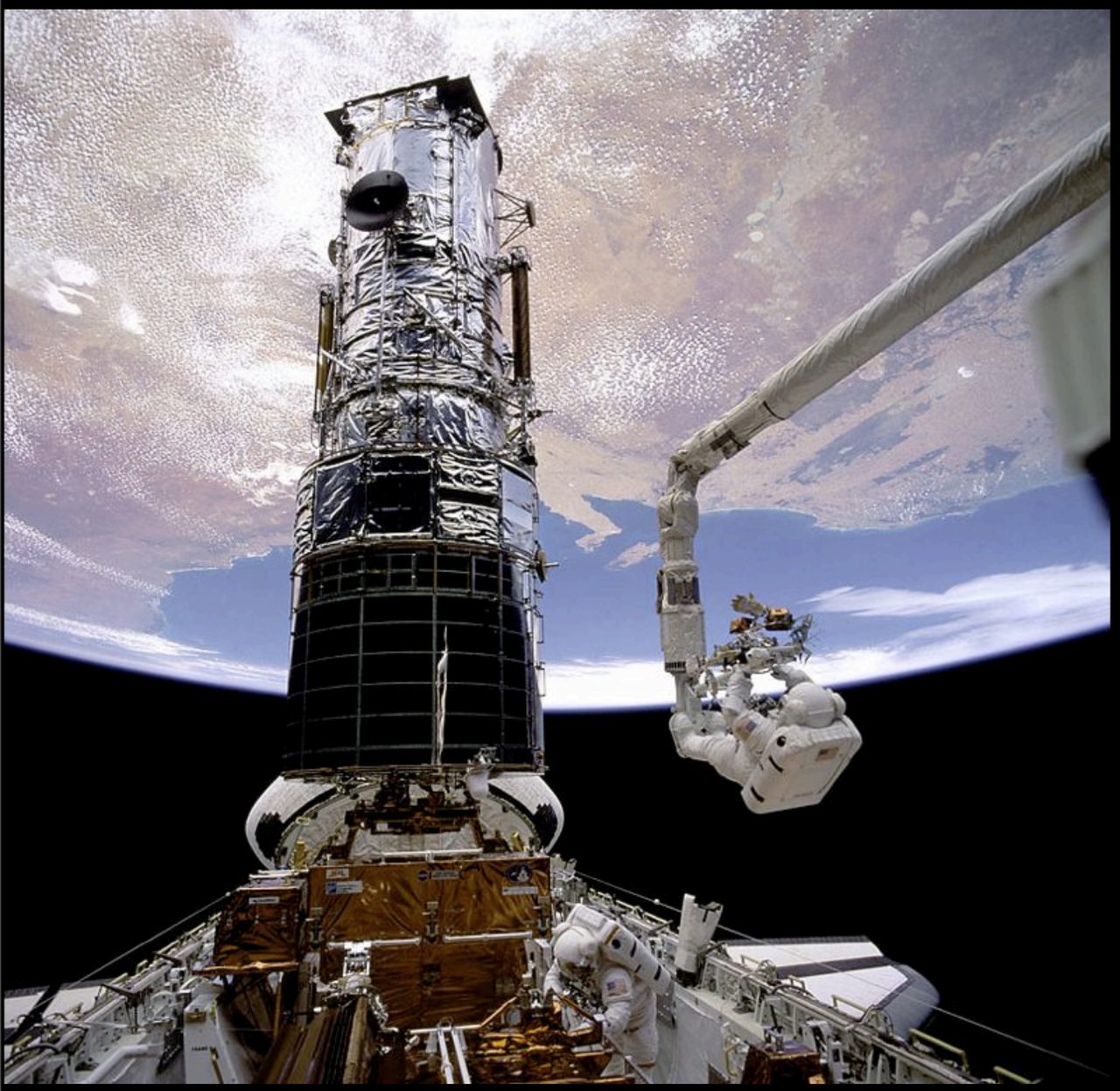
Cosmic Origins Spectrograph: IGM Science & Key Project



ESA/Bologna, Italy
Jan 30, 2008

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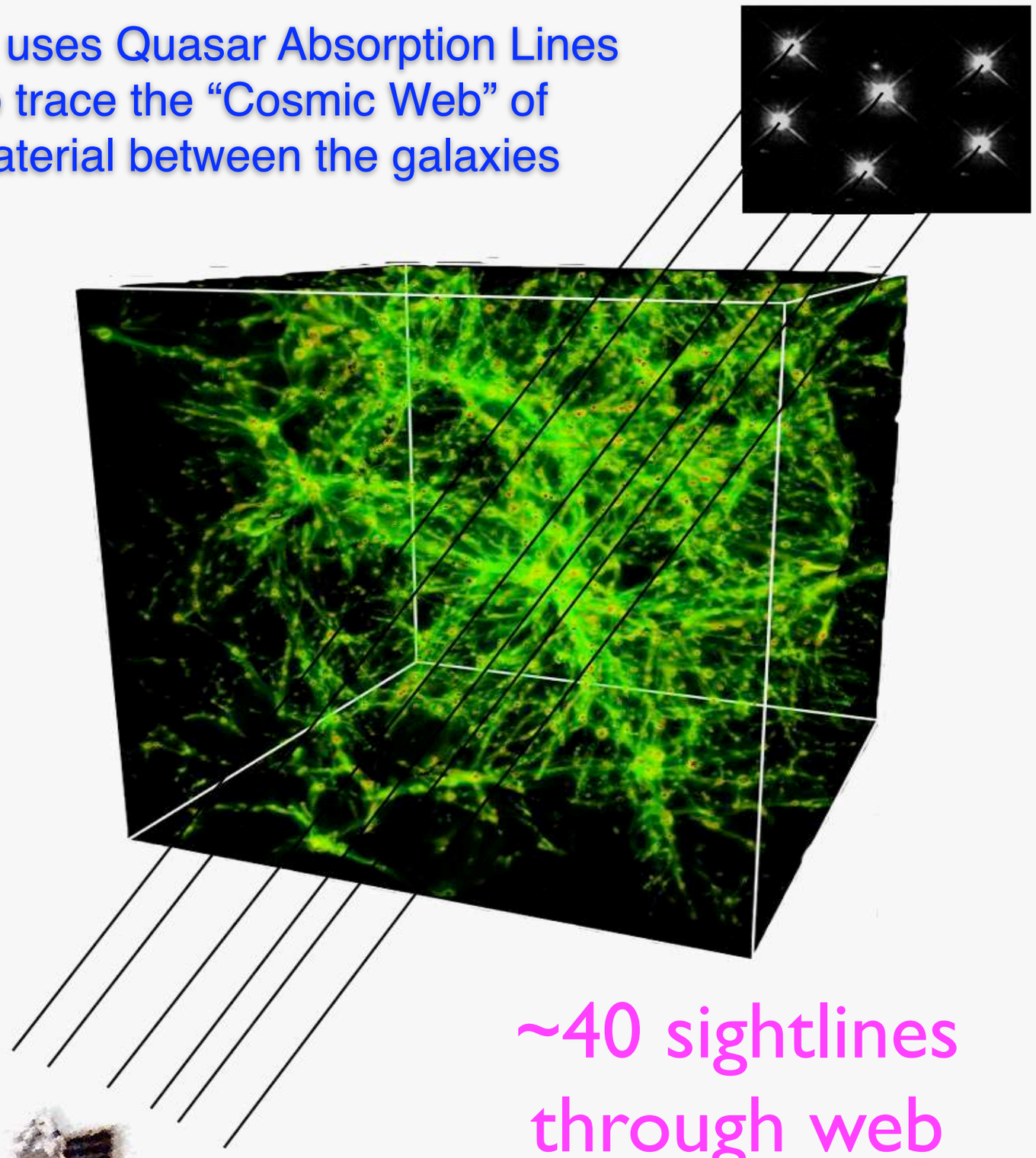
In collaboration with:
John Stocke (CU)
Charles Danforth (CU)
Blair Savage (Wisc)
Ken Sembach (STScI)

