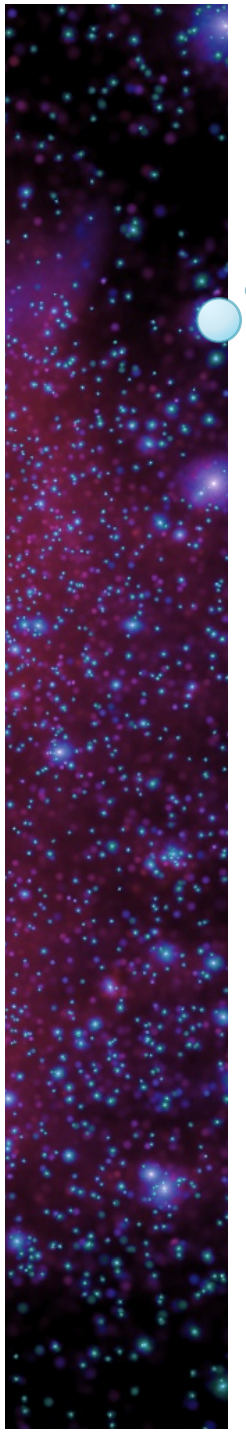

The earliest phases of star formation: The extremely metal-poor tails of the classical dwarf spheroidal galaxies

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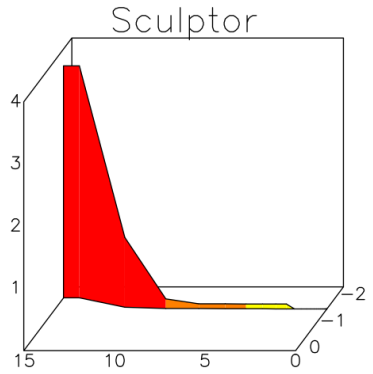
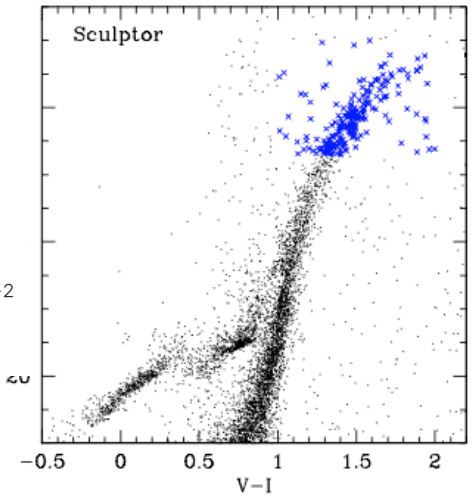
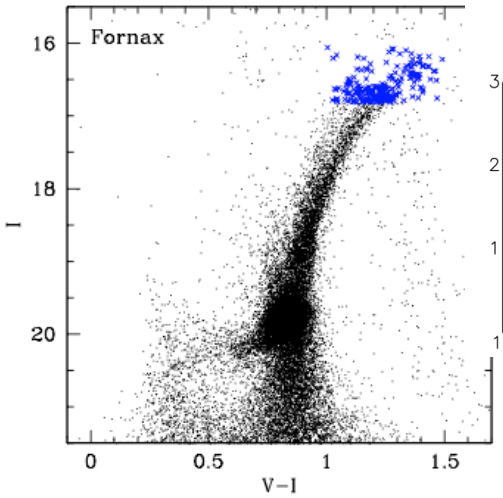
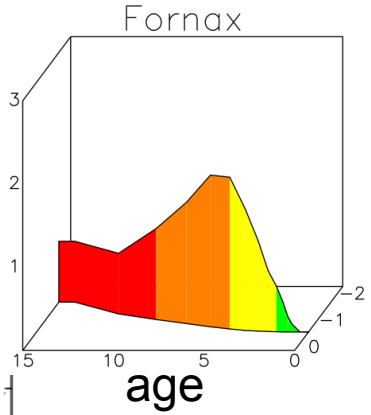
In collaboration with: Vanessa Hill, Eline Tolstoy, Mike Irwin, Patrick Francois, Amina Helmi, Kim Venn, Pascale Jablonka, Martin Tafelmeyer, Giuseppina Battaglia, Matthew Shetrone, Thomas de Boer, Jonay Gonzalez Hernandez, Bertrand Lemasle, Leon Boschman

