4DWARFS: 4MOST survey of dwarf galaxies and their stellar streams

Ása Skúladóttir (PI)
University of Florence / INAF

4DWARFS

ESO Public Spectroscopic Survey Phase 1 LoI

4MOST survey of dwarf galaxies and their stellar streams (4DWARFS): Small but fundamental

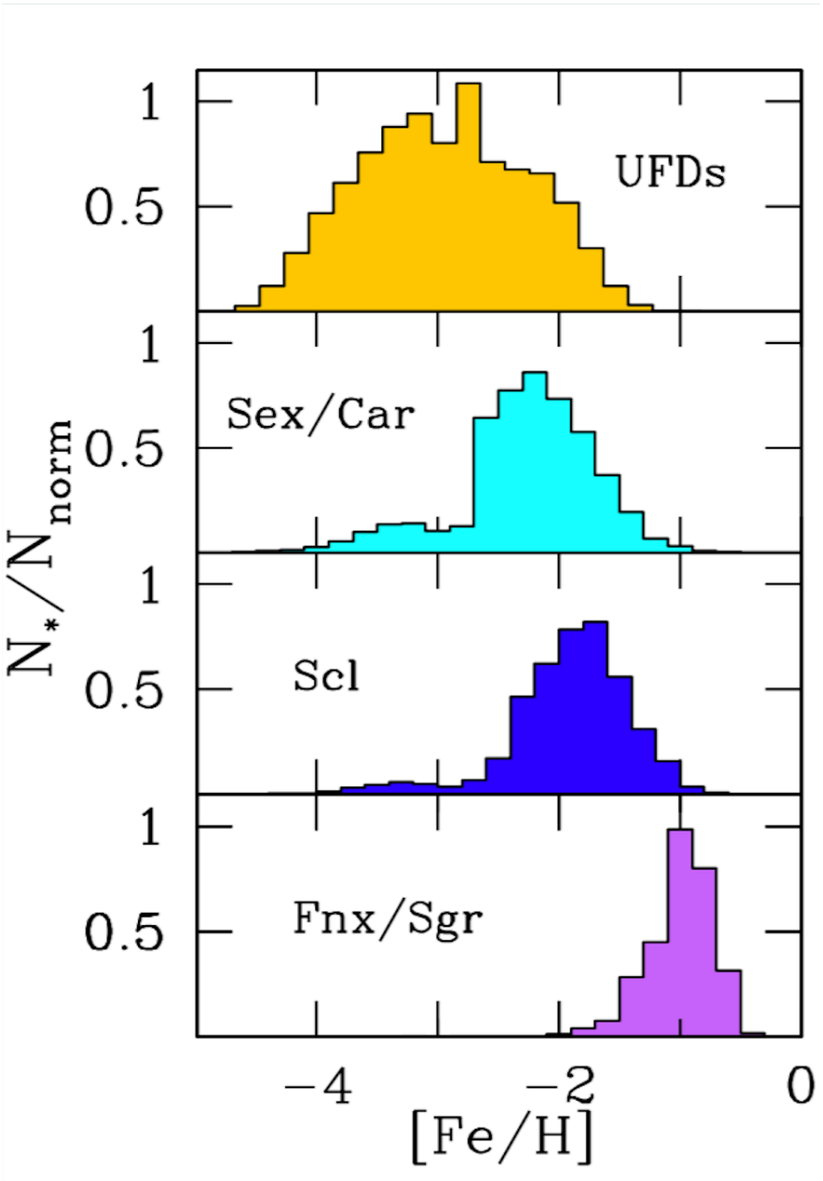
PI: Ása Skúladóttir [1,2] e-mail: asa.skuladottir@unifi.it

Cols: Anish M. Amarsi [3], Almudena Arcones [4,5], Giuseppina Battaglia [6,7], Sven Buder [8], Benoit Côté [9], Simon W. Campbell [10], Marius Eichler [4], Diane Feuillet [11], Andrew J. Gallagher [12], Viola Gelli [1,2], Melanie Hampel [10], Michael Hanke [13], Camilla J. Hansen [12], Sten Hasselquist [14,15], Vanessa Hill [16], Rodrigo Ibata [17], Nikolay Kacharov [12], Amanda Karakas [10], Andreas Koch [13], Karin Lind [18], Maria Lugaro [9], Davide Massari [19,20,21], Thomas Nordlander [8,22], Moritz Reichert [4], Martina Rossi [1,2], Ashley Ruiter [23], Stefania Salvadori [1,2], Ivo Seitenzahl [23], Eline Tolstoy [21], Theodora Xilaki-Dornbusch [24].

Survey planning and execution: Davide Massari (dPI), Eline Tolstoy (dPI)
3D/NLTE spectroscopy: Anish M. Amarsi (dPI)
Stellar ages & chemical clocks: Diane Feuillet (dPI)
Chemodynamics: Giuseppina Battaglia (dPI)
Stellar streams: Rodrigo Ibata (dPI)
First stars: Stefania Salvadori (dPI)
Supernovae type Ia: Ashley Ruiter (dPI), Ivo Seitenzahl (dPI)
Heavy elements: Camilla J. Hansen (dPI)