~250 GTO orbits for IGM science

(over 3 yrs)

Much more time available including community Treasury Projects

COS uses Quasar Absorption Lines to trace the "Cosmic Web" of material between the galaxies



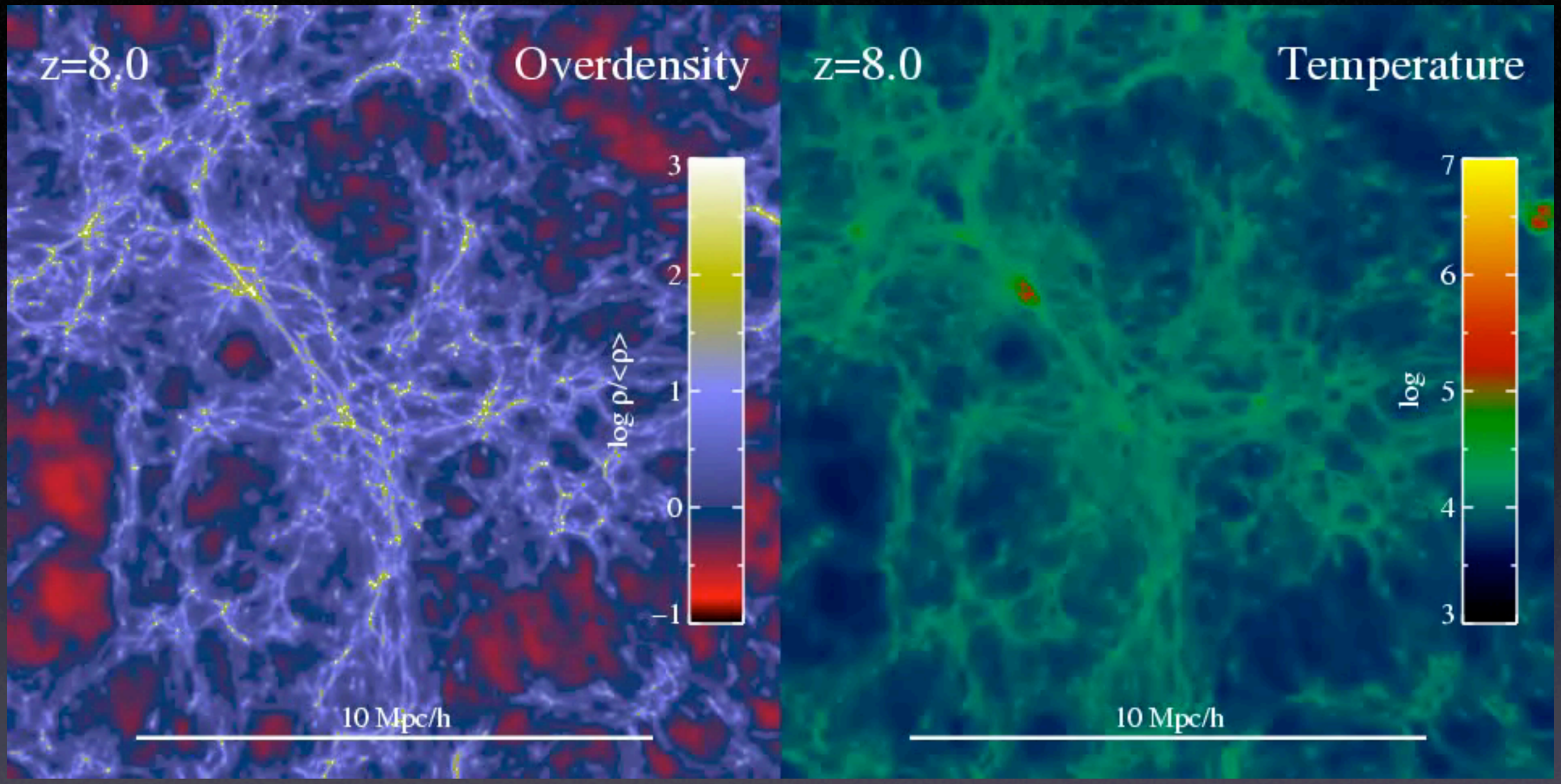
~40 sightlines through web filaments, galactic halos, WHIM

Large galaxy

Metal-polluted regions

IGM at z = 0.1

Simulations of Structure Formation



Oppenheimer, Davé, & Finlator (Princeton Univ.)

IGM Evolution from z = 8 → 1.5

COS-GTO Studies of IGM
(253 orbits)

$\Delta z \approx 10$ pathlength

Large-Scale Structure in Baryons .....

100 orbits
18 QSOs

Cloud sizes, Lyα, metal lines, blazars (broad Lyα absorbers), starburst wind outflows, galaxy halos, high-velocity clouds

WHIM in Cosmic Web and Halos .....

100 orbits
17 QSOs

High ions (O IV/V/VI, N V, C IV), BLAs, survey redshifts z out to 0.67

Great Wall Tomography .....

19 orbits, 4 QSOs

He II Reionization Epoch .....

27 orbits, 4 AGN

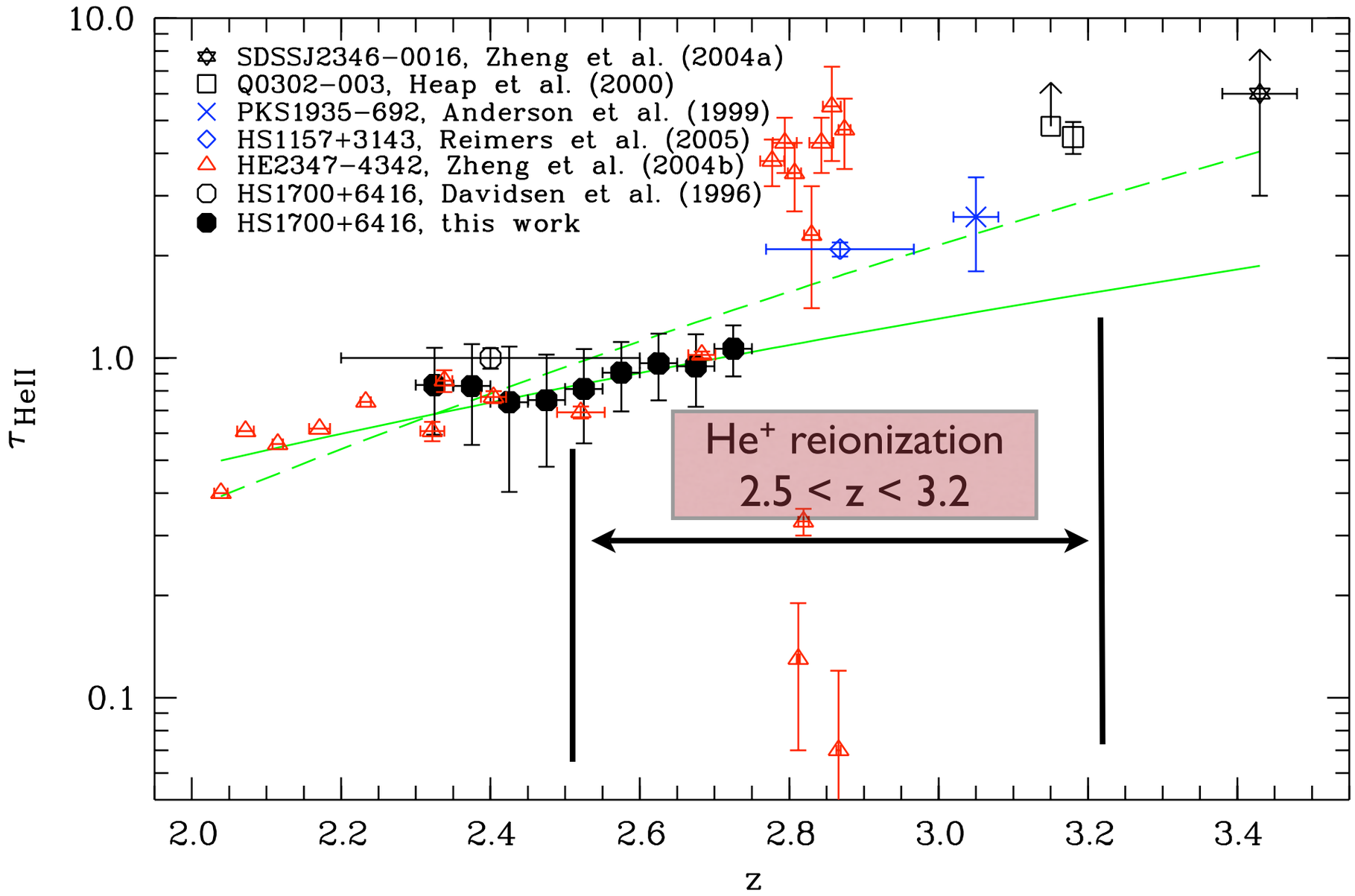
(4 AGN at z = 2.7-3.2)

