The massive dark halo of the compact, early-type galaxy NGC 1281

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ABSTRACT

We investigate the compact, early-type galaxy NGC 1281 with integral field unit observations to map the stellar line-of-sight velocity distribution (LOSVD) out to 5 effective radii and construct orbit-based dynamical models to constrain its dark and luminous matter content. Under the assumption of mass-follows-light, the H-band stellar mass-to-light ratio (M/L) is $\Upsilon_\star = 2.7\pm0.1\ \Upsilon_\odot$, and higher than expected from our stellar population synthesis fits with either a canonical Kroupa ($\Upsilon_\star = 1.3\ \Upsilon_\odot$) or Salpeter ($\Upsilon_\star = 1.7\ \Upsilon_\odot$) stellar initial mass function. Such models also cannot reproduce the details of the LOSVD. Models with a dark halo recover the kinematics well and indicate that NGC 1281 is dark matter dominated, making up ~ 90 per cent of the total enclosed mass within the kinematic bounds. Parameterised as a spherical NFW profile, the dark halo mass is $11.5 \leqslant \log(M_{DM}/M_\odot) \leqslant 11.8$ and the stellar M/L is $0.6 \leqslant \Upsilon_\star/\Upsilon_\odot \leqslant 1.1$. However, this M/L is lower than predicted by its old stellar population. Moreover, the halo mass within the kinematic extent is ten times larger than expected based on ΛCDM predictions, and an extrapolation yields cluster sized dark halo masses. Adopting $\Upsilon_\star = 1.7\ \Upsilon_\odot$ yields more moderate dark halo virial masses, but these models fit the kinematics worse. A non-NFW model might solve the discrepancy between the unphysical consequences of the best-fitting dynamical models and models based on more reasonable assumptions for the dark halo and stellar mass-to-light ratio, which are disfavoured according to our parameter estimation.

NGC1281
удивительный компактная массивная Е-галактика с преобладанием темной материи

- The program’s target sample was a result of the Hobby-Eberly Massive Galaxy Survey (HETMGS), which looked for high velocity dispersion galaxies that are candidates for hosting (over-)massive supermassive black holes (SMBHs).
- Объект по размеру и дисперсии скоростей похож на компактные массивные галактики на больших z.

NGC1281
E5, D=60 mpc

- Наблюдения охватывают 5R_e – до 7 кпк.
- Индекс Серсика – 3.9, либо два компонента: n=2.2 , Re=1.7”(inner), и n=1/3, Re=10” (outer); сплюснутости примерно одинаковы
- Представление распределение яркости:

A set of multiple Gaussians (MGE; Monnet et al. 1992; Emsellem et al. 1994). In our case, the

MGE consists of 8 Gaussians with a common centre and a fixed position angle (PA).

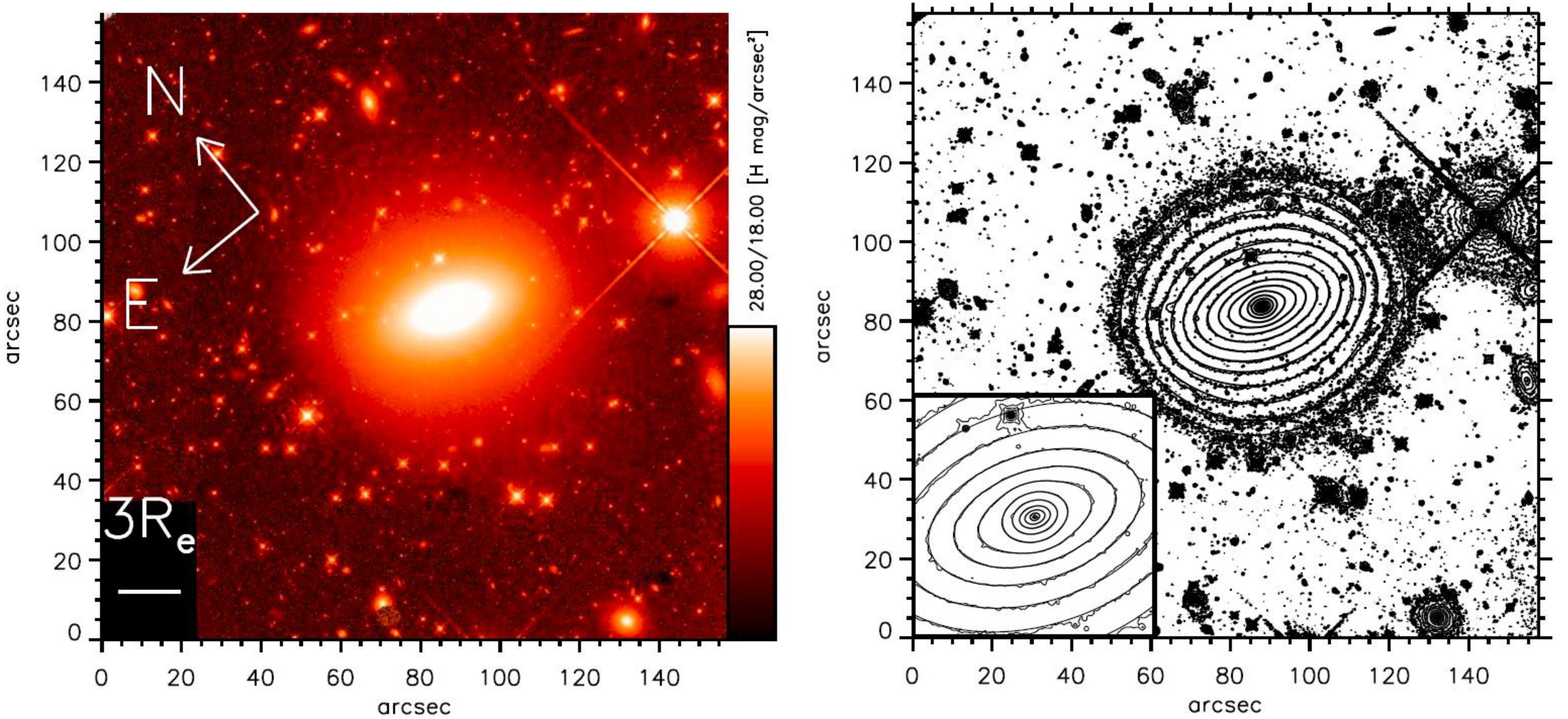


Figure 1. *Left: HST H*-band image of NGC 1281, which covers a field of 150 $\square''$, with a final scale of $0.06''$/pixel. *Right:* Contour ma of the same image. The MGE contours are over-plotted in black. The bottom left plot shows the accurate reproduction of the surfa brightness profile within the central 30 arcsec^2.

