# SURVIVAL OF PURE DISK GALAXIES OVER THE LAST 8 BILLION YEARS

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## ABSTRACT

Pure disk galaxies without any bulge component, i.e., neither classical nor pseudo, seem to have escaped the affects of merger activity inherent to hierarchical galaxy formation models as well as strong internal secular evolution.

We discover that a significant fraction ($\sim 15-18\%$) of disk galaxies in the Hubble Deep Field ($0.4 < z < 1.0$) as well as in the local Universe ($0.02 < z < 0.05$) are such pure disk systems (hereafter, PDS). The spatial distribution of light in these PDS is well described by a single exponential function from the outskirts to the center and appears to have remained intact over the last 8 billion years keeping the mean central surface brightness and scale-length nearly constant. These two disk parameters of PDS are brighter and shorter, respectively, than of those disks which are part of disk galaxies with bulges.

Since the fraction of PDS as well as their profile defining parameters do not change, it indicates that these galaxies have not witnessed either major mergers or multiple minor mergers since $z \sim 1$. However, there is substantial increase in their total stellar mass and total size over the same time range. This suggests that smooth accretion of cold gas via cosmic filaments is the most probable mode of their evolution. We speculate that PDS are dynamically hotter and cushioned in massive dark matter haloes which may prevent them from undergoing strong secular evolution.

*Subject headings:* galaxies: bulges — galaxies: evolution — galaxies: formation — galaxies: spiral — galaxies: structure – galaxies: high-redshift

## 1. INTRODUCTION

The $\Lambda$ Cold Dark Matter paradigm based on hierarchical structure formation (White & Rees 1978) has shown remarkable success in explaining the large scale structure of our Universe. Since according to the models based on this paradigm, galaxies grow hierarchically, this in turn implies the inevitable role of major mergers and/or multiple minor mergers during their life-time (Bournaud et al. 2007; Hopkins et al. 2010; Naab et al. 2014). Depending on the strength of these mergers, the final outcome could be scrambling of the preexisting disks, thickening of the disk structure (Toth & Ostriker 1992) and formation of a classical bulge at the centre produced with significant bulge fraction.

Apart from the externally driven evolutionary causes, there is growing evidence that internally driven evolution of the disks also leads to the destruction of the pure exponential due to bulge formation (Kormendy 2015). This formation is driven by non-axis-symmetric features (i.e., bars, spiral arms, etc.) which facilitate the transport of gas to the inner region (Kormendy & Kennicutt 2004a; Saha et al. 2012; Athanassoula 2012). Whatever might have been the dominant evolutionary route (whether external or internal) - exponential stellar disks without any bulges (whether classical or pseudo) are not expected to be observed at the present epoch.

