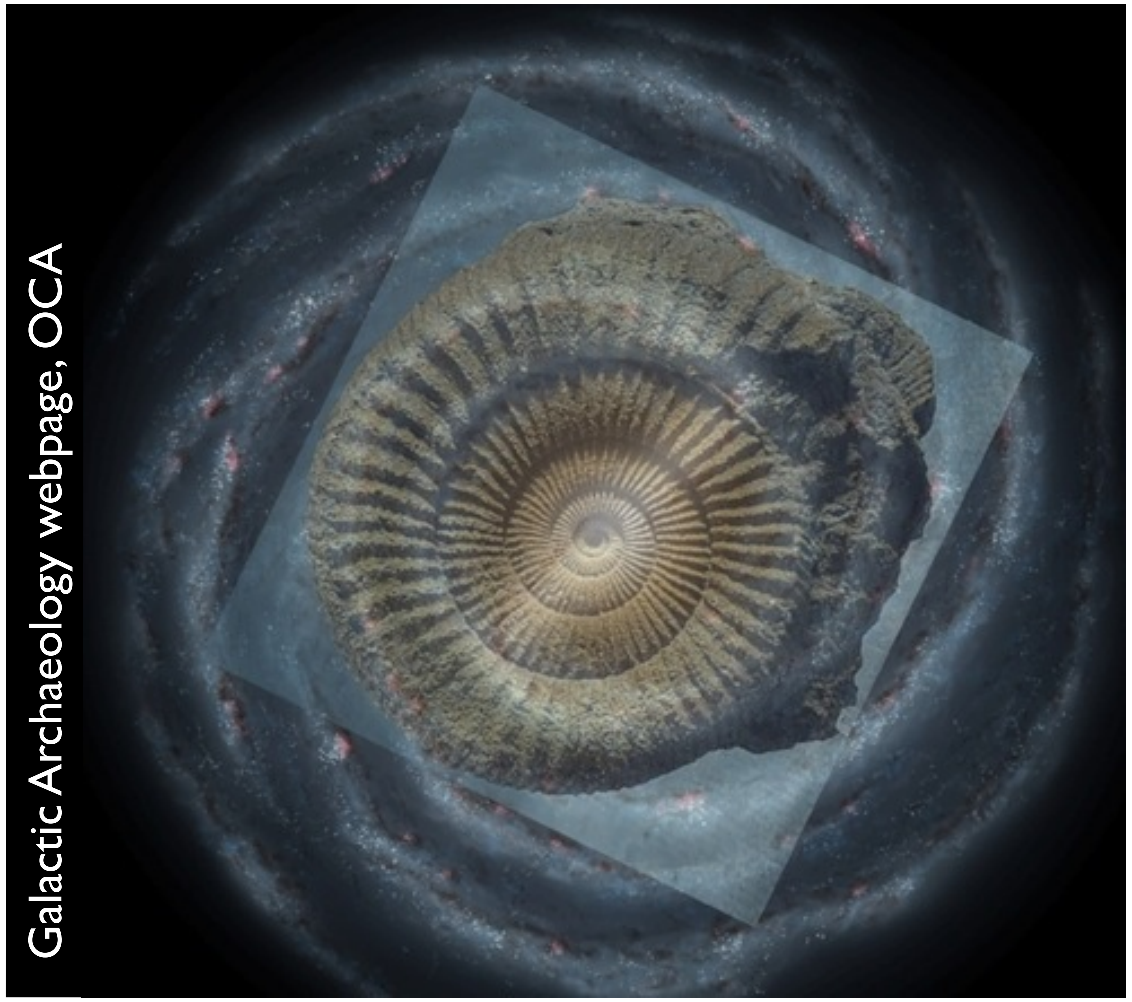
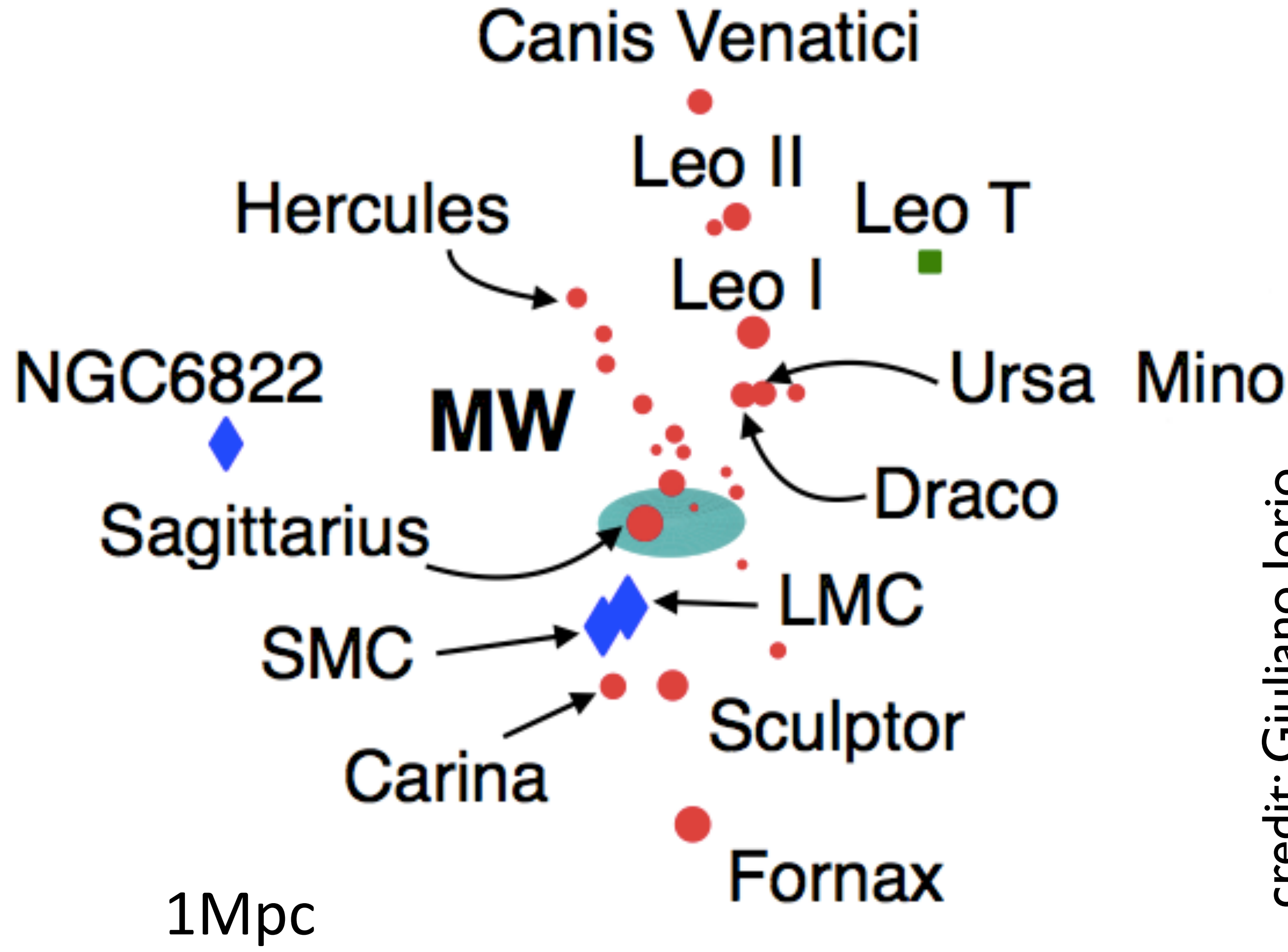
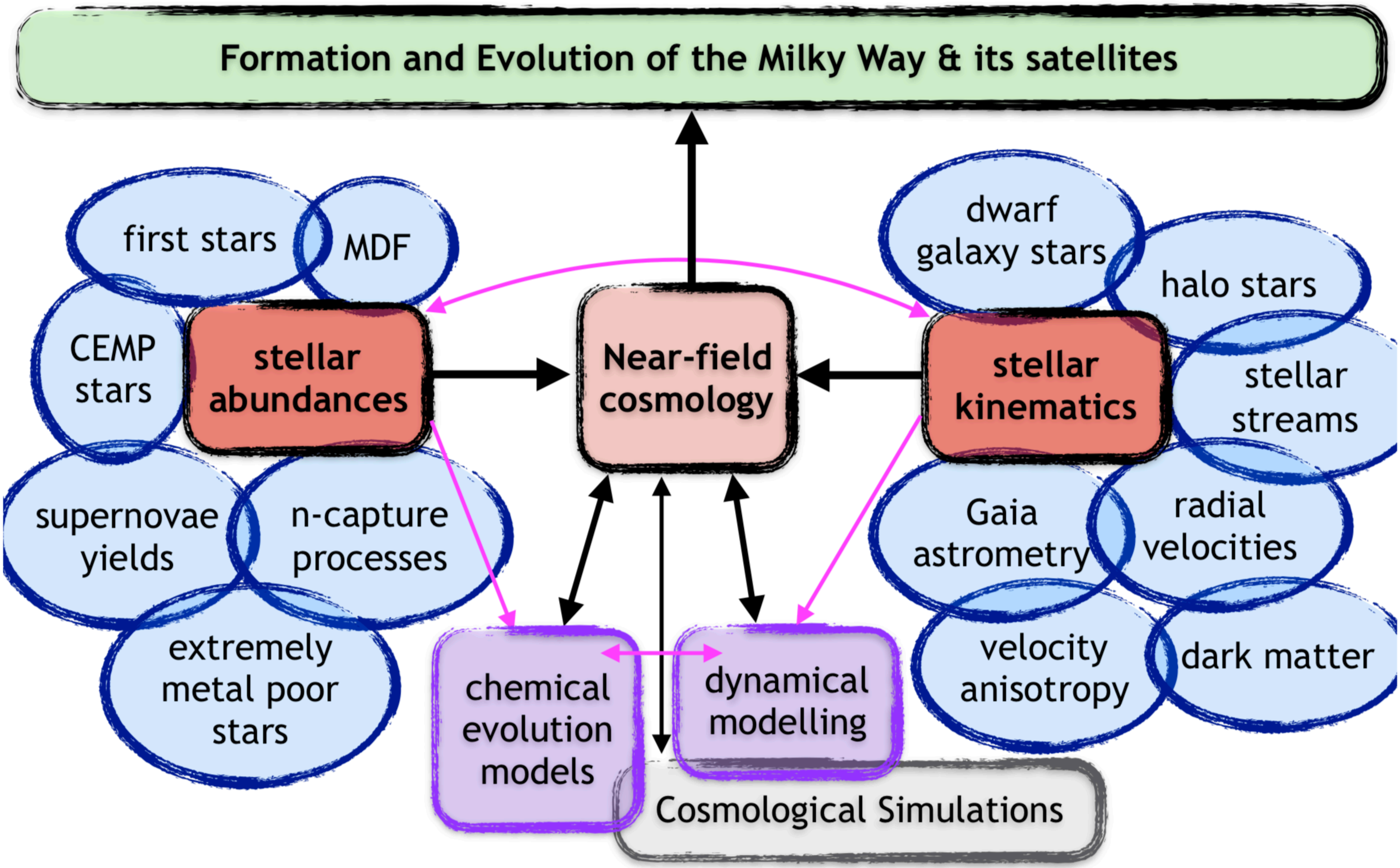




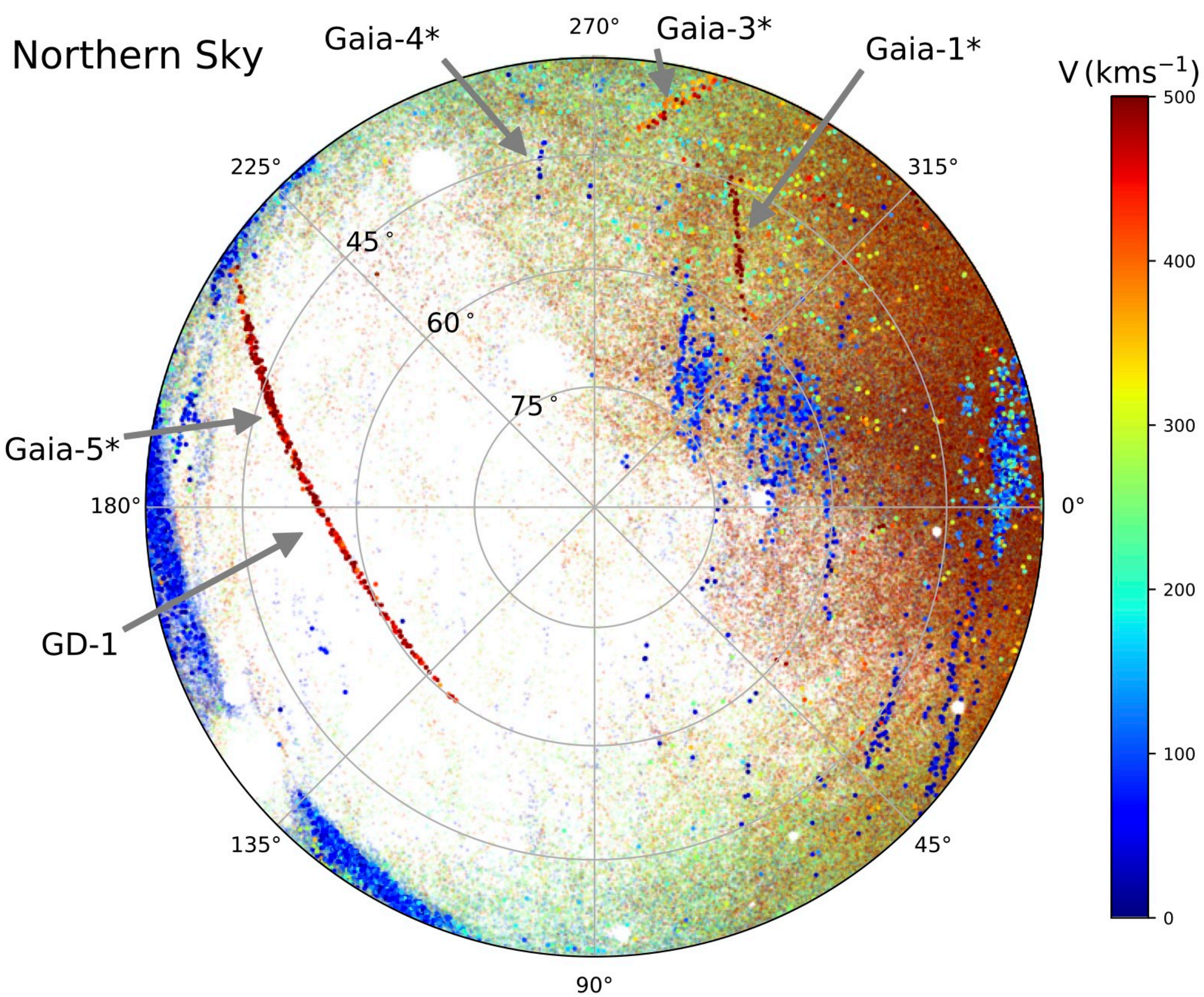
Observations of Chemo-dynamical evolution of dwarf galaxies and future large spectroscopic surveys

Eline Tolstoy, Kapteyn Astronomical Institute, University of Groningen


Formation and Evolution of the Milky Way & its satellites
first stars
MDF
CEMP stars
stellar abundances
supernovae yields
n-capture processes
extremely metal poor stars
Near-field cosmology
dwarf galaxy stars
halo stars
stellar kinematics
stellar streams
Gaia astrometry
radial velocities
velocity anisotropy
dark matter
chemical evolution models
dynamical modelling
Cosmological Simulations

Coherent sub-structure in (outer) halo

Gaia DR2 All Sky pictures



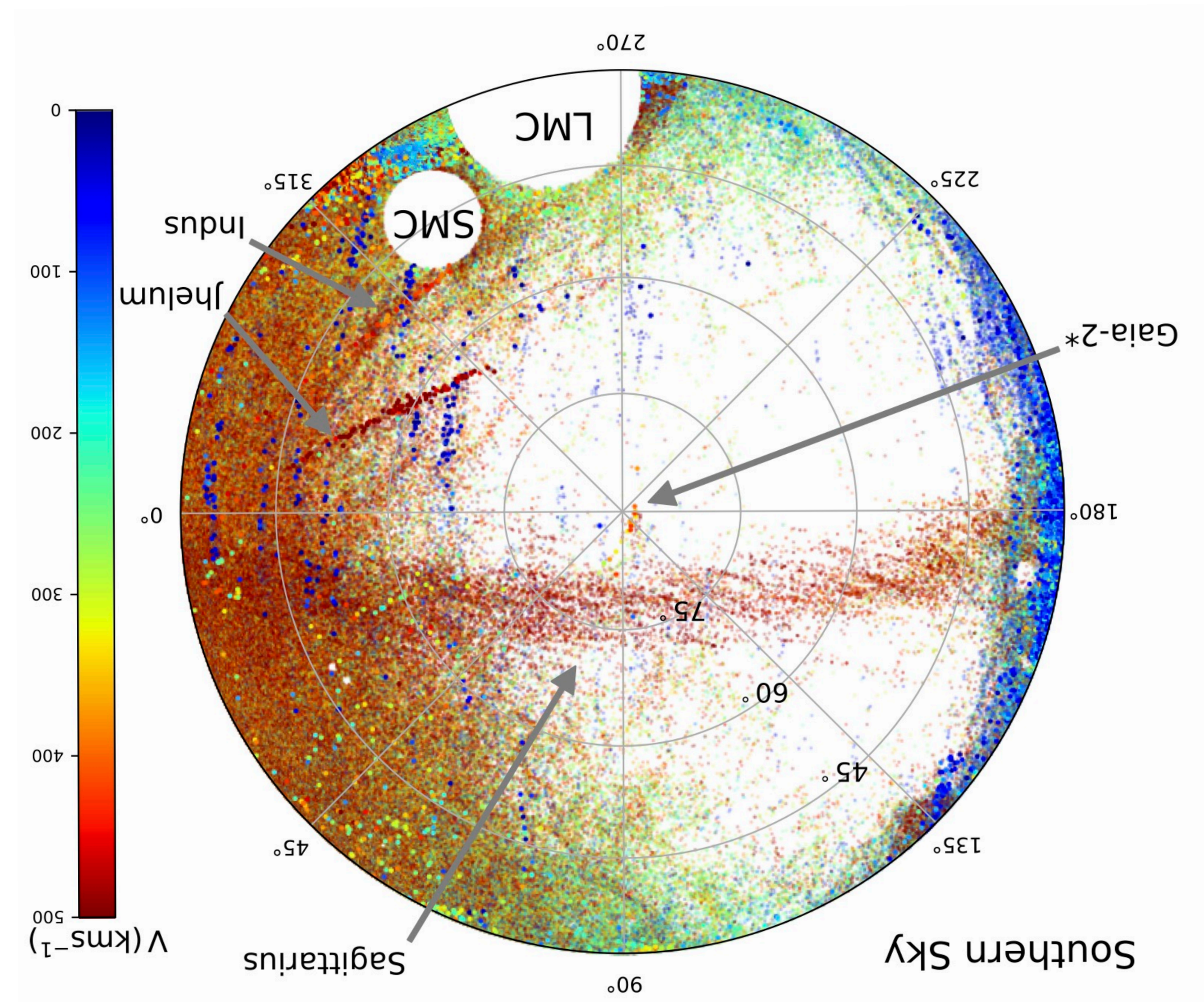
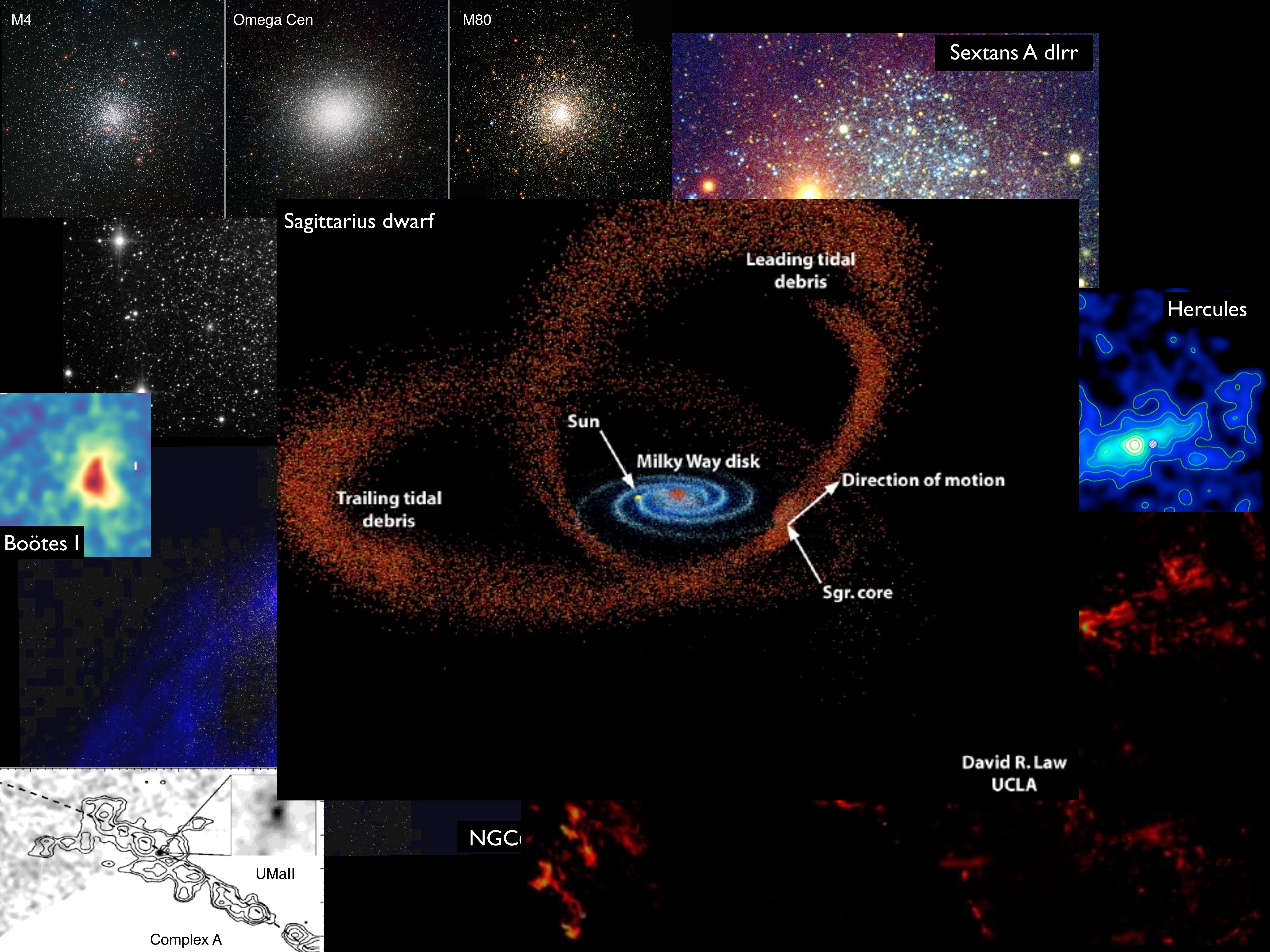
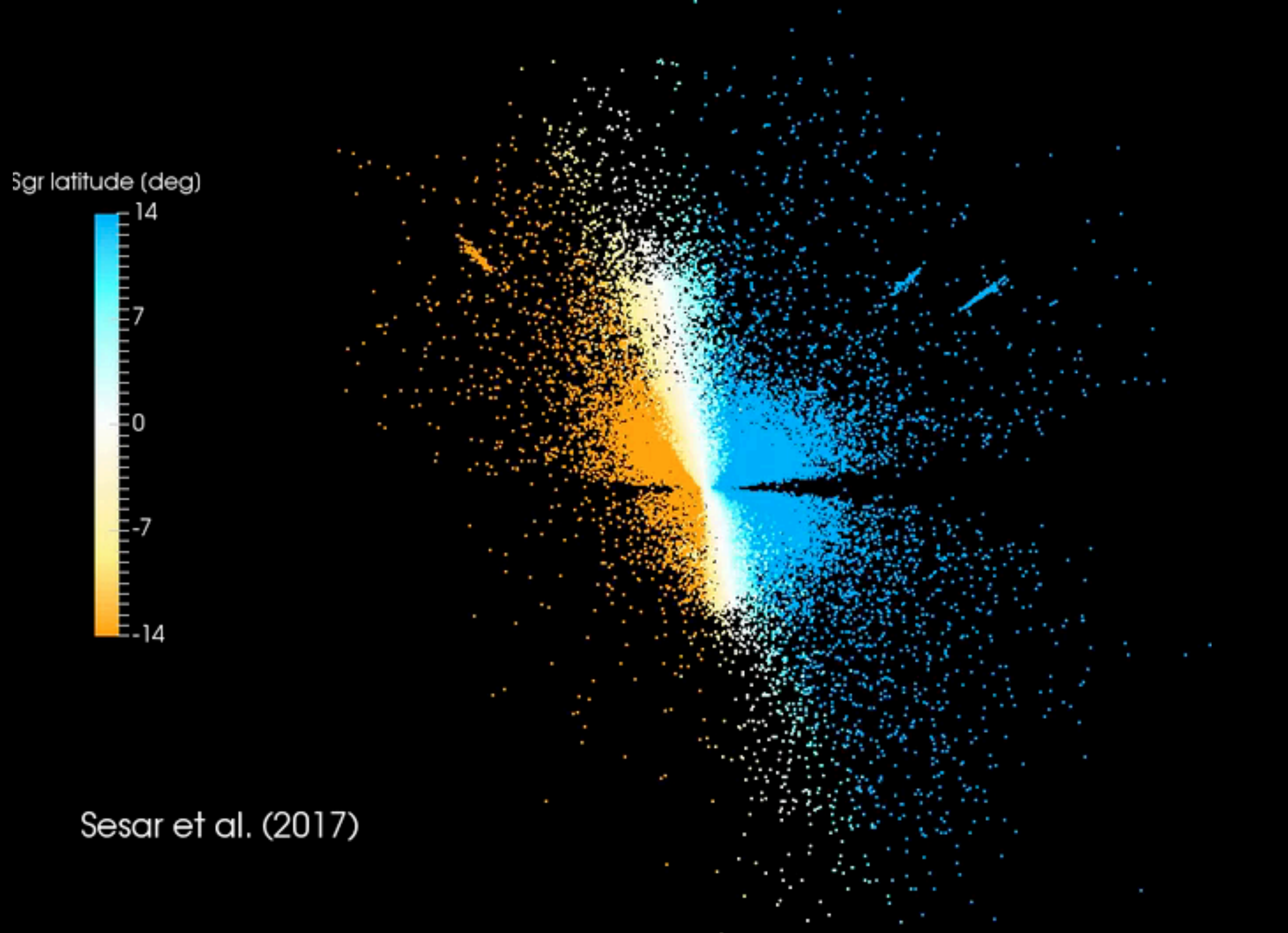


