DEEP OPTICAL IMAGES OF MALIN 1 REVEAL NEW FEATURES

Gaspar Galaz[1], Carlos Milovic[2,3,4], Vincent Suc[1,5], Luis Busta[6], Guadalupe Lizana[1], Leopoldo Infante[1,7],
Santiago Royo[5]

Draft version December 4, 2015

ABSTRACT

We present Megacam deep optical images (g and r) of Malin 1 obtained with the 6.5m Magellan/Clay telescope, detecting structures down to ~ 28 B mag arcsec^{-2}. In order to enhance galaxy features buried in the noise, we use a noise reduction filter based on the total generalized variation regularizator. This method allows us to detect and resolve very faint morphological features, including spiral arms, with a high visual contrast. For the first time, we can appreciate an optical image of Malin 1 and its morphology in full view. The images provide unprecedented detail, compared to those obtained in the past with photographic plates and CCD, including HST imaging. We detect two peculiar features in the disk/spiral arms. The analysis suggests that the first one is possibly a background galaxy, and the second is an apparent stream without a clear nature, but could be related to the claimed past interaction between Malin 1 and the galaxy SDSSJ123708.91 + 142253.2. Malin 1 exhibits features suggesting the presence of stellar associations, and clumps of molecular gas, not seen before with such a clarity. Using these images, we obtain a diameter for Malin 1 of 160 kpc, $\sim$ 50 kpc larger than previous estimates. A simple analysis shows that the observed spiral arms reach very low luminosity and mass surface densities, to levels much lower than the corresponding values for the Milky Way.

Subject headings: galaxies: general — galaxies: spiral — techniques: image processing

1. INTRODUCTION

One of the main factors precluding the observability of the extragalactic universe is the limitation in surface brightness (SB) by different surveys. In the seventies, different authors have shown that the universe is populated by low surface brightness galaxies (LSBGs) having much lower SB than the dark night sky (Disney 1976; Bothun et al. 1987). Dalcanton et al. (1997) showed using data from CCD drift scans from the eighties, that one can expect about 4 galaxies/deg^2 between the range 23-25 mag arcsec^{-2}. In the nineties and already entering in the new millennium, there were no surveys with significantly fainter surface brightness limits. Some progress on the statistical significance of the population of LSBGs has been made in recent years because of the higher volumes sampled, thanks to massive surveys like the SDSS and others, but still barely reaching $\sim$ 23.0 mag arcsec^{-2}. On the other hand, and quite unexpectedly, van Dokkum et al. (2015); Koda et al. (2015) reported on the discovery of a dozen of Milky Way (MW) sized, passively evolving, ultra diffuse galaxies (UDG) in the Coma cluster. This population is very likely dark-matter dominated and thus represents a challenge to the current theories of galaxy formation. Without the presence of large fractions of dark matter in LSBGs, it is very difficult to prevent the rapid destruction of low density galaxies within a massive cluster like Coma (Toomre & Toomre 1972; Moore et al. 1999; McGee & Balogh 2010).

Thus, there are still many unsolved issues concerning the nature of LSBGs. One of these issues is the nature of the class of the so-called giant LSBGs: large format spiral galaxies with a similar or larger size than the MW and very low SB. Big spirals exhibiting similar morphologies of the grand design spiral galaxies like M31 and the MW, but with much lower stellar density, as described in Sprayberry et al. (1995); Impey et al. (1996); Galaz et al. (2002, 2011), and references therein. The best and more extreme example in this category is Malin 1, a disk/spiral active galaxy (Impey & Bothun 1989; Barth 2007) with a disk SB of ≥ 24 B mag arcsec^{-2}, an uncertain inclination (the HI data indicate that this galaxy has an inclination of about 50 deg), and a barred inner disk (Barth 2007). In addition to this faint SB, what makes Malin 1 exceptional is its size: about 110 kpc diameter in HI and presumably a similar or larger diameter in the optical, making this galaxy the largest

---

[1] This paper includes data gathered with the 6.5 meter Magellan Telescopes located at Las Campanas Observatory, Chile.

Наблюдения

Magellan 6.5 m

Seeing 0.”8

Exposure 4.8h (r), 4.2h (g)

Spirals

Two cigar-like features (background galaxies? Jet?)

