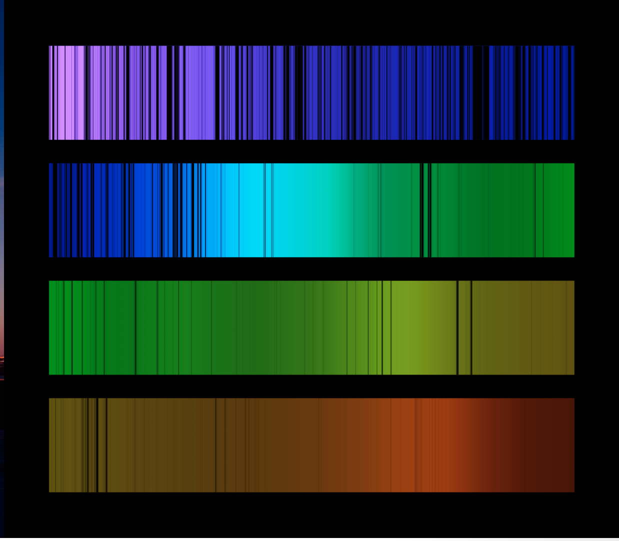




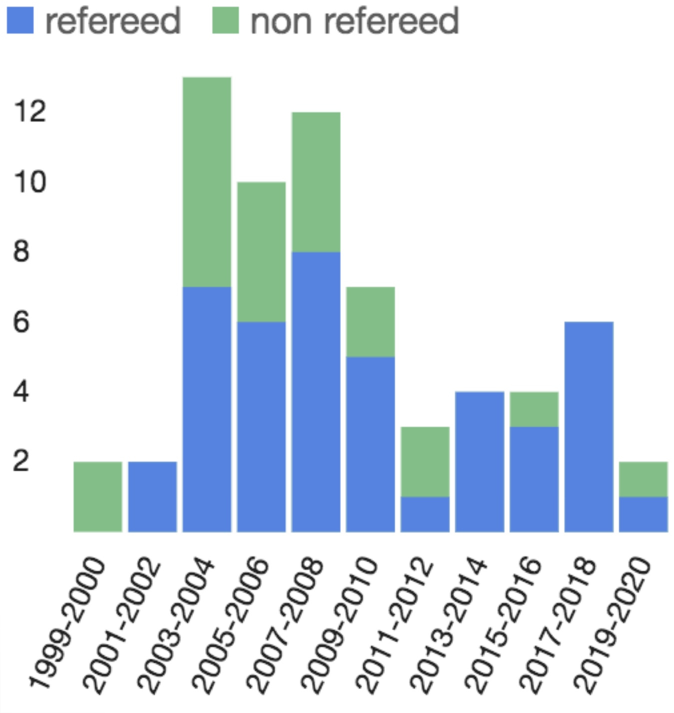
UVES investigations into Local Group Dwarf Galaxies and streams

Else Starkenburg

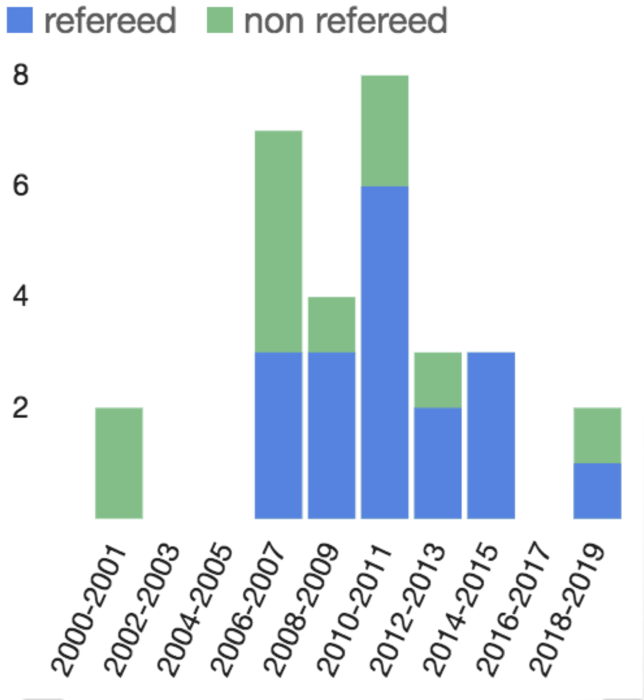
This talk

- Very **personal** and **incomplete** summary of how UVES has helped to change our view on the "local" dwarf galaxies and streams

ADS search "UVES + dwarf galaxy" in the abstract

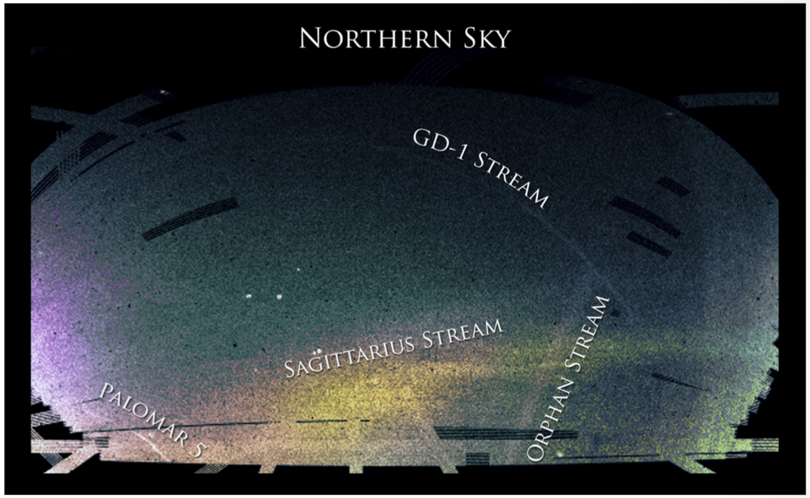


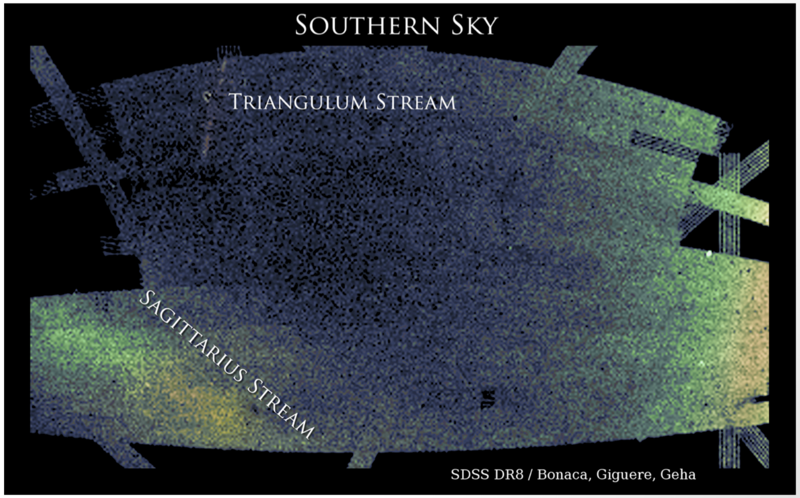
ADS search "UVES + stream" in the abstract



Dwarf galaxies as "building blocks"? The framework

- Dwarf galaxies show a range of masses and star formation histories
  - Studying galaxy formation in much detail
- The general framework: The halo of our Galaxy is formed out of destroyed dwarf galaxies
  - A process happening to the Sagittarius dwarf galaxy now (Ibata et al., 1994)
  - But are the surviving galaxies like the building blocks?