Studying the classical satellites: ESO Large Program DART



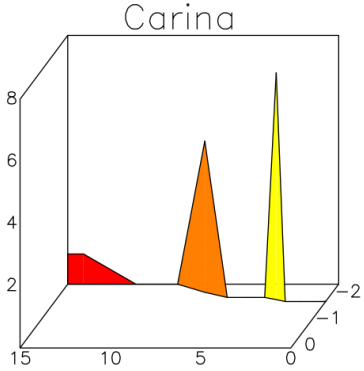


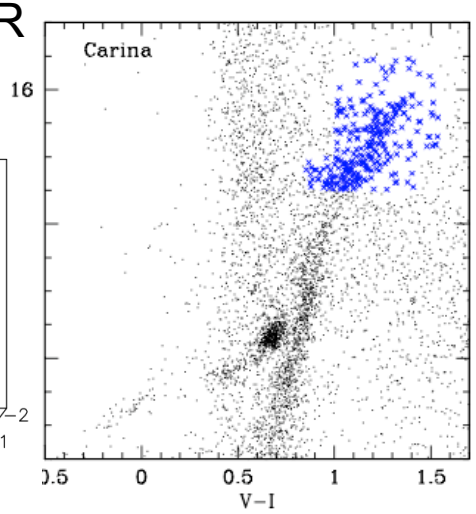


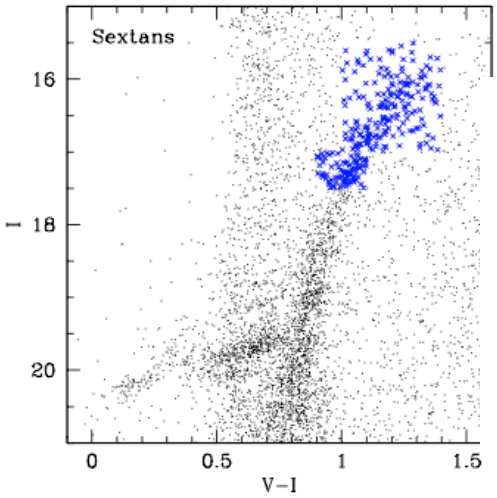


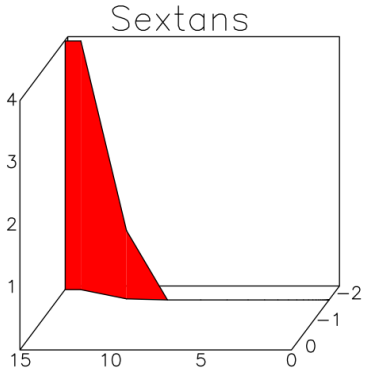
~100 stars HR

~300-1000 stars LR



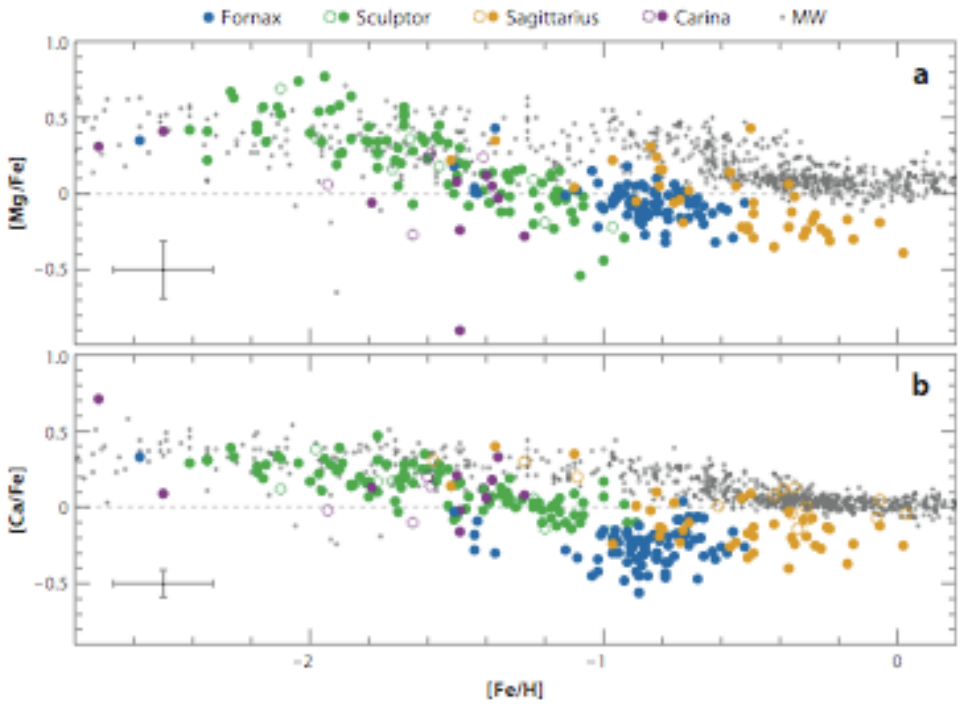






High-resolution results: The dwarf galaxies & the building blocks

- They are chemically distinct!



Tolstoy et al., 2009

- But are they different also in the earliest stages?

Low resolution program results: Where are the EMP stars?

Problem: Lack of [Fe/H]<−3 stars in dwarf galaxies compared to Milky Way halo

(Helmi et al., 2006)

Question: Are the dwarf galaxies intrinsically different or did we miss the metal-poor stars?

Context: This [Fe/H] is measured via the broad Ca II triplet lines, using linear relation line widths, abs. mag., and [Fe/H]

BUT calibrated on globular clusters [Fe/H] > -2.3

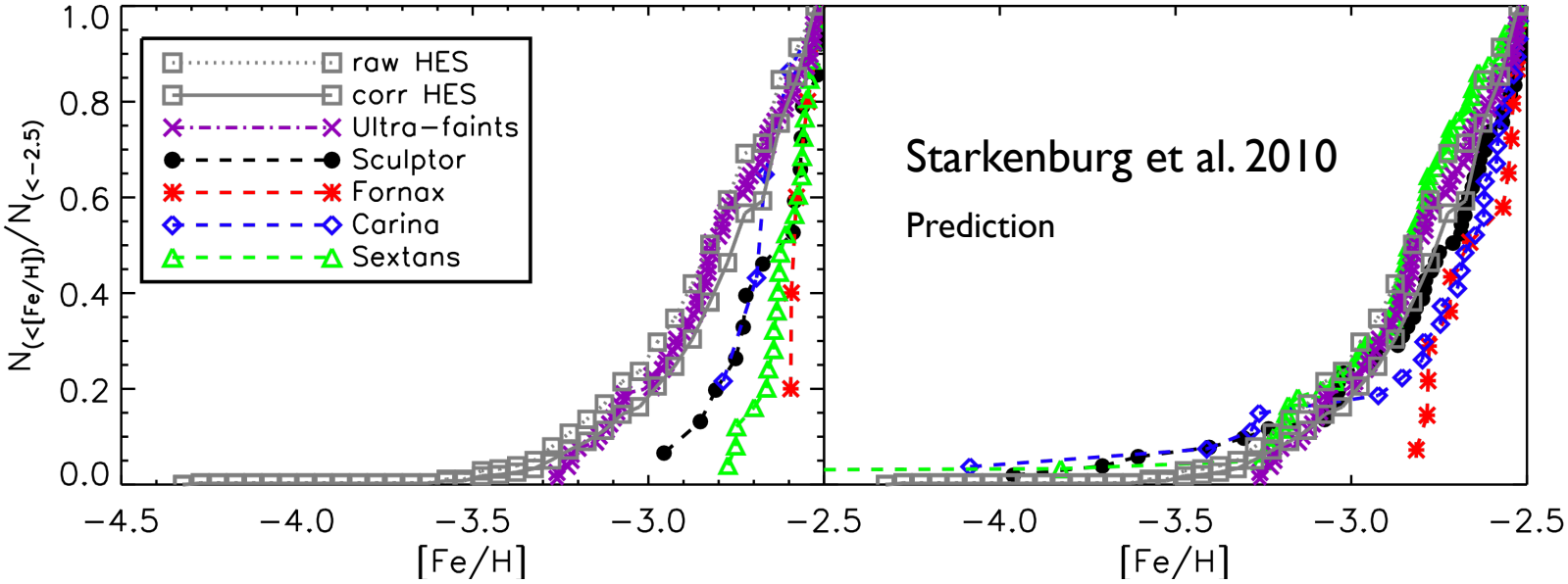
Method: Study CaII triplet lines at lowest [Fe/H] through synthesis and observations

Result: At low [Fe/H] linearity does not hold ➔ we provide recalibration

(Starkenburg et al., 2010)

Old vs. new calibration

Predicts better match with the metal-poor tail of the Milky Way



Many stars deserve follow-up!

