

Properties of Galaxies in Cosmic Filaments around the Virgo Cluster

YOUNGDAE LEE,¹ SUK KIM,¹ SOO-CHANG REY,¹ AND JIWON CHUNG²

¹*Department of Astronomy and Space Science, Chungnam National University, Daejeon 34134, Republic of Korea*

²*Korea Astronomy and Space Science Institute 776, Daedeokdae-ro, Yuseong-gu, Daejeon 34055, Republic of Korea*

ABSTRACT

We present the properties of galaxies in filaments around the Virgo cluster with respect to their vertical distance from the filament spine using the NASA-Sloan Atlas catalog. The filaments are mainly composed of low-mass, blue dwarf galaxies. We observe that the $g-r$ color of galaxies becomes blue and stellar mass decreases with increasing vertical filament distance. The galaxies were divided into higher-mass ($\log h^2 M_*/M_\odot > 8$) and lower-mass ($\log h^2 M_*/M_\odot \leq 8$) subsamples. We also examine the $g-r$ color, stellar mass, $H\alpha$ equivalent width ($\text{EW}(H\alpha)$), near-ultraviolet (NUV)– r color, and HI fraction distributions of the two subsamples against the vertical distance. The lower-mass galaxies exhibit a negative $g-r$ color gradient, whereas higher-mass galaxies have a flat $g-r$ color distribution. We observe a negative $\text{EW}(H\alpha)$ gradient for higher-mass galaxies, whereas lower-mass galaxies show no distinct $\text{EW}(H\alpha)$ variation. In contrast, the $NUV-r$ color distribution of higher-mass galaxies shows no strong trend, whereas the lower-mass galaxies show a negative $NUV-r$ color gradient. We do not witness clear gradients of HI fraction in either the higher- or lower-mass subsamples. We propose that the negative color and stellar mass gradients of galaxies can be explained by mass assembly from past galaxy mergers at different vertical filament distances. In addition, galaxy interactions might be responsible for the contrasting features of $\text{EW}(H\alpha)$ and $NUV-r$ color distributions between the higher- and lower-mass subsamples. The HI fraction distributions of the two subsamples suggest that ram-pressure stripping and gas accretion could be ignorable processes in the Virgo filaments.

Keywords: galaxies: dwarf — galaxies: evolution — galaxies: interactions — cosmology: large-scale structure of universe

1. INTRODUCTION

In the frame of the hierarchical structure formation in the standard cold dark matter universe, the build-up of galaxy clusters is characterized by the accretion of galaxies into higher-density cluster environments through fil-

aments that control the transitioning of galaxies in less-dense environments to cluster galaxies.

Recently, the specific role of pre-processing in filaments has been extensively explored in different surveys. In particular, there is a growing body of observational evidence indicating that the properties of

Предлагавшиеся физические механизмы, действующие на галактику в филаментах:

Tidal interactions в филаментах

Gas stripping на периферии скоплений

Аккреция газа в филаментах (есть в числ.экспериментах)

Имеющиеся данные относятся в основном лишь к массивным галактикам, а не к карликам, хотя последних больше.

Подходящий для этого материал – Virgo filaments (Kim et al., 2016, 7 филаментов).

В работе анализировались свойства галактик и измерялись их 3D расстояния до оси для 6 из 7 филаментов.

