Explaining the enhanced star formation rate of Jellyfish galaxies in galaxy clusters

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ABSTRACT

We study the recently observed JellyFish galaxies (JFGs), which are found to have their gas content ram-pressure stripped away in galaxy clusters. These galaxies are observed to have an enhanced star formation rate of about 0.2 dex compared with a control sample of the same stellar mass in their disks. We model the increase in the star formation efficiency as a function of interacluster medium pressure and parametrize the cold gas content of the galaxies as a function of cluster-centric distance. We show that regarding the external pressure as a positive feedback results in agreement with the observed distribution of enhanced star formation in the JFGs if clouds are shielded from evaporation by magnetic fields. Our results predict that satellites with halo mass $< 10^{11}$ $M_\odot$ moving with Mach numbers $\mathcal{M} \approx 2$, and inclination angles below 60 degrees, are more likely to be detected as JFGs.

Key words: methods: analytical – galaxies: evolution – galaxies: clusters: general – galaxies: groups: general – galaxies: clusters: intracluster medium

1 INTRODUCTION

Ram pressure stripping (RPS) of the gas content of the galaxies entering a cluster-like environment (Gunn & Gott 1972) have long been observed (Kenney et al. 2004; Chung et al. 2007; Boselli et al. 2014; Brown et al. 2017; Hayashi et al. 2017), and modeled in numerical simulations (Mayer et al. 2006; Roediger & Brüggen 2007; Tonnesen & Bryan 2009; Steinhauser et al. 2016; Ruggiero & Lima Neto 2017;

Ramos-Martínez et al. (2018) showed that in interaction of a face-on disk with the interacluster medium (ICM), gas from the outskirts of the disk flows towards the center leading to high gas surface densities and therefore higher star formation rate. Bekki et al. (2010) showed that the strong compression of cold gas in gas-rich cluster members leads to a starburst phase of the satellites when the ICM pressure is boosted in cluster merging events. Bieri et al. (2015) showed that AGN

Figure 1. *HST* images of extreme cases of ram-pressure stripping in galaxy clusters at $z > 0.2$. From left to right: galaxy C153 in A2125 at $z = 0.20$ (WFPC2, F606W+F814W, Owen et al. 2006); galaxy 234144–260358 in A2667 at $z = 0.23$ (ACS, F450W+F606W+F814W, Cortese et al. 2007); galaxy F0083 in A2744 at $z = 0.31$ (ACS, F435W+F606W+F814W, Owers et al. 2012).

Неопределенные результаты моделирования:

- Fujita & Nagashima (1999) studied the impact of ram pressure on the SFR of satellites in clusters and found a factor of 2 increase in SFR at pericenter distances. In their model the molecular gas is never stripped.
- Tonnesen & Bryan (2009) have found that only low ram pressures can compress the gas into high density clouds and therefore lead to higher SFR, while high ram pressure will likely strip the gas rather than compress it.
- Kapferer et al. (2009) found that the enhanced SFR due to ram pressure stripping should be a more sensitive function of the ambient density than the relative velocity.

Here we focus on the timespan during which the cold gas is being stripped and show how to calculate the elevated SFR in the satellite

Модель

- $R_{g,d} = 1.7R_d$
- $R_e = 0.015R_{200}(M_{sat})$
- Давление межзвездной среды

$$P_{ISM} \approx \frac{\pi}{2} G \Sigma_g \left[\Sigma_g + \left(\frac{\sigma_g}{\sigma_*}\right) \Sigma_* \right]$$

- Внешнее давление

$$P_{tot} = \rho_{ICM} c_s^2 (1 + \mathcal{M}^2) \cos(\theta)$$

Параметры – для Abell 1785

- GMC mass function of $dN/dM \sim M^{-2}$
- $SFR = \varepsilon \cdot M_{coldgas}$
- Оценка ε - определяется отношением давлений ICM и IGM-до входа в скопление (Elmegreen, Efremov, 1997).

Ключевой фактор – отношение давлений.

Потеря газа из-за выметания приводит к росту P_{tot}/P_{ISM}.

Поэтому при приближении к центру скопления эффективность SF растет, а SFR падает из-за выметания HI.

