Tracing the stellar halo with BHB stars

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Stellar Halos Across the Cosmos

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Blue horizontal branch stars in the Canada-France Imaging Survey I. The stellar halo of the Milky Way traced to large radius

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ABSTRACT

We present the stellar density profile of the outer halo of the Galaxy traced over a range of Galactocentric radii from $15 < R_{GC} < 250$ kpc by blue horizontal branch (BHB) stars. These stars are identified photometrically using $u-$band imaging from the new Canada-France-Imaging-Survey (CFIS), which reaches 24.5 mag, combined with $griz$ bands from Pan-STARRS 1, covering a total of $\sim$ 4200 deg^2 of the northern sky. We present a new method to select BHB stars that has low contamination from blue stragglers and high completeness. We use this sample to measure and parameterize the three dimensional density profile of the outer stellar halo, using both a simple power-law with a constant flattening, and a flattening that varies as a function of Galactocentric radius. In the case of a constant flattening, we find that the density profile is well described by a slope of $\gamma = 3.42 \pm 0.02$ and an oblateness of $q = 1.06 \pm 0.2$, consistent with the recent result of Fukushima et al. (2017). In the case of the radius-dependent flattening, we find that the inner halo is more oblate ($q_0 = 0.96 \pm 0.03$) than at large distance ($q_\infty = 1.25^{+0.07}_{-0.06}$), and has a power-law slope of $\gamma = 3.60 \pm 0.04$. With these two models, the profile of the stellar halo trace by BHB stars is shallower than when traced by RR Lyrae, a surprising result given the similarity of these stellar populations.

Key words: stars: horizontal branch – stars: distances – stars: statistics – Galaxy: structure – Galaxy: halo

1 INTRODUCTION

It is now generally accepted that large galaxies, like the Milky Way, have been formed by a succession of mergers and via the accretion of smaller galaxies, in a process called hierarchical formation. In the case of accretions, the smaller galaxy is disrupted due to the tidal effects generated by the larger (host) galaxy. This leads to the formation of stellar streams clearly visible around many massive galaxies of the Local Group (e.g. Martínez-Delgado et al. 2010; Martin et al. 2013; Grillmair & Carlin 2016; Bernard et al. 2016; Malhan et al. 2018). Although these structures stay spatially coherent for many Gyr (Johnston et al. 2008), they tend to be eventually destroyed by mixing effects and are in turn assimilated to form part of the "smooth" stellar halo.

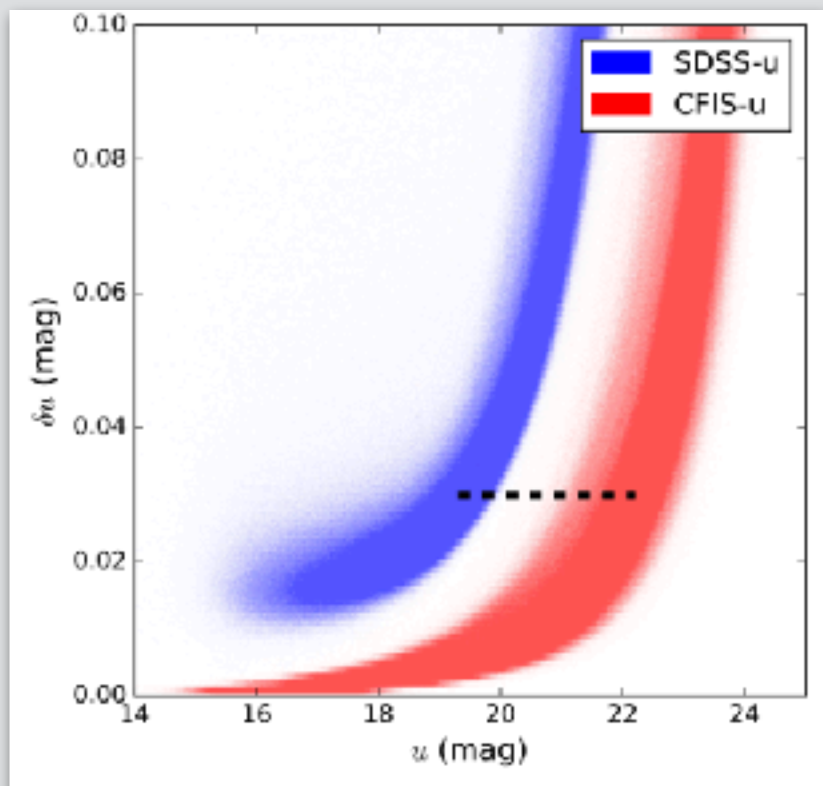
CFIS &

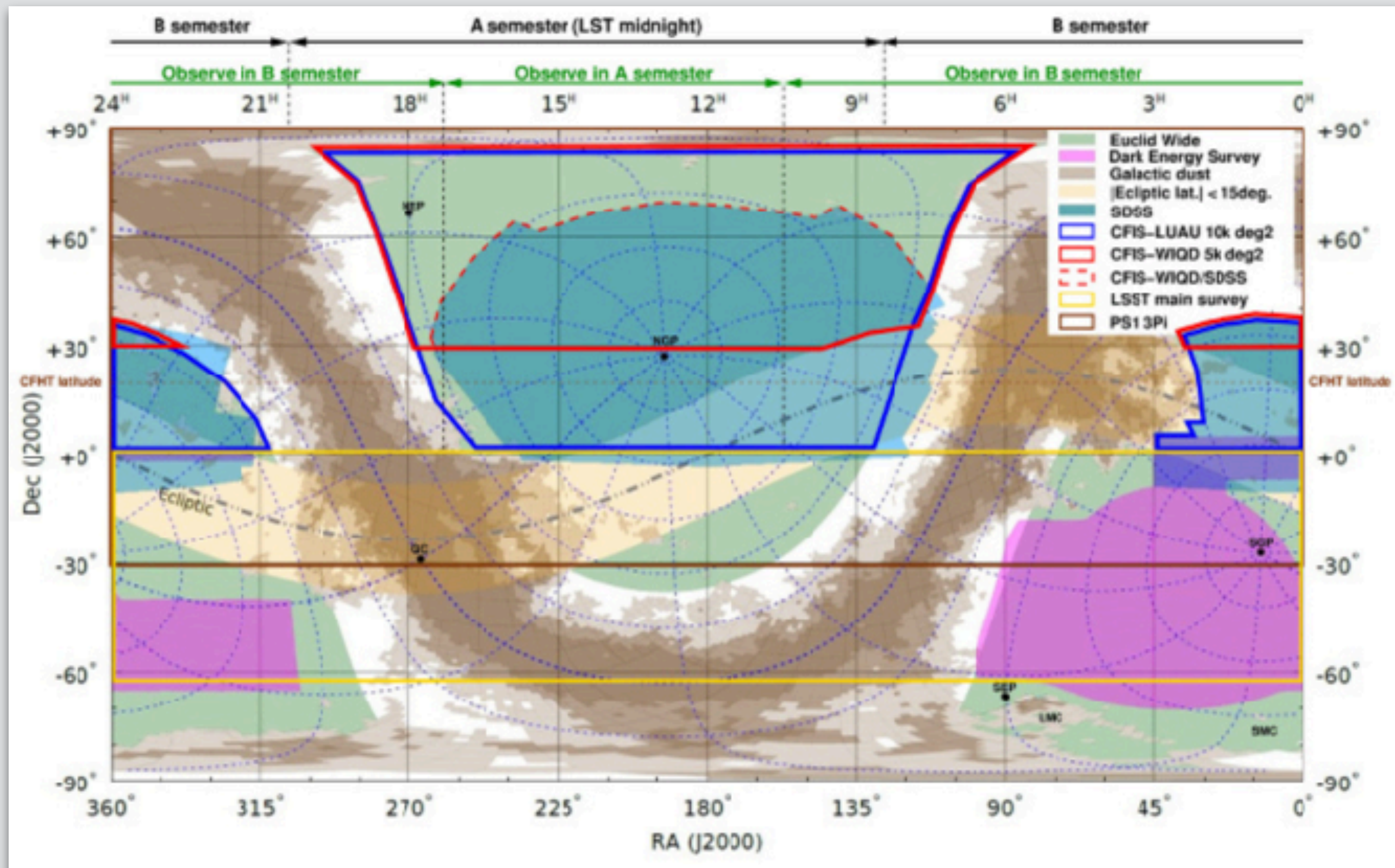
UNIONS

CFIS

- ***u*-band** : 10,000 deg^2
- ***r*-band** : 5,000 deg^2

Ibata et al., 2017





- ***u*-band** : **3 mag** deeper than SDSS

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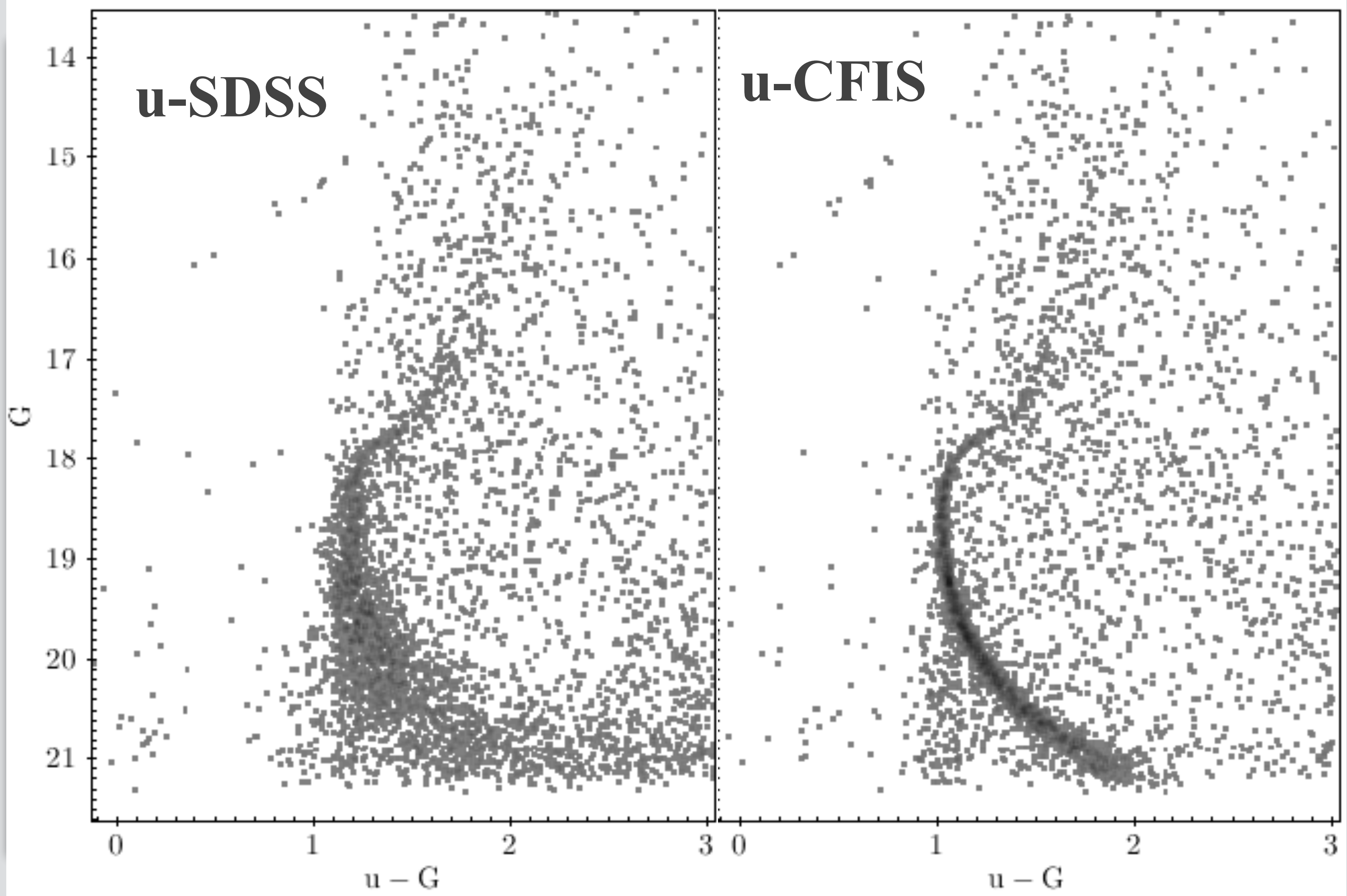