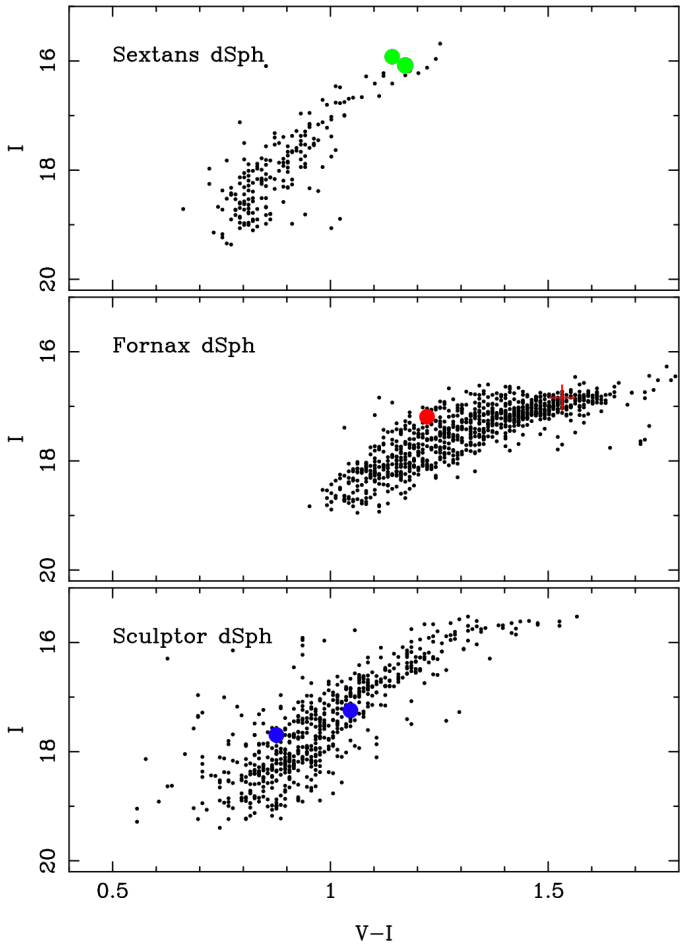
MW halo:
Schörck et al. 2009
Ultrafaints:
Kirby et al. 2008

Discussing DART follow-up, but see also EMP stars in:
Aoki et al. 2009 (Sextans), Frebel et al., 2010a,b (Sculptor, ultra-faints), Norris et al., 2010a,b (Bootes), Lai et al., 2011 (Bootes), Fulbright et al., 2004 (Draco), Cohen & Huang 2009 (Draco)

Follow-up efforts:

Tafelmeyer et al., 2010

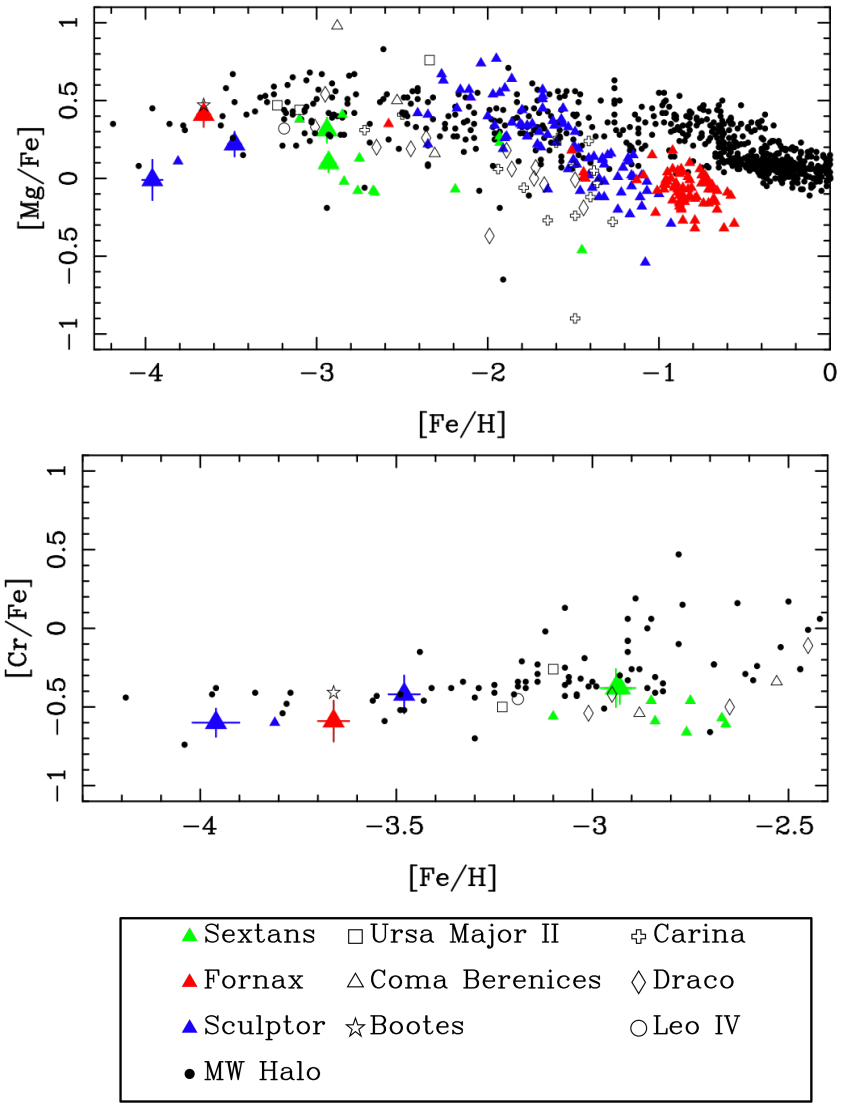
- High-resolution ESO/UVES follow-up:
  - 5 RGB stars
- Results [Fe/H]:
  - All [Fe/H] < -3
  - Three [Fe/H] < -3.5
    - Most metal-poor extragalactic star: [Fe/H]=-3.96 ± 0.10



Follow-up efforts:

Tafelmeyer et al., 2010

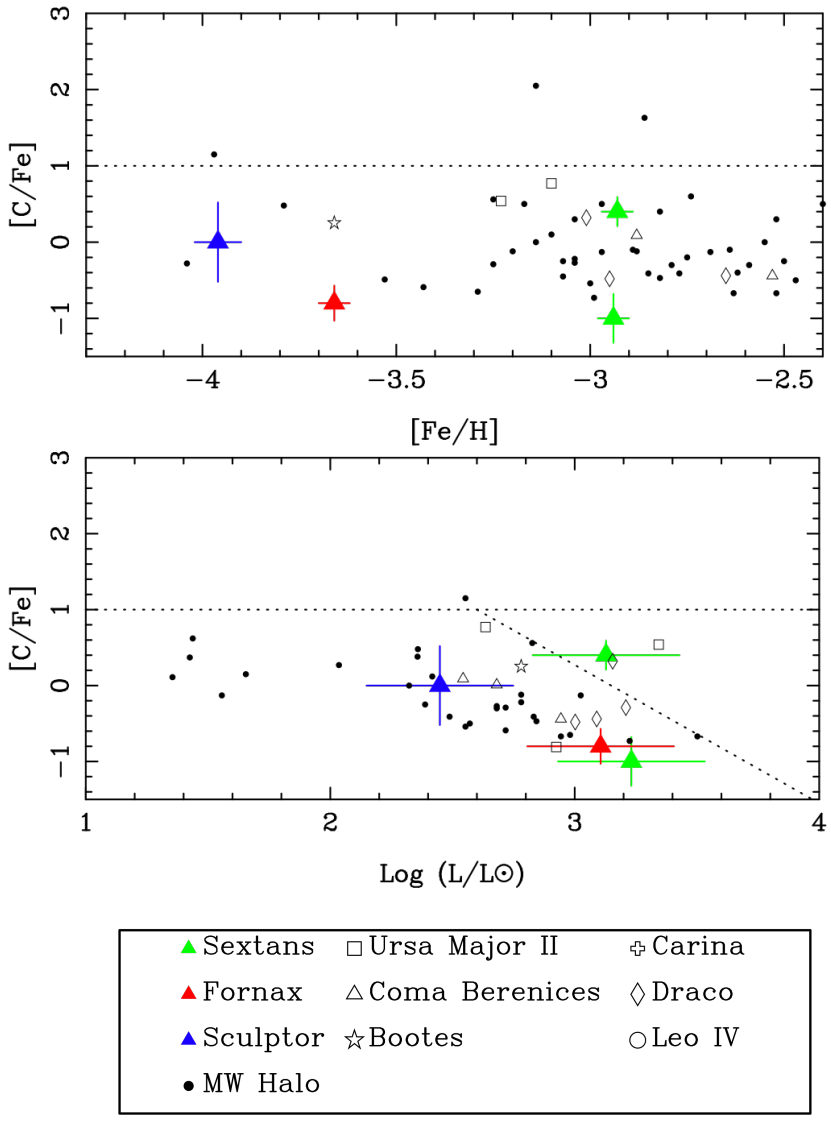
- Alpha elements:
  - Consistent with halo < [Fe/H]= -3
- Iron peak elements:
  - Same behaviour
- Early enrichment of ISM universal and independent of galaxy properties?



Follow-up efforts:

Tafelmeyer et al., 2010

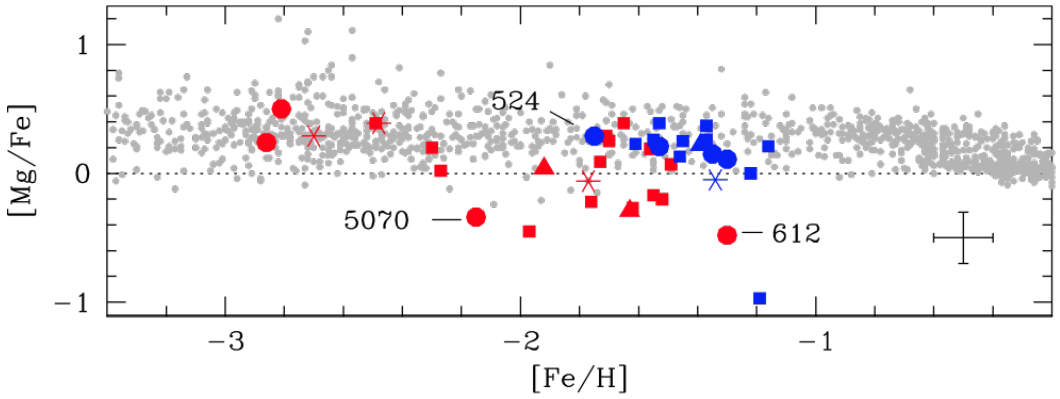
- Carbon
  - None classical C-rich (MW ~25%)
  - One carbon enhanced if mixing is considered (Aoki et al., 2007)
  - Inhomogenities in Sextans
    - Stars similar in [Fe/H], but diverge in [C/Fe] (and in [Mg/Fe])

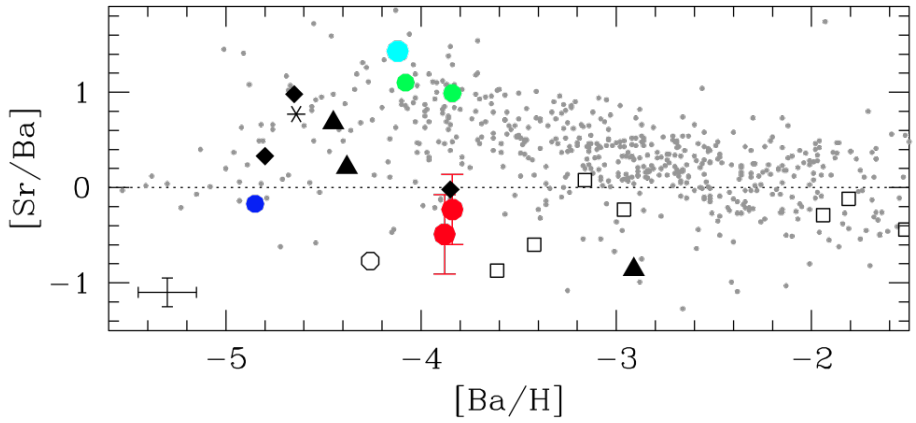


Follow-up efforts Carina:

Venn et al., 2012, Lemasle et al., 2012

- Evidence for inhomogeneous mixing in the oldest population!