Кинематика

3.5м Calar Alto

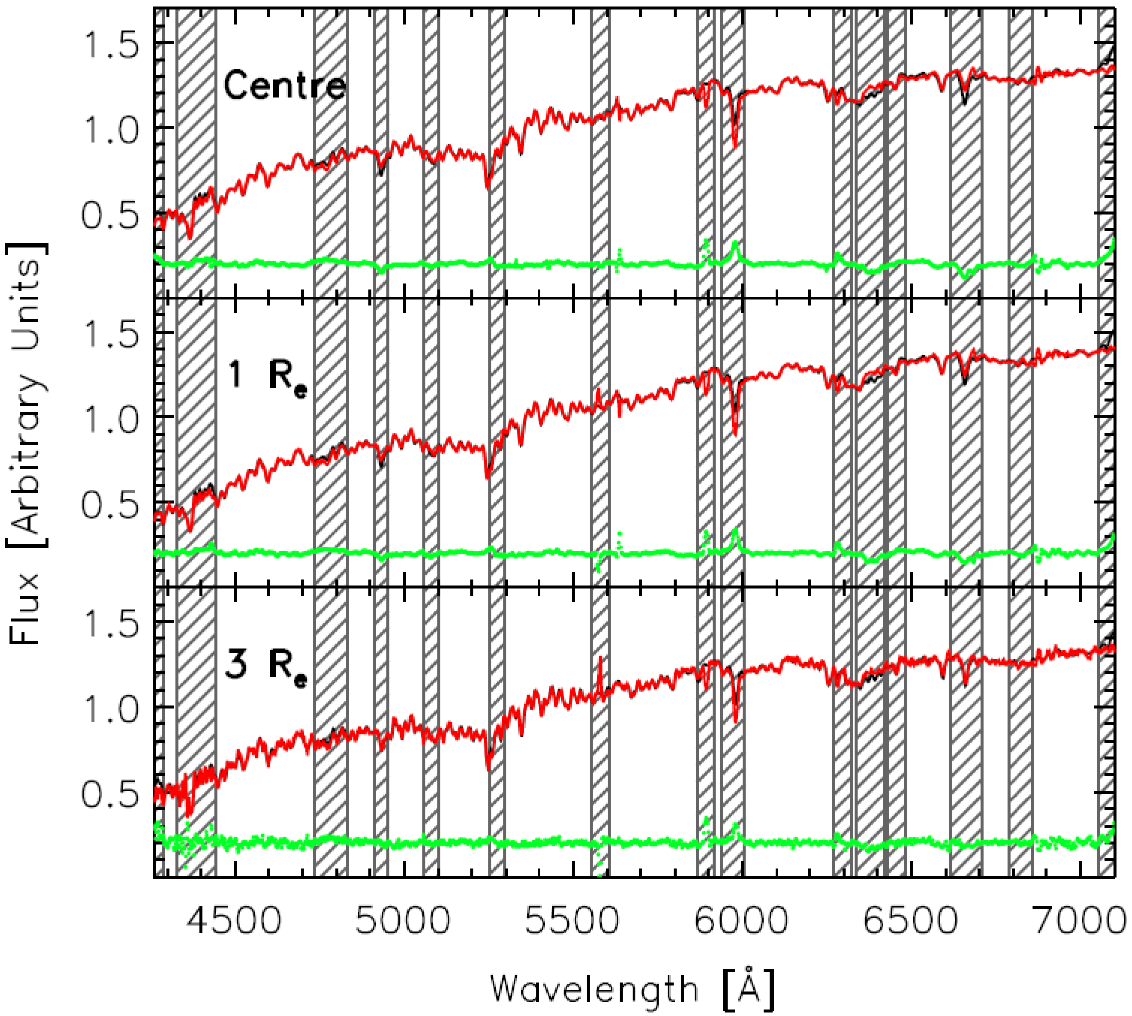


Figure 2. : The *PPAK* IFU spectra (black), the stellar templates convolved with the best-fitting LOSVD (red) and the model resid-