Redshift Evolution of He II (IGM) Opacity

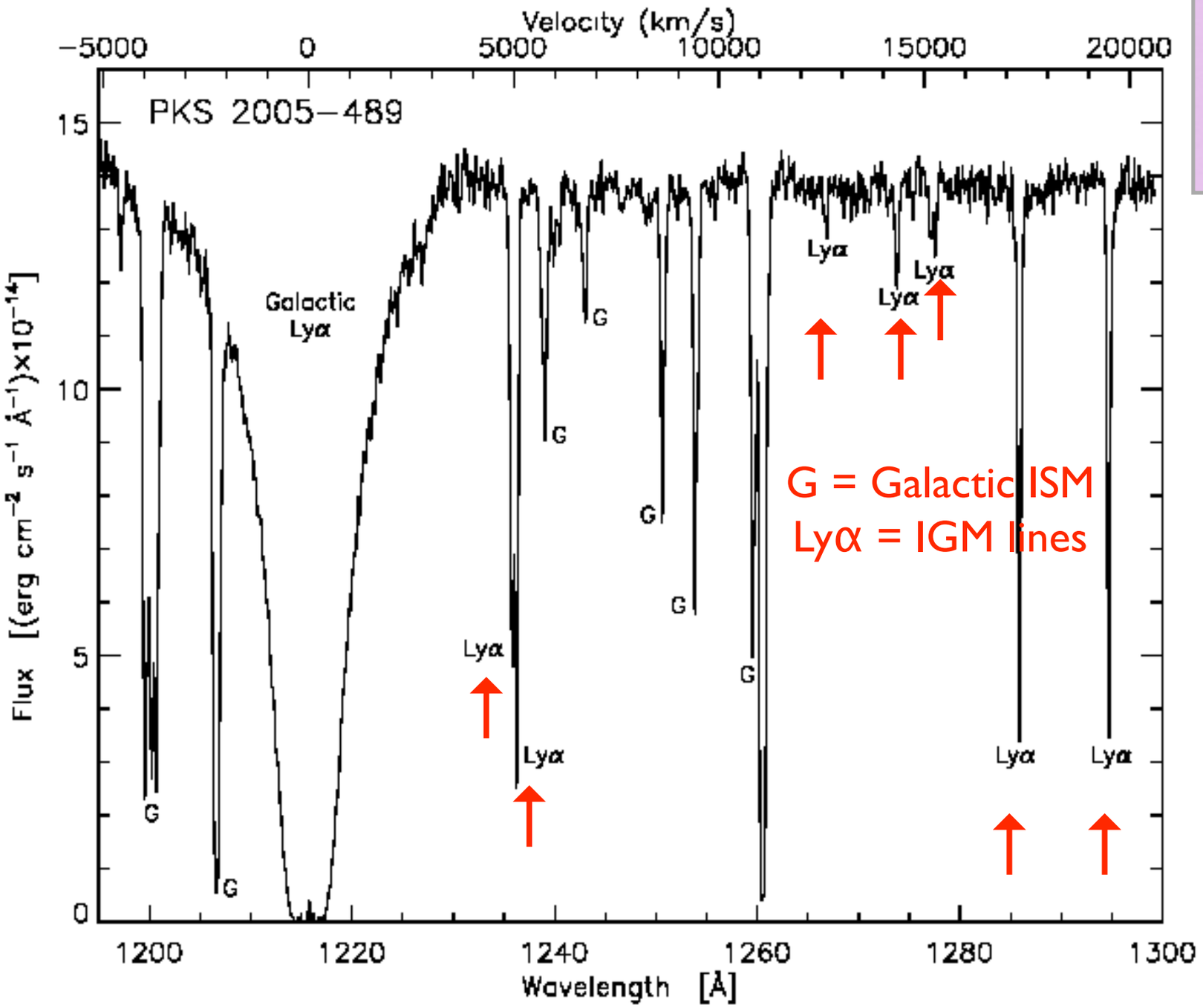
Previous Work:

Fechner et al 2006
Zheng et al 2004
Shull et al 2004
Kriss et al 2001

HST/COS at z > 2.78 (λ > 1150 A)
and perhaps z > 2.45 (λ > 1050 A)



Hubble/STIS Spectrum of low-z Lyα absorbers toward the blazar PKS 2005-489



Lyα absorbers

$N_{HI} = 10^{13\text{-}15}$ cm^{-2}

$M_H \approx 10^{8\text{-}9}\ M_{sun}$

(with ionization correction $f_{HI} \approx 10^{-4}$ to 10^{-5} for HI)

One Lyα line every 2300 km/s (dN/dz ≈ 130)