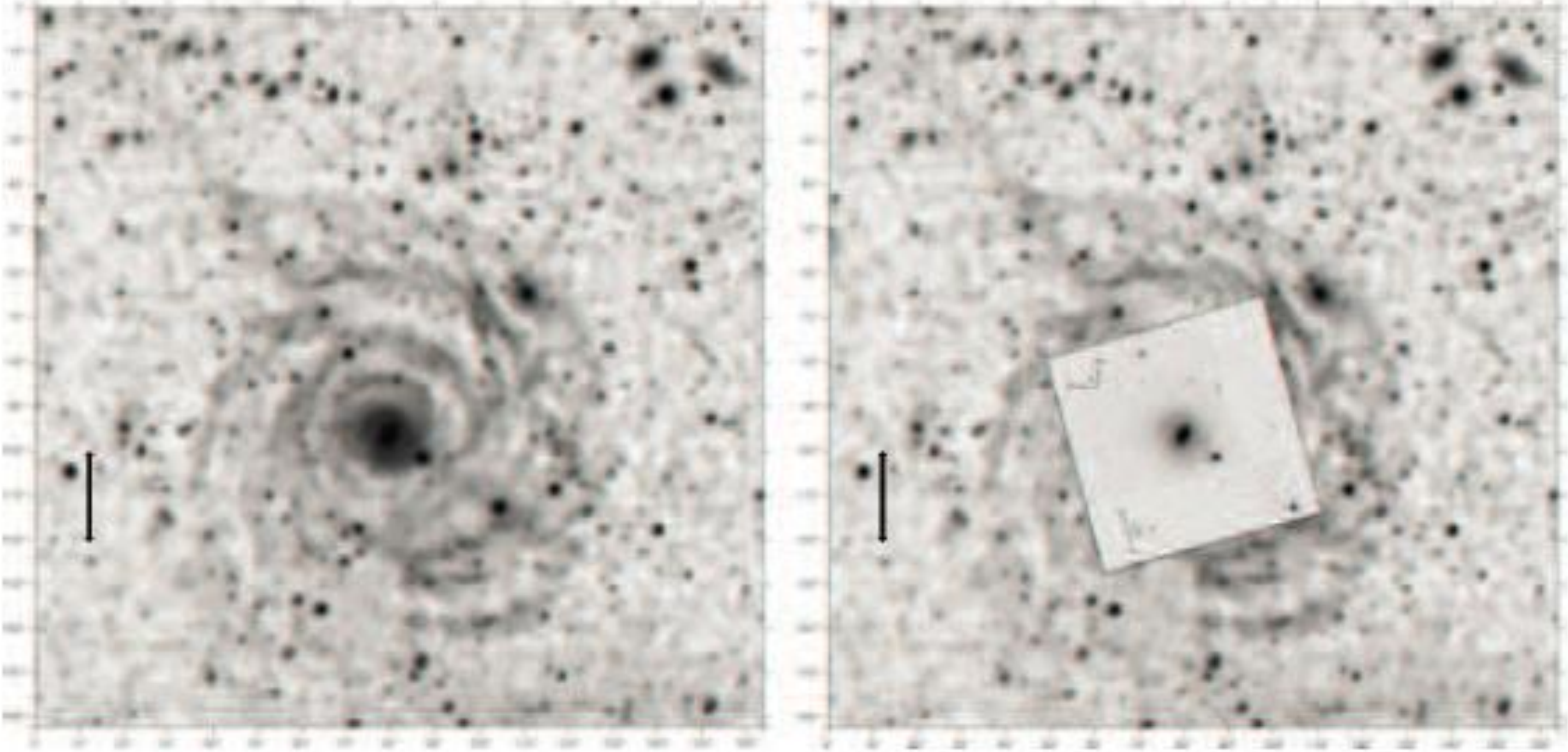