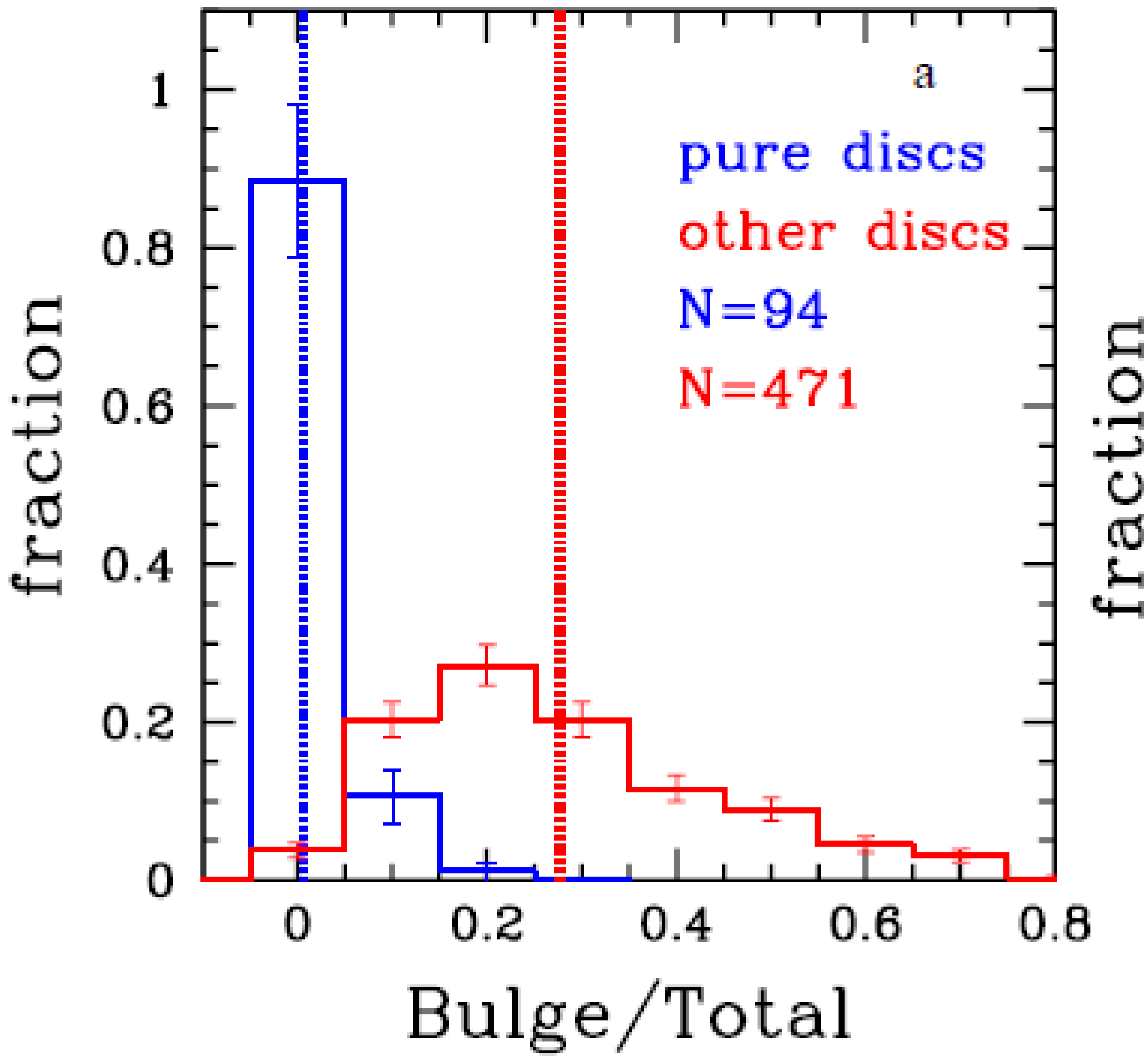
- **Цель работы:** исследование pure disc systems (PDS) - дисковых галактик без балджа на низких z и на $0.4<z<1.0$ (HST). Эти объекты не должны были испытать merging or strong interaction or bar-induced radial gas motion. Казалось бы, их должно быть мало.
- Однако Fisher & Drory (2011) finds that roughly 35% ± 12% of the disk galaxies within the 11Mpc volume are bulgeless.

- Выборка: 565 галактик, где преобладает диск. Анализ изофот (полосы B,z) каждого изображения.

- . As per definition, PDS are the ones whose intensity profile can be fitted well by a single

exponential function (Id(R)) all the way to the centre from the outskirts without requiring any bulge component. В среднем, B/T = 0.01pm0.03.

Доля PDS-галактик – 15-18% независимо от z!


a
pure discs
other discs
N=94
N=471
fraction
fraction
Bulge/Total
0
0.2
0.4
0.6
0.8
1

Рост R_p на ~60%
(диск обрывается
дальше от центра)



