DECam photometry covering the entirity of the puzzling ω Cen globular cluster

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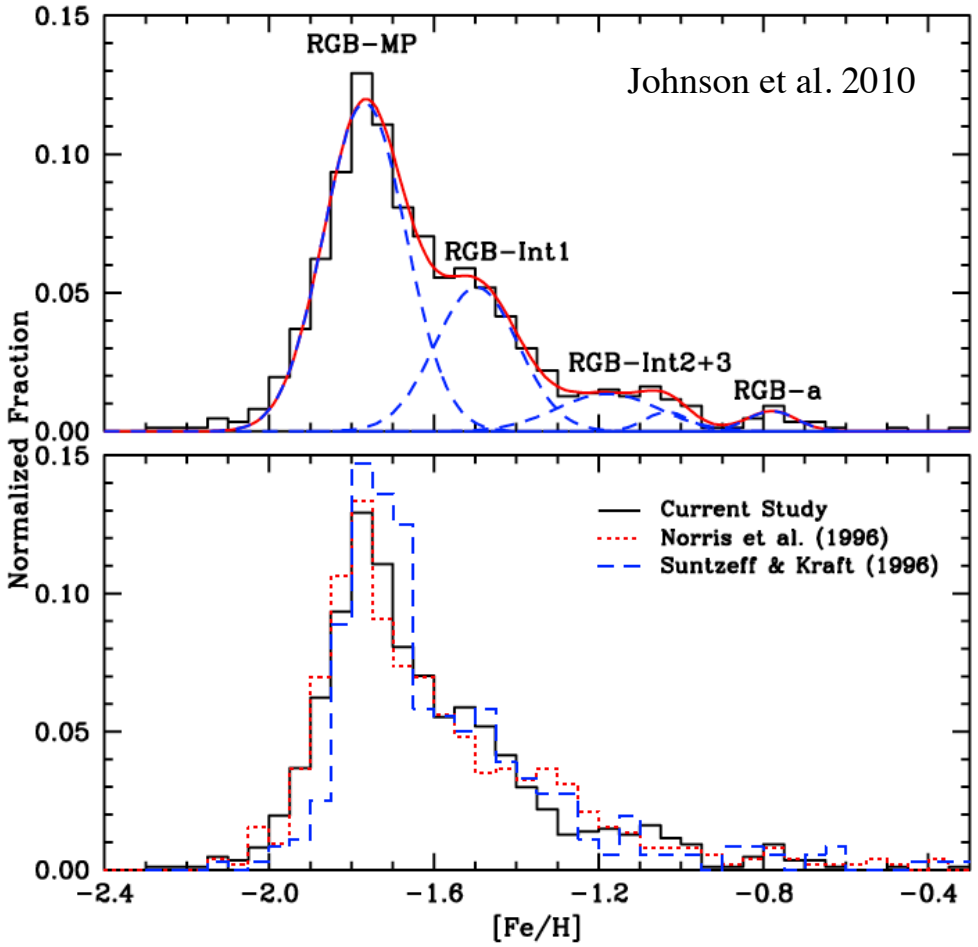
Why ω Cen?

- Most luminous and most massive galactic globular cluster
- **Metallicity dispersion of more than 1 dex: -2.2 < [Fe/H] < -0.5**

Properties	GCs	**ω Cen**	dSphs
Magnitude (M_V)	< -9	**-10**	-8/-13
Mass ($M_\odot$)	~ 10^5	~ **$3 \cdot 10^6$**	10^6-10^8
Metallicity spread, Δ [Fe/H] (dex)	< 0.1	~ **1**	0.2-1.4

➢ **Relic of a dwarf galaxy accreted on the Milky Way**

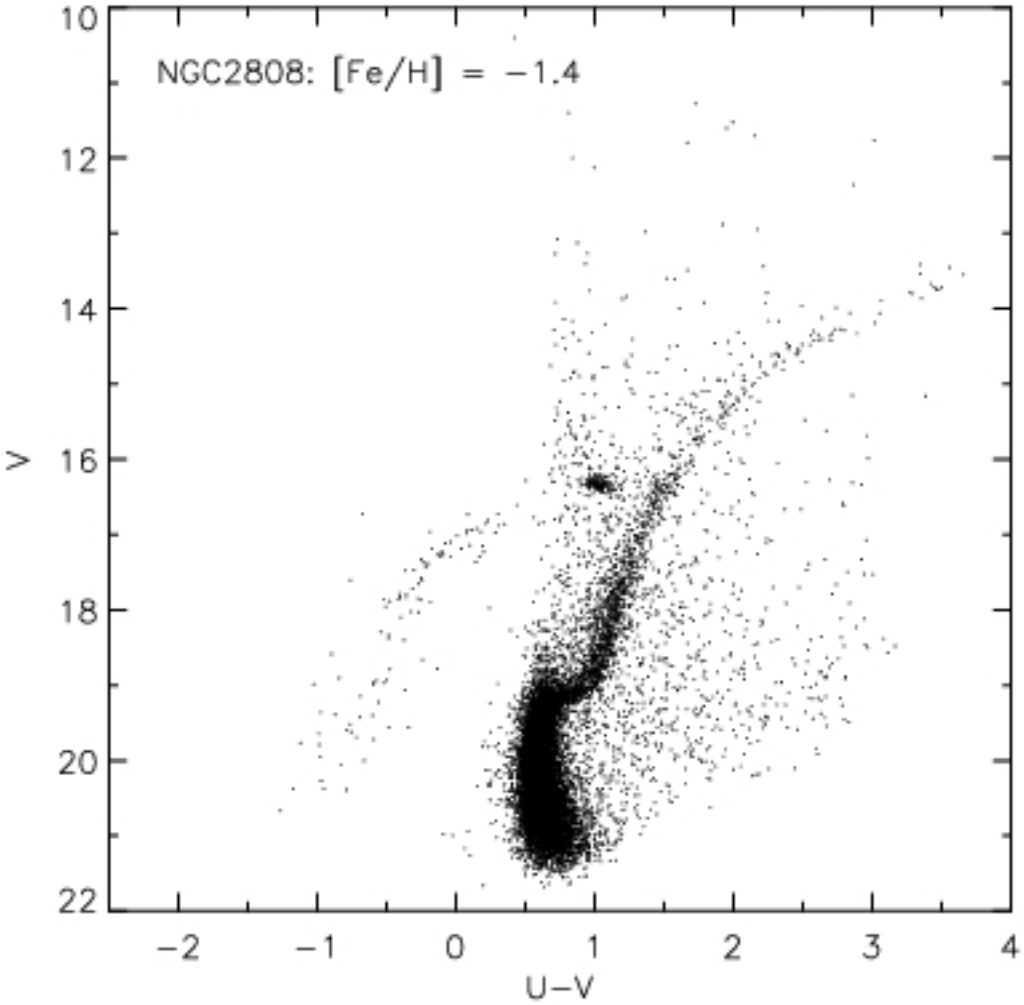
➢ **"Merging" of two different stellar systems**



– **Main peak: [Fe/H] ~ -1.8 dex**

– **Secondary peaks: [Fe/H]~ -1.5/-1.2 dex**

– **Tail up to [Fe/H] ~ -0.5 dex**



Many different RGBs:

– **Metal-poor (main sub-pop)**

– **Metal-intermediate (different sub-pop)**

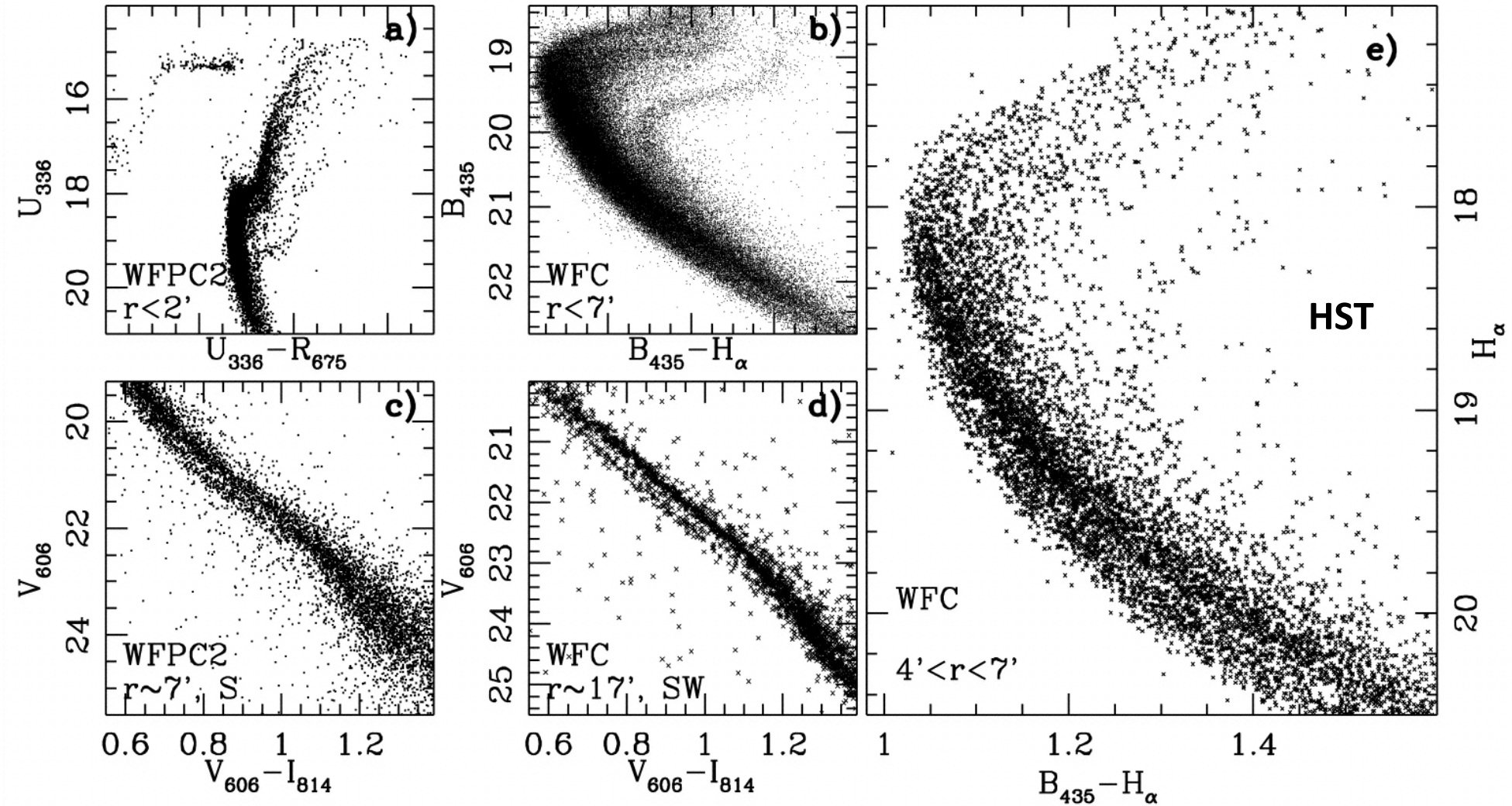
– **Metal-rich (RGB-a, ω3 branch)**

U, V photometry from **WFI@2-2m**

The Blue & the Red main-sequence

- ✓Super-metal-poor sub-population ([Fe/H] <<-2.0) -> 30% of ω Cen stars!!!
- ✓Helium enhanced population (ΔY ~ 0.15)
- ✓Population of stars located behind ω Cen

(Bedin et al. 2004)



Helium enhancement?

