Gas in the Local Group in the HESTIA simulations

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Introduction

The **HESTIA** (High-resolution Environmental Simulations of the Immediate Area) suite of constrained cosmological simulations are a set of intermediate and high-resolution simulations of the Local Group (LG) at $z = 0$ and are a part of the (larger) CLUES Collaboration (Constrained Local UniversE Simulations) collaboration.

This study consists of ***three high-resolution realizations*** of the Local Group, each of which comprises of a pair of Milky Way (MW)- Andromeda (M31) analogue along with a host of satellite galaxies, all of whose positions and kinematics are unique owing to their distinct parent initial conditions. Diffuse gas (more commonly referred to as the ***Circumgalactic medium*** or CGM) is seen extensively even at super-virial radial distances in all the runs.

One can crudely define two distinct regimes within a CGM-

- cold, dense gas (mainly characterized by photo-ionization process); traced by low-ionization state ions like H I, O I, Si II, Si III, etc.
- hot, diffuse gas (characterized by collisional ionization process); traced by high-ionization state ions like O VI, O VII, O VIII, Mg X, etc.

Ionization modeling helps break down, to a large extent, the internal structure of the CGM.

Our place in the MW gives us, as observers, a very special vantage point from which we can make detailed observations of our Local Group. Yet our knowledge about the CGM of our own Local Group constituents remains far from being complete.

The HESTIA simulations recreate, to a fair extent, both the ***local large*** as well as ***small scale cosmography*** of our observed Local Group. Hence, the mock observations of the CGMs of MW-M31 are likely to shed some light on the statistical properties of the CGMs of MW-like galaxies at $z = 0$.

Motivation

We aim to study the CGM of MW-M31 analogue systems in three of the highest-resolution Local Group realizations in the HESTIA suite of constrained simulations.

CLOUDY, a photoionization code, is used for the purpose of generating mock observations for an ensemble of ions tracing the cold (**H I & Si III**; *hereafter, Low ions*) and hot (**O VI, O VII and O VIII**; *hereafter, High ions*) CGM. With this setup we intend to delve deeper into the small scale structure of the CGM and tease out some of its statistical properties in order to make predictions for future observational surveys.

Simulation features

LG Simulations	DM particles	DM and Gas cell resolution	DM Softening length	Redshift
17-11 09-18 37-11	8192^3	$M_{\rm dm} = 1.5 \times 10^5 {\rm M}_\odot$ $M_{\rm gas} = 2.2 \times 10^4 {\rm M}_\odot$	220 pc	$z = 0$