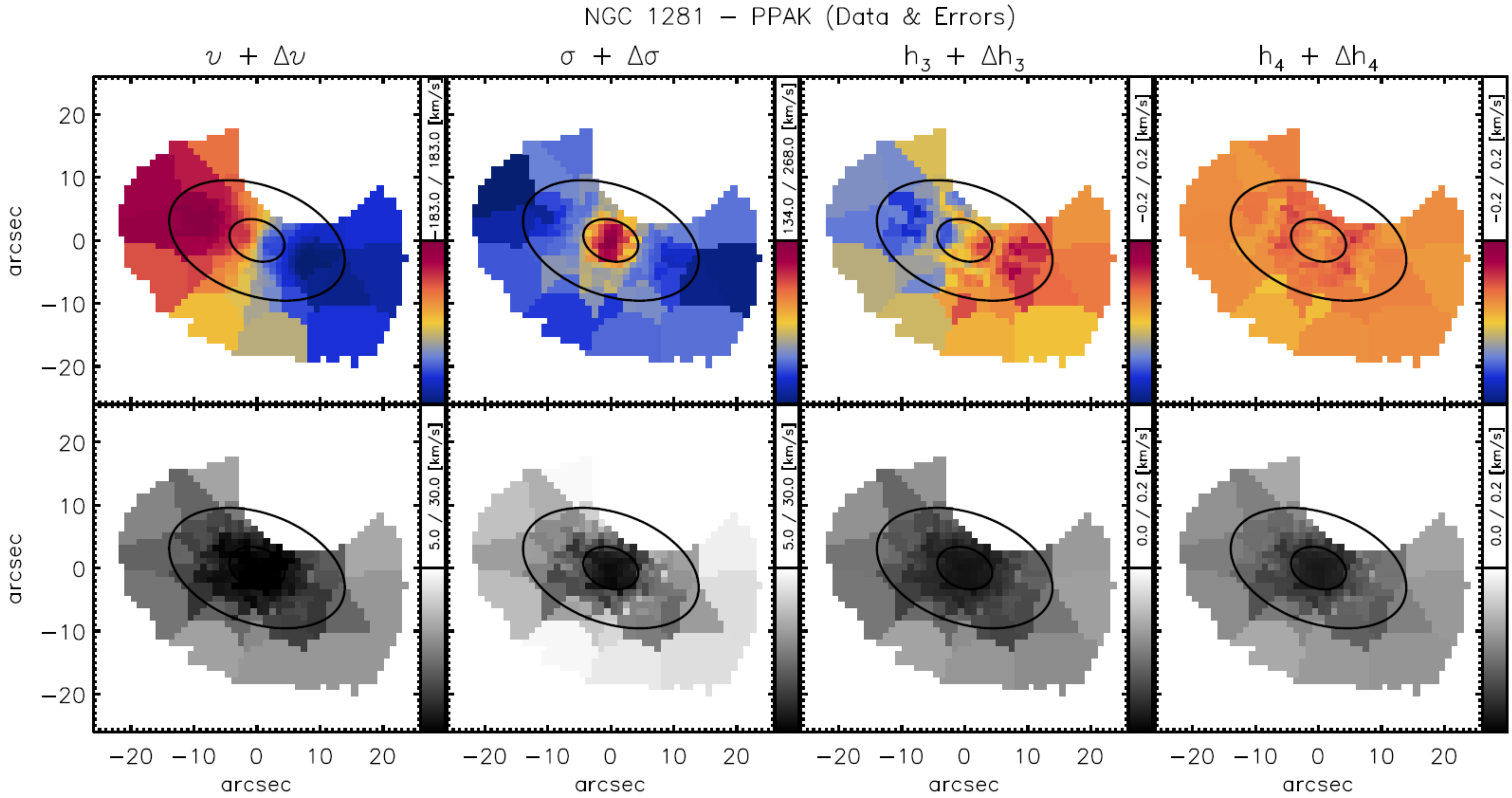


Figure 3. *Top*: PPAK IFU stellar kinematic maps of NGC 1281, showing the mean line-of-sight velocity v, velocity dispersion σ, and Gauss-Hermite moments h_3 and h_4. The maps show a fast rotation around the short axis of 183 $\mathrm{km\,s^{-1}}$ and a central velocity dispersion of 268 $\mathrm{km\,s^{-1}}$. Overplotted are contours of constant surface brightness at 1 and 3 R_e, as measured from the deep *HST* photometry. The empty region above the centre is generously masked due to the presence of a bright foreground star. *Bottom*: Corresponding uncertainty maps. Maps are oriented N.-E., i.e. north is up and east is left.

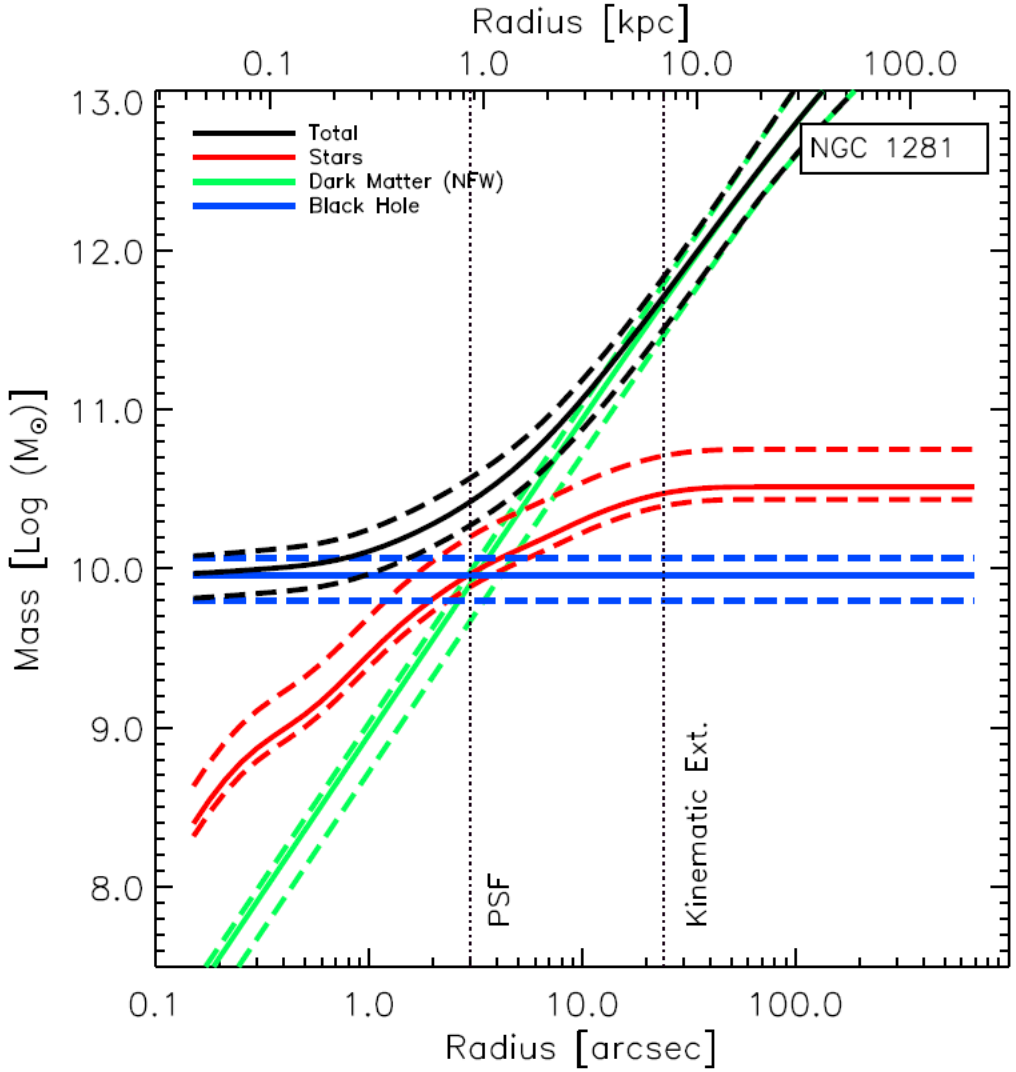


Figure 4. Intrinsic, enclosed mass distribution of NGC 1281 as a function of radius, obtained from our orbit-based dynamical models with a spherically symmetric NFW halo. Solid lines represent best-fitting values and dashed lines 3σ confidence intervals. The dotted vertical lines indicate the resolution limit and the extent of the kinematic observations.

В пределах 7 крс:

NFW profile:

We obtain a stellar mass of log(M*/Mc) = 10.5+0.2-0.1, a dark halo to stellar mass ratio of log(M_{DM}/M*) = 3.6+1.5-0.5, a black hole mass of log(M/Mc) = 10.0+0.1-0.2 and an H-band stellar M/L = 0.7+0.4 -0.1.

At small radii (<3”) the black hole is the dominant contributor to the total mass budget but quickly released from its role by the dark halo, which already takes over at 4.5” (i.e. 1 Re or roughly 1.3 kpc). The total enclosed mass within the kinematic extent is log(M_{TOT} /Mc) = 11.7+0.1-0.2.