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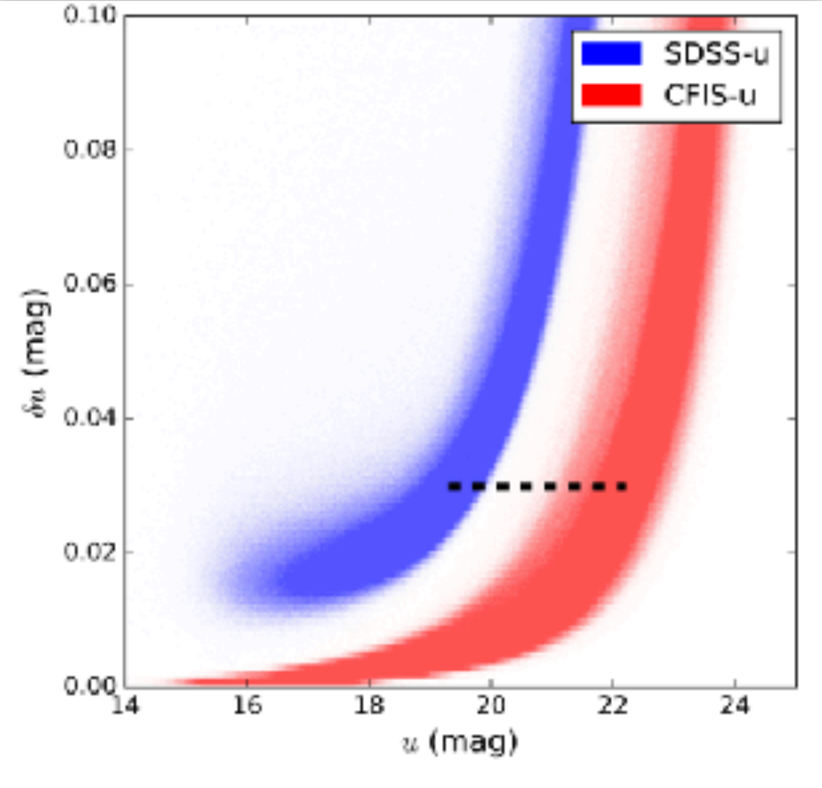

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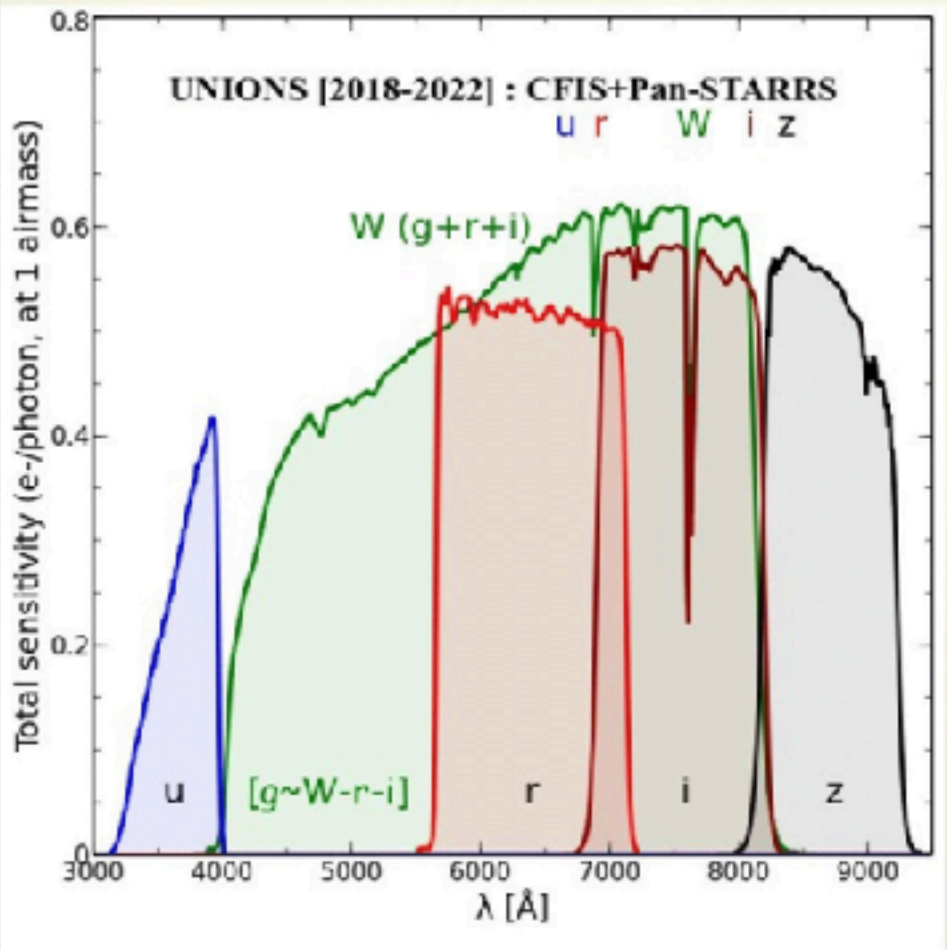
UNIONS

The Ultraviolet Near-Infrared Optical Northern Survey



- **MoU** between **CFIS** and **Pan-STARRS**
- **u W r i z photometric bands**

What is the stellar halo?

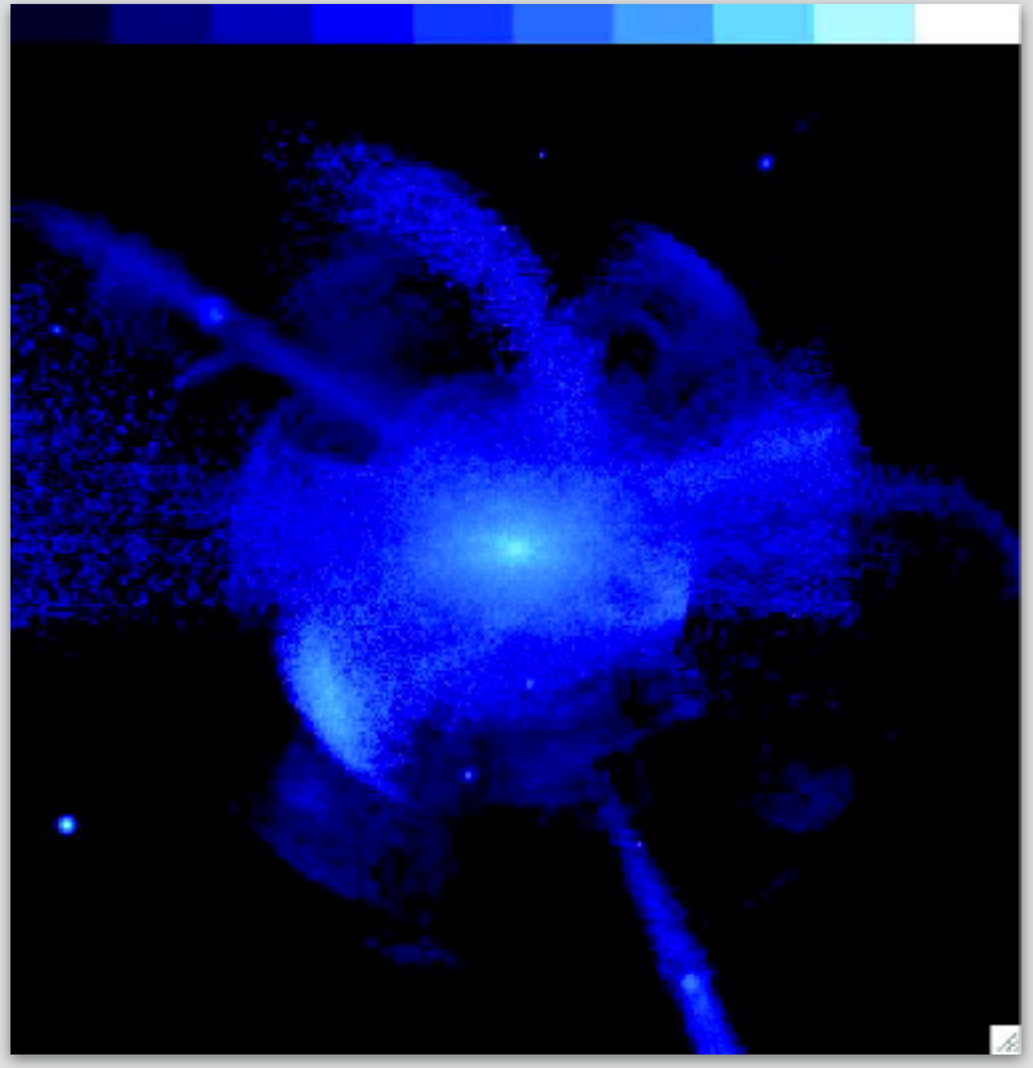
How does it form?

How was the Stellar Halo formed?

- Two mechanisms:

    - ***In-situ* stars:** formed initially in the stellar halo or kicked out of the disc
      * **metal rich** ([Fe/H]>-1.0)
      * dominant < 20 kpc

    - **Accreted stars:** coming from the accreted galaxies/globular clusters
      * **metal poor** ([Fe/H]<-1.0)
      * dominate the **outer stellar halo**



Bullock & Johnston 2005

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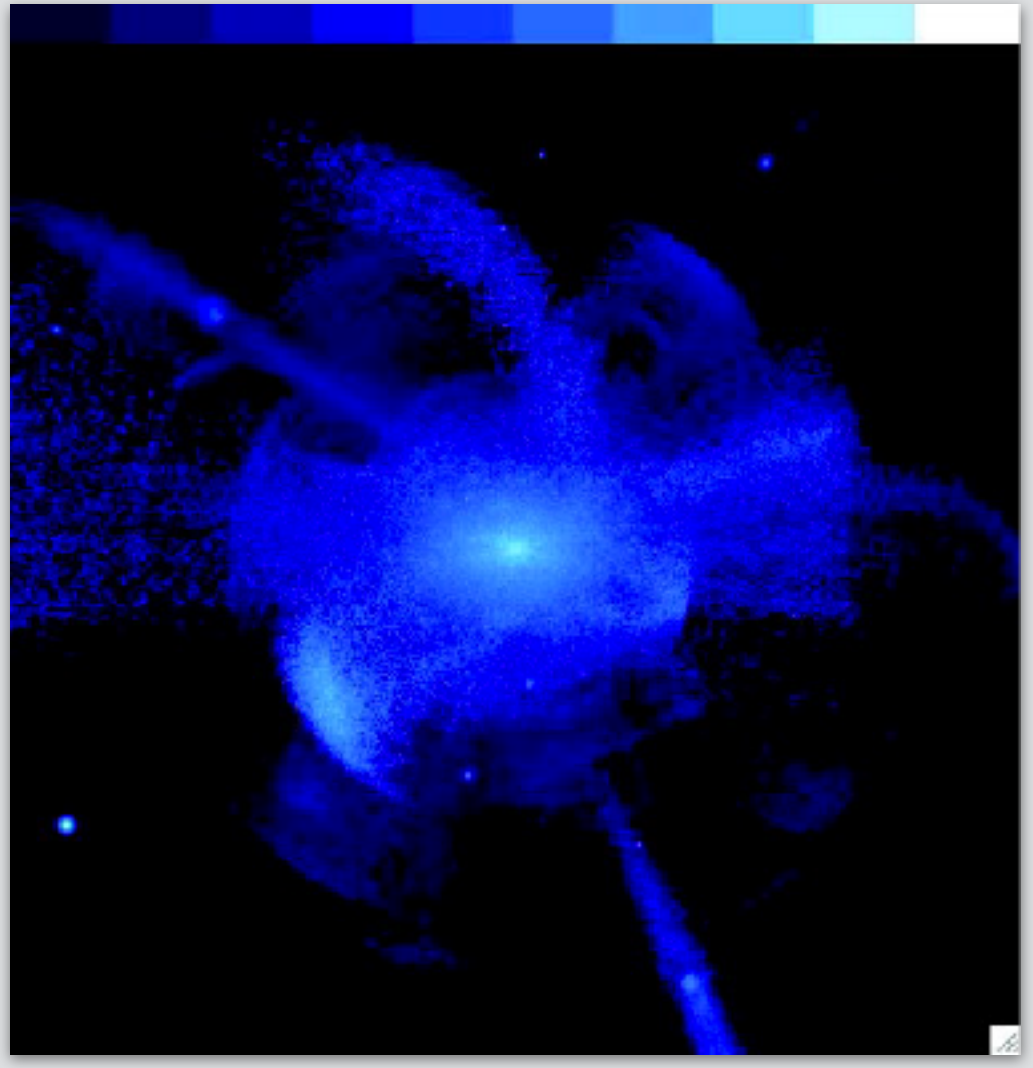