Motivation:
The Science

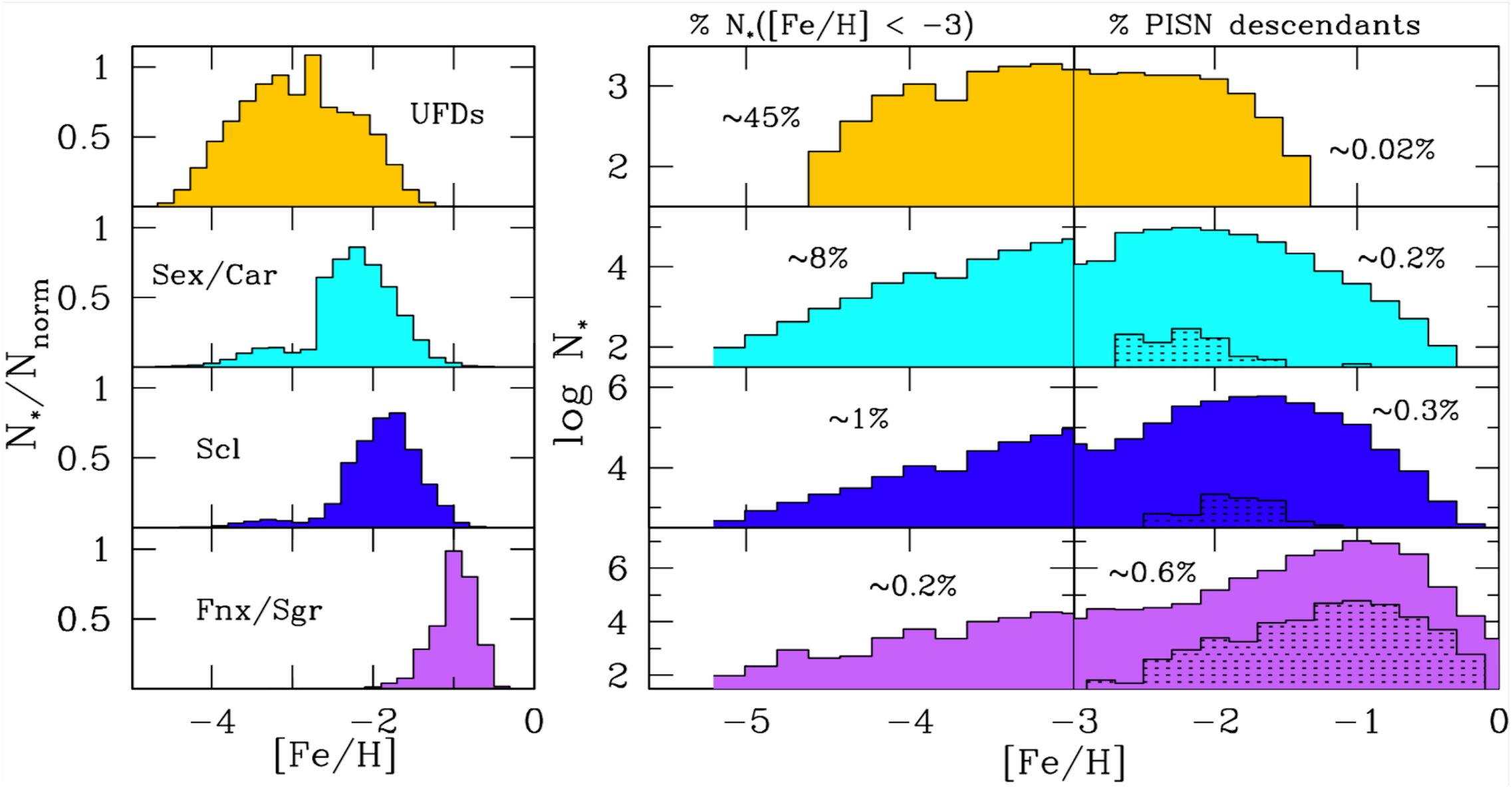
(I) ORIGIN



- Dwarf galaxies are intrinsically metal-poor.
- Ideal laboratories to study yields of the first zero-metallicity stars
- Detailed comparison between surveys will reveal how much dwarf galaxies of different sizes have contributed to the metal-poor halo, [Fe/H]<-2

Salvadori et al. 2015, 2019

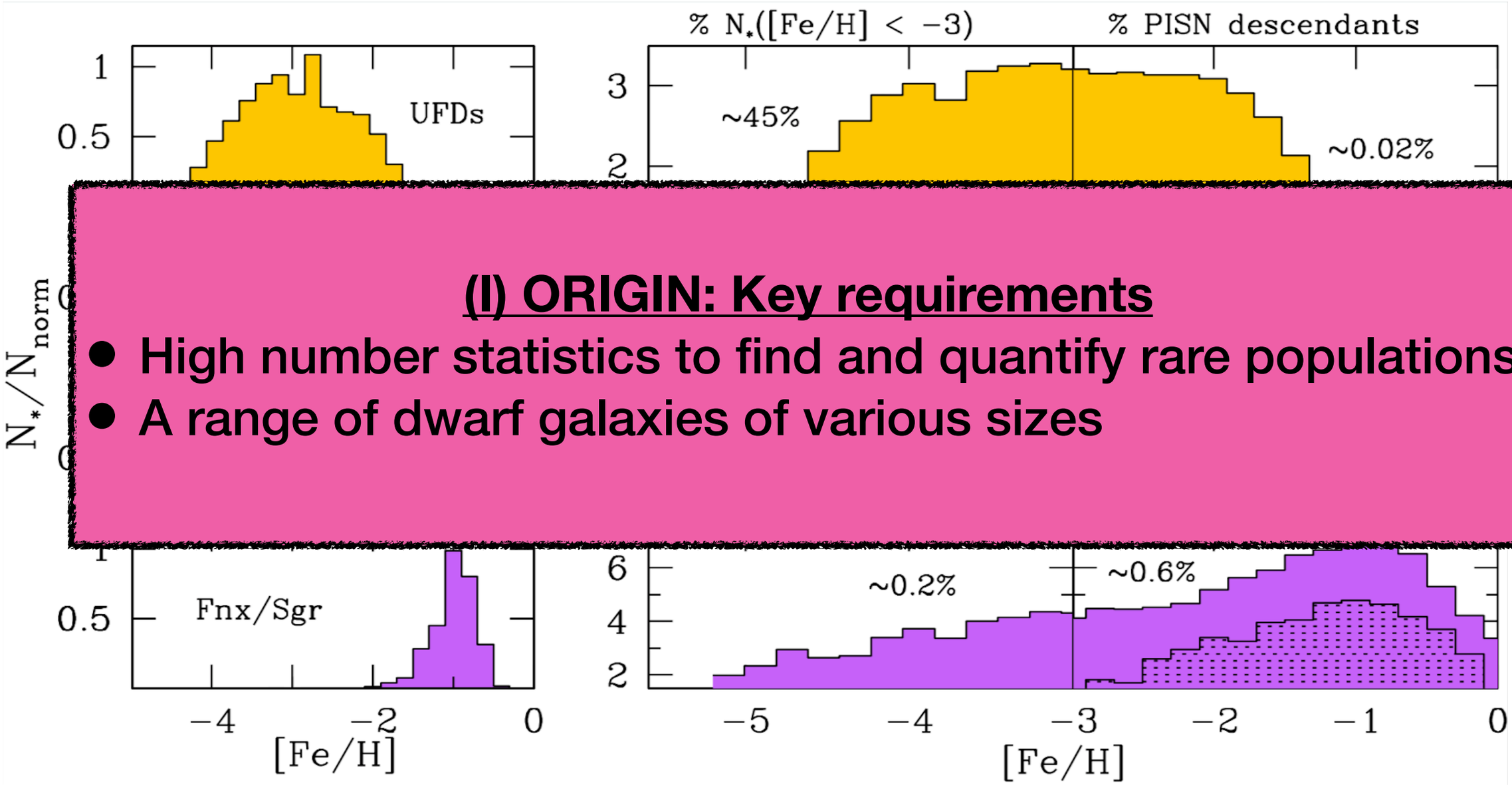
(I) ORIGIN



- 4DWARFS will quantify the fraction of stars that were born from material produced by zero-metallicity, massive (>150 $M_\odot$), pair instability supernovae (PISN).