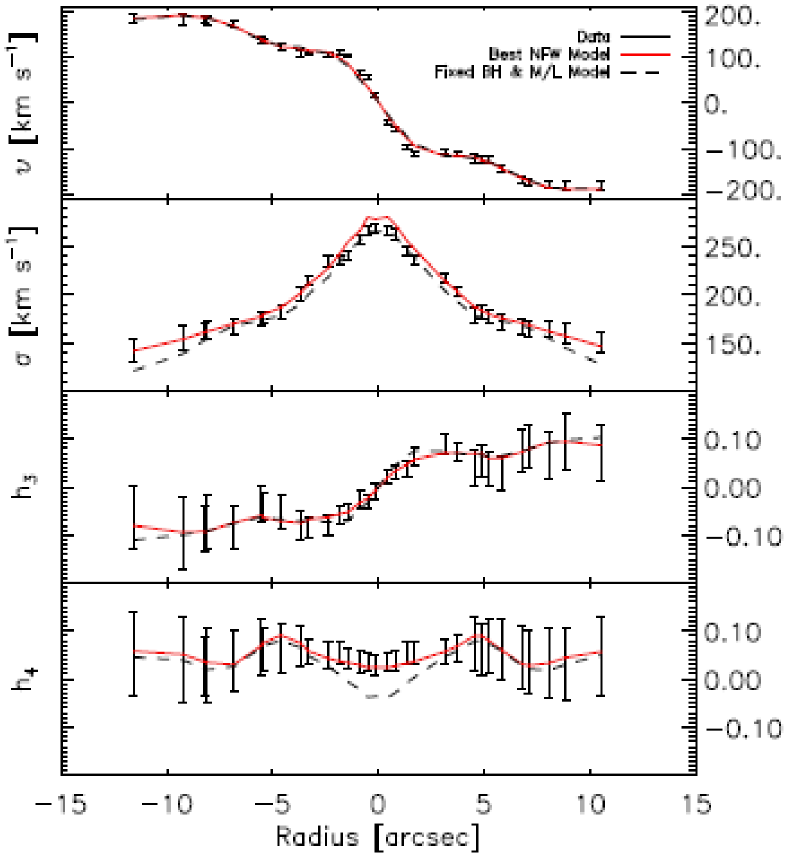
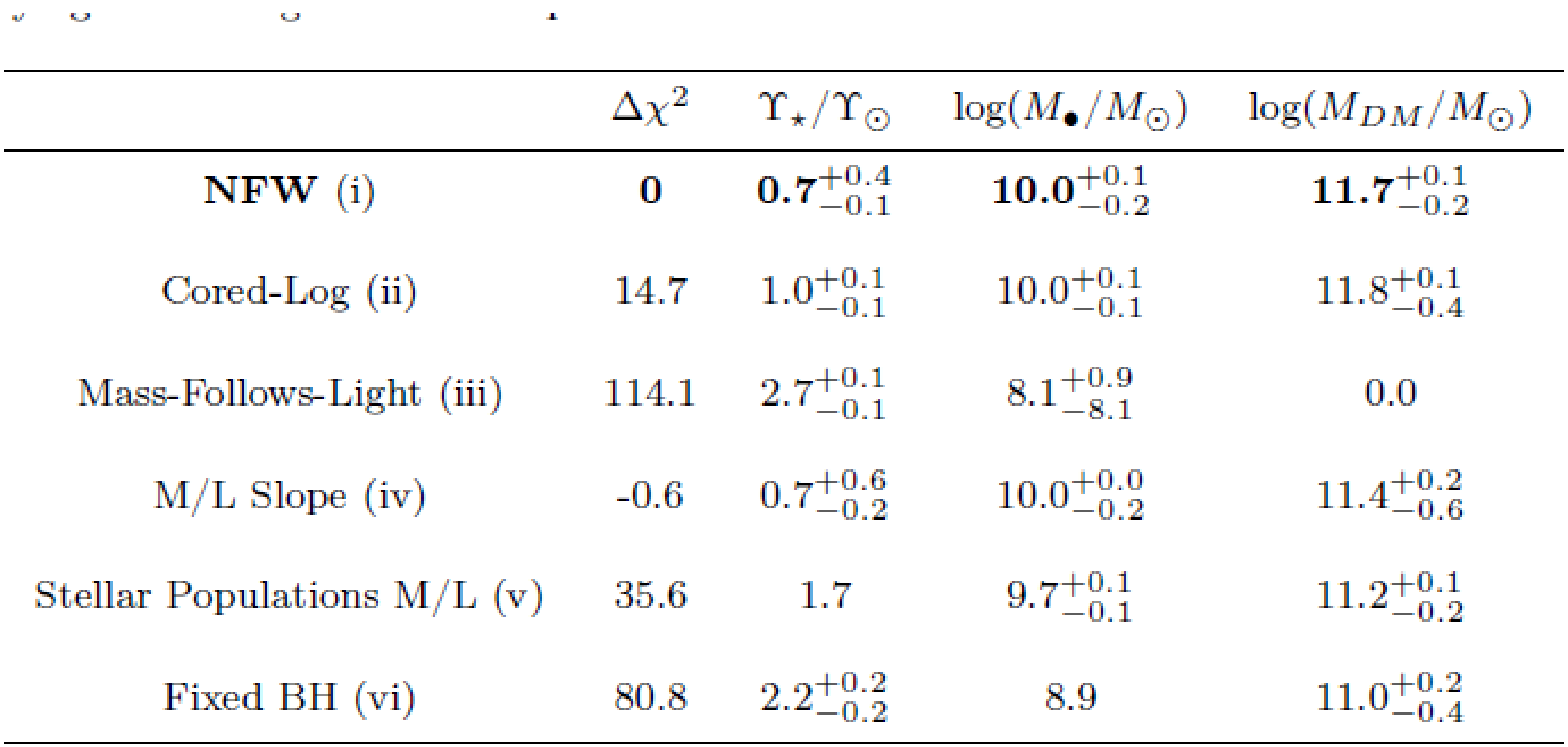


Figure 10. LOSVD of NGC 1281, for the Voronoi bin centroids which fall within a 1″wide strip along the major axis. The red and dashed line correspond to the recovered LOSVD of the best-fitting NFW model and a model with a fixed black hole mass of $\log(M_\bullet/\mathrm{M}_\odot) = 9.1$, a stellar M/L of 1.8 $\Upsilon_\odot$ and a dark halo of $\log(M_{DM}/M_\star) = 2.5$. If fixed to parameters that are promoted by the black hole scaling relations and its stellar populations, the velocity dispersion peak can be recovered well, but the models fail to fit the outer velocity moments which stresses the need for a massive dark halo.