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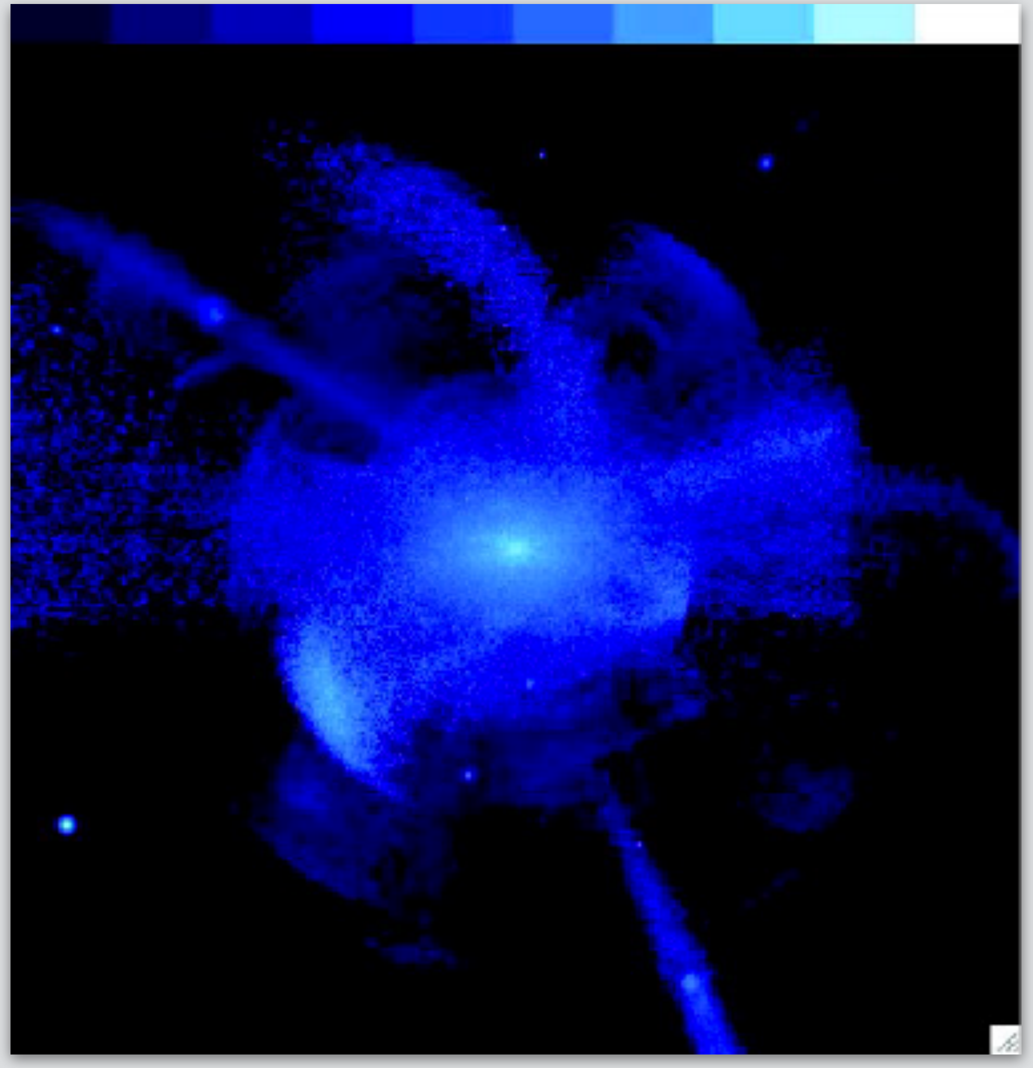
"...a study of these subsystems allows us partially to reconstruct the Galactic past..." Olin Eggen



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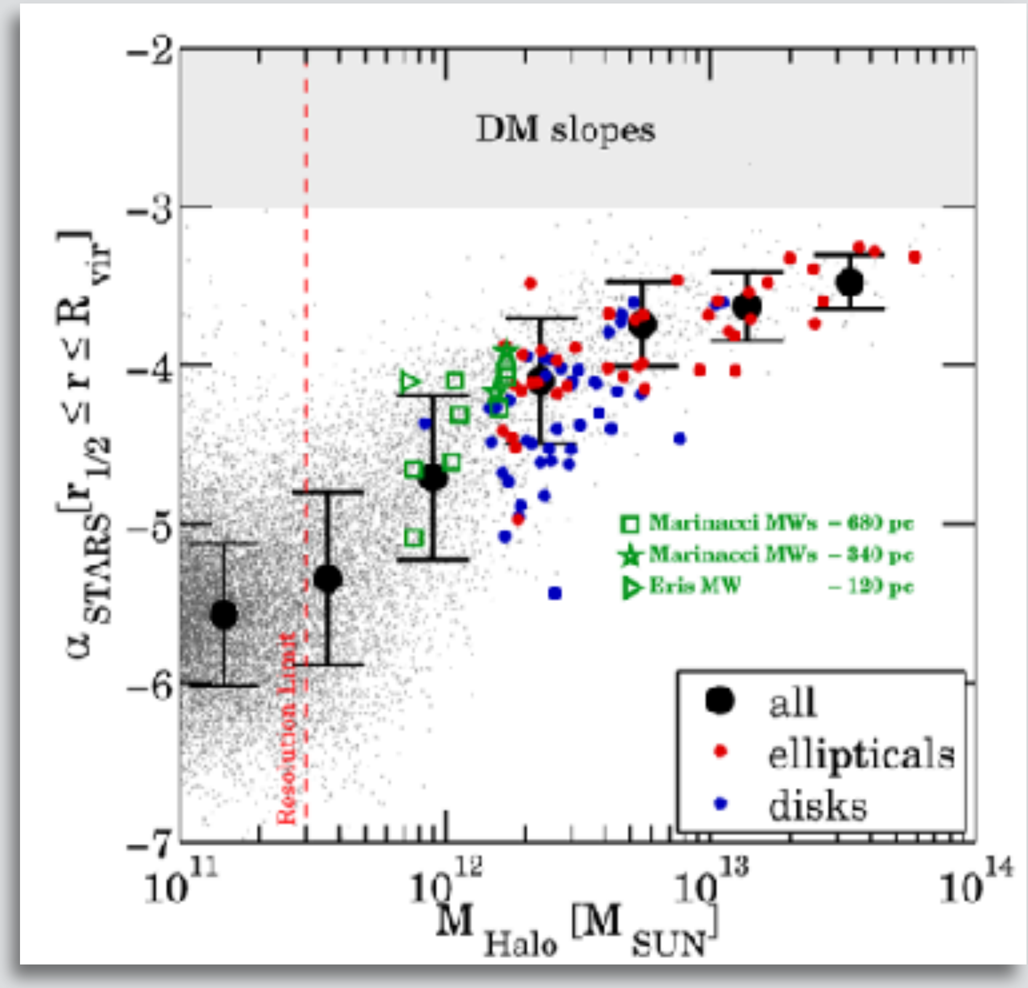

Pillepich et al., 2014, 2018

- **Correlation** between the **slope** of the stellar halo and the **total mass** of a galaxy
- **Correlation number** of principle **progenitors**

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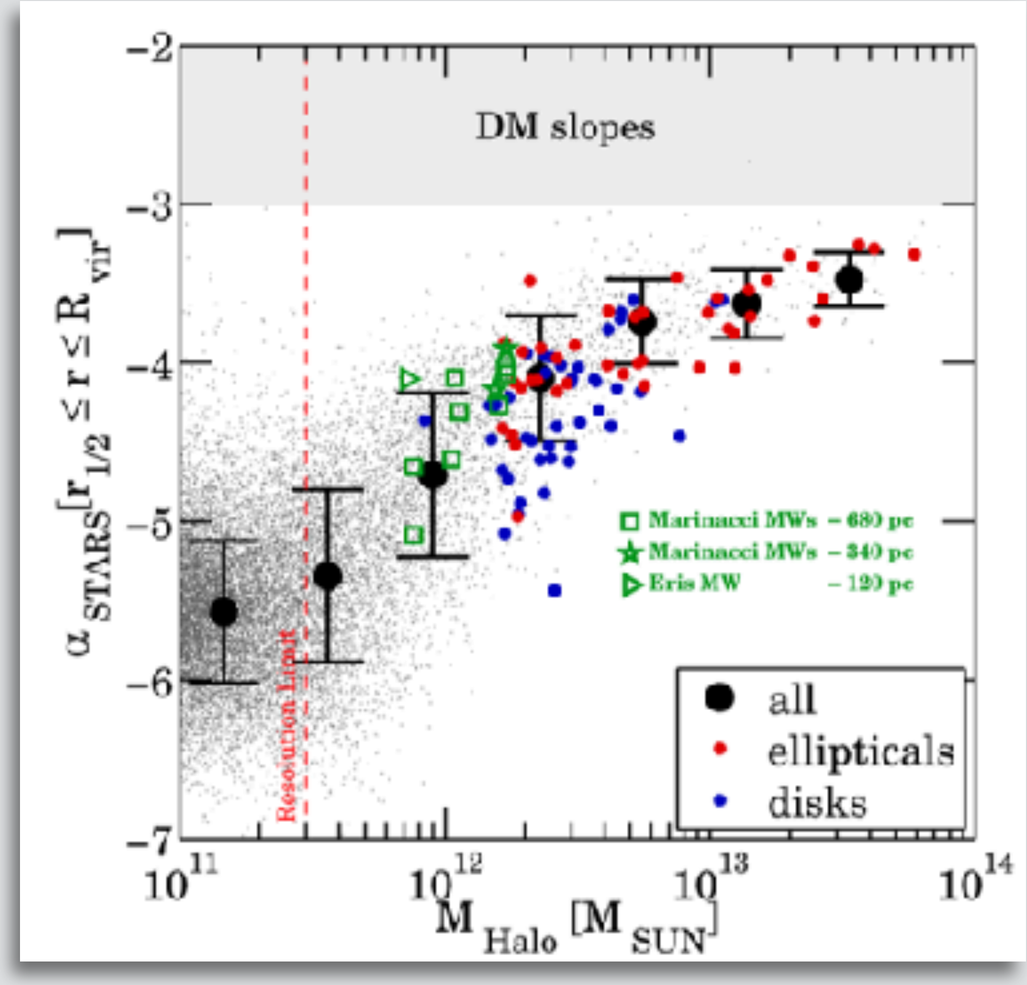