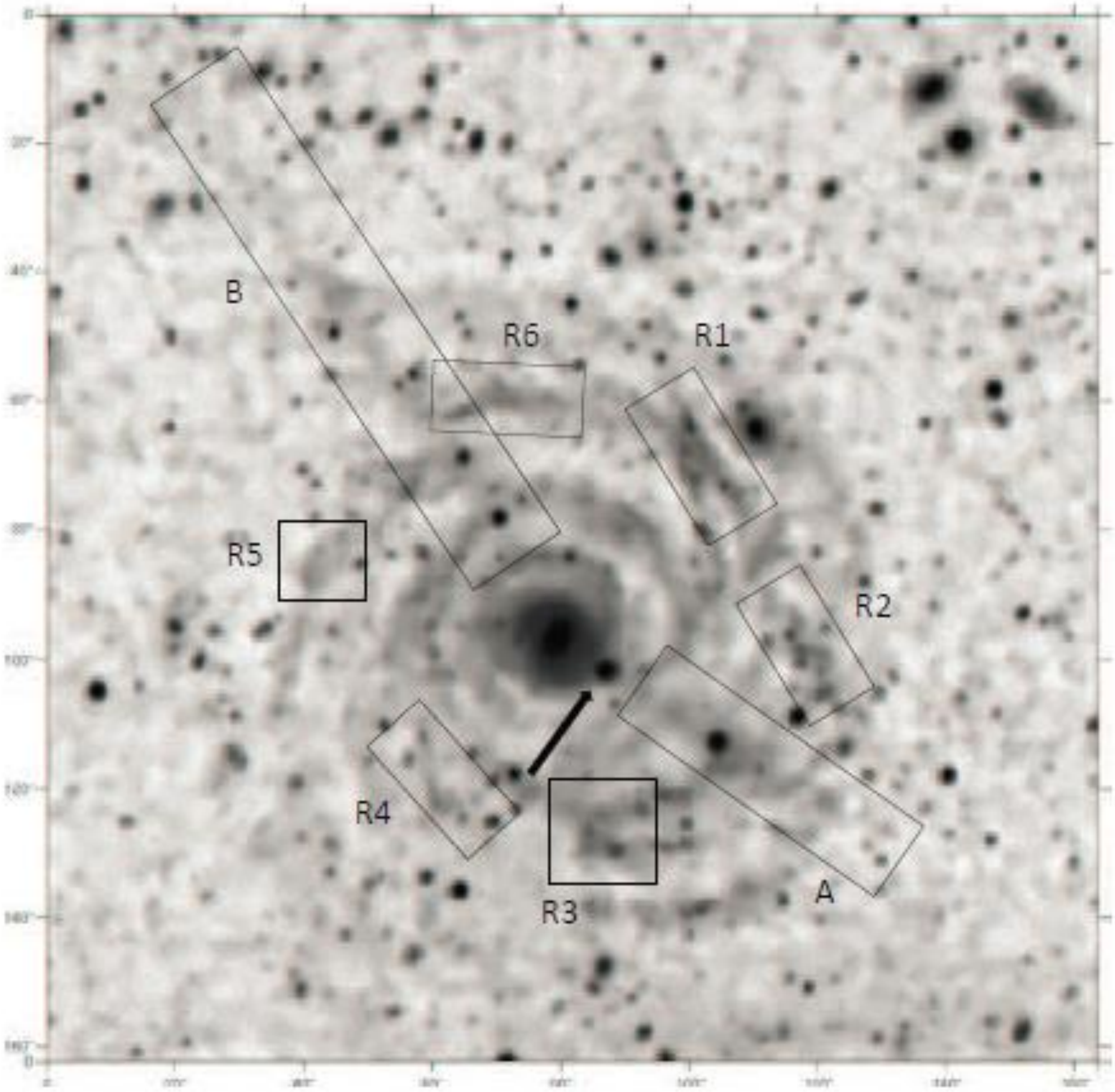