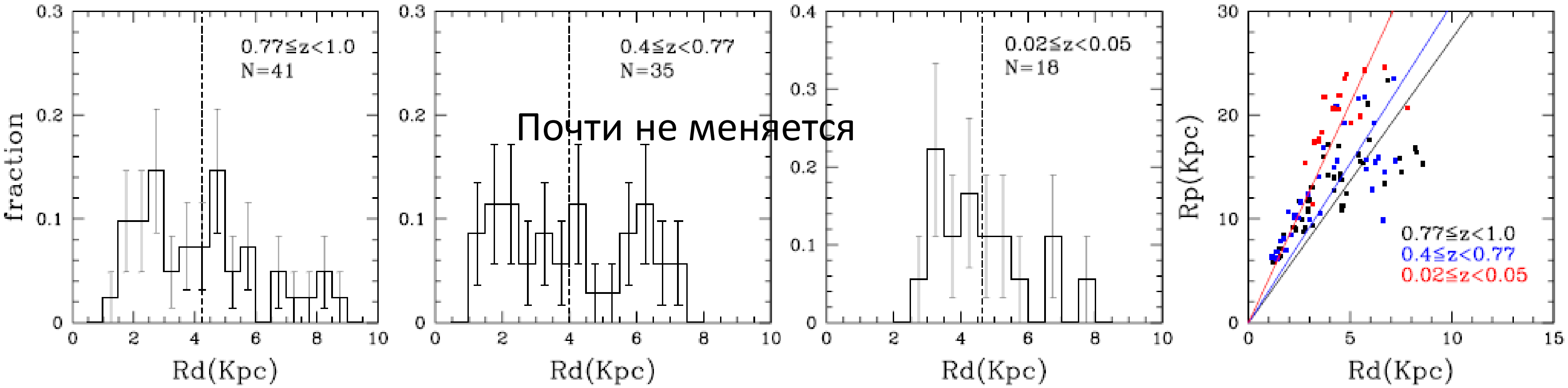



FIG. 3.— First three panels from left: The distribution of intrinsic scale length of PDS galaxies in the three redshift ranges. The solid line marks the mean at each redshift range. Extreme right panel: The Petrosian radius of PDS galaxies is plotted against their scale length. The solid lines mark the slope for a given redshift range.

На z=0.4 светимости
ниже чем на z=0

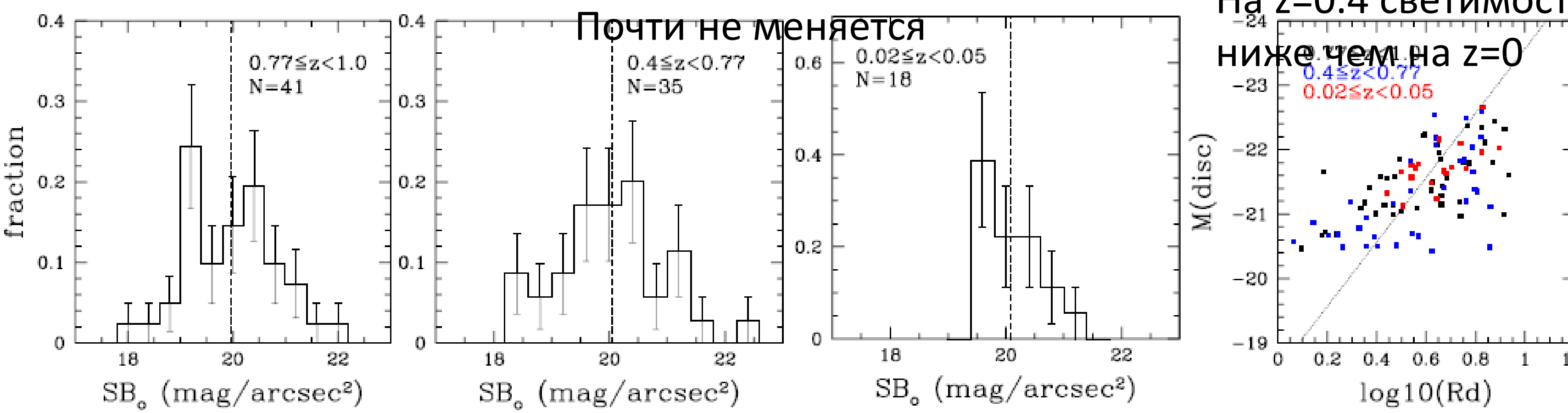



FIG. 4.— First three panels from left: same as in Fig. 3 but central surface brightness. Extreme right panel: The absolute magnitude of the PDS galaxies is plotted against their scale-length for the three redshift ranges. The solid line corresponds to $SB_0 = 20 mag/arcsec^2$.

# Выводы

- Доля PDS составляет 15-18% на всех Z (нет эволюции последние 8 млрд лет). Среди остальных галактик доля галактик с классическим балджем со временем растет, а с псевдобалждем падает (Sachdeva+, 2015).
- Шкала диска не эволюционирует from z=1 to the present epoch.
- A significant increase in stellar mass and size occurs from z = 0.4 to 0.02−0.05, with mean mass going up to 40% , size – up to 60% change. Светимость галактик при этом возросла на 30%.
- This suggests that PDS galaxies support distinct evolutionary histories.