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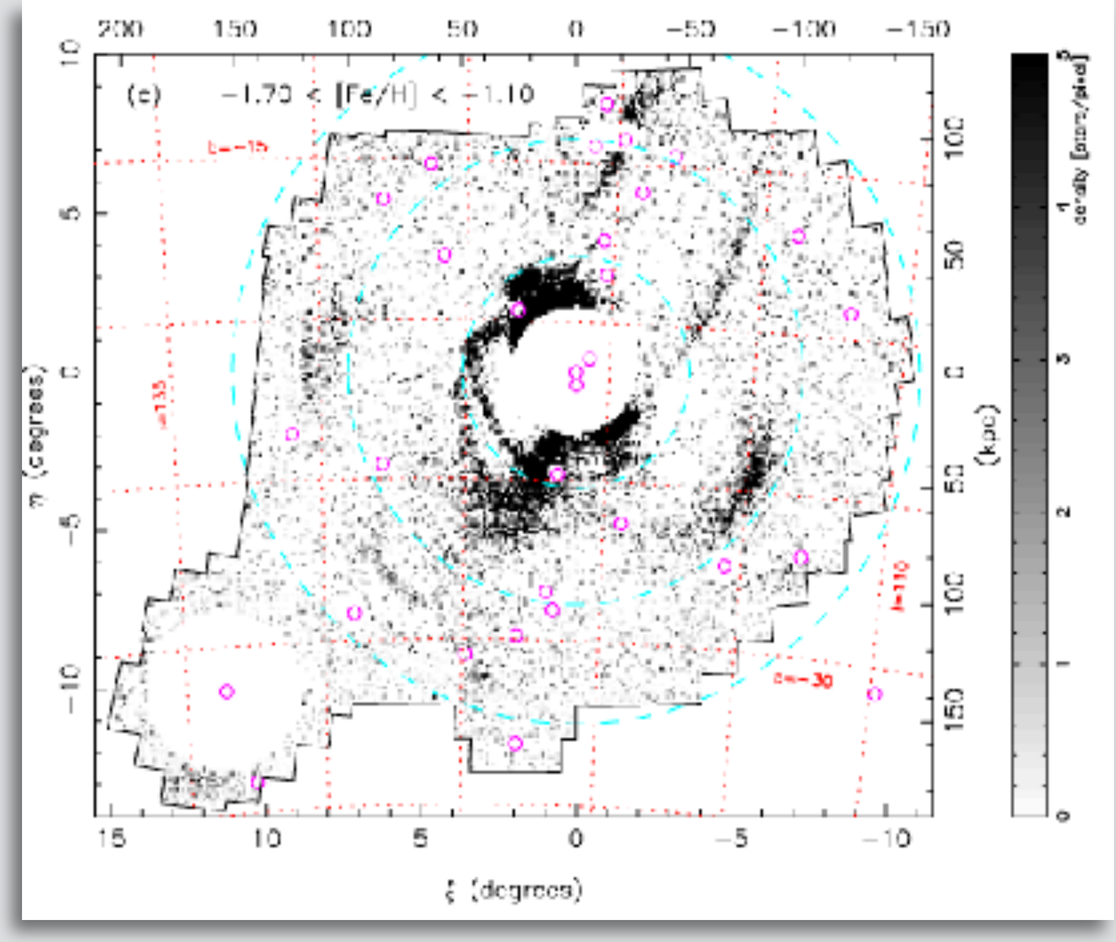

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- Presence of **substructures** → bias the slope

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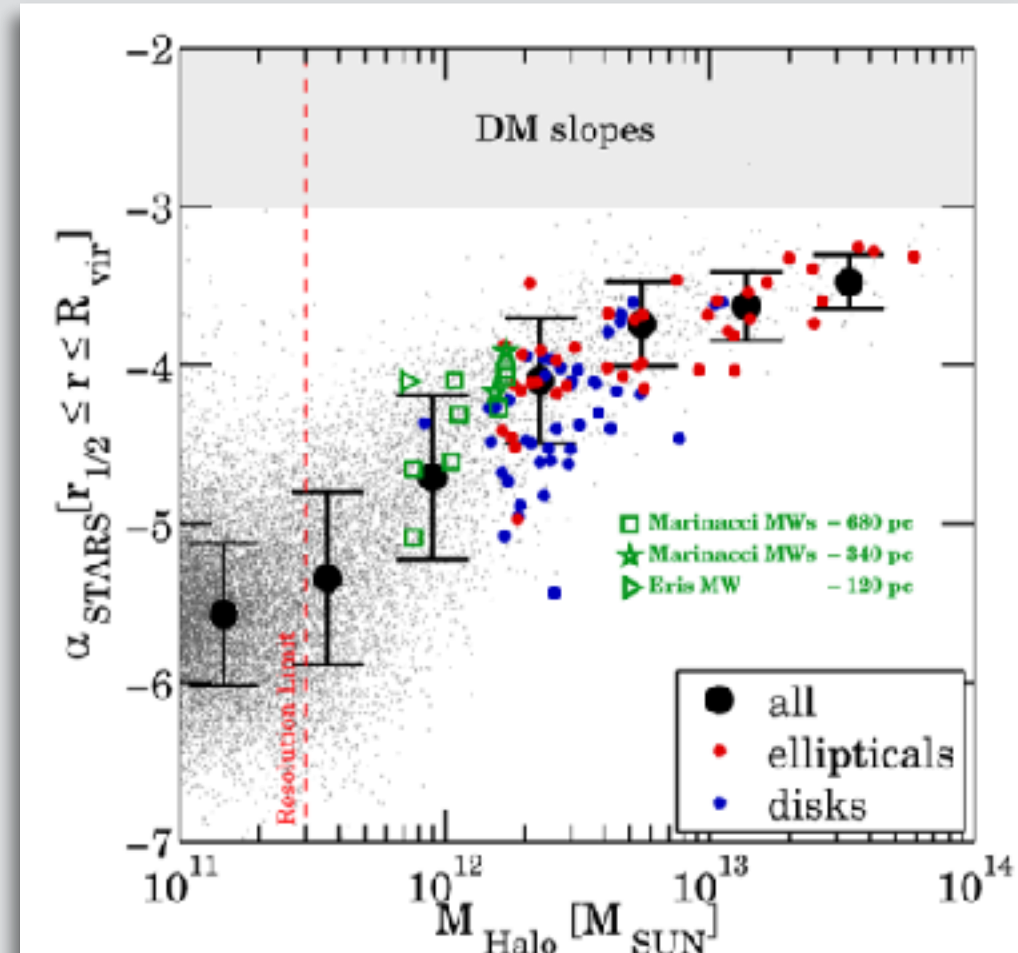

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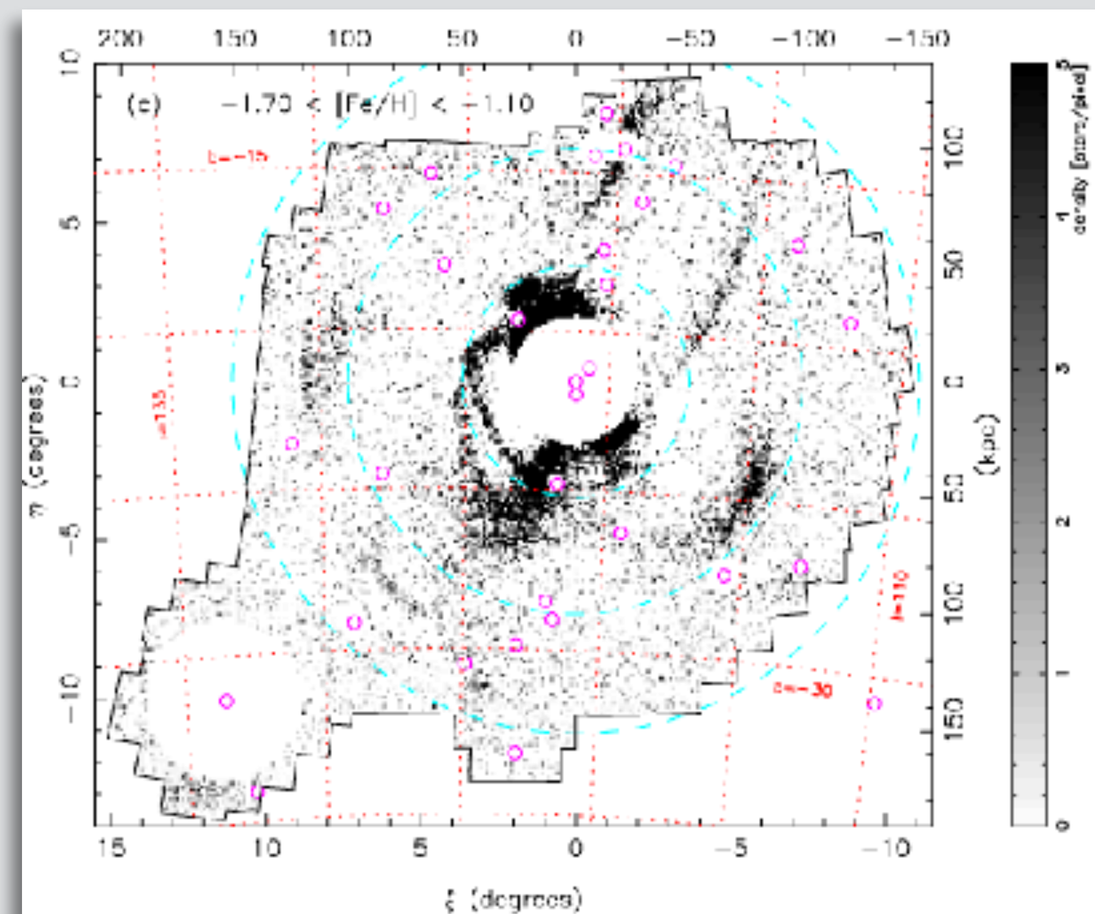

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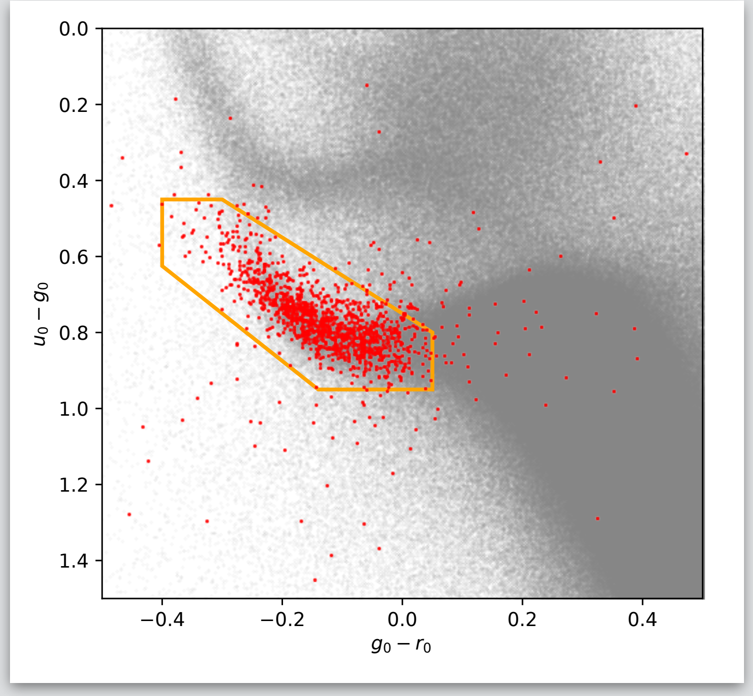
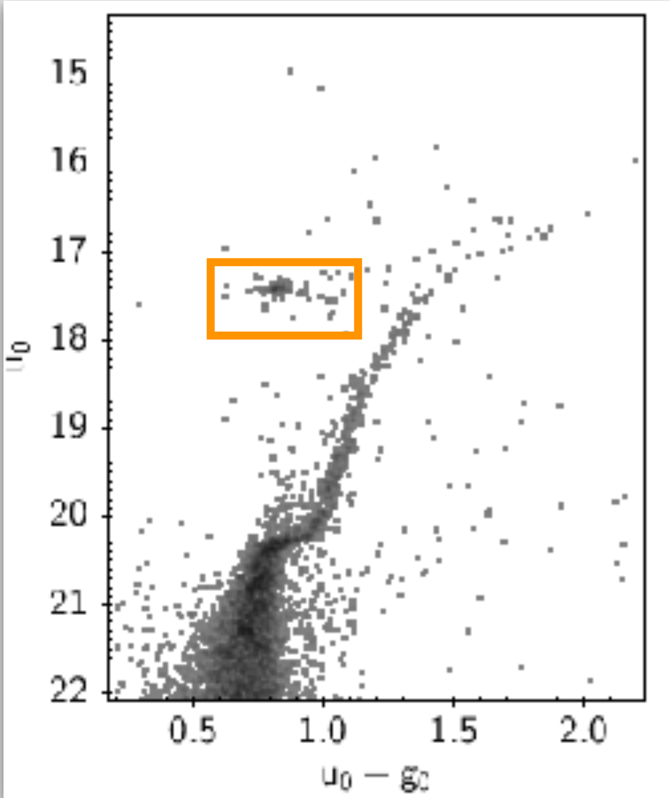
→ Need **accurate distance**

The BHB stars

How to use them as distance tracers?