FIG. 2.— Zoom images of the monochrome versions of bottom right panel of Figure 1. In the right panel, an inset with an HST/WFPC2 image, from Barth (2007), is shown. Both panels include the image scale in arcsecs. The double arrows represent the physical scale (30.6 kpc, the approximate diameter of the Milky Way).



G. 3.— The same as left panel of Figure 2 but showing some regions discussed in the text. The arrow indicate the position of Malin (Reshetnikov et al. 2010).

Resume

- Высокий градиент цвета (внешние области голубые)
- Спиральные ветви – до 28m/sec2 ~0.6Mc/pc2
- Две линейных размытых детали. Их природа непонятна.

An assessment of the “too big to fail” problem for field dwarf galaxies in view of baryonic feedback effects

E. Papastergis[1,⋆] and F. Shankar[2]

[1] Kapteyn Astronomical Institute, University of Groningen, Landleven 12, Groningen NL-9747AD, The Netherlands
e-mail: `papastergis@astro.rug.nl`
[2] School of Physics and Astronomy, University of Southampton, Southampton SO17 1BJ, UK
e-mail: `f.shankar@soton.ac.uk`

November 30, 2015

ABSTRACT

Recent studies have established that extreme dwarf galaxies –whether satellites or field objects– suffer from the so called “too big to fail” (TBTF) problem. Put simply, the TBTF problem consists of the fact that it is difficult to explain both the measured kinematics of dwarfs and their observed number density within the ΛCDM framework. The most popular proposed solutions to the problem involve baryonic feedback processes. For example, reionization and baryon depletion can decrease the abundance of halos that are expected to host dwarf galaxies. Moreover, feedback related to star formation can alter the dark matter density profile in the central regions of low-mass halos. In this article we assess the TBTF problem for field dwarfs, taking explicitly into account the baryonic effects mentioned above. We find that 1) reionization feedback cannot resolve the TBTF problem on its own, because the halos in question are too massive to be affected by it, and that 2) the degree to which profile modification can be invoked as a solution to the TBTF problem depends on the radius at which galactic kinematics are measured. Based on a literature sample of ∼90 dwarfs with interferometric observations in the 21cm line of atomic hydrogen (HI), we conclude that the TBTF problem persists despite baryonic effects. However, the preceding statement assumes that the sample under consideration is representative of the general population of field dwarfs. In addition, the unexplained excess of dwarf galaxies in ΛCDM could be as small as a factor of ≈ 1.8, given the current uncertainties in the measurement of the galactic velocity function. Both of these caveats highlight the importance of upcoming uniform surveys with HI interferometers for advancing our understanding of the issue.

1. Introduction

The lambda cold dark matter (ΛCDM) cosmological model has been long established as the prevailing paradigm for cosmology and extragalactic astronomy. Even though ΛCDM is extremely

& Di Cintio 2015a; Ferrero et al. 2012; Papastergis et al. 2015). Just as in the case of the bright MW satellites, the observed kinematics of field dwarfs imply that they are hosted by low-mass halos. These halos are produced in large enough numbers in a ΛCDM universe, that we would expect to detect significantly

Проблема числа карликовых спутников галактик со своими «мини-гало».

- Возможные решения:
- Не-типичность MW (но проблема есть и для Local Group).
- «Baryonic feedbacks»: подавление SF, изменение профиля DM в карликах.

Что оригинального в работе

- Использование большего объема данных по карликам
- Новый подход при использовании метода abundance matching (сопоставление функций круговых скоростей галактик и гало). Построение функции скоростей вращения с учетом а) feedback-motivated halo profiles; б) учет неравенства максимальной скорости вращения диска и максимальной скорости вращения гало.

- Определение функции распределения для ширин линий W (на 50%

$$n(W) = \frac{< dN_{\rm gal} >}{dV \, d\log_{10} W} \quad . \quad V_{\rm rot,HI} = W \,/\, (2 \times \sin i)$$

с последующим переходом к функции скоростей вращения n(Vrot), которая задавалась в форме функции Schechter’a

$$n(V_{\rm rot}) = \frac{dN_{\rm gal}}{dV \, d\log_{10} V_{\rm rot}} = \ln(10)\, n^* \left(\frac{V_{\rm rot}}{V^*}\right)^{\alpha} e^{-\left(\frac{V_{\rm rot}}{V^*}\right)^{\beta}} \quad .$$

Наклон дисков считался случайным.