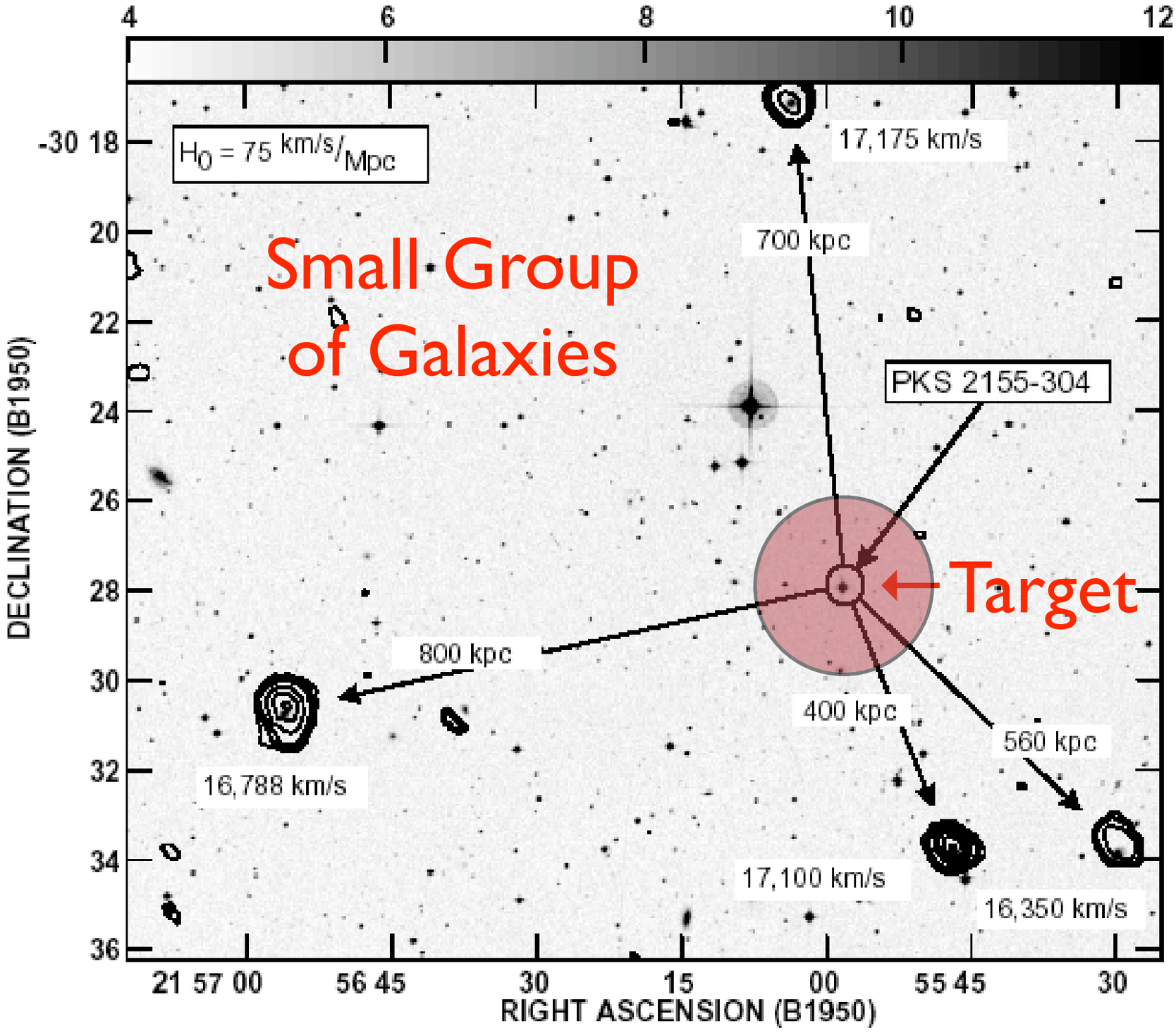
(EW > 30 mA)