Image credit: Khyati Malhan, Rodrigo A. Ibata, Nicolas F. Martin

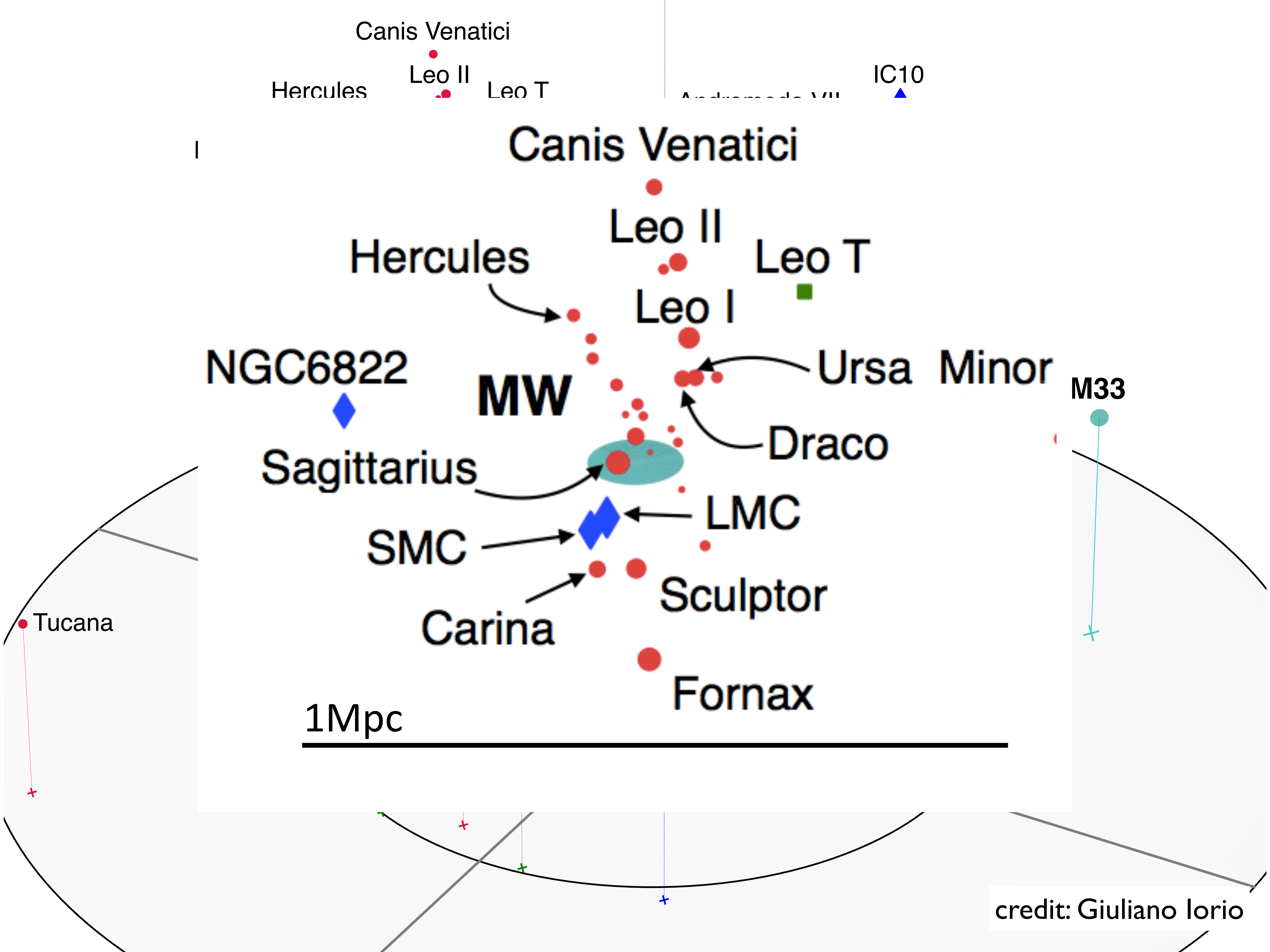
Malhan, Ibata & Martin 2018, in press



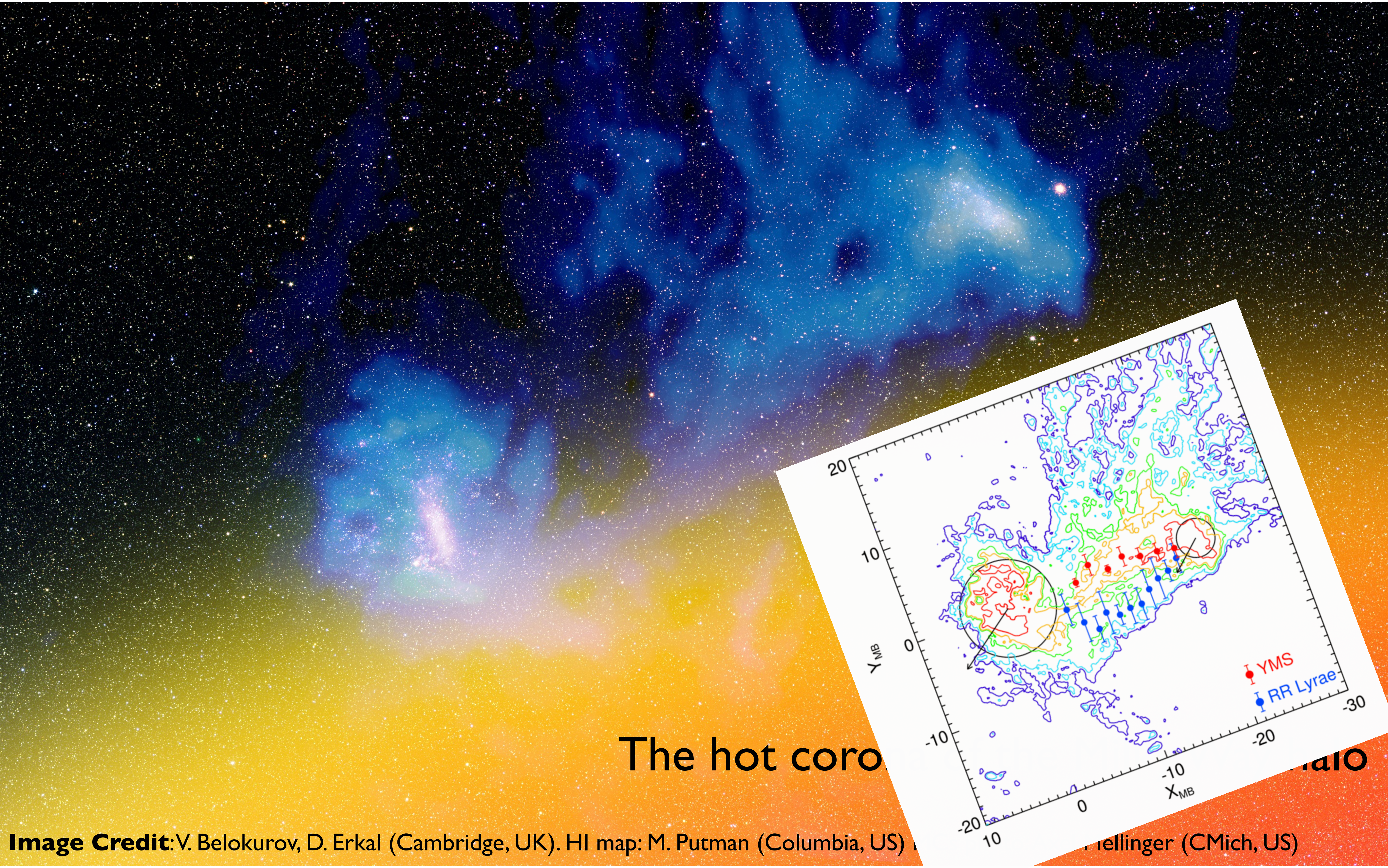
M4
Omega Cen
M80
Sextans A dIrr
Sagittarius dwarf
Leading tidal debris
Sun
Milky Way disk
Direction of motion
Trailing tidal debris
Sgr. core
David R. Law
UCLA
Hercules
Boötes I
NGC
UMaII
Complex A



Pan-STARRS1: RR Lyrae

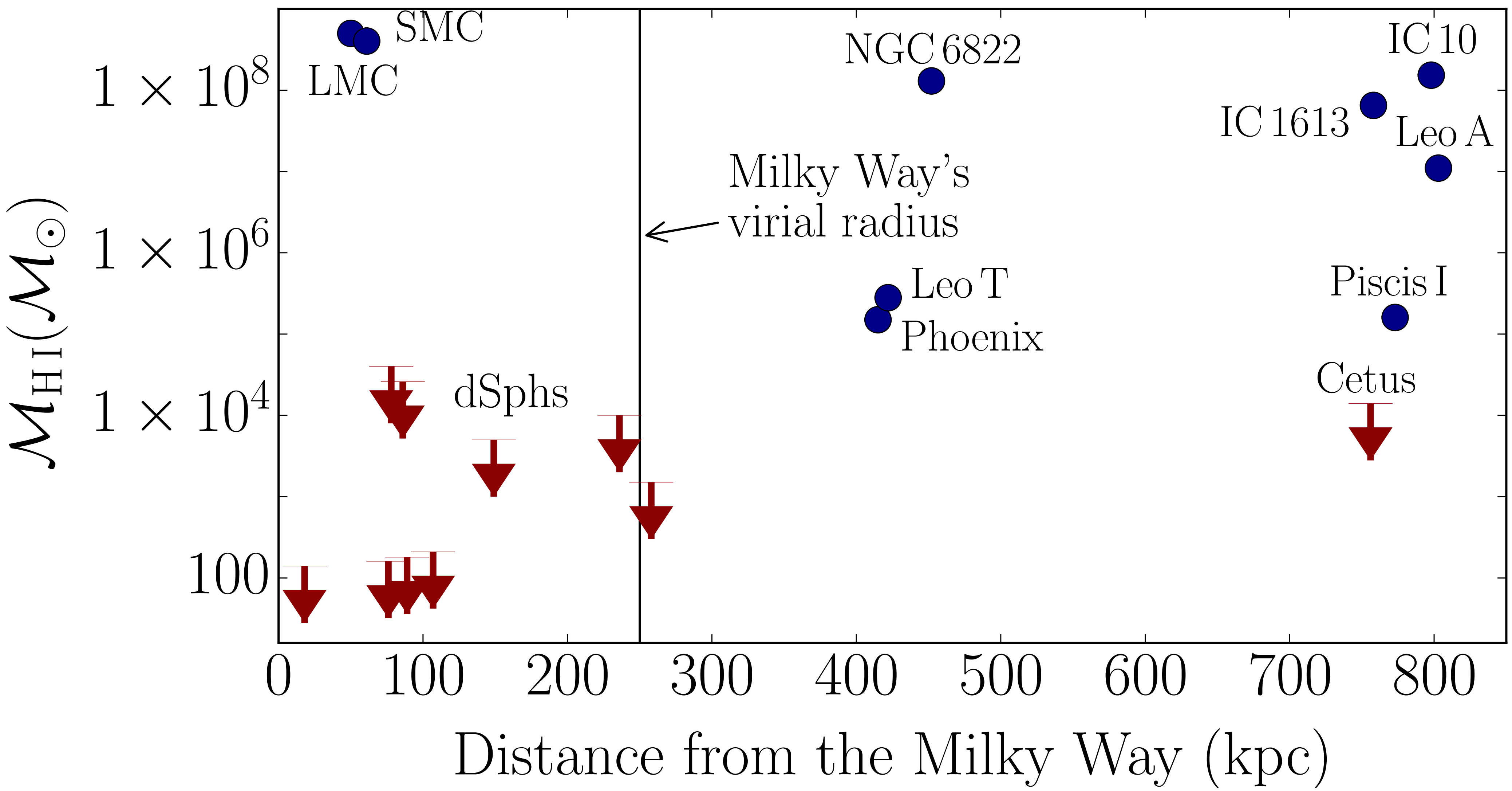

Canis Venatici
Leo II
Hercules
Leo T
IC10
Canis Venatici
Leo II
Hercules
Leo T
Leo I
NGC6822
MW
Ursa Minor
M33
Draco
Sagittarius
LMC
SMC
Sculptor
Carina
Tucana
Fornax
1Mpc
credit: Giuliano Iorio

HI gas around the Magellanic Clouds



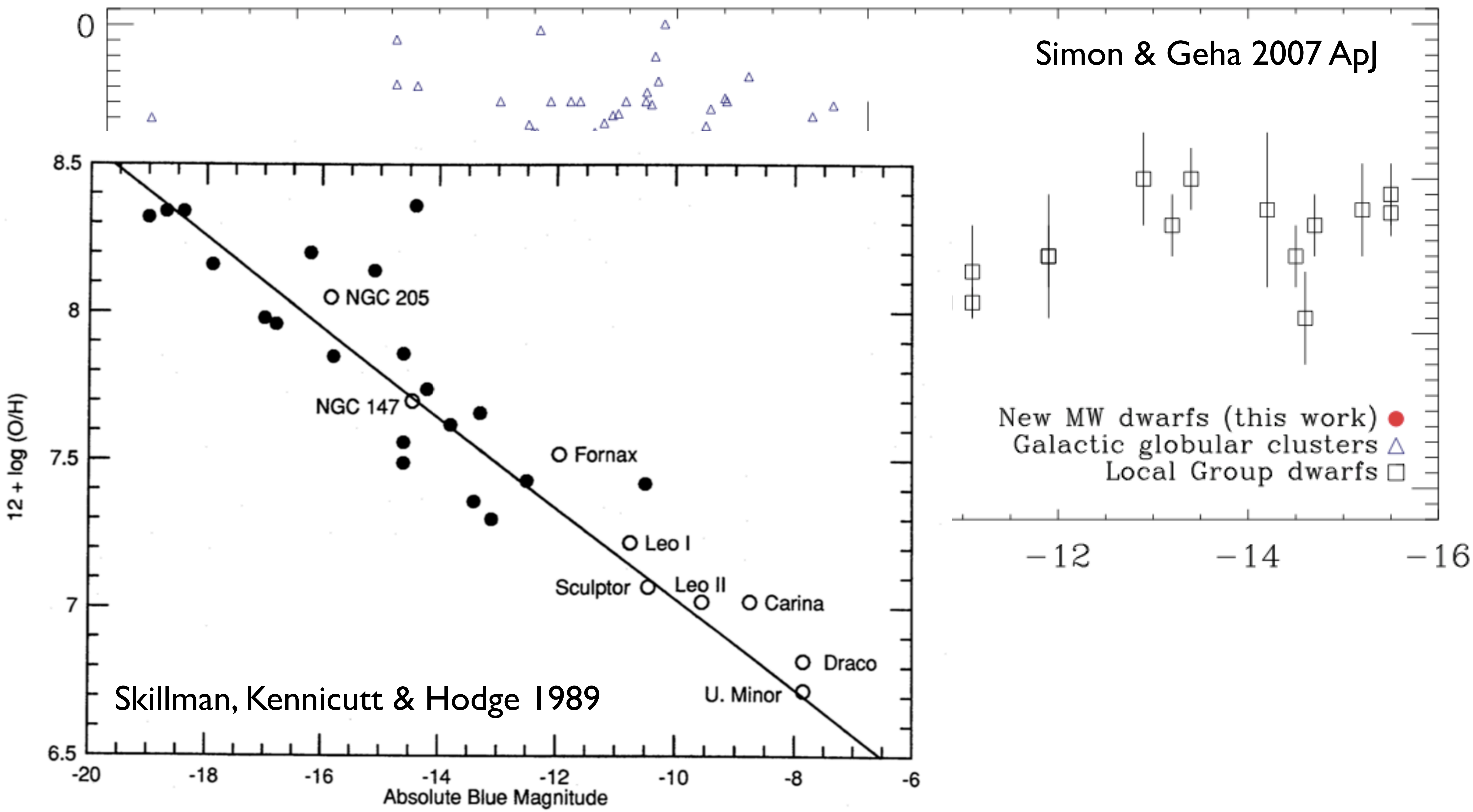
Gatto et al. 2013 MNRAS, 433, 2749 $n_{\rm cor} \sim 3 \times 10^{-4}\,{\rm cm}^{-3}$ Belokurov et al. 2017 MNRAS, 466, 4711

Morphology-Density Relation



from Filippo Fraternali

Metallicity-luminosity relationship for dwarf galaxies in the Local Group.