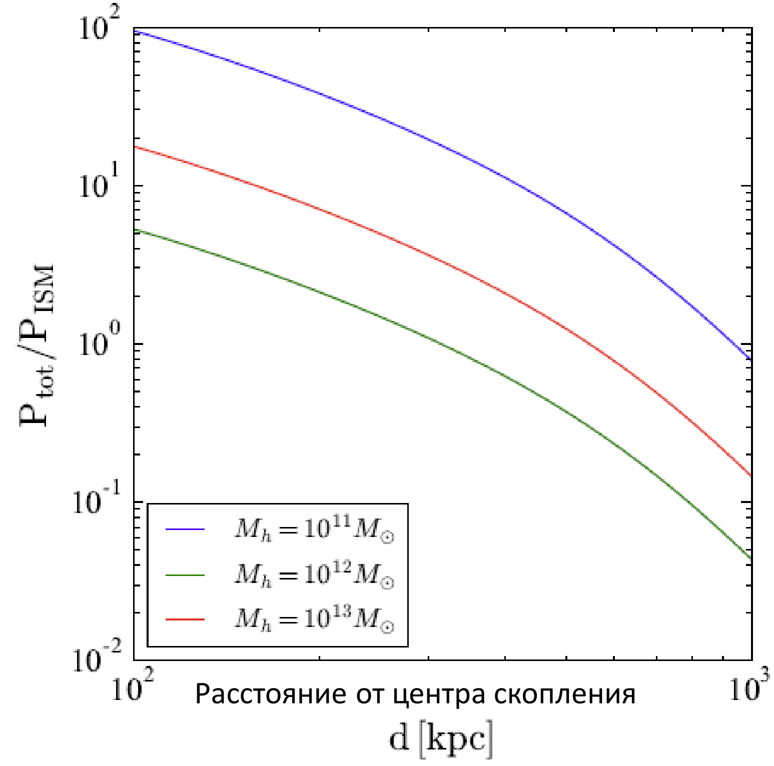

Figure 2. The ratio of the ICM pressure to the ISM pressure of the disk of the satellites at the location of the effective radius of the disk. The gas density and temperature profile of A1795 is modeled following Vikhlinin et al. (2006). We have assumed $\mathcal{M}$ = 1.4 for the satellites.

