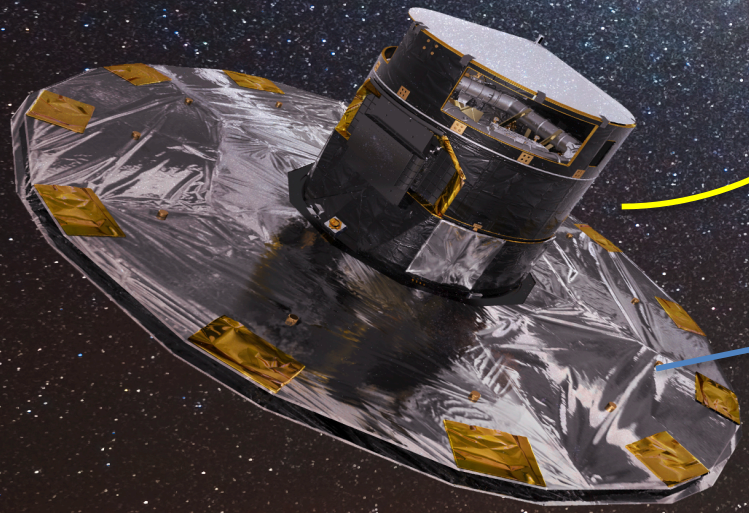
Spectroscopic surveys in the Gaia era

Vanessa Hill, Laboratoire Lagange,
Observatoire de la Cote d'Azur



?

Target selection

PFS SuMIRe

MEAVE

LAMOST Experiment for Galactic Understanding and Exploration

SDSS-V

APOGEE

MOONS Multi Object Optical and Near-infrared Spectrograph

4MOST

GALAH

GaiaESO

RAVE Radial Velocity Experiment

Beatriz

ACADEMIA BRASILEIRA DE CIÊNCIAS
MCMXVI

PRÊMIO LORÉAL- UNESCO PARA MULHERES NA CIÊNCIA

ARQUIVO | 20 de março de 2009

Compartilhar Compartilhar Compartilhar Compartilhar

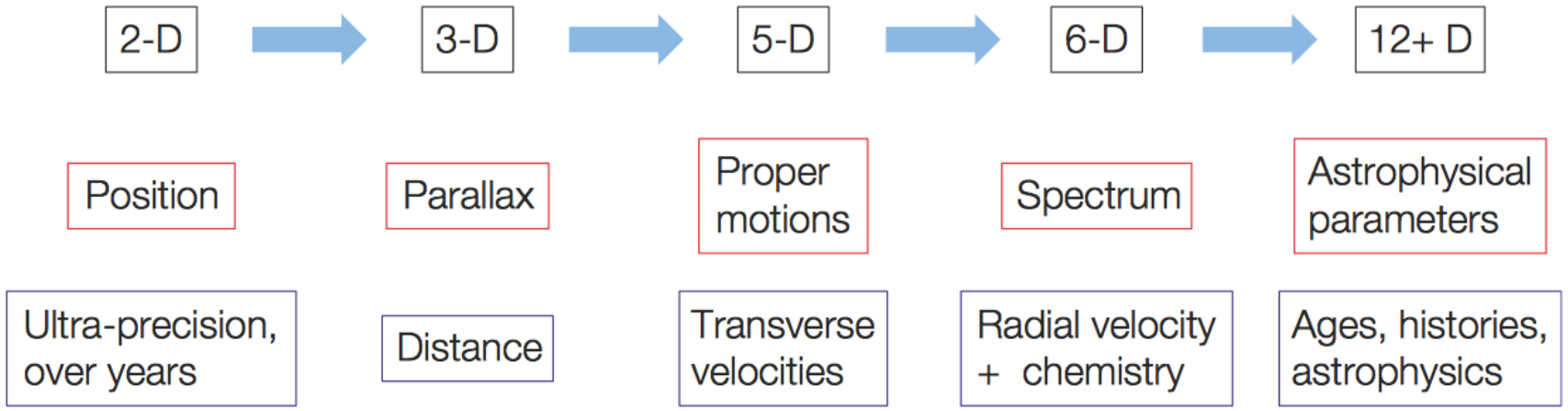
WO

A great scientist, a sucess story,

…. a great human …

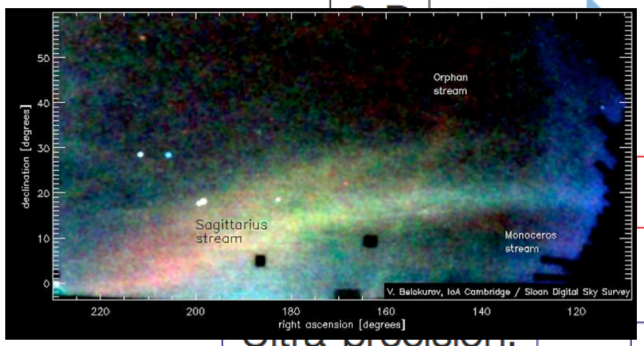
On behalf of the *« French connection »:* Félicitations !