# Почему PDS избегают merging, сохраняют центр. яркость, и тем не менее растут в размерах?

- Perhaps, these PDS -galaxies grew their mass and size through the smooth accretion of cold gas (Lemonias et al. 2011; Moffett et al. 2012; Moran et al. 2012) via cosmic filaments.
- Also, these galaxies might actually be located in the filaments connecting different clusters of galaxies.

А не является ли это результатом двух разных источников информации: HST для больших Z и SDSS для более близких галактик?

# Suppression of galactic outflows by cosmological infall and circumgalactic medium



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## ABSTRACT

We investigate the relative importance of two galactic outflow suppression mechanisms : a) Cosmological infall of the intergalactic gas onto the galaxy, and b) the existence of a hot circumgalactic medium (CGM). Considering only radial motion, the infall reduces the speed of outflowing gas and even halts the outflow, depending on the mass and redshift of the galaxy. For star forming galaxies there exists an upper mass limit beyond which outflows are suppressed by the gravitational field of the galaxy. We find that infall can reduce this upper mass limit approximately by a factor of two (independent of the redshift). Massive galaxies ($\gtrsim 10^{12} M_{\odot}$) host large reservoir of hot, diffuse CGM around the central part of the galaxy. The CGM acts as a barrier between the infalling and outflowing gas and provides an additional source of outflow suppression. We find that at low redshifts ($z \lesssim 3.5$), the CGM is more effective than the infall in suppressing the outflows. Together, these two processes give a mass range in which galaxies are unable to have effective outflows. We also discuss the impact of outflow suppression on the enrichment history of the galaxy and its environment.


**Key words:** Galaxies: Haloes; Galaxies: Intergalactic medium

## 1 INTRODUCTION

The two components of matter in galaxies– dark matter and baryons– have contrasting properties, a fact which makes the study of galactic evolution a complex one. Unlike dark matter, baryons undergo collisions, radiate, and condense towards the central part of the galaxy in or-

(IGM) (Birnboim & Dekel 2003; Kereš et al. 2005; Oppenheimer et al. 2010). Together, the infall and outflows regulate the evolution of the host galaxies. However, the interaction between these two opposing processes is not yet well understood.

The CGM can also act as a barrier for infalling gas

- Circumgalactic medium (CGM) – это горячий газ гало вокруг (только) массивных галактик (где время охлаждения – миллиарды лет). Этот газ может препятствовать как выбросу газа (outflow), так и аккреции (infall) (see Gabor, Dave,2015).
- Вопрос – как влияет на отток газа наличие падающих потоков (gas infall) и присутствие CGM в гало?
- Метод: аналитика для outflow и cosmological numerical simulations для infall.