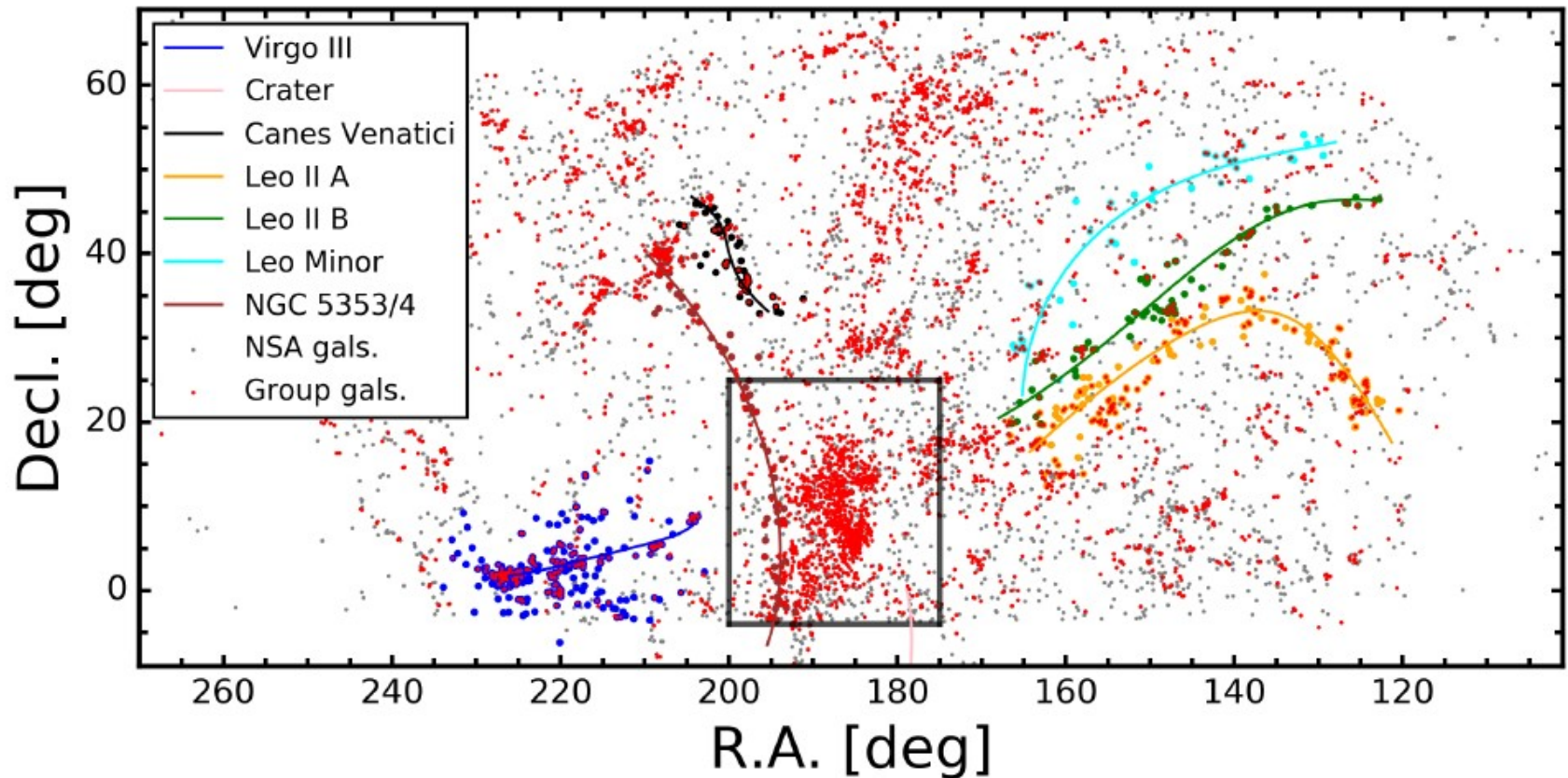
Филаменты в окрестностях скоплений

are ideal places for the investigation of the physical processes that control the transitioning of galaxies in less dense environments to cluster galaxies.

Что известно:

Galaxies close to filaments show a tendency to have redder colors, lower H α emission-line equivalent width (EW(H α)), and higher early- to late-type galaxy fraction, indicating that the efficiency of star-formation quenching varies with distance from filaments.

- Составляется каталог групп (friends-of-friends for group detection), чтоб исключить эти галактики из рассмотрения



красные точки – галактики в группах, серые точки – все галактики с $z < 0.014$

Figure 1. Spatial distribution of galaxies around the Virgo filaments in the equatorial coordinate system. Colored curves are spines of seven filaments identified by Kim et al. (2016) and colored circles are selected member galaxies that belong to the filaments. NSA galaxies at $z < 0.014$ and group galaxies are denoted as gray dots and red circles, respectively. The large rectangular box is the region of the Virgo cluster covered by the Extended Virgo Cluster Catalog (EVCC, Kim et al. 2014). In our study, we only consider galaxies that do not belong to galaxy groups (colored circles without red dots).

Ход плотности аппроксимировался

$$\rho_{\text{gal}} = \rho_0 \exp(-D_{\text{ver}}/R_s) \text{ в пределах } 3.5 R_s$$