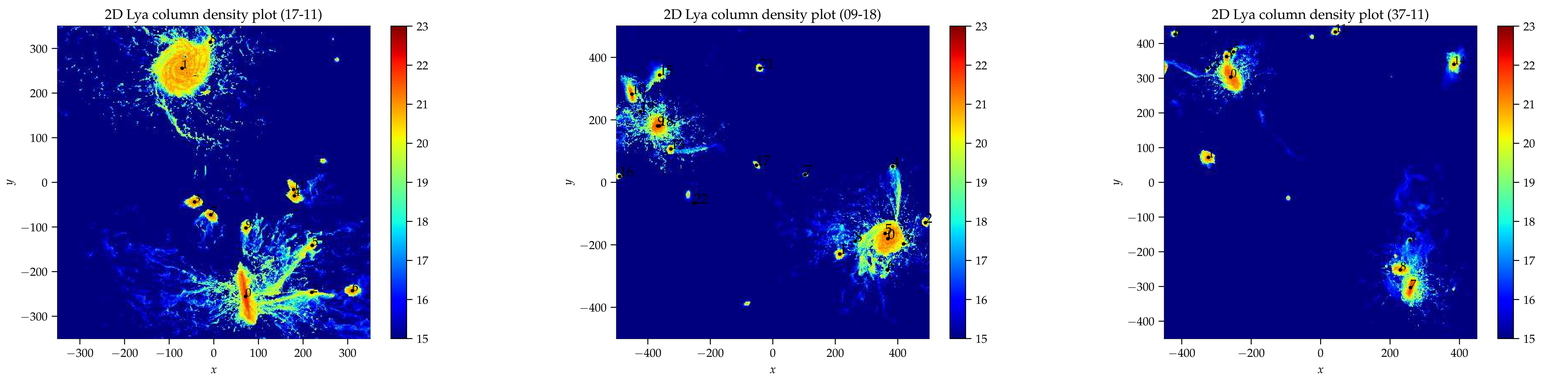
Methods

Parameters \ Realization	17–11		09–18		37–11	
	MW	M31	MW	M31	MW	M31
Distance (kpc)	327.09	327.09	419.21	419.21	411.56	411.56
log $M_\star$ ($M_\odot$)	11.05	11.06	10.89	11.10	10.76	10.71
log $M_{\rm dm}$ ($M_\odot$)	12.17	12.30	12.14	12.26	11.94	11.94
log $M_{\rm gas}$ ($M_\odot$)	10.90	11.20	11.06	11.18	10.75	10.86
$R_{\rm vir}$ (kpc)	255.35	269.33	254.57	262.40	205.34	206.80

Table 1: Relevant parameters for the three HESTIA realizations at $z = 0$

Ions \ Parameters	Wavelength (Å)	Ioniz. energy (eV)	log T (K)	log $n_{\rm H}$ (cm^{-3})
H I	1216	10.19	4.0-4.5	~2.0
Si III	1206	10.28	<5.0	~2.0
O VI	1031	113.896	5.5	-4.5
O VII	21	739.29	5.9	-5.0
O VIII	18.96	871.410	6.4	-5.5

Table 2: Relevant parameters for the ions considered



L-R: 2D projection maps in XY plane for log H I column density for 17-11, 09-18 and 37-11. Each constituent within the corresponding realization is marked by its subhalo number.

Setup

1. We use the *healpy* python package, in conjunction with ***Cloudy*** ionization modeling to generate Mollweide projection maps for the ions in consideration.
2. Keeping the midpoint of MW-M31 as our frame of reference, we define 20,000 sightlines, each 700.0 kpc in length, spread out across the Mollweide map.
3. Ion column densities as a function of impact parameter, H I covering fraction profiles, Power spectra and 3D density profiles for the ions are plotted.

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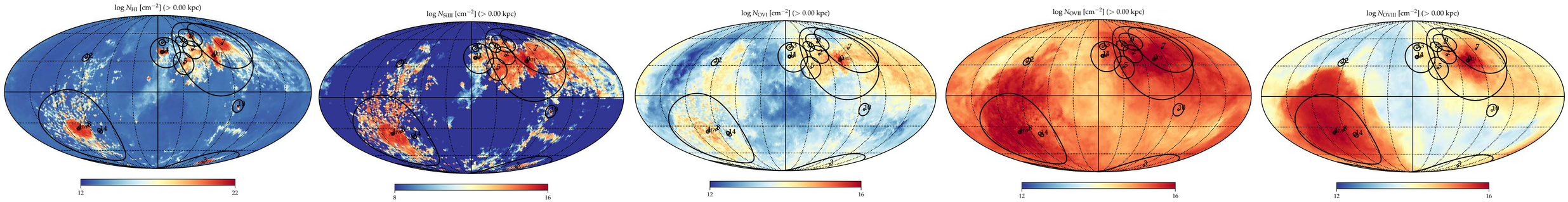
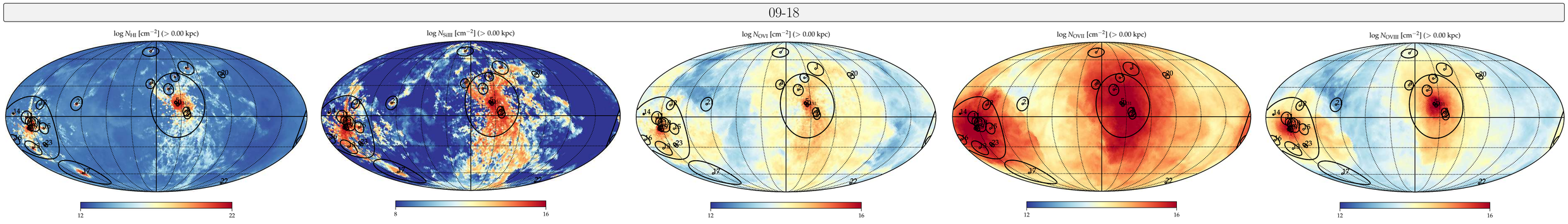
Results