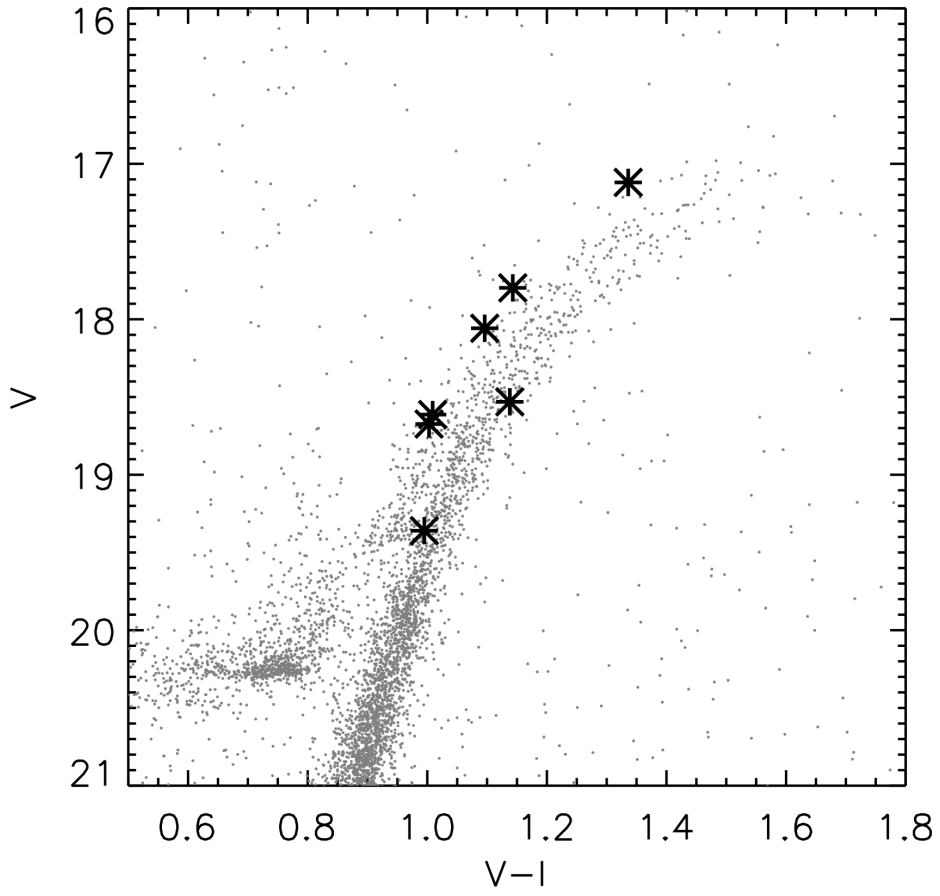
- Is the Sr/Ba ratio indicating different enrichment in r-process in the smallest galaxies?

Follow-up efforts Sculptor:

Starkenburg et al., in prep.

- We have followed-up seven stars in Sculptor with X-shooter (VLT)
- CaT predictions:
  - [Fe/H]=-3.6 ± 0.2
  - [Fe/H]=-3.0 ± 0.1
  - [Fe/H]=-3.0 ± 0.1
  - [Fe/H]=-2.9 ± 0.3
  - [Fe/H]=-3.4 ± 0.5
  - [Fe/H]=-3.0 ± 0.5
  - [Fe/H]=-2.8 ± 0.3

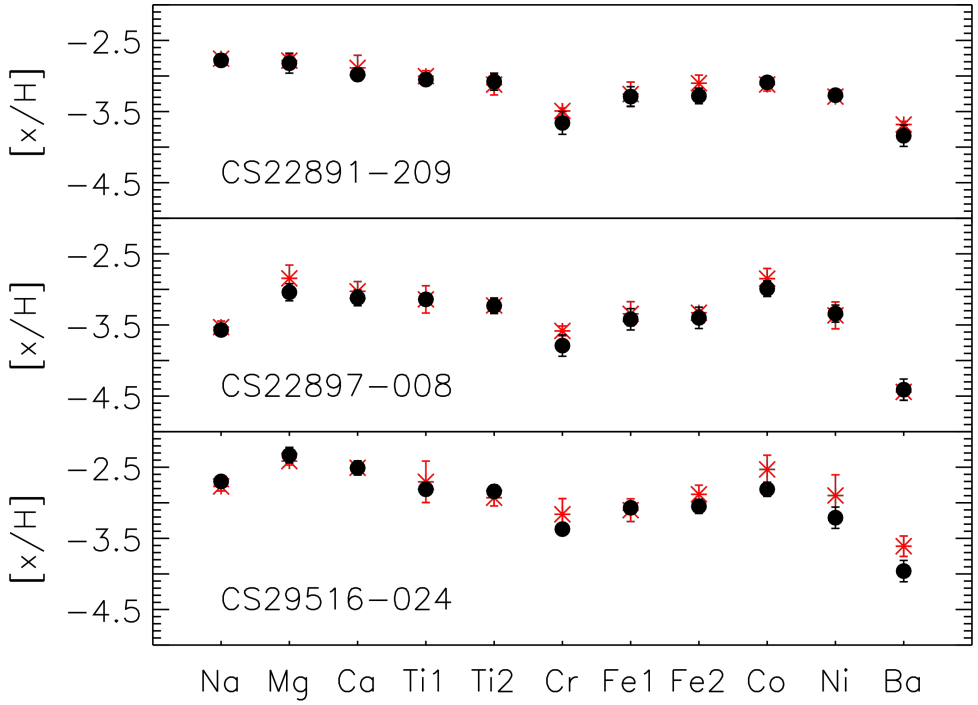
Starkenburg et al., in prep.



Follow-up efforts Sculptor:

Starkenburg et al., in prep.

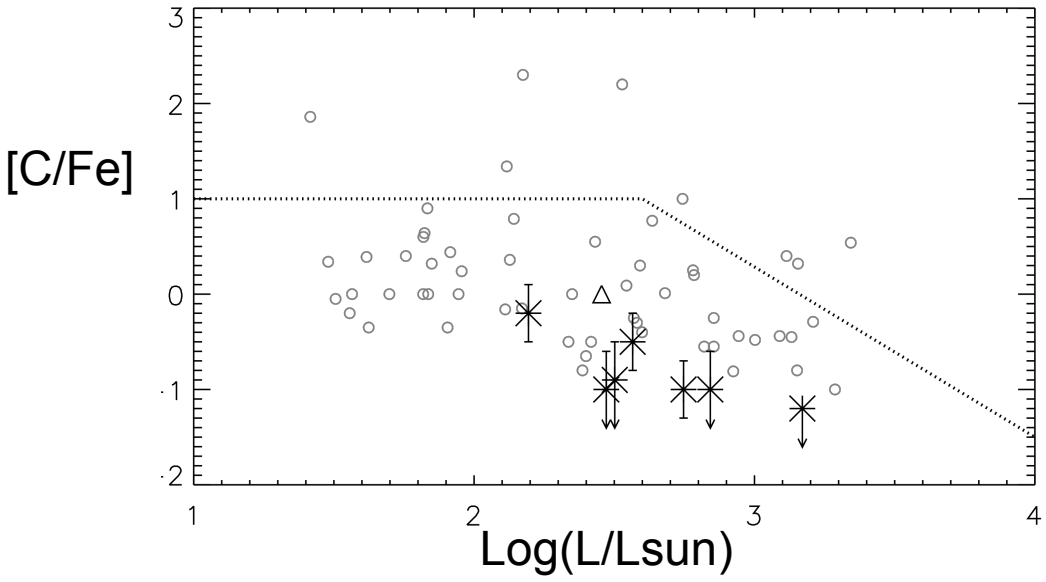
- Temperatures & gravities from photometry (de Boer et al. 2011, IR from VISTA commissioning)
- All lines measured with splot then Turbospectrum code
  - Typically ~25 Fe I lines per spectrum