From VLT's GIRAFFE **spectra of 17 stars** (Piotto et al. 2005):

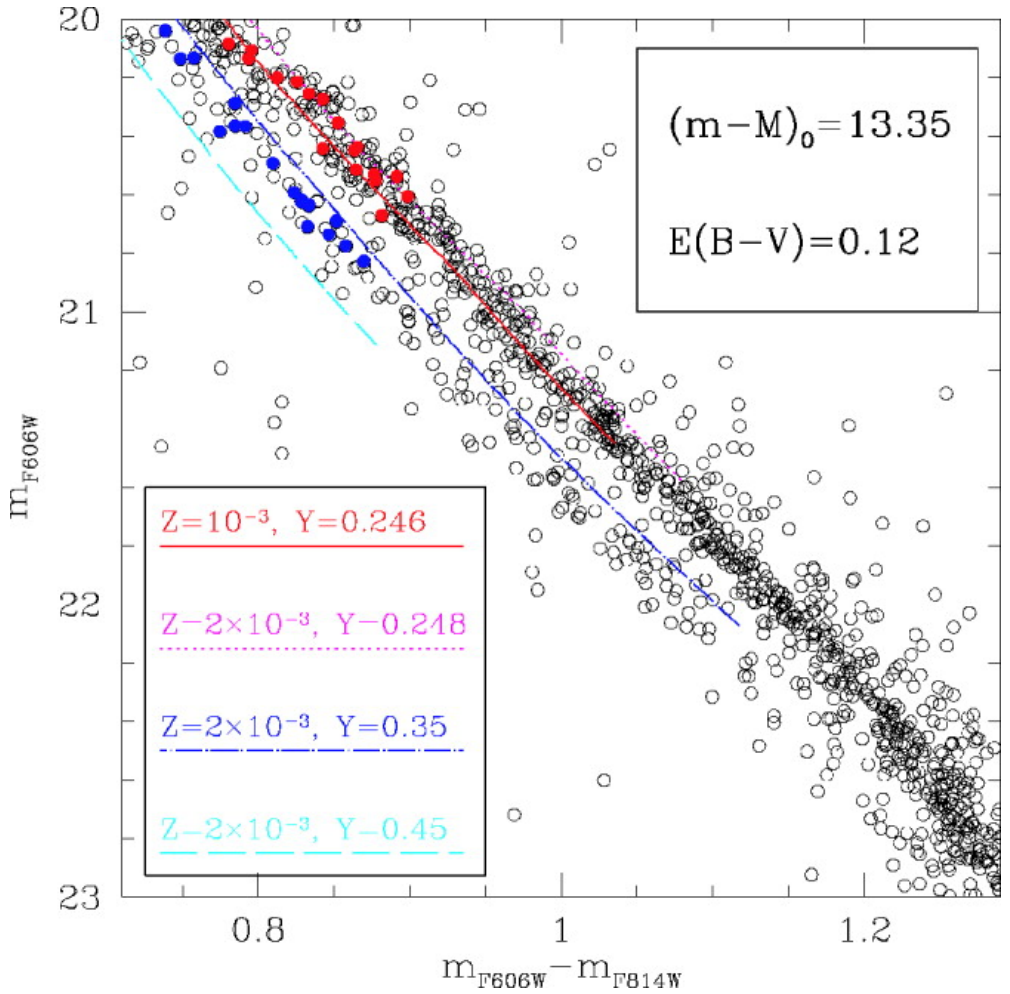
Red main-sequence (rMS): [M/H] = -1.57 , **blue main-sequence (bMS):** [M/H] = -1.26

bMS is 0.3 ± 0.2 dex more metal-rich than the rMS

CMD:

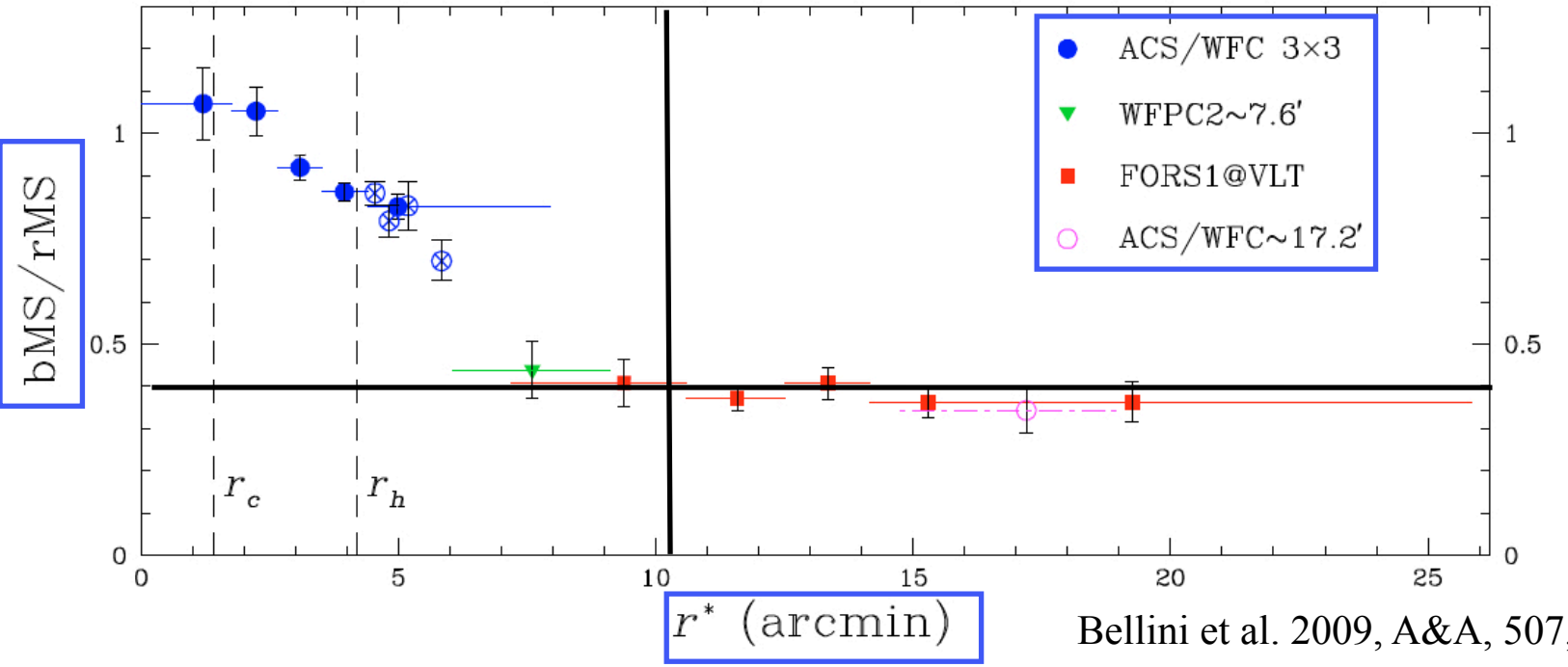
Isochrone best fit with

[M/H] = -1.26, Y~ 0.35

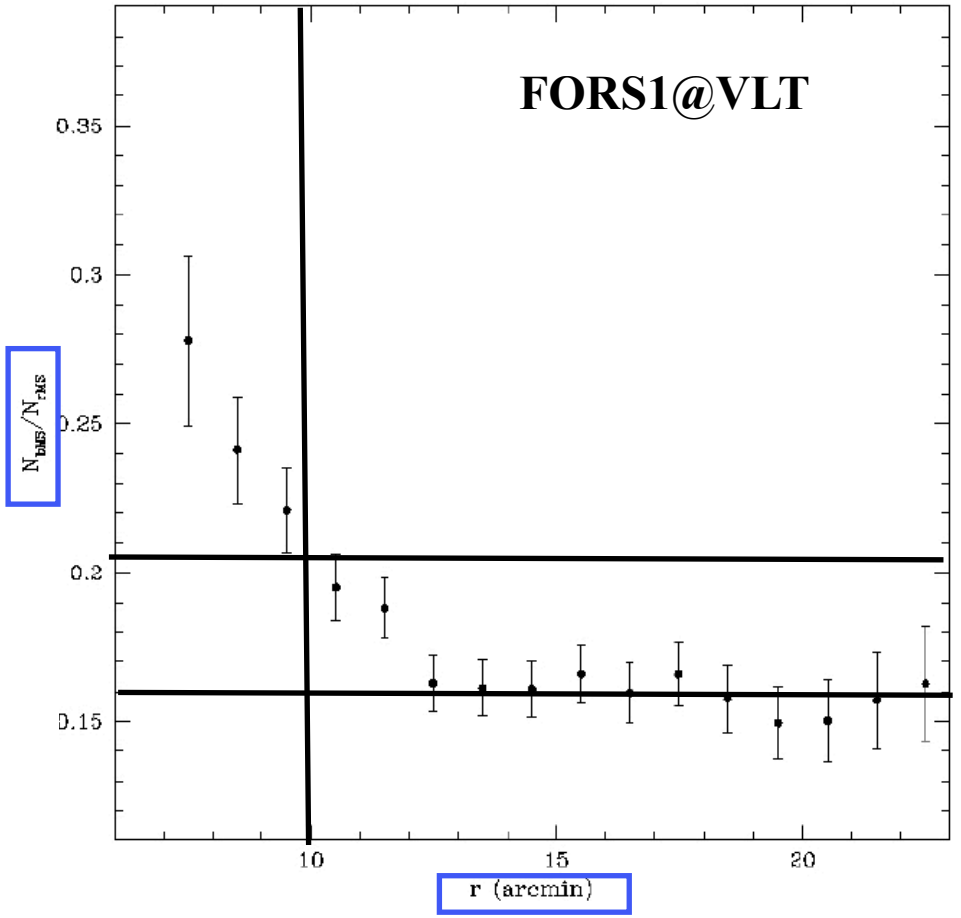


Spatial distribution of the bMS and the rMS

- Bellini et al. (2009) find a constant **bMS** to **rMS** ratio of ~ 0.4 from r ~ 10 to 20'
- Sollima et al. (2007) finds a decreasing ratio and then a constant value of ~ 0.15 from r ~ 12 to 25'
- No photometric study until know analyzed the **bMS** to **rMS** ratio for **distances r > 25' -> Need field coverage and high photometric accuracy**