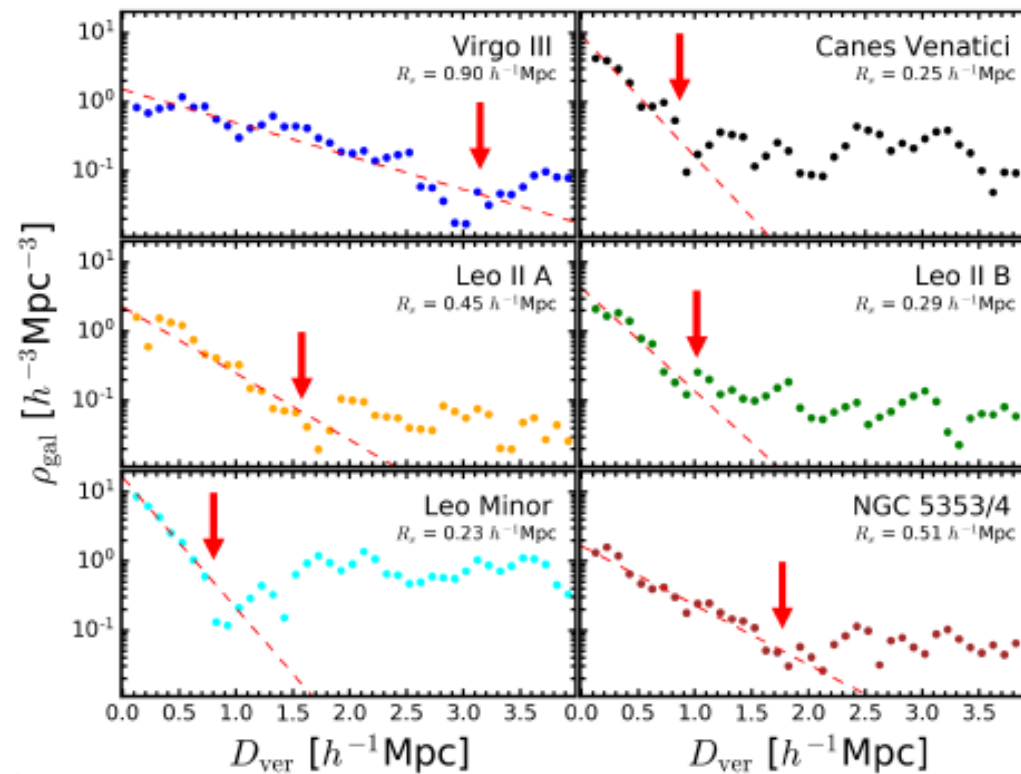


Figure 2. Galaxy number density profiles of six filaments as a function of the vertical distance from the filament spine (D_{ver}). Circles are observed number densities at different D_{ver} and dashed lines denote the best-fit exponential models.

- Всего рассмотрено 289 г-к на расстояниях 14 – 41 Мпс , 88% из

Н

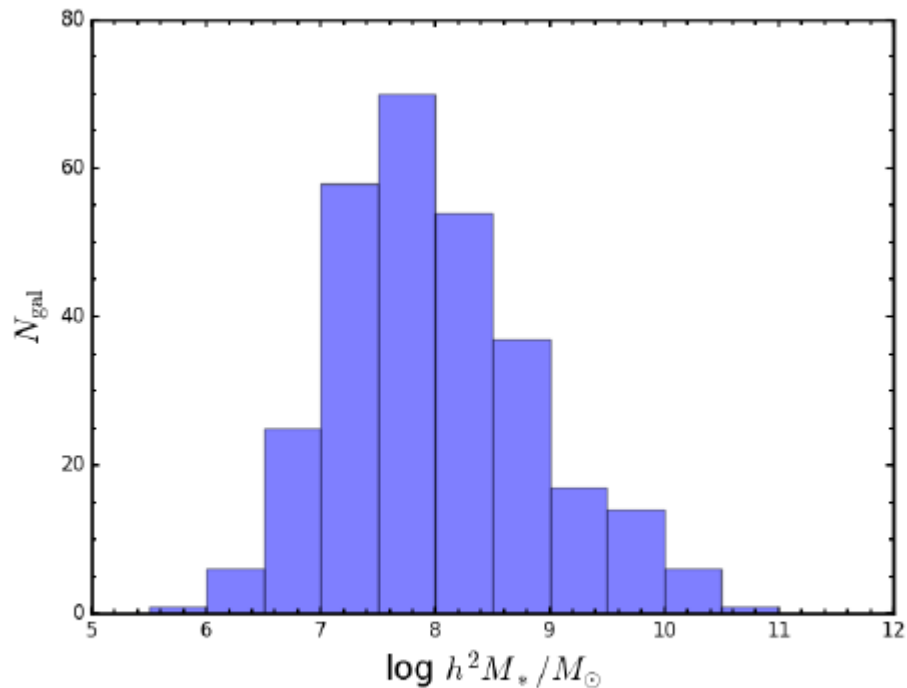


Figure 3. Stellar mass distribution of member galaxies in filaments.