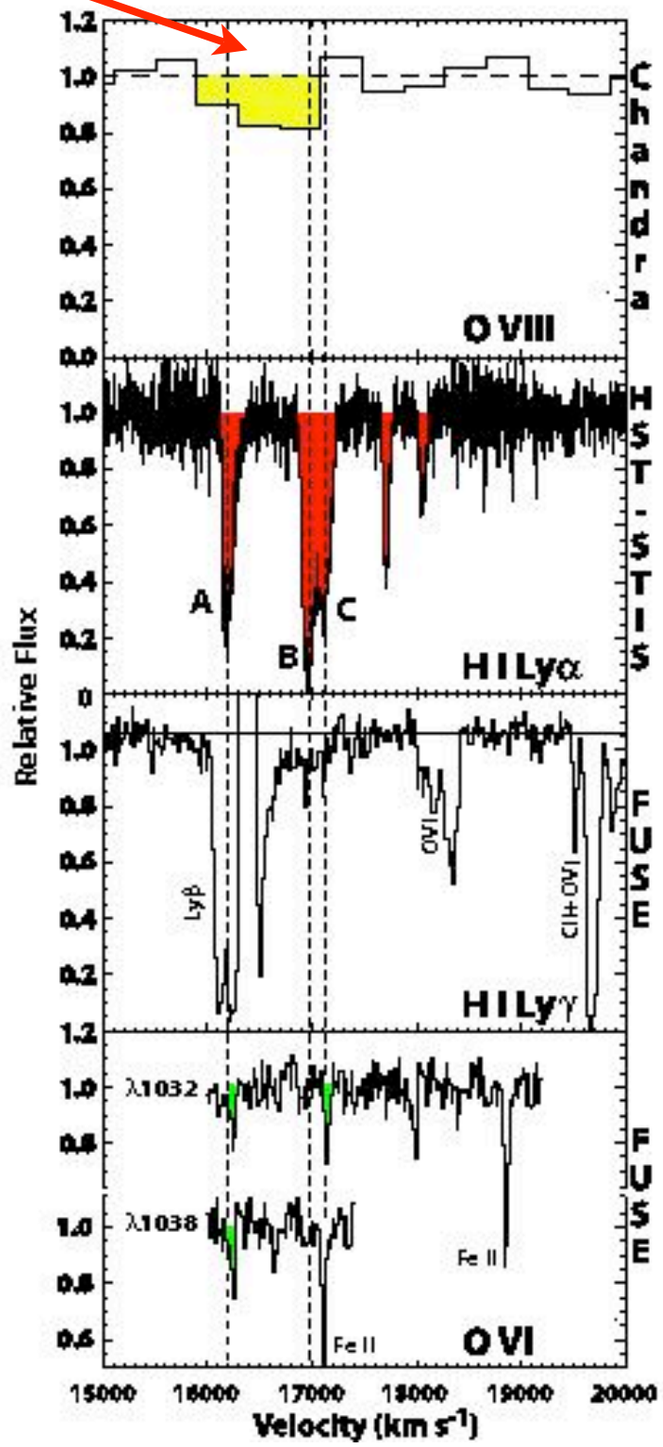
Many more at 10 mA

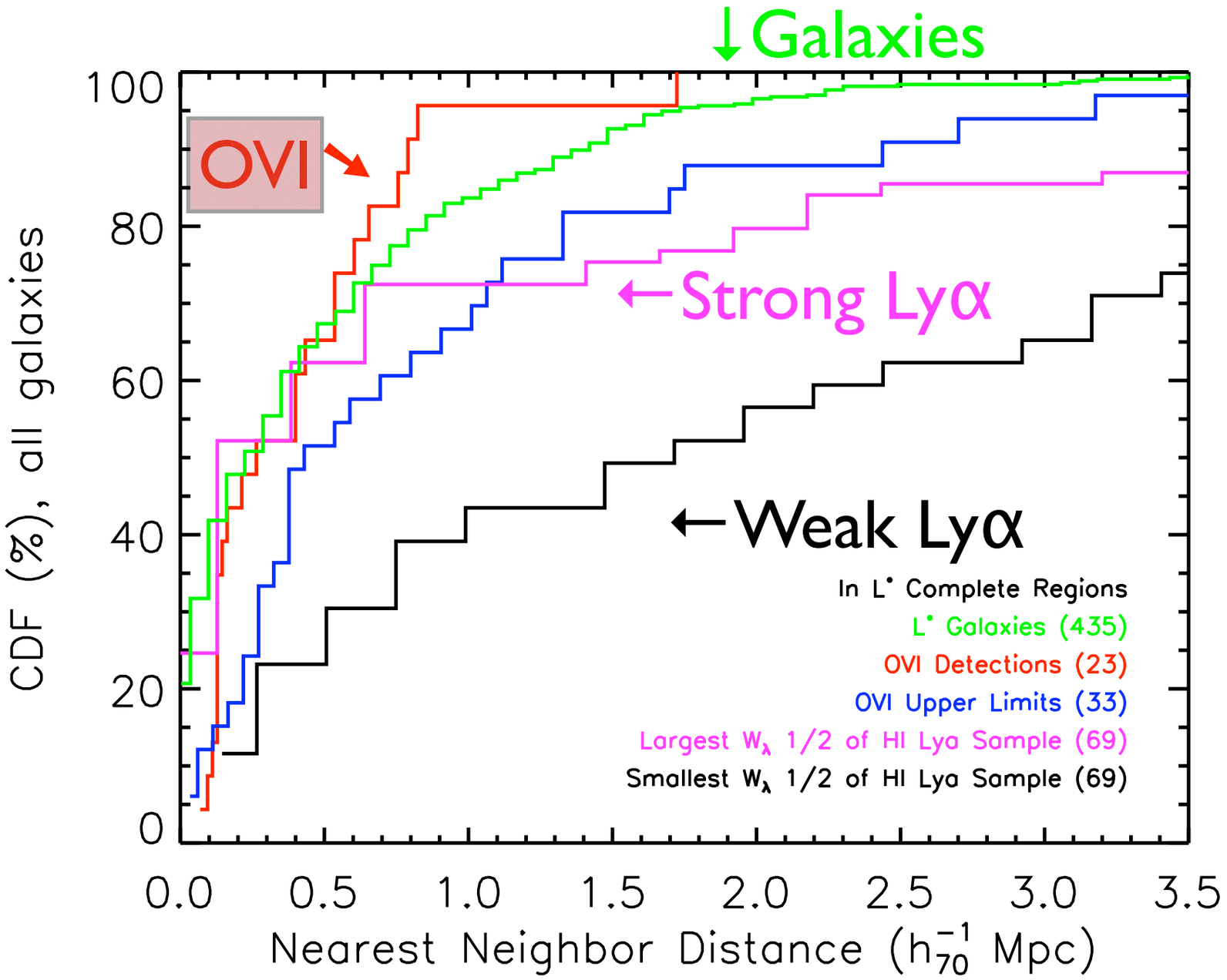
Galaxy/Lyα absorbers (PKS 2155-304)
Group at z ≈ 0.053 Shull et al. (1998, 2004)

X-ray (O VIII absorber?) - Fang et al 2005, 2008

Chandra, HST, and FUSE data







Nearest-galaxy distributions

Stocke et al. (2006)

OVI absorbers track galaxies:

OVI absorbers lie within 800 kpc of L* galaxies

& within 200 kpc of 0.1 L* galaxies

FUSE/HST Survey

(Danforth & Shull 2008)

7 km/s (HST)
20 km/s (FUSE)

- 28 AGN with known Lyα absorbers (STIS/E140M)
- Measured absorbers in hydrogen Lyman series, plus five metals [O VI, C III, Si III, Fe III, N V, C IV, Si IV]

- z < 0.4 for Lyman lines (650 absorbers)
- z < 0.2 for C III 977Å (found 39 systems)
- z < 0.4 for O VI 1032, 1038Å (found 83 systems)
- z < 0.4 for Si III 1206 (found 53 systems)

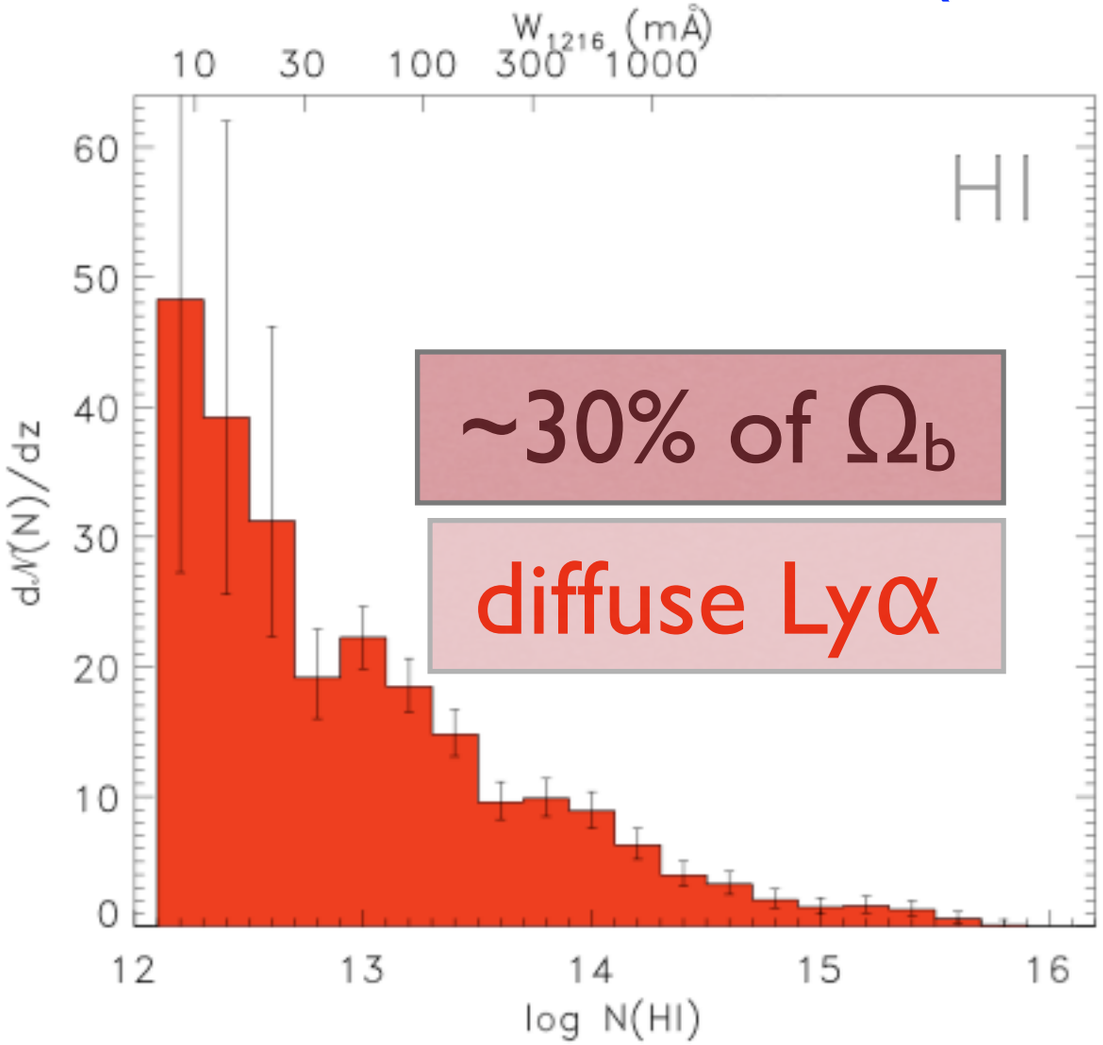
Survey Results (H I and 7 metal ions)

ion	z_{abs}	Δz	$\mathcal{N}$	$d\mathcal{N}/dX$ (W > 30mÅ)	β (power-law slope)	traces...
HI	**<0.4**	**5.27**	**650**	**151^{+7}_{-6}**	**1.73±0.04**	**Lyα forest (photoionized)**
OVI	**<0.4**	**5.22**	**83**	**18^{+3}_{-2}**	**1.98±0.11**	**shocked gas (WHIM)**
NV	<0.4	5.30	24	3±1	1.87±0.17	mostly WHIM
CIV	<0.12	2.42	24	10^{+4}_{-2}	1.79±0.17	WHIM + photoionized
CIII	<0.4	4.84	39	12^{+4}_{-2}	1.79±0.10	enriched photoionized gas
SiIV	<0.24	4.21	20	5^{+2}_{-1}	1.9±0.2	enriched photoionized gas
SiIII	<0.4	5.14	53	7^{+2}_{-1}	1.80±0.09	enriched photoionized gas
FeIII	<0.4	5.11	14	~1	2.2±0.4	enriched photoionized gas