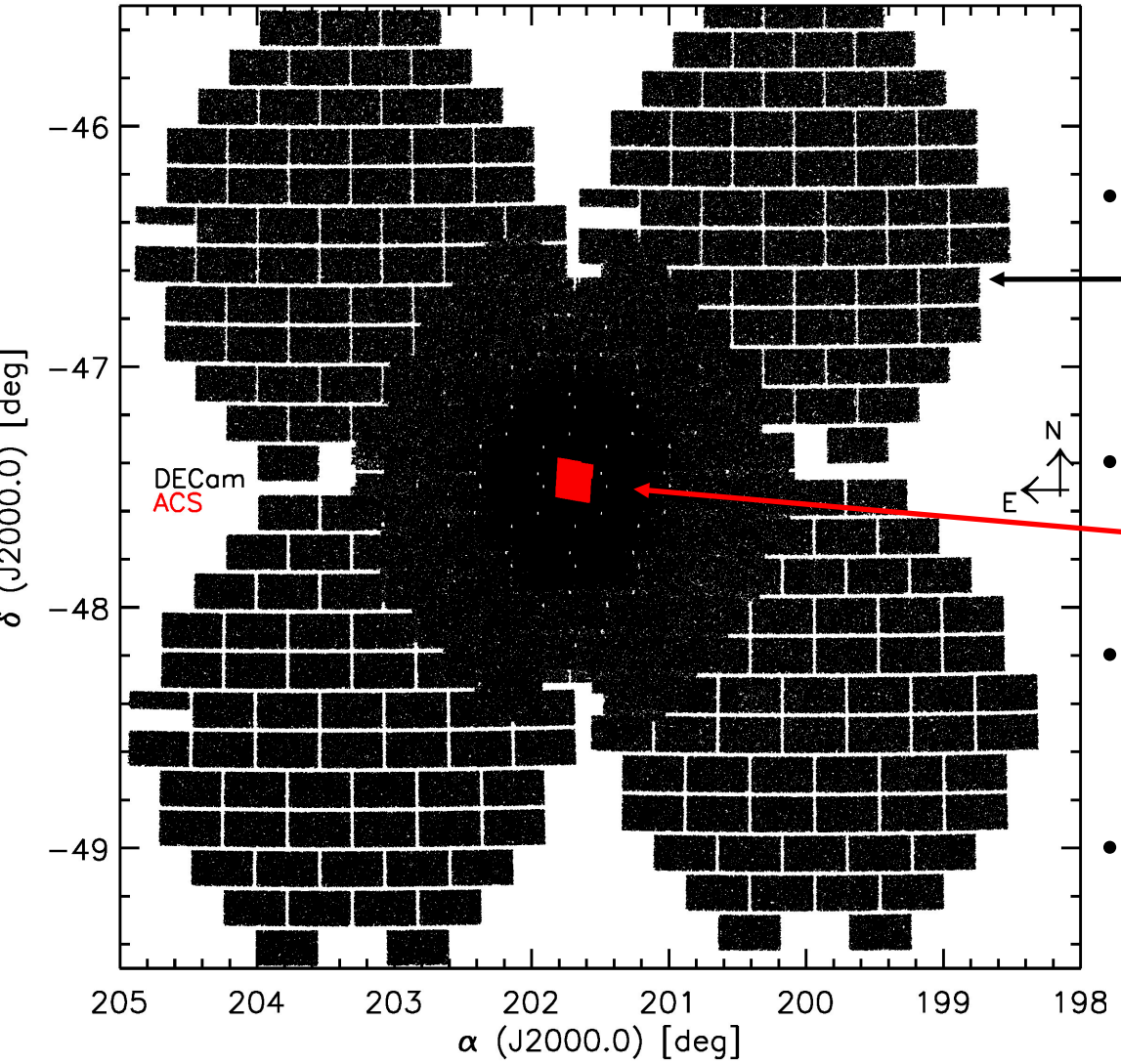


Bellini et al. 2009, A&A, 507, 1393



Sollima et al. 2007, ApJ, 654, 915

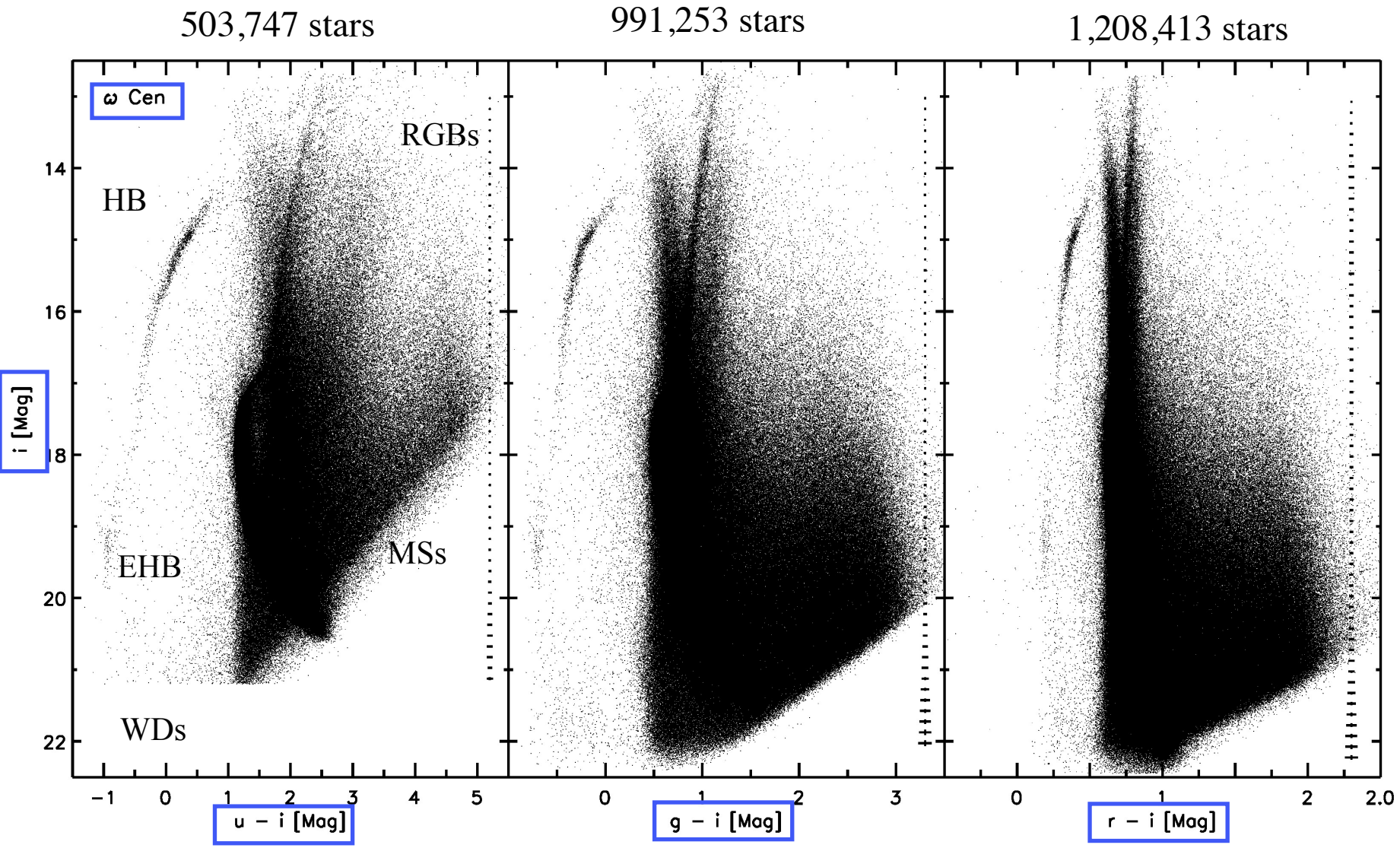
DECam & ACS photometric catalogs



- **171 u,g,r,i DECam@4m-Blanco images** (3.5 nights, proposals 2014A-0327, 2015A-0151, 2016A-0189, 2017A-0308, PIs: A. Calamida, A. Rest) covering a **FoV of 6.5 °x 4.0°**
- **36 ACS@HST images in F475W, F625W, F658N** for 9 fields and a total **FoV of 9'x 9'**
- Photometric calibration with **standards of Stripe82** transformed to DECam natural system
- **Total combined ACS-DECam photometric catalog of ~ 3 million of stars** (~1.8 million cluster members)

DECam FoV: ~ 6.5° x 4.0 °

DECam color-magnitude diagrams



FoV: ~ 6.5° x 4.0°

S/N >= 20 down to u ~ 23, g ~ 23, r ~ 23, i ~ 22.5 mag

CMD is contaminated by field stars!!