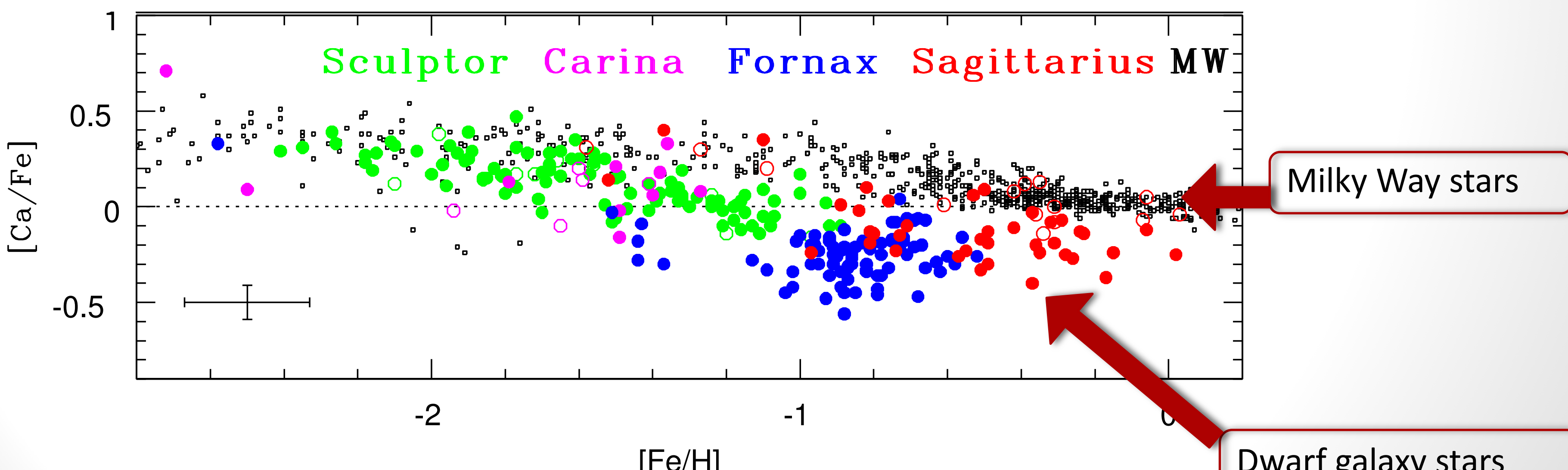




Dwarf galaxies as “building blocks”?

- Few detailed observations of stars in dwarf galaxies available when UVES joins this game
  - Shetrone et al., 2003: 15 red giants in Sculptor, Fornax, Carina, and Leo I
  - This work and following studies conclude: The dwarf galaxies do **not** have the same abundance patterns as known halo stars…

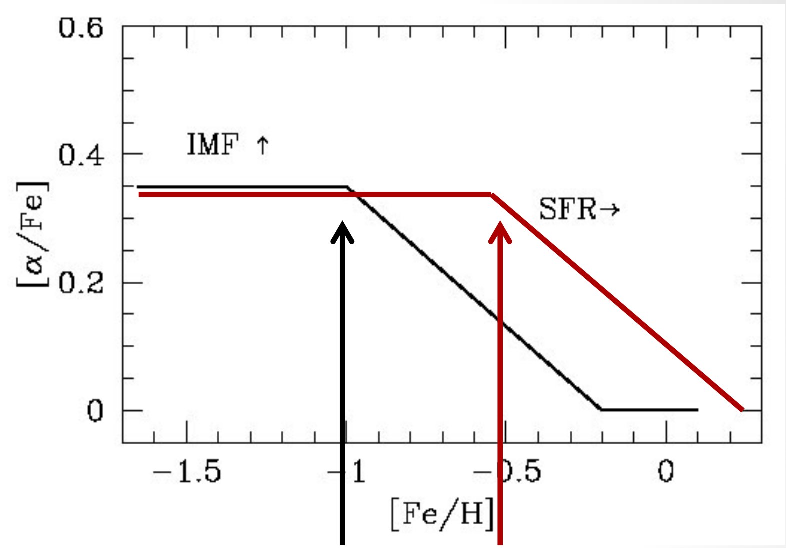
(Tolstoy et al. 2003; Venn et al., 2004; Geisler et al. 2005…)



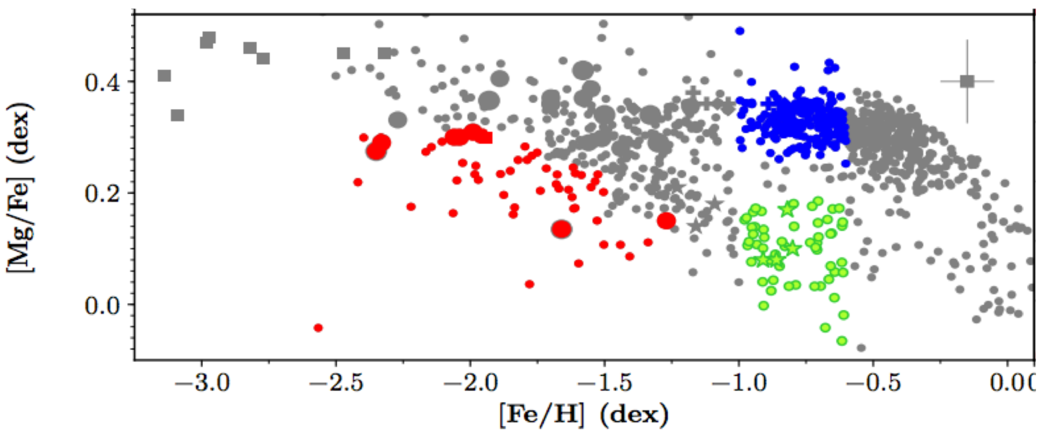
Compilation in Tolstoy, Hill & Tosi 2009
Large compilation effort also in the SAGA database (Suda et al., 2017)

Interpretation?

- Different contribution of SN II and Sn Ia products at similar metallicity
  - Dependence on mass and chemical enrichment history of the system
  - Possibly also influence of the Initial Mass Function in the system



Onset SN Ia: Same **time** different **metallicity**!