Две базы данных:
Local Volume
И
ALFALFA blind survey
Dmin= 3 mpc

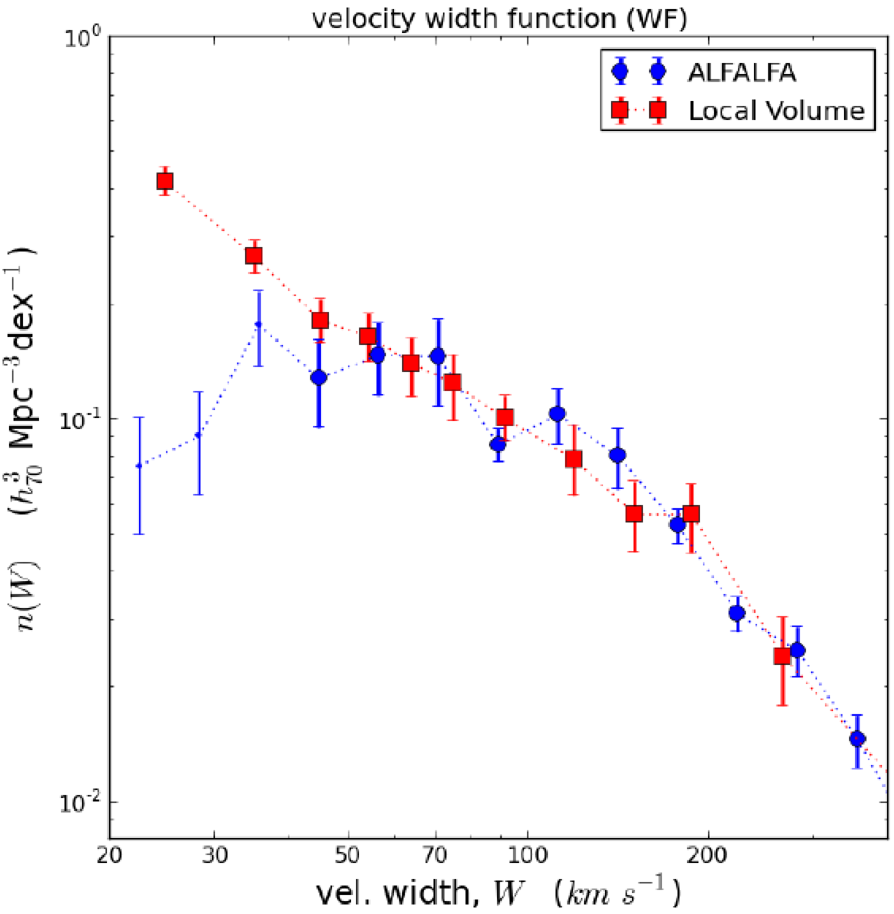
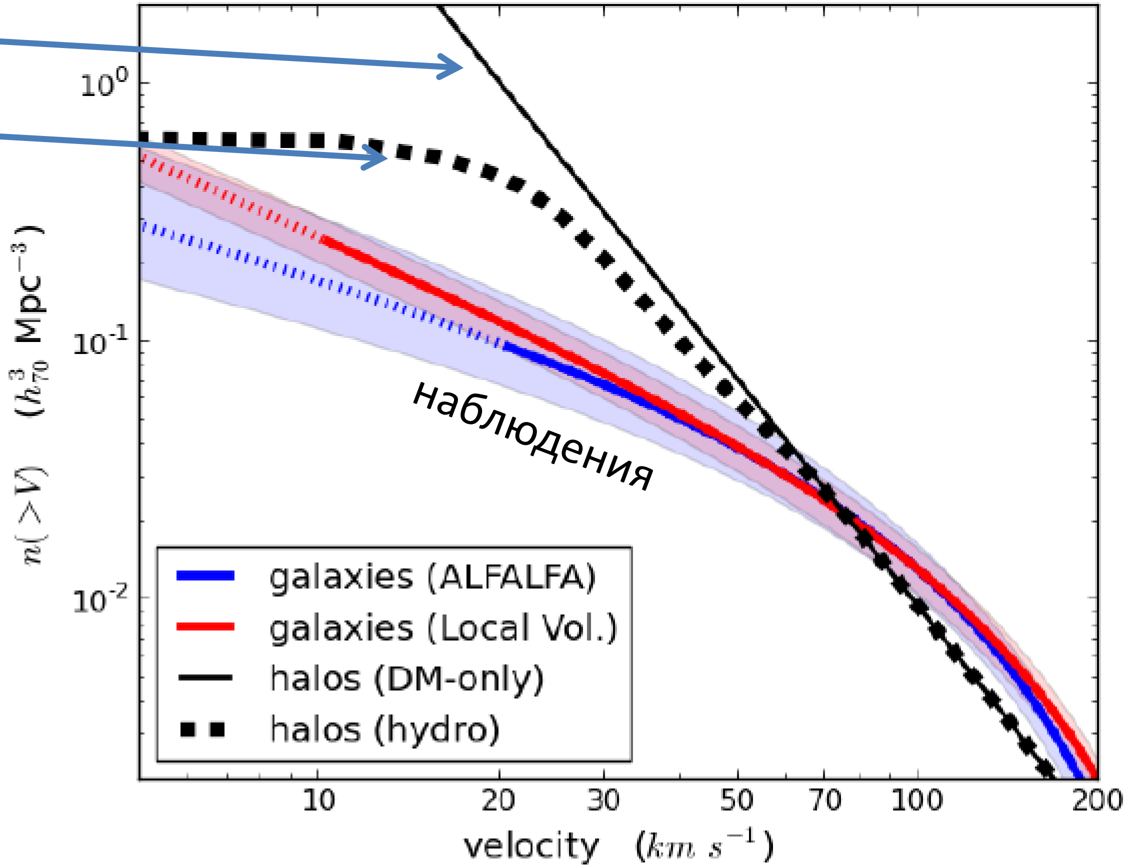