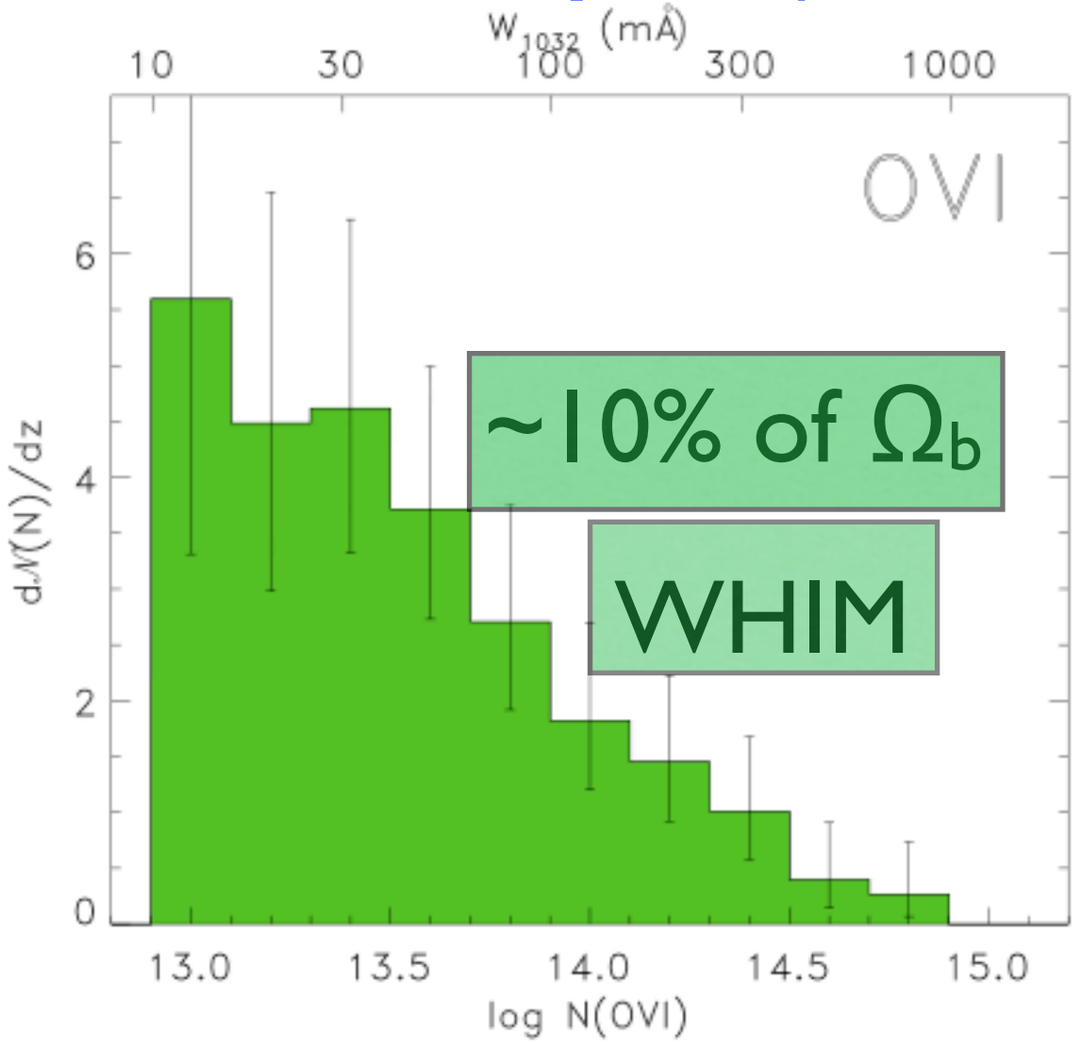
Danforth & Shull 2008, ApJ, submitted

Nucleosynthesis: C, O, Si, Fe

Low-z IGM (≥40% of the baryons)



$\mathcal{N}$=650, β=1.73±0.04



$\mathcal{N}$=83, β=1.98±0.11

Danforth & Shull 2008, ApJ, submitted

➥ ***arXiv:0709.4030***

IGM + wind shocks

O VI

Vertical fit adjusted to ~10% solar metallicity

Line Freq

Models (Cen & Fang 2006)

GSW, non−LTE

no GSW, non−LTE

GSW, LTE

100

10

1

10

100

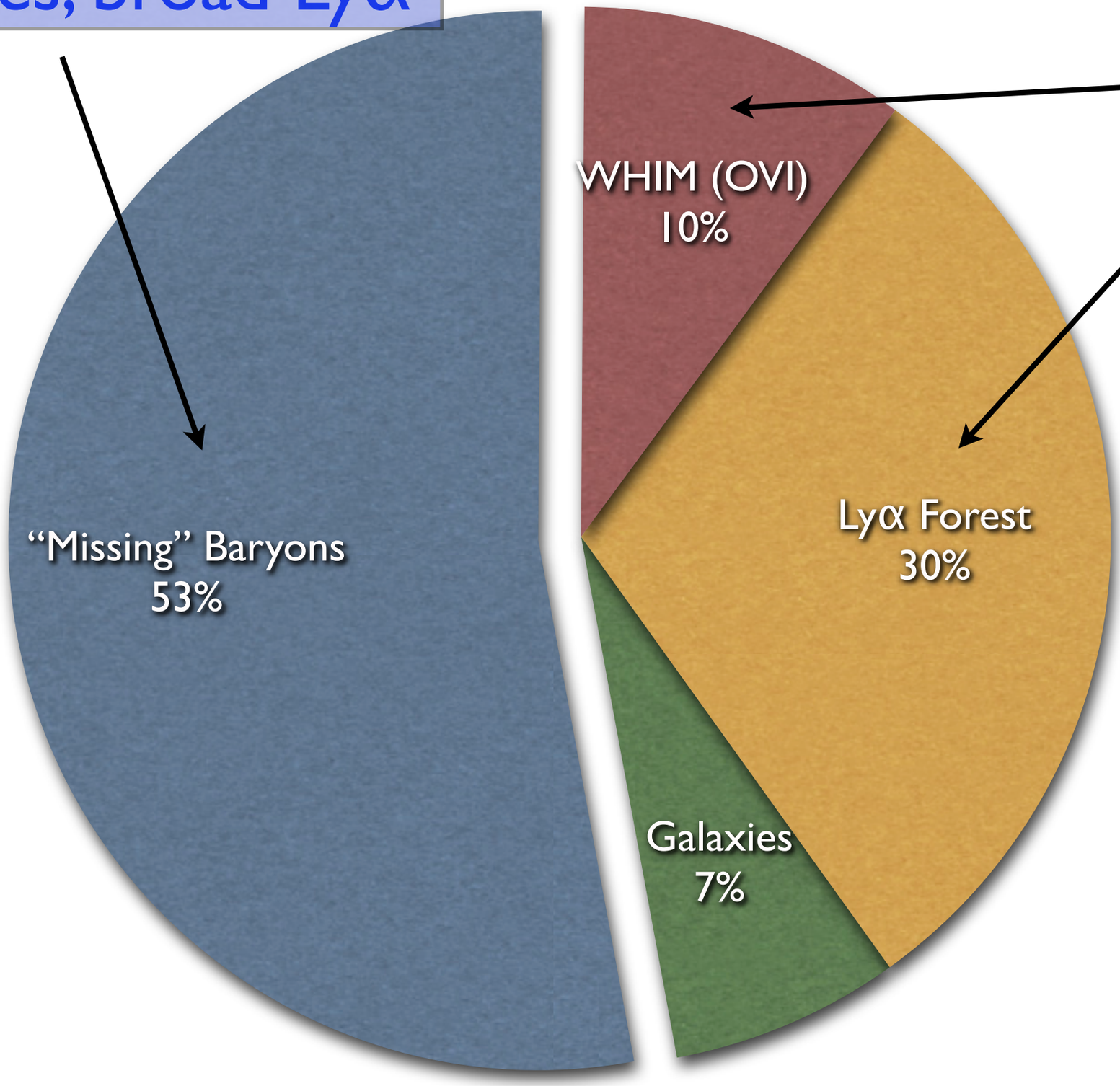
dN/dz (OVI)