We have **no accurate proper motions** for all the stars in the FoV, in particular below the main-sequence Turn-Off

-> **GAIA DR2**: **not useful below the MS Turn-Off!!**

DECam and GAIA DR2

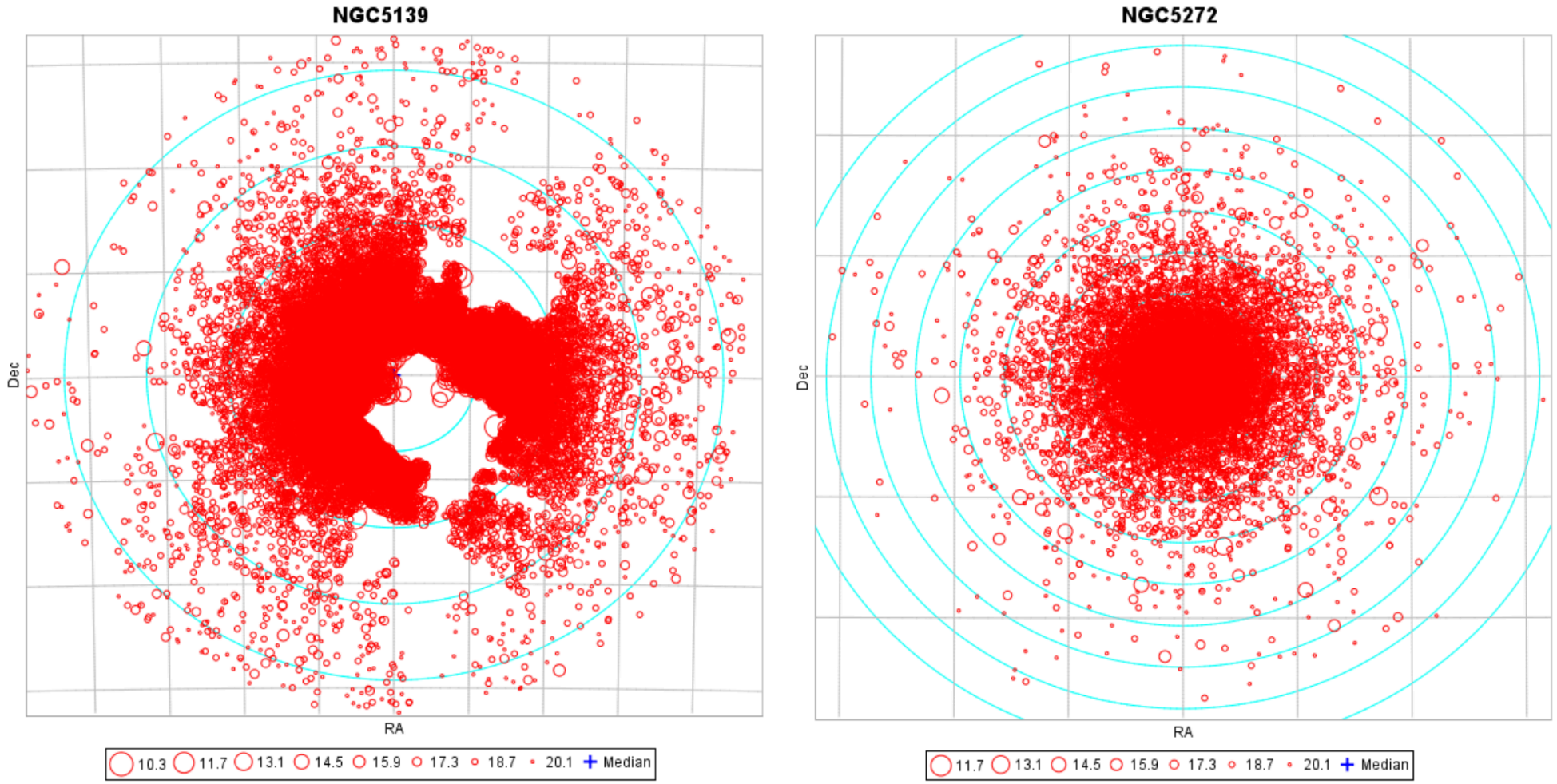
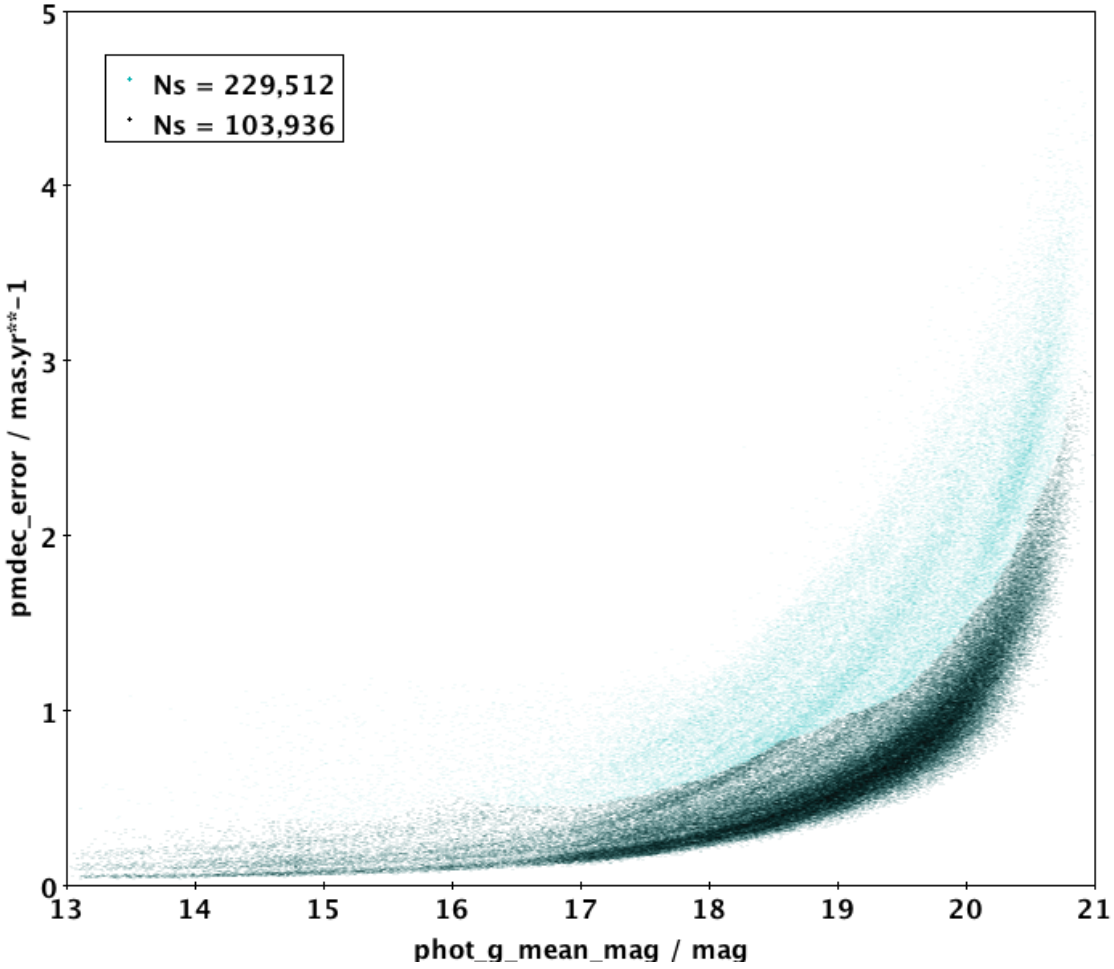
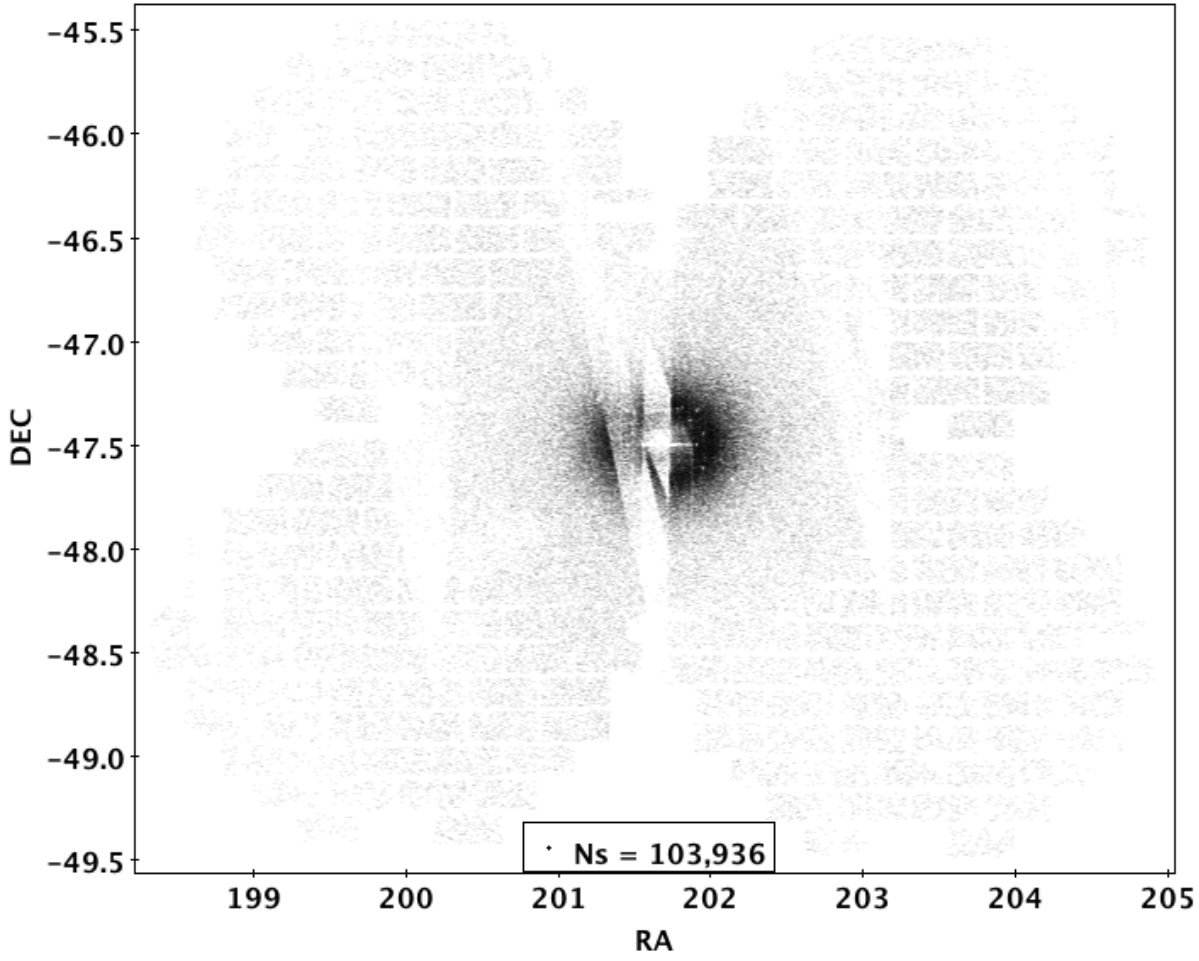


Fig. A.6. Two examples of astrometric data coverage with five-parameter solutions. On the left, ω Cen, the worst case, on the right NGC 5272, a more average example of coverage. The gaps in the coverage for ω Cen are the result of the filters that have been applied to the astrometric data. The cyan circles are at intervals of 35 pc in ω Cen and 10 pc in NGC 5272.