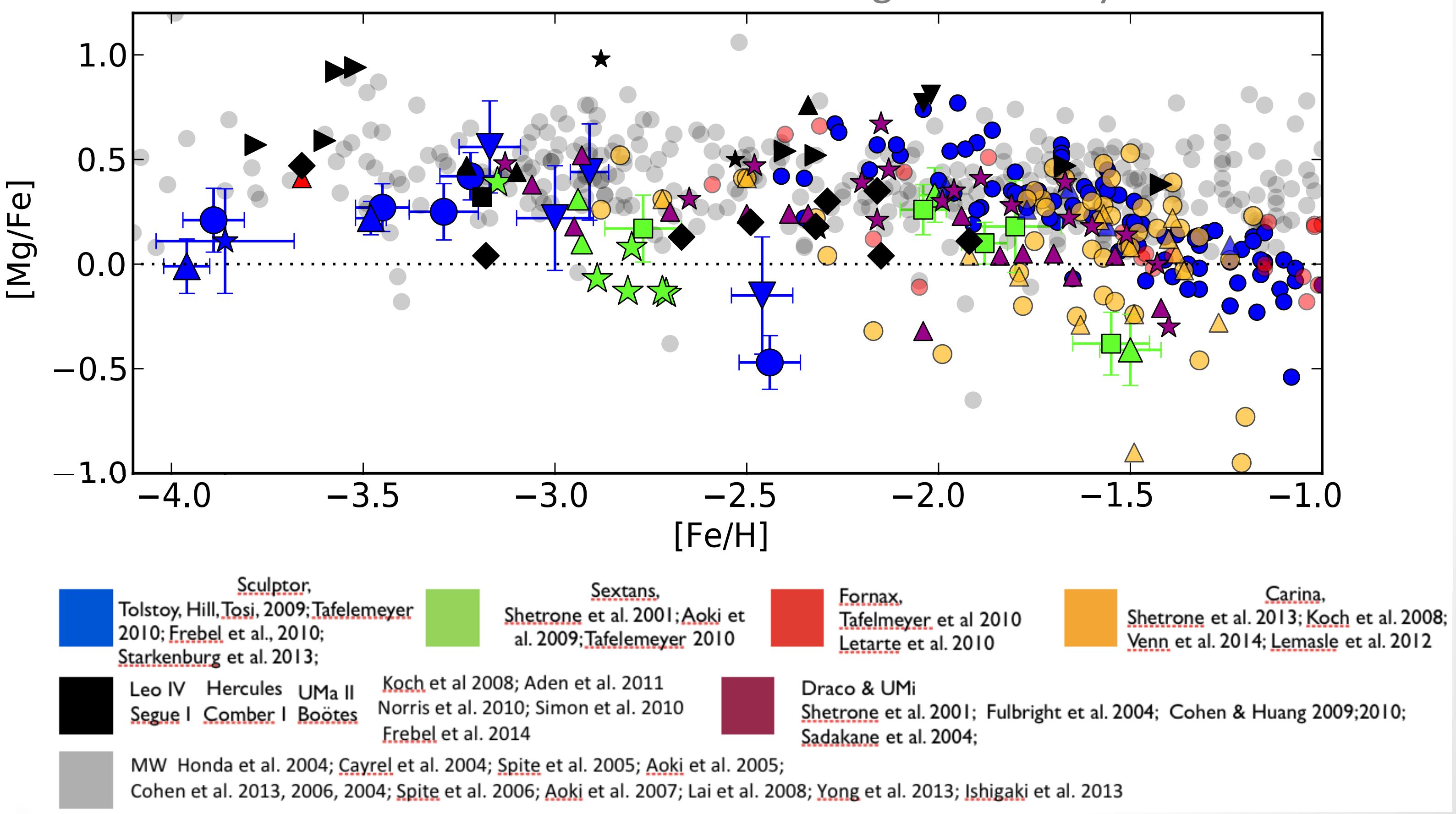
Recio-Blanco et al., 2020

Small system – slow evolution
Intermediate system
Massive system – fast evolution

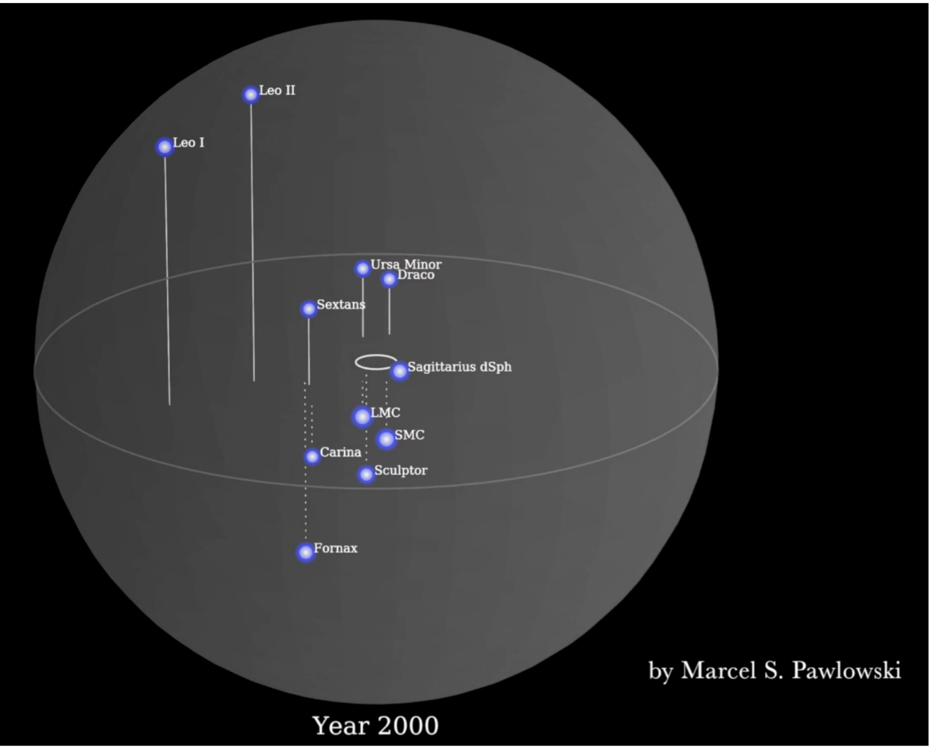
Metal-poor stars in the dwarfs

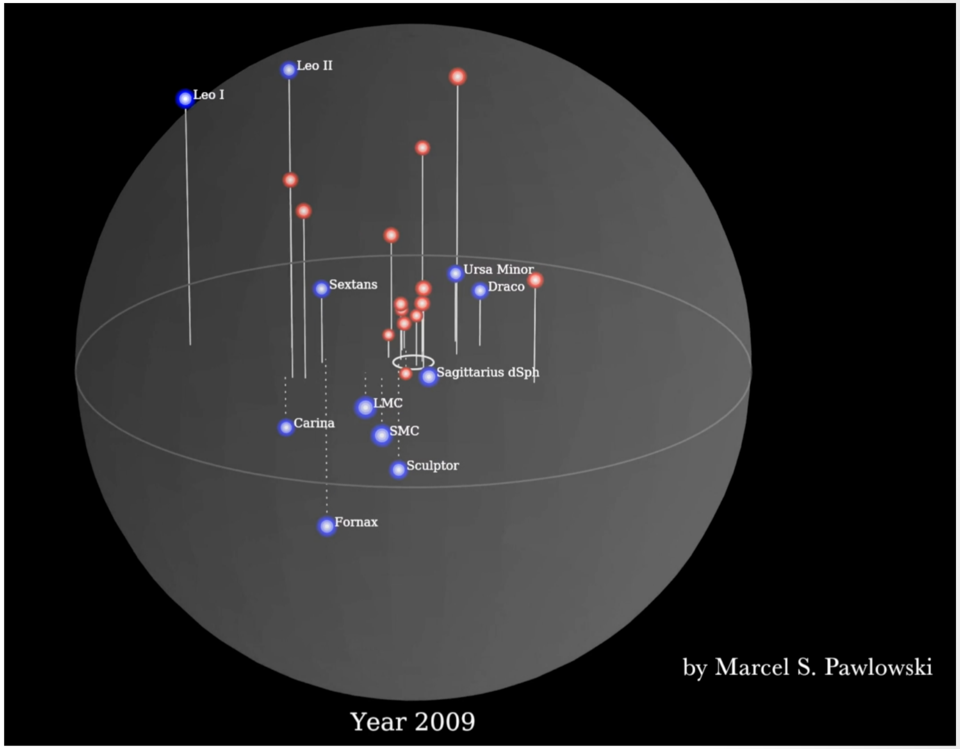
- Most metal-poor stars follow the halo better in **α** – elements
- Are the earlier phases of star formation more universal?