The BHB stars

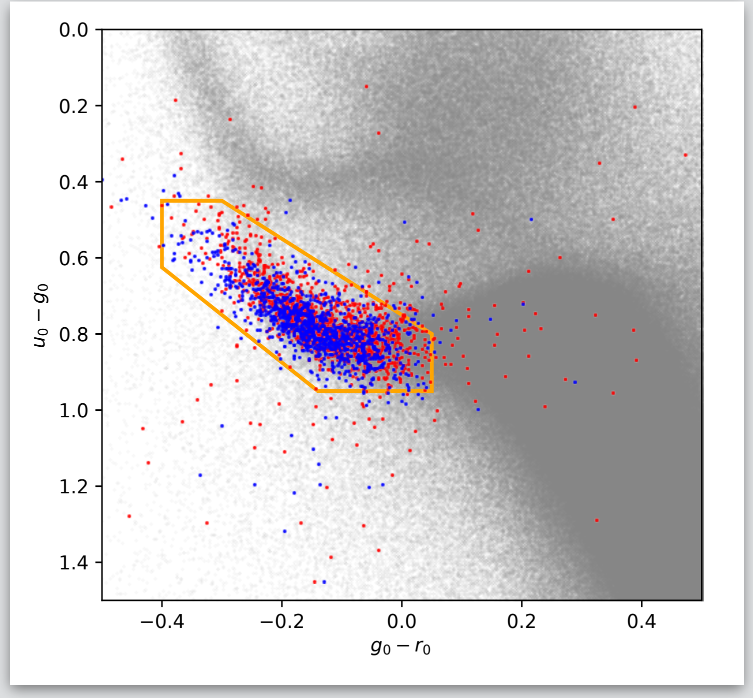


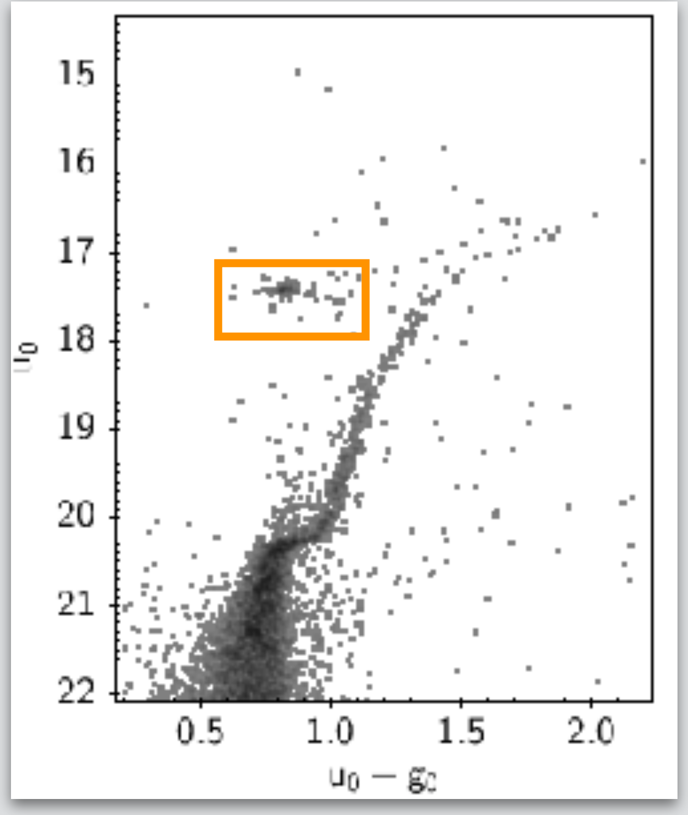


- The Blue Horizontal Branch stars:
  - **Hot stars** 7400 < T_{eff} < 9300 K
  - Member of the Horizontal Branch

→ **Accurate photometric distance**
(5% of precision)

The BHB stars





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- **Contaminated** by the Blue Stragglers (BS)

The BHB selection with CFIS

- **Disentangle** the BHB and the BS with **hydrogen lines** sensitive to the **surface gravity**:
    - Balmer lines : ***u-band***
    - Paschen lines : ***z-band***

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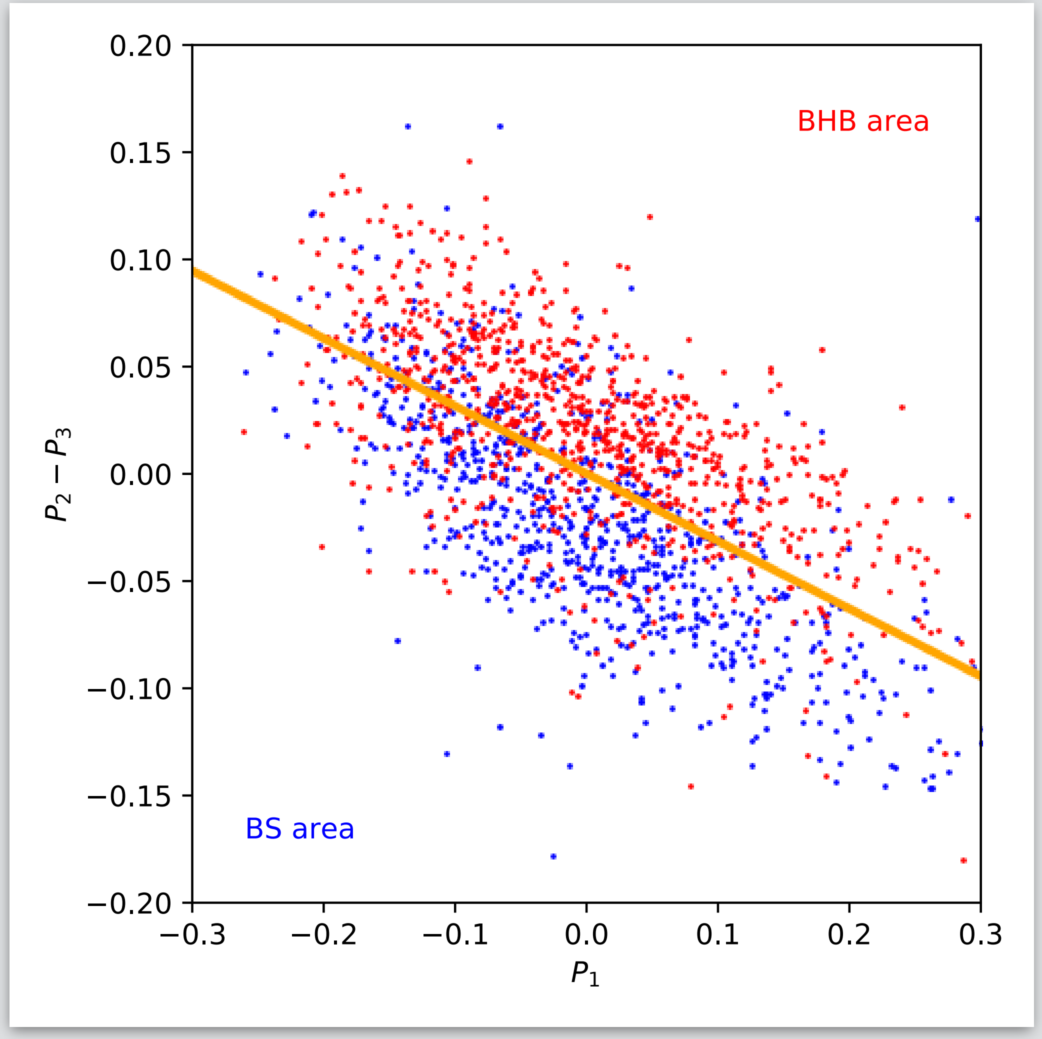

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    - 75% pure and **71% complete**
    - Deeper thanks to CFIS (up to **240 kpc**)

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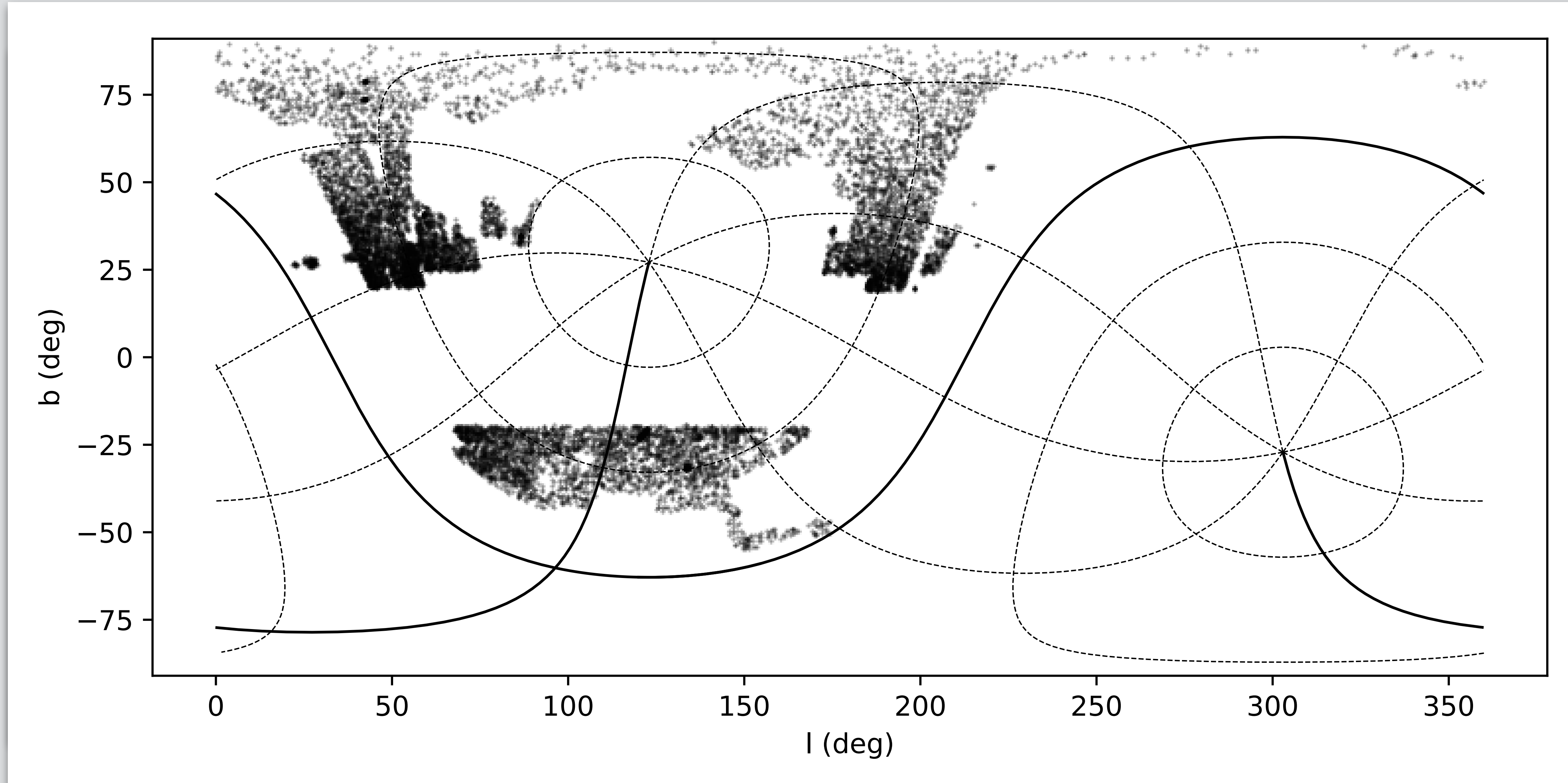

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The BHB stars

Radial profile of the stellar halo

The radial profile of the BHBs

- Find the radial profile that fit the BHB distribution :

$$\boxed{p(\mathcal{D}_i|\boldsymbol{\theta}) = \frac{\rho_{\mathrm{BHB}}(\mathcal{D}_i|\boldsymbol{\theta})\,|\mathbf{J}|\,\mathcal{S}(l_i, b_i, D_i)}{\int\int\int \rho_{\mathrm{BHB}}(l, b, D|\boldsymbol{\theta})\,|\mathbf{J}|\,\mathcal{S}(l, b, D)\,\mathrm{d}l\,\mathrm{d}b\,\mathrm{d}D}}$$