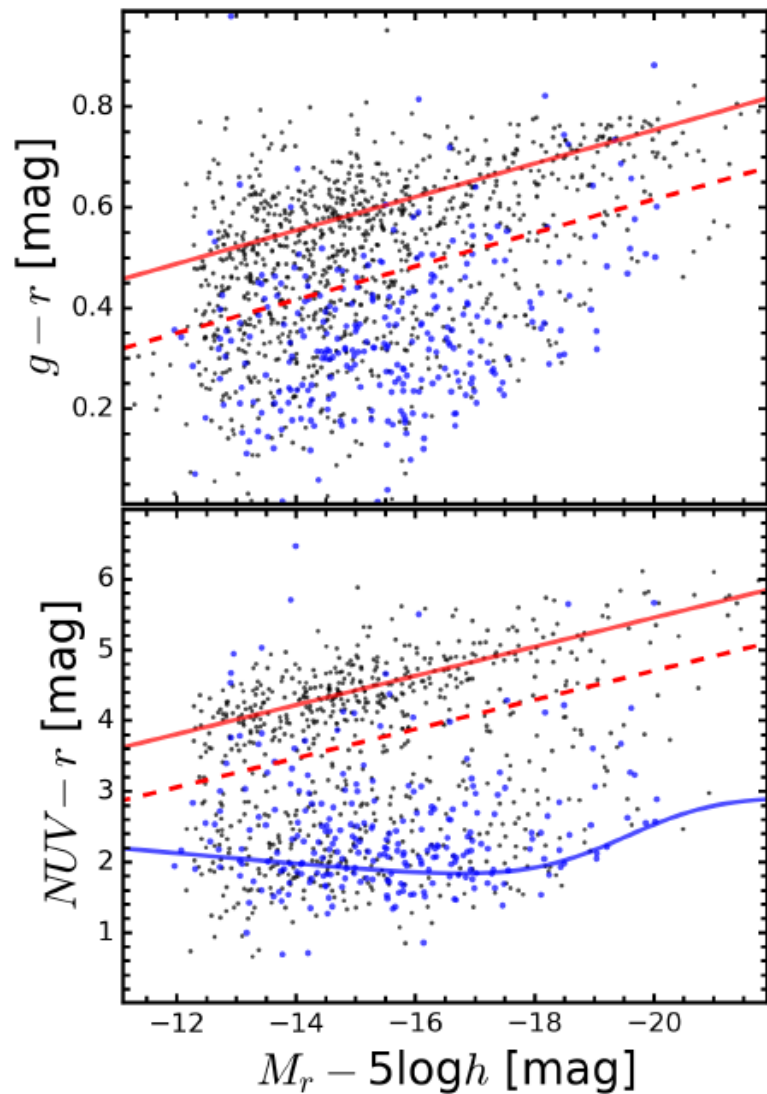


Figure 4. $g - r$ (top) and $NUV - r$ (bottom) color-magnitude diagrams of galaxies in filaments (blue circles). For comparison, galaxies in the Virgo cluster are also over-plotted (black dots). The red solid lines represent the red sequence of the Virgo cluster and the red dashed lines are -3σ deviation from the red sequence. In the $NUV - r$ CMD, the blue curve indicates the blue cloud defined by Wyder et al. (2007).

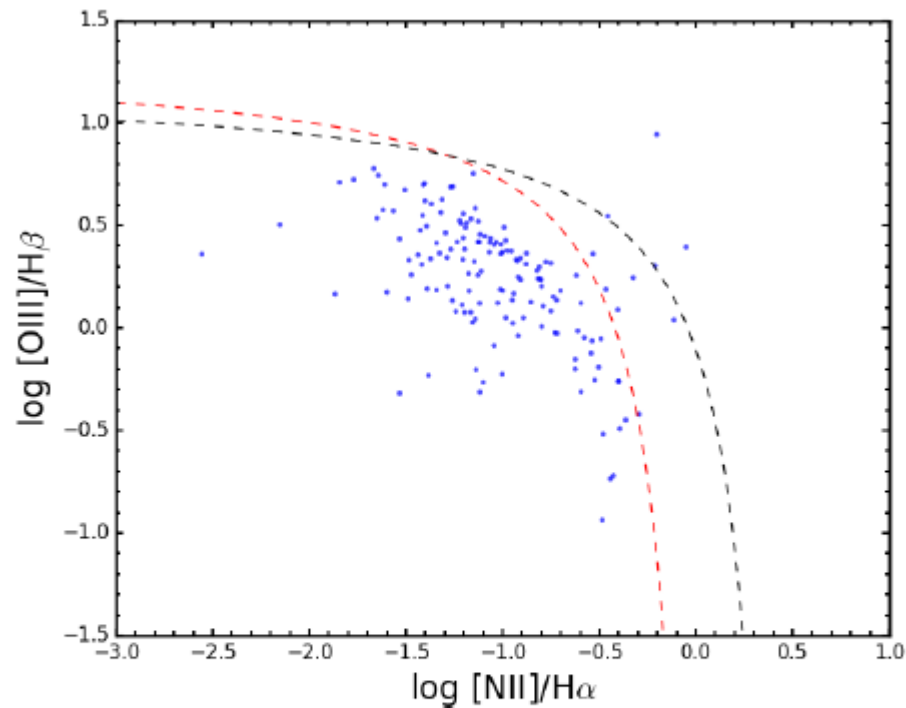


Figure 7. BPT diagram of filament galaxies. Star-forming galaxies are defined as those below the red curve of Kauffmann et al. (2003). AGNs are those above the black curve of Kewley et al. (2001).