Figure courtesy: Pascale Jablonka



SDSS comes along…

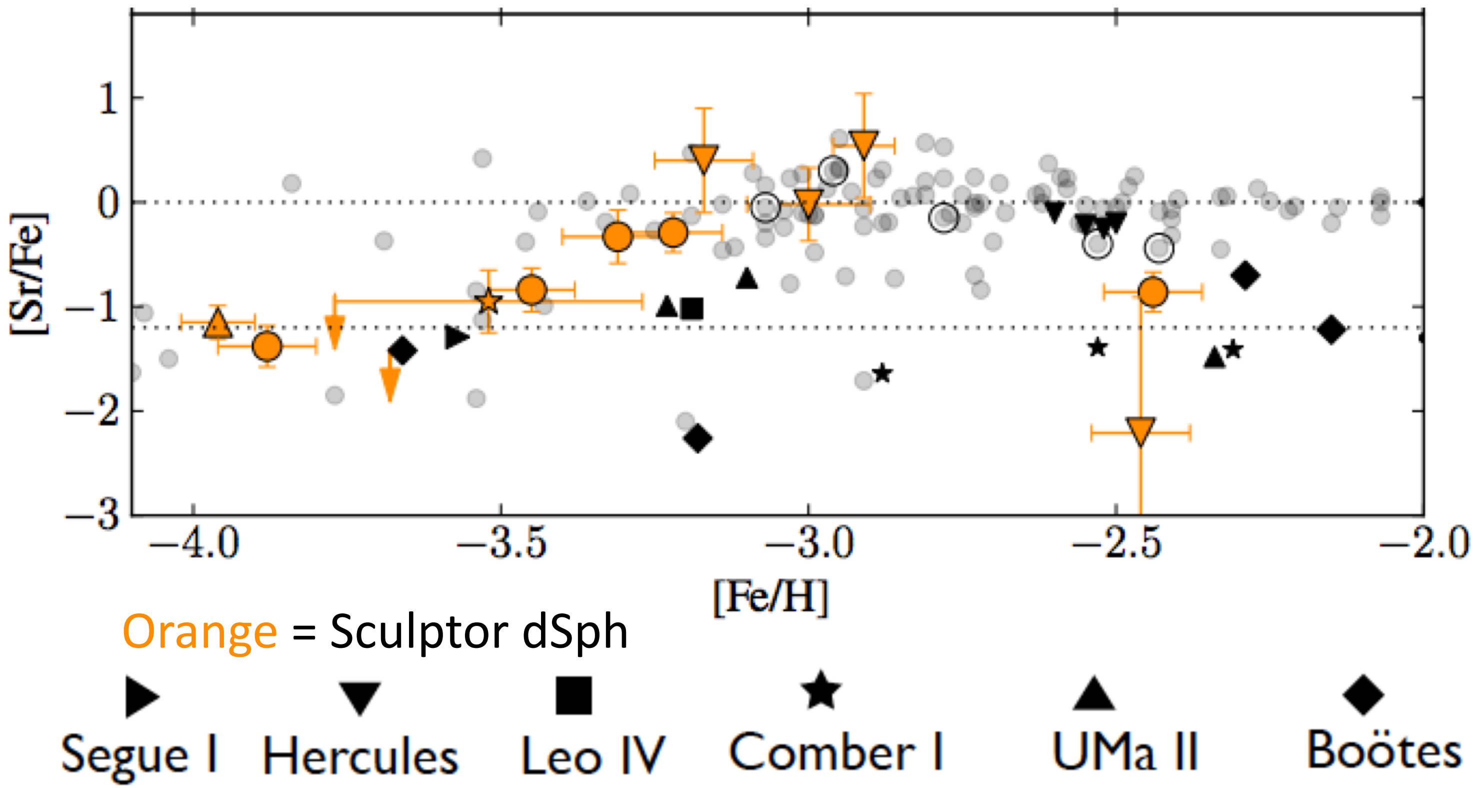




Blue: ”classical” satellites
Red: SDSS “ultra-faint” satellites

SDSS comes along…

- UVES plays important role studying these new systems
  - No clear "knee" in **α** – elements – old stellar populations
  - Ultra-faints show differences in heavy elements
    - Implications for sites that make these elements (neutron-star-mergers)



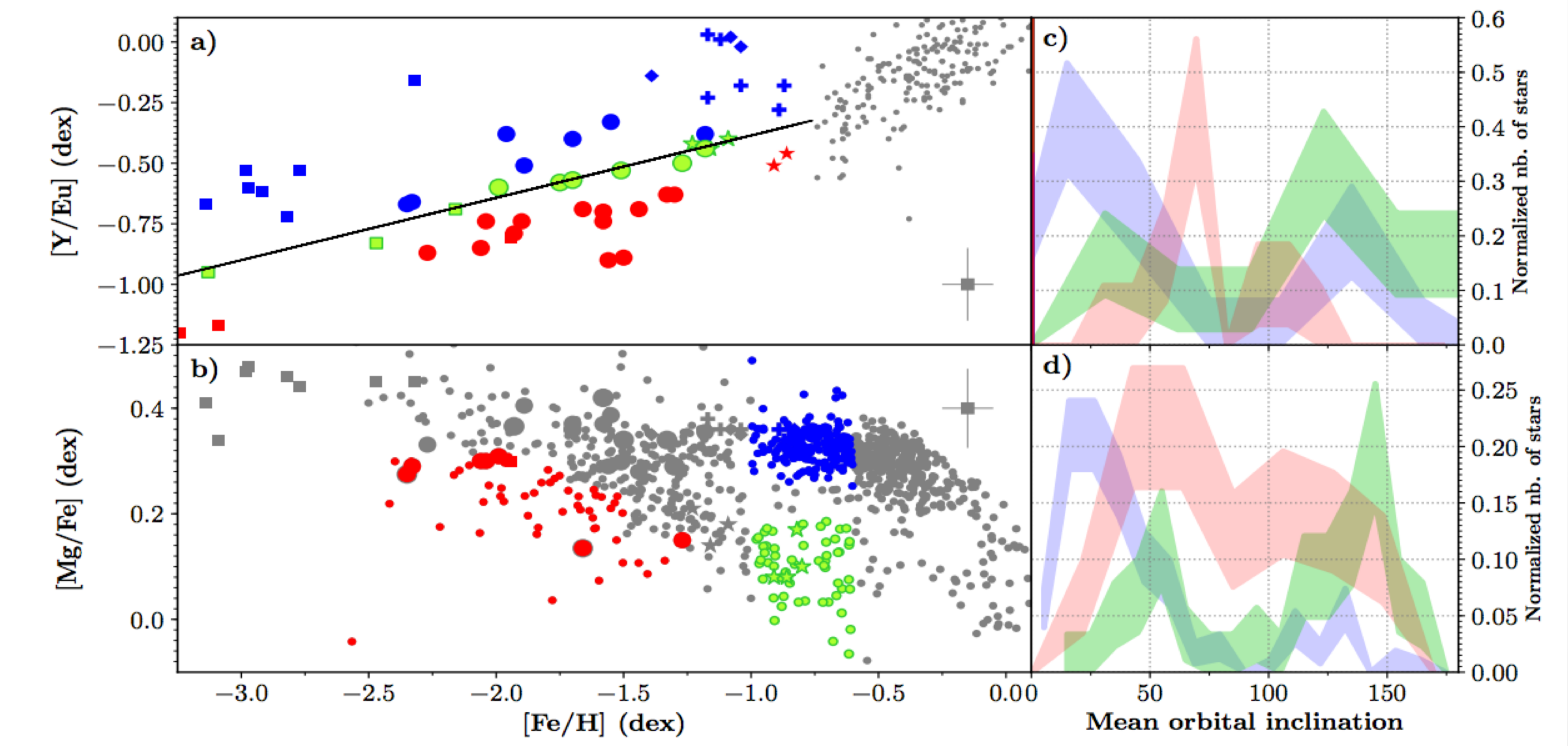
Jablonka et al., 2015

Including: Koch et al., 2008, Aden et al., 2011, Norris et al., 2010, Simon et al., 2010, Frebel et al., 2014

The importance of *s* and *r*

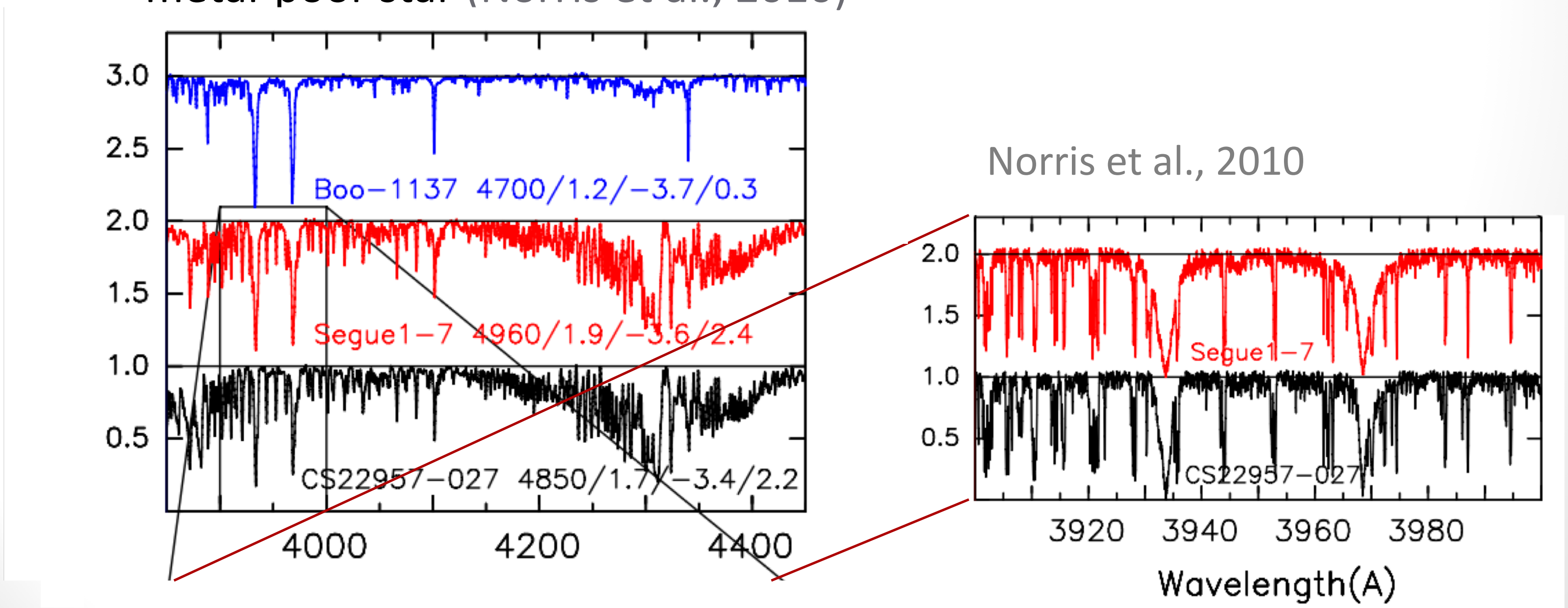
- Recio-Blanco et al., 2020: [Y/Eu] ~ [s-process/r-process] dependence on mass, even at the metal-poor end?
- These type of elements need high-resolution and high efficiency (in the blue) – UVES is ideal

