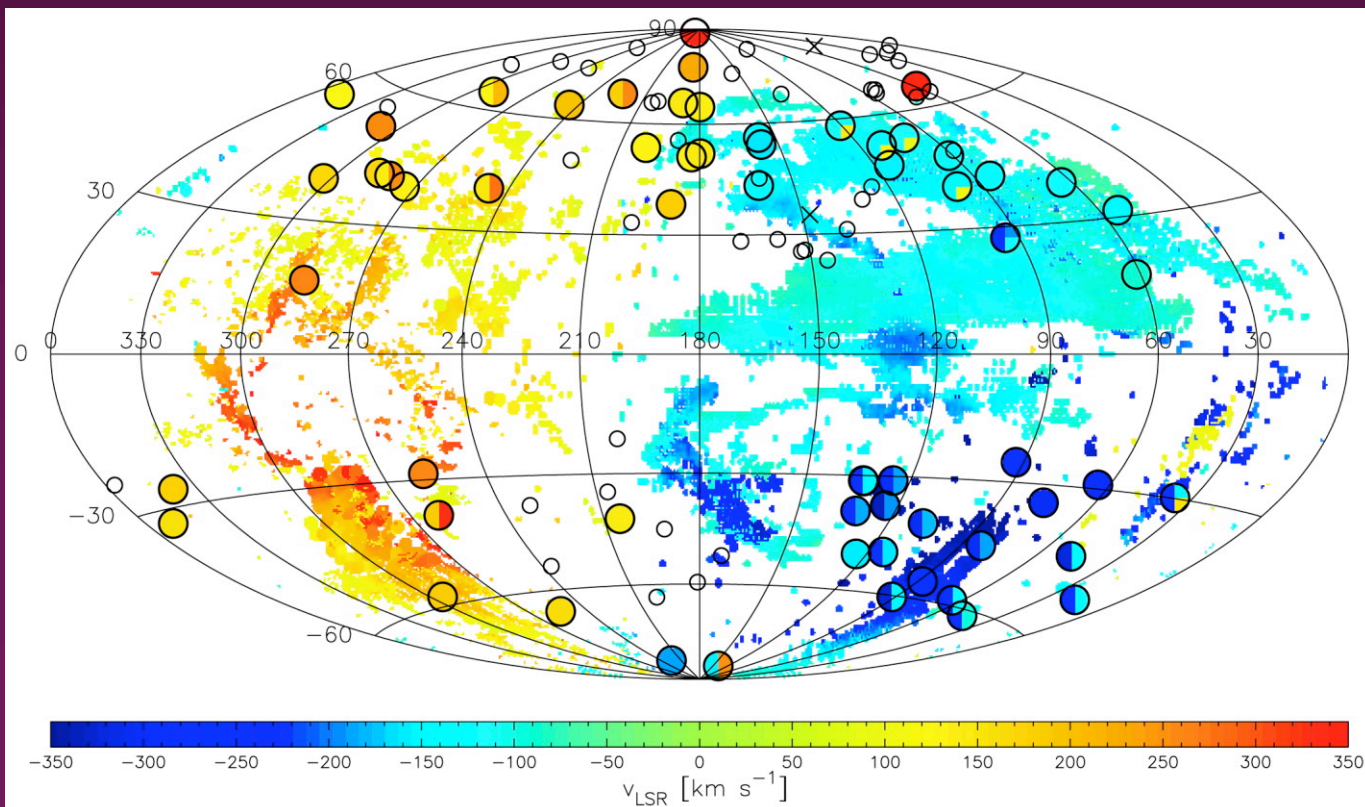


# O VI Absorption Lines and the IGM Baryon Content

Todd M. Tripp

University of Massachusetts



Left: All-sky HVC map (Galactic coords.) High-velocity clouds detected in 21cm emission (contours) and O VI absorption (filled circles). Colors indicate velocity as shown by the scale bar.