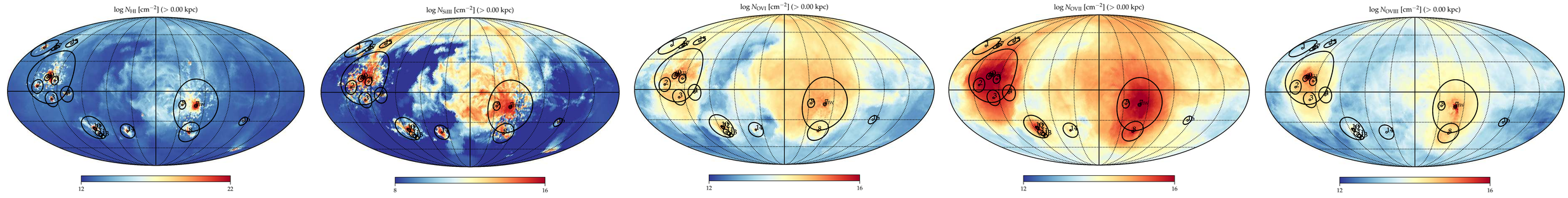
17-11



09-18



37-11



L-R: Mollweide column density projection maps for H I, Si III, O VI, O VII and O VIII for 17-11 (*Top panel*: MW is in third quadrant; M31 is in first quadrant), 09-18 (*Middle panel*: MW is in third quadrant; M31 is in first quadrant) and 37-11 (*Bottom panel*: MW is in fourth quadrant; M31 is in second quadrant). In each case, the line-of-sight passes through the center of the maps. Black circles represent respective $R_{\rm vir}$ for MW-M31 and surrounding satellites. Numbers in each plot denote the subhalo number, corresponding to each component in the MW-M31-Satellites ecosystem, unique to each of the three realizations. Colorbar denotes the respective range of logarithmic ion column densities.

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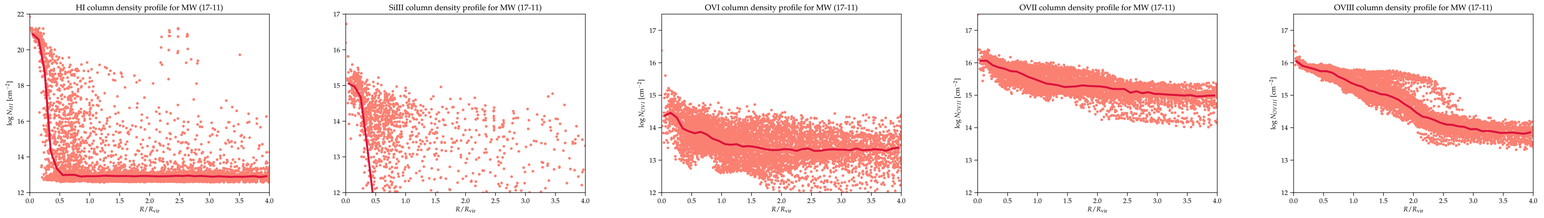
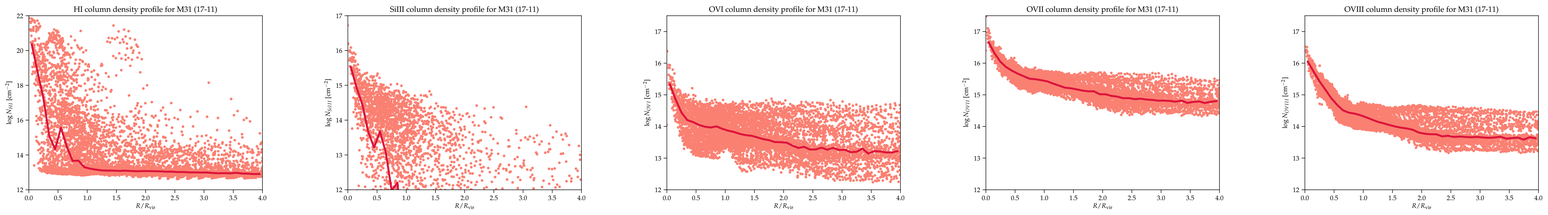
Results