Recio-Blanco et al., 2020



Special stars with UVES

- Ultra-faint galaxies also contain some extremely metal-poor stars
  - These stars provide important clues for early chemical evolution
  - Particularly well studied with UVES Boo I and Segue I (e.g., Norris et al., 2010a,b, Gilmore et al., 2013)
  - Ultra-faint Segue I: First discovery of carbon-enhanced extremely metal-poor star (Norris et al., 2010)

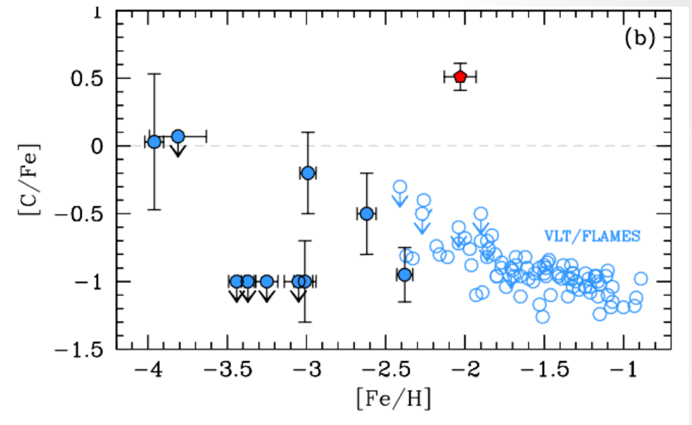


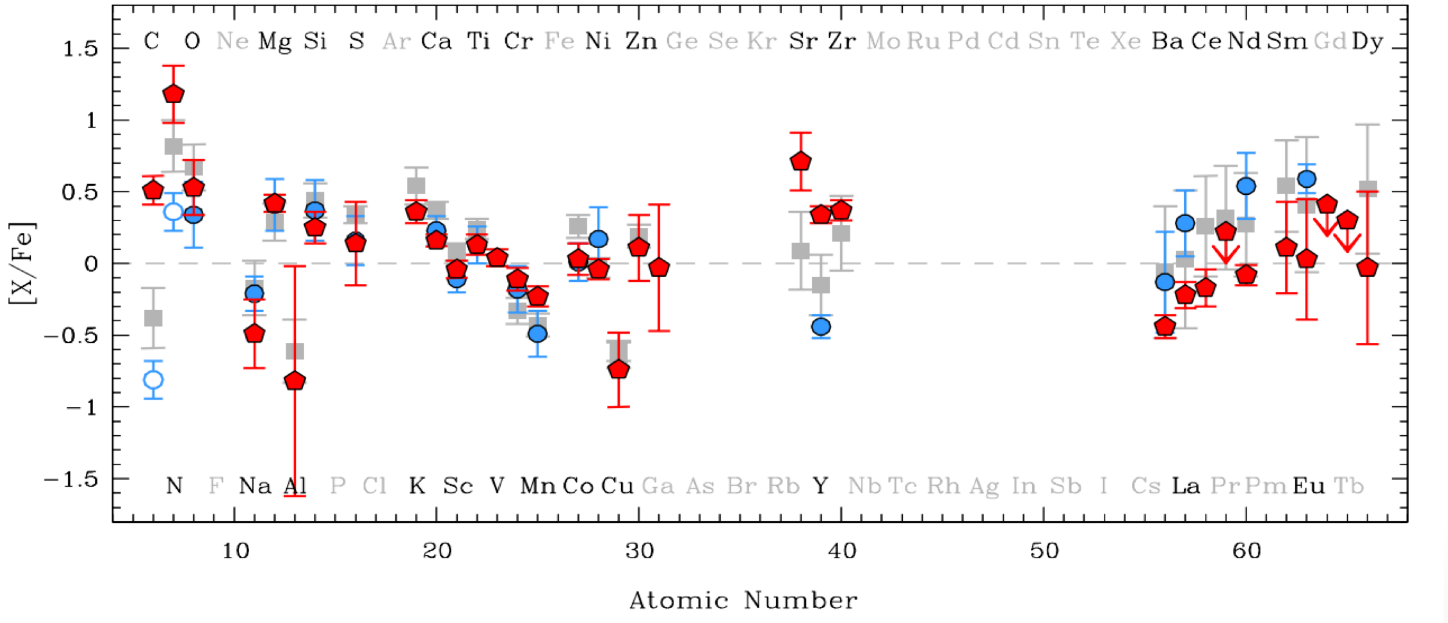
Norris et al., 2010

Special stars with UVES

- First discovery of carbon-enhanced metal-poor star in Sculptor dwarf galaxy (Skuladottir et al., 2015)
  - Fits well expectations for pattern of faint supernovae mixed with "normal" supernova products

Skuladottir et al., 2015

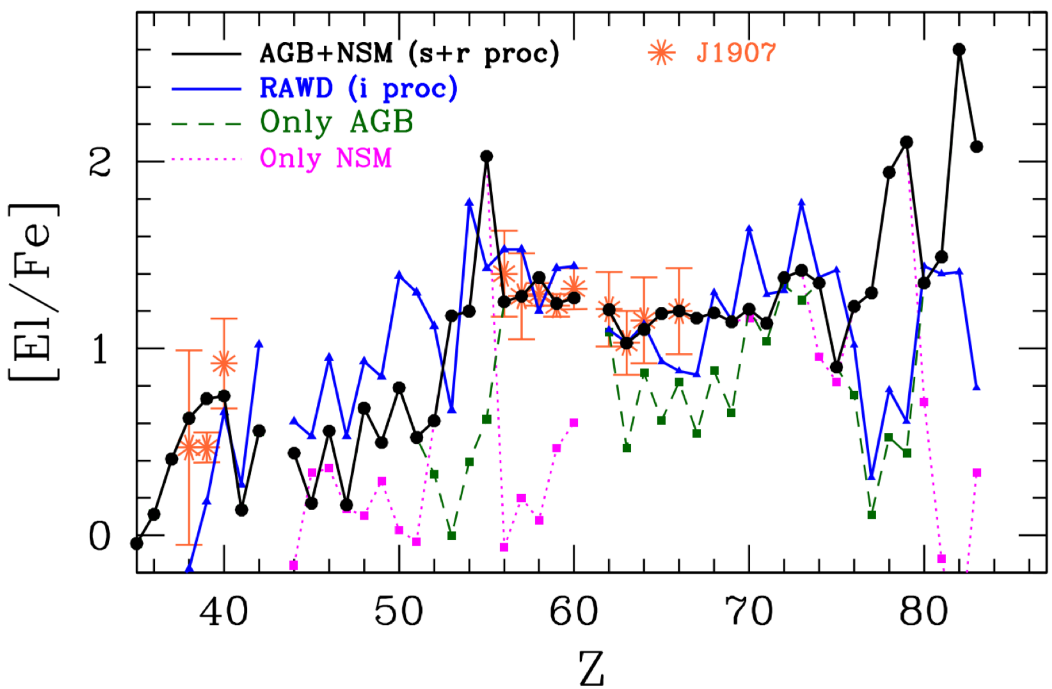




CEMP star
Scl stars
Halo stars

Special stars with UVES

- First carbon-enhanced metal-poor star with an r/s-pattern in Sgr dSph and clearest example in any dSph (Sbordone et al., 2020)
  - Best explanation: mass exchange from an AGB companion within a binary system pre-enriched at high concentration by the yields of a neutron star – neutron star merger