Другие модели по сравнению с reference model (NFW)



	$\Delta\chi^2$	$\Upsilon_\star/\Upsilon_\odot$	$\log(M_\bullet/M_\odot)$	$\log(M_{DM}/M_\odot)$
NFW (i)	$\mathbf{0}$	$\mathbf{0.7^{+0.4}_{-0.1}}$	$\mathbf{10.0^{+0.1}_{-0.2}}$	$\mathbf{11.7^{+0.1}_{-0.2}}$
Cored-Log (ii)	14.7	$1.0^{+0.1}_{-0.1}$	$10.0^{+0.1}_{-0.1}$	$11.8^{+0.1}_{-0.4}$
Mass-Follows-Light (iii)	114.1	$2.7^{+0.1}_{-0.1}$	$8.1^{+0.9}_{-8.1}$	0.0
M/L Slope (iv)	-0.6	$0.7^{+0.6}_{-0.2}$	$10.0^{+0.0}_{-0.2}$	$11.4^{+0.2}_{-0.6}$
Stellar Populations M/L (v)	35.6	1.7	$9.7^{+0.1}_{-0.1}$	$11.2^{+0.1}_{-0.2}$
Fixed BH (vi)	80.8	$2.2^{+0.2}_{-0.2}$	8.9	$11.0^{+0.2}_{-0.4}$

The effective radius in NGC1281 encompasses a dark matter fraction of fDM = 0.47, and as such, is 3 times higher than inferred from the population of regular ETGs in the ATLAS3D sample (Cappellari et al. 2013) for galaxies with stellar masses in the range of log(M*) ~ 11. It is, however, in line with the dark matter fraction of BCGs such as NGC4889.

Taking into account the prediction of an unreasonably low stellar M/L as well as the presence of an over-massive supermassive black hole, we conclude that a spherical NFW profile cannot be a fair assumption of the dark halo profile of this galaxy.

Выводы

NGC1281 is a dark matter dominated galaxy with a dark matter fraction of 90 percent to the total enclosed mass within the kinematic extent, irrespective of the adoption of a NFW or CL halo.

The extrapolated dark halo profile (NFW) would imply a dark halo virial mass of $\log(M_{DM}/Mc) = 14.1$. This halo mass is typically ascribed to the halo of galaxy clusters and in contrast to findings based on CDM cosmology and the halo abundance matching mechanism.

Model M/L=const = 1.7 (stellar) provides a significantly worse fit to the stellar kinematics and is neither able reconcile the dark halo mass with those predicted within the CDM framework nor the stellar M/L with the values promoted by its stellar populations.

Требуется компромиссная модель! Профиль NFW не пригоден для описания галактики в целом, конфликтуя со звездным отношением M/L.

The Orbits and Total Mass of the Magellanic Clouds

Gurtina Besla

Abstract This proceeding overviews our current understanding of the orbital history and mass of the Large and Small Magellanic Clouds. Specifically I will argue that the Clouds are on their first infall about our Milky Way and that their total masses are necessarily ∼10 times larger than traditionally estimated. This conclusion is based on the recently revised HST proper motions of the Clouds and arguments concerning the binary status of the LMC-SMC pair and their baryon fractions.

1 Introduction

Owing to their proximity to our Galaxy, the Magellanic Clouds (MCs) have been observed in wavebands spanning almost the entire electromagnetic spectrum, allowing us to study the interstellar medium (ISM) of two entire galaxies in unprecedented detail. Such observations have facilitated studies of how turbulence, stellar feedback and star formation are interrelated and how these internal processes affect galactic structure on small to large scales (e.g., Elmegreen, Kim & Staveley-Smith, 2001; Block et al., 2010).

Две причины пересмотра масс Магеллановых Облаков.

- 1. Измерение собственных движений: галактики движутся быстрее, чем ожидалось (HST)
- SMC: 217 ± 26 km/s with respect to the MW and 128 ± 32 km/s with respect to the LMC; the SMC cannot be on a circular orbit about the LMC
- 2. Концепция массивных темных гало.

The LMC has a well defined rotation curve that peaks at Vc = 91.7 ± 18.8 km/s and remains flat out to at least 8.7 kpc (van der Marel & Kallivayalil, 2014), consistent with the baryonic Tully-Fisher relation. This implies a minimum enclosed total mass of M(8.7 kpc) = $1.7 *10^{10}\ M_\odot$; the LMC is dark matter dominated.

The high speed LMC-SMC makes it very difficult to maintain a long-lived binary, unless the LMC is substantially more massive than traditionally modeled