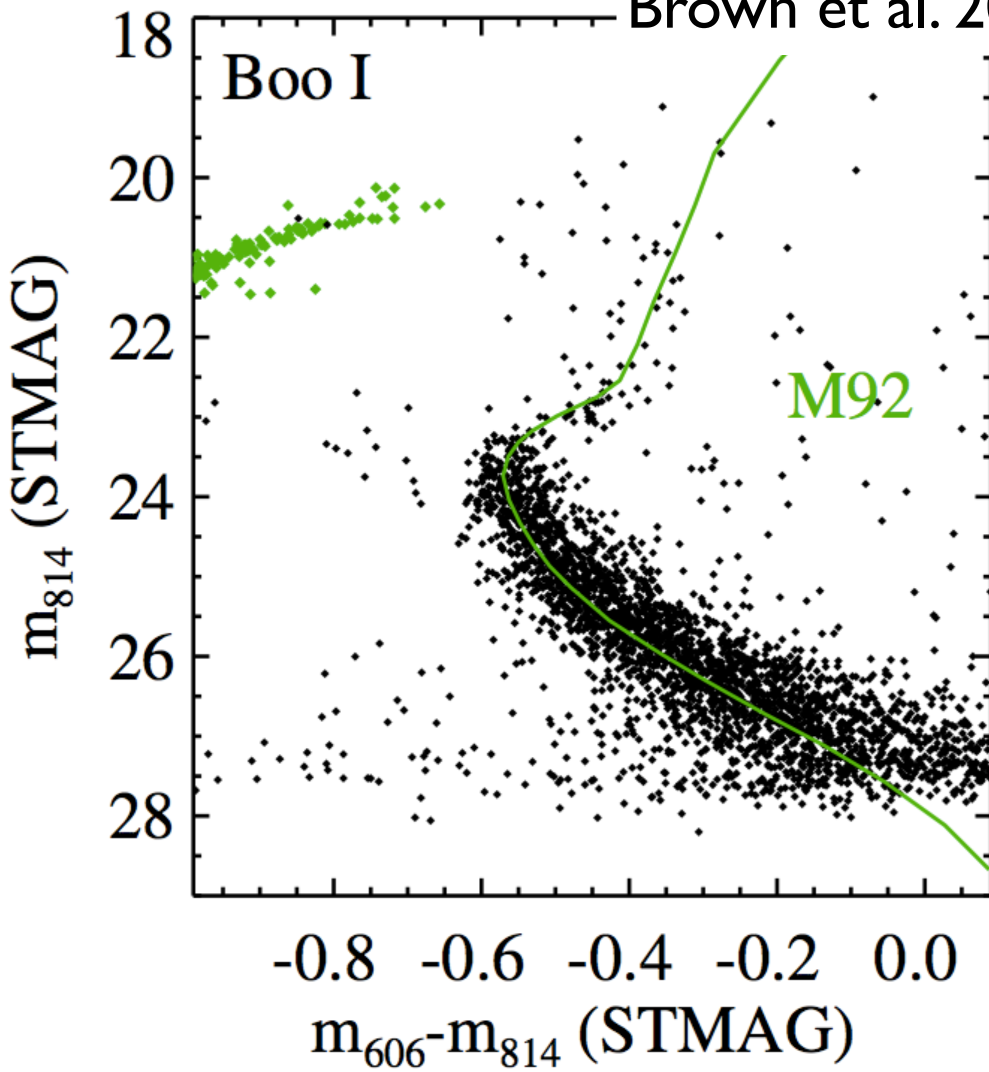


Bootes I

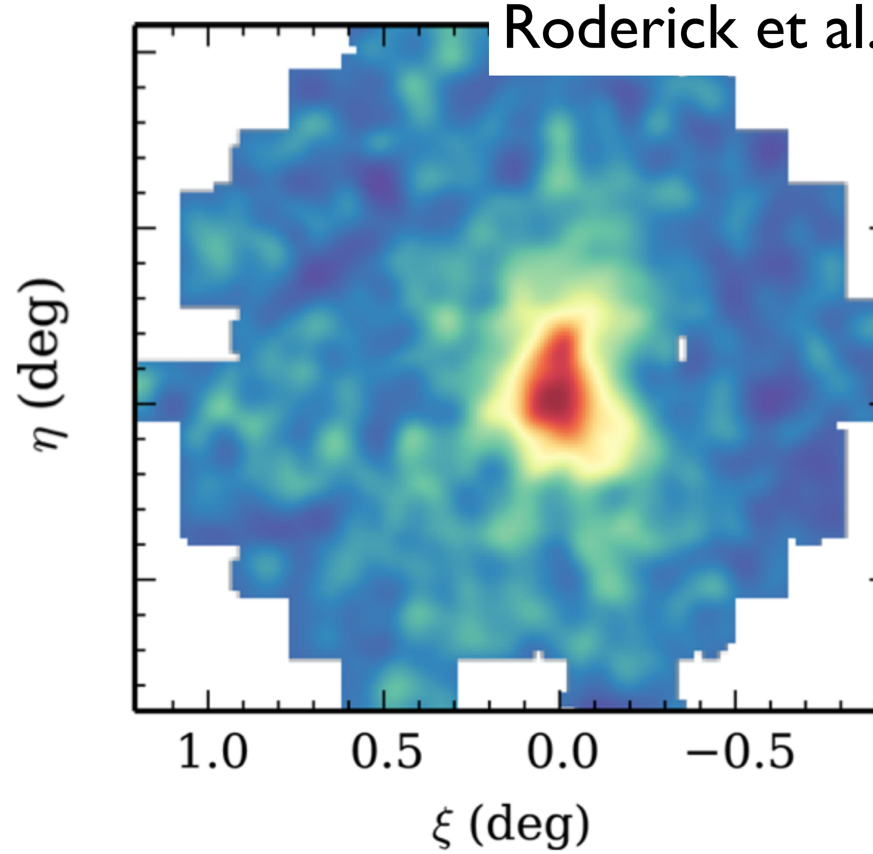
$M_V \sim -6.3$

60kpc

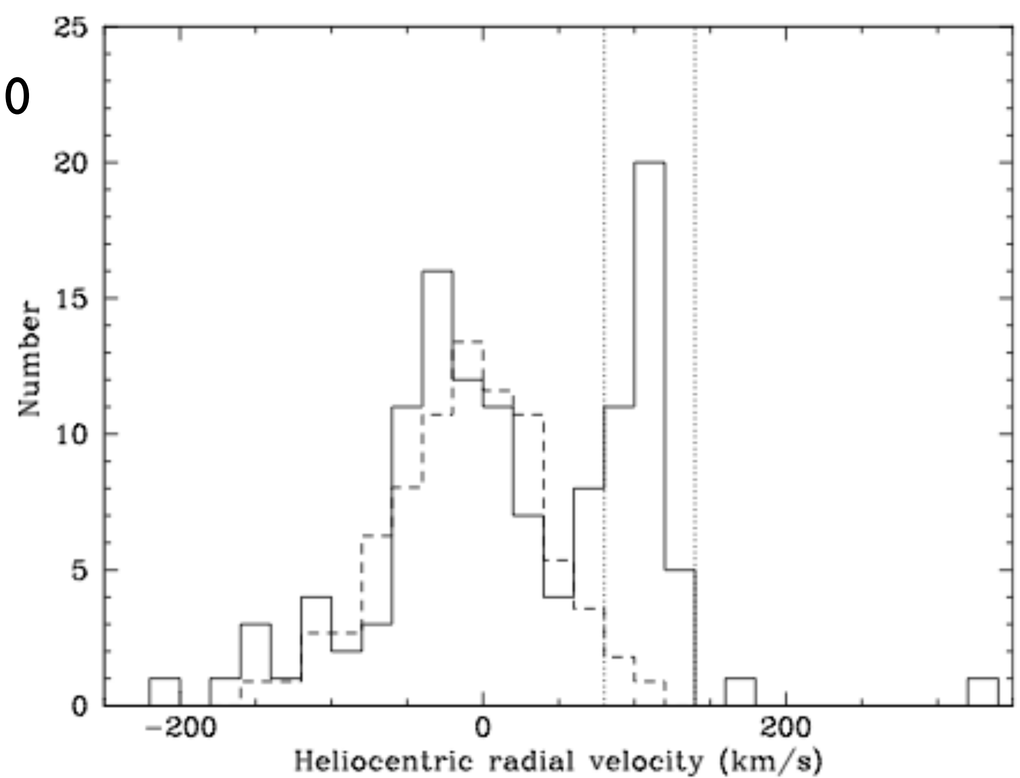
ACS survey
Brown et al. 2014

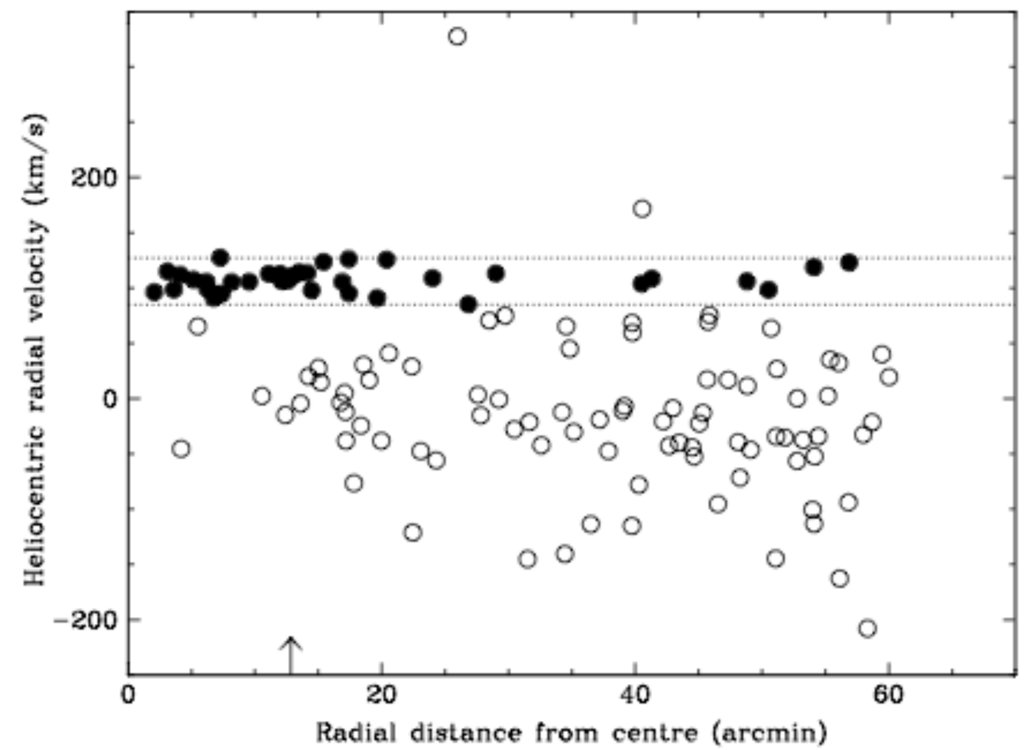


DECam imaging
Roderick et al. 2016



Norris et al. 2010

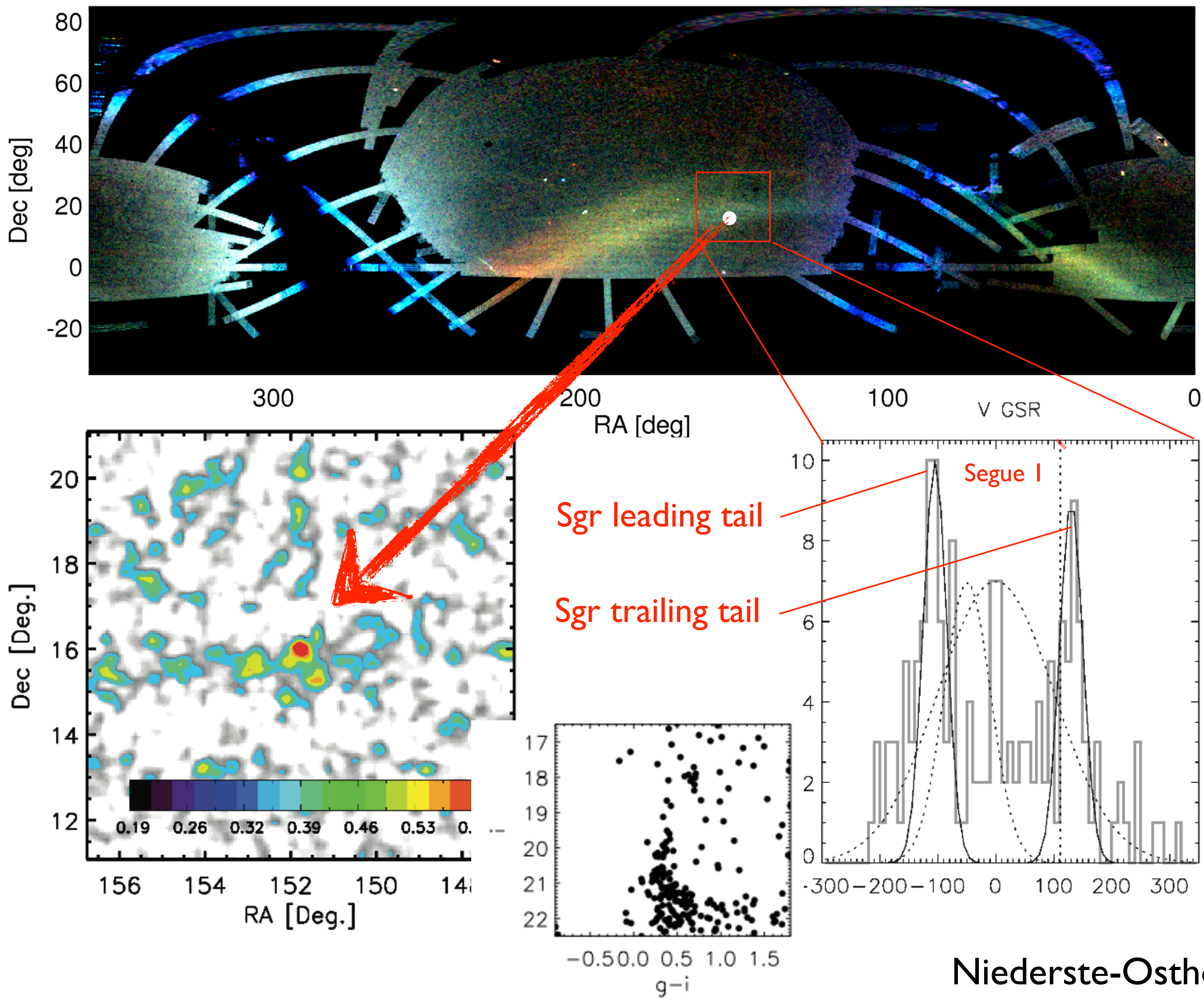




Segue 1

M_V ~ -1.5

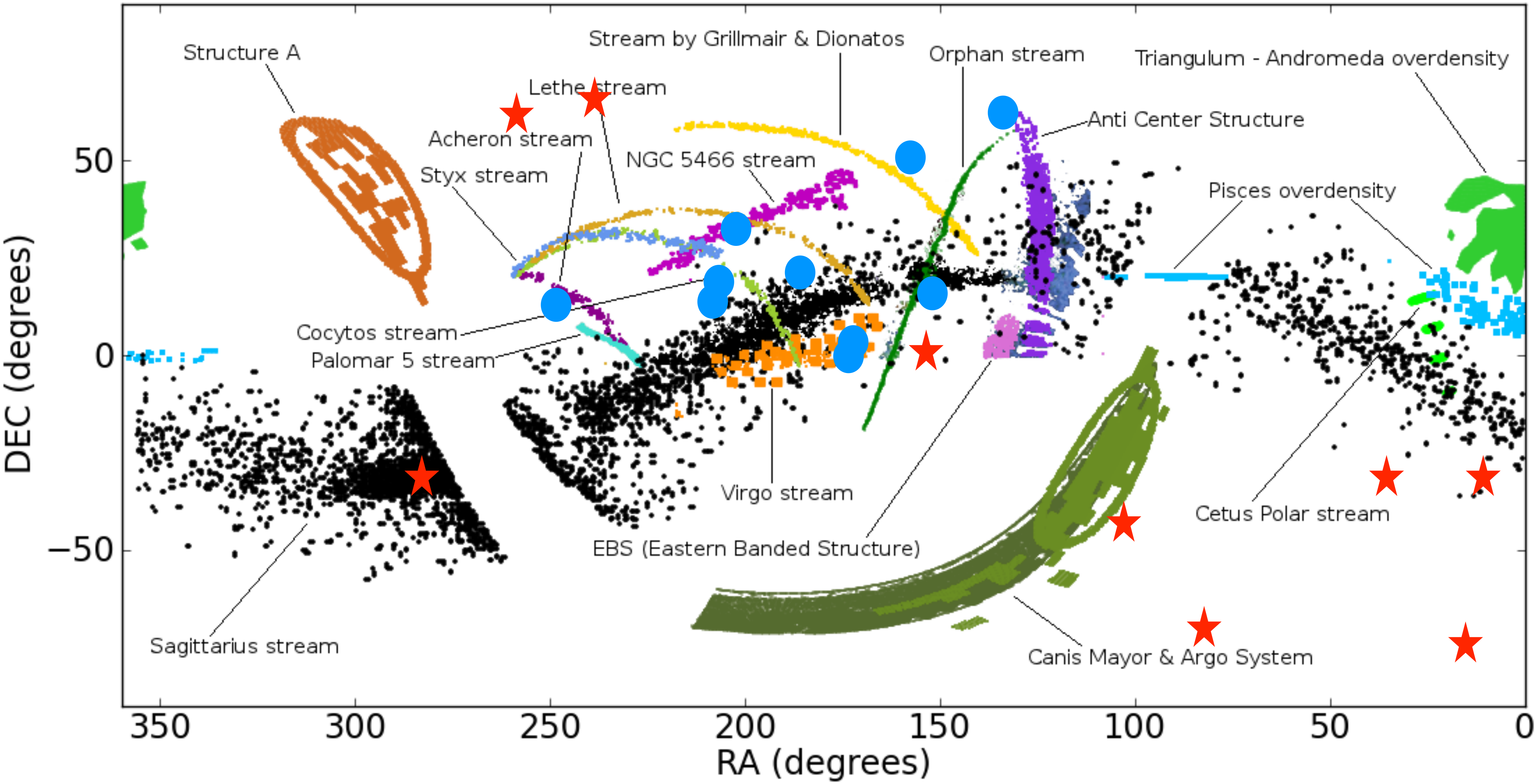
23kpc



Niederste-Ostholt et al, 2009

Pre-Gaia

Coherent Structures in the outer halo

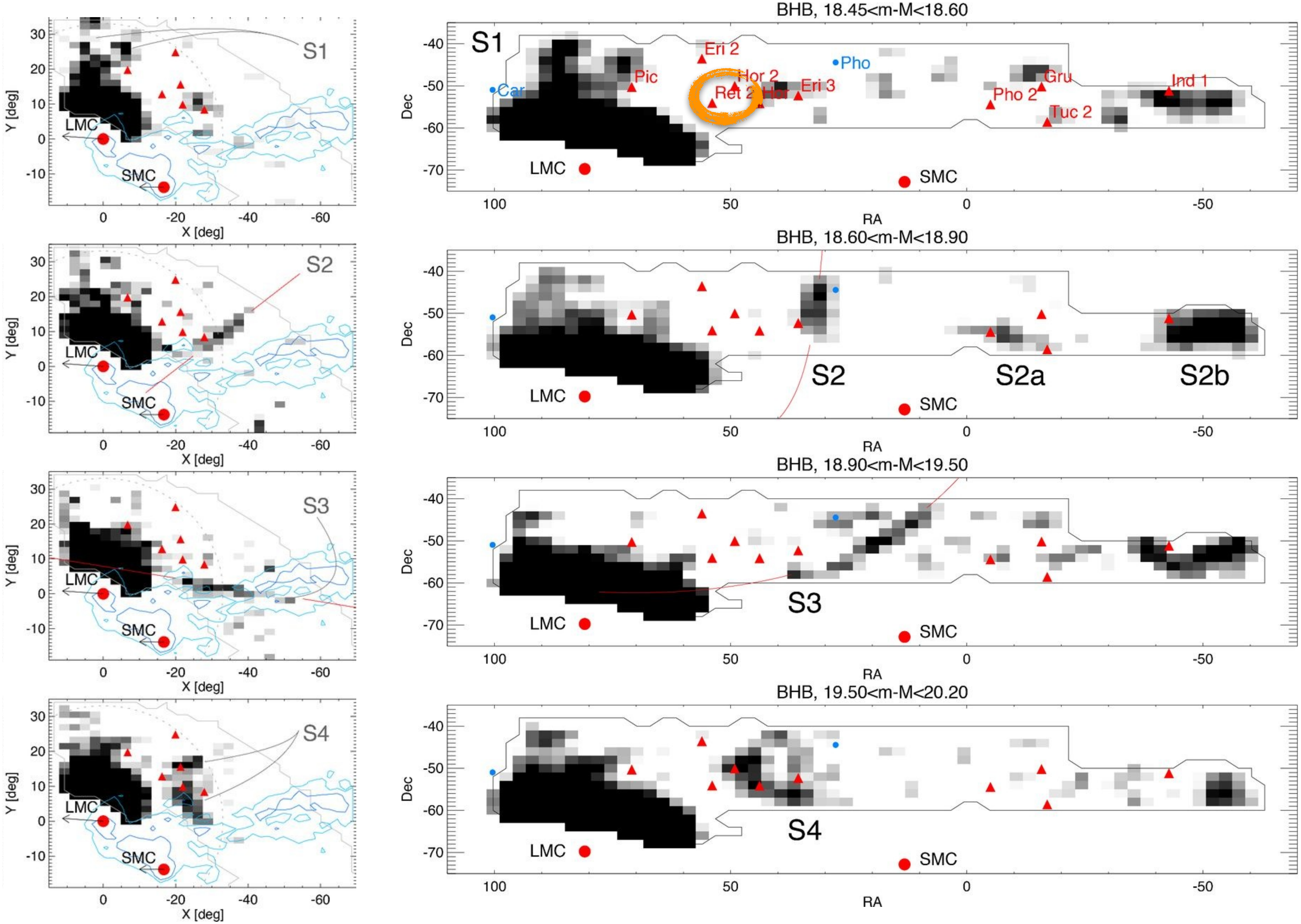


black points: Majewski et al. 2003 M-giant survey

from Berenice Pila Diez

Coherent Structures around the MCs

using BHBs

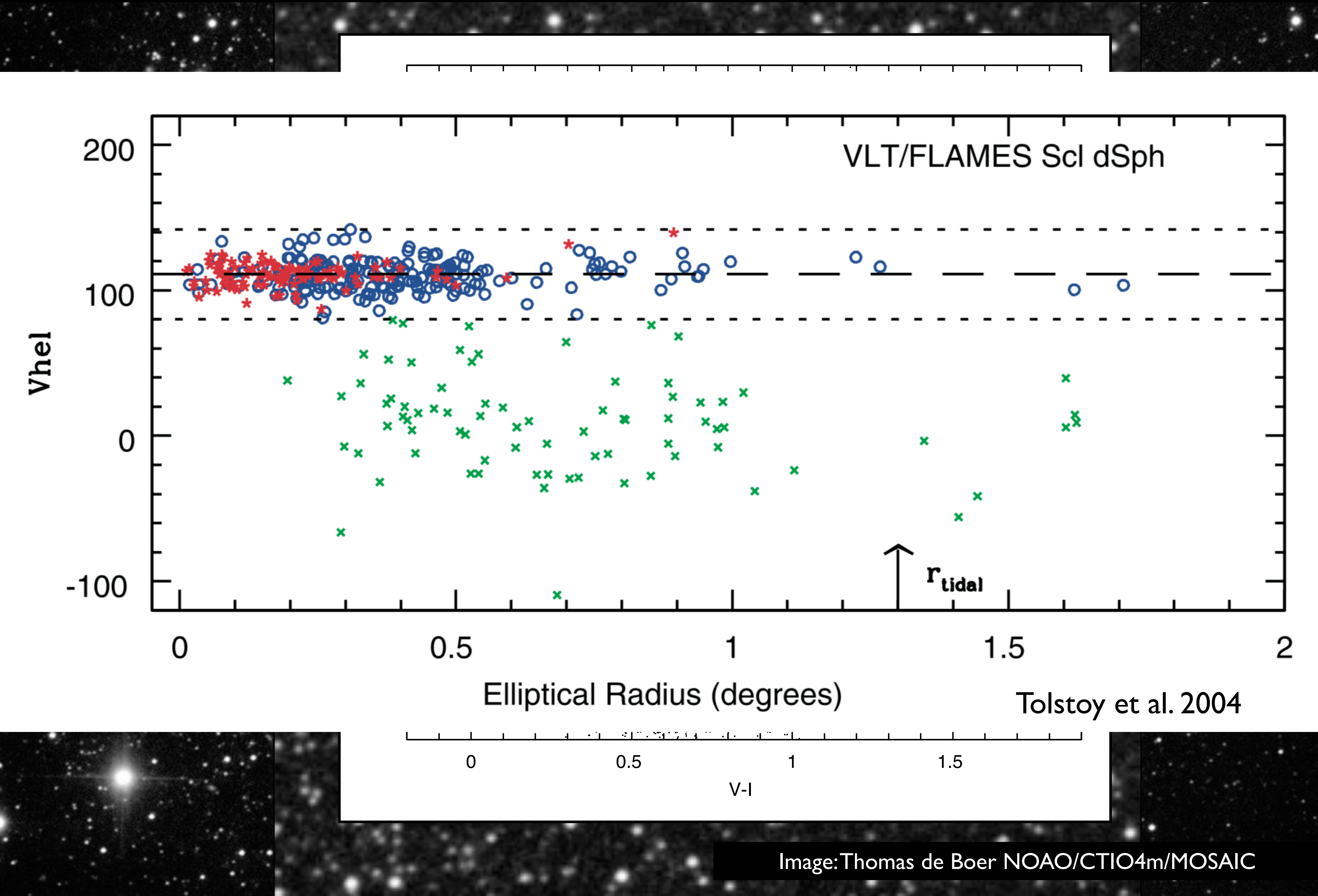


Belokurov & Koposov 2016 MNRAS, 456, 602

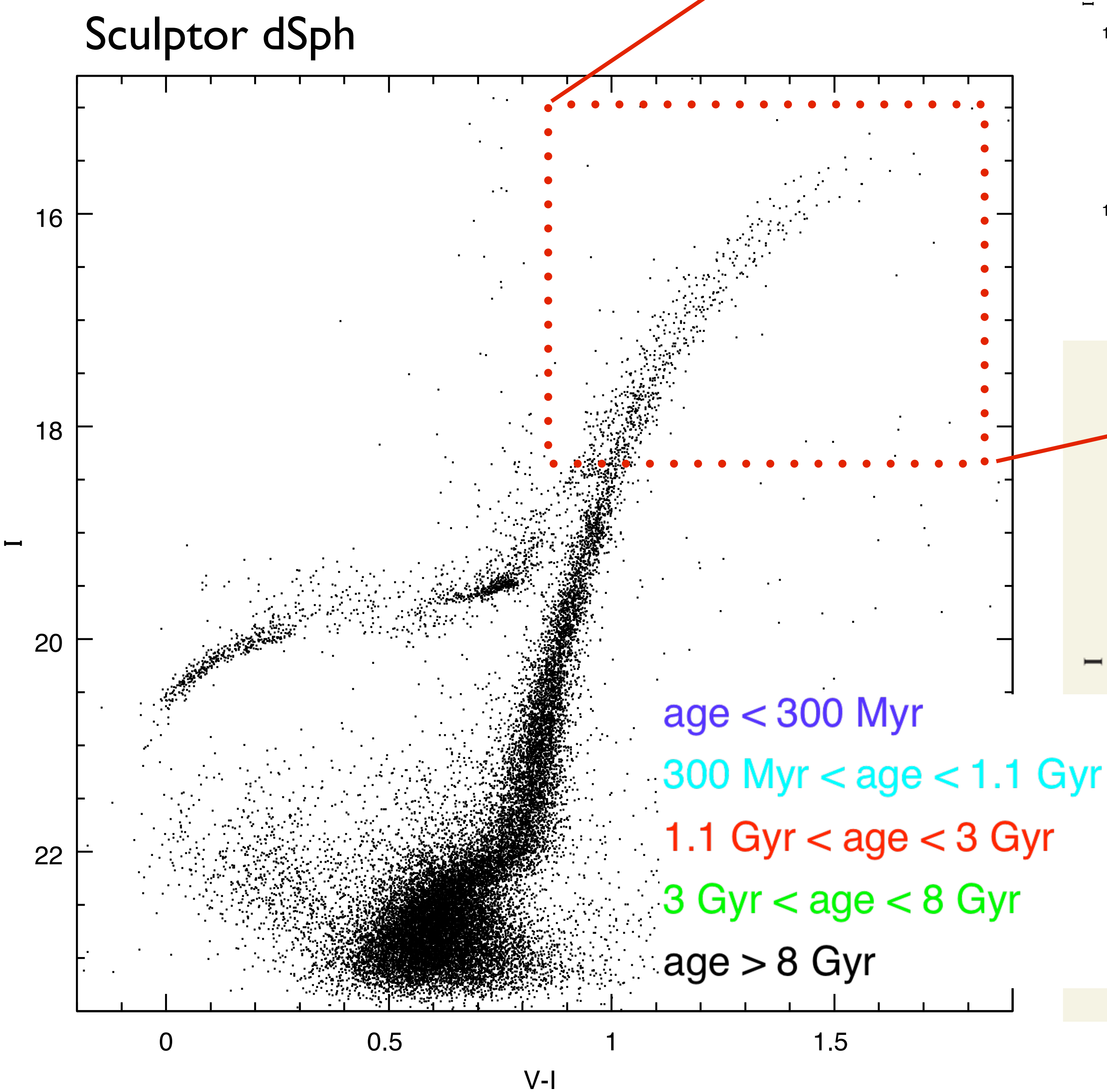
Let's get into details of…

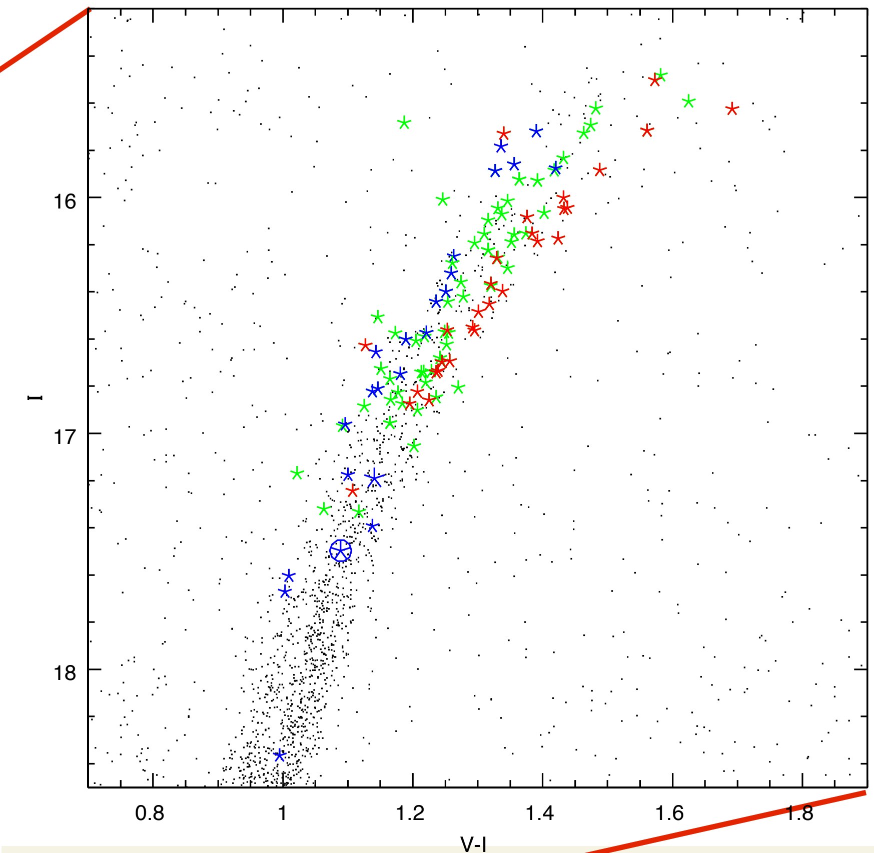
Classical dwarf spheroidals

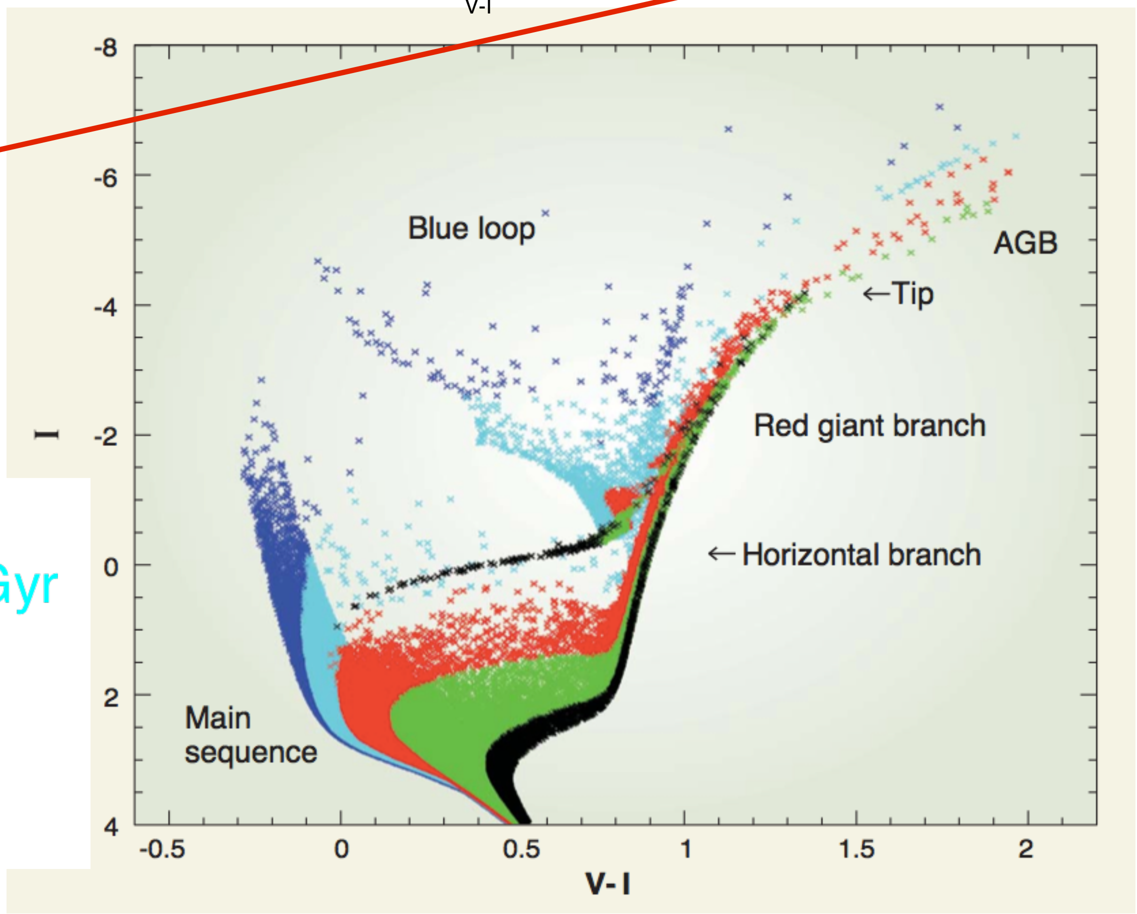
Sculptor: a textbook dwarf spheroidal galaxy



Selecting Targets for Spectroscopy







FLAMES DART project

low resolution (R~4-6k)

medium resolution (R~15-25k)

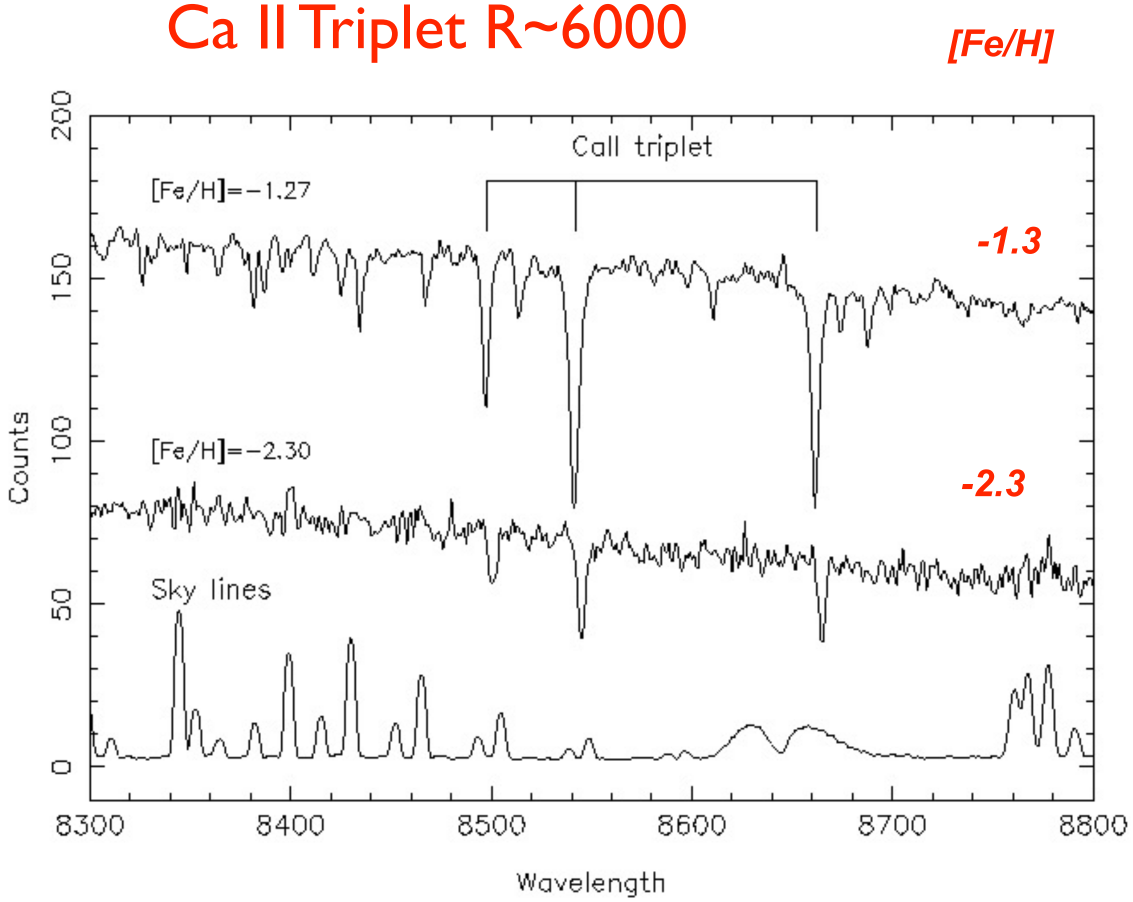
high resolution (R~30-50k)

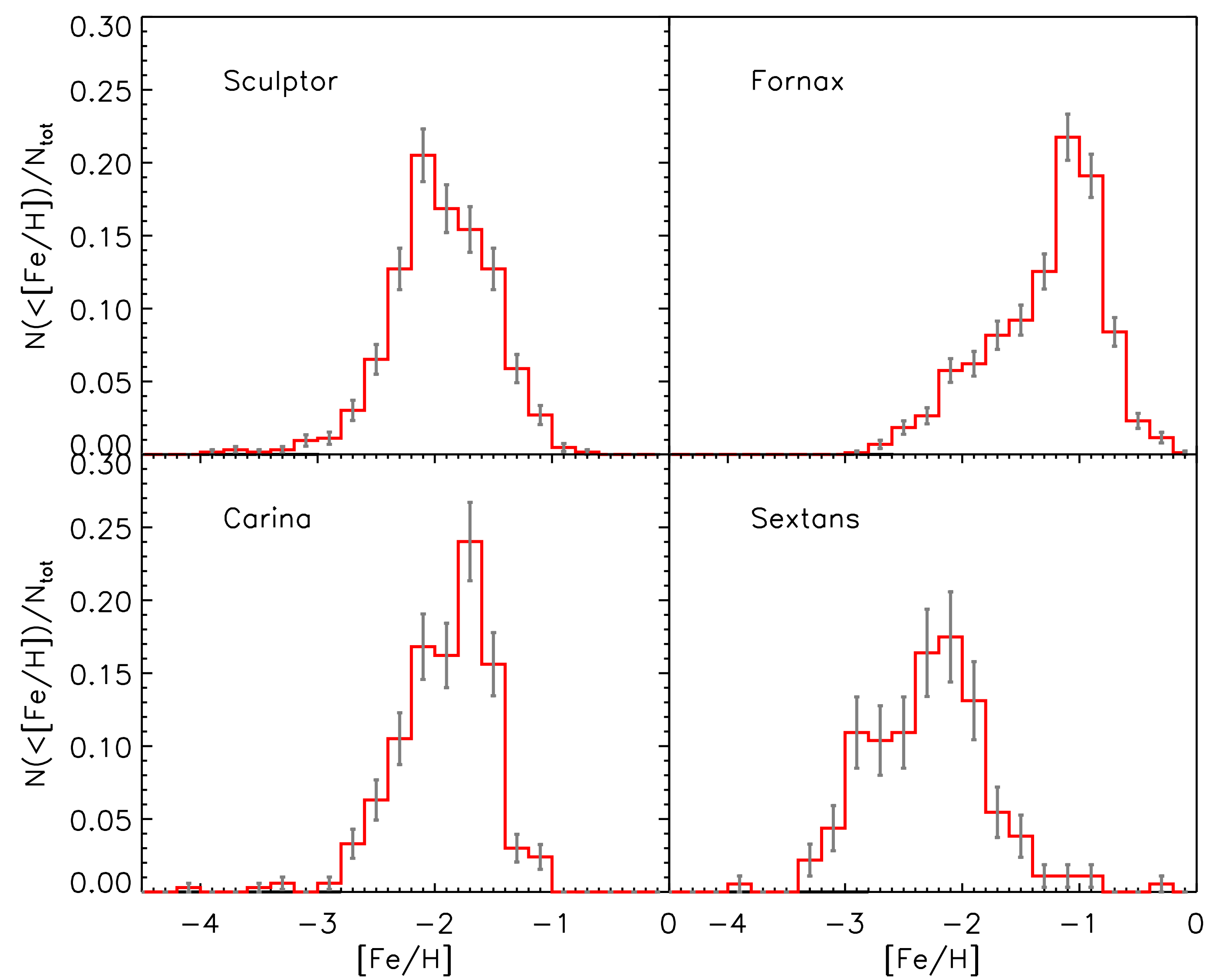
Low Resolution Spectroscopy

[Fe/H] ∝ EW of CaII triplet lines

$$[Fe/H] = -2.87 + 0.195 \times (V - V_{HB}) + 0.458 \times EW_{(2+3)} - 0.913 \times EW_{(2+3)}^{-1.5} + 0.0155 \times EW_{(2+3)} \times (V - V_{HB})$$

Ca II Triplet R~6000

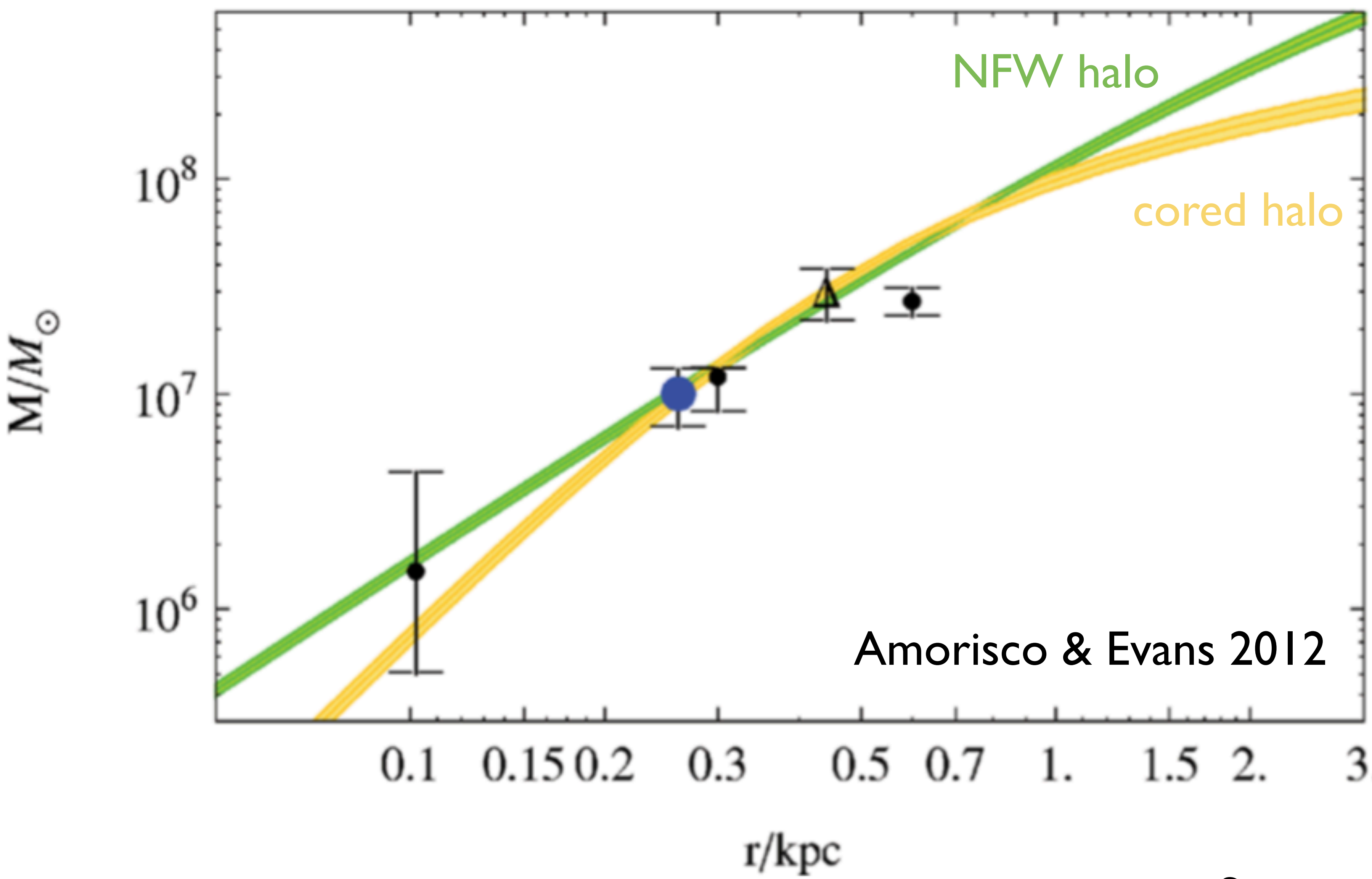




Also surveys by Walker et al. and Kirby et al. in different wavelength regions from different telescopes/instruments.