W_{1032} (mÅ)

O VI Absorber Strength

Baryon Census (low-z)

Probed by X-ray lines, broad Lyα



Both of these are uncertain

IGM Systematics:

- EUV radiation field
- Oxygen metallicity
- Ioniz corrections
- Cloud geometry

Summary of Results:

We have accounted for ~50% of the baryons

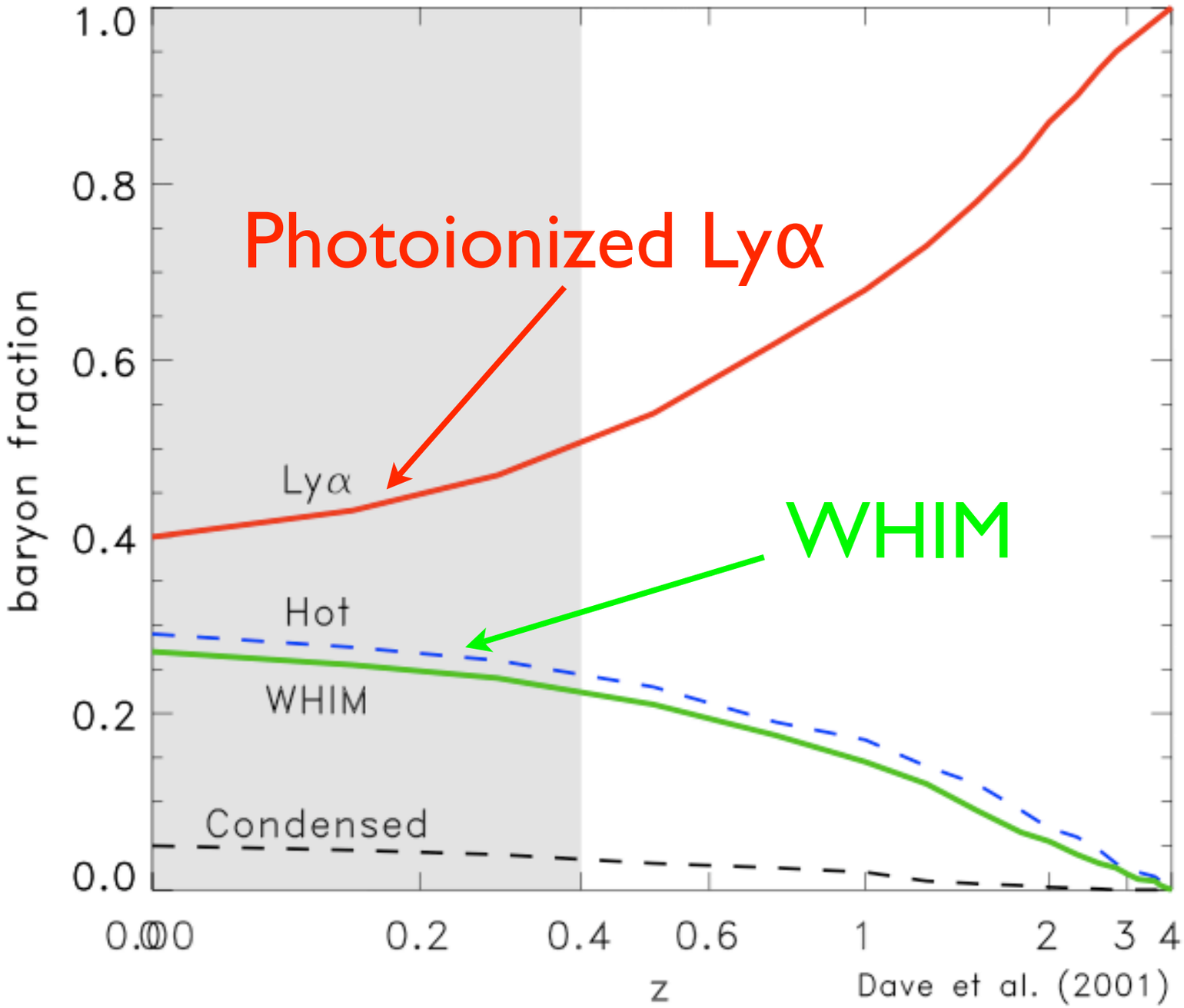
- 10% in collapsed structures (galaxies, clusters)
- 30% in warm (10^4 K) photoionized gas (Lyα)
- 10% in hot ($10^{5.5}$ K) gas (O VI ultraviolet lines)

Other 50% may be in even hotter (10^6 K) gas

The hot (O VI) gas is close to galaxies, and thus is a reservoir for low-Z gas infall