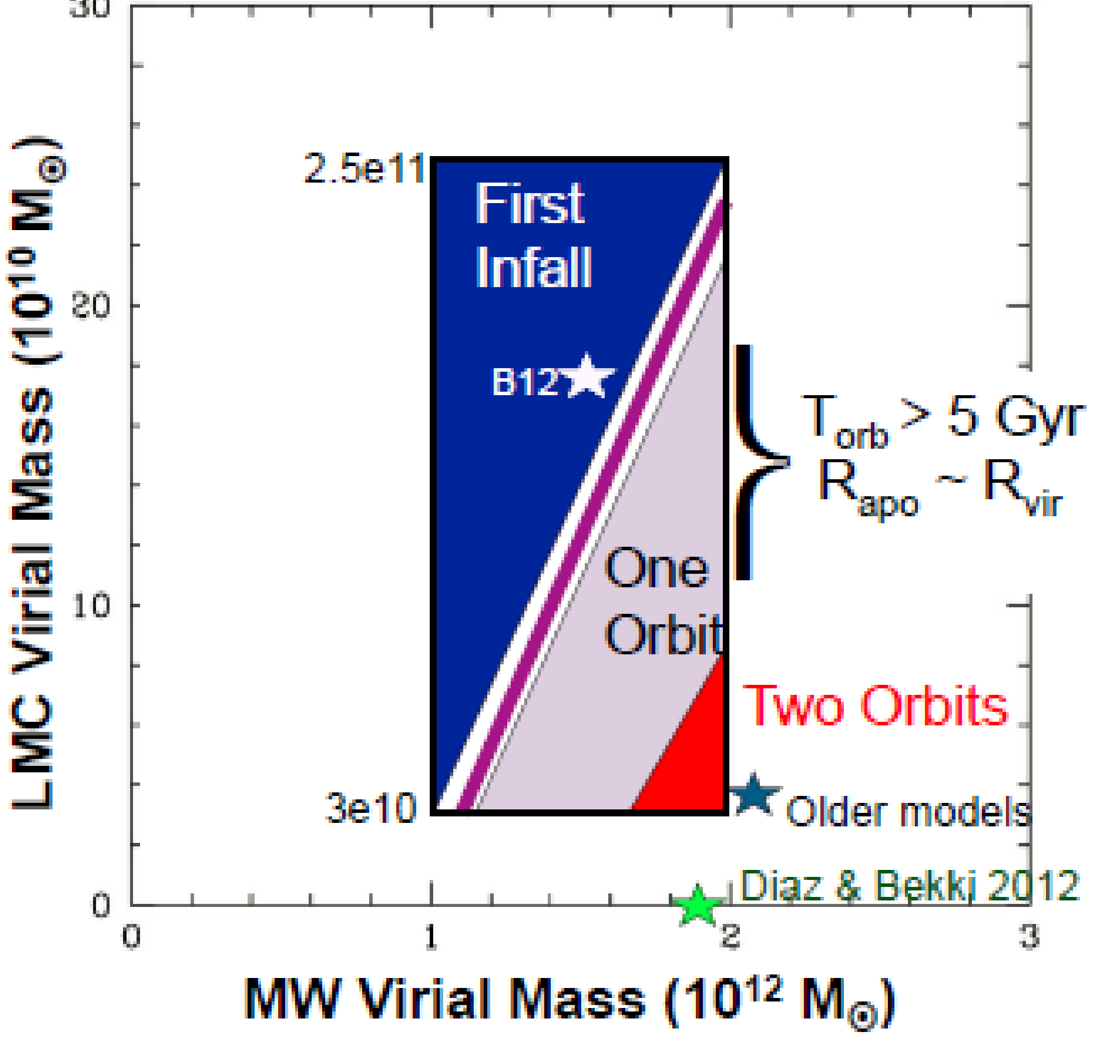


Fig. 1 Typical orbital histories for the LMC are indicated as a function of LMC and MW mass. Orbits are determined by searching the 4σ proper motion error space in Monte Carlo fashion and computing the mean number of pericentric passages completed within 10 Gyr. High mass LMC models experience greater dynamical friction and are consequently on more eccentric orbits, yielding first infall solutions (dark blue regions). Lower mass models allow for orbits where the

Выводы

The Magellanic Clouds are recent interlopers in our neighborhood.

Their total masses must be at least a factor of 10 larger than traditionally modeled. Dynamical friction is ~M^2. It requires their orbits to be highly eccentric, preventing short period orbits.

Finally, the existence of a high relative velocity, LMC-SMC binary today strongly argues against their having completed a previous pericentric approach about our Galaxy, as MW tides can efficiently disrupt such tenuous configurations.

- The star formation histories (SFHs) of the MCs also suggest a common evolutionary history. Weisz et al. (2013) illustrate that∼4 Gyr ago, the SFHs of both the LMC and SMC appear to increase in concert. It is thus reasonable to assume the MCs have maintained a binary status for at least the past 4 Gyr.

- The high speed LMC-SMC makes it very difficult to maintain a long-lived binary, unless the LMC is substantially more massive than traditionally modeled

- Orbits for the SMC in MOND have small periods and apocenters (Zhao et al., 2013). Such orbital solutions cannot explain the absence of quenching in the star formation history of the SMC and the fact that there is currently just as much gas in the SMC as there is in its much larger

Stellar streams around the Magellanic Clouds

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ABSTRACT
Using Blue Horizontal Branch stars identified in the Dark Energy Survey Year 1 data, we report the detection of an extended and lumpy stellar debris distribution around the Magellanic Clouds. At the heliocentric distance of the Clouds, overdensities of BHBs are seen to reach at least to $\sim 30^\circ$, and perhaps as far as $\sim 50^\circ$ from the LMC. In 3D, the stellar halo is traceable to between 25 and 50 kpc from the LMC. We catalogue the most significant of the stellar sub-structures revealed, and announce the discovery of a number of narrow streams and diffuse debris clouds. Two narrow streams appear approximately aligned with the Magellanic Clouds' proper motion. Moreover, one of these overlaps with the gaseous Magellanic Stream on the sky. Curiously, two diffuse BHB agglomerations seem coincident with several of the recently discovered DES satellites. Given the enormous size and the conspicuous lumpiness of the LMC's stellar halo, we speculate that the dwarf could easily have been more massive than previously had been assumed.

Key words: Galaxy: fundamental parameters — Galaxy: halo — Galaxy: kinematics and dynamics — stars: blue stragglers — stars: horizontal branch

1 INTRODUCTION

This Universe is conjectured to have assembled hierarchically, from the bottom up, yet the evidence for accretion onto dwarf galaxies with luminosities $\leqslant 10^{10} L_\odot$ is currently scarce (Rich et al. 2012; Martínez-Delgado et al. 2012; Amorisco et al. 2014). In the cosmic pecking order, the Magellanic Clouds are just a position down from the Milky Way and, hence could, in principle, given their proximity, serve as a typical example of the sub-L_* satellite galaxy assembly in the ΛCDM Cosmology. The extent and the amount of lumpiness in the stellar halo (if it exists) of the Large Magellanic Cloud (LMC) would not only present another crucial piece of evidence

Lin et al. 1995) as well as its gaseous halo (Meurer et al. 1985; Moore & Davis 1994; Heller & Rohlfs 1994; Mastropietro et al. 2005) depending on the mechanism assumed responsible for the production of the Stream. Very quickly it was established that the Stream ought to originate from the SMC rather then the LMC (Murai & Fujimoto 1980; Connors et al. 2006), thus bringing into light the complex history of three-body encounters between the Clouds and the Galaxy. Even though the time the Clouds have spent together is not well constrained, several MS simulations revealed that it was possible for the LMC and the SMC to become a pair only recently as most of the salient MS features could be repro-