Без разделения по массам получается как в предшествующих работах (Mahajan et al. 2018; Luber et al. 2019; Sarron et al. 2019);
 Оказалось, что только для маломассивных есть зависимость интегрального цвета от D_{ver}

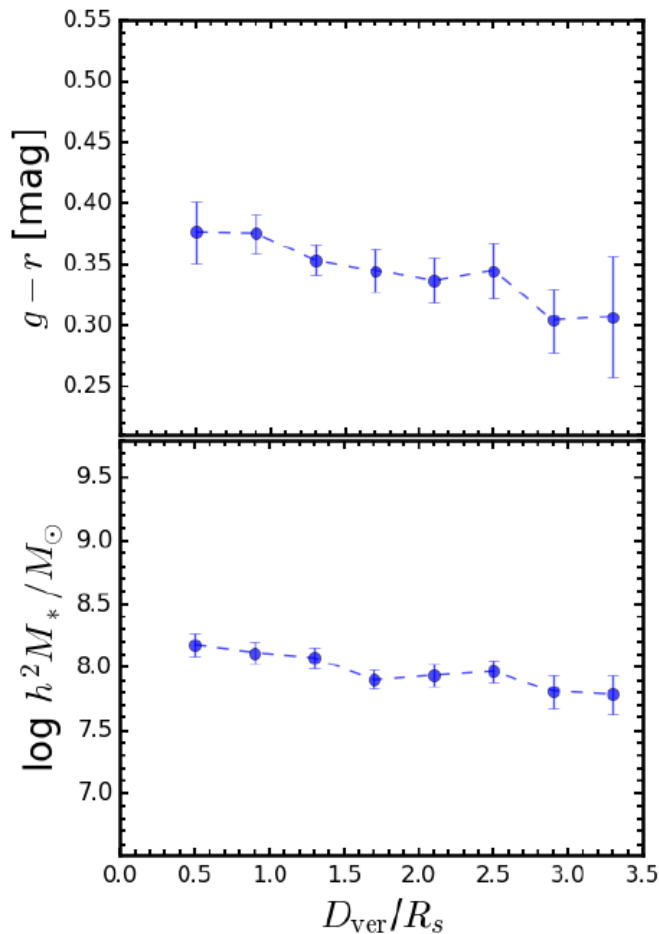


Figure 5. $g-r$ color (top) and stellar mass (bottom) versus scaled vertical distance from the filament spine (D_{ver}/R_s). The error bar of each bin indicates bootstrap resampling uncertainty.

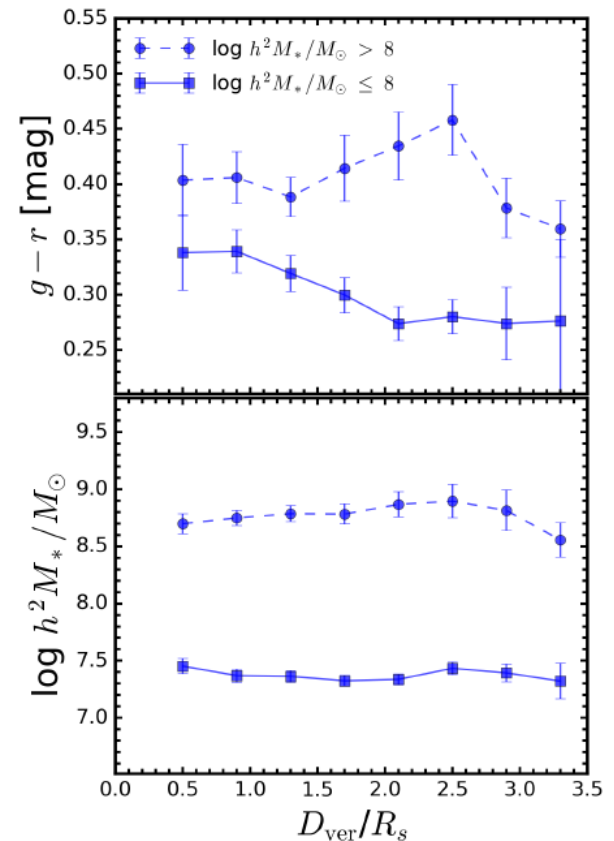


Figure 6. $g-r$ color (top) and stellar mass (bottom) versus scaled vertical distance from the filament spine (D_{ver}/R_s) for galaxies in different mass ranges. The circles and dashed lines represent higher-mass ($\log h^2 M_* / M_\odot > 8$) galaxies and the squares and solid lines are lower-mass ($\log h^2 M_* / M_\odot \leq 8$) galaxies. The error bar of each bin indicates bootstrap resampling uncertainty.