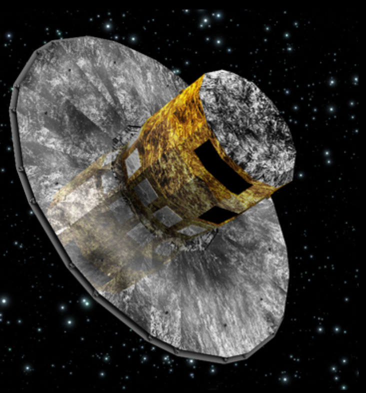
Starkenburg et al. 2010 A&A
Battaglia et al. 2008 MNRAS

Mass profiles: Sculptor



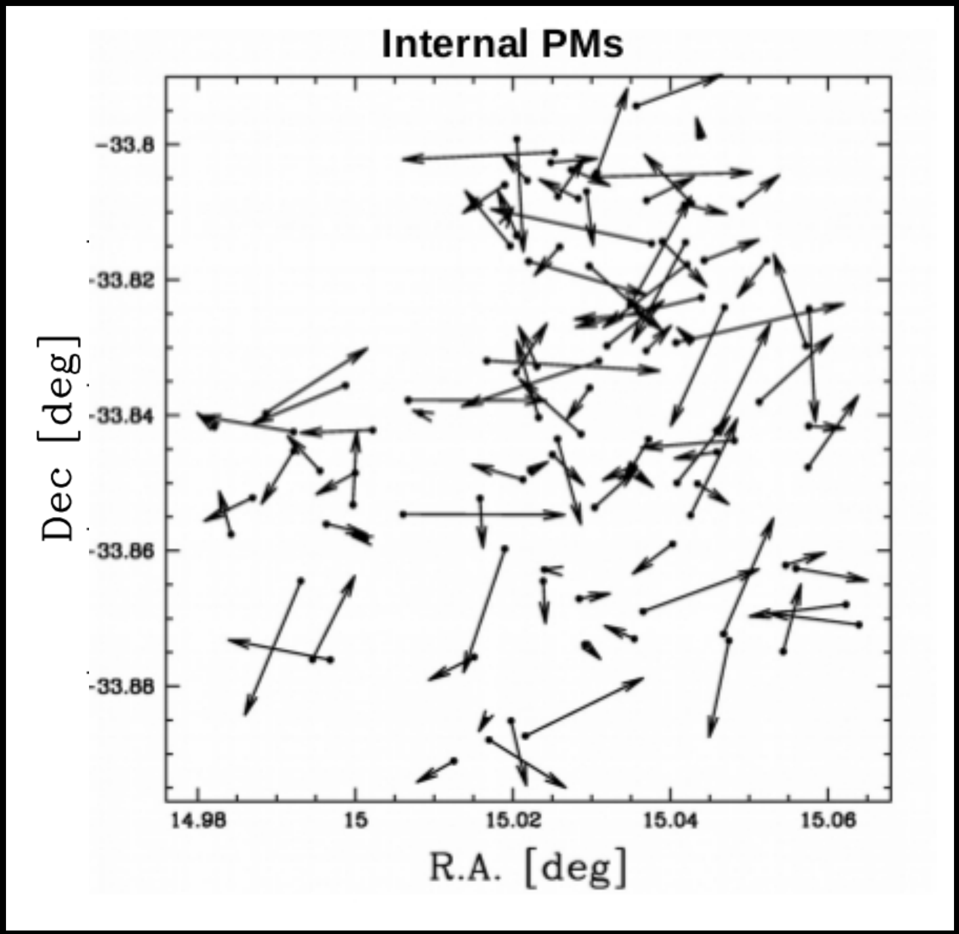
Strigari et al. (2007, 2009) black dots;
Walker et al. (2009) blue dot;
Amorisco & Evans (2011) triangle.

Proper Motions: GAIA, HST



motion on plane of sky after 12 years

Sculptor dSph

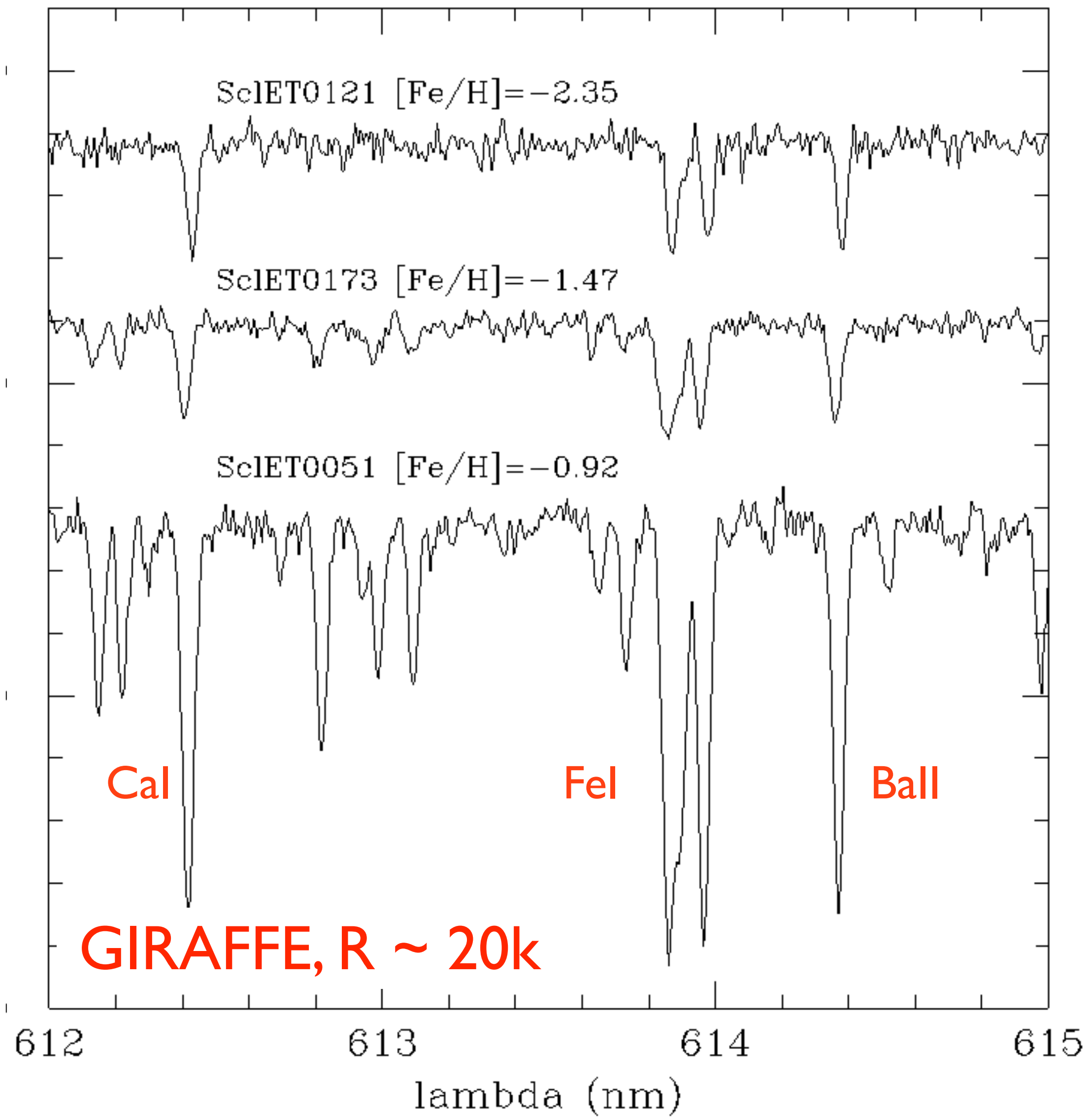


Massari et al. (2018) Nat. Astron.

Intermediate Resolution Spectroscopy

Fe Mg, Si, Ti, Ca Ni, Cr, Y, Ba, La, Nd, Eu

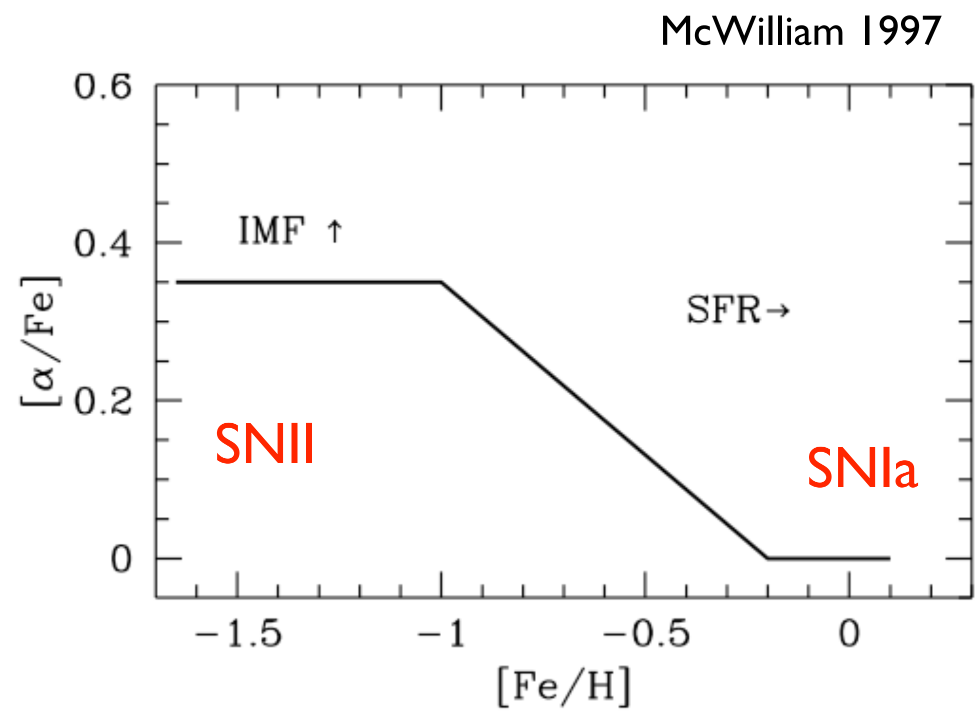
alpha-elements

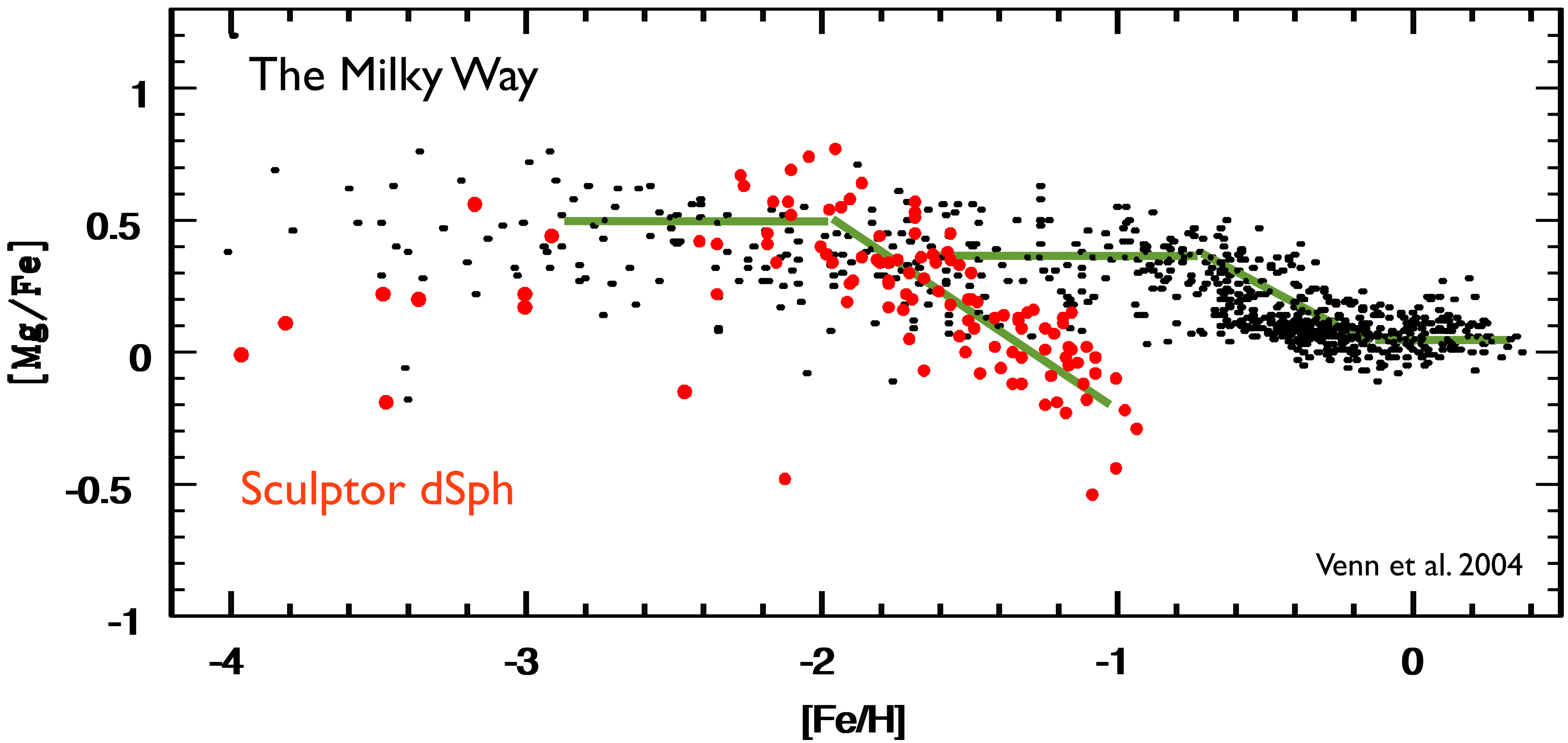


Scl: Alpha-Elements

"The Knee"

can only make halo out of Scl-like galaxies at very early times



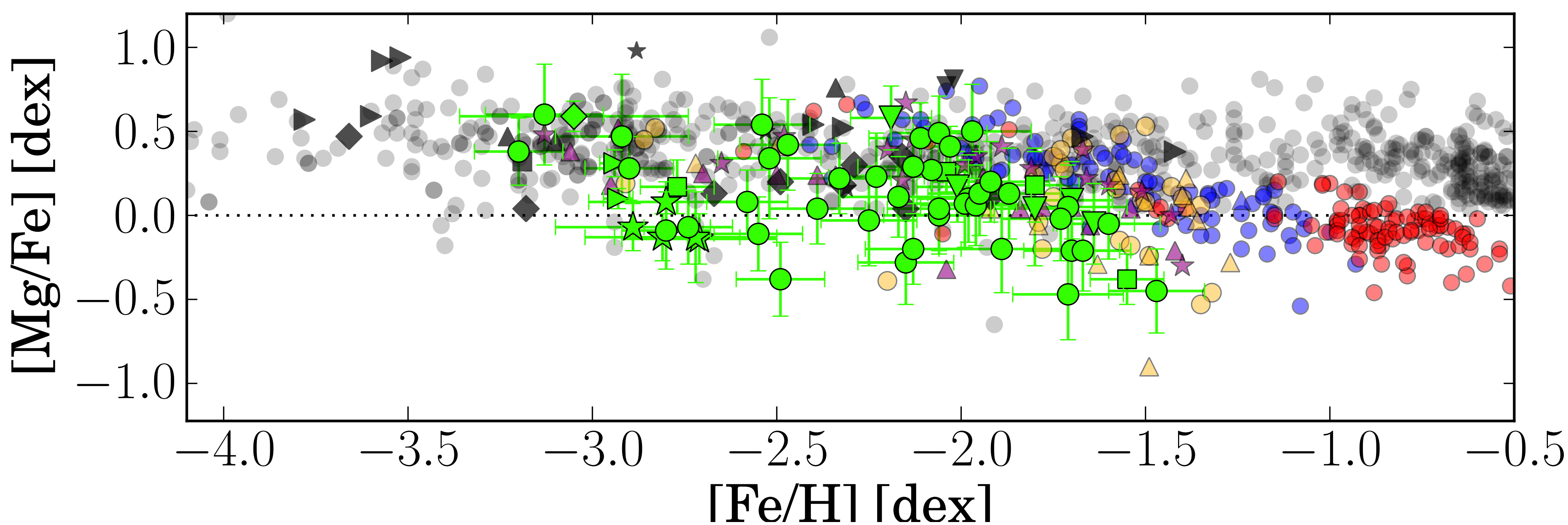


Hill, Skúladóttir et al. 2018 A&A, in press arXiv:1812.01486

Alpha elements: nearby galaxies

DART FLAMES results on Sextans dSph

Aoki et al. 2009

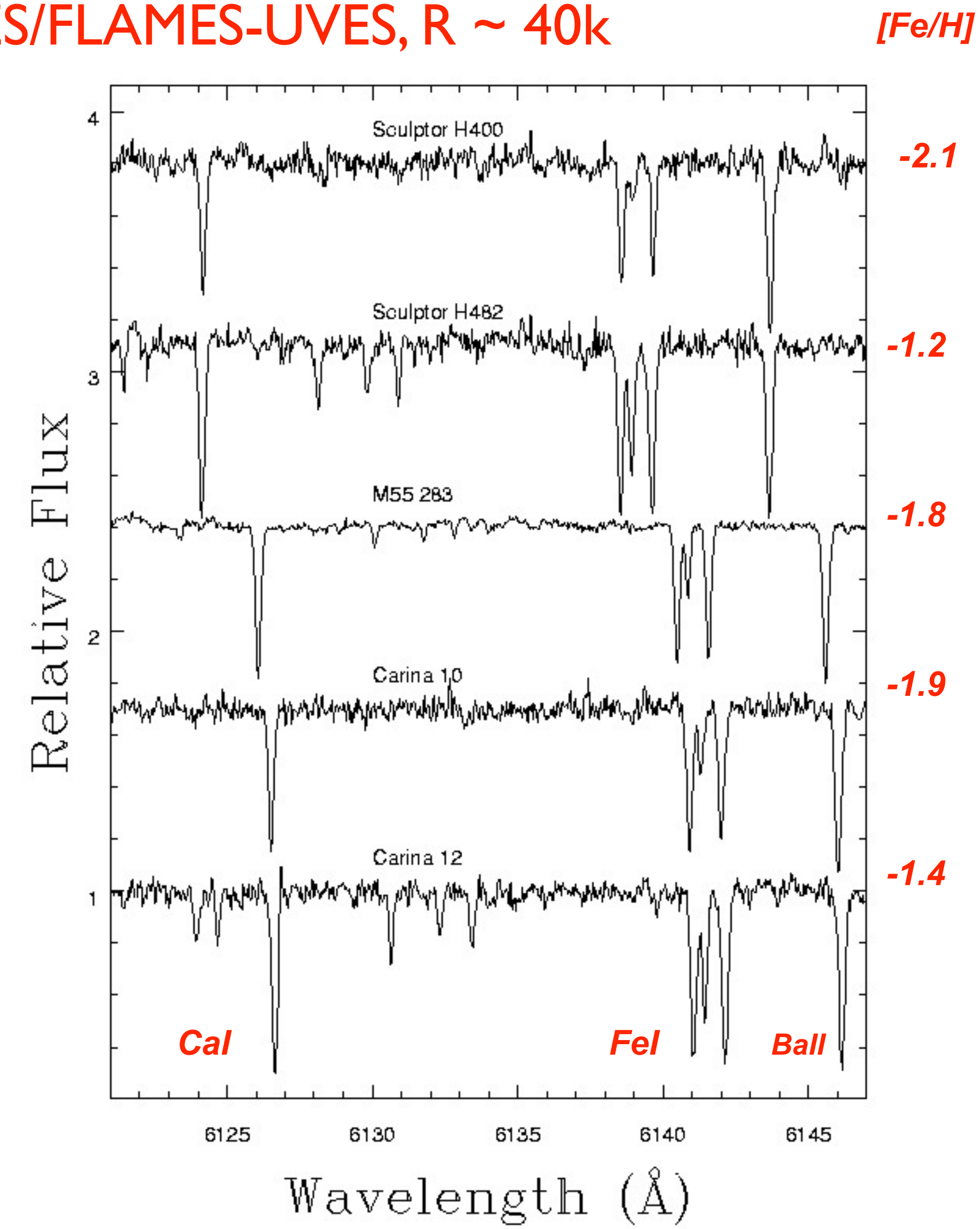


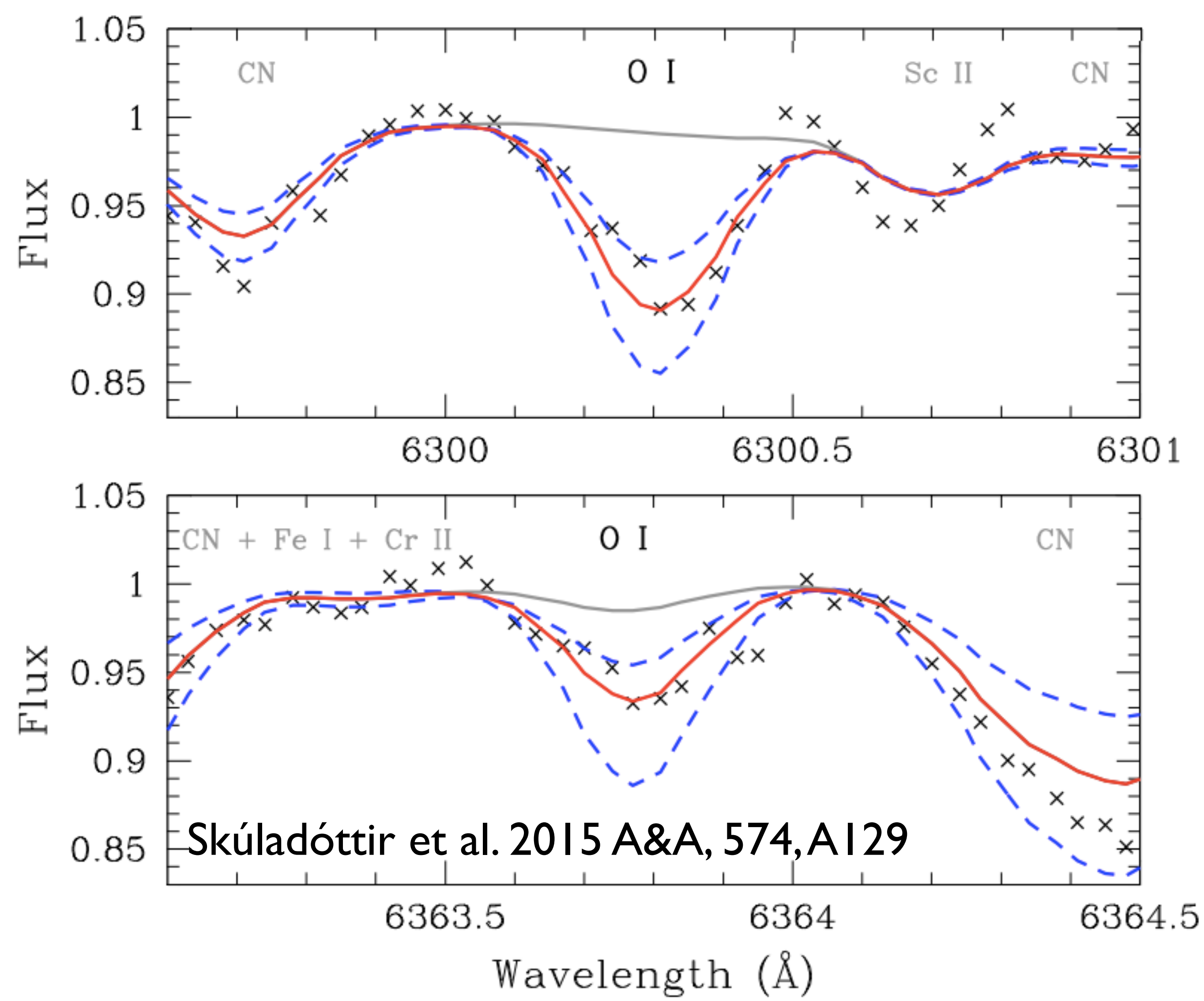
Theler, Jablonka, Primas et al. in prep

High Resolution Spectroscopy

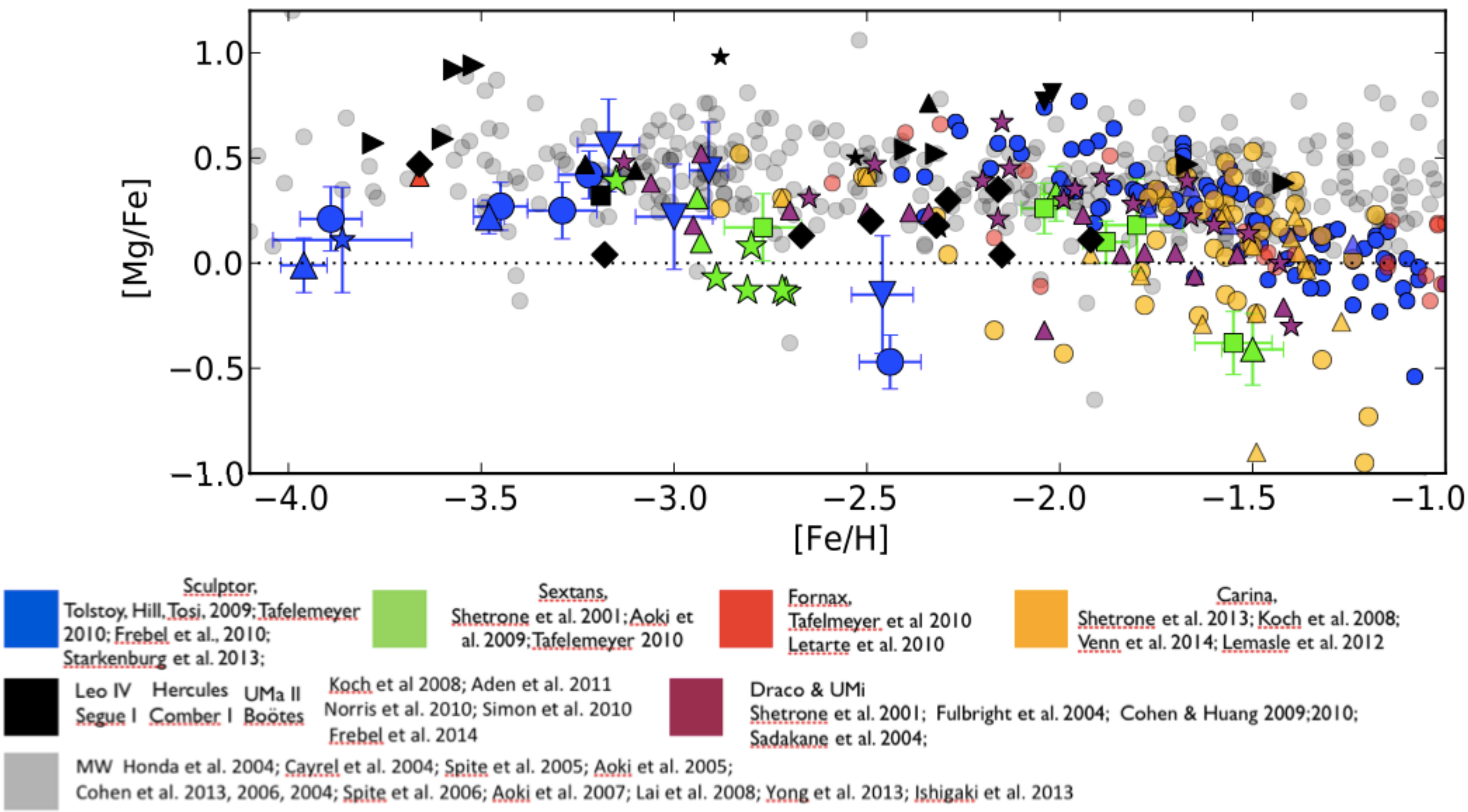
Fe, Mg, Si, Ti, Ca, Ni, Cr, Y, Ba, La, Nd, Eu +
O, Na, Sc, Nd, FeII, TiII