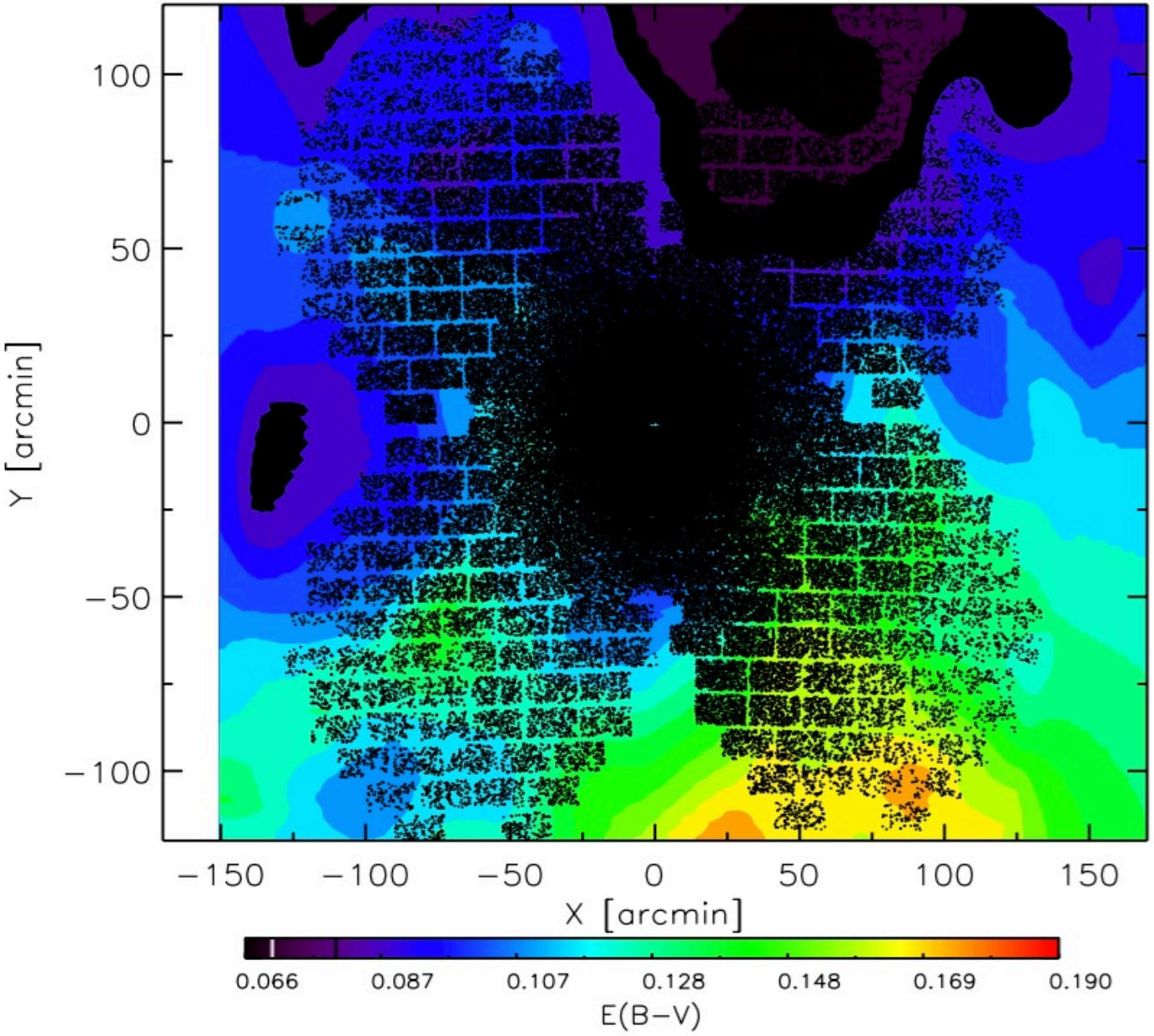
GAIA collaboration Helmi al. 2018, arXiv180409381G

DECam and GAIA DR2





Reddening correction



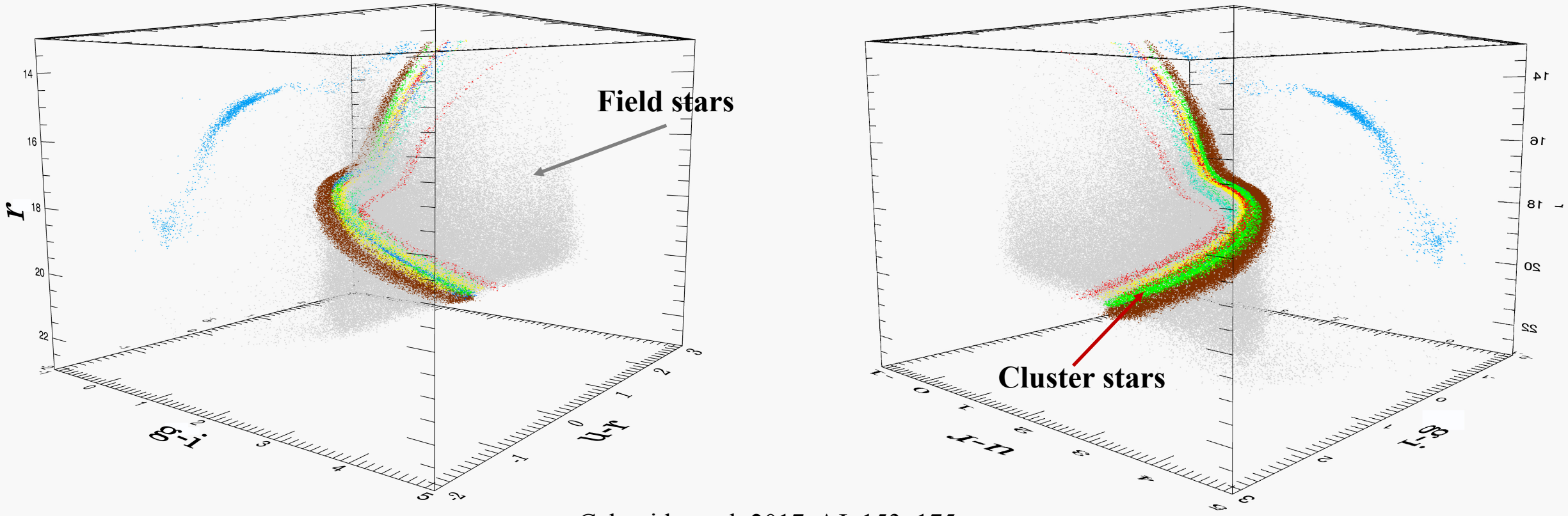
- **Differential reddening** is present around ω Cen
- We use the reddening map of Schlafly & Finkbeiner 2011 (ApJ 737, 103) to correct DECam photometric catalog