Fig. 1. Red squares correspond to the velocity width function (WF) of galaxies as measured in the Local Volume (Klypin et al. 2015). The Local Volume WF is based on a nearly volume-complete optical catalog of nearby galaxies (Karachentsev et al. 2013), and includes both late-type and early-type dwarfs. Blue circles correspond to the WF measured in this work, based on the galaxy catalog of the ALFALFA HI survey (Haynes et al. 2011). The $W < 40\ \mathrm{km\,s^{-1}}$ section of the ALFALFA WF (blue dots) is not used in the analysis that follows, due to possible incompleteness (see Sec. 2.1.1 for details). In both cases, the errorbars represent the uncertainties due to counting statistics only.

- Зависимость по ΛCDM
- Учет барионнного воздействия на гало (модель Savala et al., 2015). Здесь V_{rot} считалась равной $V_{h,max}$

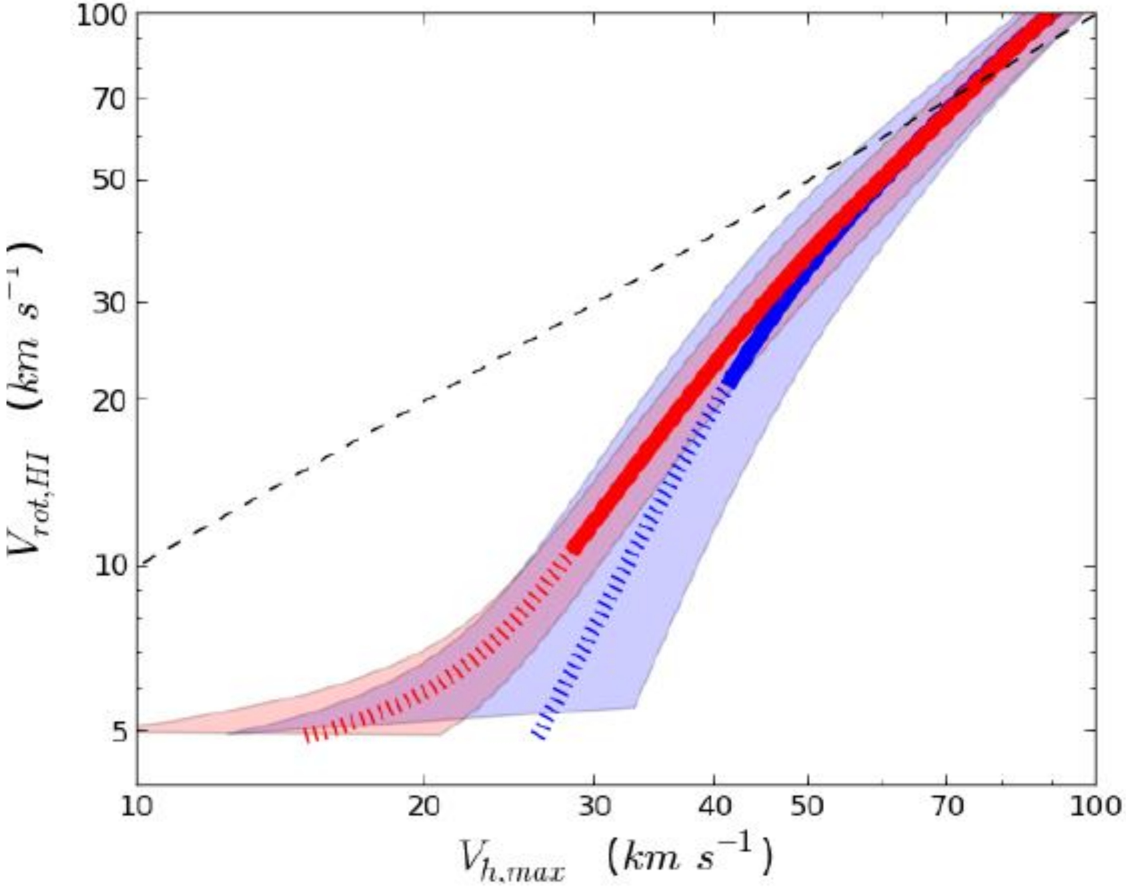


Результат
abundancre matching

Отказ от условия

$V_{rot} = V_{h,max}$

То есть, для согласия с abundance matching скорость вращения Vrot карликов должна быть значительно выше наблюдаемой!



Отдельно рассмотрены ~200 карликов с Vrot <50 km/s с известными кривыми вращения.

- Оценены звездные массы M* (IR-фотометрия, цвет B-V, CM-диаграммы).
- «Подгонялась» кривая вращения для гало

максимально возможной массы, motivated by hydrodynamic simulations of galaxy formation (модель DC14)– кроме случаев log(M^*/M_h) <4, для которых принимался профиль NFW.

- Примеры сопоставления теоретической кривой вращения темного гало с максимальной скоростью вращения карликов.

