The Physical Properties of Low-z Ovi Absorbers in the OverWhelmingly Large Simulations

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Astroseminar
September 24, 2009
The Baryon Budget ($z \geq 2$)

**OBSERVATIONS:**

- e.g. Weinberg+97, Butler & Tytler 97, 98, Rauch+98
- $\sim 90\%$: Ly$\alpha$ Forest
- $\sim 10\%$: gravitationally bound structures (clusters, galaxies, etc.)

**SIMULATIONS:**

- e.g. Cen+94, Zhang+95, Miralda-Escudé+96, Hernquist+96
- $\sim 75 - 90\%$: diffuse component ("intergalactic gas")
- $\sim 10 - 25\%$: contained in other phases, mainly condensed gas ("stars" and "galaxies")

**Good News:**

Simulations in good agreement with observational results
The Baryon Budget \((z \approx 0)\)

- **OBSERVATIONS**
  - \(\sim 30\%\)
  - \(\sim 10\%\)
  - \(\sim 10\%\)
  - ?

- **SIMULATIONS**
  - \(\sim 40\%\)
  - \(\lesssim 20\%\)
  - WHIM

Legend:
- Green: Diffuse Gas
- Red: Hot Gas
- Blue: Stars
- Purple: "Condensed"
### Warm-Hot-Intergalactic Medium (WHIM)

#### Characteristics

- **Shock-heated intergalactic gas**
- **High temperatures:** \( T \approx 10^5 - 10^7 \) K
- **Low densities:** \( n_H \approx 10^{-6} - 10^{-5} \text{ cm}^{-3} \)
- **Highly-ionised plasma**
- \( \text{H}^{\text{II}}, \text{He}^{\text{II}}, \text{He}^{\text{III}}, \) and traces of highly-ionized O, Ne, C
- **Observationally Challenging:**
  - Diffuse, soft (< 0.25 keV) X-ray emission (\( \text{Davé+01} \))
  - Broad and shallow Ly\( \alpha \) absorption (BLAs; e.g. Richter+04)
  - X-ray / E(F)UV line absorption from highly-ionized O, Ne, C (e.g. Cen & Ostriker '99)
OVERALL RESULTS

- High incidence rate (relative to e.g. Mg\text{\textsc{ii}})
- Heavy metal content $\sim 10\%$ Solar
  $\rightarrow$ well reproduced by simulations
- Multi-phase systems (as traced by H\text{\textsc{i}} and O\text{\textsc{vi}})
- Significant baryon reservoirs ($\sim 0.1 \Omega_b$)

No general consensus about:

- O\text{\textsc{vi}} absorbers being tracers of WHIM
  
  e.g. Tripp+08, Thom & Chen 08, Oppenheimer & Davé 09 vs. Danforth & Shull 08, Cen & Fang 06

- Ionization state (photoionized, collisionally ionized, or both) of O\text{\textsc{vi}} bearing gas

  $\rightarrow$ Uncertainty in the baryon content of the gas traced by O\text{\textsc{vi}}
Cosmological SPH Simulations of Structure Formation:

- Initial conditions taken from WMAP3
- CDM, gas, stars, optically thin radiation
- Evolution of structure from $z = 127 \rightarrow z = 0$
- Self-consistently Computed:
  - Star Formation (Dalla Vecchia & Schaye 08, Schaye & Dalla Vecchia)
  - SNe Feedback (Galactic Winds) (Wiersma+09b)
  - Timed Release of Heavy Elements (Wiersma+09b)
  - Radiative Cooling including photoionization (Wiersma+09a)
  - AGN Feedback (Booth & Schaye 09)
Spectrum 32 short z0.403 o6 DEFAULT–L100N512 S/N= 50.000 region: 1 / 1  lines: 9 / 9

SpecWizard Spec Fit (modified AutoVP)

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Transmission
Restframe Velocity [km/s]

9 $N_{\text{O}_6}=10^{13.88} \pm 10^{12.62}$ $b=9.41 \pm 0.18$ $EW=57.41$ $z=0.4209$
8 $N_{\text{O}_6}=10^{14.00} \pm 10^{12.61}$ $b=17.17 \pm 0.24$ $EW=86.35$ $z=0.4209$
7 $N_{\text{O}_6}=10^{13.37} \pm 10^{12.78}$ $b=15.35 \pm 2.25$ $EW=26.04$ $z=0.4206$
6 $N_{\text{O}_6}=10^{13.43} \pm 10^{12.72}$ $b=7.42 \pm 0.47$ $EW=26.19$ $z=0.4205$
5 $N_{\text{O}_6}=10^{13.73} \pm 10^{11.95}$ $b=6.81 \pm 0.07$ $EW=41.15$ $z=0.4204$
4 $N_{\text{O}_6}=10^{13.74} \pm 10^{11.51}$ $b=5.90 \pm 0.04$ $EW=39.24$ $z=0.4203$
3 $N_{\text{O}_6}=10^{13.83} \pm 10^{11.86}$ $b=8.53 \pm 0.09$ $EW=51.63$ $z=0.4201$
2 $N_{\text{O}_6}=10^{13.94} \pm 10^{11.88}$ $b=7.96 \pm 0.09$ $EW=50.59$ $z=0.4200$
1 $N_{\text{O}_6}=10^{14.54} \pm 10^{11.85}$ $b=10.17 \pm 0.02$ $EW=107.95$ $z=0.4199$

SpecWizard Spec Fit (modified AutoVP)
MOST mass in LARGE volume

OVI traces tail at moderate densities
photoionized

shock-heated

Probability Distribution Function

Temperature [K]

OVI absorbers
mass weighted
OVI absorbers
mass–weighted

OVI is found in gas with \( \langle Z \rangle \sim 0.1Z_\odot \)
Cooling time contours adapted from Wiersma+08

\[ t_{\text{cool}} \equiv \frac{3}{2} \frac{k T}{n \Lambda} \]

\[ \begin{align*}
  t_{\text{cool}} &> t_{\text{Hubble}} \\
  t_{\text{cool}} &< t_{\text{Hubble}}
\end{align*} \]
Cooling time contours adapted from Wiersma+08

\[ t_{\text{cool}} \equiv \frac{3 k T}{2 n \Lambda} \]

Photoionization cannot be neglected
Stronger absorbers trace higher (over-)densities
→ observations might be biased towards lower temperatures
Summary

- **UNCERTAINTY** in the nature and physical properties of O\textsc{vi} bearing gas inferred from observations
  - Need for simulations

- **RESULTS:**
  - O\textsc{vi} traces gas in the low-temperature regime of the predicted WHIM phase, with a mean heavy-element content around 10% solar and overdensities in the range 10 - 100
  - Estimated average baryon content of 6.22 %, i.e.
    \[ \Omega_{\text{WHIM}}(O\textsc{vi}) \approx 0.062\Omega_b \]

- **DISAGREEMENT** between different studies of O\textsc{vi} absorbers using simulations
  - Need for more detailed analysis and more constraints from observations