UVES/FLAMES-UVES, R ~ 40k





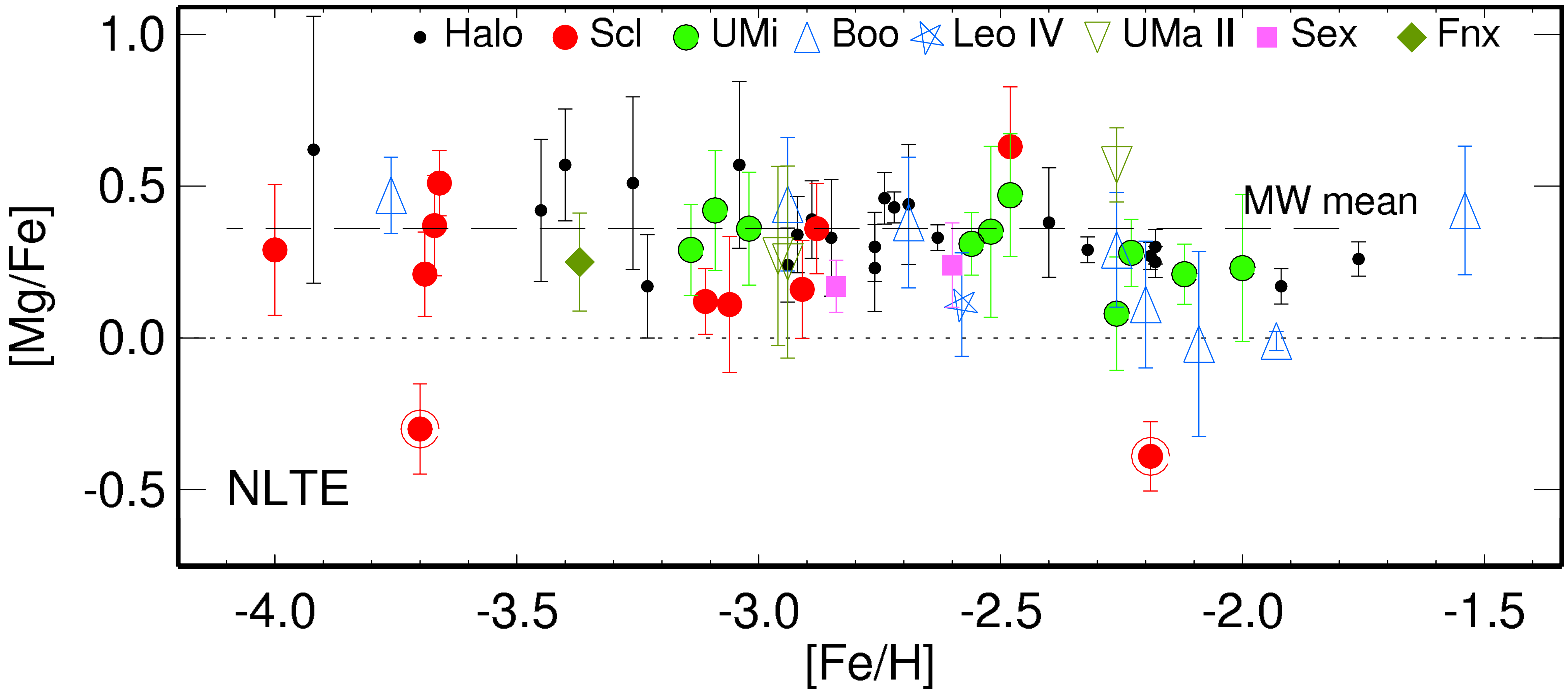
Overview of alpha in different systems



from Pascale Jablonka

Extremely precise

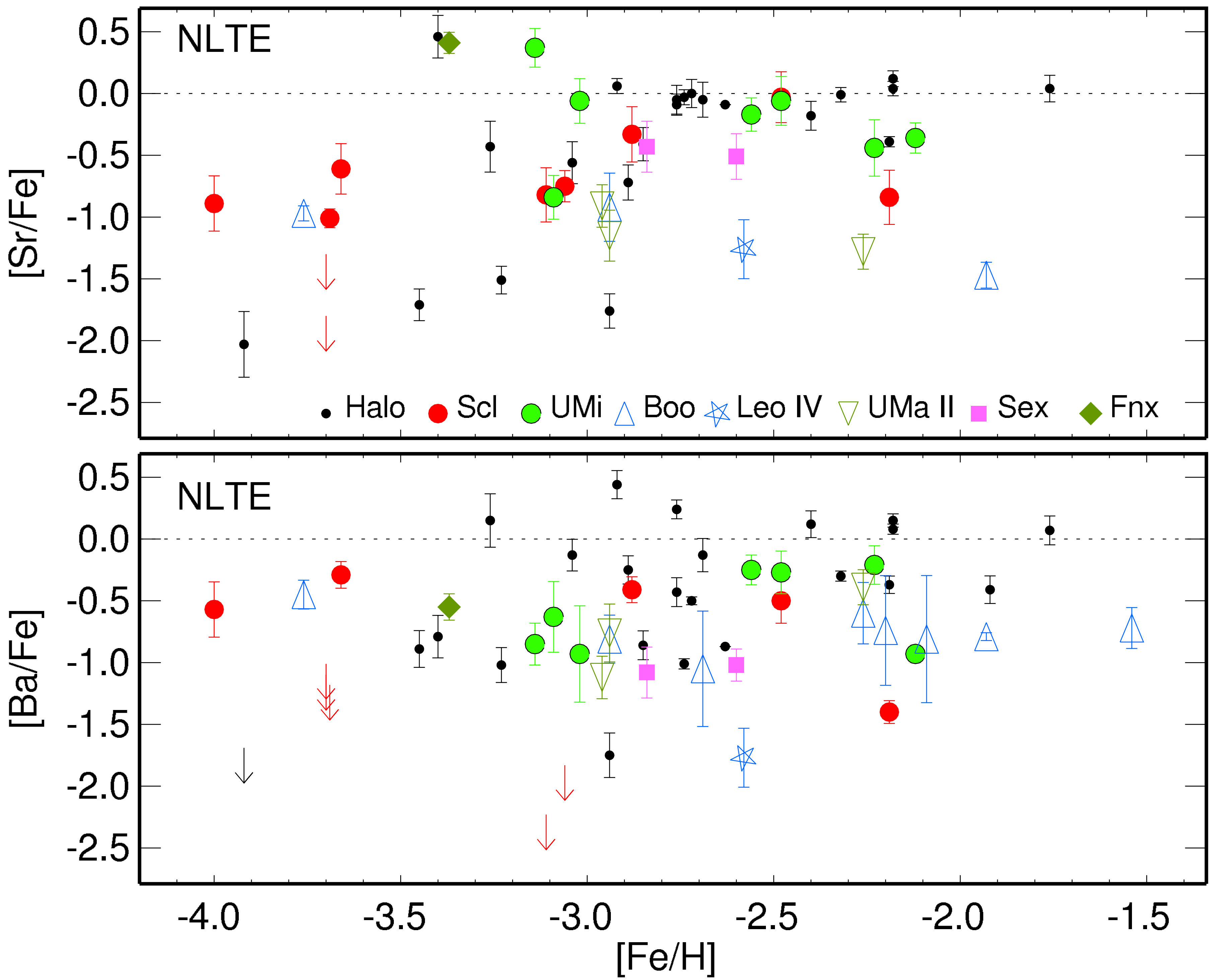
Overview of alpha in different systems



R>25 000 spectra

Mashonkina et al. 2017a,b

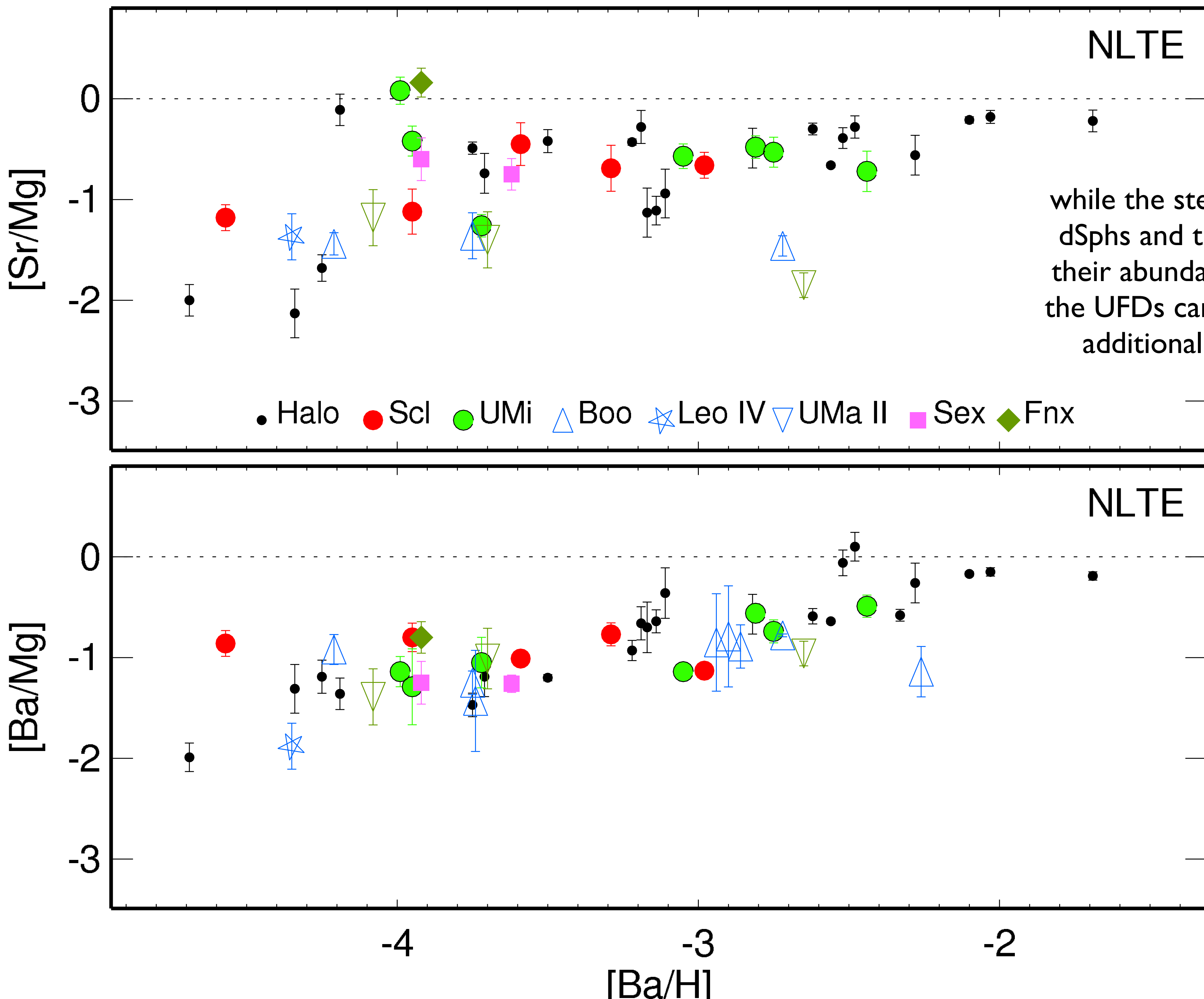
Heavy Elements: Strontium & Barium



Mashonkina et al. 2017b

Strontium & Barium & Magnesium

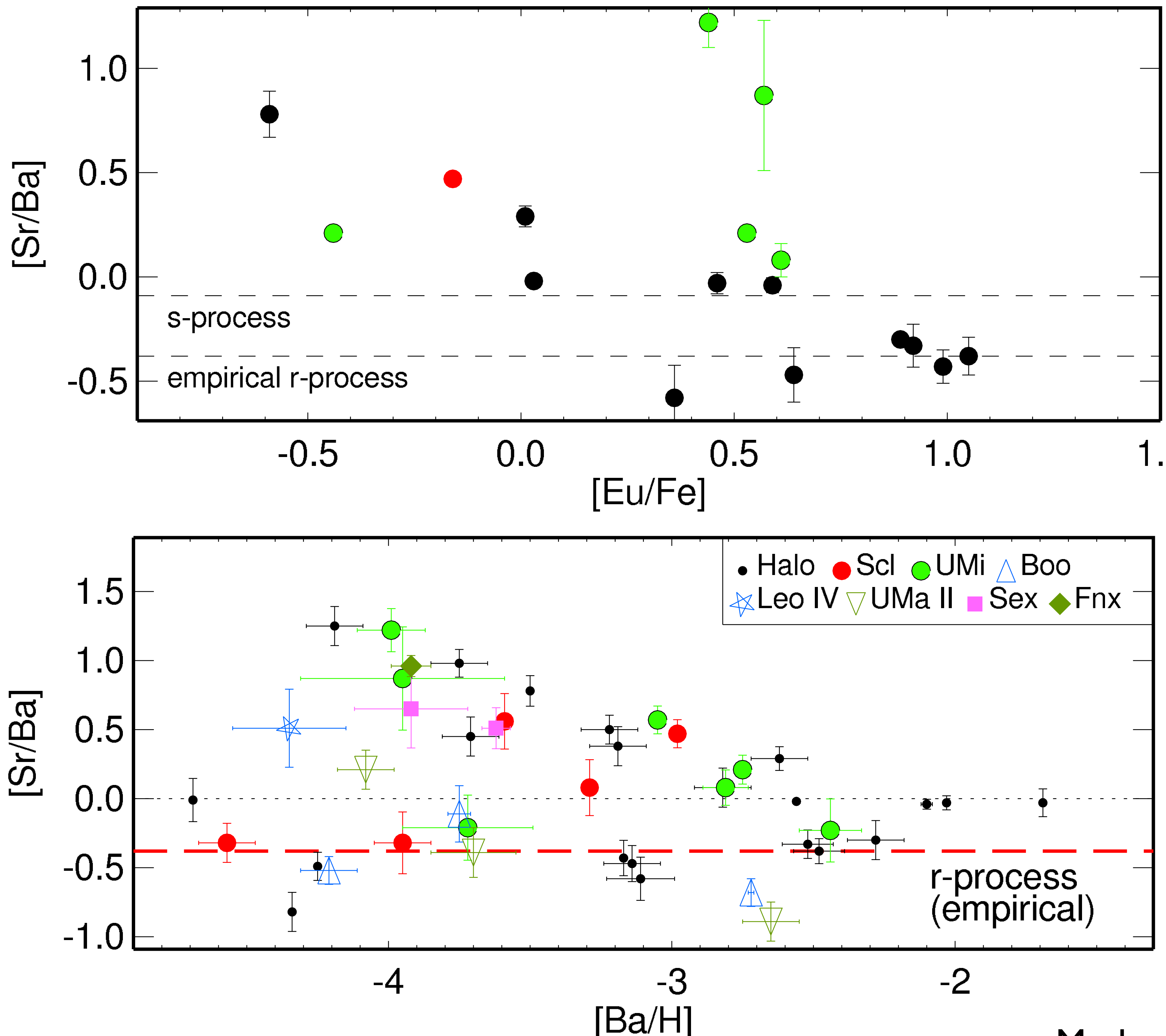
to remove any potential pollution of Fe by the ejecta of SNIa



while the stellar population of massive dSphs and the MW halo can increase their abundance of Sr relatively to Mg, the UFDs cannot and thereby, miss this additional Sr production channel.