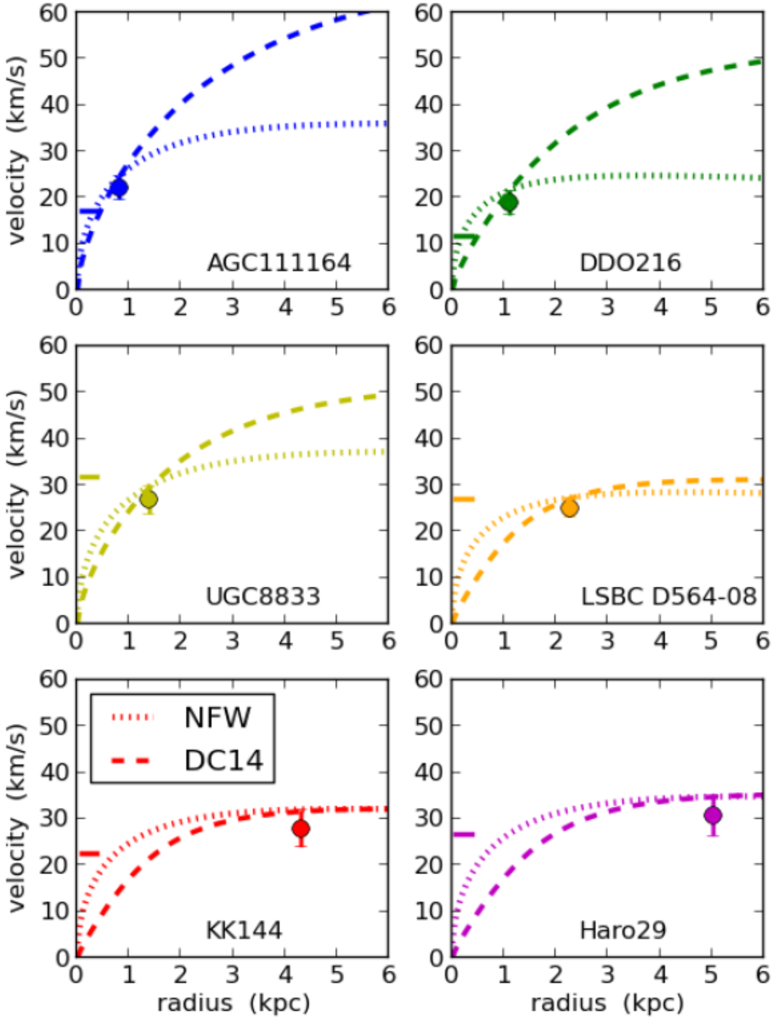


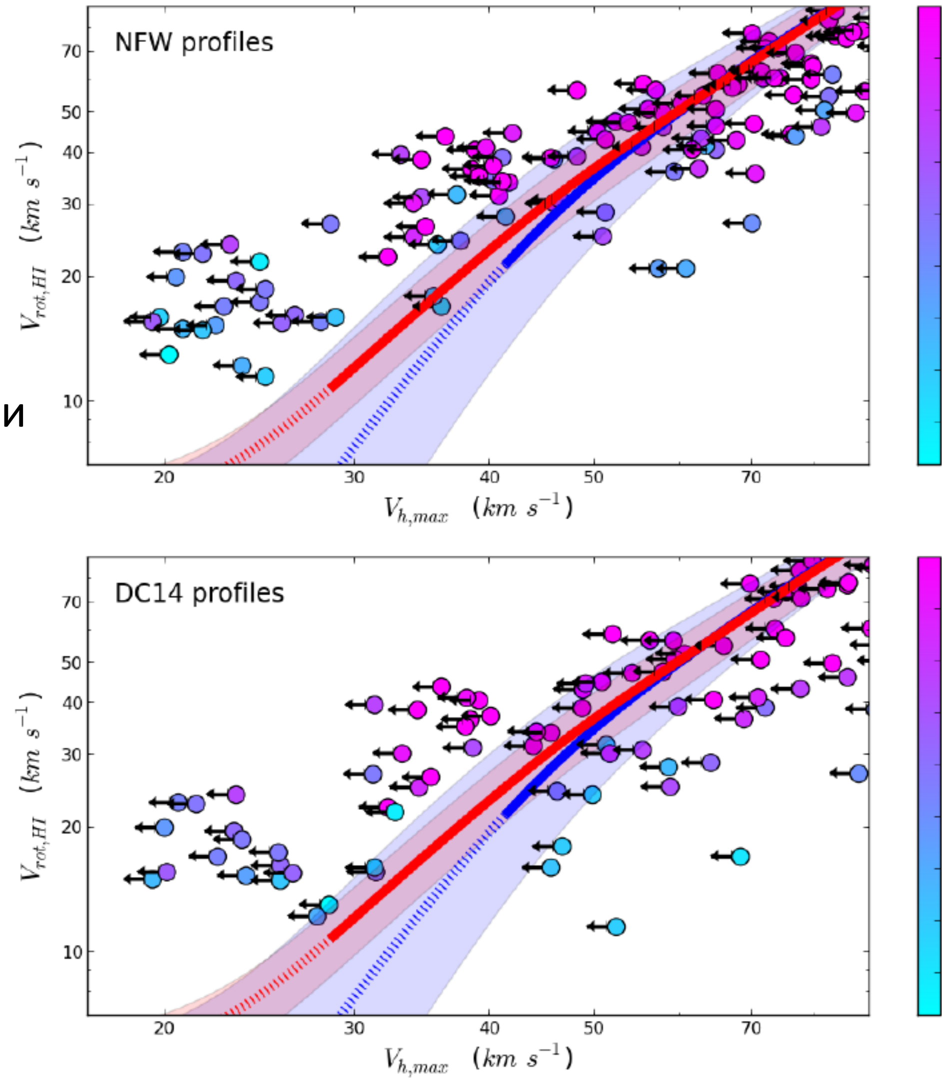
Fig. 3. Datapoints with errorbars represent the rotational velocity me
sured at the outermost HI radius, $V_{\rm out,HI}=V(R_{\rm out,HI})$, for six examp
galaxies. The galaxies are ordered from top left to bottom right in or
of increasing $R_{\rm out,HI}$. In each panel, the dotted and dashed lines c
respond to the RCs of the most massive halo that is compatible w
the observed datapoint within 1σ, assuming an NFW and DC14 pro
respectively. The horizontal mark denotes the value of the linewid
derived $V_{\rm rot,HI}$ for each galaxy.

E. Papastergis & F. Shankar: TBTF problem versus baryonic feed

Линии- что можно было бы ожидать для решения поблемы карликов, точки – что дают наблюдения конкретных галактик. Для галактик принимались два типа профилей кривых вращения: NFW (вверху) и feedback-inspired по модели

Di Cintio et al, 2014

(внизу).



Основной вывод

- Проблема дефицита карликов не решается даже с учетом feedback, то есть перераспределения массы DM в карликах, хотя с ее учетом рассогласованность с космогоническим моделированием становится не такой большой (~фактора 2) для $V_{\mathrm{rot,HI}} > 15\ \mathrm{km\,s^{-1}}$.