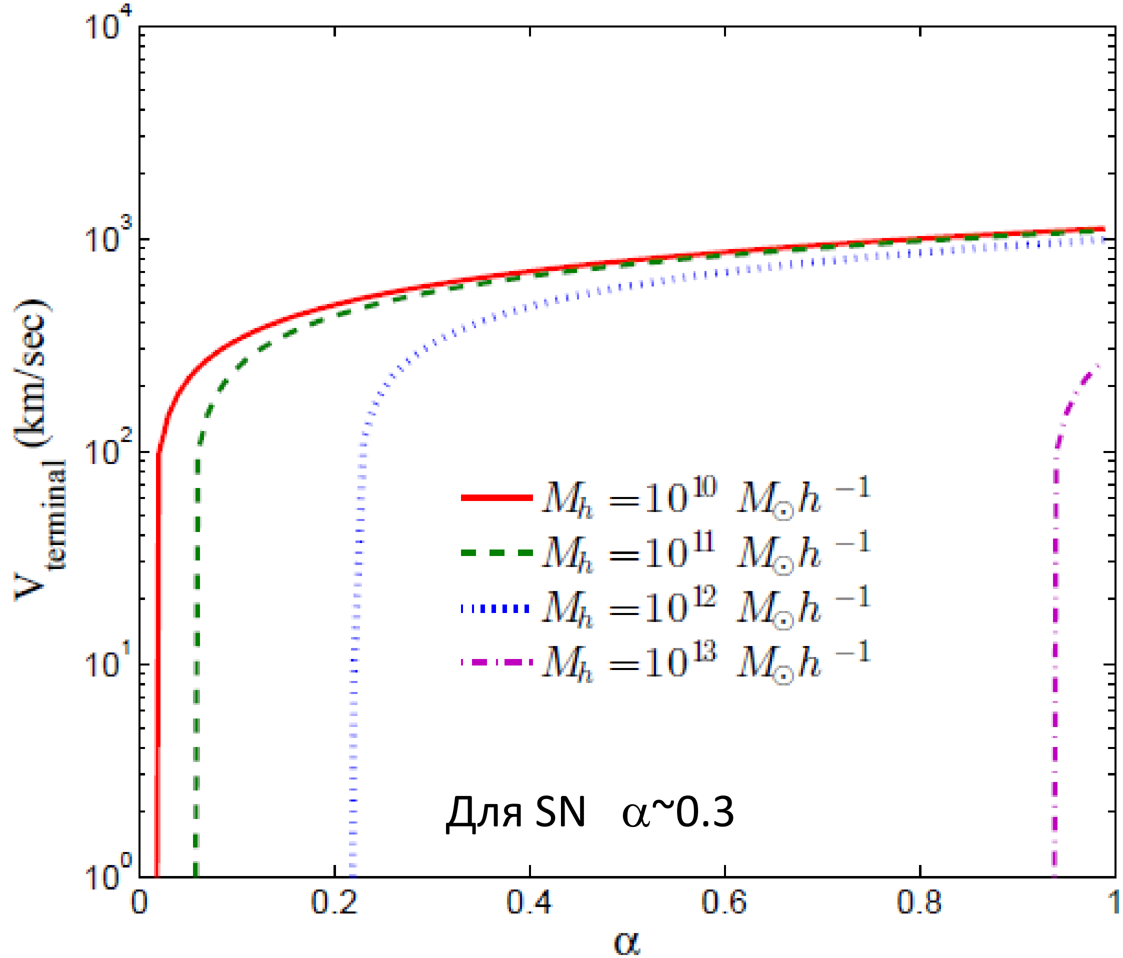


**Figure 1.** Terminal wind velocity as a function of energy injection efficiency $\alpha$, due to stellar feedback processes, for galactic haloes in the mass range, $10^{10-13} M_\odot h^{-1}$ (shown in different colors), at redshift, $z = 0$.

• Net outflow velocity – это outflow velocity minus inflow velocity.

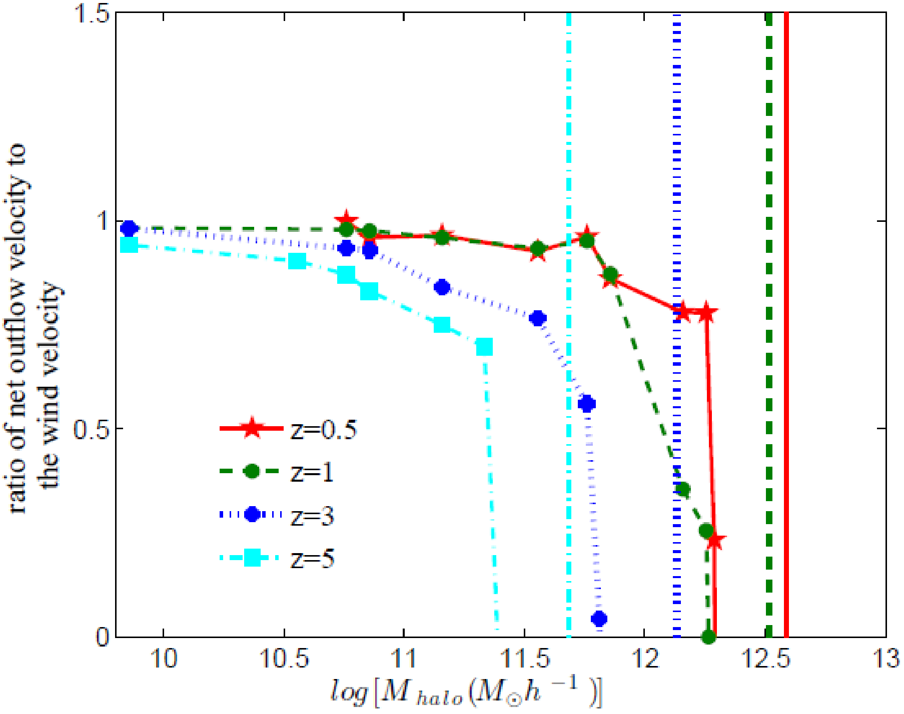


Figure 3. Ratio of net outflow velocity with and without the infall, as a function of the halo mass, for different redshifts (shown in different colors). The vertical lines represent the mass limit above which the outflows cannot overcome the gravitational field of the galaxy and the galaxies do not host the outflows even in the absence of the infall.