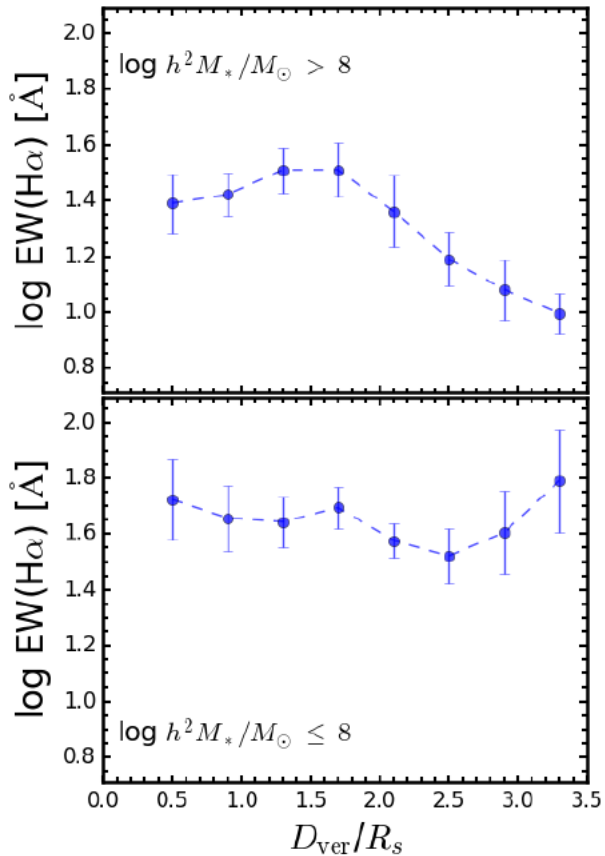


Figure 8. Equivalent width of H α emission line (EW(H α)) versus scaled vertical distance (D_{ver}/R_s) from the filament spine of higher-mass ($\log h^2 M_*/M_\odot > 8$) galaxies (top) and lower-mass ($\log h^2 M_*/M_\odot \leq 8$) galaxies (bottom). The error bar of each bin indicates bootstrap resampling uncertainty.

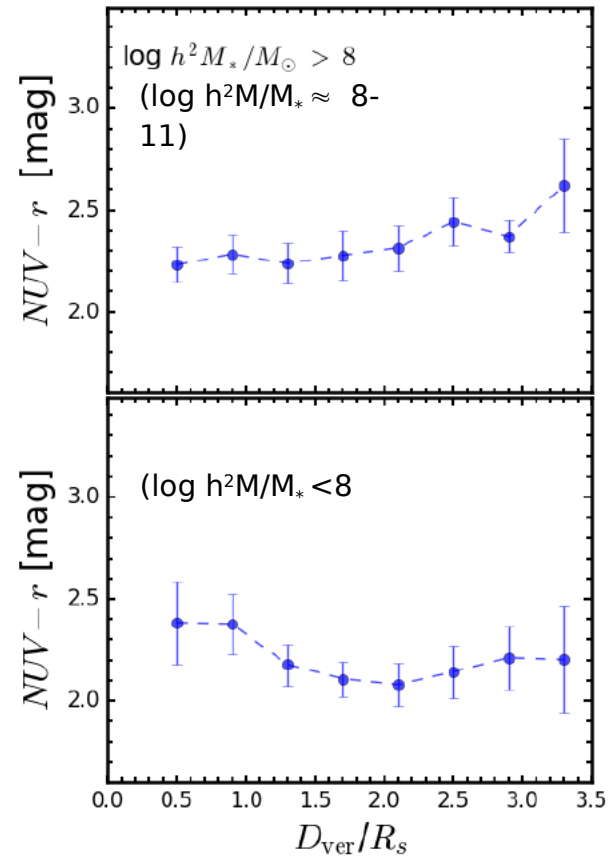
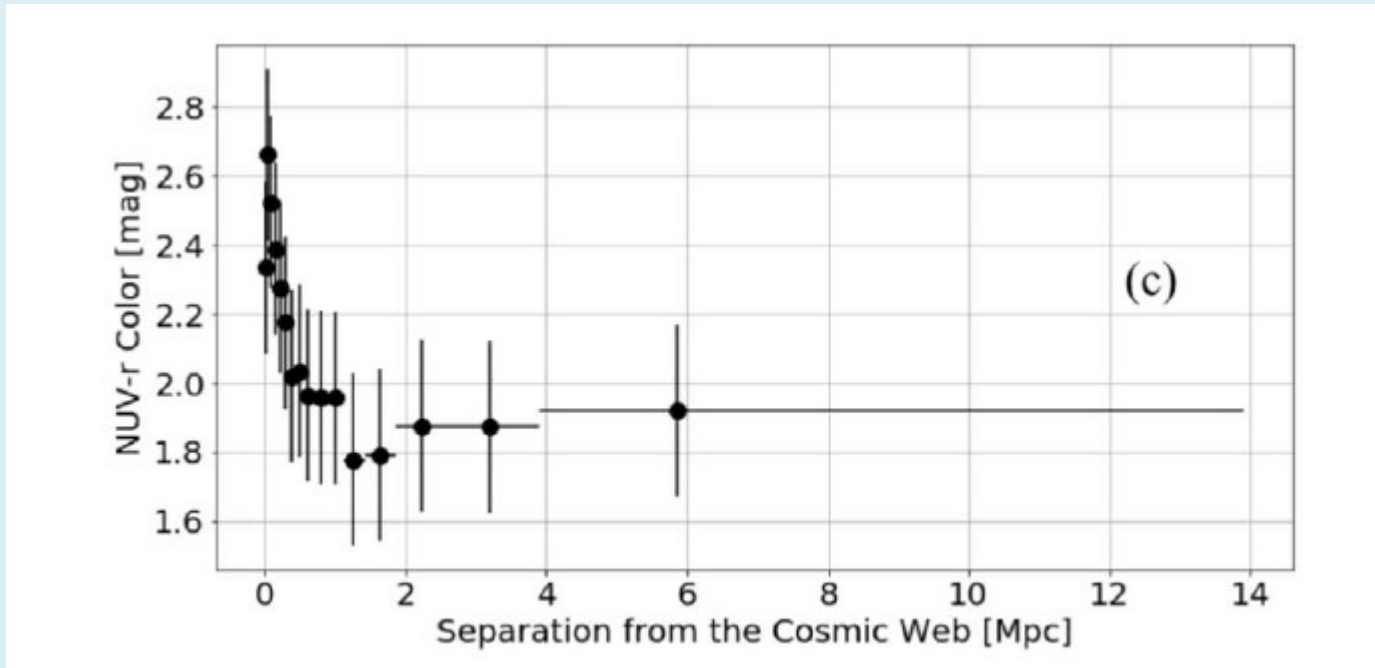