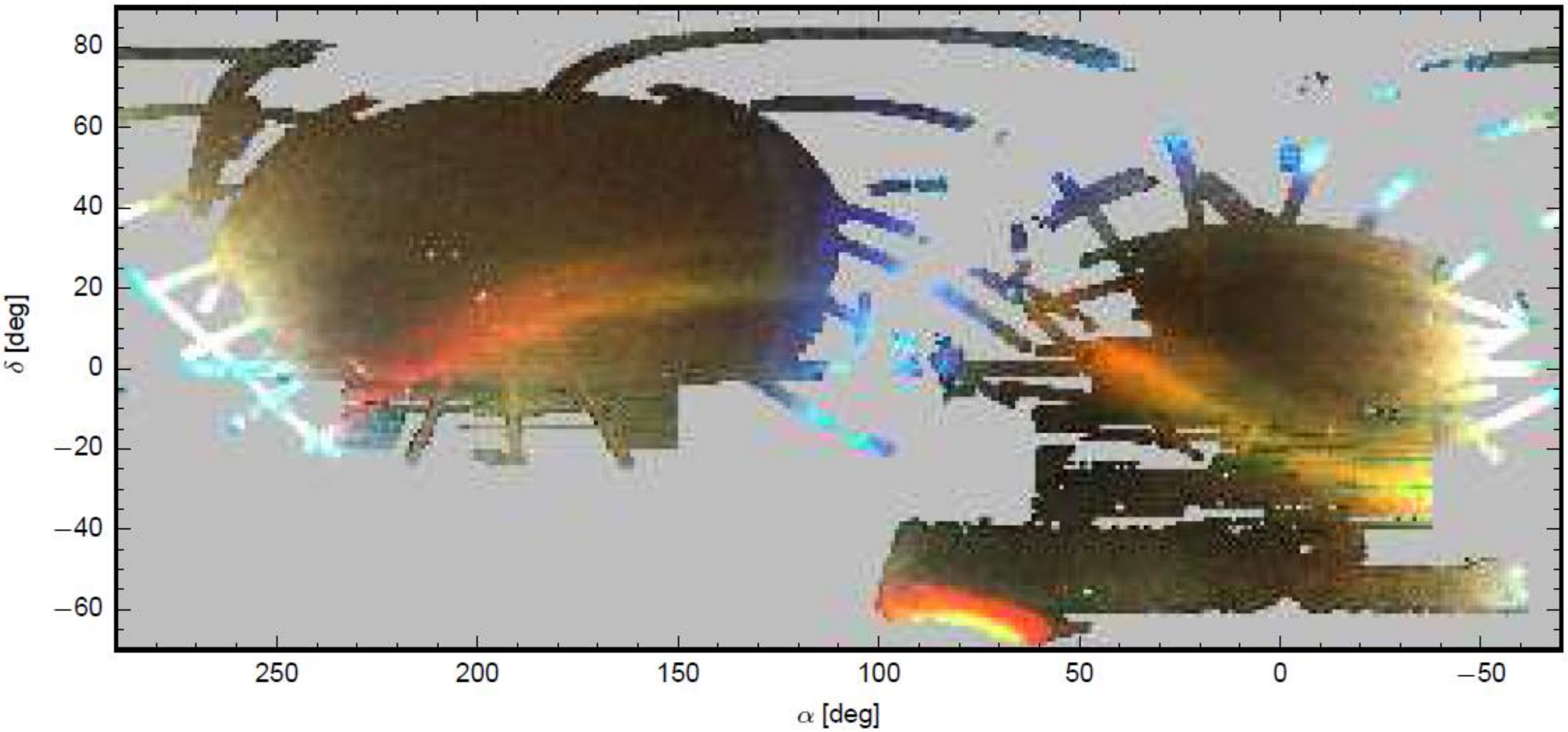
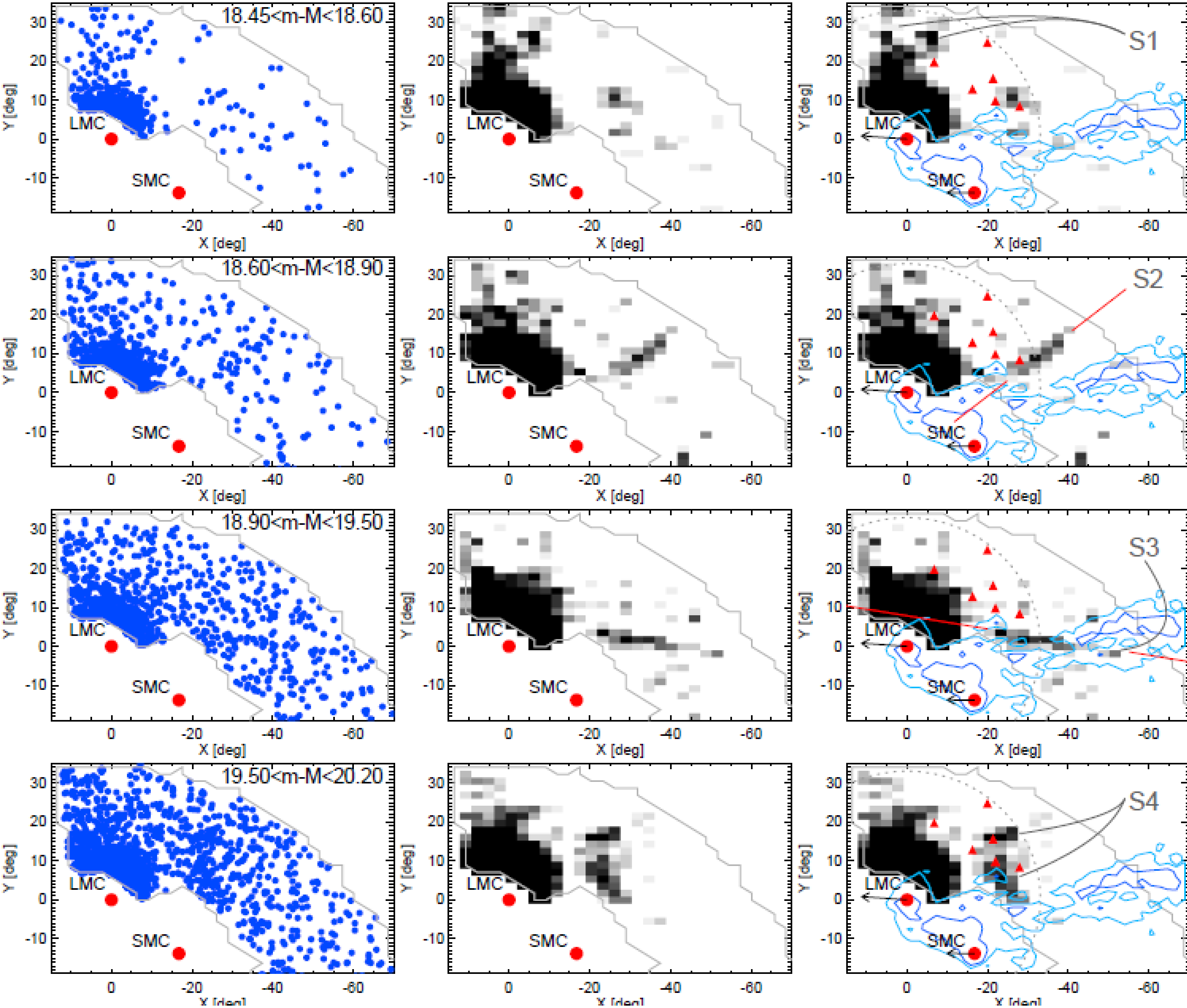