- 3 halo EMP stars in common with Cayrel et al. 2004
- Really good convergence for LTE abundances
- Check of linelist and method

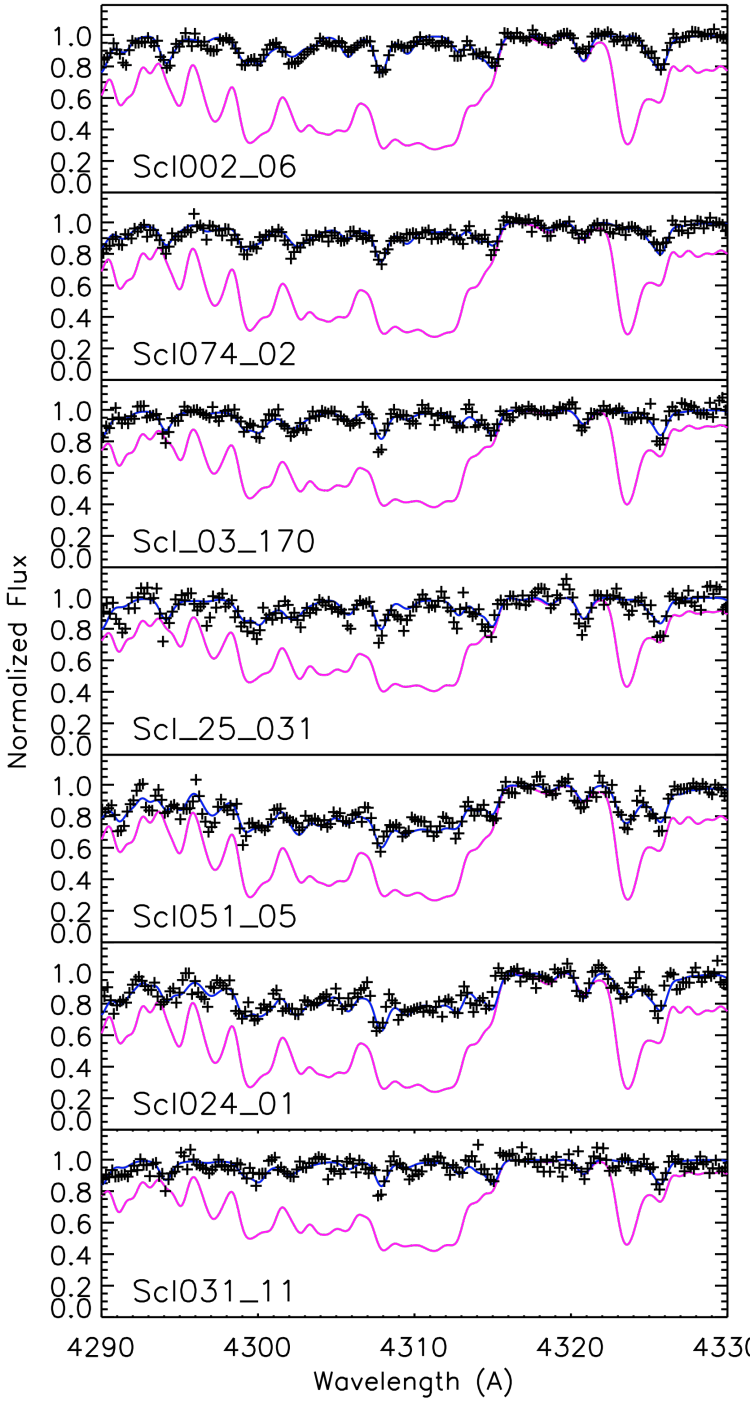
Carbon

- Measuring CH-band (molecule!)
- None are Carbon-rich
  - But C-rich stars in MW (~25%)
- Even when mixing is considered



Other work: Tafelmeyer et al. (2010) for Scl (open triangle).

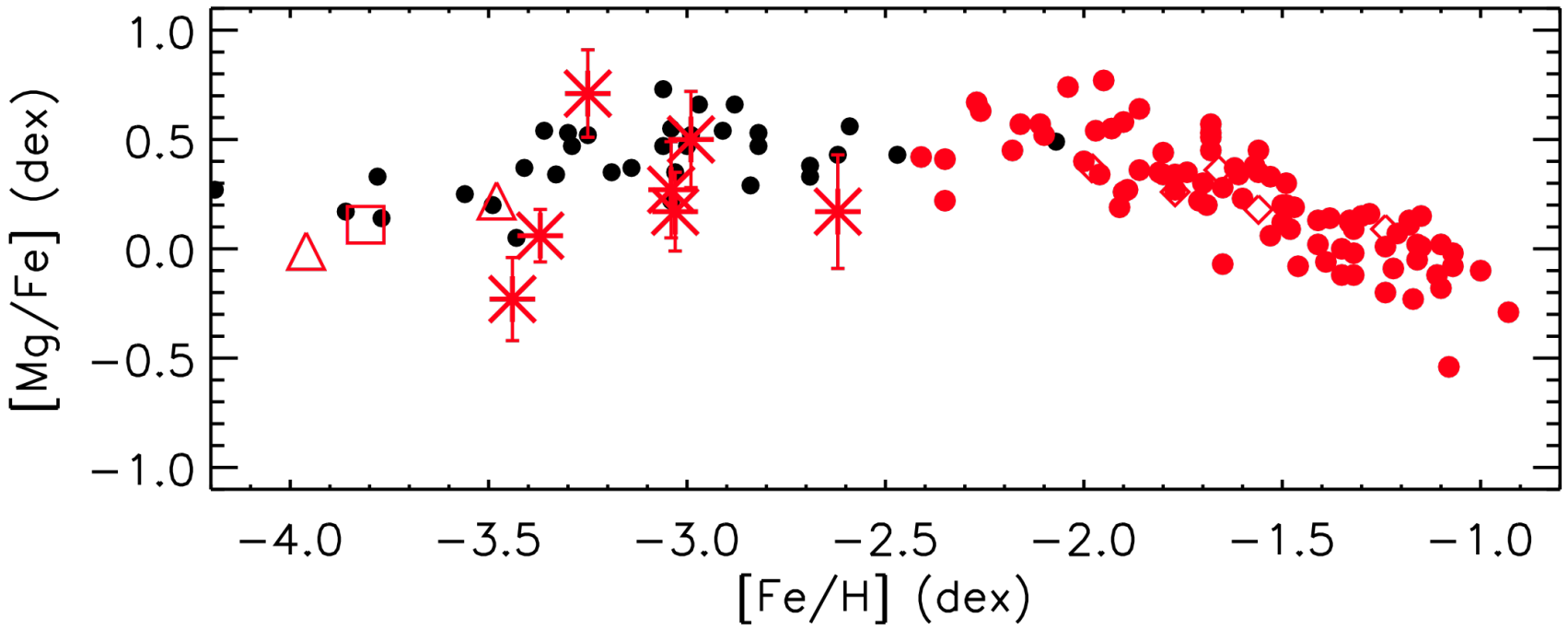
Gray circles are other dwarfs (Fulbright et al. 2004; Cohen & Huang 2009; Tafelmeyer et al. 2010; Norris et al. 2010,a, Honda 2010, Lai 2011).