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- Selection function :

  - **Footprint**

$$\mathcal{S}_{area}(l, b) = \begin{cases} 1 \text{ if } (l, b) \text{ in CFIS} \\ 0 \text{ otherwise} \end{cases}$$

  - **Distance** (15< R_{GC} < 240 kpc)

$$\mathcal{S}_{outer\,halo}(R_{GC}) = \begin{cases} 1 \text{ if } 15 < R_{GC} < 240 \text{ kpc} \\ 0 \text{ otherwise} \end{cases}$$

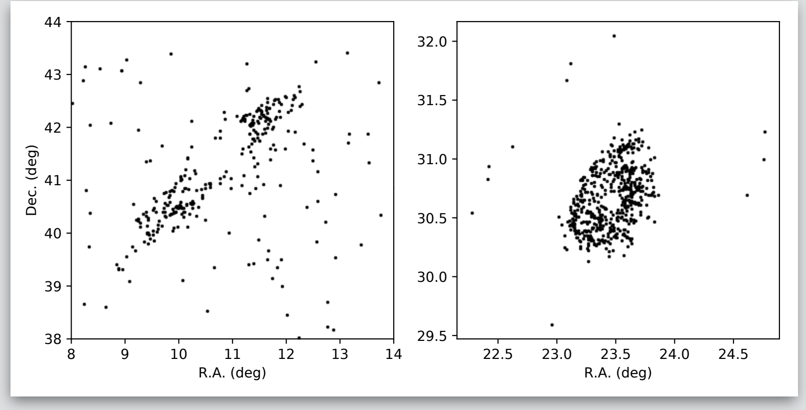
  - **Presence of the Sgr stream**

$$\mathcal{S}_{Sgr}(l, b) = \begin{cases} 0 \text{ if } |\tilde{B}| < 10.0 \text{ deg} \\ 1 \text{ otherwise} \end{cases}$$

  - **Contamination of compact objects**

$$\mathcal{S}_{conta}(l, b) = \begin{cases} 0 \text{ if } \quad d_{M31} < 4.0 \text{ deg} \\ 0 \text{ if } \quad d_{M33} < 2.0 \text{ deg} \\ 0 \text{ if } d_{NGC5466} < 0.4 \text{ deg} \\ 0 \text{ if } \quad d_{Draco} < 0.5 \text{ deg} \\ 1 \text{ otherwise} \end{cases}$$

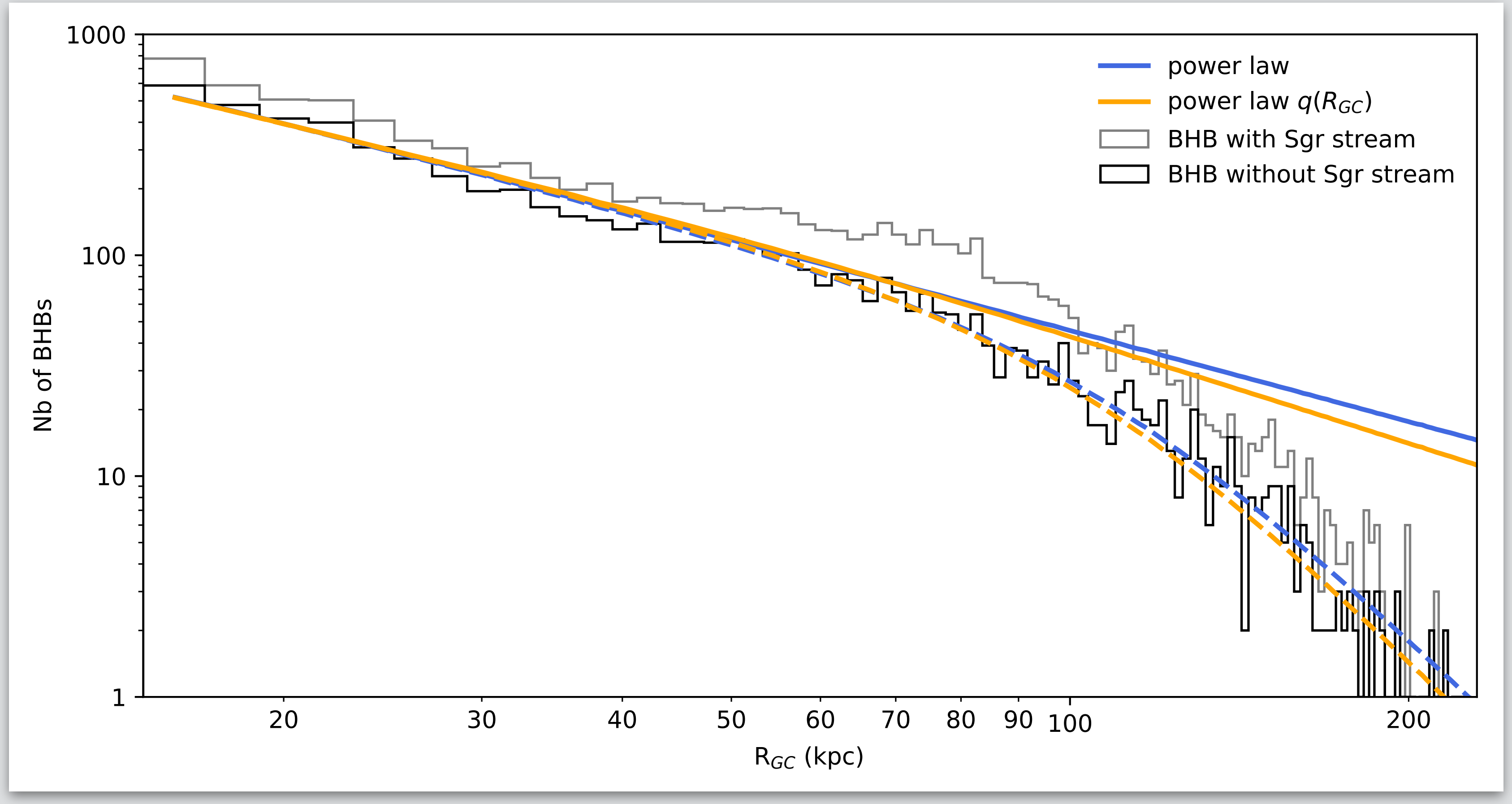
M 31 **M33**



  - **Completeness**

$$\mathcal{S}_{comp}(l, b, r_{helio}) = C_z\,(z_{\rm BHB} - z_{lim}(l, b) + z_{lim,ref})$$

The radial profile of the BHBs



Two models with a single power law:

- **Constant oblateness**

$$\gamma = 3.42 \pm 0.02$$
$$q = 1.06 \pm 0.02$$

- ***q*(RGC) :**

$$\gamma = 3.60 \pm 0.04$$
$$q_0 = 0.96 \pm 0.03$$
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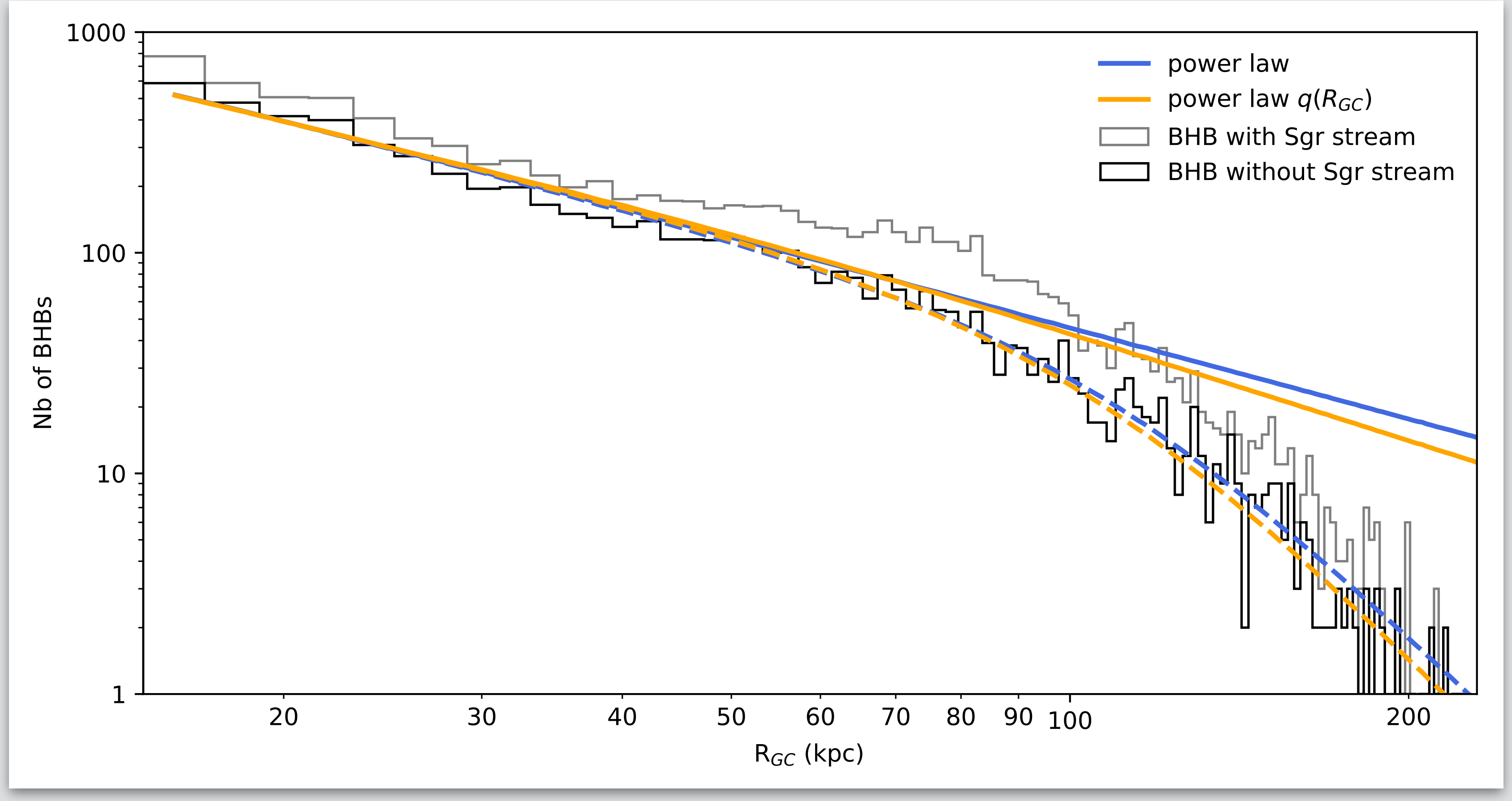

