What is a good phenomenological picture of the CGM?

Ballistic?
Cold material launched, propagates effectively in vacuum, governed by gravity.

Cool clouds in hot background?
Are they pressure confined?
How long do they survive?
Are they replenished?
How much recycles?

Turbulent?
Constant cycling between hot and cold?
What maintains the turbulence?
How much recycles?
Milky Way Hot Gas Halo

Most lines of sight out of MW show OVII and/or OVIII absorption, typical N = 2e16 cm\(^{-2}\).

Emission measure observations yield values of \(n_e^2 R = 0.0003 - 0.005\) cm\(^{-6}\) pc, modeled assuming solar metallicity, \(f_{\text{OVII}} = 0.5\).

For constant density, \(N = nR\),

\[
EM = n^2 R \left(\frac{Z}{Z_{\text{sun}}}\right) \left(\frac{f}{0.5}\right).
\]

Simultaneous solution yields

\[
R = 90 \kpc \left(\frac{N}{2e16}\right)^2 \left(\frac{EM}{0.003}\right)^{-1} f_{0.5}^{-1} Z_{1.0}^{-1} C
\]

\[
M = 1.5e10 M_{\odot} \left(\frac{N}{2e16}\right)^5 \left(\frac{EM}{0.003}\right)^{-2} f_{0.5}^{-3} Z_{1.0}^{-3} C^2
\]

where \(C > 1\) is clumping factor.

Note that upper limit on EM = lower limit on R, M.

Changing to constant density core with radius \(R_c = x_c R\) boosts implied mass by \(\sim x_c^{-2}\).
MgII from BOSS cross-correlations

Stacking of quasar spectra behind BOSS galaxies at $z \sim 0.5$ yields galaxy-MgII cross correlation with clear 1-halo term.

MgII present in $10^{13.5} M_{\text{sun}}$ halos, lower velocity dispersion than dark matter.

Consistent with $\Omega_{\text{MgII}} = 3 \times 10^{-9}$ in CGM, constant ratio of MgII mass to DM mass.
CGM/IGM dust from cross-correlation

Reproducing the Menard et al. reddening-galaxy cross-correlation in cosmological simulation with vzw winds requires $\frac{1}{4}$ of metal mass to be in dust (compared to $\frac{1}{2}$ in Milky Way ISM).

Half of the extinction arises > 100 $h^{-1}$ kpc from an $M_* > 5.5e10 M_{\text{sun}}$ galaxy.

Zu et al. 2011, modeling Menard, Scranton, Fukugita, & Richards 2010
COS-Halos, OVI and HI

OVI absorption ubiquitous around star-forming galaxies, $N > 2 \times 10^{14}$ cm$^{-2}$ to 150 kpc.
Often absent around passive galaxies.

Implied mass within 150 kpc:
\[ M_\text{O} = 1.2 \times 10^7 \, M_\text{sun} \left( f_{\text{OVI}} / 0.2 \right)^{-1} \]
\[ M_\text{gas} = 2 \times 10^9 \, M_\text{sun} \left( f_{\text{OVI}} / 0.2 \right)^{-1} \left( Z/Z_{\text{sun}} \right)^{-1} \]

HI absorption (typically $N > 1 \times 10^{15} - 1 \times 10^{16}$ cm$^{-2}$) is ubiquitous around star-forming galaxies, common around passive galaxies.

Line widths imply $T < 1 \times 10^5$ K.
COS-Halos, low-ionization metals

CLOUDY modeling of COS-halos low-ionization line data (CII, CIII, SiII, SiIII, MgI, MgII, H, …)

Mass of cool component ~ mass of stars + ISM

OVI not in equilibrium w/ low-ionization lines

Inferred $n_e$ not consistent (by factor 100) with pressure equilibrium in a hot gas halo.

**Survival model:**

$$M_{\text{cool}}(<r) = M_\ast \eta (\text{sSFR}) t_{\text{survive}}(<r)$$

Hard to have $M_{\text{cool}} \sim M_\ast$ if $t_{\text{survive}} \sim t_{\text{dyn}}(100 \text{ kpc})$

**Replenishment model:**

$$M_{\text{cool}}(<r) = M_{\text{hot}}(<r) t_{\text{cool-to-hot}} / t_{\text{hot-to-cool}}$$

Requires comparable timescales.

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