Alpha elements

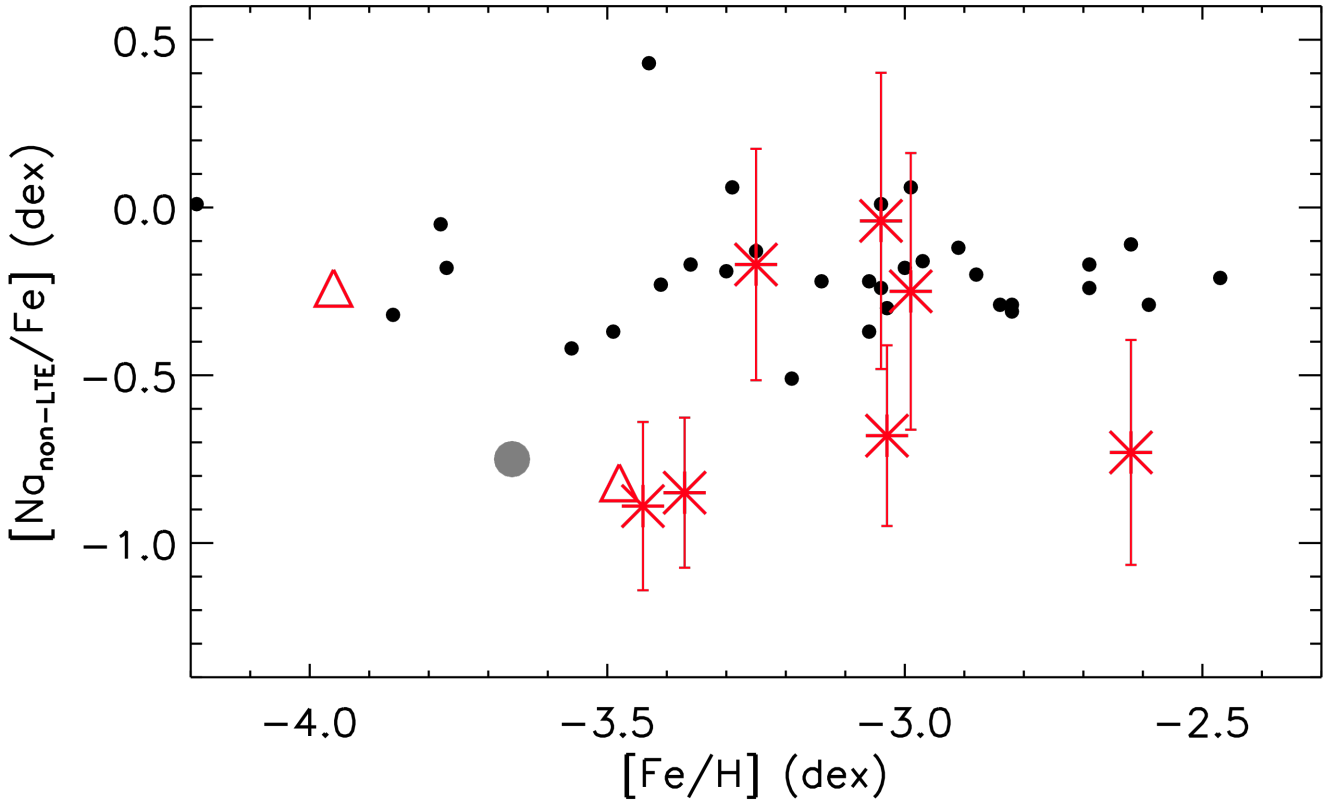
- Much more in common with halo trend than at higher metallicities
- More scatter??

Sculptor (red: Hill et al, Frebel et al, Tafelmeyer et al., Starkenburg et al.) and the Milky Way (black: Cayrel et al, Bonifacio et al.)