Sembach et al. 2003

Wakker et al. 2003

Savage et al. 2003

# The Baryon Inventory and the Missing Baryons

THE ASTROPHYSICAL JOURNAL, 503:518–530, 1998 August 20  
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THE COSMIC BARYON INVENTORY  
M. FUKUDA

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*Mon. Not. R. astr. Soc.* (1992) **258**, *Short Communication*, 14P–18P

## The baryon content of the Universe

Massimo Persic<sup>1,2</sup> and Paolo Salucci<sup>1</sup>

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<sup>2</sup>*Osservatorio Astronomico, via G.B. Tiepolo 4, I-34139 Montebelluna, Italy*

Accepted 1992 June 22. Received 1992 May 27

S  
V  
a  
c  
v

- Summing up the well-observed baryons in the nearby universe, only 30–50% of the baryons predicted by D/H and the CMB can be readily accounted for.

## LIGHT ELEMENT NUCLEOSYNTHESIS: A FALSE CLUE?

N. YU. GNEDIN AND J. P. OSTRIKER  
Princeton University Observatory, Princeton, NJ 08544  
*Received 1992 February 10; accepted 1992 May 27*

### ABSTRACT

We propose that the dynamically estimated value for the cosmological density  $\rho_b \times 10^{\pm 0.20}$ , reflects the baryon density at decoupling, resulting in lower initial, primordial abundances than are observed. An early generation of massive stars, forming somewhat after decoupling, could account for the observed abundances.

# The Missing Baryons: Shock-Heated Intergalactic Gas?

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THE ASTROPHYSICAL JOURNAL, **241**:1–24, 1980 October 1

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## THE EFFECTS OF X-RAY ABSORPTION ON THE SPECTRA OF DISTANT OBJECTS

PAUL R. SHAPIRO AND JOHN N. BAHCALL

Institute for Advanced Study

*Received 1980 March 5; accepted 1980 April 22*

### ABSTRACT

We have calculated in detail the X-ray absorption spectrum above 0.1 keV that would be introduced into the continuous X-ray spectrum of a quasar by an intervening uniform, hot ( $T \geq 10^6$  K), intergalactic gas with a small admixture of atoms of C, N, O, Ne, Mg, Si, S and Fe. This work is relevant to the well-known search for cosmologically distributed “missing mass.” Our results indicate that soft X-ray absorption can be appreciable (i.e.,  $\tau \gtrsim 1$ ) for all quasar X-ray

# The Missing Baryons: Shock-Heated Intergalactic Gas?

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*Received 1980 March 5; accepted 1980 April 22*

## X-RAY ABSORPTION BY THE HOT INTERGALACTIC MEDIUM

ROSALBA PERNA AND ABRAHAM LOEB

Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138

*Received 1998 April 7; accepted 1998 June 24; published 1998 July 22*

### ABSTRACT

The current census of observed baryons in the local universe is still missing a significant amount according to standard big bang nucleosynthesis. Numerical simulations predict that most of the missing baryons are in a hot intergalactic medium, which is difficult to observe through its X-ray emission and the Compton-Zeldovich effect. We show that the next generation of X-ray satellites will be able to detect this gas.

# The Missing Baryons: Shock-Heated Intergalactic Gas?

THE ASTROPHYSICAL JOURNAL, **241**:1–24, 1980 October 1

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## ABSTRACT

## THE X-RAY FOREST: A NEW PREDICTION OF HIERARCHICAL STRUCTURE FORMATION MODELS

UFFE HELLSTEN,<sup>1</sup> NICKOLAY Y. GNEDIN,<sup>2</sup> AND JORDI MIRALDA-ESCUDE<sup>3,4</sup>