Mean E(B-V) = 0.11

$\sigma_{E(B-V)}$ = 0.02 mag

Cluster and field star separation

Color (g - i) – Color (u - r) – Magnitude (r) diagrams

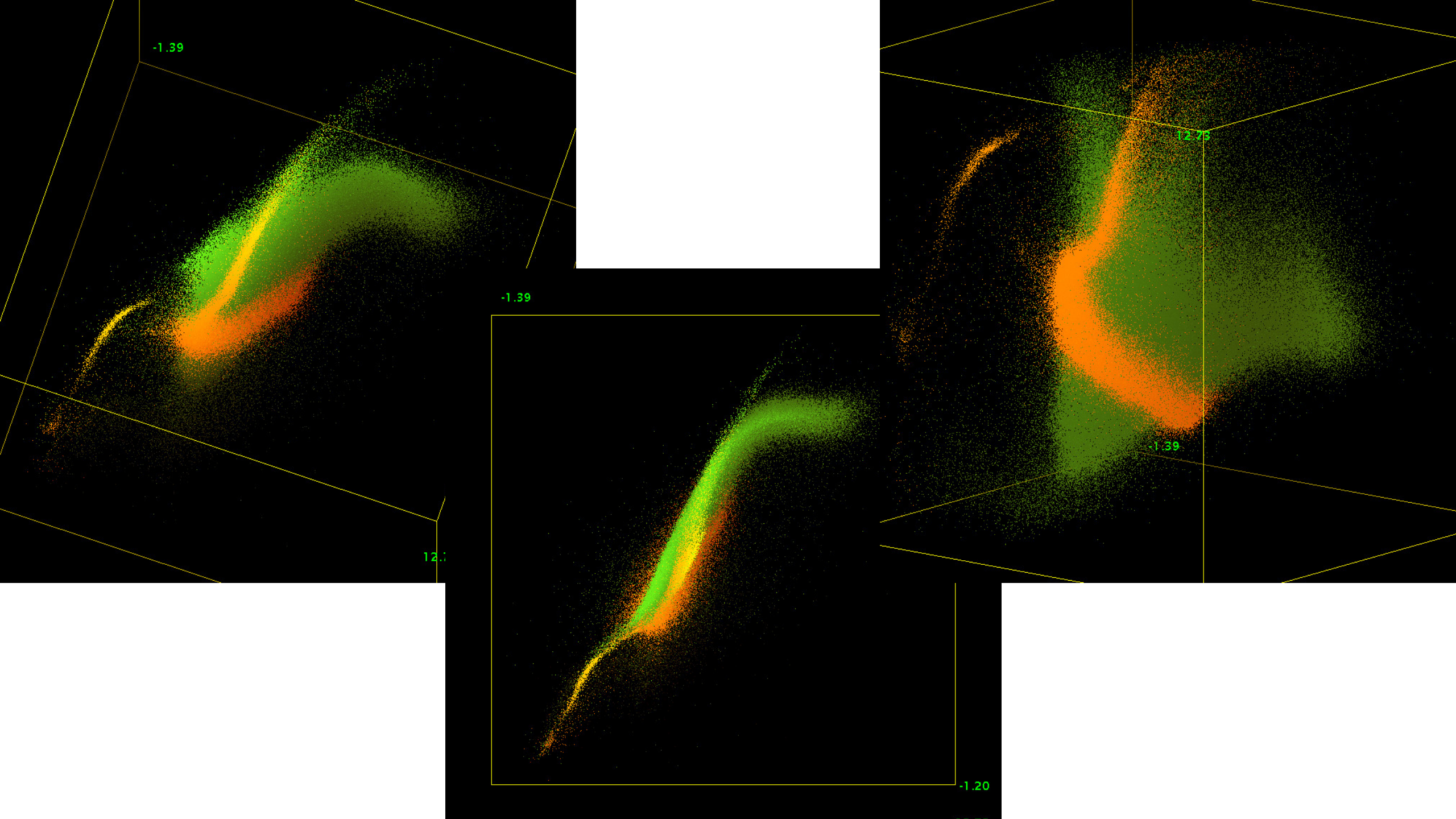


Calamida et al. 2017, AJ, 153, 175

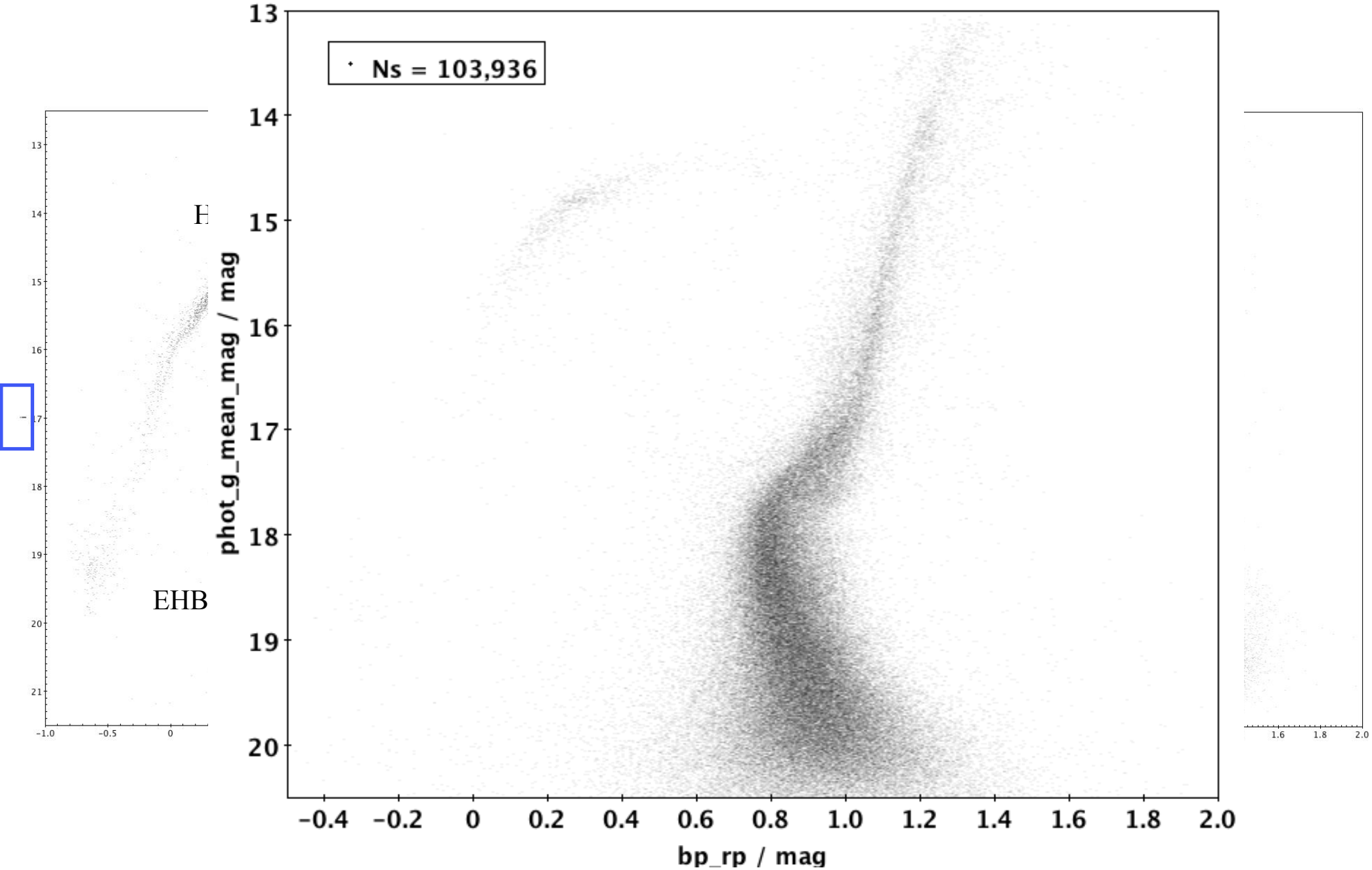
Stars with a measurement in all 4 filters, *ugri.* Thanks to the **u filter** we have an increased sensitivity to temperature and metallicity that allows us to better separate cluster and field stars

Interactive figure IOP

Interactive figure OAR


-1.39
-1.39
-1.39
-1.20

DECam CMDs for cluster members



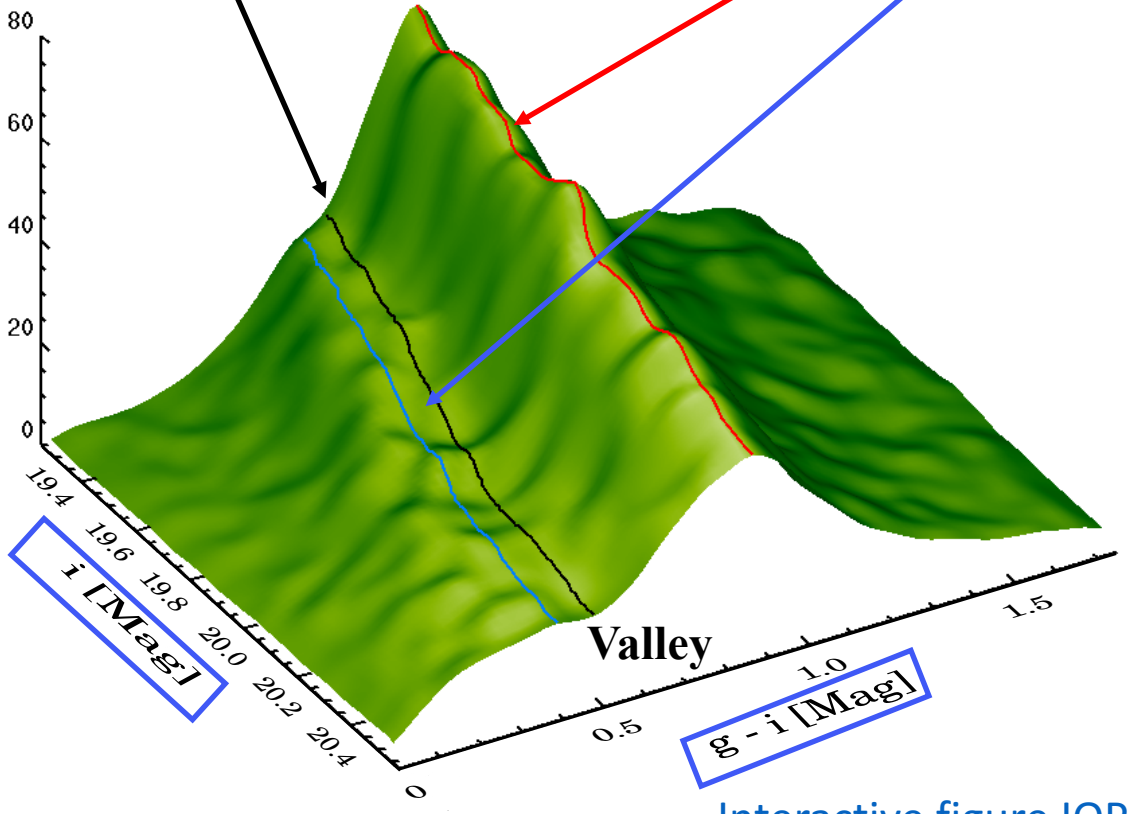
Double MS:
First time detected with a 4m-class ground-based telescope