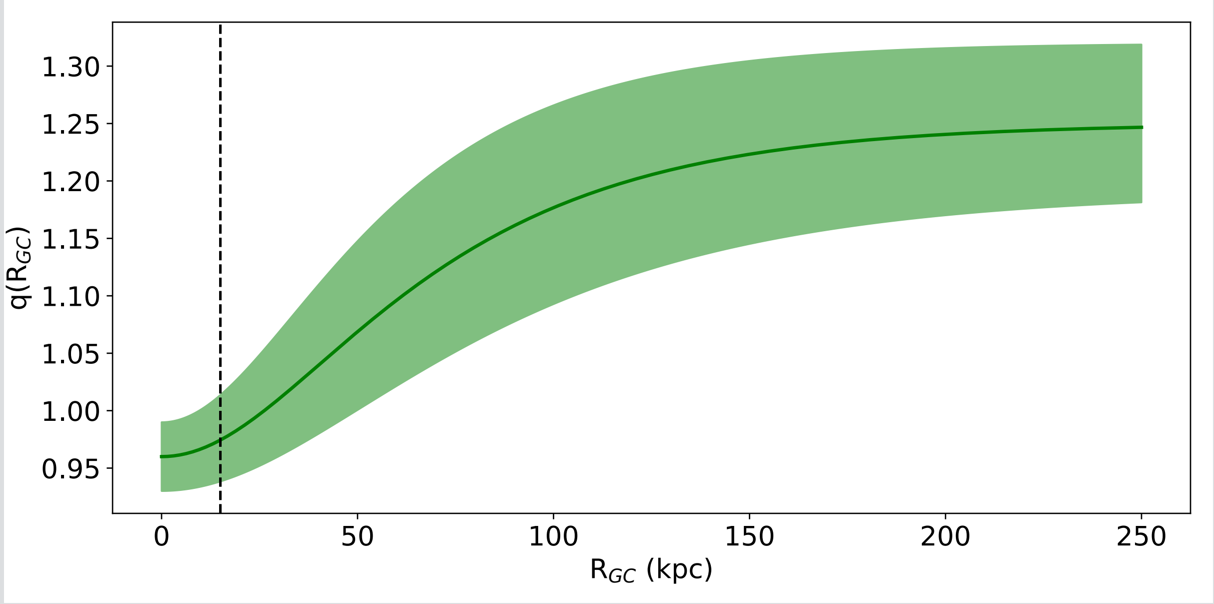

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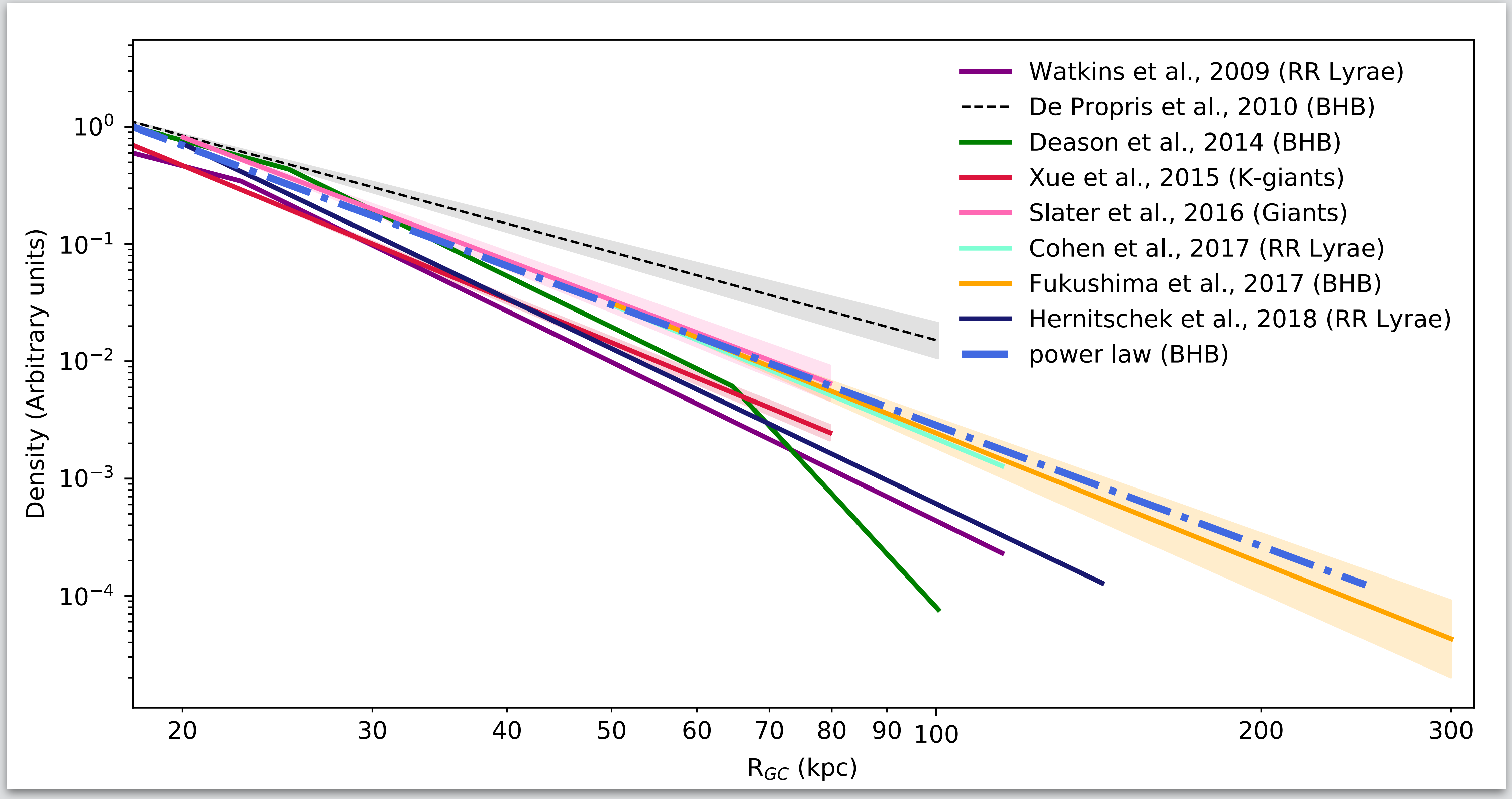
Comparison with previous results



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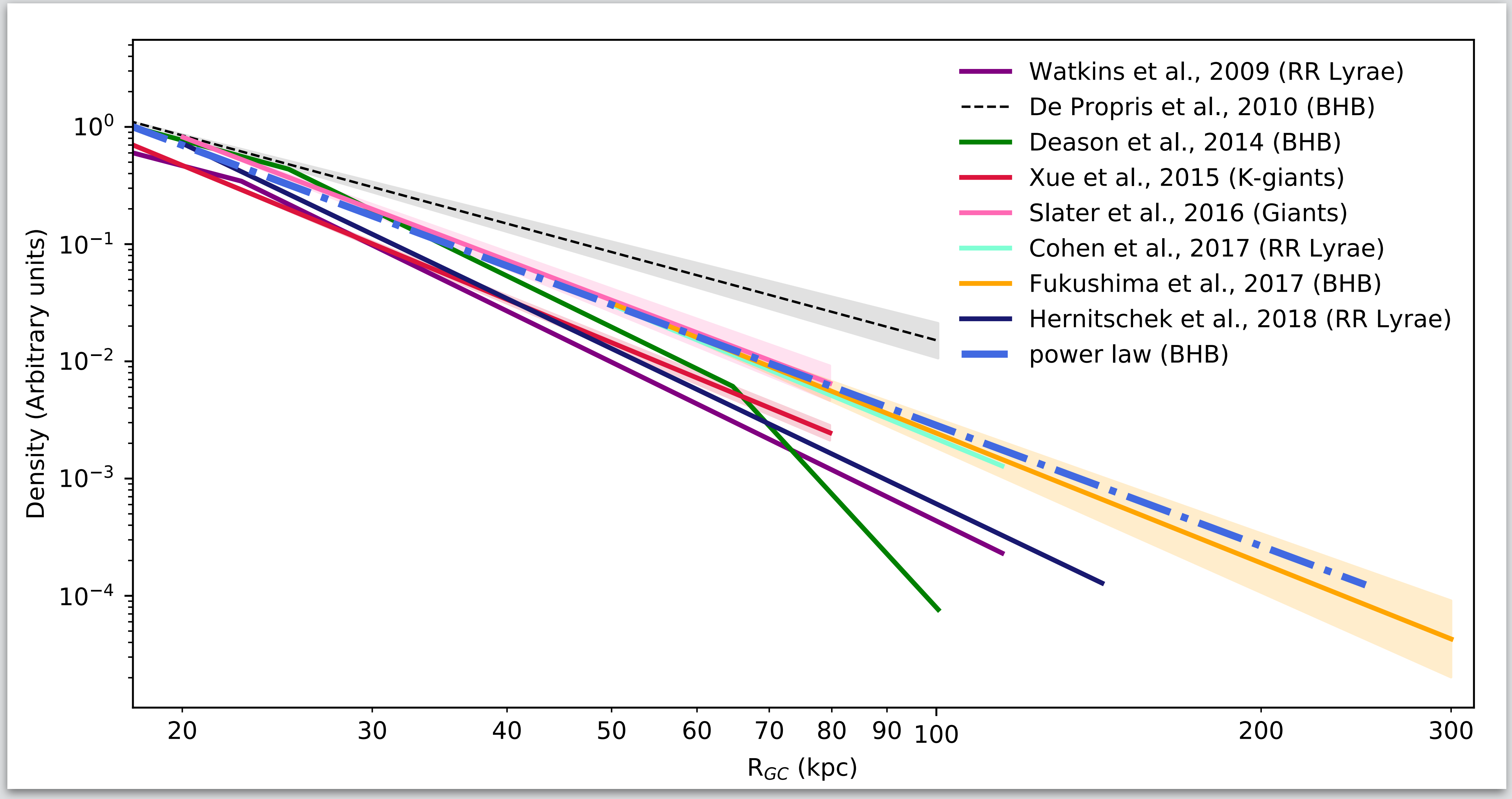
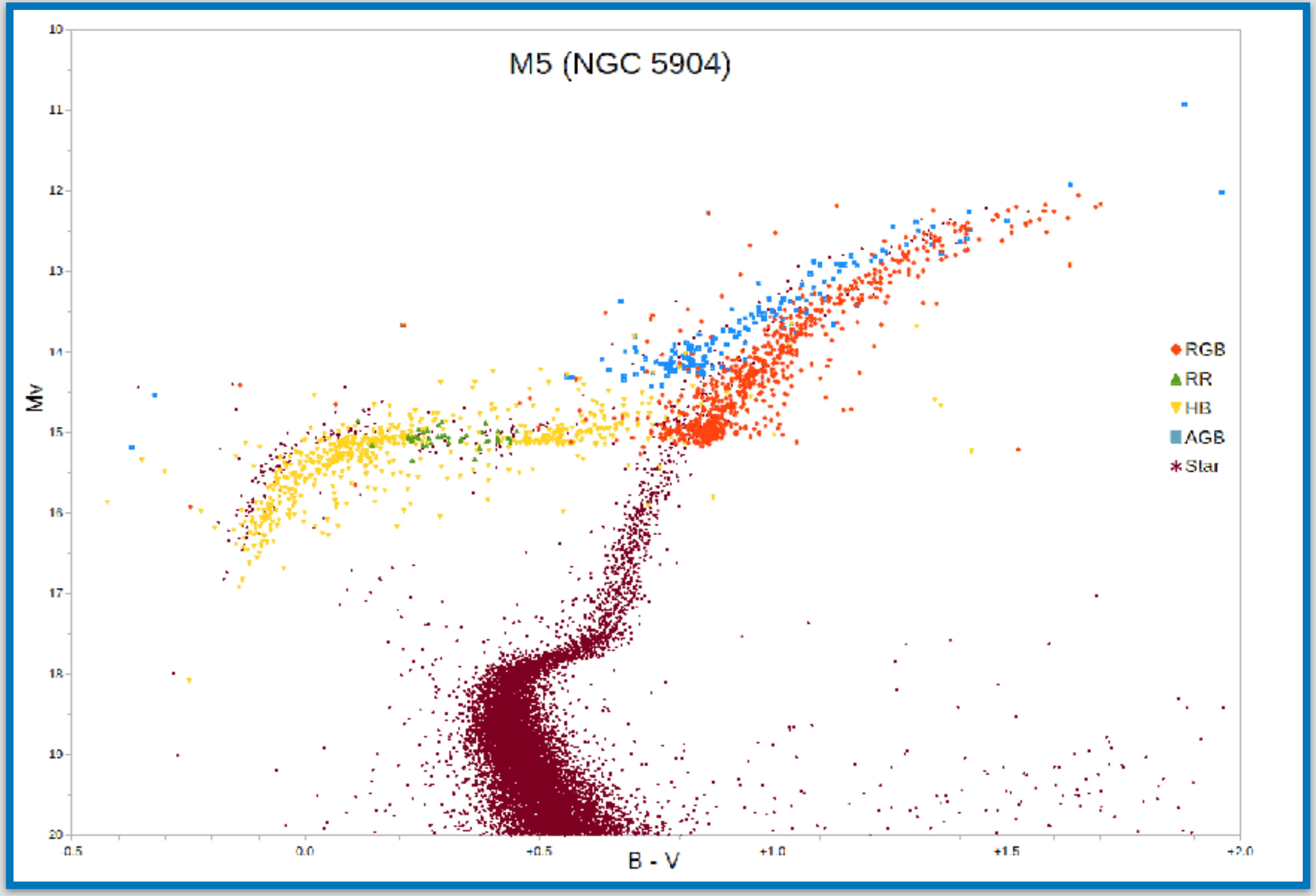


