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HI and OVI Emission from the Circum-Galactic Medium with a large sample of cosmological hydrodynamical simulations

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ABSTRACT
We use the NIHAO galaxy formation simulations to study ultra-violet (UV) emission from circum-galactic medium (CGM) in galaxies ranging from dwarf ($M_{\rm halo} \sim 10^{10}{\rm M}_\odot$) to Milky Way ($M_{\rm halo} \sim 10^{12}{\rm M}_\odot$) masses. We analyze the spatially-extended structures of emission lines from OVI and HI.

Key words: galaxies: evolution – galaxies: formation – galaxies: dwarf – galaxies: spiral – methods: numerical – cosmology: theory

1 INTRODUCTION

A complete galaxy formation model does not only require the understanding of galactic components, such as stars and interstellar medium (ISM), but also the gaseous medium surrounded galaxies and extended to virial radius and beyond, the circumgalactic medium (CGM) namely. The galactic components dominate the energy output of the system, and always be focused by baryon counting (Bell et al. 2003). Compared to the cosmological baryonic fraction Ω_b/Ω_m, stars and ISM come up significantly short on baryons. If we include the hot X-ray halo gas (Baldry et al. 2008; Yang et al. 2009; McGaugh et al. 2010; Anderson & Bregman 2010; Gupta et al. 2012; Fang et al. 2013), the fracion is still under the prediction from the cosmic baryonic fraction.

Galaxies have possibility apparently to exhibit a diffuse baryonic content within CGM (**citation**) which is observed via UV absorption lines and has much lower temperature and density (Werk et al. 2013). Such CGM cannot be traced directly by X-ray emission or any other radiative emission process. The installation of the Cosmic Origins Spectrograph (COS) greatly increased the capability of UV spectroscopy on the Hubble space Telescope (HST) platform (e.g. Savage et al. 2010), enabling the use of fainter quasar targets illuminating foreground galactic haloes. COS-Halos (Tumlinson et al. 2011; Thom et al. 2012; Werk et al. 2012, 2013) has been working to investigate the properties of this elusive multiphase medium. One of COS-Halos results demonstrated CGM is a large reservior of baryons extanding far beyond the stellar disk of the galaxy. This significant reservoir of halo gas clearly plays a central role in the cycling of baryons into and our of a galaxy, regulating this growth.

HI is mainly from cold gas ($T \approx 10^4$K), and therefore provides an excellent route to detecting cold gas in CGM. In the other hand, most gas in CGM is in the warm or hot phase with temperature $T > 10^{4.5}$ K, either through photoionization, accretion shock or shock caused by galactic winds (van de Voort & Schaye 2012). Such dilute halo gas is at $T \sim 10^{4.5-7}$K, the detection is dominated by metal lines for Z>0.1 $Z_\odot$ (Wiersma et al. 2009a).

A number of large volume simulations (Ford et al. 2013, 2015; **?**; Oppenheimer et al, 2016) and zoom-in cosmological simulations (Stinson et al. 2012; Hummels et al. 2013; Shull 2014) have investigated the properties of CGM and the link between galaxies and their metal-enriched CGM. Ford et al. (2015) do not include Active Galactic Nucleus (AGN) and do not reproduce the OVI bimodality, while Suresh et al. (2015b) argue that AGN feedback can remove the CGM around passive galaxies then reduce the OVI column densities around passive galaxies. Gutcke et al. (2016) compared the column density profiles of OVI and HI in CGM of galaxies of the cosmologycal hydrodynamical simulation suite NIHAO (Wang et al. 2015) with observations, studied the covering fraction of dense HI, looked at the shape of the CGM and its chemical composition. The simulations have a good agreement with observations and show observers and modellers can compare with them in future studies.

Comparing with Absorption line measurement, in gen-

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eral, emission from gas outside of galaxies is to faint to detect. However, Absorption line measurements have several limitations. Firstly, suitable background sources are rare so that there is typically only one or no background sight line per foreground galaxy(**citation**). Because the area covered scales as the square of the impact parameter, the resulting measurements preferentially probe large impact parameters from foreground galaxies. Finally, because of the 1D nature of absorption line constraints it is often unclear what physical structure are probed. Intergral field measurement of emission lines are complementary to absorption line measurements. In particular, they allow us to directly obtain a 3D picture of the distribution of gas in the CGM by combining the 2D map of emission on the sky with line-of-sight velocity information.

The next generation of spectrographs should be able to detect certain metal lines, so that several cosmological hydrodynamical simulations have quantified the expected emission from the warm-hot IGM (Furlanetto et al. 2004; Bertone et al. 2010a,b; Takei et al. 2011; Bertone & Schaye 2012; Frank et al. 2012; Rocarelli et al. 2012). van de Voort & Schaye (2013) employed several large cosmological hydrodynamical simulations from the OverWhelmingly Large Simulations (Owls) project (Schaye et al. 2010) to explore the possibility to detect metal-line emission if the metallicity Z > 0.1 $Z_\odot$. They found, at given detection limit, the proposed X-ray telescope and future UV telescope can detect various metal lines depending on halo mass. Sravan et al. (2015) studied ultra-violet (UV) metal line emission from the CGM of high-redshift ($z = 2 - 4$) galaxies using cosmological simulations from the Feedback in Realistic Environments (FIRE) project. For each simulation, they predicted the emission from multiple metal lines including HI and OVI, and found more massive haloes are on average more UV-luminous and the UV metal line emission is primarily from collisionally ionized gas and strongly time variable. The high UV-luminous event correspond high star formation and CIII, SiIII, CIV and SiIV should be detectable by current and upcoming intergral field spectrographs such as the Multi Unit Spectroscopic Explorer (MUSE**citation**).