Salvadori et al. 2015, 2019

(I) ORIGIN



(I) ORIGIN: Key requirements

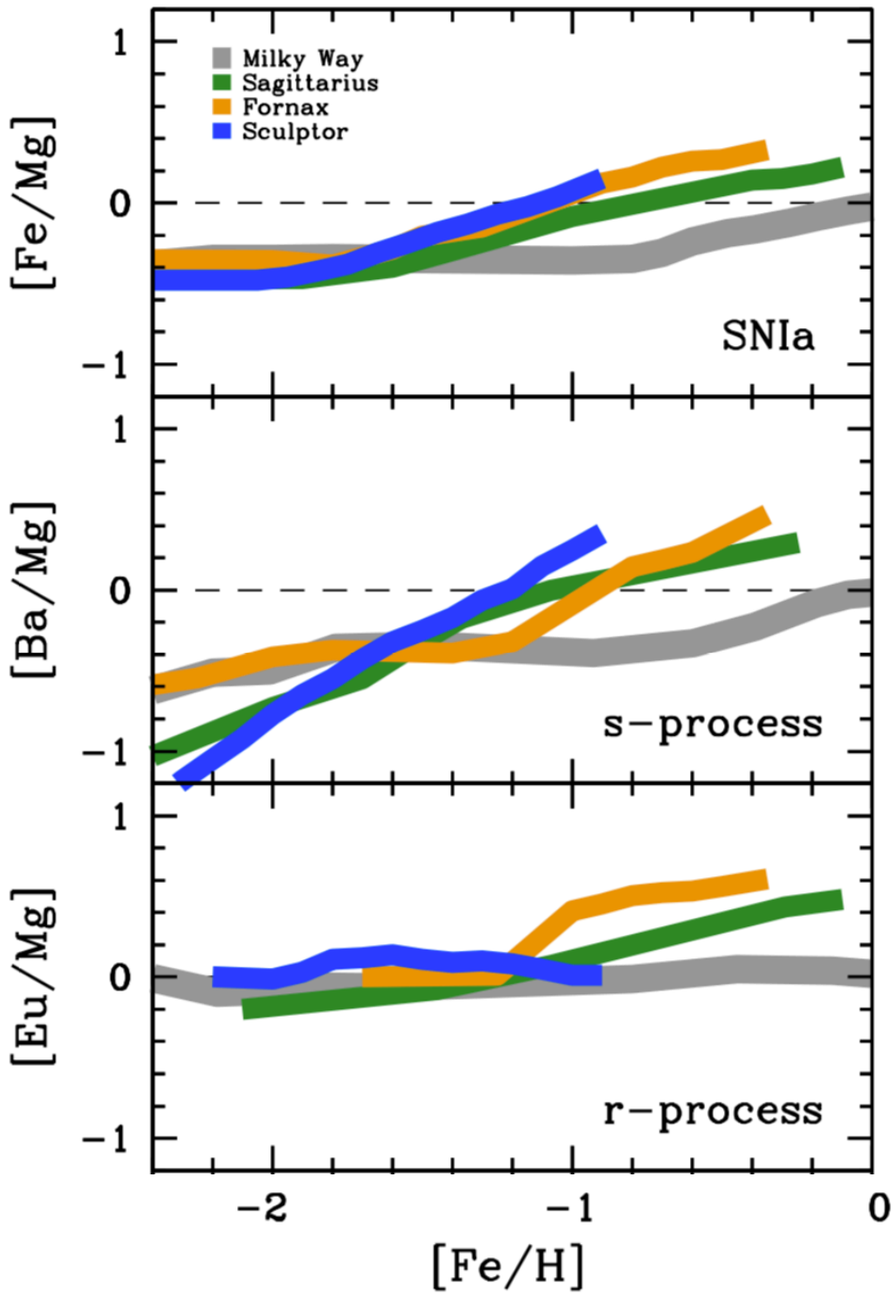
- High number statistics to find and quantify rare populations
- A range of dwarf galaxies of various sizes

- 4DWARFS will quantify the fraction of stars that were born from material produced by zero-metallicity, massive (>150 M⊙), pair instability supernovae (PISN).