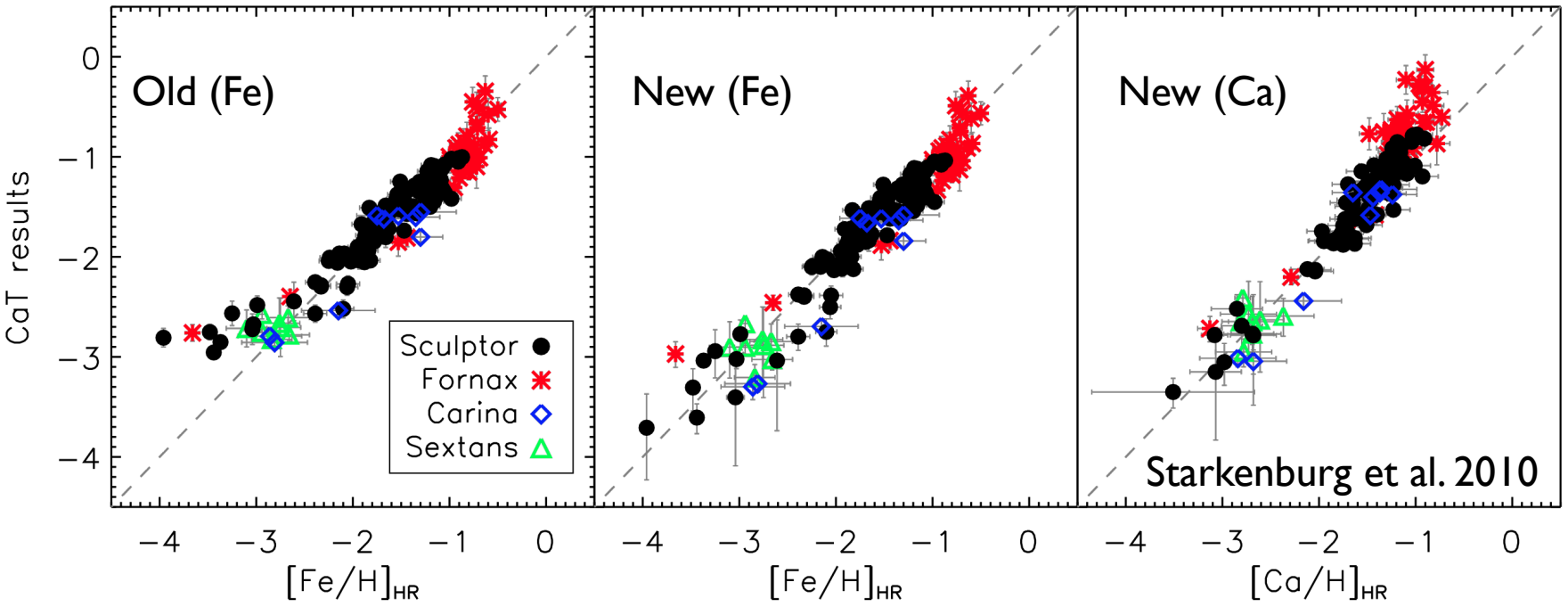


Sodium

- Na corrected for non-LTE effects (Andrievsky et al. 2007)
- Are the lowest [Fe/H] stars below the trend?



All follow-up: Old vs. new calibration



- Both [Fe/H] and [Ca/H] correlate well with new CaT predictions
- Scatter in [Ca/H] relation smaller?

HR results:
Battaglia et al. 2008,
Aoki et al. 2009,
Venn et al. 2012,
Tafelmeyer et al., 2010,
Starkenburg et al., in prep.

Conclusions

We provide a new CaT calibration down to [Fe/H]= -4

- The amount of EMP candidates is now more in agreement with the nr. of EMPs in the Galactic halo
- Follow-up validates the new calibration and help us understand evolution processes
- Possibly larger scatter in alpha-abundances, inhomogeneous mixing, Na low, nr. C-rich stars, origin of heavy elements?
- But generally much evidence for more universal first star formation epoch!
- We need more data!

- And in my last minutes…

Dark satellites and the morphology of dwarf galaxies

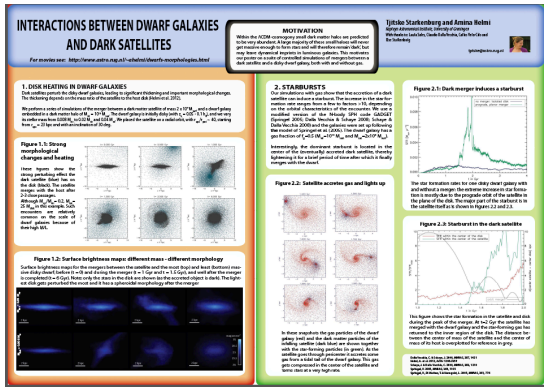
Helmi, Sales, Starkenburg, Starkenburg et al. submitted

- Dwarf galaxies have lower baryon content
- But dark matter is approx. scale-free

➔Interactions with (dark) satellites have a larger impact in dwarfs!

- Depending on gas-content this could lead to
  - Morphological changes: disk ➔spheroid
  - Merger-induced star formation

See poster by Tjitske Starkenburg!



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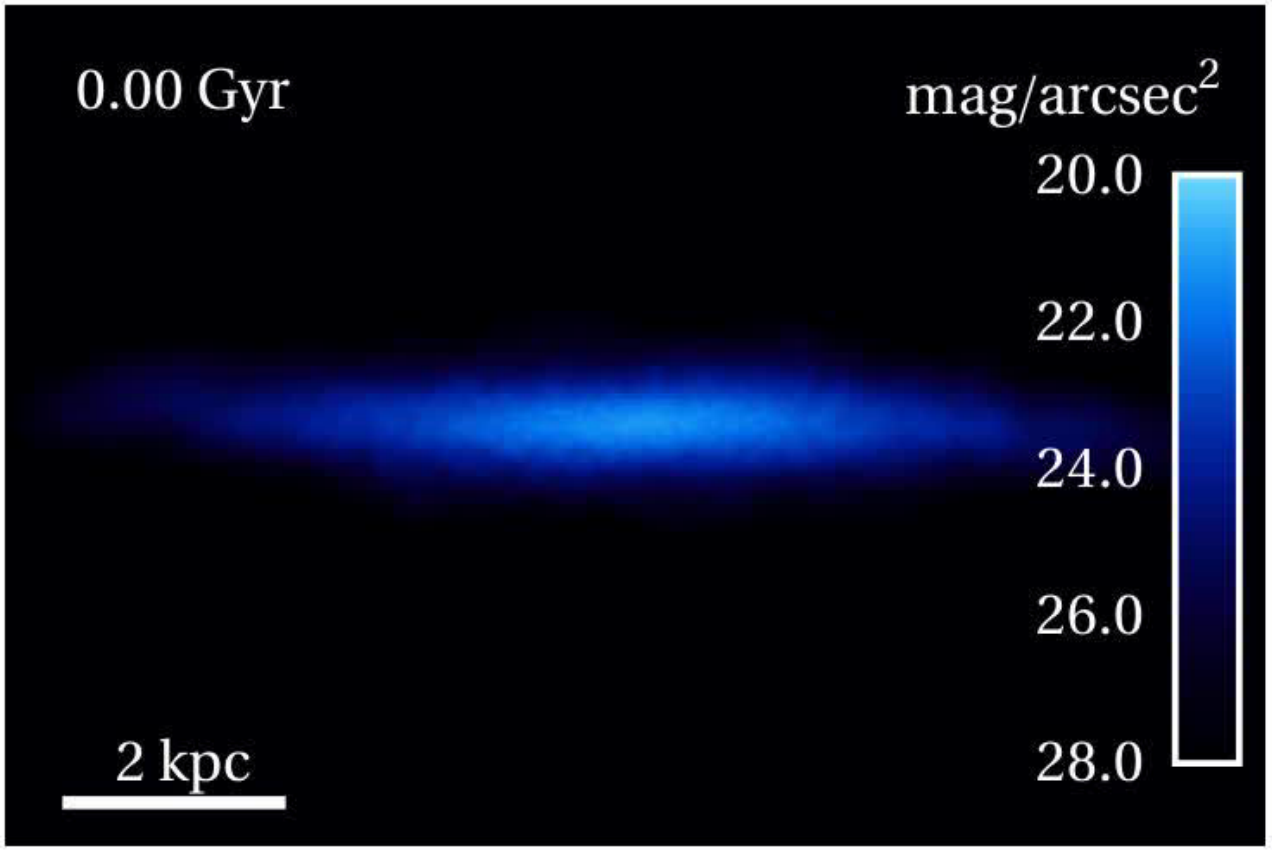

See poster by Tjitske Starkenburg!