*Received 1998 April 3; accepted 1998 July 17*

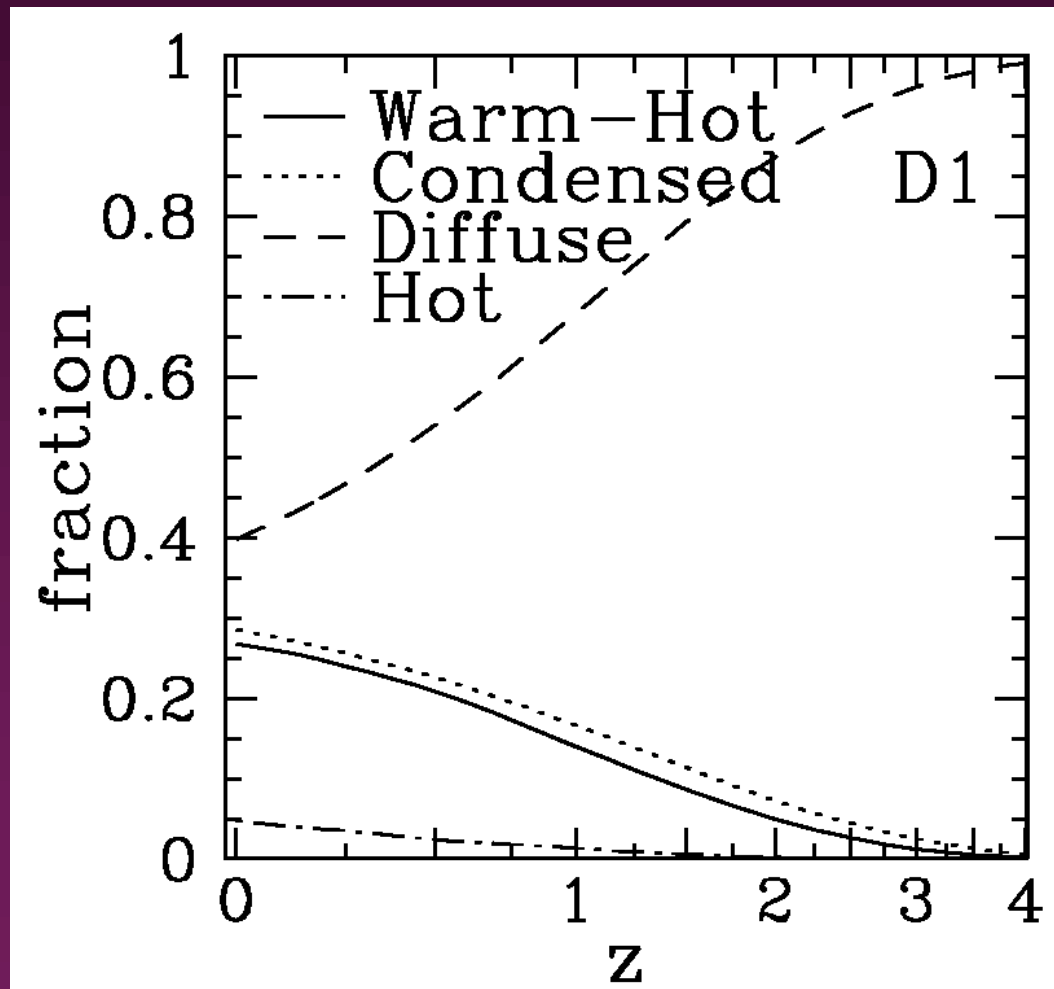
## ABSTRACT


We use numerical simulations of structure formation in a cold dark matter model to predict the absorption lines in the soft X-rays produced by heavy elements in the shock-heated intergalactic medium at low redshift. The simulation incorporates a model for heavy-element production in galaxies and the

# The Missing Baryons: Shock-Heated Intergalactic Gas?

- Cen & Ostriker (1999)
- Dave et al. (1999)
- Hydrodynamic simulations of cosmological structure growth
- **30 - 50 % predicted to be in low-density, shock-heated gas at  $10^5 - 10^6$  K**