Figure 9. $NUV - r$ color versus scaled vertical distance (D_{ver}/R_s) from the filament spine of higher-mass ($\log h^2 M_*/M_\odot > 8$) galaxies (top) and lower-mass ($\log h^2 M_*/M_\odot \leq 8$) galaxies (bottom). The error bar of each bin indicates bootstrap resampling uncertainty.

массивных галактик – более молодое зв. население дальше от оси филамента. У массивных – все как ожидается.

А вот так это выглядит для массивных галактик в далеких филаментах по Luber et al 2019 ($z=0.1-0.45$)



- HI- по ALFALFA (127 г-к)
- Зависимость – только для более массивных галактик, но статистически не очень достоверно

$$f_{\text{HI}} = \log \frac{M_{\text{HI}}}{M_*}$$

Этот параметр чувствителен к “cosmic-web stripping” при пресечении филамента. Но этого эффекта здесь нет! (низкая плотность газа в филаментах Virgo?)
 Эффекты аккреции, ожидаемые по численным экспериментам, здесь тоже не заметны.

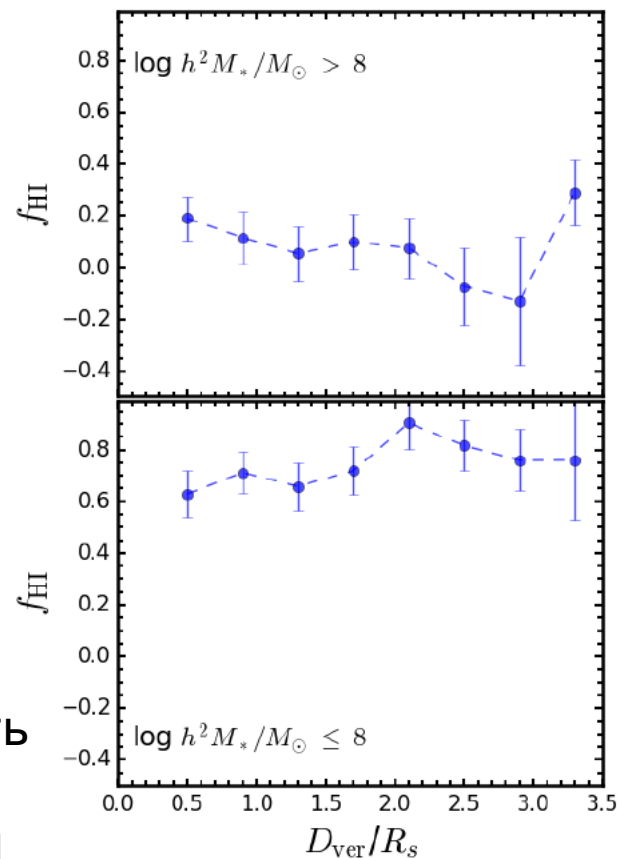
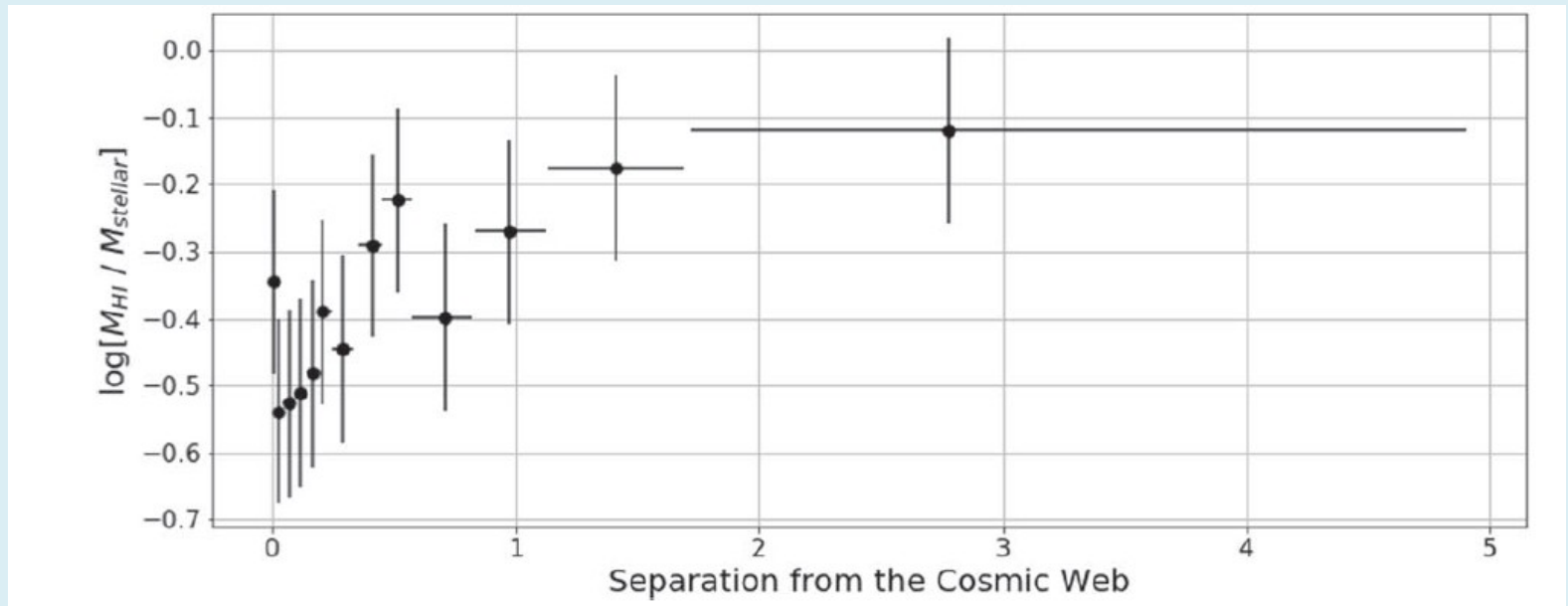


Figure 11. HI gas fraction (f_{HI}) versus scaled vertical distance (D_{ver}/R_s) from the filament spine of higher-mass ($\log h^2 M_*/M_\odot > 8$) galaxies (top) and lower-mass ($\log h^2 M_*/M_\odot \leq 8$) galaxies (bottom). The error bar of each bin indicates bootstrap resampling uncertainty.

А вот так это выглядит для массивных галактик в далеких филаментах по Luber et al 2019 ($z=0.1-0.45$)