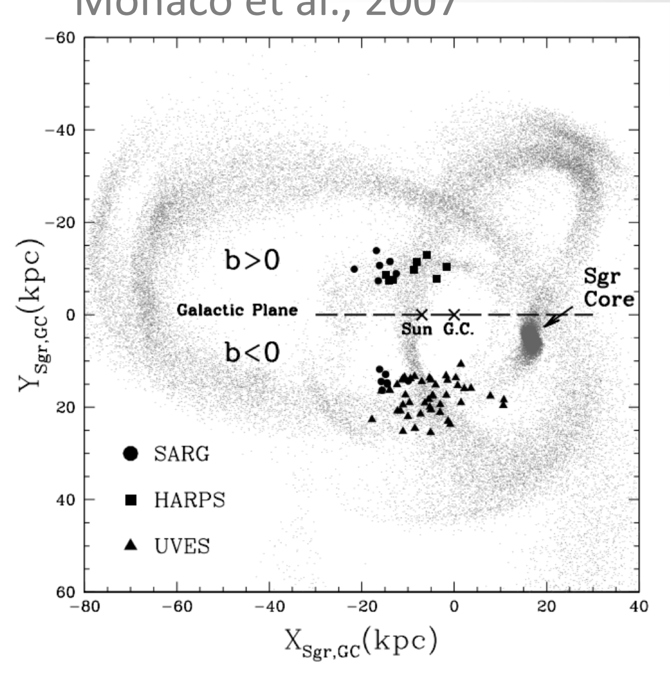


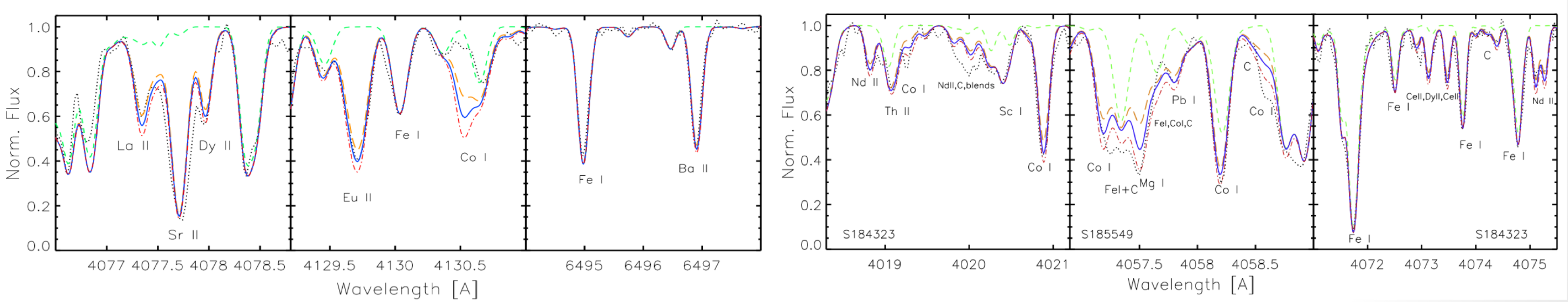
Sbordone et al., 2020

Streams with UVES

- Target densities are low
  - But can be more accessible (Sgr)
  - Metallicity gradients → different populations along streams & body
- Detailed UVES follow-up gives insight in nucleosynthesis processes in parent galaxy

Monaco et al., 2007





- Hansen et al., 2018: Sgr stream stars at low metallicity complementing studies in the body

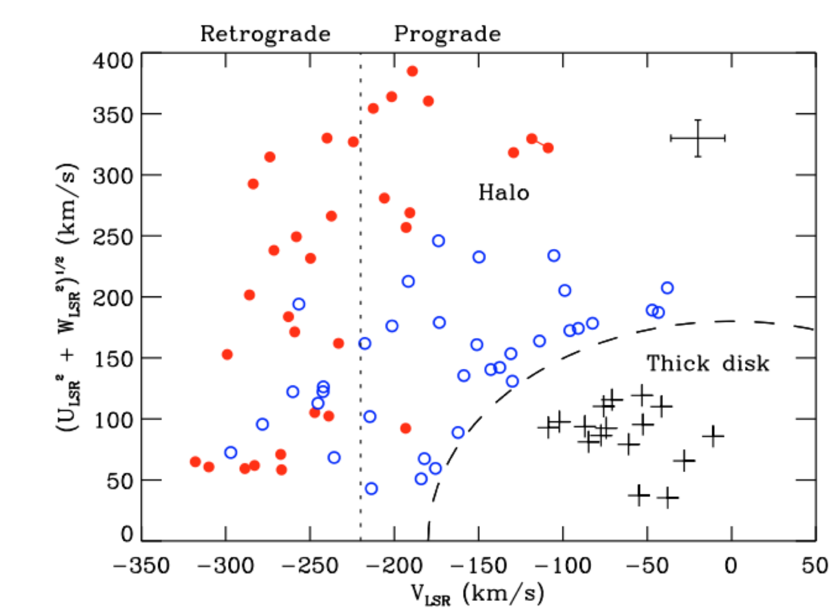
  (Bonifacio et al. 2000; McWilliam et al. 2003, 2013; Monaco et al. 2005; Sbordone et al. 2007)

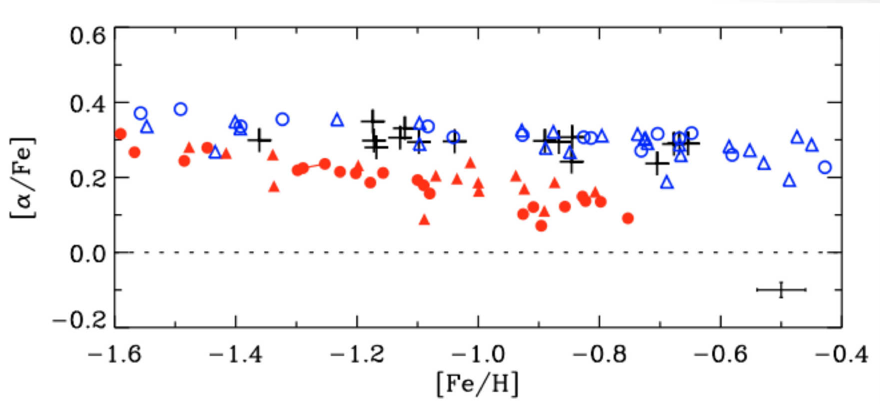
  - Need mixture of low- and high-mass stars, no top-light IMF

Streams are not always coherent

- Nissen & Schuster 2010: "The halo stars fall into two populations, clearly separated in [α/Fe] … The kinematics of the "low-α" stars suggest that they have been accreted from dwarf galaxies"

- Inner halo dominated by debris of dwarf galaxy "Gaia-Enceladus" slightly more massive than SMC now (Helmi et al., 2018)
  - Also "Gaia-Sausage" (Belokurov et al., 2018)