Salvadori et al. 2015, 2019

(II) EVOLUTION

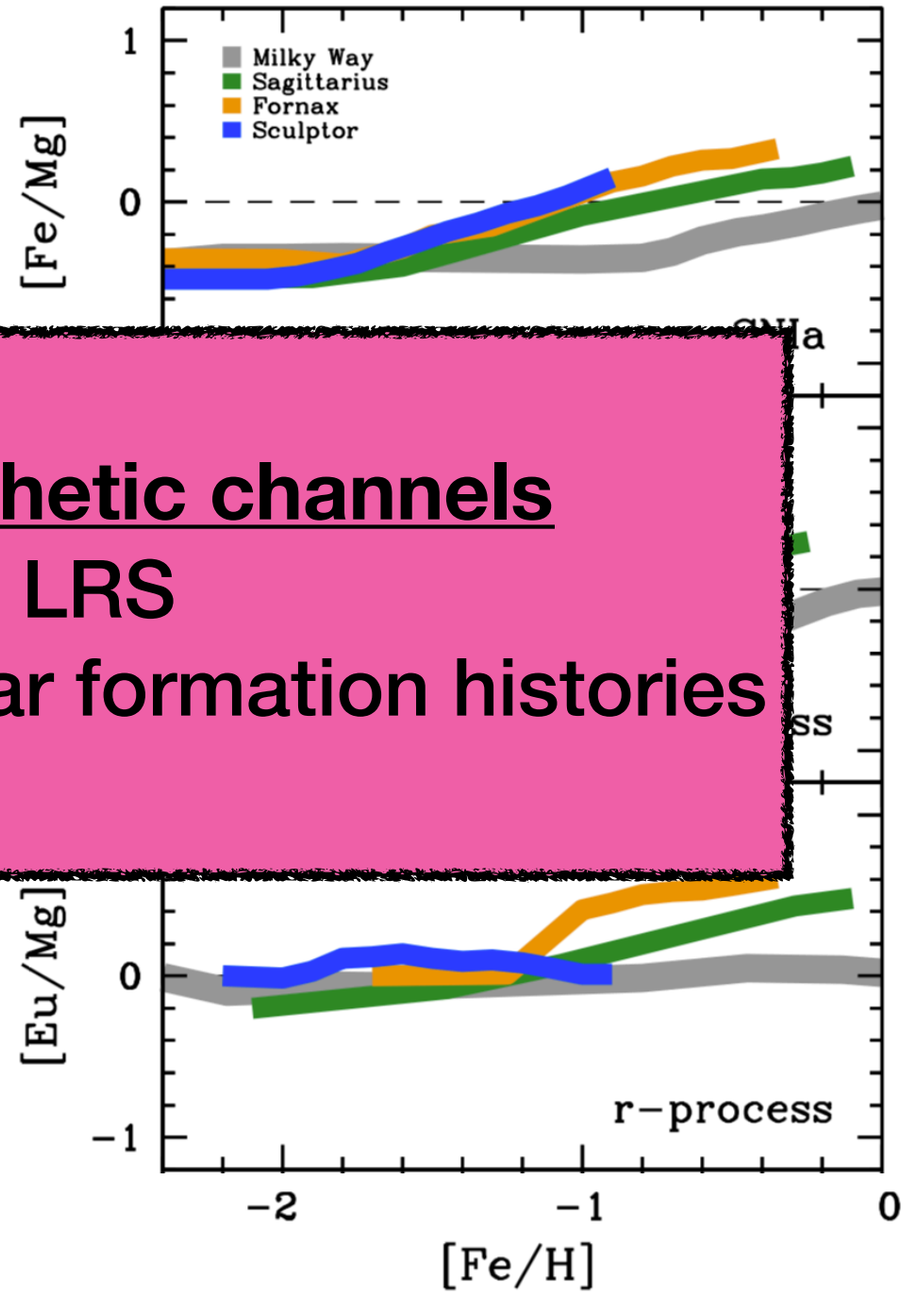
- The effects of delayed nucleosynthetic channels are especially prominent in dwarf galaxies
- 4DWARFS will constrain the fundamental physics of nucleosynthesis, i.e. measure yields, metallicity dependence and time-delay distributions.
- Especially important for the r-process, where Sagittarius and Fornax show a unique enhancement
- Highly complimentary to the Consortium Galactic HR surveys & S10 TiDES



Skúladóttir & Salvadori 2020

(II) EVOLUTION

- The effects of delayed nucleosynthetic channels are especially prominent in dwarf galaxies
- 4
p
y
c
- E
v
unique enhancement
- Highly complimentary to the Consortium Galactic HR surveys & S10 TiDES



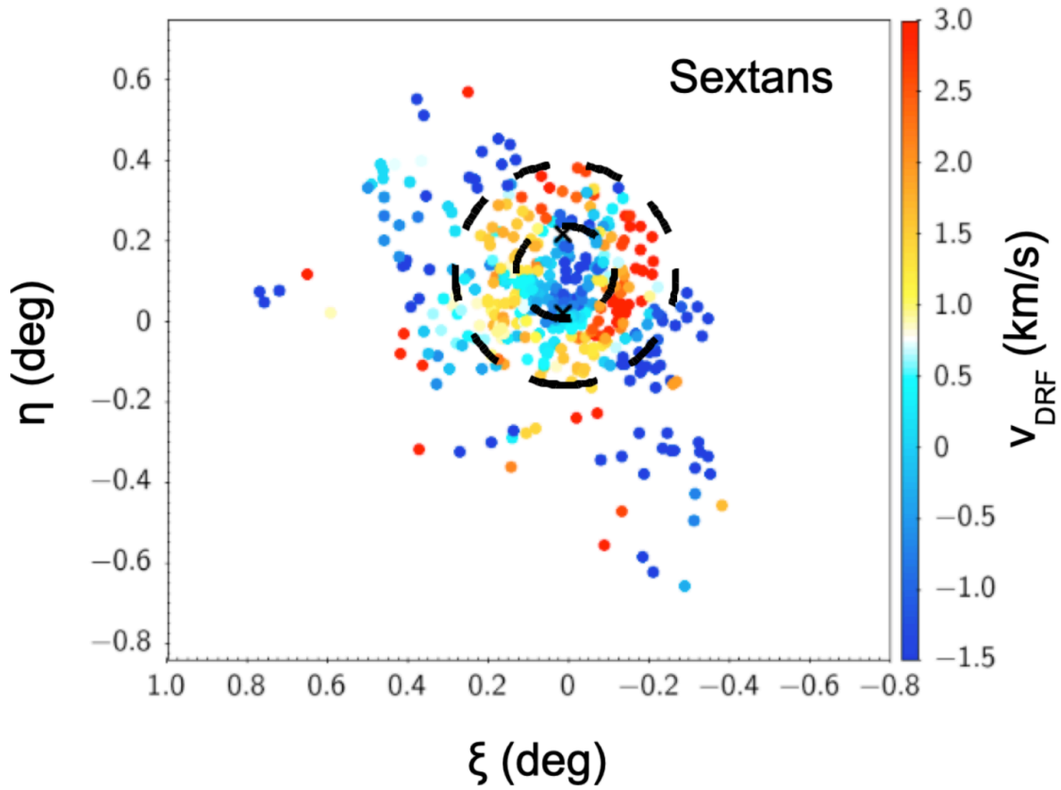
(I) EVOLUTION: Nucleosynthetic channels

- High S/N spectra with HRS and LRS
- Dwarf galaxies with different star formation histories

(III) GLOBAL PICTURE

Dwarf galaxies are key for the study of the hierarchical galaxy formation

- 4DWARFS will quantify the number of mergers happening in dwarf galaxies of various sizes
- 4DWARFS will be vital to quantify how much dwarf galaxies (and of which sizes) have contributed to the build-up of the Milky Way
- High-precision radial velocities, chemical abundances and age estimates will allow us to fully characterise the disruption of Sagittarius and its influence on the Milky Way.
- Reveal the structure of dark-matter in these dark-matter-dominated systems
- Highly complementary to all other Galactic 4MOST surveys