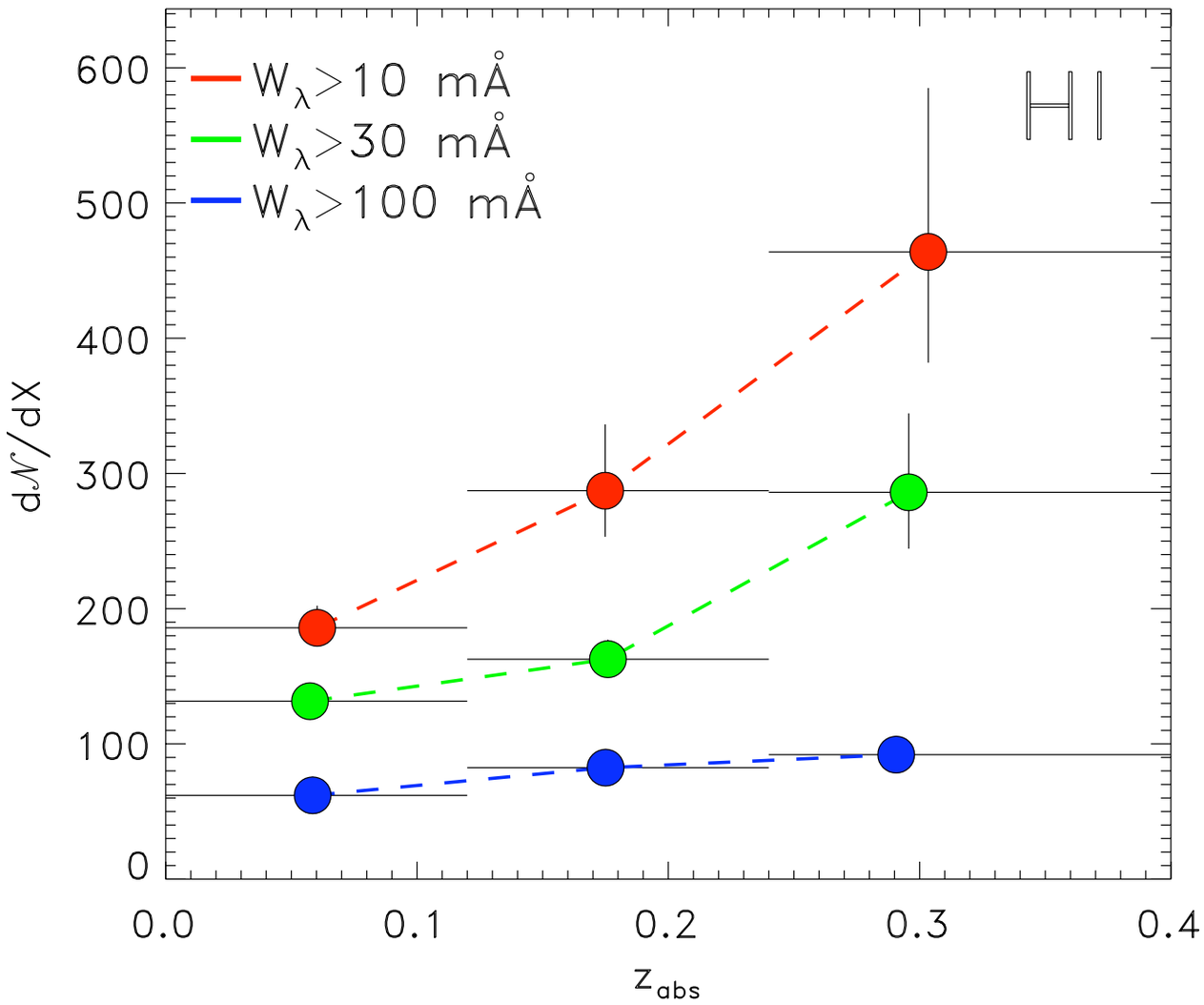
- Within 200 kpc of 0.1 L^* galaxies (outflows?)
- Cooling ⇒ 0.1 M_{sun}/yr infall to halos?

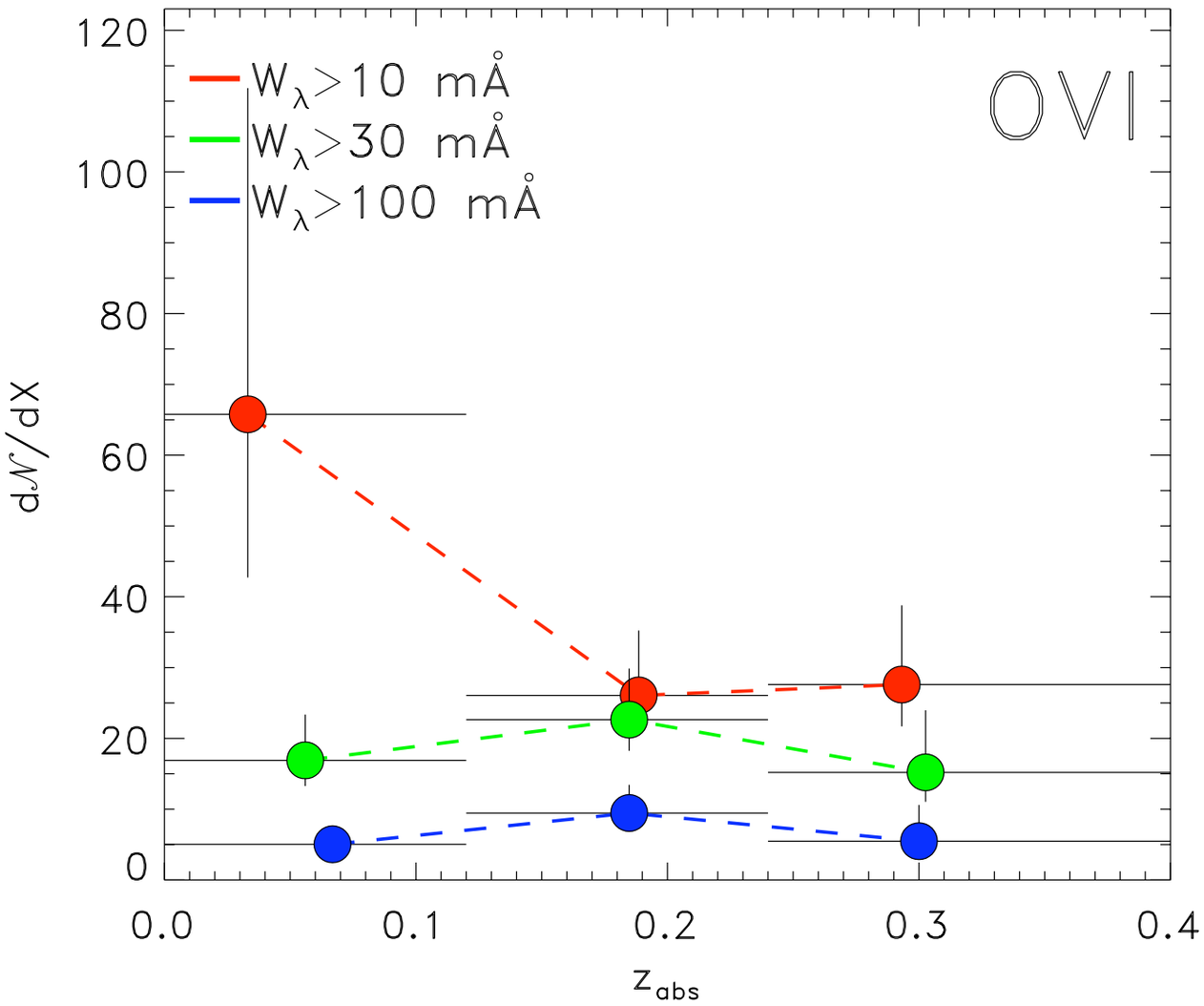
Predicted Phase Evolution



IGM Absorber Redshift Evolution

(We see a hint of this already)





Shull & Danforth 2008

HST/COS Community Legacy Project?

QSO Absorption-Lines: Δz ≈ 40 pathlength

500 orbits, 140 AGN (R = 20,000, S/N = 30)

- IGM Large-Scale Structure ("Cosmic Web")
- Multiphase IGM and ISM (including WHIM)
- IGM metallicity (content, evolution, transport)
- Chemical extent of galactic halos & winds
- Feedback (energy, radiation, metals) to IGM
- Galactic high-velocity clouds, AGN outflows

Such proposals may be accepted for Cycles 18-20
Director Discretionary Time added for Treasury Programs?

IGM/Halo Key Project (sample)

300 orbits: High-S/N Survey (R = 20,000)

G130M/G160M (30 targets, 10 orbits each, S/N = 30)

Large redshift coverage ($\Delta z \approx 40$) (4 x GTO pgm)

15,000 Lyα, 500 O VI absorbers, many metal lines

100 orbits: mid-UV spectral survey (z = 0 to 1.5)

Baryons & metal evolution out to z > 1

100 orbits: low-resolution survey

100 AGN targets with G140L (R = 3000)

Cosmology (power-spectra, voids, web geometry)

Survey for DLA and Lyman-limit systems