Nissen & Schuster 2010

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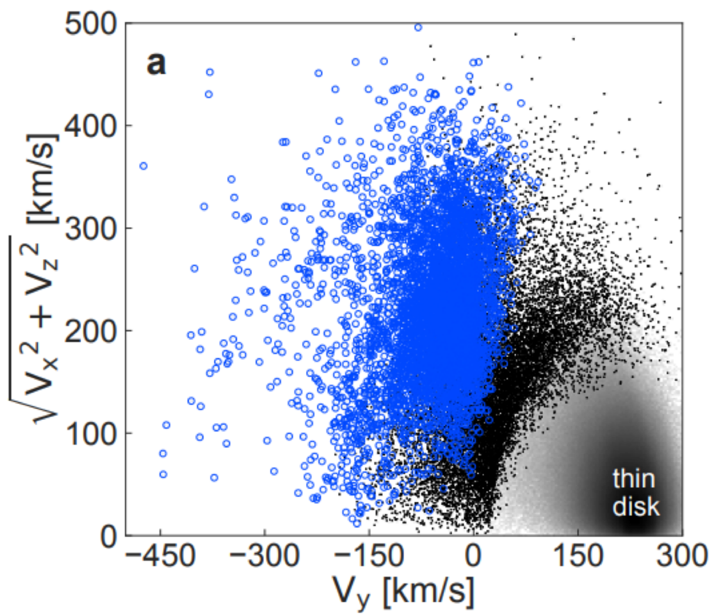
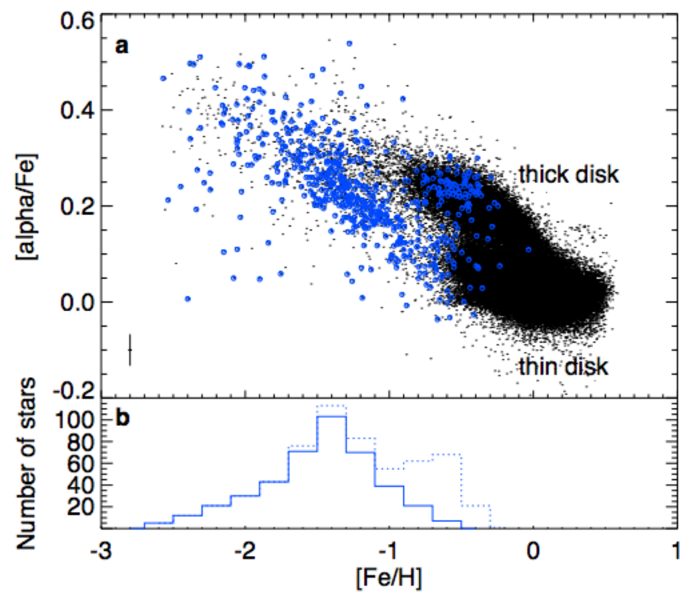
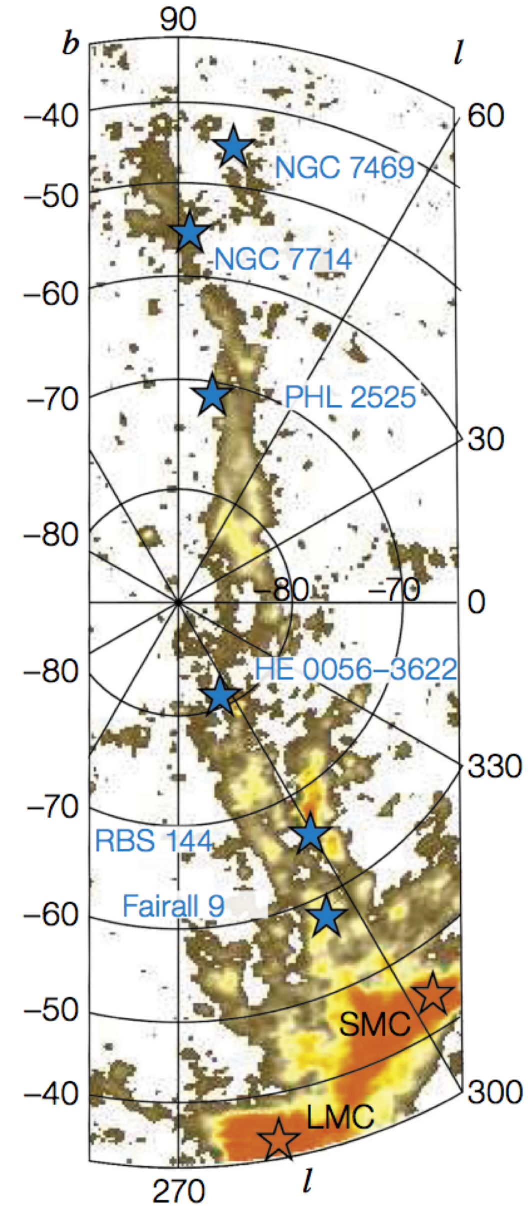




Not just stars…

- UVES is also very well-suited for line absorption studies towards background sources (quasars)
  - For example in the Magellanic Stream – a ribbon of gas trailing the LMC & SMC orbit
  - Combined with UV from HST/COS
  - UVES provides much better velocity precision
- Results reveal a surprisingly complex structure with different abundance patterns along different sightlines – both SMC and LMC material?

(Fox et al., 2013, Richter et al., 2013)



Magellanic Stream in HI
(Fox et al., 2013)

In summary

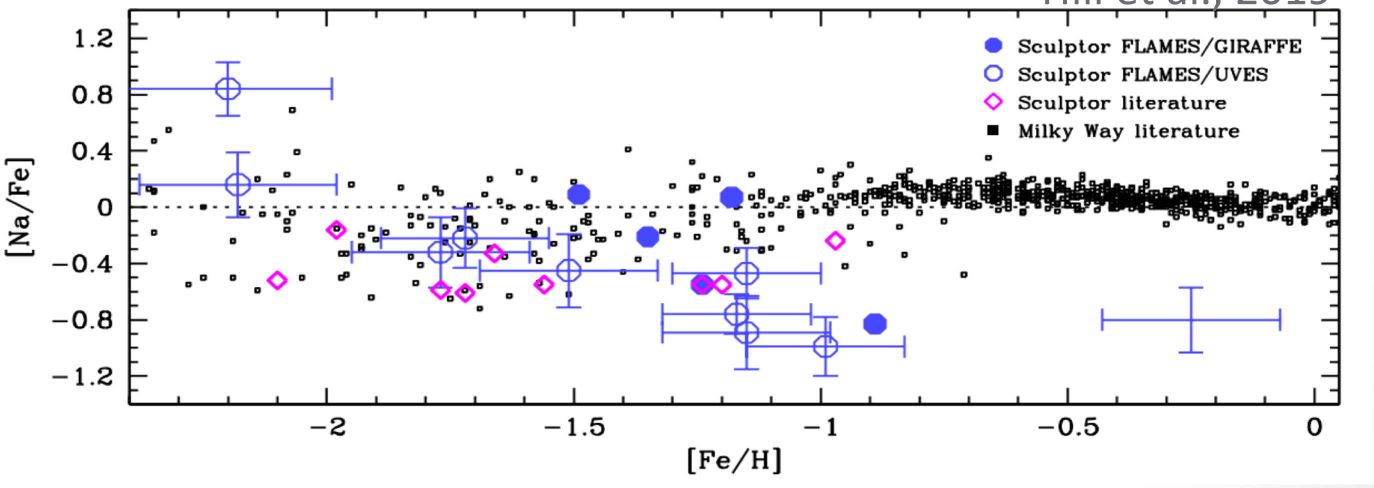
- UVES has been instrumental for our understanding of dwarf galaxies and streams
  - From some of the first detailed chemical analyses of stars in dwarf systems to very special stars that tell their own stories…
  - From stellar abundances to gas abundances…
  - From the biggest dwarf galaxies to the smallest satellites…
  - From coherent streams to phase-mixed material that relates to the main building blocks of the Galaxy…

- How can it keep such an important role in the future?