Mashonkina et al. 2017

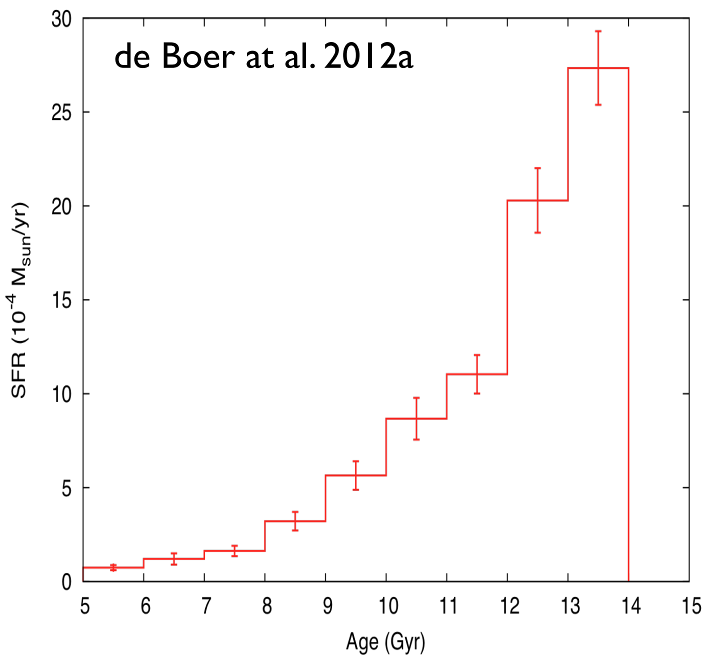
Heavy Elements: Europium

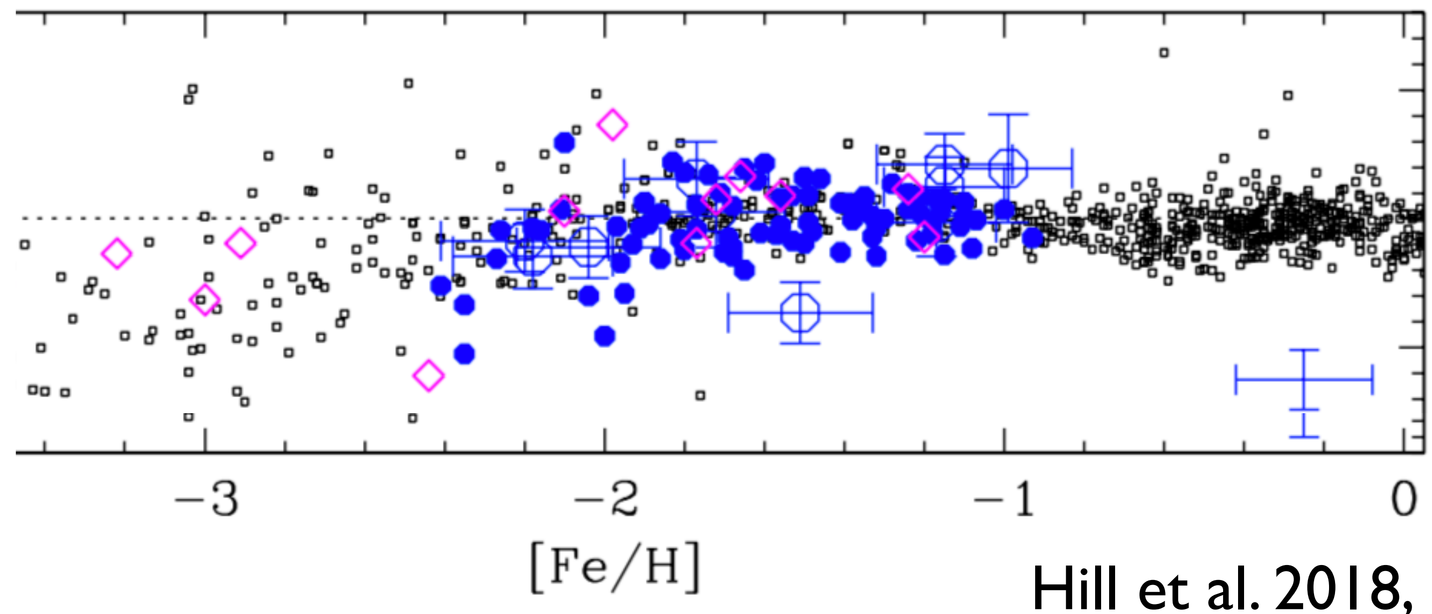


Mashonkina et al. 2017

s-process Elements

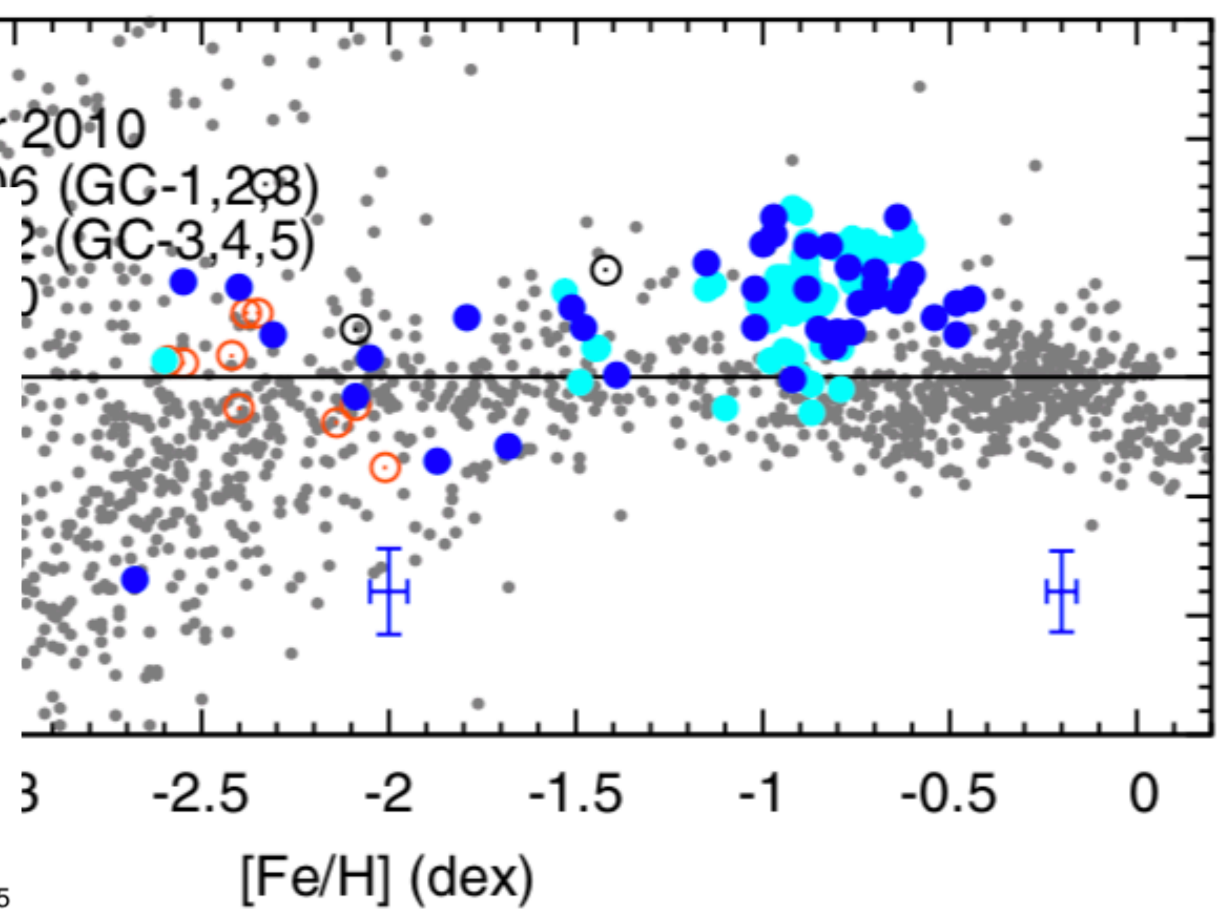
Scl

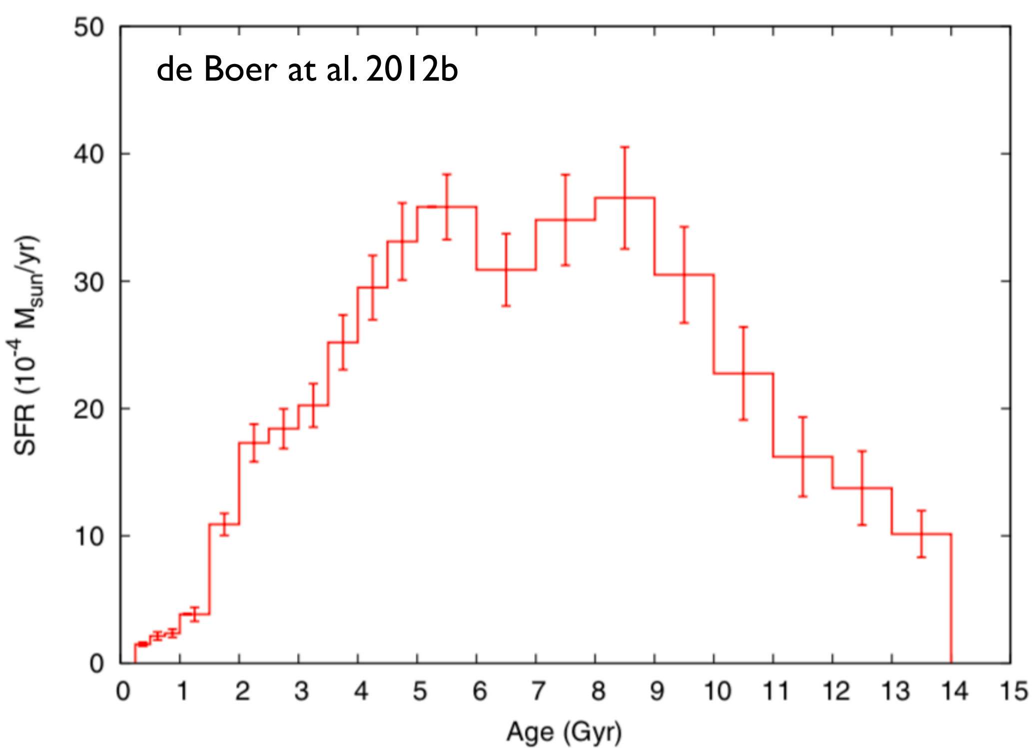




Hill et al. 2018, A&A in press

Fnx





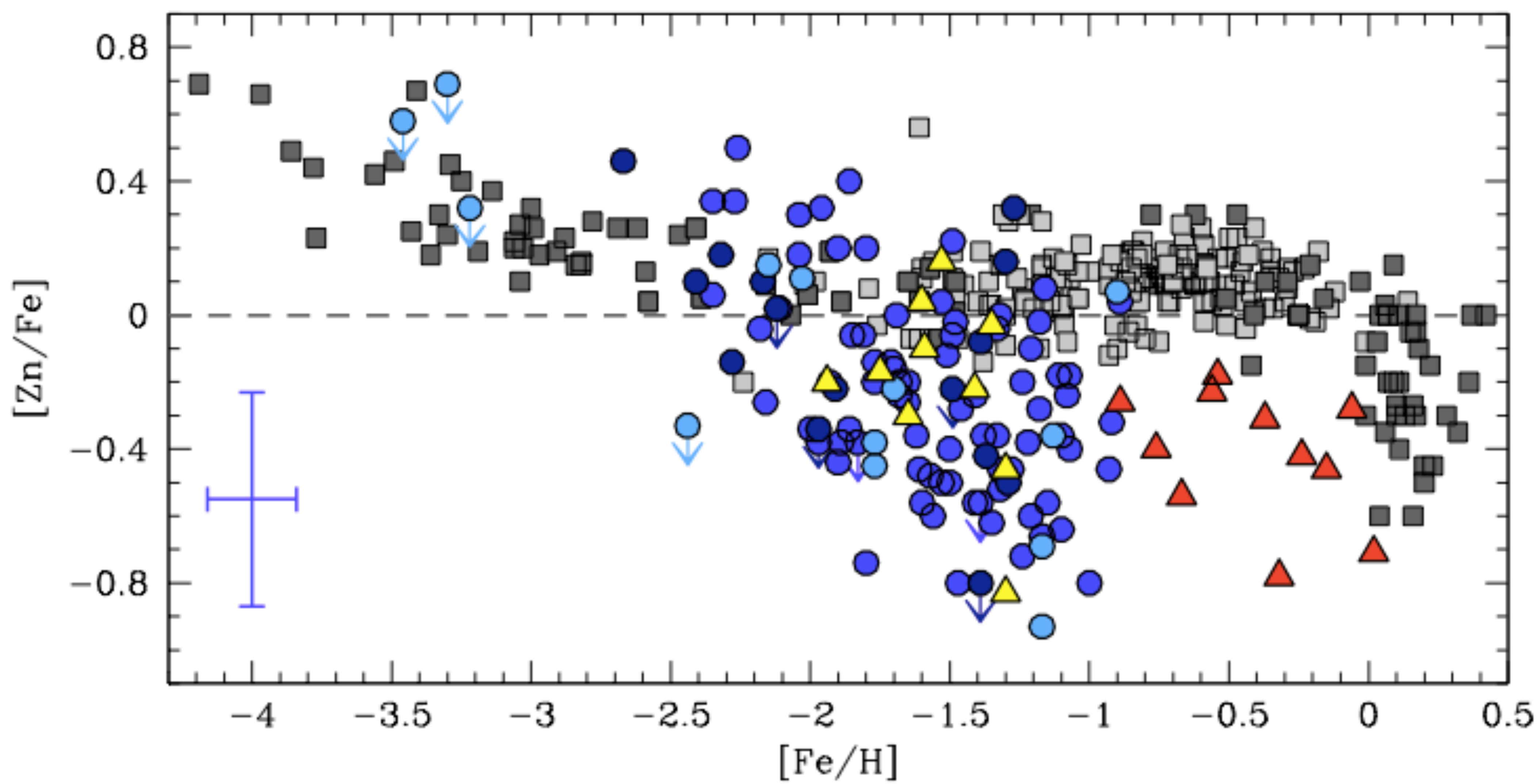
Lemasle et al. 2014

Letarte et al. 2018 corrigendum to Letarte et al. 2010

Heavy Elements: Zinc

Sculptor
Carina
Sagittarius

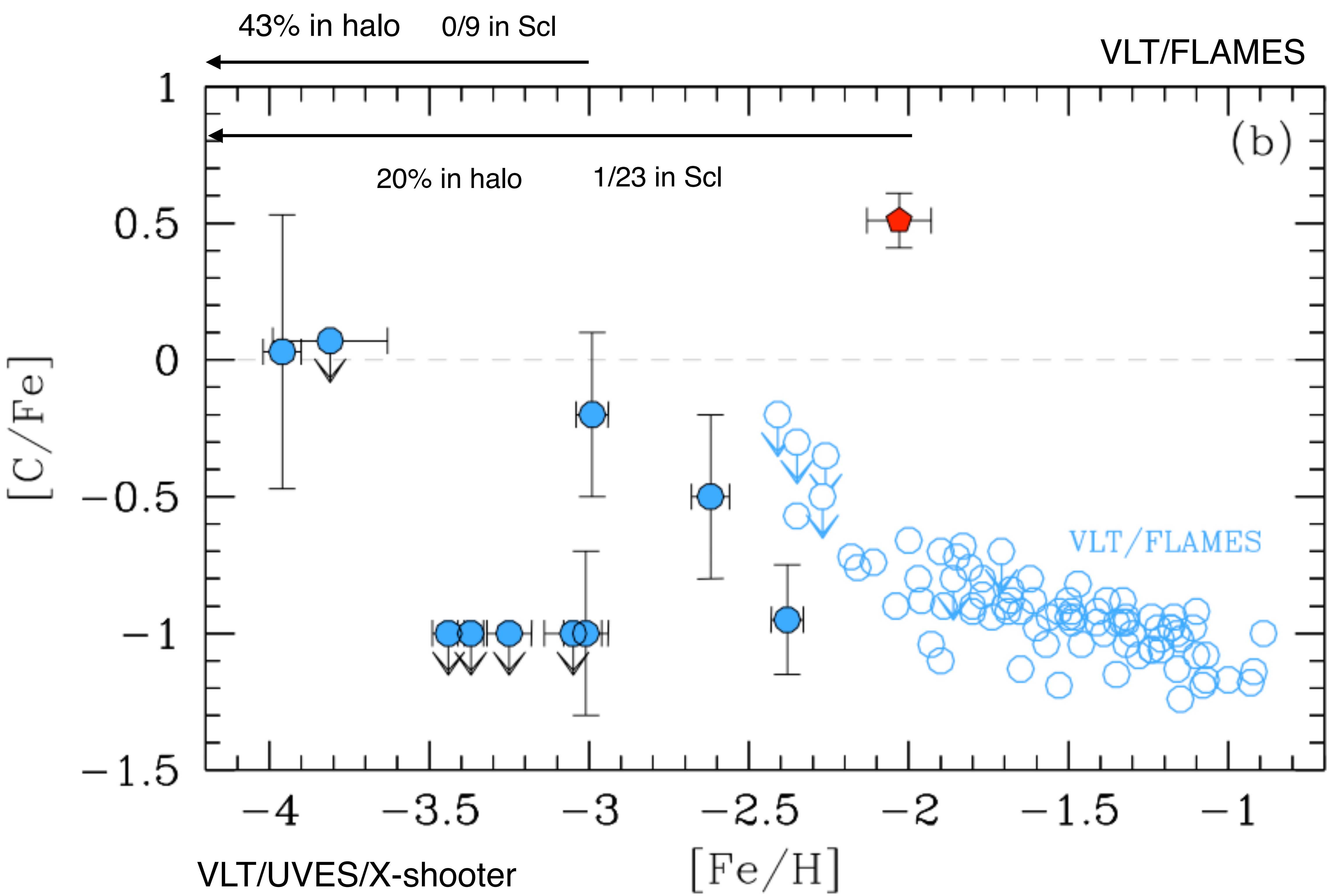
VLT/FLAMES/UVES



Zinc is an important element for tying down supernovae masses and energies

Skúladóttir et al. 2017 A&A, 606, A71

Carbon in Sculptor

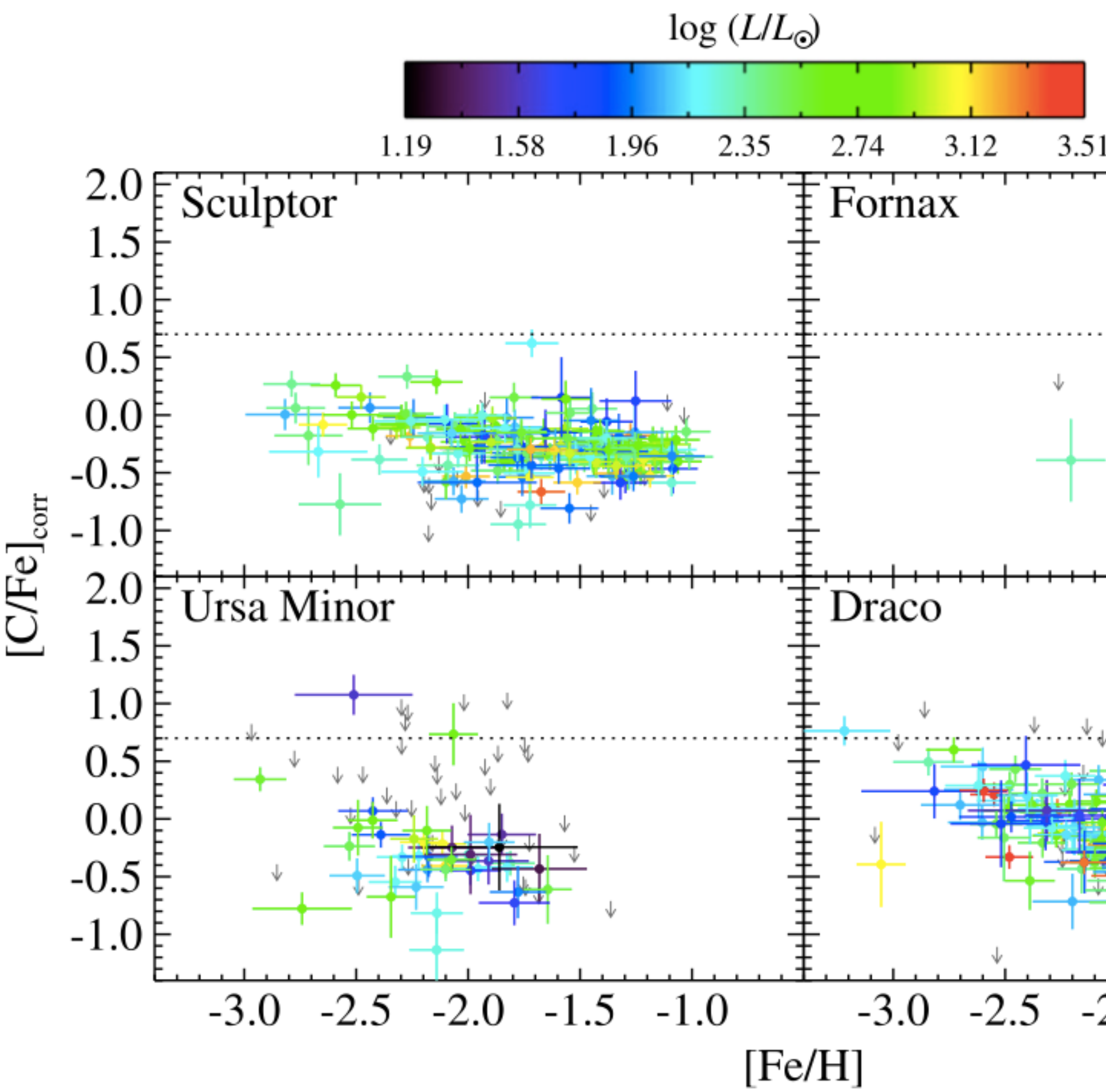


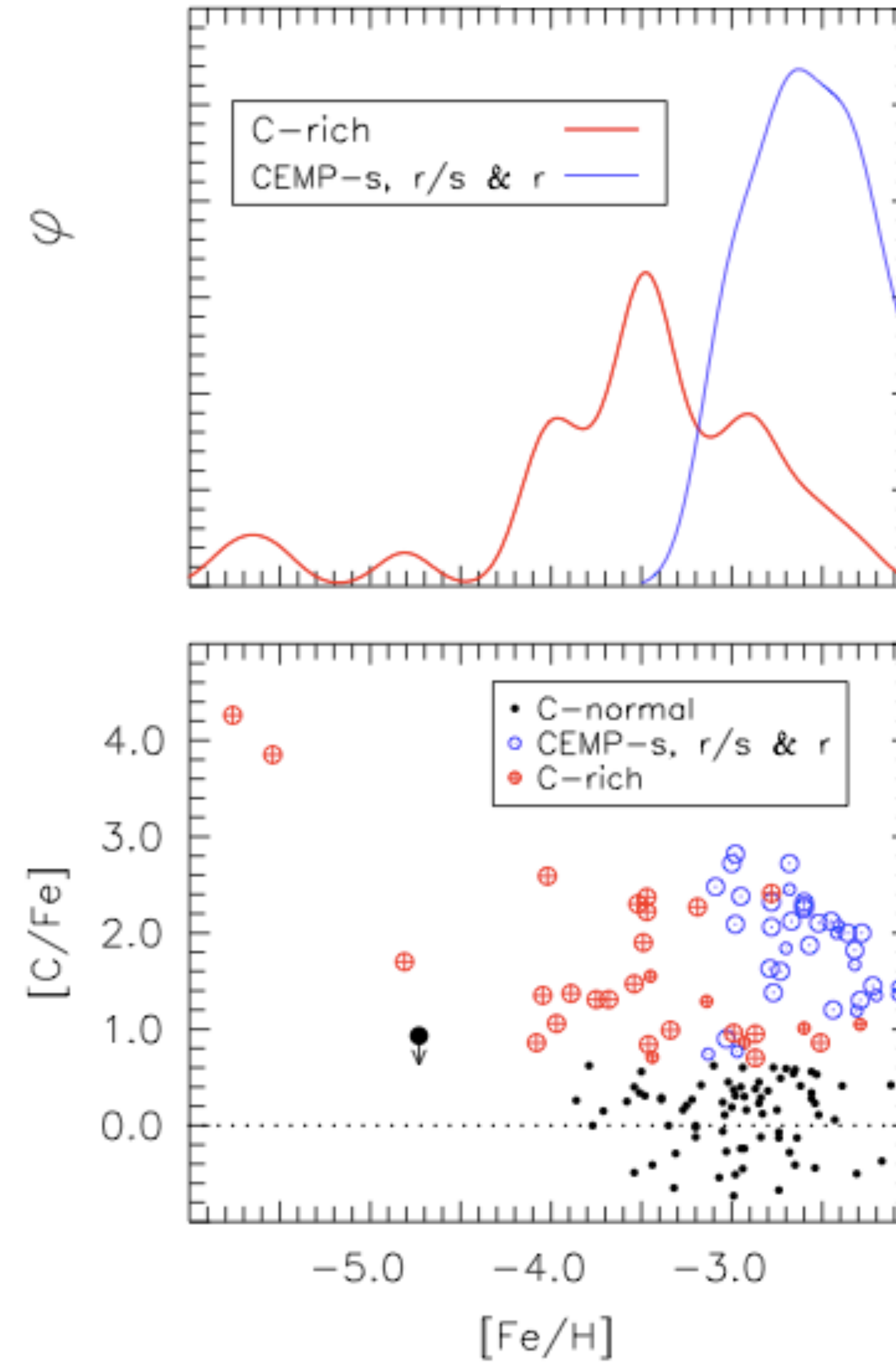
Starkenburg et al. 2013 A&A, 549, A88
Tafelmeyer et al. 2010 A&A, 524, A58

Skúladóttir et al. 2015, A&A, 574, A129

Carbon Rich Stars in classical dSph?

Norris et al. 2013



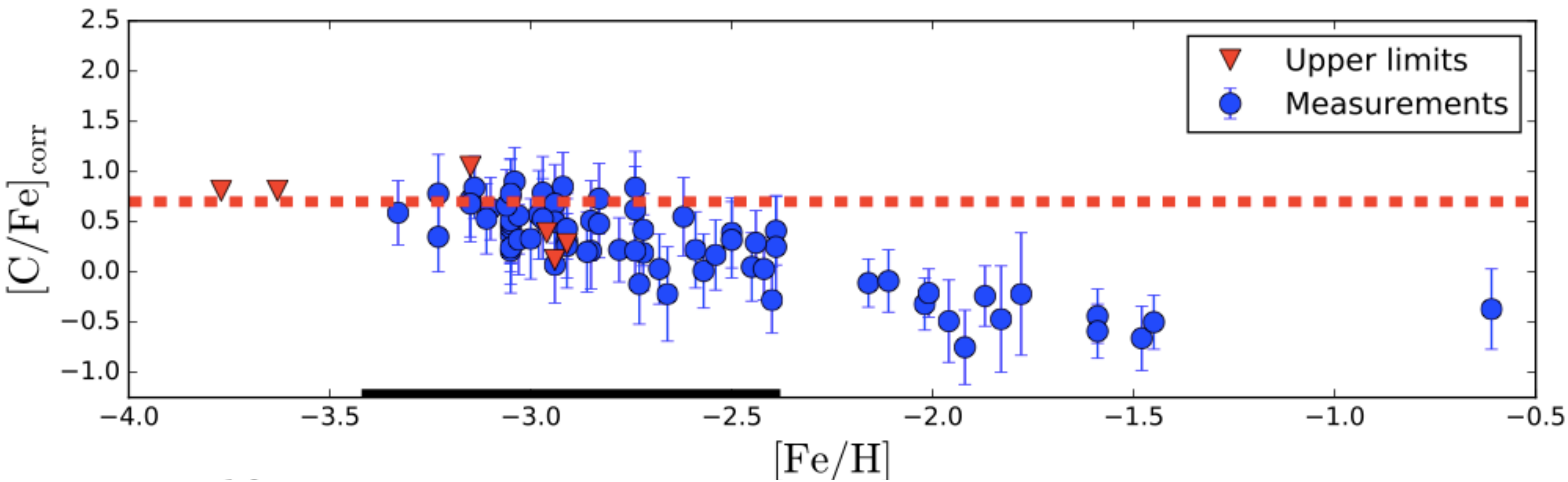


Keck/DEIMOS, 400 RGB stars

Kirby et al. 2015 ApJ, 801, 125

Scl CEMP stars

Sculptor dSph

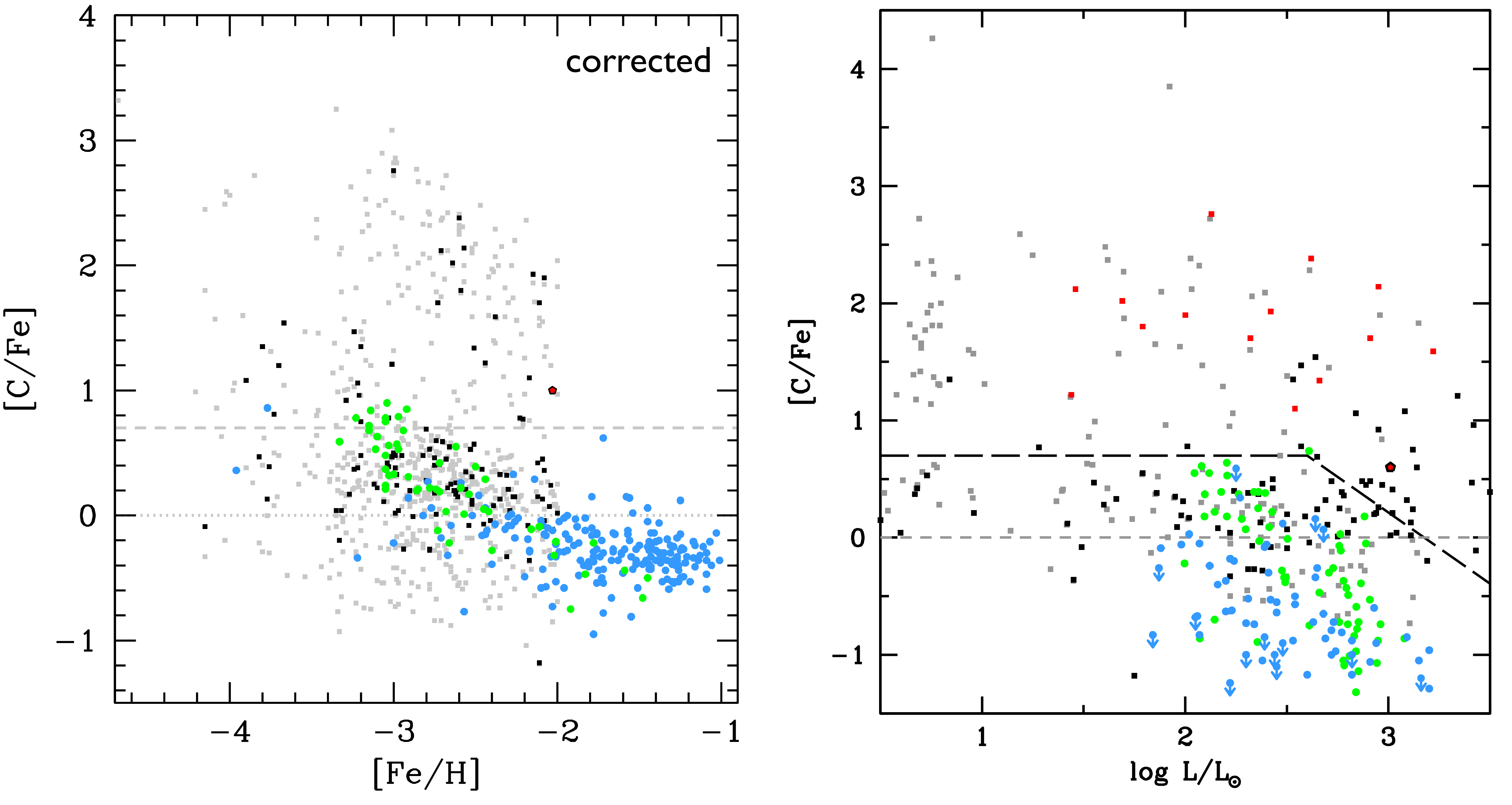


Chiti et al. 2018 ApJ

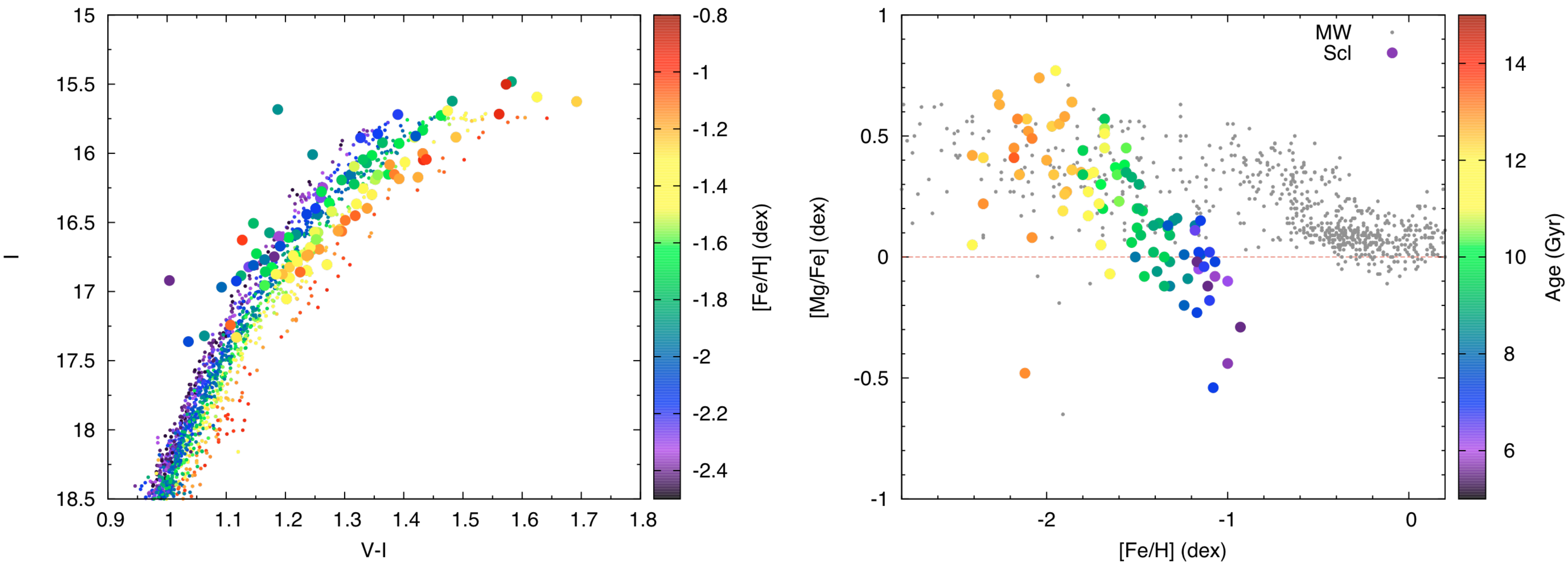
Scl CEMP stars

Chiti et al. 2018

Kirby et al. + Simon et al.; Jablonka et al.



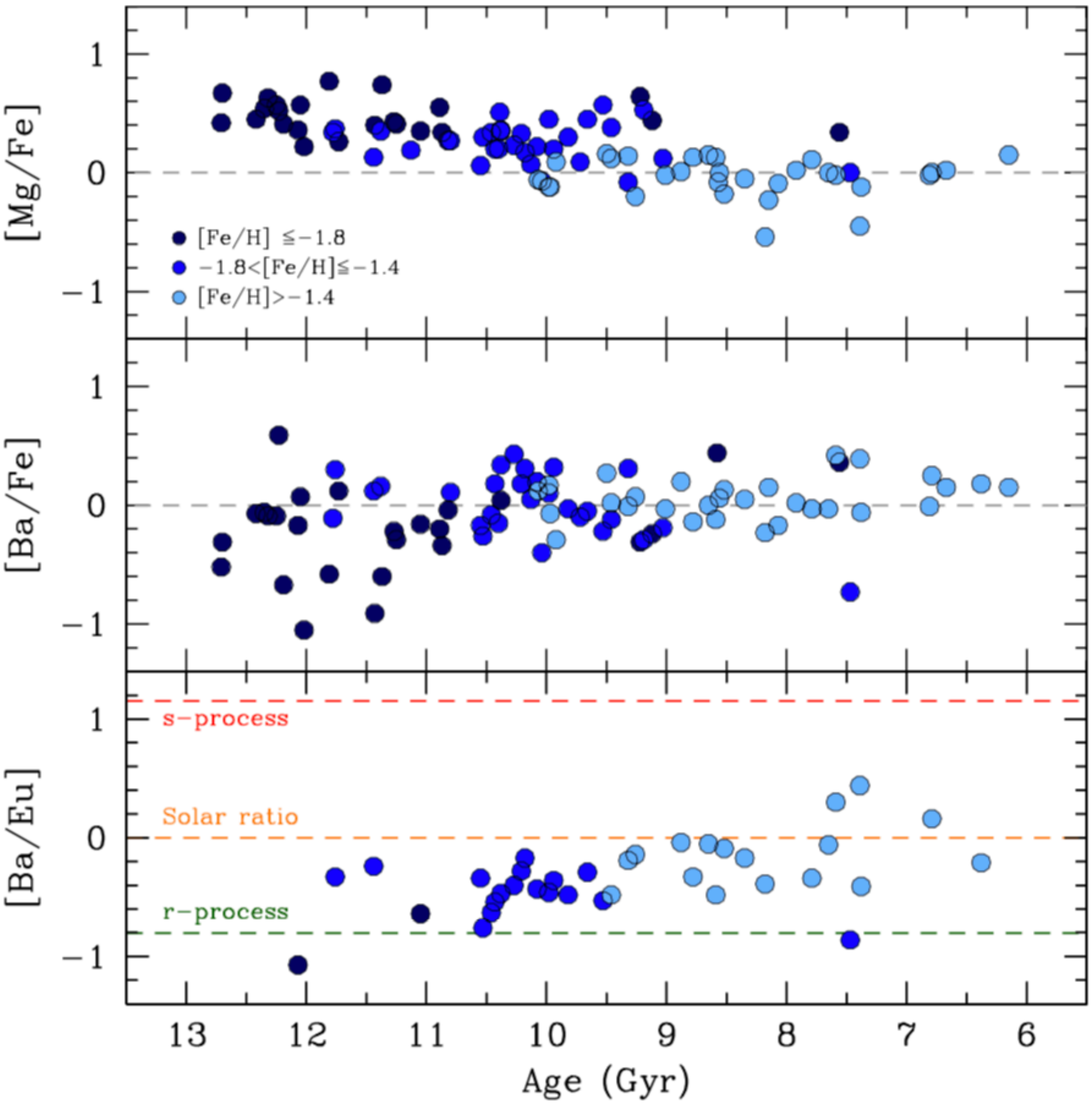
Measuring the Timescale for Chemical Evolution in Sculptor



SNIa start to contribute to the chemical enrichment of the Sculptor dSph galaxy 2±1 Gyr after star formation began

de Boer et al. 2012, A&A, 539, A103

Other elements with ages



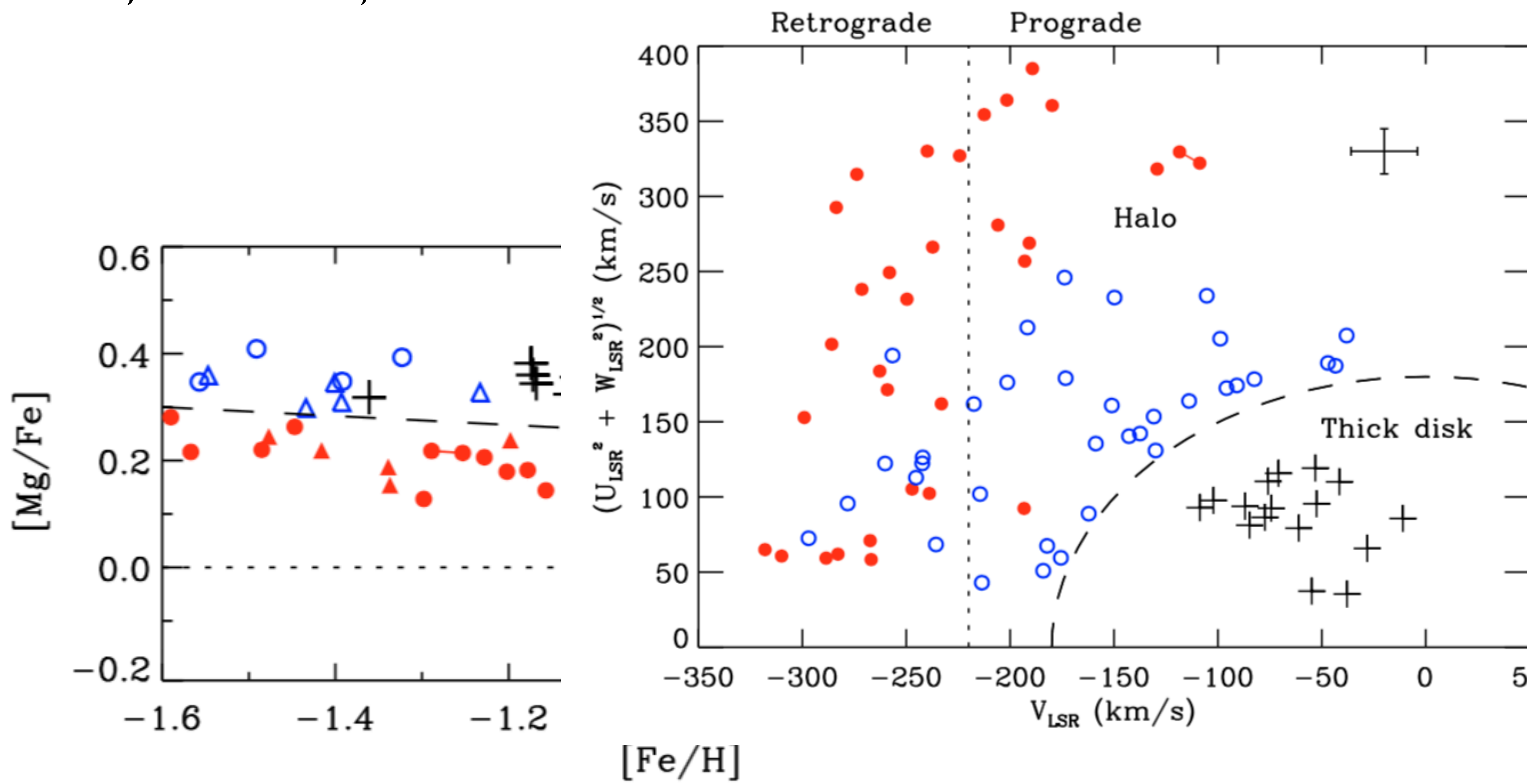
Hill, Skúladóttir et al. 2018 A&A, in press arXiv:1812.01486

Going back to Milky Way halo….