Cicuendez & Battaglia 2018

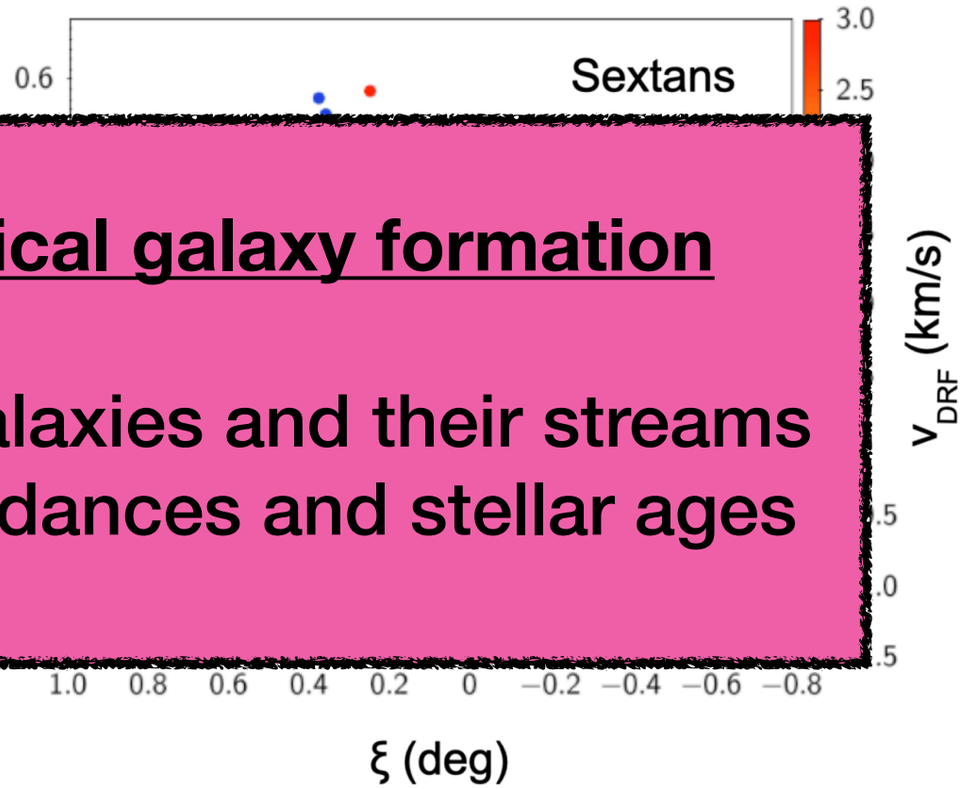
(III) GLOBAL PICTURE

Dwarf galaxies are key for the study of the hierarchical galaxy formation

- 4DWARFS will quantify the number of mergers happening in dwarf galaxies of various sizes
- 4DW
  dwar
  contr
- High-
  abun
  to ful
  Sagit
  Way.
- Reveal the structure of dark-matter in these dark-matter-dominated systems
- Highly complementary to all other Galactic 4MOST surveys

(I) GLOBAL PICTURE: Hirarchical galaxy formation

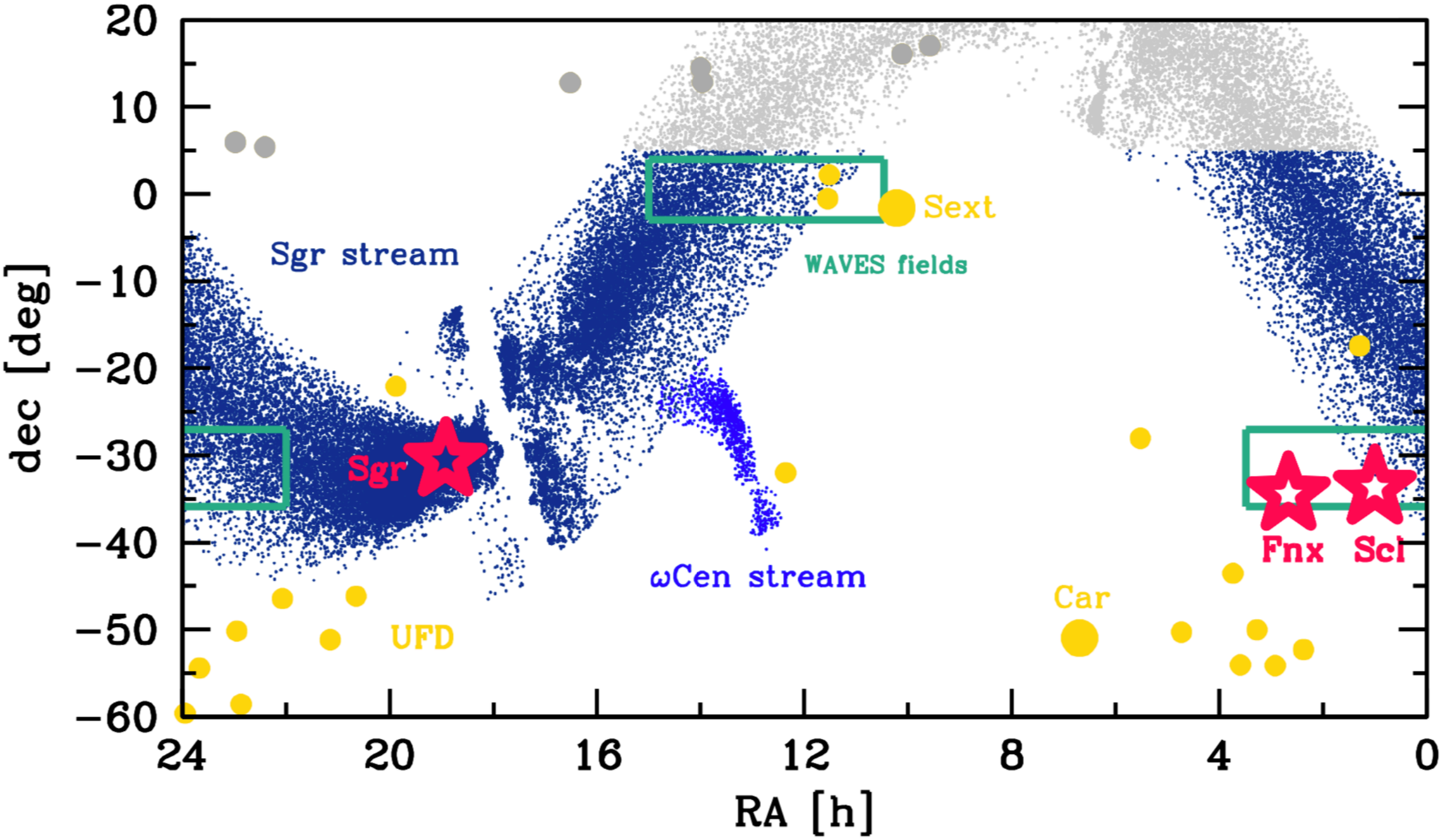
- **Large number statistics**
- **Full spatial coverage of dwarf galaxies and their streams**
- **Radial velocities, chemical abundances and stellar ages**