In this paper we investigate the CGM OVI and HI emissivity distribution and shape in Numerical Investigation of a Hundred Astrophysical Objects, NIHAO (Wang et al. 2015) project. NIHAO project produced nearly 100 hydrodynamical, cosmological zoom-in galaxies across a range in mass from

This paper is organized as follows: The cosmological hydrodynamical simulations and the methodology for computing metal line emission are briefly described in §2; In §3 we present the results including the HI and OVI emission map, surface brightness and luminosity evolutions of all galaxies in NIHAO sample; §4 gives discussion and summary of our results.

2 METHODOLOGY

2.1 Simulations

The simulations studied in this work are from the NIHAO project (Wang et al. 2015). The halos to be re-simulated with baryons have been extracted from 3 different pure N-body simulations with a box size of 60, 20 and 15 h^{-1} Mpc respectivelyDutton & Macciò (2014). All halos across the whole mass range with typically a million dark matter particles inside the virial radius of the target halo at redshift $z = 0$. We adopted the latest compilation of cosmological parameters from the Planck satellite (the Planck Collaboration et al. 2014).

We use the SPH hydrodynamics code GASOLINE (Wadsley et al. 2004), with a revised treatment of hydrodynamics as described in Keller et al. (2014). The code includes a subgrid model for turbulent mixing of metal and energy (Wadsley et al. 2008), heating and cooling include photoelectric heating of dust grains, ultraviolet (UV) heating and ionization and cooling due to hydrogen, helium and metals (Shen et al. 2010). The star formation and feedback modeling follows what was used in the MaGICC simulations (Stinson et al. 2013). There are two small changes in NIHAO simulations: The change in number of neighbors and the new combination of softening length and particle mass means the threshold for star formation increased from 9.3 to 10.3 cm^{-3}, the increase of pre-SN feedback efficiency ϵ_{ESF}, from 0.1 to 0.13. The more detail on star formation and feedback modeling can be found in Wang et al. (2015).

2.2 Emissivity Calculation

We first assign the hydrogen number densities and temperatures of all gas particles inside $2R_{\mathrm{vir}}$ to $200\times200\times200$ grids according SPH spline kernel (Monaghan & Lattanzio 1985):

$$W(r,h) = \frac{8}{\pi h^3}\begin{cases} 1-6\left(\frac{r}{h}\right)^2+6\left(\frac{r}{h}\right)^3, & 0\leqslant\frac{r}{h}\leqslant\frac{1}{2},\\ 2\left(1-\frac{r}{h}\right)^3, & \frac{1}{2}<\frac{r}{h}\leqslant 1,\\ 0, & \frac{r}{h}>1.\end{cases} \quad (1)$$

The distribution of emissivities are then computed as a function of gas temperature and hydroden number density on each grid by bi-linearly interplating the grids of emissivities generated using CLOUDY (**version and citation**). The temperature of the grids are in the range $?? < T <??$K in intervals of $\Delta\log_{10} T = ?.??$ and hydrogen number densities are in the range $?? < n_H < ??\mathrm{cm}^{-3}$ in intervals of $\Delta\log_{10} n_H = ??$. The grids are computed at redshift z = 0 assuming gas is of solar metallicity, optical thin and **blabla**.

To compute the HI neutral fraction, like (Gutcke et al. 2016), we used the self-shielding approximation presented in (Rahmati et al. 2013). **say more detail about it**. Contrastly, To compute the OVI, the self-shielding approximation is not necessary to consider. **reason**

2.3 Luminosity Calculation

In order to estimate the evolution of total OVI and HI luminosities inside $2R_{\mathrm{vir}}$, we employ the grids of emissivities computed since z=4 to present to evaluate the evolution of luminosities of all galaxies in NIHAO sample from particle data directly. The method is similar to the one used by (Sravan et al. 2015), the OVI and HI luminosities of each gas particle are calculated as

$$L = \epsilon_\odot\left(z, n_H, T\right)\left(\frac{m_{gas}}{\rho_{gas}}\right)\left(\frac{Z_{gas}}{Z_\odot}\right), \quad (2)$$

where m_{gas}, ρ_{gas} and Z_{gas} are the mass, density and metallicity of the gas particle, and $\epsilon_\odot\left(z, n_H, T\right)$ is the emissivity interpolated bi-linearly from pre-computed grids of emissivities with given redshift, hydrogen number density and temperature.

3 RESULTS

3.1 OVI and HI Emissivity Maps and Radial Profile

3.2 Evolution of Luminosities

4 SUMMARY

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