A dwarf galaxy in the Milky Way halo?

VLT/UVES: 4800–6800Å; R ≃ 55 000; S/N ~ 250–500.

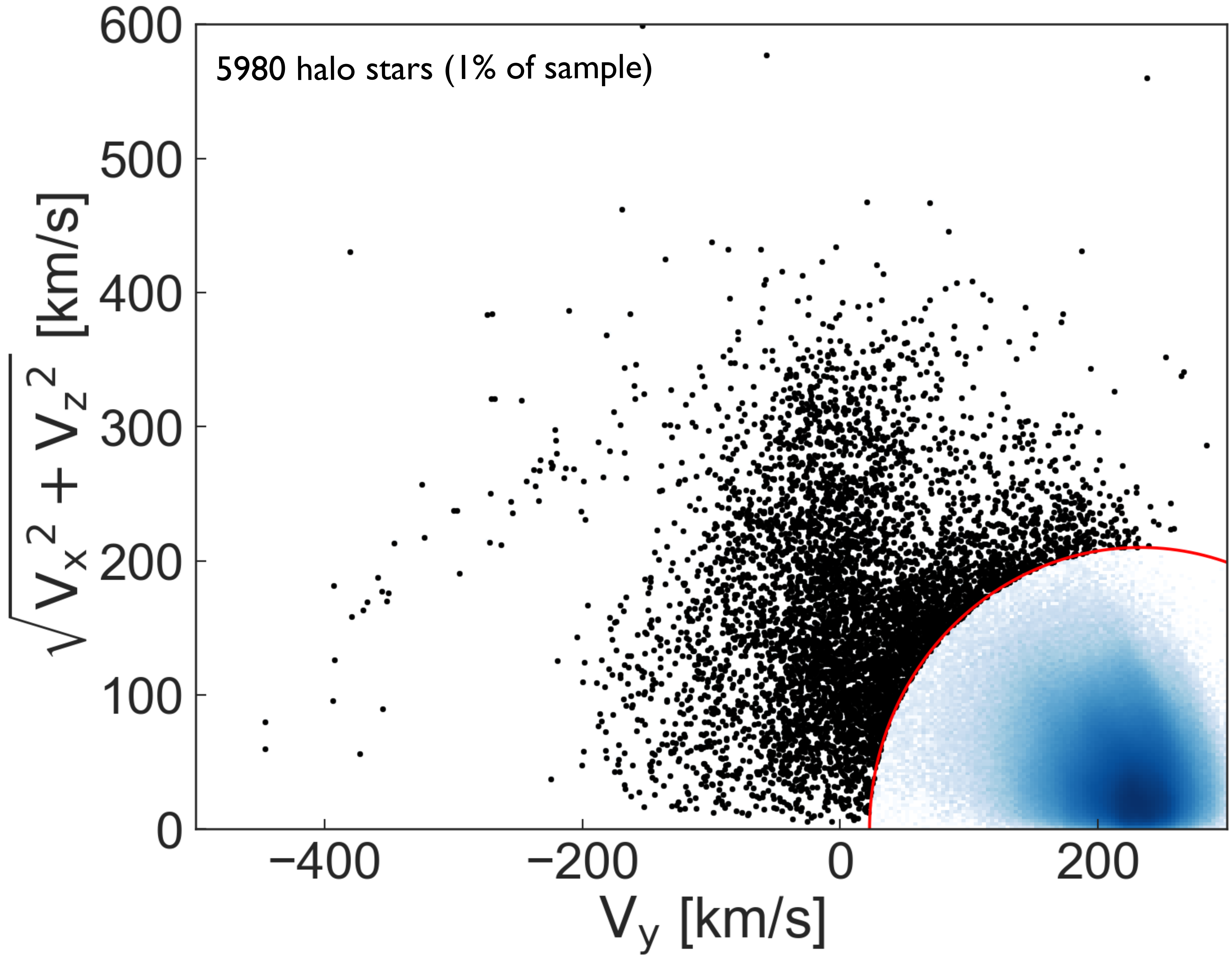
NOT/FIES: 4700–6400Å; R ≃ 40 000; S /N ~ 140–200.



Nissen & Schuster 2010 A&A

Halo stars near the Sun with Gaia DR2

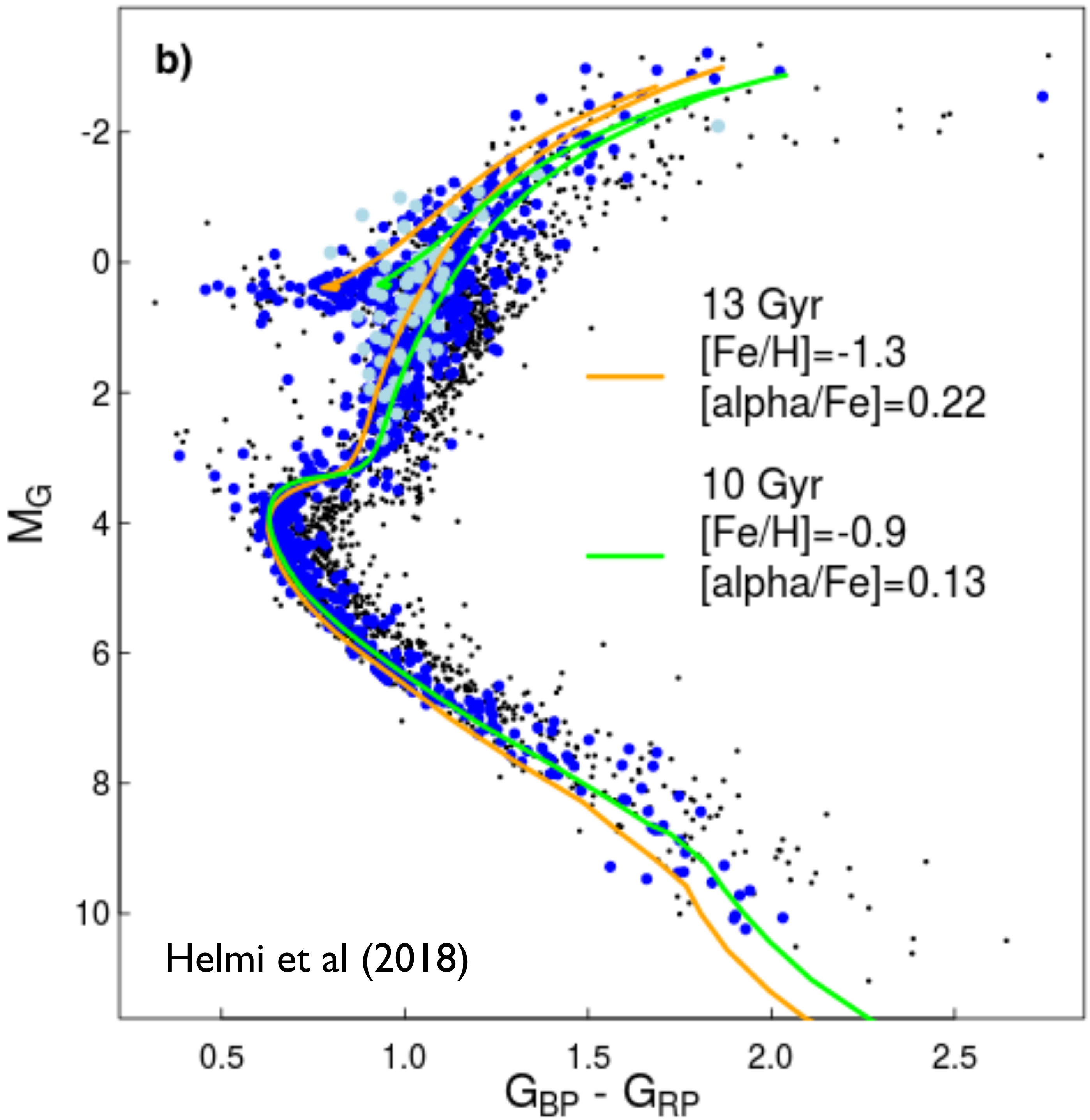
within 2.5kpc radius of Sun
<u>6 366 744 stars</u>. 6D sample

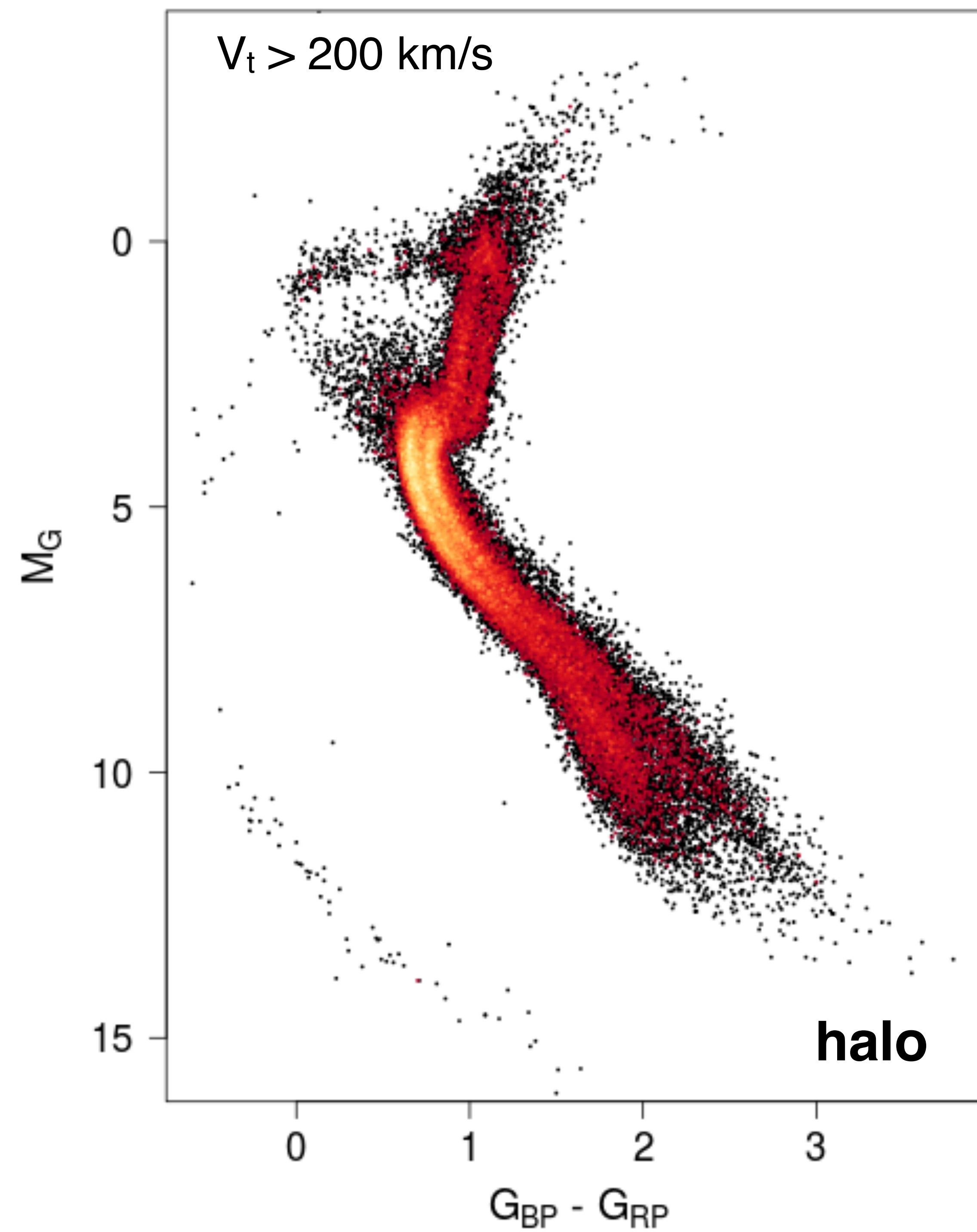


Koppelman, Helmi & Veljanoski (2018)

Colour-Magnitude Diagram

stars younger than thick disk

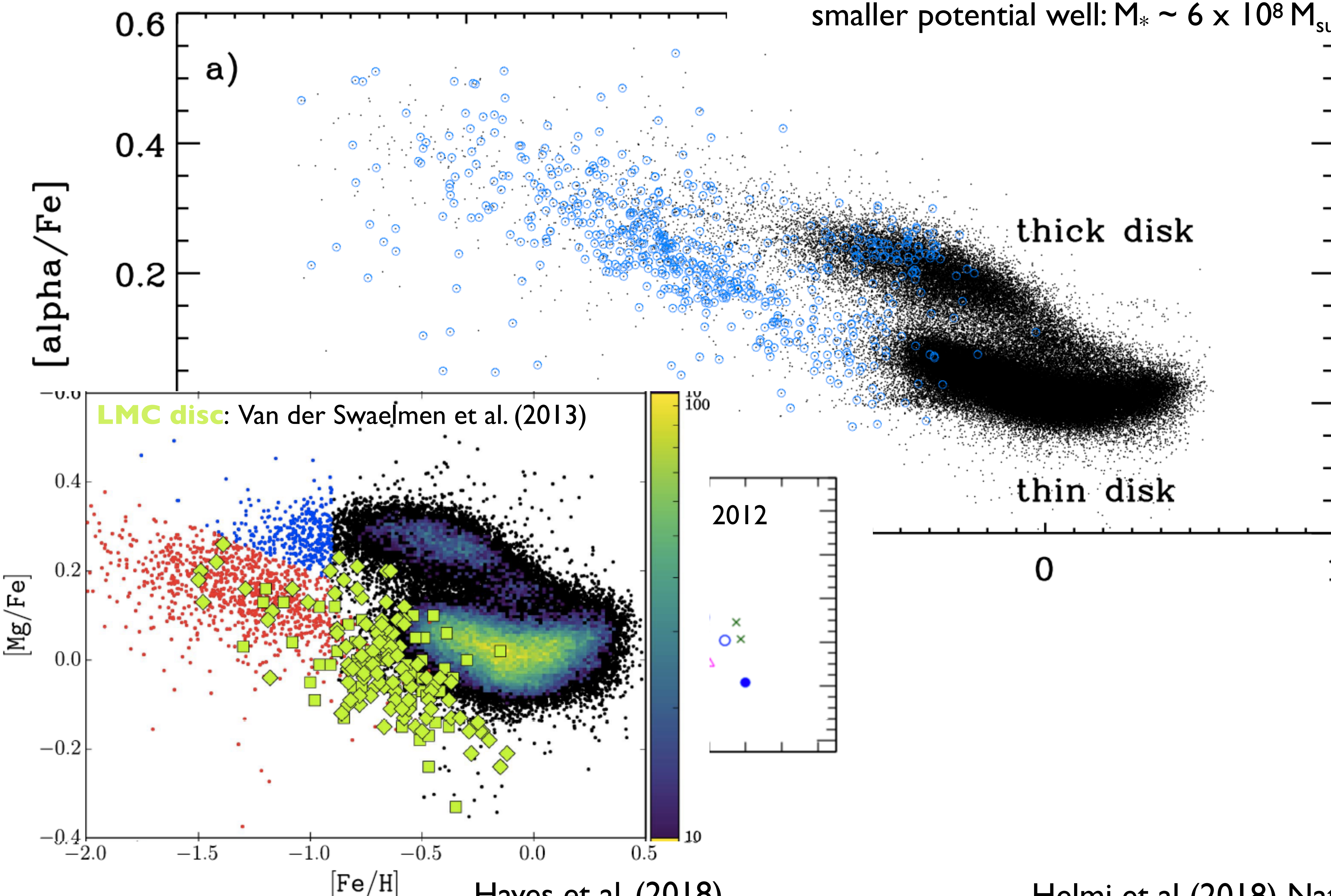




Gaia Collaboration (2018): Babusiaux, et al

Abundances from APOGEE

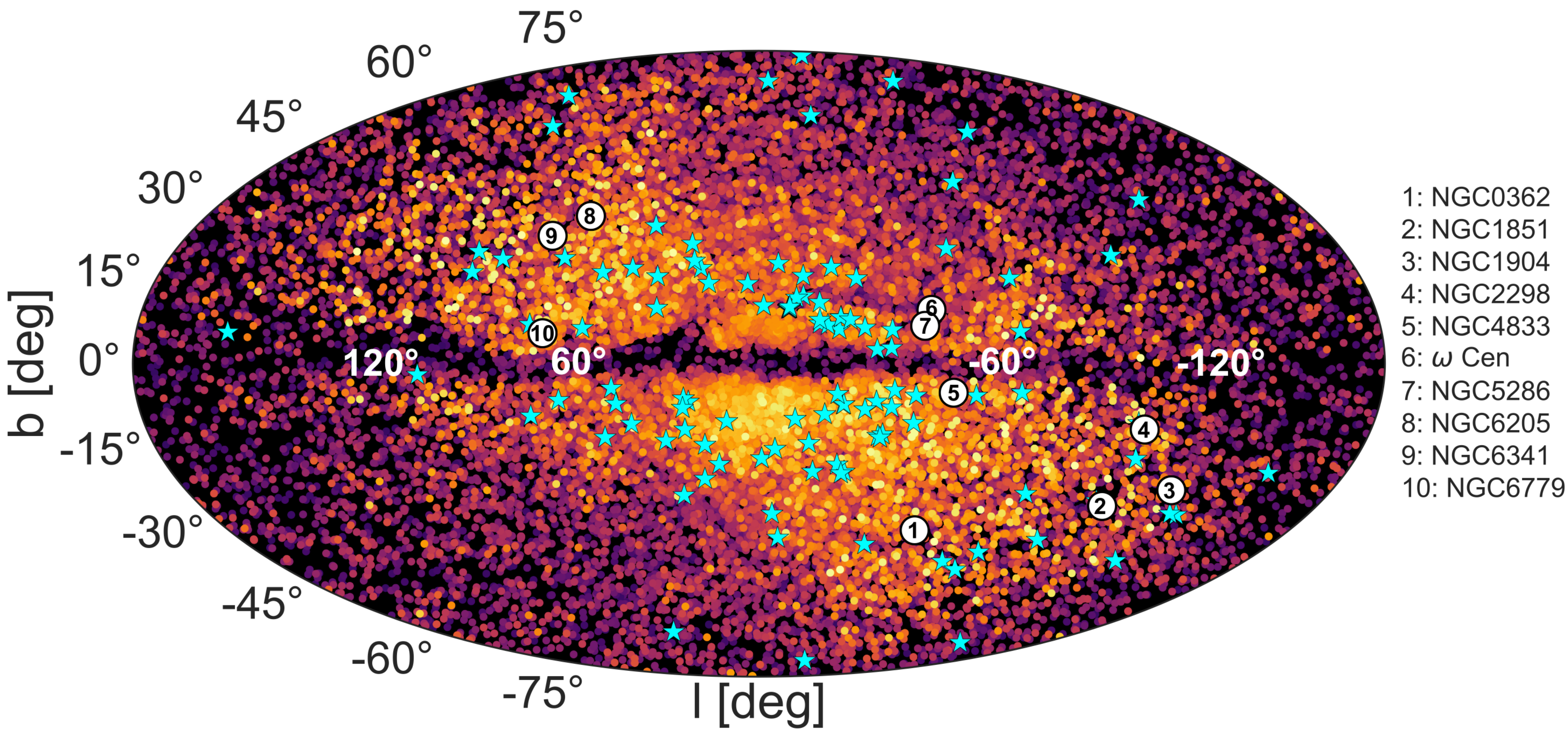
lower [alpha/Fe] at same [Fe/H] than thick disk
stars formed elsewhere with lower SFR
smaller potential well: $M_* \sim 6 \times 10^8\ M_{sun}$



Hayes et al. (2018)

Helmi et al (2018) Nature

Gaia-Enceladus



Debris across tens of thousands of sq degrees (no overlap with SDSS structures)

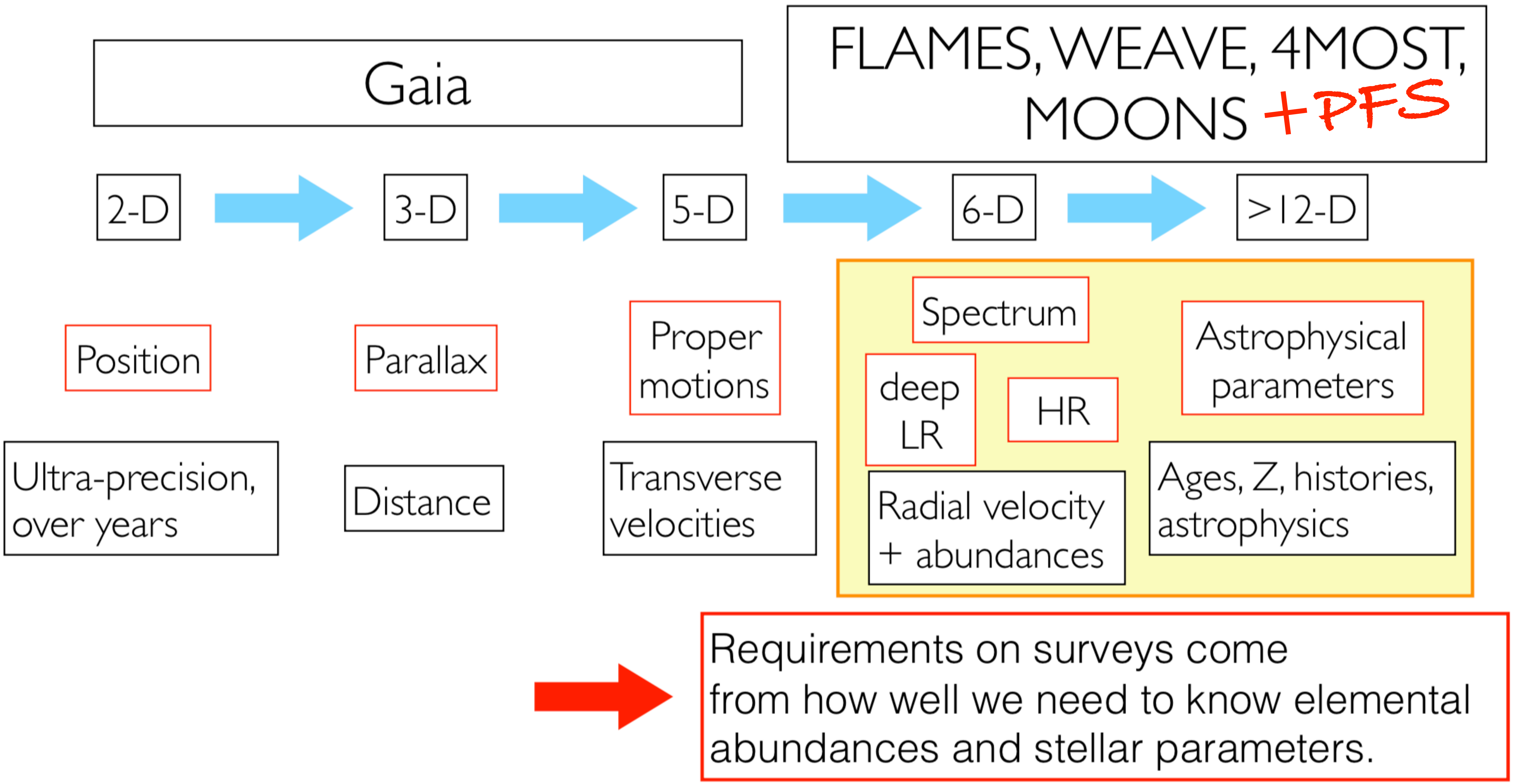
Ten globular clusters (with retrograde orbits) can be associated

follow a tight age-metallicity relation

Helmi et al (2018), Nature

Back to the future…

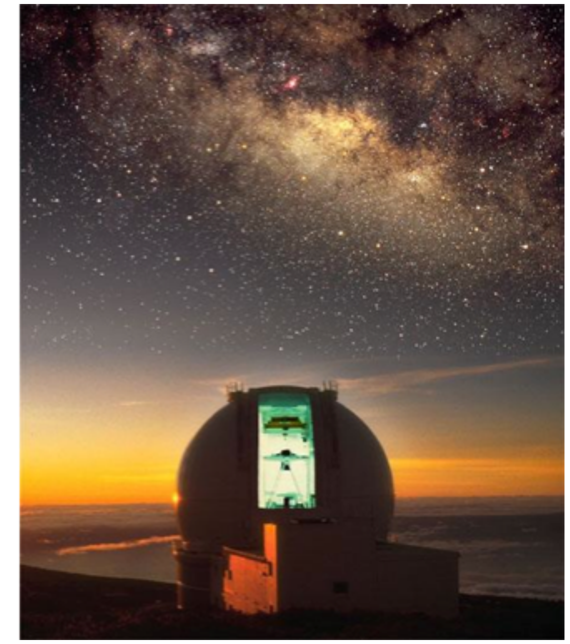
Importance of large spectroscopic surveys