**Difficult to observe!**





# Halo physical conditions and chemical enrichment constrain fundamental aspects of galaxy evolution.

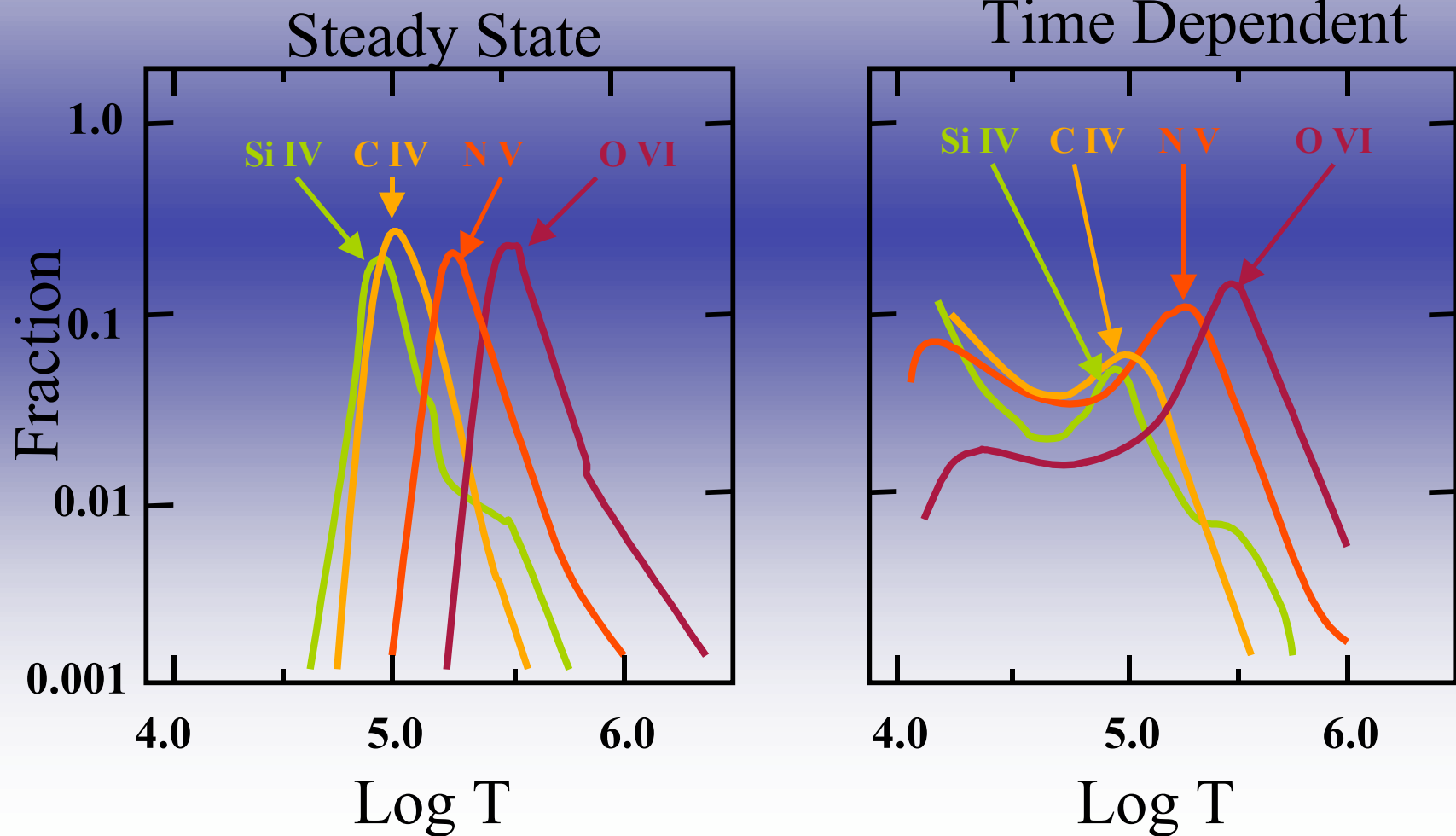
For example, when gas accretes onto galaxies, is it shock heated to  $\sim 10^6$  K (conventional model), or does it remain cool, (i.e., “cold mode” accretion, Keres et al. 2005)?

WIYN + HST image  
of M82  
(Gallagher et al.)