Cicuendez & Battaglia 2018

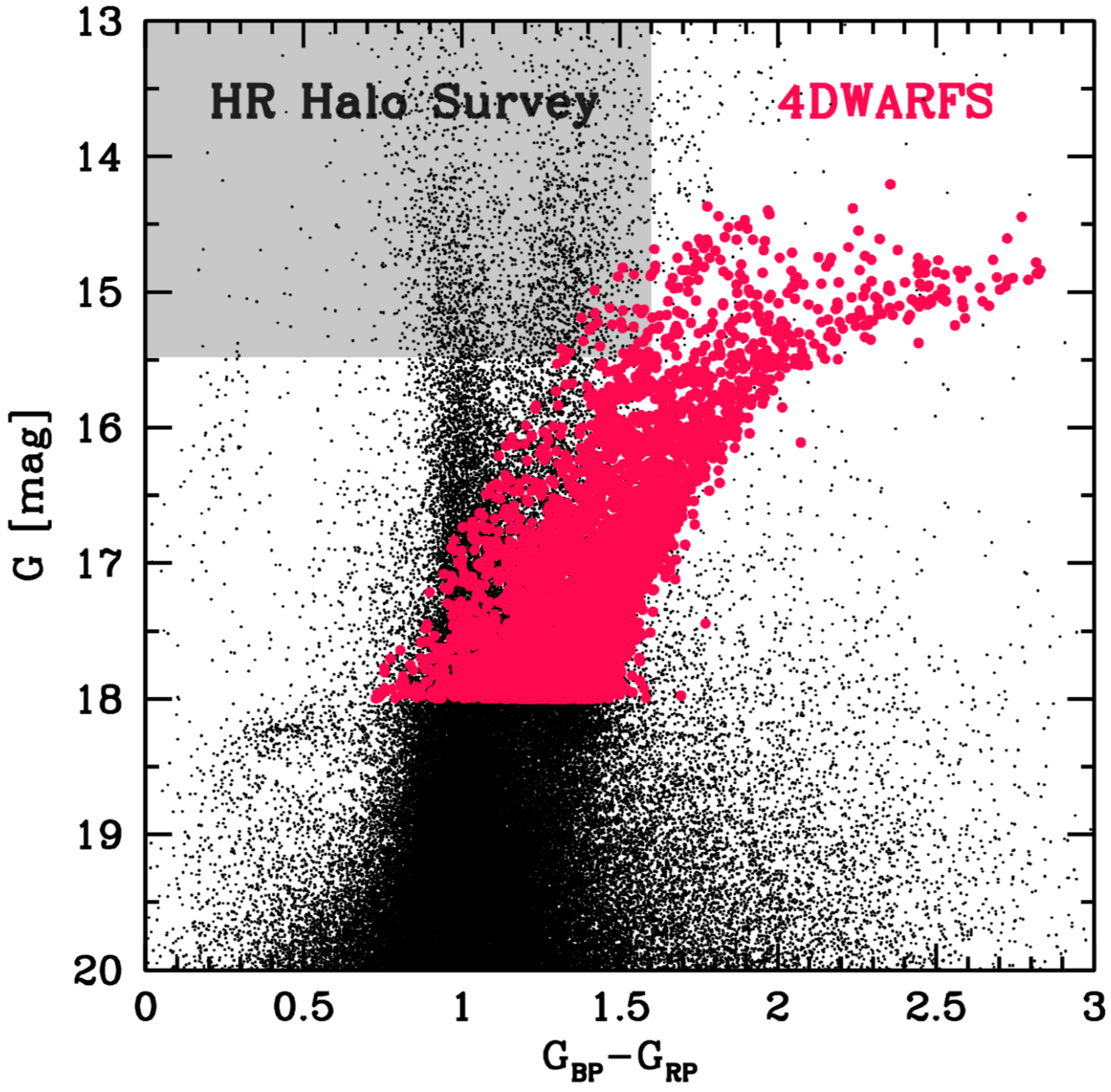
The 4DWARFS survey

4DWARFS


Sgr stream
WAVES fields
Sext
Sgr
ωCen stream
UFD
Car
Fnx
Scl
dec [deg]
RA [h]
20
10
0
−10
−20
−30
−40
−50
−60
24
20
16
12
8
4
0