The main-sequence split: star selection

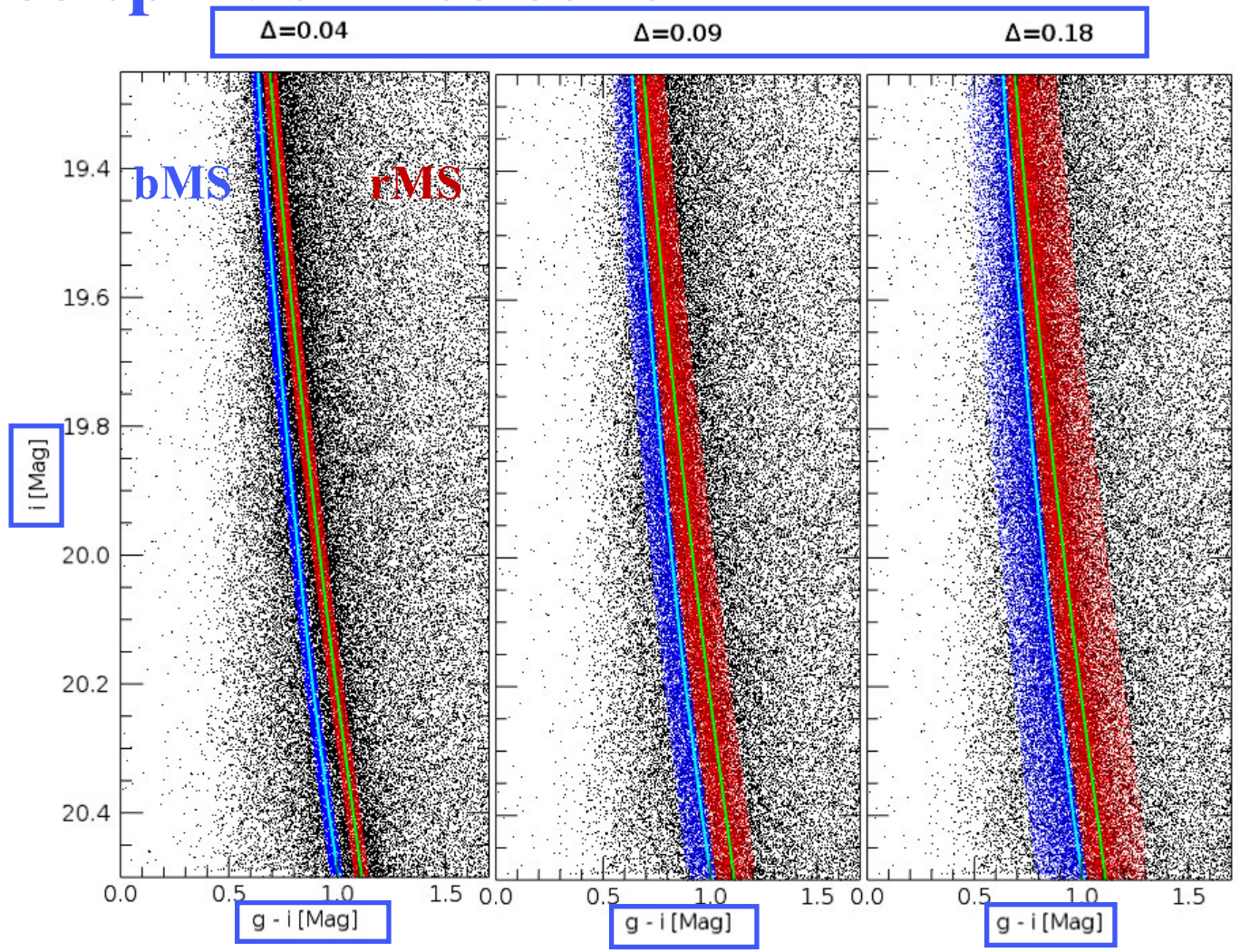
Color-magnitude surface

Interactive figure OAR

Minimum between the 2 peaks, **rMS**, **bMs**

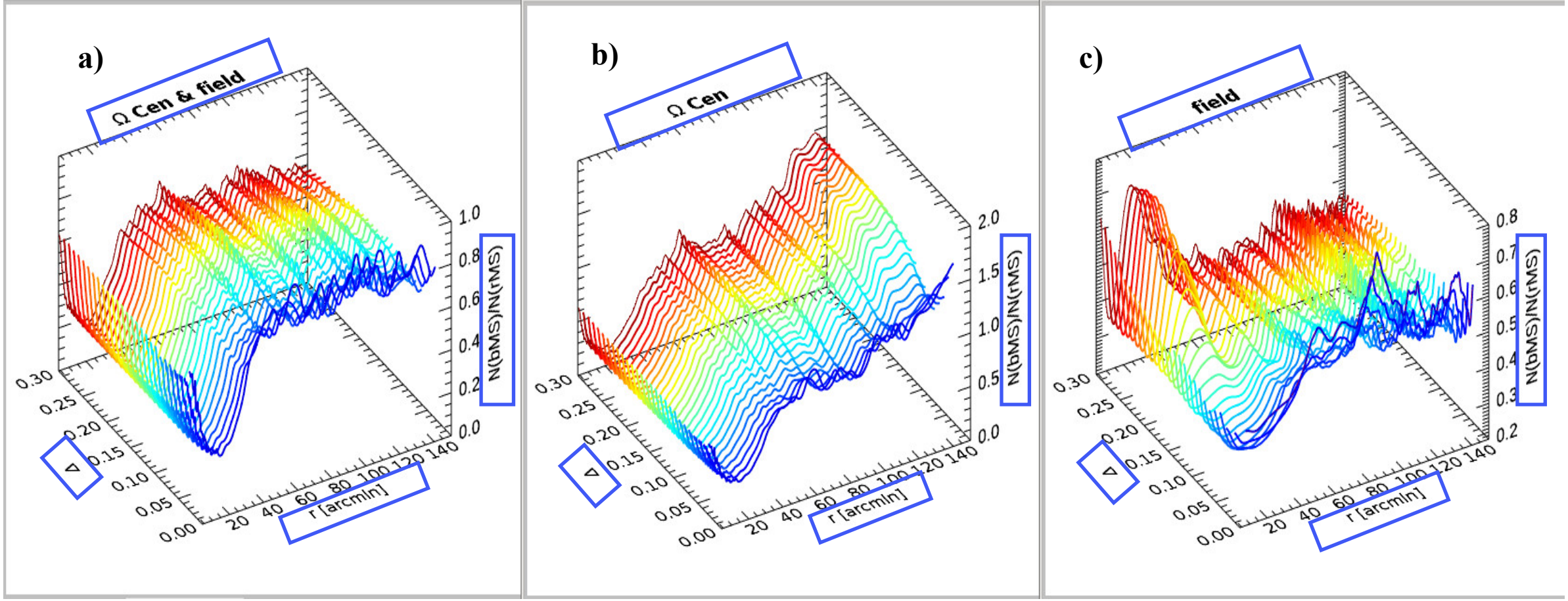


Interactive figure IOP



$\Delta = \Delta(g - i)$: size of the $(g - i)$ color bin from the **bMS** or **rMS** ridge lines to select **bMS** and **rMS** stars

We used 28 color bins from $\Delta = 0.02$ **mag** (min avg. photometric error) to $\Delta = 0.30$ **mag** for the selection

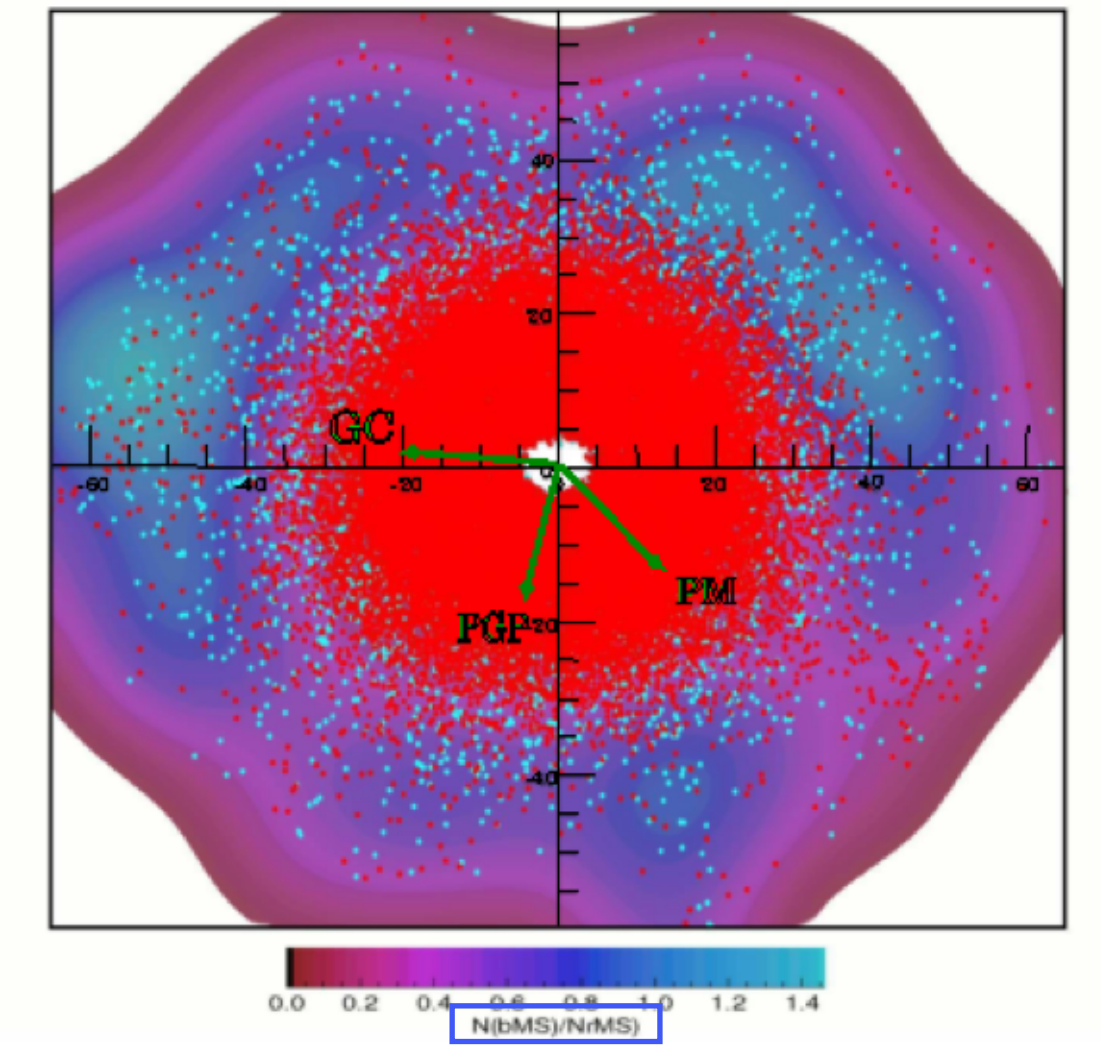


N(bMS)/N(rMS) for different (g-i) color bins, **Δ**, and for **all the observed stars (a)**, ω **Cen members (b), field stars (c)** as a function of distance from the cluster center, **r**

For ω Cen: N(bMS)/N(rMS) is decreasing from ~ 0.3-0.4 at r ~ 5’ (half-mass radius) **to ~ 0.2** at r ~ 20’

N(bMS)/N(rMS) then steadily increases until ~ 0.8 at r ~ 60’. The ratio keeps increasing beyond the tidal radius until ~ 1.4

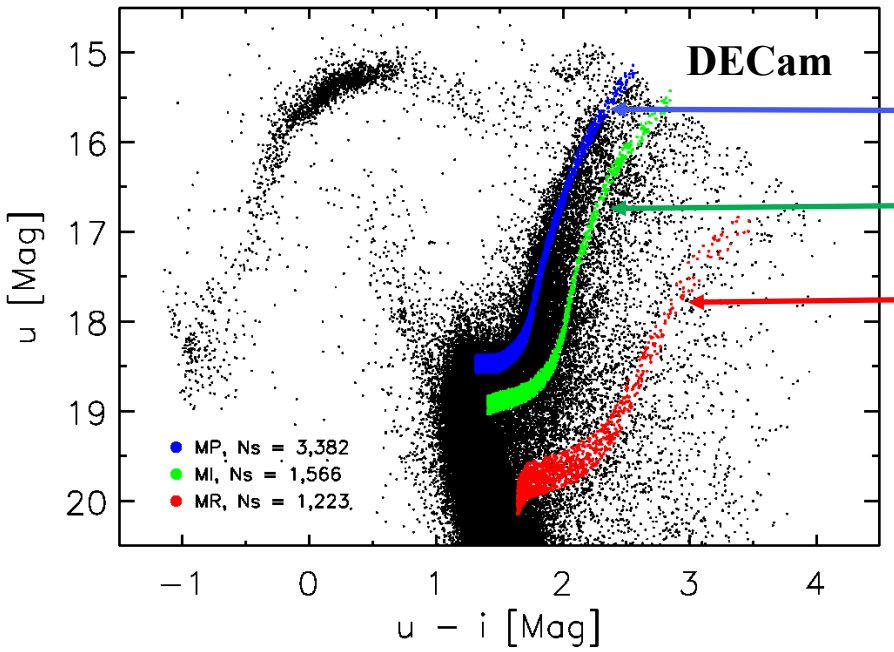
Density map of N(bMS)/N(rMS) as a function of position