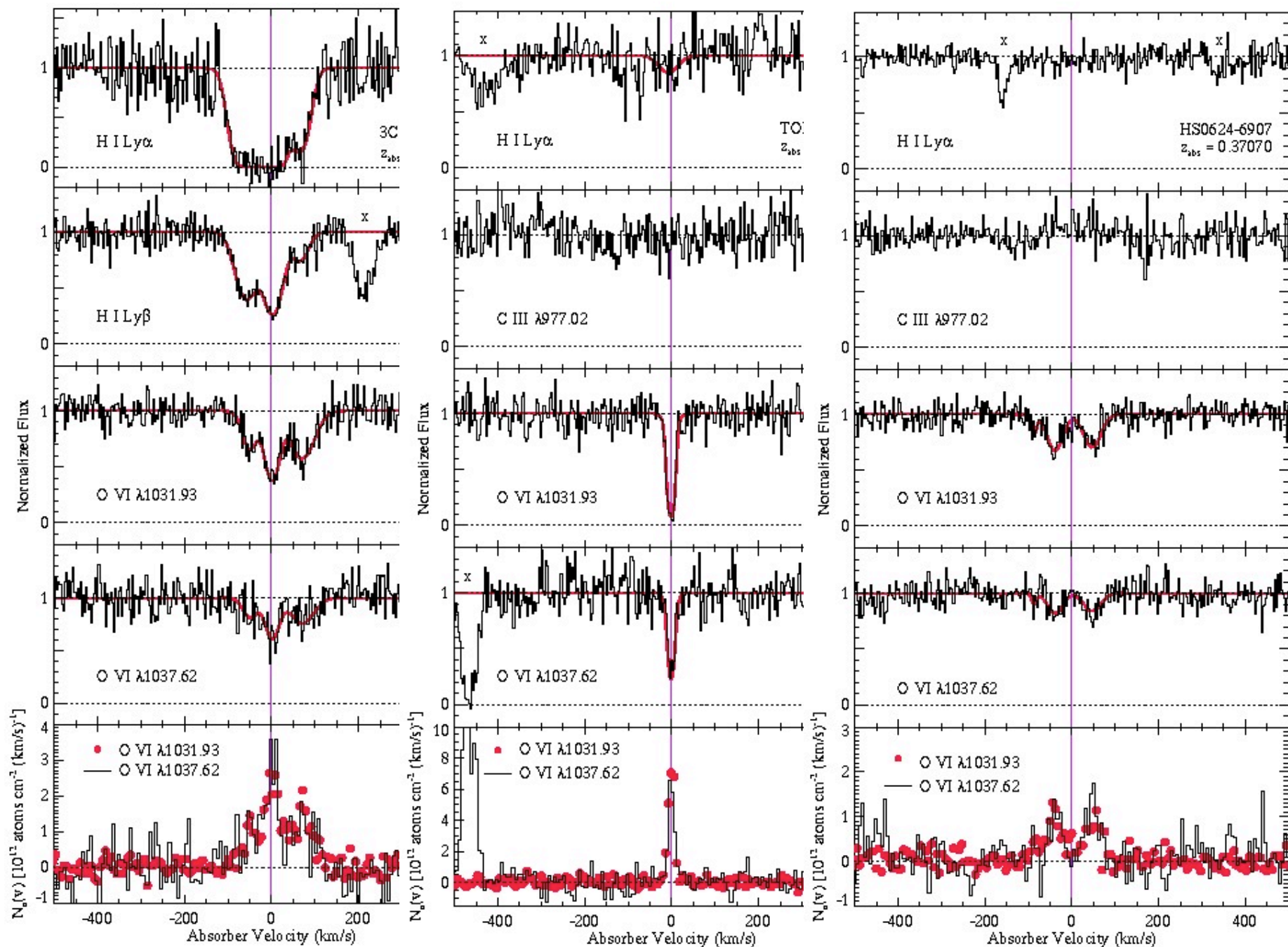
How do galactic superwinds affect galaxy  
and large-scale structure evolution?

# Searching for the Missing Baryons with UV and X-ray Absorption

Ion fractions from Shapiro & Moore:





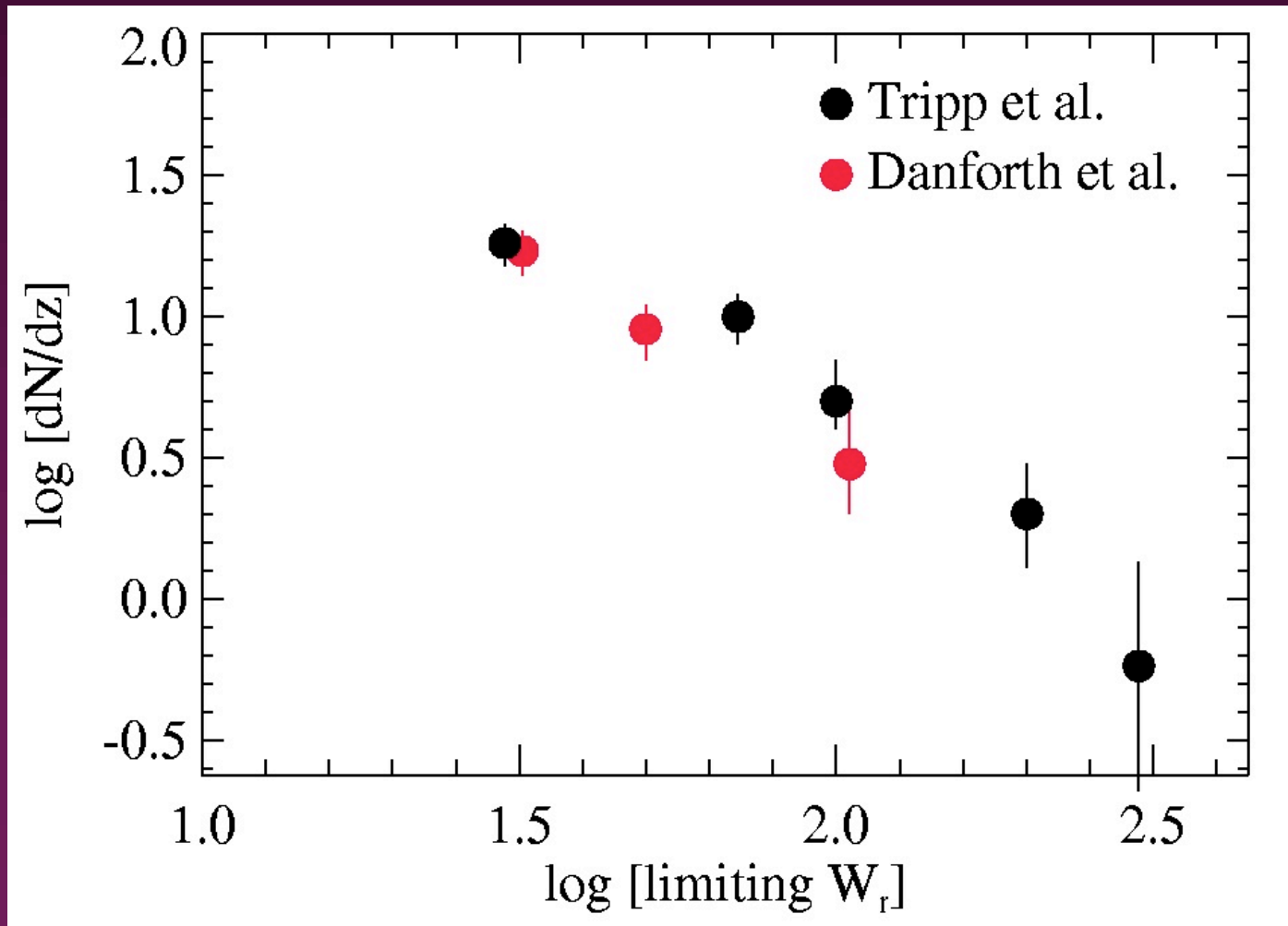


# Number of O VI Absorbers per Unit Redshift:

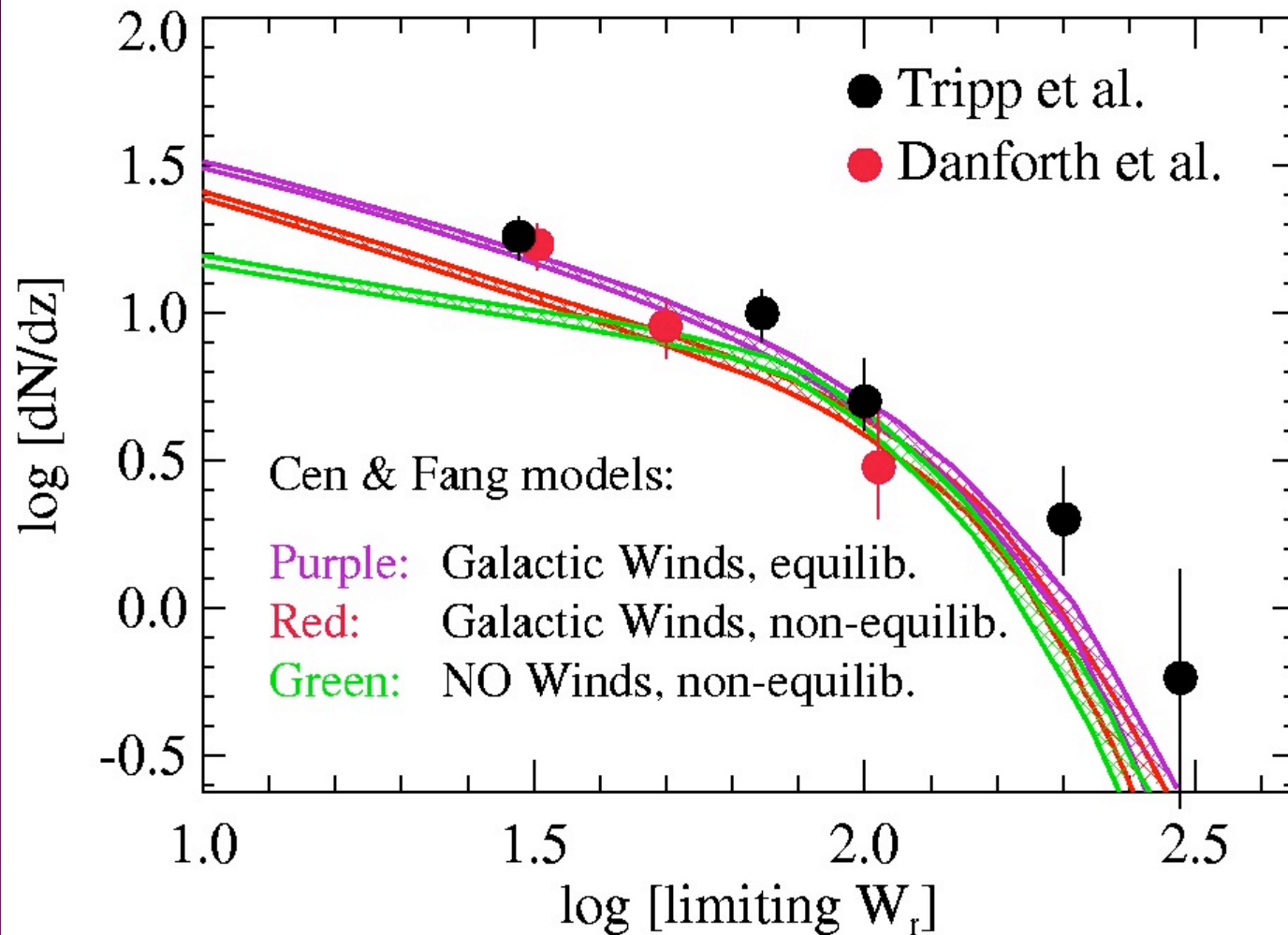
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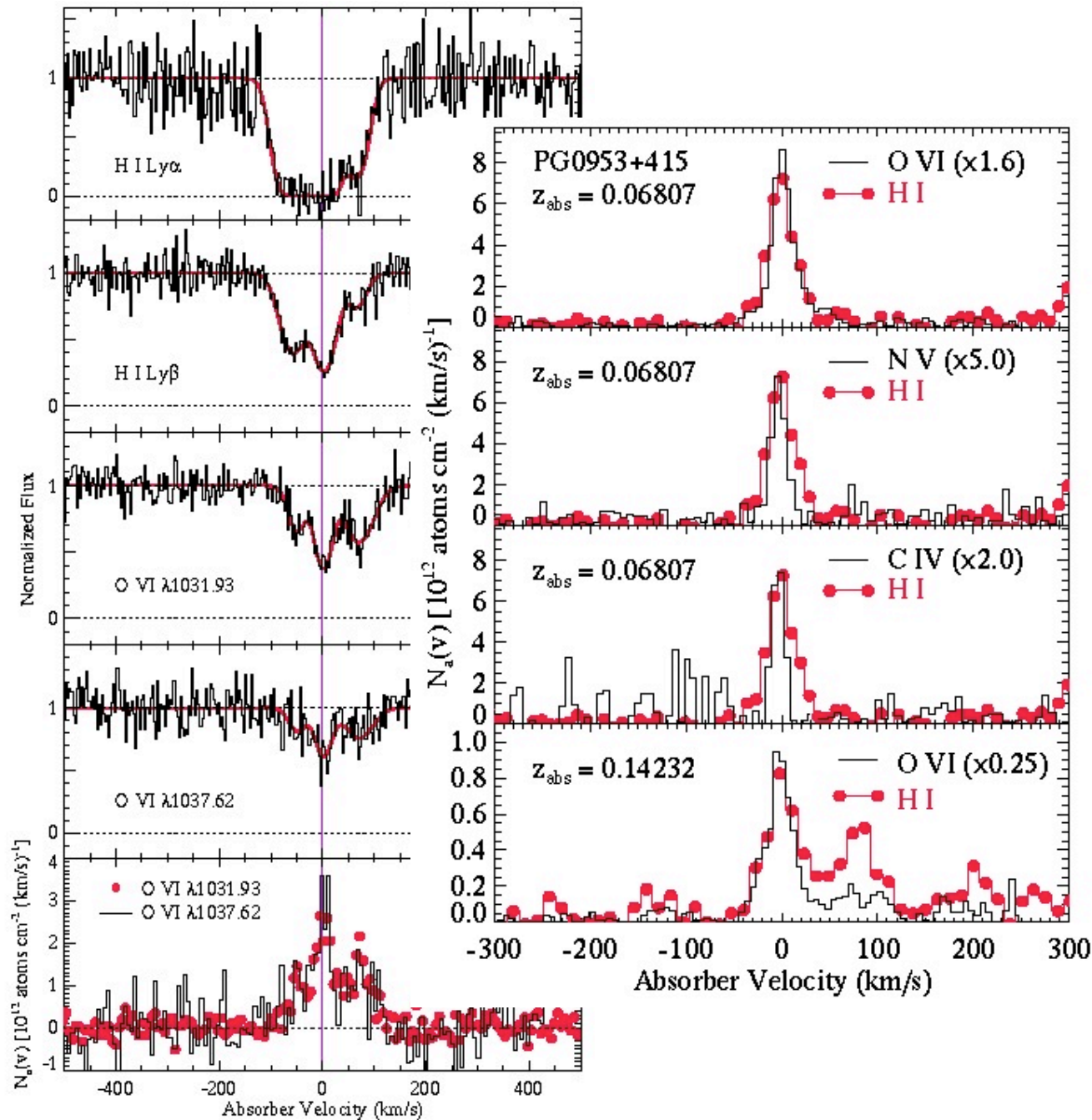
- Tripp et al. (2006): survey of extragalactic O VI absorbers in the spectra of 16 QSOs
- STIS echelle (E140M) and FUSE spectra
- 51 intervening O VI absorbers (excluding systems within 5000 km/s of the QSO redshift)
- Absorber redshifts range from 0.002 to 0.495
- Danforth et al. (2006): survey of lower-redshift QSOs/AGNs observed with FUSE

# Number of O VI Absorbers per Unit Redshift:



# Number of O VI Absorbers per Unit Redshift: Observations vs. Theory





Closest galaxy  
 is at a projected  
 distance of 999  
 kpc, and yet the  
 absorber has  
 a high metallicity:  
 $[M/H] = -0.3$

**How did such  
 highly enriched  
 (and quiescent)  
 gas end up in  
 this location?**

# Searching for the Missing Baryons with UV and X-ray Absorption

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## SUMMARY

- We're finding lots of extragalactic O VI absorbers
- $dN/dz$  statistics are consistent with predictions from hydrodynamic simulations
- MORE WORK (AND MORE DATA) ARE NEEDED.
- The detailed properties differ from naive expectations, and it is likely that these absorbers will provide a variety of insights about the role of the IGM in galaxy evolution