## Accurate ages and abundances of GCs from integrated spectra

Ivan Cabrera-Ziri



**UNIVERSITÄT HEIDELBERG** ZUKUNFT SEIT 1386



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What if we had accurate ages of extragalactic globular clusters?



#### Accurate GC ages help us constrain...



**GC** formation



Reionisation

Vigorous star formation (e.g. Reina-Campos+19)

### approx. 1<z<6



approx. z>7

Mergers of minihaloes (e.g. Trenti+15)



#### Accurate GC ages help us constrain...

#### **GC** formation

#### Galaxy formation/assembly



Reionisation

Assembly history of galaxies from the age, metallicity and mass of GCs (e.g. Kruijssen+19)



-0.75	[Fe/H]
-1.00	stars
-1.25	rmed
-1.50	vly-fo
-1.75	of nev
-2.00	licity
-2.25	Metal
-2.50	

Accurate GC ages help us constrain...

**GC** formation

#### Galaxy formation/assembly

Reionisation

GCs could have contributed an appreciable fraction of the photons that reionised the Universe (e.g. Boylan-Kolchin 18, He+20, Ma+21)





Our ability to date extragalactic GCs is holding us back in these fronts...







### isochrone age (gold std.)

Conroy+18



Johnson+21



#### Distant GCs cannot be resolved, so we rely on their integrated light to infer their ages...







# Some isochrones fail to reproduce the extent of the horizontal branch (HB) of GCs (we cannot predict $\Delta$ Y, $\eta$ , etc.)

The presence of these hot/bright stars makes the spectrum of an old pop. (~12 Gyr) look young (~6Gyr)!!!

This is the major source of systematic error in dating old metal poor stellar populations (e.g. Worthey 94; de Freitas Pacheco & Barbuy 95; Lee+ 00; Beasley+ 02; Schiavon+ 04; Thomas+ 05; Koleva+ 08; Ocvirk 10; Percival & Salaris 11)



### Spectral fits with alf (Cabrera-Ziri & Conroy 2022)

#### To overcome this we complement the spectrum given by the isochrones used with the flux of hot HB stars (see Koleva+ 08)





**Optical spectrum of a galactic globular cluster** Best fit using models with hot HB stars: ~13 Gyr (old) + 6% flux of eHB Best fit using models w.o. extended HB stars: ~5 Gyr (young)

Cabrera-Ziri & Conroy (2022)



Solutions of the fits to the integrated spectra

#### Models w/o hot HB: young age (~5.3±0.1 Gyr)

Models with hot HB: old (~12.9±0.6 Gyr) + 6% of flux from hot HB stars (diamond)

Age from isochrone fits (~11.2±0.7 Gyr)

Difference between a formation redshift z~0.5 vs. z>6!!! Cabrera-Ziri & Conroy (2022)



Cabrera-Ziri & Conroy (2022)



### isochrone age (gold std.)

## *Models w. hot HB:* ~81% within 0.1 dex of CMD age *Models w/o hot HB:* ~28% within 0.1 dex of CMD age



#### What's going on when it fails?

(long story short... although we converge on the right amount of flux from hot HB stars, we don't converge on the right Teff)

but there are different ways to flag these solutions...

#### Cabrera-Ziri & Conroy (2022)





#### Flux from hot HB stars

Integrated spectra values within <0.15 dex of CMD values

(hot HB detection also from spectral features, UV photometry)



#### [Fe/H] recovered within ~0.1 dex on average (regardless of HB, as expected)







(Credit: interwebs)







Grudić+ 22

**Brown & Gnedin 22** 









#### M31 sample 239 GCs with masses >1e5Msun ~70% complete within < 21kpc

#### No GCs <8 Gyr (previous claims turned out to be GCs with hot HBs)

## Fast chemical enrichment of main progenitor

One clear 'accreted branch' @ high [Fe/H] (massive progenitor)

#### **Cabrera-Ziri+ in prep.**



![](_page_17_Picture_6.jpeg)

![](_page_18_Figure_1.jpeg)

**Cabrera-Ziri+ in prep.** 

**Cabrera-Ziri+ in prep.** 

We recover the same scaling relations between the multiple populations and cluster mass for Galactic GCs...

![](_page_19_Figure_2.jpeg)

![](_page_19_Picture_3.jpeg)

**Cabrera-Ziri+ in prep.** 

We recover the same scaling relations between the multiple populations and cluster mass for Galactic GCs...

... and M31!!!

Also a pop. of 'metal rich' GCs with hot HBs

![](_page_20_Figure_4.jpeg)

![](_page_20_Figure_5.jpeg)

![](_page_21_Figure_0.jpeg)

Cabrera-Ziri & Conroy (2022) High SNR (~100) low resolution (~100km/s) optical (~3700-9000Å) spectra

## Galaxy assembly:

- We can learn about the assembly history of many nearby galaxies.
- Test different models.
- Multiple stellar pops.:
- Are the scaling relations universal? New manifestations of phenomenon: metal rich GCs with hot
- HBs

with archival data I have shown that we can start doing some pretty interesting science, e.g.:

ages & [Fe/H] within ~0.1 dex of ref. values extended HB flux ~0.15 dex & Temp. ~20% we know how to identify spurious solutions

![](_page_22_Picture_9.jpeg)

![](_page_22_Picture_10.jpeg)

![](_page_22_Picture_11.jpeg)