Outflow тормозится гравитационным полем гало и уменьшается благодаря inflow.

Вертикальные линии – предел массы, начиная с которого outflow сдерживается гравитацией гало даже если нет inflow. При наличии Inflow выброс газа начитает тормозиться при меньших массах.

# Максимальная масса гало, при которой еще возможен outflow

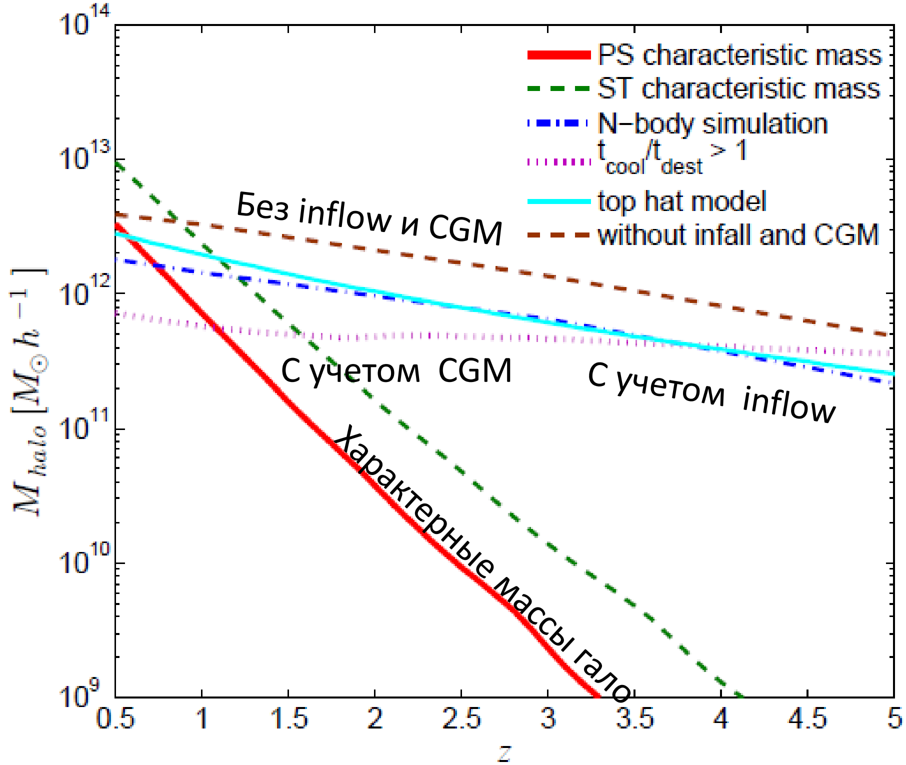


**Figure 4.** Comparison between $M_{\rm max}$ (thin dashed, brown line) which does not include the suppression of outflows by infall and CGM, $M_{\rm max}^{\rm infall}$ calculated for N-body simulation (dot-dashed, blue line) and the top hat model (thin solid, cyan line), $M_{\rm max}^{\rm CGM}$ (dotted, pink line) and $M_{\rm char}$ calculated for the PS (thick solid, red line) and ST (dashed, green line) mass function.

# Основные выводы

- Падение газа уменьшает outflow. Этот эффект тем сильнее, чем массивнее галактики. Верхний предел масс, ограничивающий появление outflow, падает примерно вдвое при наличии infalling gas на всех z<5.
- При наличии CGM максимальная масса гало, при которой возможен outflow, составляет ~10^12 Мс на всех z. На низких z =0-3.5  CGM более эффективно влияет на outflow чем падение газа. На больших z ситуация обратная.
- The fraction of galaxies with unsuppressed outflows predicted by the simulation decreases from 90% at z = 5 to 50% at z = 0.

Hence high feedback activity (z = 1−2), likely affecting the enrichment history of the universe.