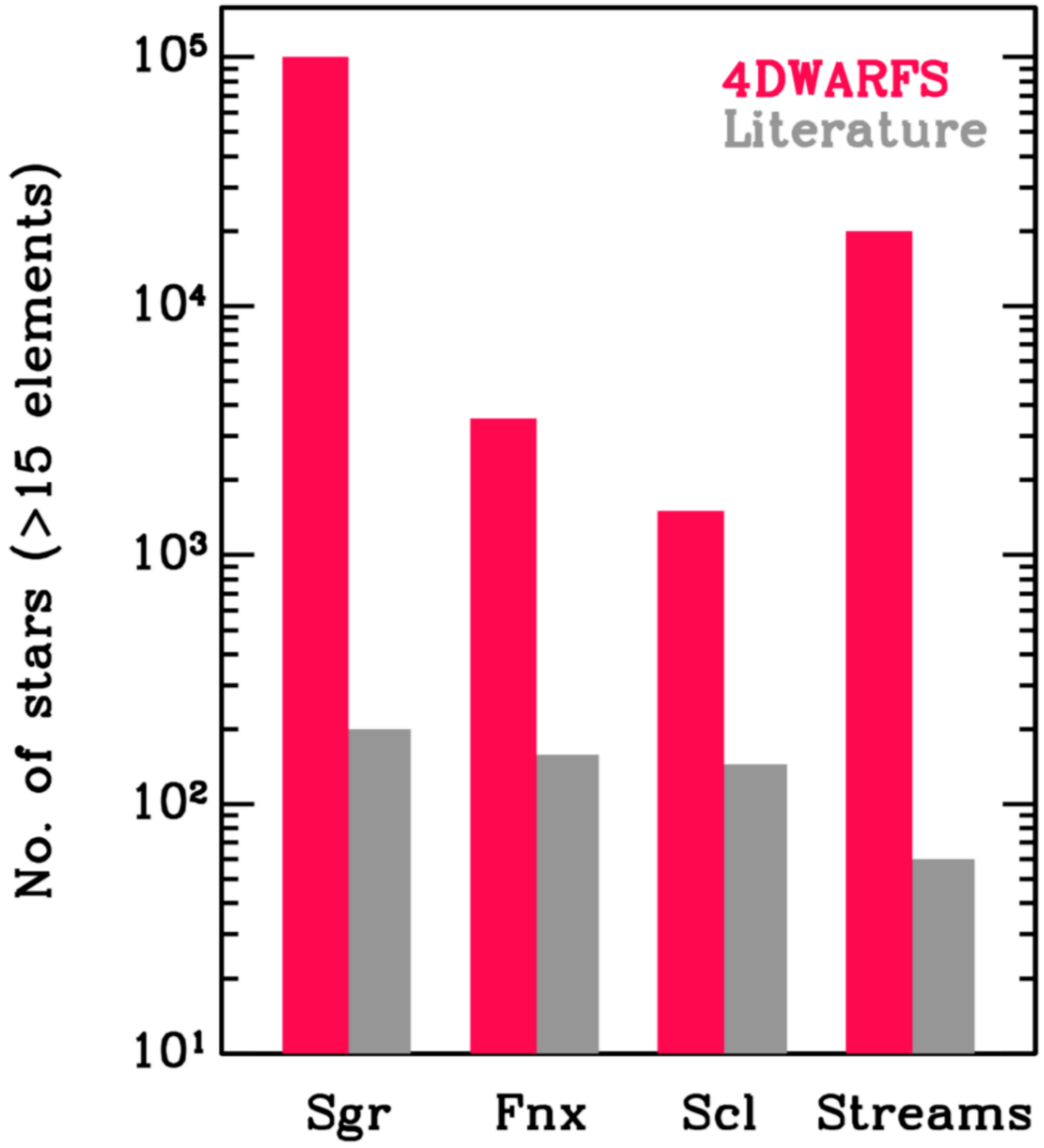
Target Selection

- Without 4DWARFS, 4MOST will have a very limited and biased view of Sagittarius and the Sagittarius stream
- Other dwarf galaxies too faint for the consortium HR halo survey.

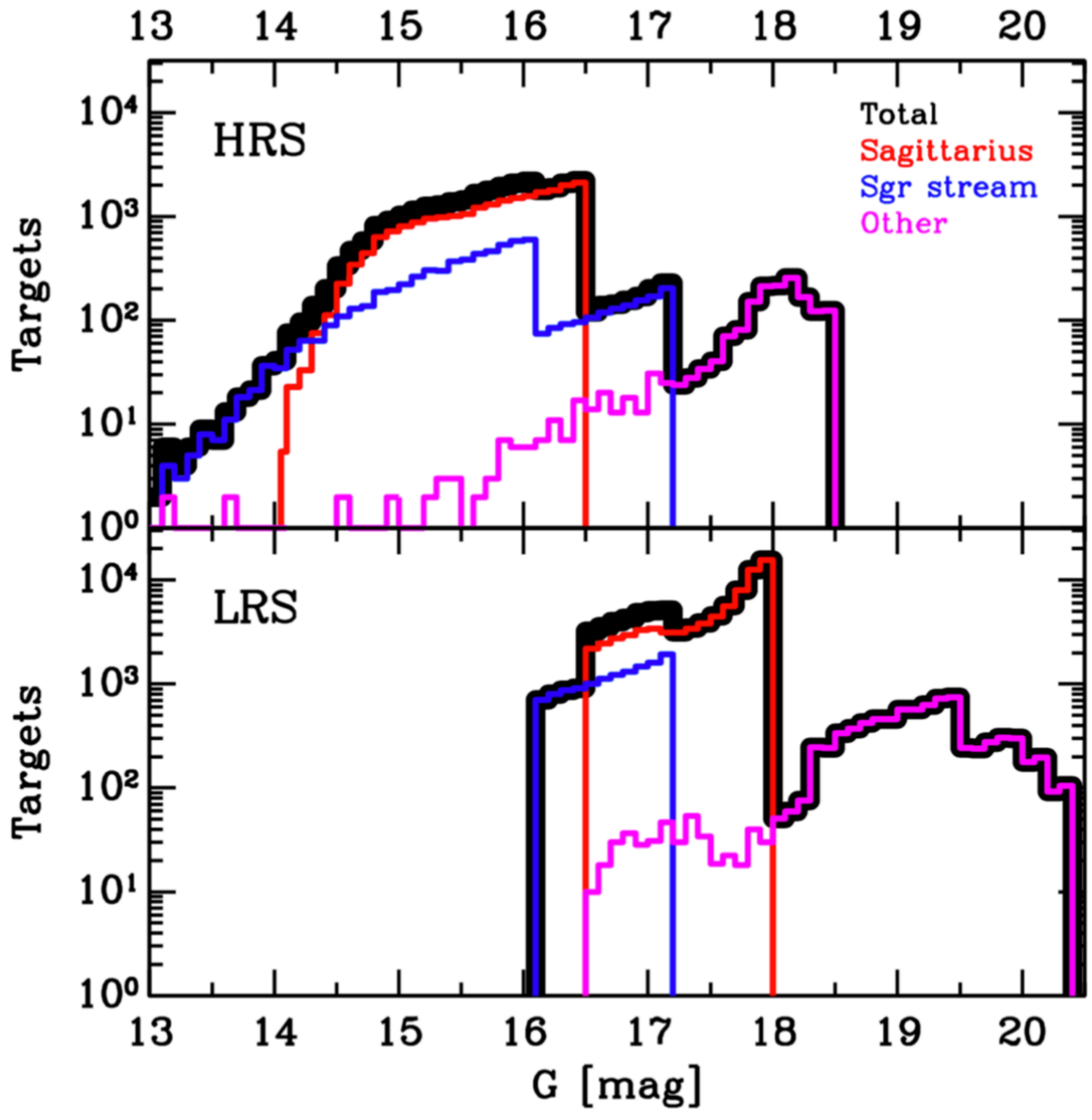


4DWARFS

- Chemical abundances in all dwarf galaxies in the Southern hemisphere using both LRS and HRS
- ~120,000 stars with detailed chemical abundance measurements (>15 elements) in dwarf galaxies + the Sagittarius stream



Magnitude distribution



Region	Targets	Total [h]
Sagittarius	100 000	353 000
Sgr stream	20 000	47 000
Fornax	5 000	67 000
Sculptor	3 000	37 300
Small dwarfs	2 000	7 700
Total	**130 000**	**512 000**

- LRS: ~2/3 of fibre hours
- HRS:~1/3 of fibre hours

4MOST needed!