Где же тут аккреция?



- (но здесь все галактики бедны газом!)

ОСНОВНЫЕ ВЫВОДЫ

- In g-r and NUV-r , галактики демонстрируют a blueward offset from the red sequence of the Virgo cluster and are dominantly located on the blue cloud.
- Если не разделять на массы, то color becomes blue and stellar mass decreases with increasing vertical filament distance – вероятно, из-за разной эффективности слияния при сборке галактик.
- При разделении галактик на массы получается иная картина. Различие в распределении EW($H\alpha$) и NUV -r, по-видимому, отражает различную эффективность процессов звездообразования при приливных взаимодействиях.
- Both higher- and lower-mass galaxies show no statistically significant variations in HI fractions with the vertical filament distance. This indicates that possible mechanisms related to intra-filament medium, such as ram-pressure stripping and gas accretion, could be ignorable for galaxies in the Virgo filaments.

P.S. Остается взаимодействие и слияние галактик как основной механизм различий.

Мой комментарий. По сравнению с данными Luber et al 19 различие в результатах связаны, по-видимому, в первую очередь, не с другими массами галактик, а с тем, что рассмотренные здесь галактики более богаты газом. У Luber et al, 2019 галактики в основном красные, потерявшие газ (E-S0?). Более мощные филаменты?