→ Profile traced by the **BHB** is **closer** to the profile traced by the **giants** than by the **RR Lyraes**



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Conclusions

- **Identified the BHBs** with an unprecedented **precision** by their photometry
- **Radial profile** of the stellar halo traced by the **BHB is similar** to the halo traced by the **giants …**
- Traced the **radial profile** of the **stellar halo** up to **~240 kpc**
- **…** but **shallower** than traced by the **RR Lyrae**

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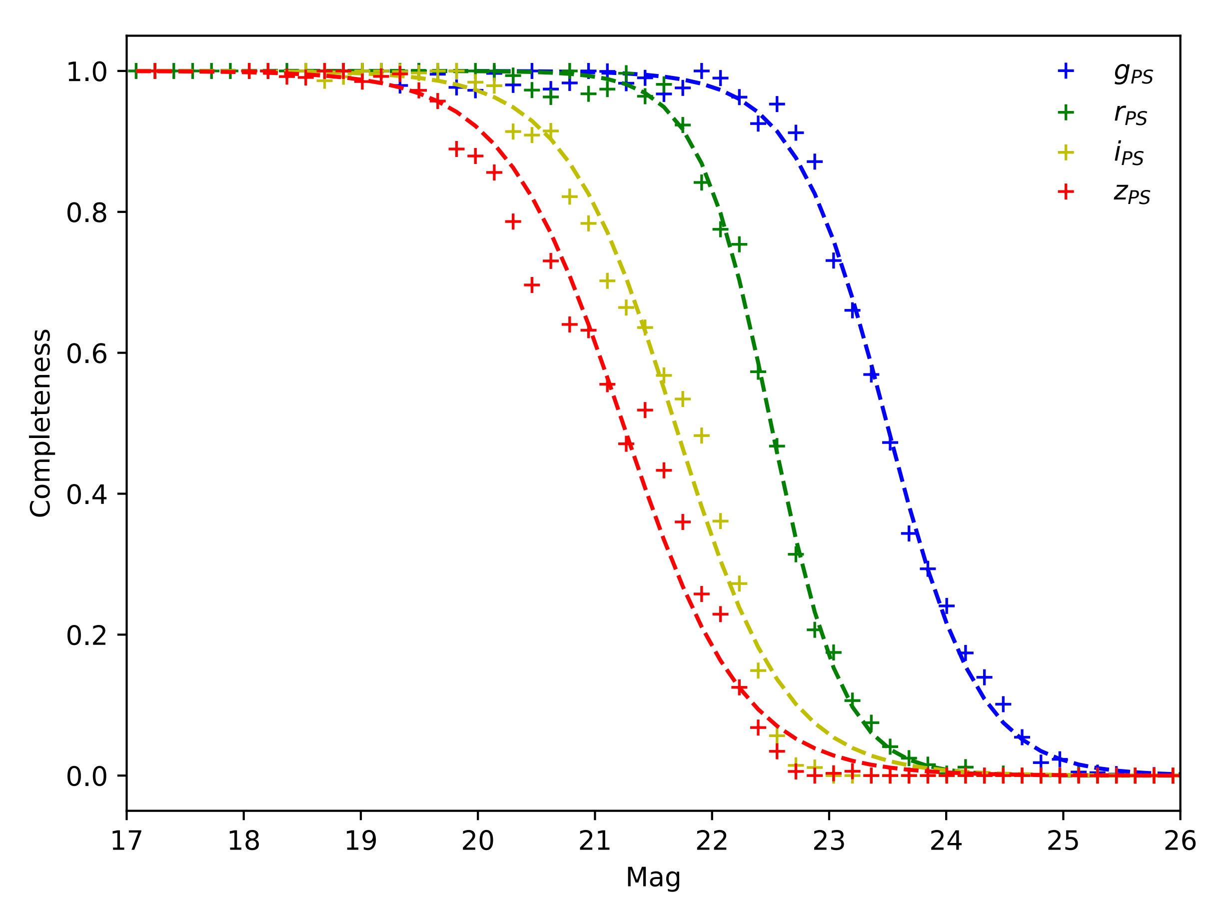
Future works

- Compare the **distribution of these different populations** with **cosmological simulations** (Auriga?) and/or the Galactic Besançon Model
- Study the **dynamics** of the BHBs => Mass of the MW and the 3D distribution of the DM halo at large distances

Completeness of the sample



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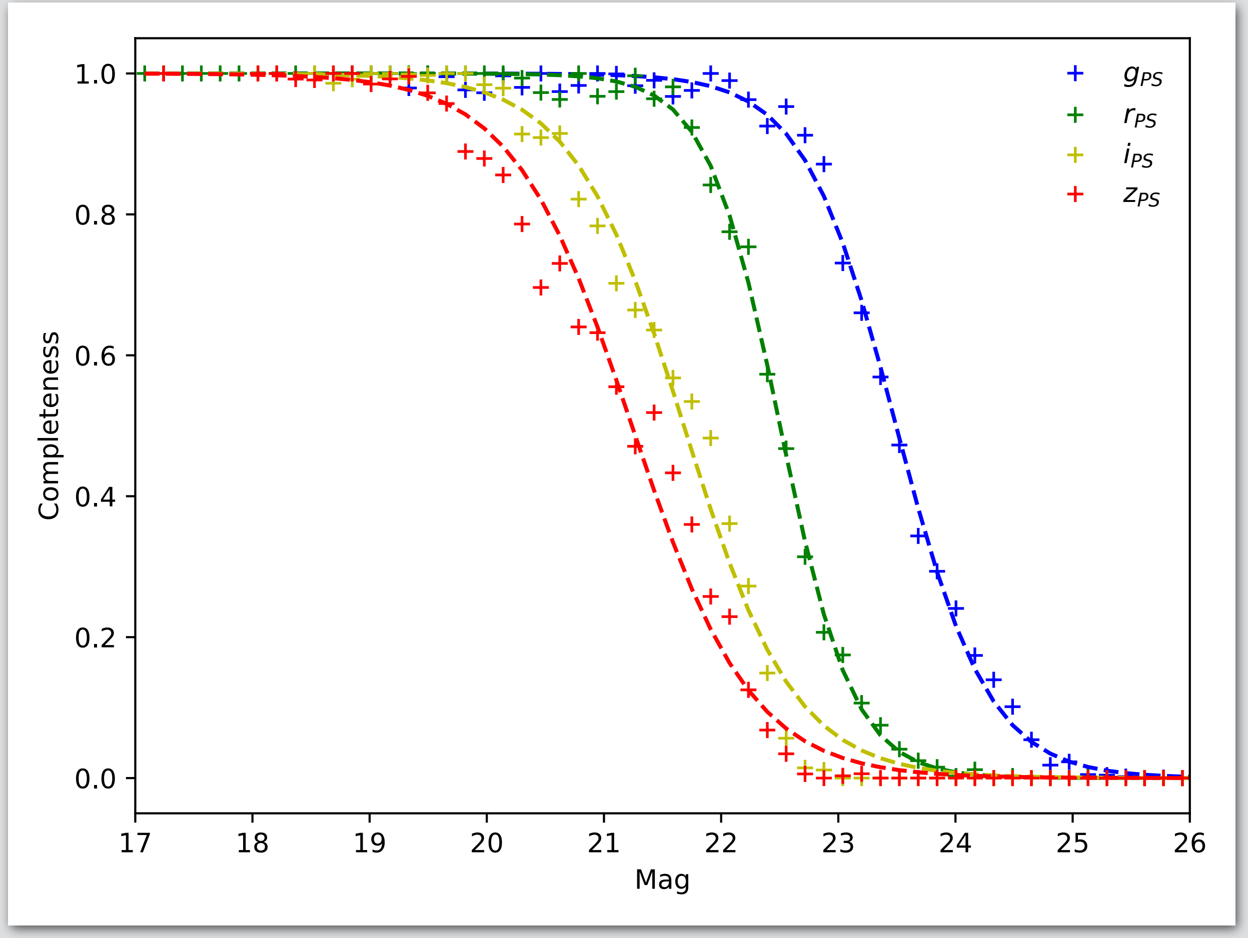

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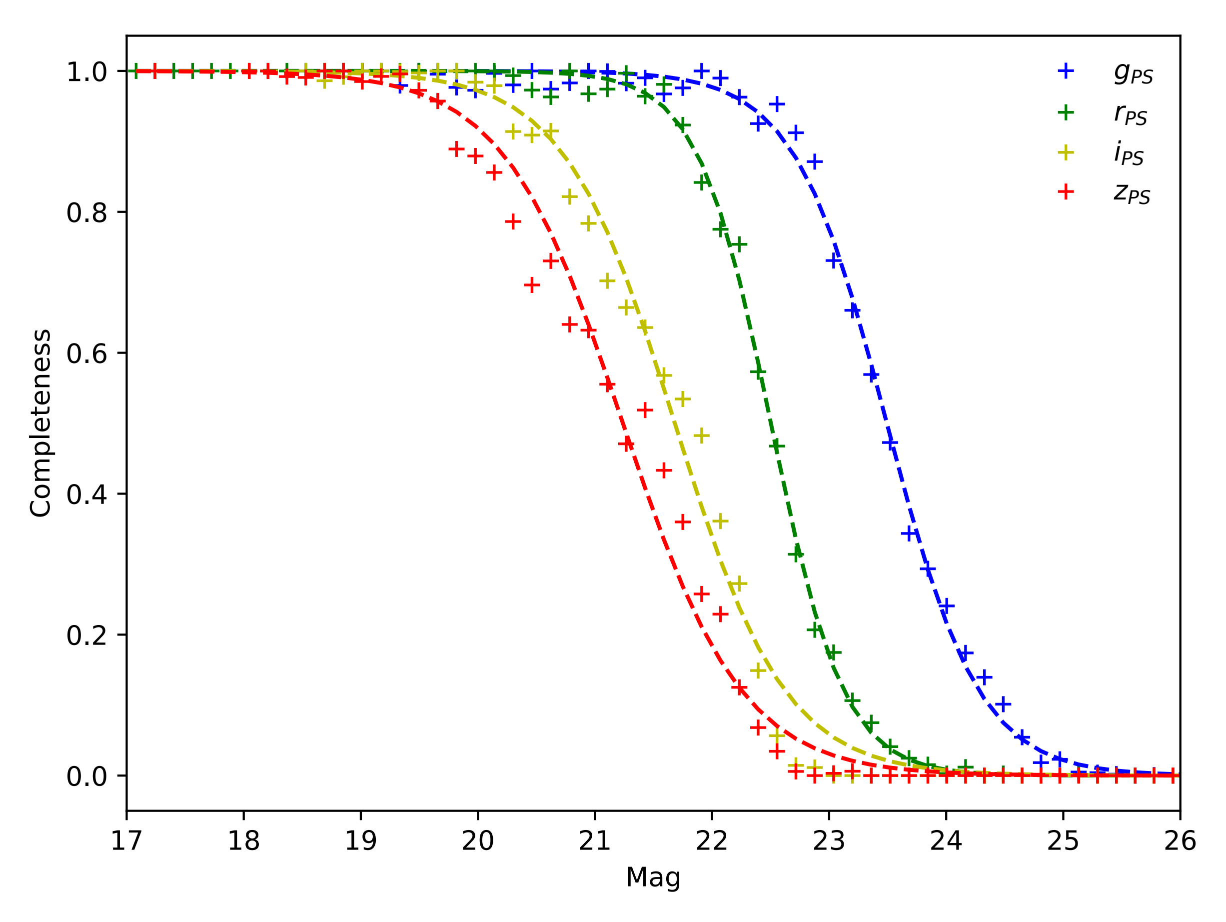

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- Used the **Luminosity Function** to see the **spatial variation** of the completeness

Field of reference