Figure 1. Jigsaw puzzle of the Galactic stellar halo as traced by the MSTO stars. This false-colour composite image combines data from three different surveys: SDSS DR9, VST ATLAS and DES Year 1. R, G and B channels of the image are greyscale density maps of stars with $0.2 < (g - i) < 0.5$ within the following magnitude ranges: $22 > i > 21$ (red), $21 > i > 20$ (green) and $20 > i > 19$ (blue). The Sgr stellar stream and the LMC (with the centre at $\alpha = 80^\circ\!.9$ and $\delta = -69^\circ\!.7$) are the most prominent halo structures visible. Note also two faint and fuzzy overdensities of approximately green colour at RA$\sim 100^\circ$ and RA$\sim 30^\circ$. These must lie much closer along the line of sight as compared to the LMC.

- m-M=

18.5 (LMC)

19.0 (SMC)



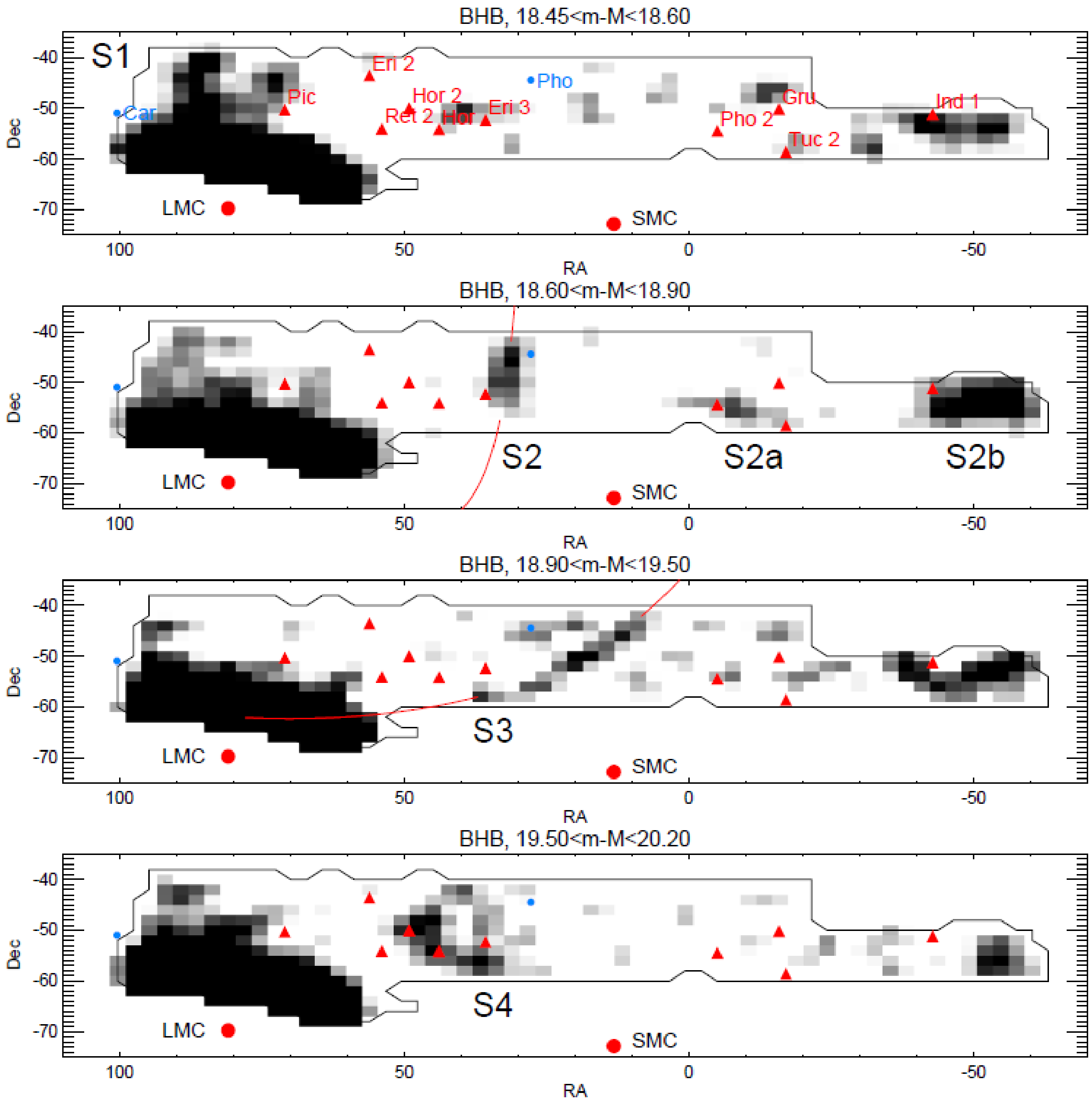


Figure 7. Magellanic stellar streams in equatorial coordinates. Top to bottom: density distributions of the BHB stars selected to lie in the four heliocentric distance bins described earlier. The maps are 60×25 pixels, and are smoothed with a Gaussian kernel with a FWHM of 2 pixels. Red filled circles show the locations of the LMC and the SMC, small blue filled circles mark the positions of the previously known satellites, while the red triangles correspond to the DES Year 1 satellites. Red lines show the great circle for streams S2 and S3. All structures identified in the gnomonic projection in the Figure 6 are also present in these maps. Additionally, three more possible detections are noticeable, i.e. those at RA$\sim -10^\circ$ and RA$\sim -50^\circ$. Given that these structures are most prominent in the distribution of BHBs falling into the 2nd distance bins, they are dubbed S2a and S2b correspondingly. Note that Hor 1, Hor 2 and Eri 3 appear to overlap with the S2 cloud and its counterpart in the 1st distance modulus bin (top panel). Additionally, three other DES Year 1 satellites Pho 2, Gru and Tuc 2 seem to coincide with the S2a cloud.

Выводы

- Звездное гало, найденное по клочковатому распределению BHB stars, прослеживается “in 3D” дальше 25 kpc от LMC. Обнаружено несколько потоков и диффузных облаков. В двух случаях потоки оказались вытянутыми примерно вдоль направления собственного движения Облака. Две диффузные области звезд совпали с найденными ранее карликовыми спутниками.
- Галактика может быть более массивна, чем это принято считать.