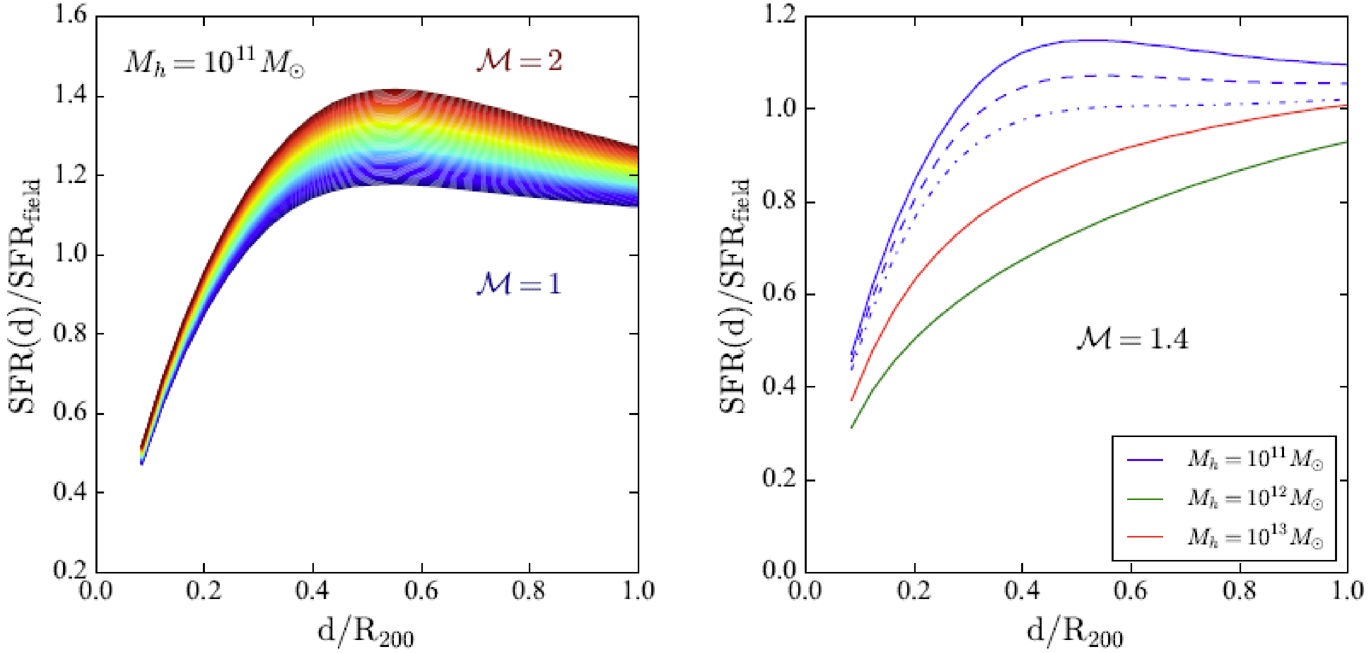

Figure 3. *Left panel*: the ratio of the SFR of the satellites as a function of cluster-centric distance to the SFR of the satellite in the field, shown for a satellite with halo masses of 10^{11} $M_\odot$ moving in a host galaxy cluster of mass ~ 2×10^{14} $M_\odot$. Lines are color coded from lowest to the highest corresponding to Mach numbers values ranging from $\mathcal{M}$ = 1 to $\mathcal{M}$ = 2 which is about maximum seen for satellites in galaxy cluster simulations (Faltenbacher et al. 2005). We are showing the enhancement of the integrated SFR over the entire disk. *Right panel*: results for different satellite halo masses assuming the satellite is moving with $\mathcal{M}$ = 1.4. The blue dashed and dot-dashed lines show the case where the inclination angle of the satellite is assumed to be 45, and 60 degrees, respectively. At inclinations above 60 degrees we expect the enhancement of the SFR in the disk to be significantly suppressed.

- **Отдельно рассматривается вопрос разрушения молекулярных облаков при обдувании (stripping).**
- For the case of a cloud with mass of 10^5M, and radius of 30 pc, the time it takes for the cloud to be 90% disrupted moving with M = 2 in the ICM of A1795 ranges from about 45 Myr at distances of 1 Mpc from the cluster center, to 3 Myr at a distance of 10 kpc. These timescales are too short with respect to the time it takes the satellite to reach the inner part of the galaxy cluster, meaning the clouds would have been largely disrupted by the ICM pressure.
- **Магнитное поле продлевает время разрушения.**

- The underlying assumption in our model is that the molecular clouds are shielded by magnetic fields from evaporation due to the hot ICM.

- Диаграмма показывает, до какого

расстояния от центра скопления

Н-поле будет препятствовать

Разрушению облака.

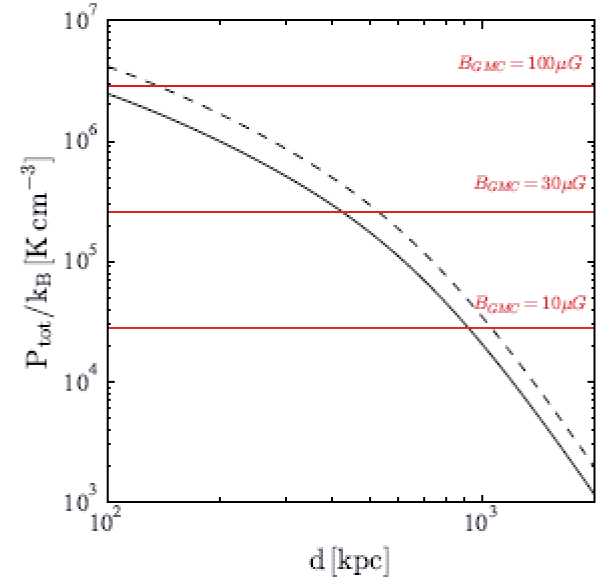

Figure 4. The ICM pressure for a satellite moving with $\mathcal{M}$ = 1.4 (2) is shown in solid (dashed) black lines respectively. The red horizontal lines indicate the magnetic field energy density in the GMCs for different assume values as labeled close to each line. GMC magnetic field strength of 30 μG can shield the molecular clouds down to about 400 kpc in a host cluster of mass $\sim 2 \times 10^{14}\ M_{\odot}$ given the Mach number of the satellite.

- The cold gas fraction of halos increase with redshift, which results in an increase in their ISM pressure. We require the JFGs to be late infallers for our model to work. Moreover, we predict no JFGs to be present at short cluster-centric distances.