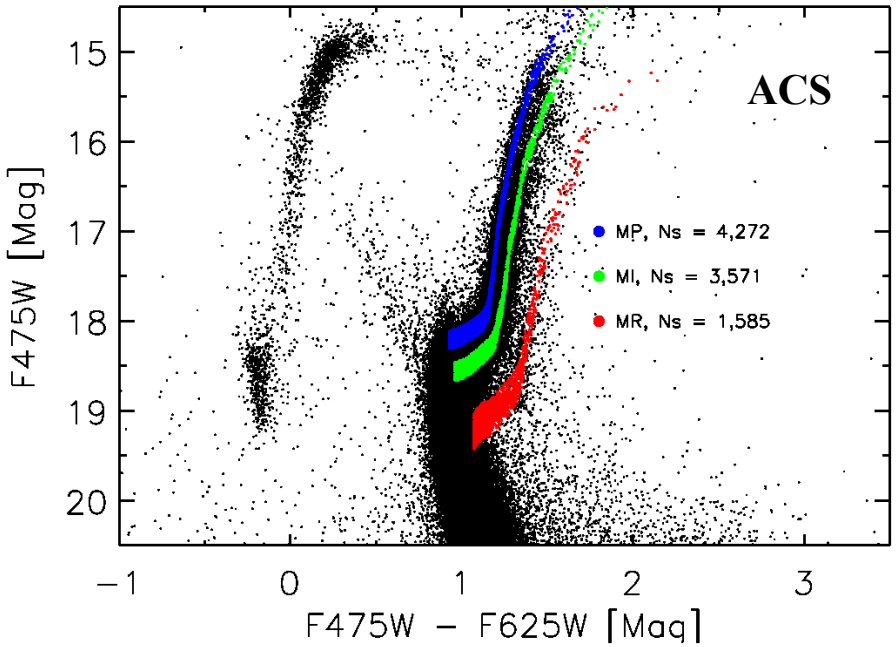


N(bMS)/N(rMS) has a clumpy distribution, with a well-defined **North/South asymmetry** in the outermost regions.

bMS stars are significantly more abundant in the Northern quadrants.

Spatial distribution of red-giant branch stars





Spectroscopy for internal regions of ω Cen says:

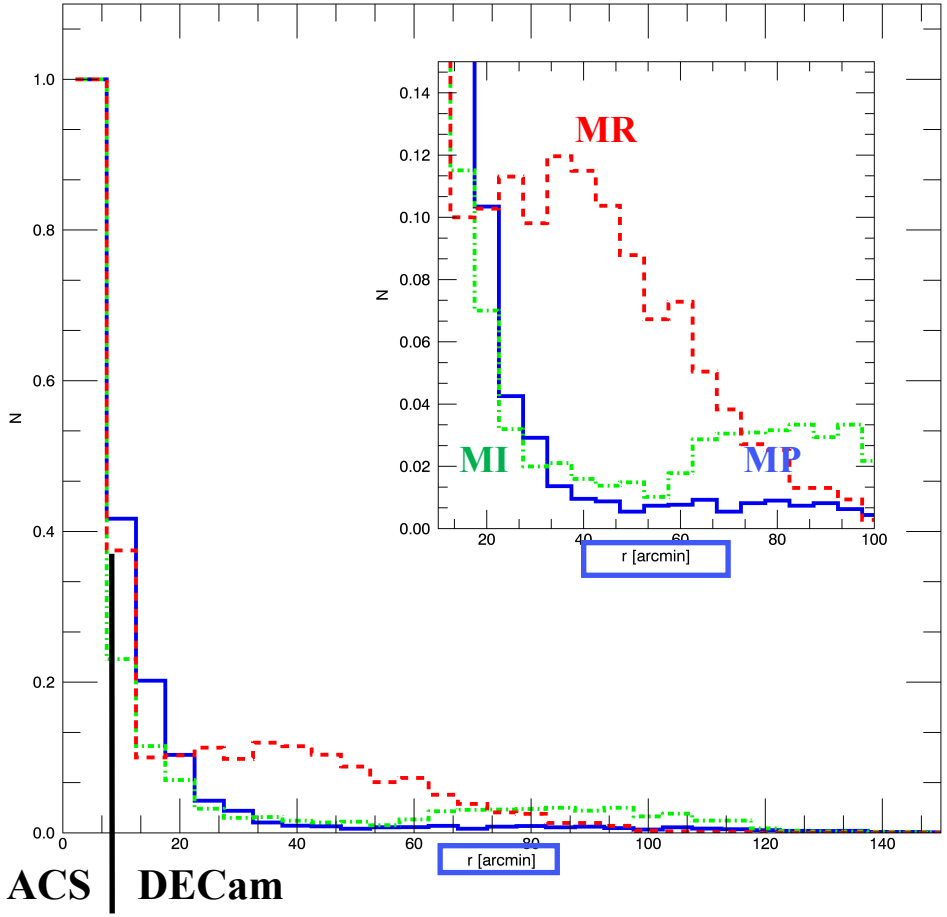
Main cluster **metal-poor population: blue and brightest RGB**

Metal-intermediate stars: one intermediate RGB

Most metal-rich stars: faintest and reddest RGB, ω3

The ω3 branch (MR) has a more extended spatial distribution starting from r ~ 15' from the cluster center

MI RGB stars are more concentrated compared to MP and MR RGB stars, but have a more extended distribution beyond the nominal tidal radius



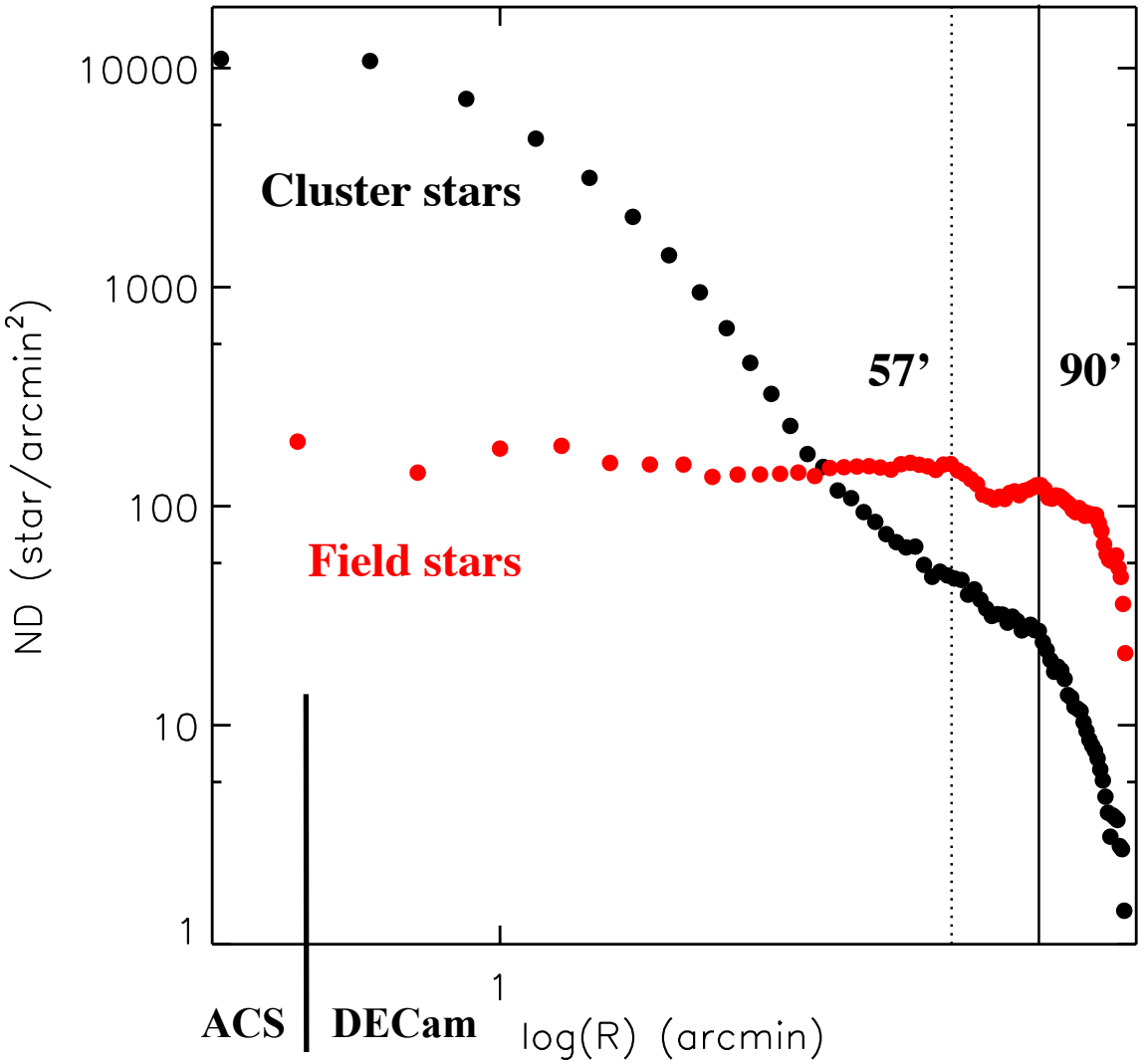
Halo and/or extra-tidal stars?

Preliminary results:

the nominal tidal radius for ω Cen (~1 degree) might be underestimated, or presence of an halo/extra-tidal stars

Similar results were found by Marconi et al. (2014, MNRAS, 444, 3809) based on VST photometry for 6° x 6° across ω Cen

Work in progress...



Summary and conclusions

- **ω Cen hosts a MR sub-population (ω3 branch) that shows a more extended spatial distribution compared to more metal-poor stars for distances r > 15';**
- **ω Cen bMS stars show a more extended spatial distribution compared to rMS stars. The frequency of bMS stars, supposedly more metal-rich than the rMS stars according to spectroscopy, steadily increases for r > 25', outnumbering the rMS stars at and beyond the tidal radius.** Their spatial distribution is clumpy, with an excess of bMS stars in the direction of the Galactic center
- ***These results, if confirmed, would make ω Cen the only stellar system currently known in the Universe to have more metal rich stars with a more extended spatial distribution compared to more metal-poor stars -> For more info see Calamida et al. 2017, AJ, 153, 175***