- **WEAVE cannot do a comparable survey**
  - Sagittarius, Fornax and Sculptor are not accessible
  - The majority of the Sagittarius stream is in the South

- **Other facilities**
  - Typically more than an order of magnitude more telescope time for only ~1/4 of 4DWARFS

- **MOONS:**
  - Field of view 500 - cannot cover full spatial extent arcmin^2
  - NIR/IR: >650nm - most of the diagnostics of heavy elements + the low metallicity tail is at <500nm
  - Different abundance scale relative to 4MOST!

No other available or planned facility that can observe these dwarf galaxies as efficiently as 4MOST

4MOST is a unique facility for 4DWARFS

Conclusions

- **4DWARFS is a proposed 4MOST community survey**
  - All dwarf galaxies in the Southern Hemisphere
  - The Sagittarius stream + the Omega Cen stream
  - Targets: 130,000 stars
  - Total observational time: 512k fibre hours (~1/3 HRS and ~2/3 LRS)

- **Science goals:**
  - (I) ORIGIN: First stars
  - (II) EVOLUTION: Nucleosynthetic channels (SNIa, AGB stars, NSM)
  - (III) GLOBAL PICTURE: Hierarchical galaxy formation
  - Other: IMF variations, globular clusters, lithium-rich giants etc.

- **Will provide radial velocities, chemical abundances and ages for all the target stars**

- **4DWARFS will increase the number of stars in dwarf galaxies and streams with detailed abundance information (>15 elements) by several orders of magnitude, ensuring the far-reaching impact of this survey.**

- **Highly complementary to existing Galactic surveys, as well as S10 TiDES**

4DWARFS can only be done with 4MOST!

Survey metrics

Table 1: Survey metrics. Target density includes intended/available targets. When the area is smaller than one 4MOST pointing, the target density is assumed over one field-of-view (4.2 deg^2).

Regions	RA [deg]	Dec [deg]	Area [deg^2]	LR/HR	Density [target/deg^2]	t_{exp} [h]	$\langle t_{exp} \rangle$ [h]	mag [G]	$\langle$mag$\rangle$ [G]	Priority
Sagittarius	275 to 295	−34.5 to −26.5	140	HRS	164/180	2-4	1.9	14-16.5	15.7	1
Sagittarius	275 to 295	−34.5 to −26.5	140	LRS	550/640	1-4	1.5	16.5-18	17.5	1
Sgr stream	0 to 360	−50 to +5	>5 000	HRS	<20/40	0.33-4	1.9	13-17.2	15.7	1
Sgr stream	0 to 360	−50 to +5	>5 000	LRS	<40/80	0.67-2	1.5	16.1-17.2	16.7	1
Fornax	40.0	−34.4	4.2	HRS	250/360	12-24	16	17.4-18.5	18.1	1
Fornax	40.0	−34.4	4.2	LRS	940/1200	2.5-14	8.9	18.3-19.6	19.4	1
Sculptor	15.0	−33.7	4.2	HRS	143/155	14	14	16.4-18.3	17.6	1
Sculptor	15.0	−33.7	4.2	LRS	570/770	2.5-14	8.8	18.0-20.2	19.4	1
Carina	100.4	−51.0	4.2	LRS	238/265	4	4	16.5-20.4	19.4	2
Sextans	153.3	−1.6	4.2	LRS	95/106	2	2	16.5-20	18.7	2
UFD	-	-	-	LRS	≤10	2	2	16.5-20	19.5	3
ω Cen stream	185 to 225	−40 to −20	200	HRS	0.25/0.5	2	2	11-16.5	15.4	3
ω Cen stream	185 to 225	−40 to −20	200	LRS	0.75/1.0	2	2	16.5-17.5	17.0	3

Targets

Table 2: Total number of targets in each galaxy, with estimated fibre hours. 'Small dwarfs' includes Carina, Sextans, UFD and the ω Centauri stream.

Region	**Targets**	**HRS [h]**	**LRS [h]**	t_{exp} **[h]**	**Overh. [h]**	**Total [h]**
Sagittarius	100 000	86 000	189 000	275 000	78 000	353 000
Sgr stream	20 000	13 000	20 000	33 000	14 000	47 000
Fornax	5 000	16 800	35 200	52 000	15 000	67 000
Sculptor	3 000	8 400	20 600	29 000	8 300	37 300
Small dwarfs	2 000	100	5 900	6 000	1 700	7 700
Total	**130 000**	**124 300**	**270 700**	**395 000**	**117 000**	**512 000**

Exposure time estimates

Table 3: Exposure time estimates, t_{exp}, for the different sub-surveys of 4DWARFS.

Region	Sub-survey	S/N [pix^{-1}]	λ_{ref}	mag [G]	Targets	t_{exp} [h]
Sagittarius	HRS: bright	>40	420	$\leq$ 15.5	8 000	32 000
Sagittarius	HRS: faint	>25	420	$\leq$ 16.5	15 000	54 000
Sagittarius	LRS	>40	520	$\leq$ 18.0	77 000	189 000
Sgr stream	HRS: WAVES	>30	520	$\leq$ 17.2	2 000	6 000
Sgr stream	HRS: all sky	>40	520	$\leq$ 16.1	5 000	7 000
Sgr stream	LRS: all sky	>40	520	$\leq$ 17.2	13 000	20 000
Fornax	HRS	>30	520	$\leq$ 18.5	1 050	16 800
Fornax	LRS: bright	>30	520	$\leq$ 19.4	2 500	29 000
Fornax	LRS: faint	>20	620	$\leq$ 19.5	1 450	6 200
Sculptor	HRS	>30	520	$\leq$ 18.3	600	8 400
Sculptor	LRS: bright	>30	520	$\leq$ 19.3	900	12 600
Sculptor	LRS: faint	>20	620	$\leq$ 20.2	1 500	8 000
Carina	LRS: bright	>30	520	$\leq$ 18.4	150	600
Carina	LRS: faint	>10	620	$\leq$ 20.4	850	3 400
Sextans	LRS	>10	620	$\leq$ 20.0	400	800
UFD	LRS	>10	620	$\leq$ 20.0	400	800
ω Cen stream	HRS	>30	520	$\leq$ 16.5	50	100
ω Cen stream	LRS	>30	520	$\leq$ 17.5	150	300