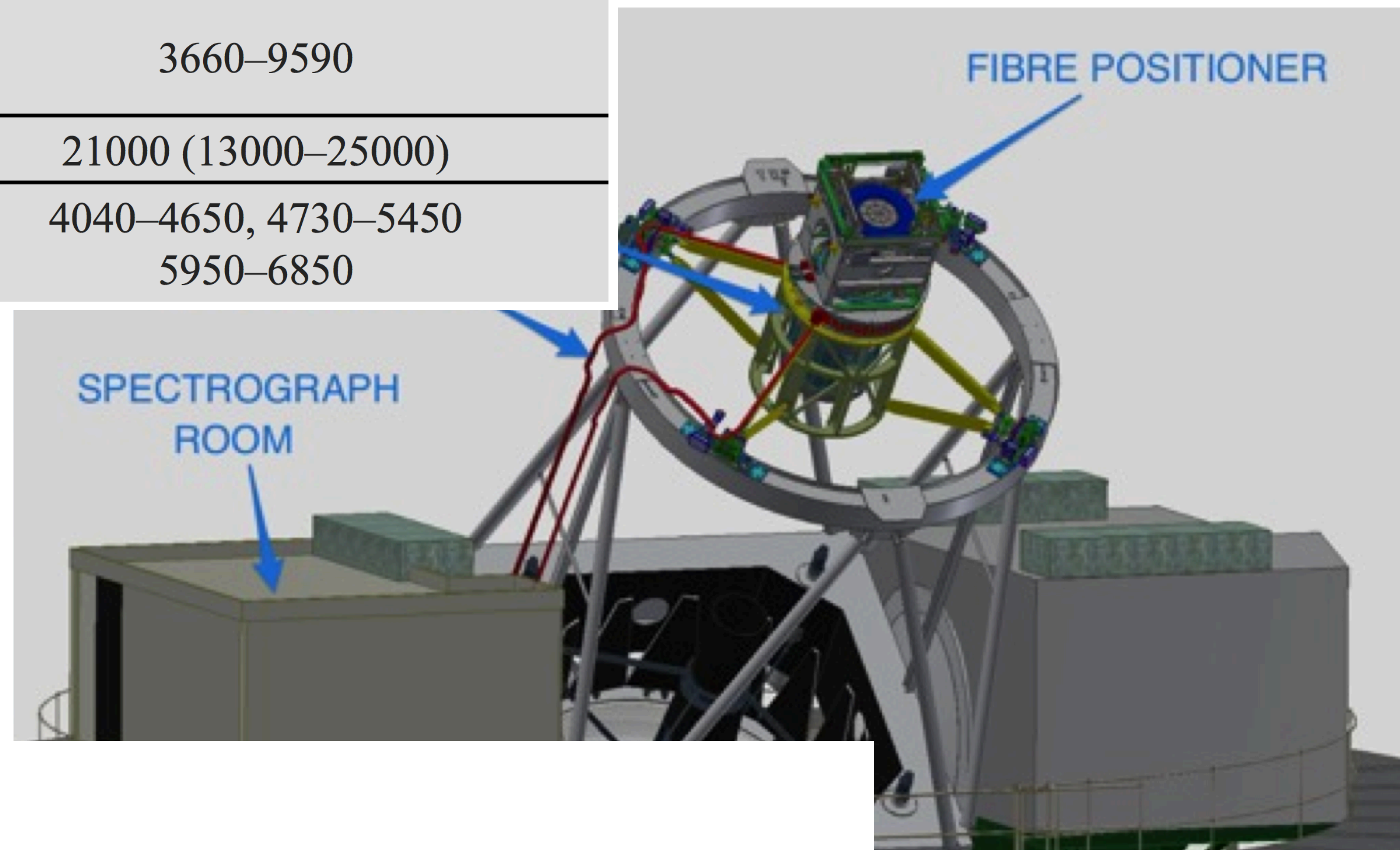


based on scheme in Gilmore et al. (2013)

The WEAVE facility @ WHT

Telescope, diameter	WHT, 4.2m
Field of view	2° ⌀
Number of fibers	960 (plate A)/940 (plate B)
Fiber size	1.3″
Number of small IFUs, size	20 x 11″x12″ (1.3″ spaxels)
LIFU size	1.3′x1.5′ (2.6″ spaxels)
Low-resolution mode resolution	5750 (3000–7500)
Low-resolution mode wavelength coverage (Å)	3660–9590
High-resolution mode resolution	21000 (13000–25000)
High-resolution mode wavelength coverage (Å)	4040–4650, 4730–5450 5950–6850

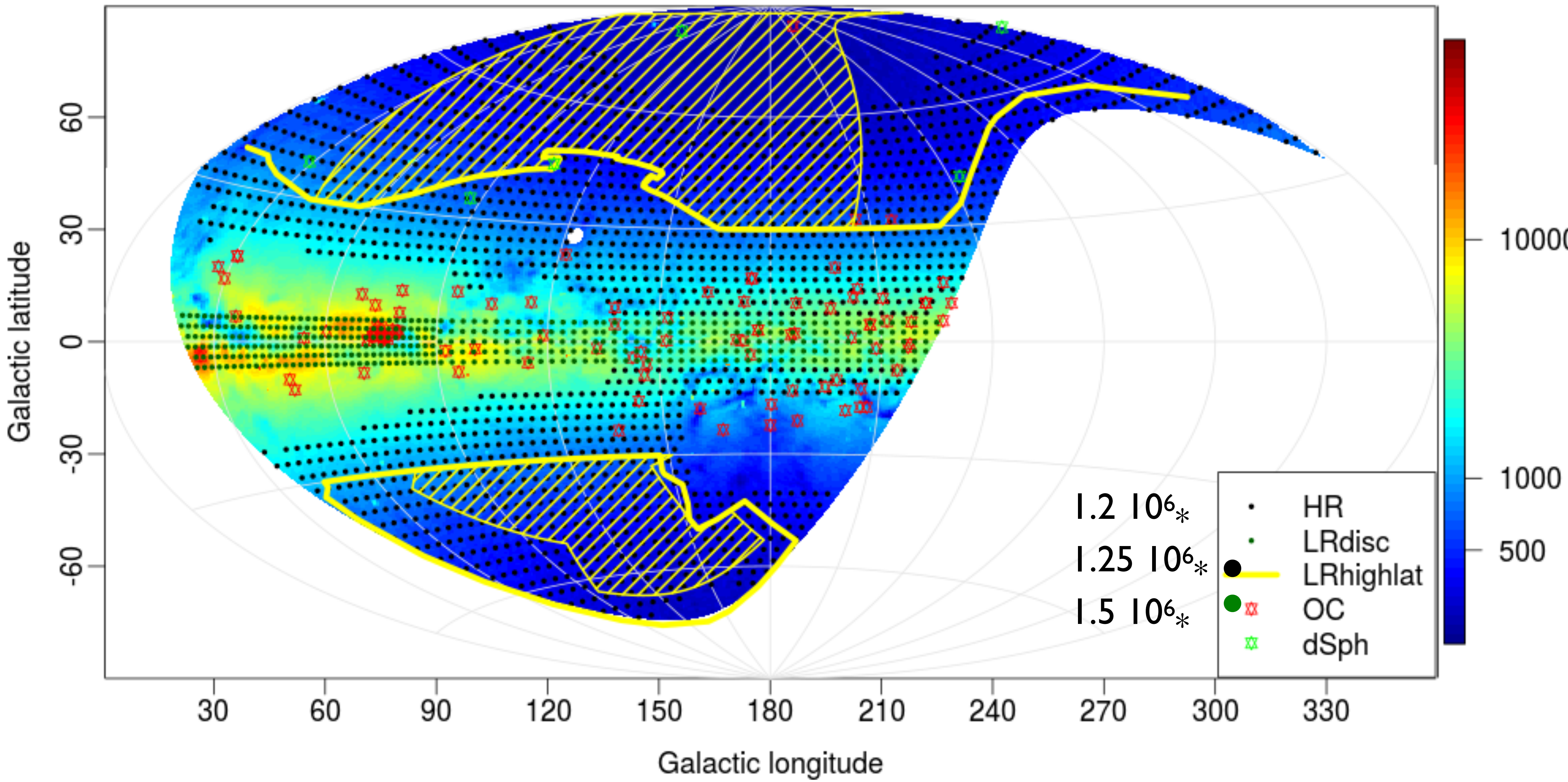




- First light Q4 2019
- Survey start Q1-Q2 2020, for 5 yrs at 70% of WHT time

om Vanessa Hill (adapted)

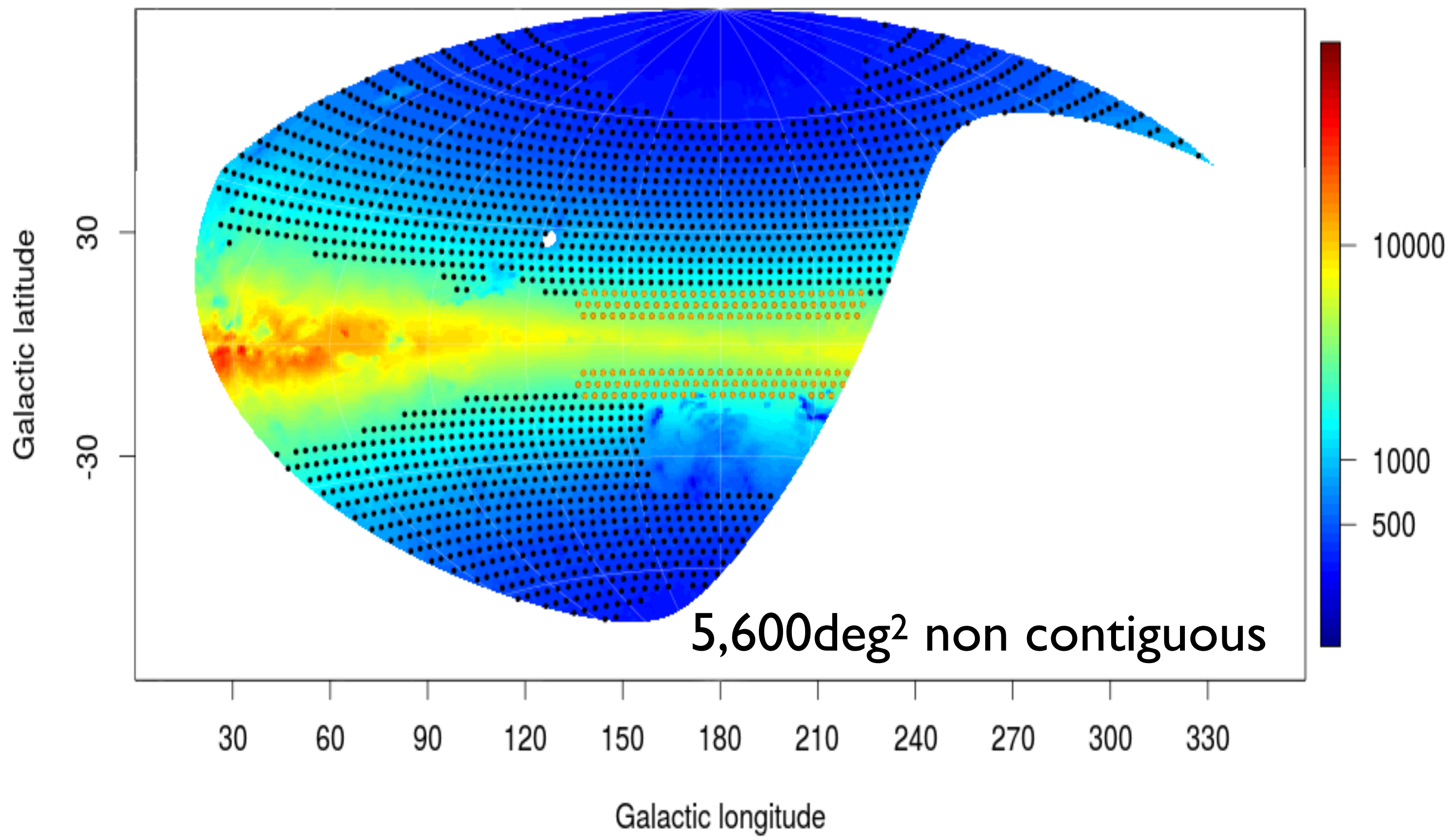
WEAVE-GA surveys at glance

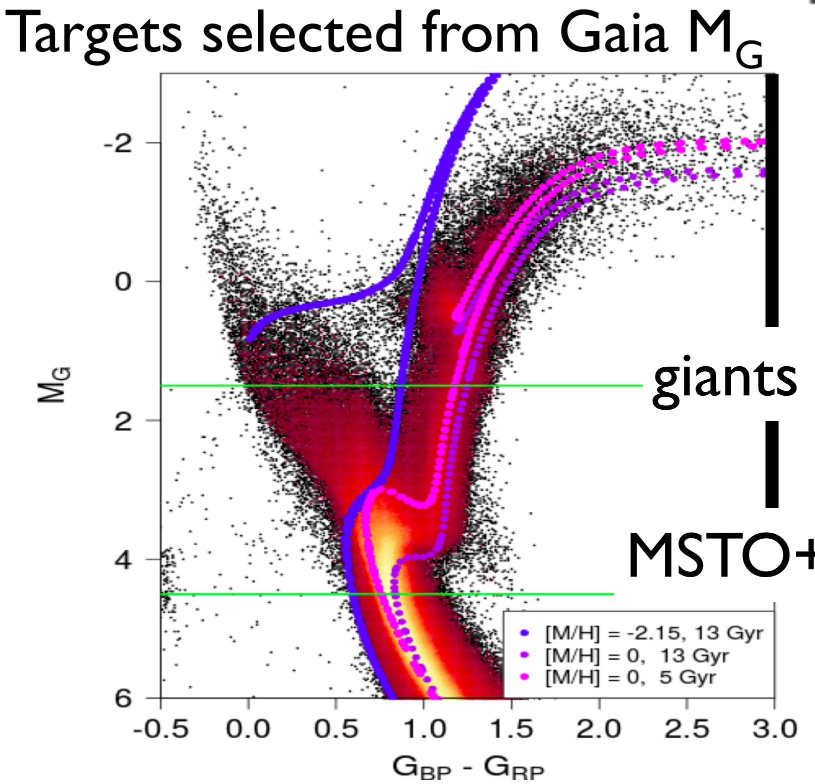


WEAVE ~4 million stars to unravel the MW history !

slide from Vanessa Hill

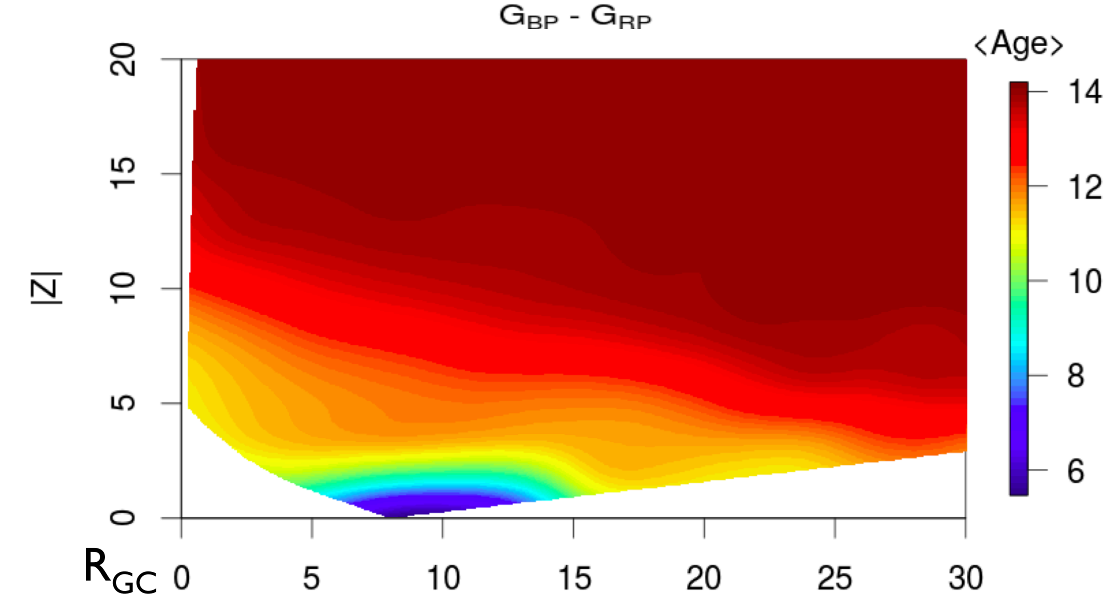
HR baseline survey

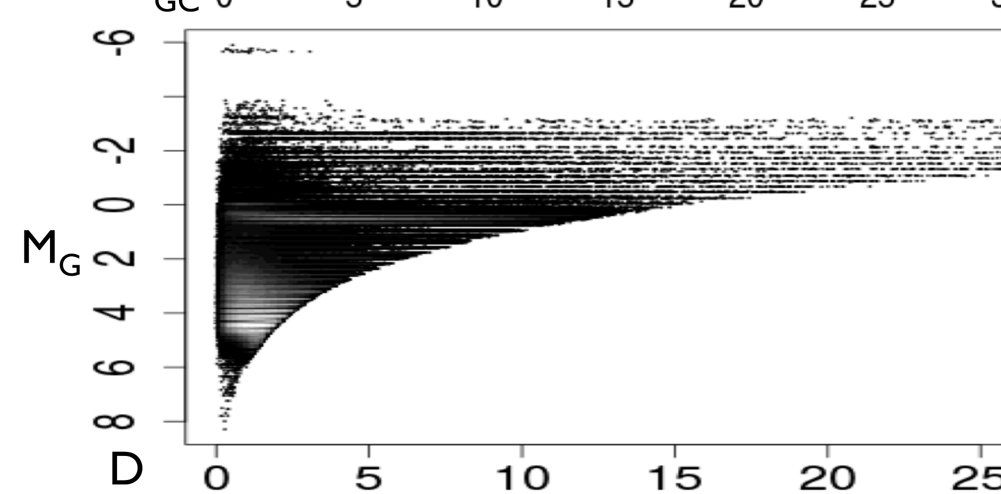




- $>10^6$ stars in Gaia's age sphere

Magnitude $2<M_G<4$	σ_π/π	Distance	%	Nb of stars
G < 16	9%	2 kpc	28%	500,000
G < 14	1%	0.8 kpc	11%	200,000





- $>2.10^5$ stars reaching out through the thick disc (giants)
- Incl. $>5.10^4$ halo giants

slide from Vanessa Hill

High latitude LR survey: baseline survey

Wide-area survey:

8500 deg², Down to r = 20-21

Tracers: MSTO and giants + BHB and EMP stars (from Pristine + JPLUS)

Halo:

~220,000 halo giants out to ~100kpc

~350,000 halo MSTO to ~30kpc

~40,000 BHB and EMP stars

Thick disc: ~6x10⁵ stars (MSTO)

Pointed survey:

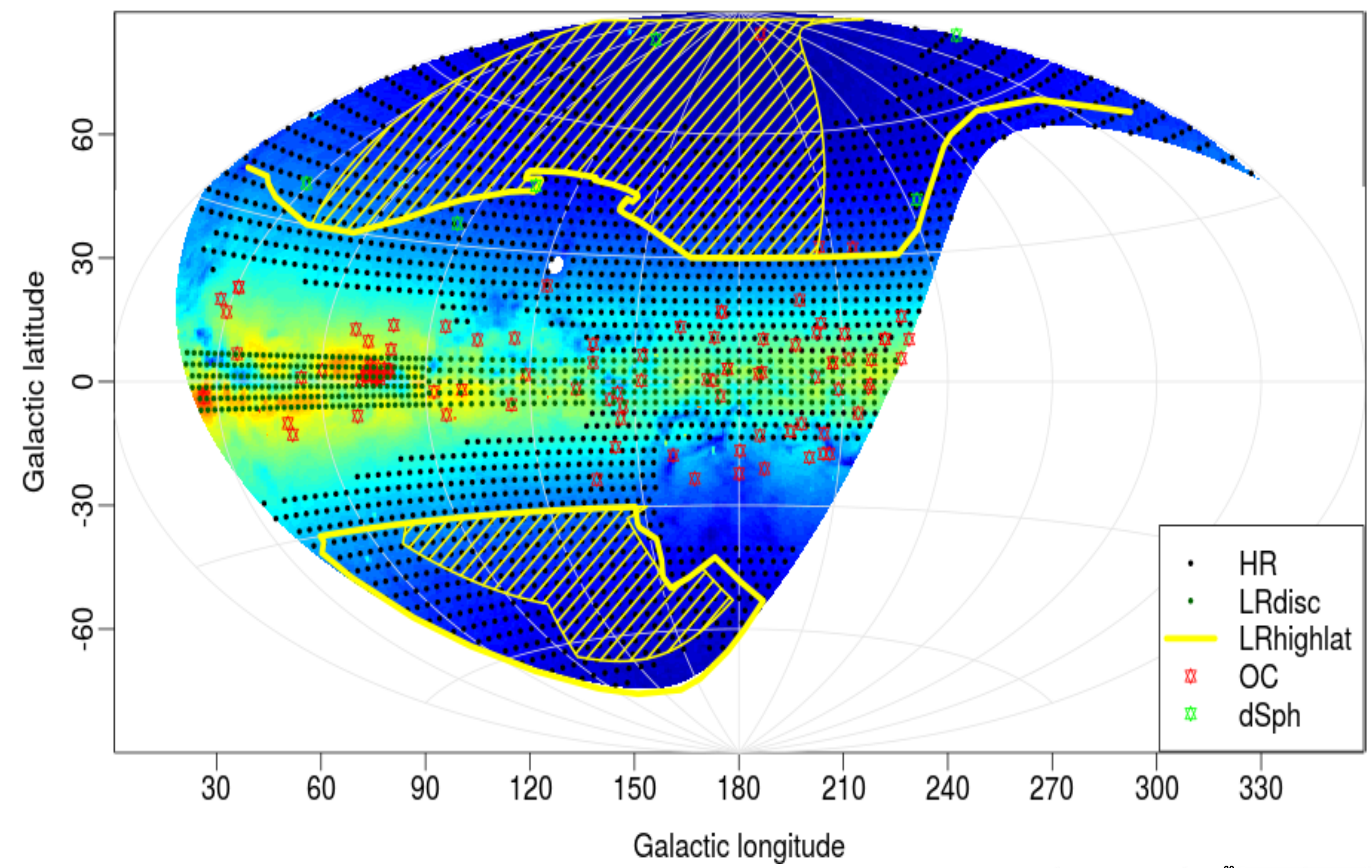
250 deg² with 4h/pointing

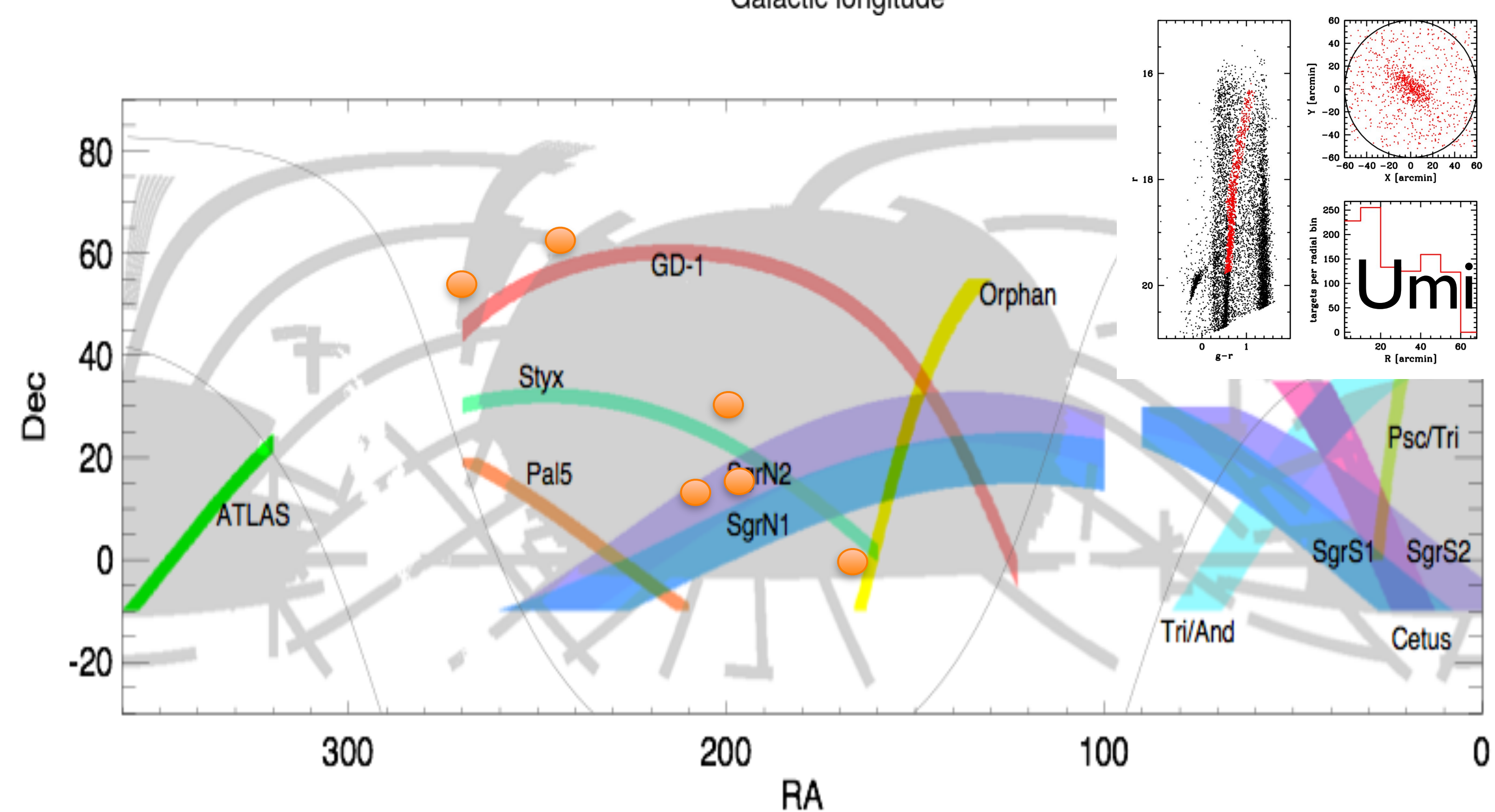
7 known streams and

6 dwarf galaxies

Down to r = 21

slide from Vanessa Hill





4MOST – 4m Multi-Object Spectroscopic Telescope

Wide-field highly multiplexed spectros

- 2.5 deg diameter FOV and 2400 fibers
- 2 LR and HR spectrographs
- High throughput/ high survey efficiency
- Start of operations in November 2022

Galactic Surveys:

Low Res MW halo (Helmi/

High Res MW halo (Christl

Low Res MW disk and bul

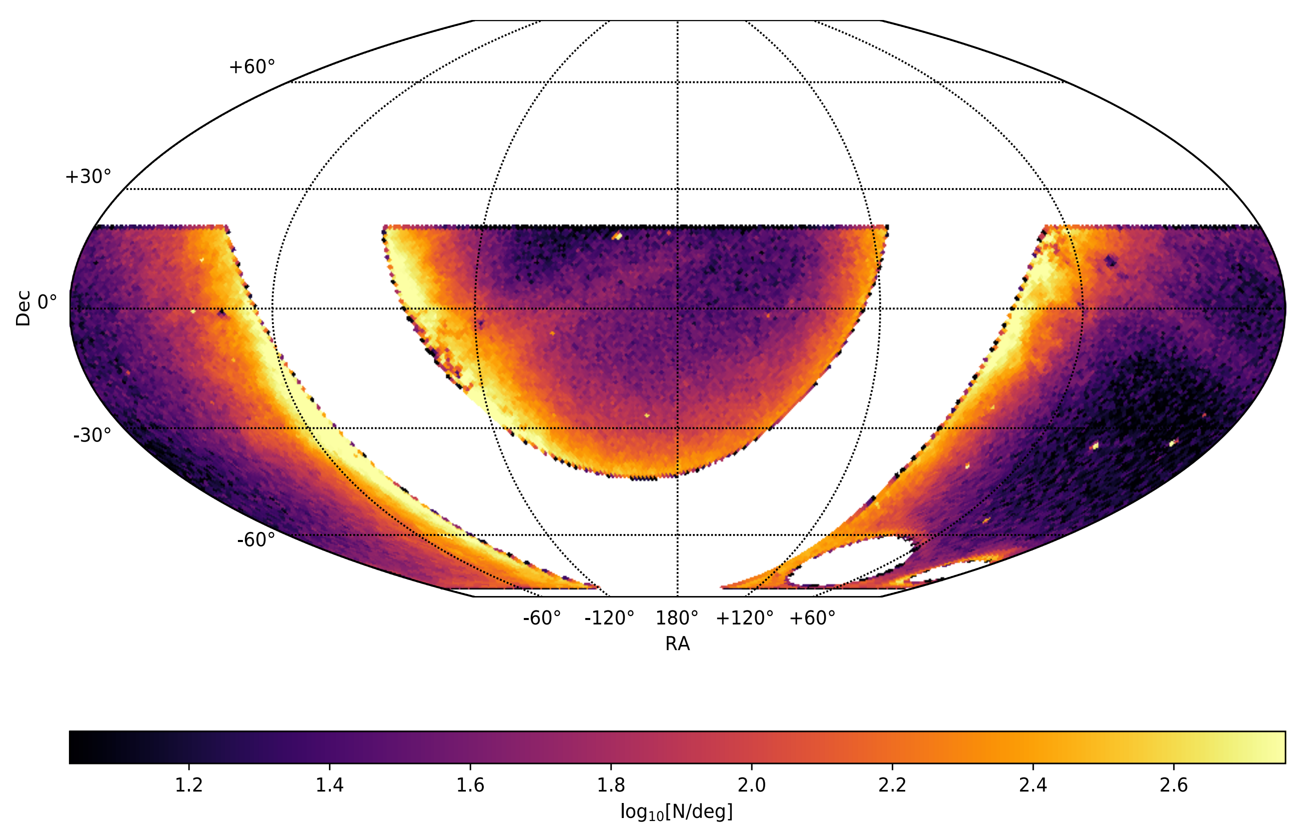
High Res MW disk and bul

Magellanic Clouds (M.R. C

Current LR halo footprint: every RGB star with G < 20 will be observed

•Radial Vel err ~ 1 – 2 km/s

•Fe/H and alpha/Fe ~ 0.1 – 0.2 dex



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NGC 5907 credit: R. Jay Gabany

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