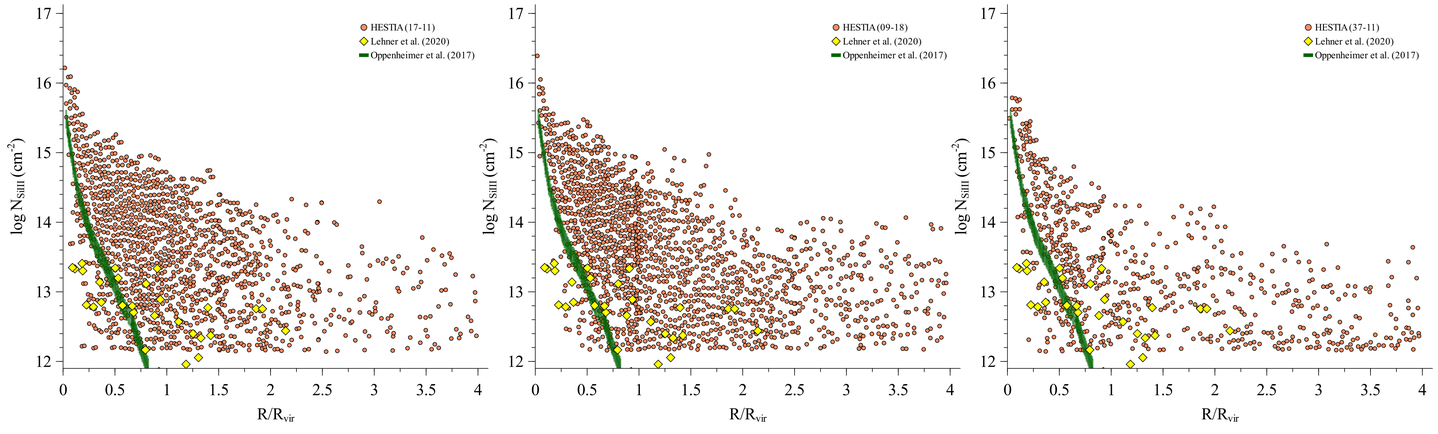
17-11 (MW)



17-11 (M31)



L-R: 2D Column density profiles (*Top panel*: MW; *Bottom panel*: M31) as a function of R/R_{vir} for H I, Si III, O VI, O VII and O VIII ions for the 17-11 realization. Solid colored lines denote respective median values.



Comparison of Si III column density profile results for M31 from HESTIA (Red circles) for our three realizations to that from EAGLE simulations (Oppenheimer et al. 2017; Green curve) and the observational survey Project AMIGA (Lehner et al. 2020; Yellow diamond markers).

Conclusions

- Numerous cold and cool-ionized gas clumps and streams (as traced by the Low ions) are seen across all the three realizations; in many cases extending well beyond the MW-M31 R_{vir}.
- As we move from the cold to the hot gas, we see that the gas increasingly becomes a monotonic function of radius near MW and M31.
- Low ions show a significantly larger column density dispersion as compared to High ions.
- Many of the satellite galaxy CGMs show significant stripping and distortion features. The presence of numerous satellite galaxies and other gaseous features is reflected in the column density profiles as well.
- We find the M31 column density profile results from HESTIA match rather well with those obtained from the EAGLE simulations.
  However, these results are about a factor of two higher than the corresponding results from the Project AMIGA survey.

Acknowledgements

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Faces to the names

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More details and updates about my work here– https://www.researchgate.net/profile/Mitali_Damle and my LinkedIn Profile