UVES and its family members

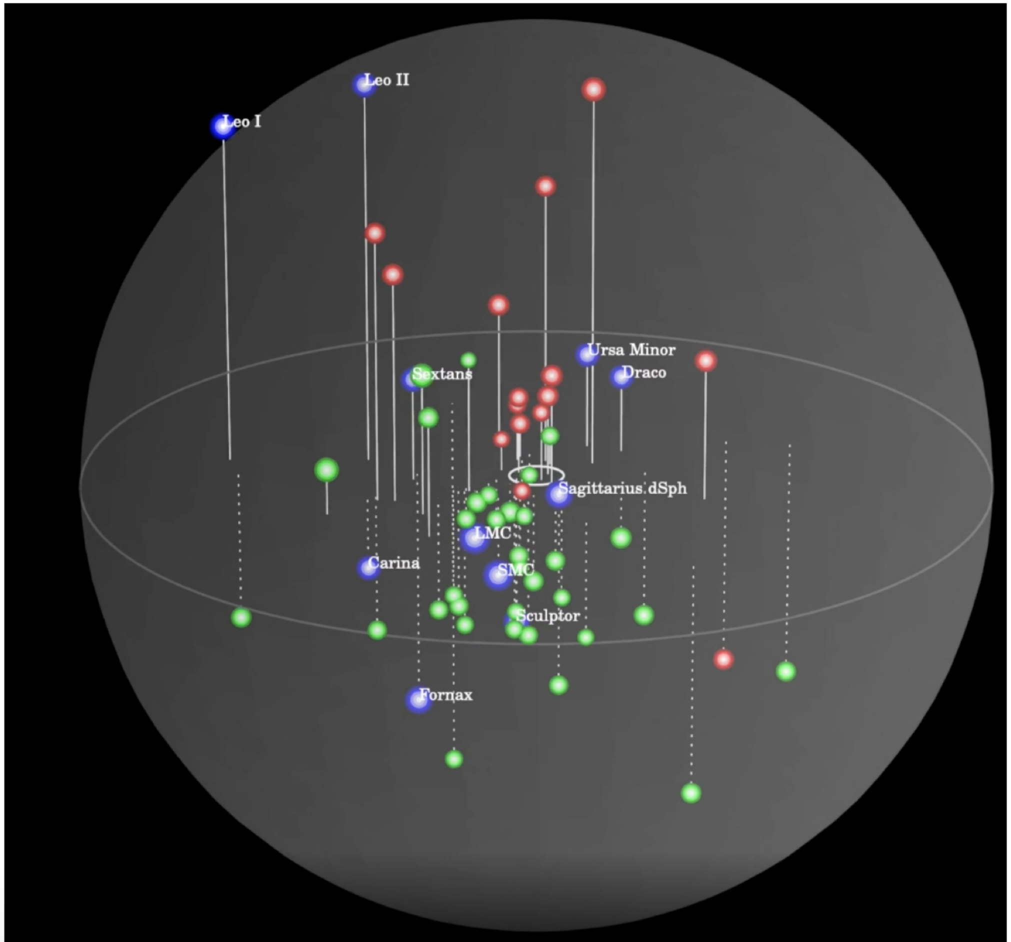
- In this field UVES has been instrumental on its own, but even more valuable because of combination with other instruments on Paranal
- 8 fibres for UVES in a FLAMES field: very valuable cross-check for multi-object work and access to more elements
  - UVES spectra higher resolution **and** larger wavelength coverage
- Combination with X-shooter for fainter stars in the same system

Hill et al., 2019



The future: Dwarf galaxies

- More and more discoveries of very faint and sparse systems
  - Well suited for UVES

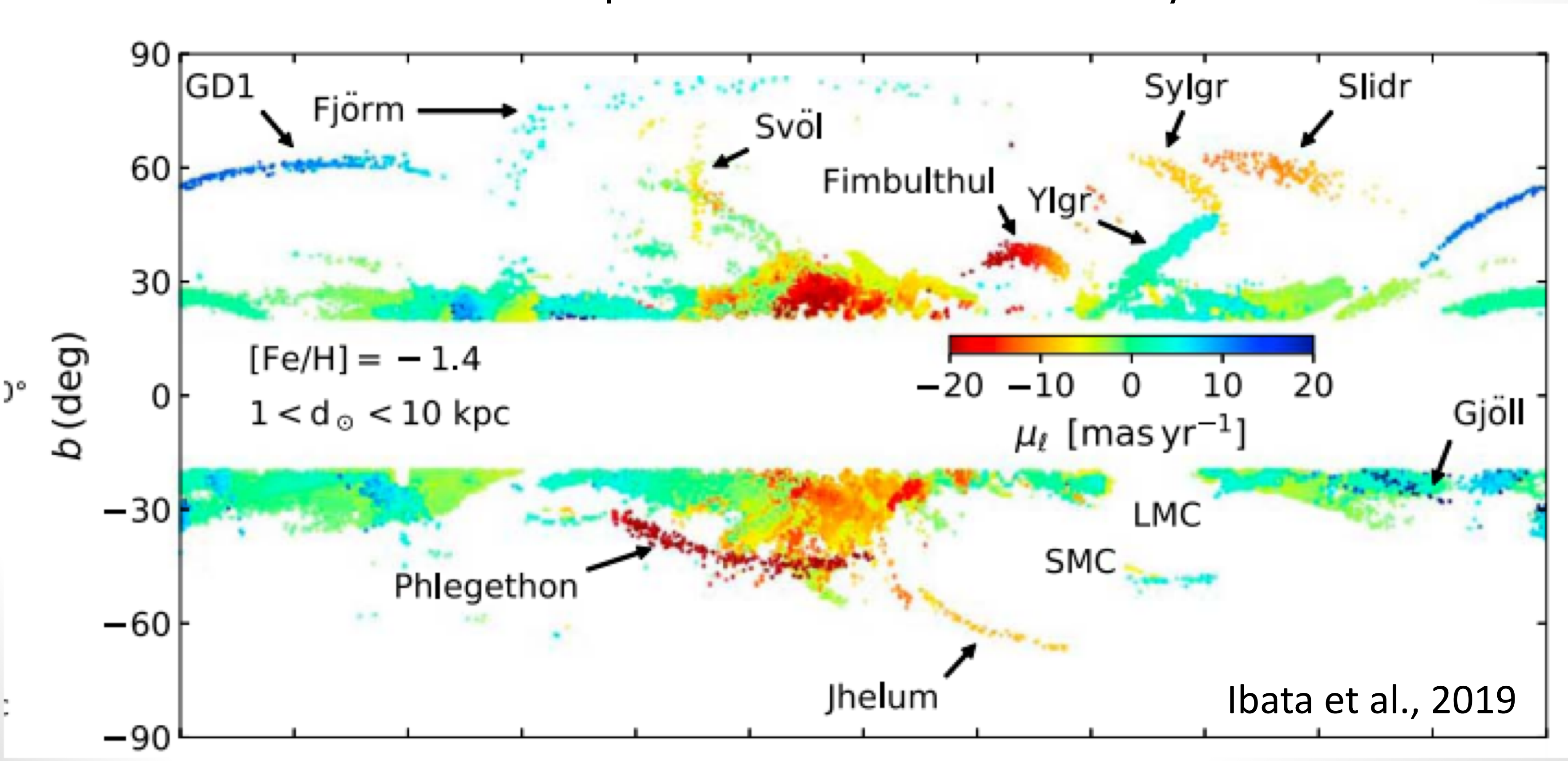


Blue: ”classical” satellites
Red: SDSS “ultra-faint” satellites
Green: Most recent (mostly DES discoveries)

Credit: Marcel Pawlowski

The future: Streams

- Similarly: more and more discoveries of very faint streams – important measuring tools for the Galactic potential and acceleration field
  - Well suited for UVES: provides crucial radial velocity information



The future: Multi-object spectrographs

- Starts 2021
- 4m telescope WHT
- <R> = 20 000
- ~1000 fibres
- Choice HR/LR
- Two arms: 4040-4650 or 4730-5450, 5950-6850 Å
- Especially in green+red setup misses much of the heavy elements

- Starts 2023
- 4m telescope ESO/VISTA
- <R> = 20 000
- 812 fibres in HR
- LR observed simultaneously
- Three arms: 3926–4355, 5160–5730, 6100–6790 Å
- Incl. dedicated survey LMC & SMC
- Misses e.g., key element Zn

UVES adds: resolution, 8m telescope and extra wavelength windows, particularly useful in the blue (most so for WEAVE)

UVES in the future

- Important role as follow-up machine for the exciting new discovery space opened by massively multiplexing spectrographs?

- Focus on what other instruments can not deliver
  - Sensitivity to key elements (for more metal-poor, or fainter stars)
    - Many future instruments focus on the (N)IR, sensitivity in the blue is crucial for heavy elements

- To allow users a fast turnaround on exciting objects
  - Already in place
    - Director's discretionary time
    - Targets of Opportunity

- In the "further" future: HRMOS/FLASH?
  - R = 60,000, multiplexing spectrograph with excellent blue capabilities