Galactic Archaeology - principle



Gilmore et al. (2012)

Galactic Archaeology - principle



3-D → 5-D → 6-D → 12+ D

Parallax

Proper motions

Spectrum

Astrophysical parameters

Distance

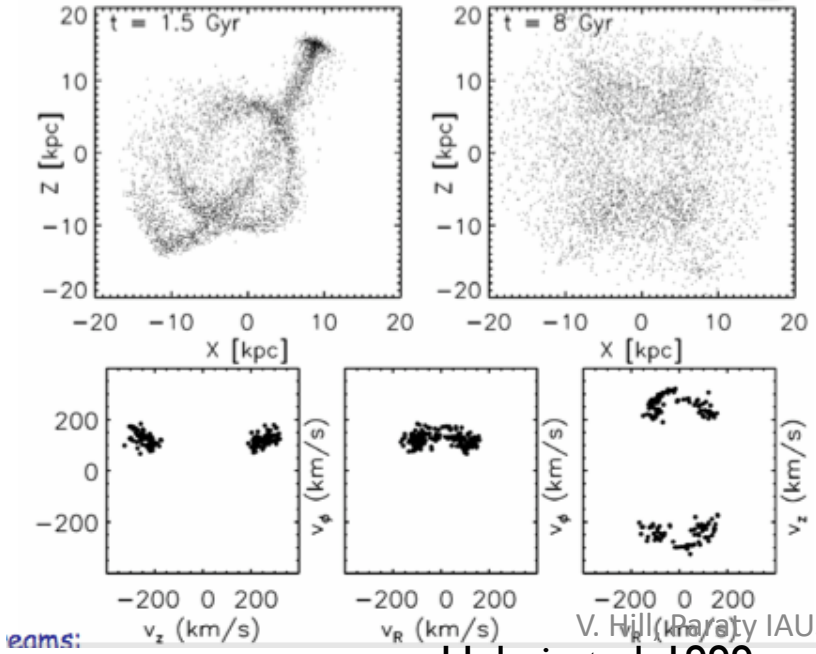
Transverse velocities

Radial velocity + chemistry

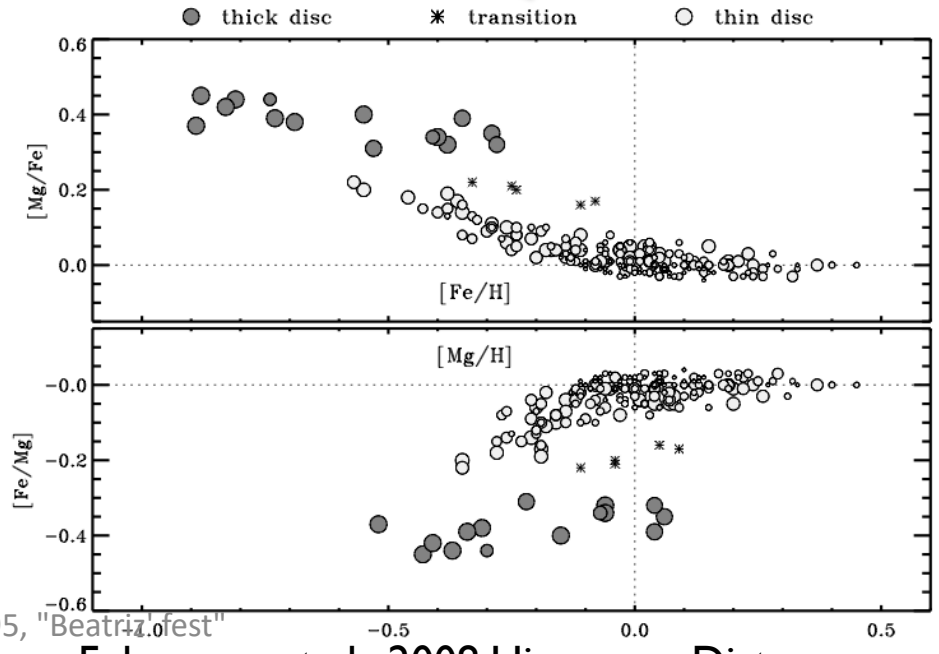
Ages, histories, astrophysics

over years

Gilmore et al. (2012)

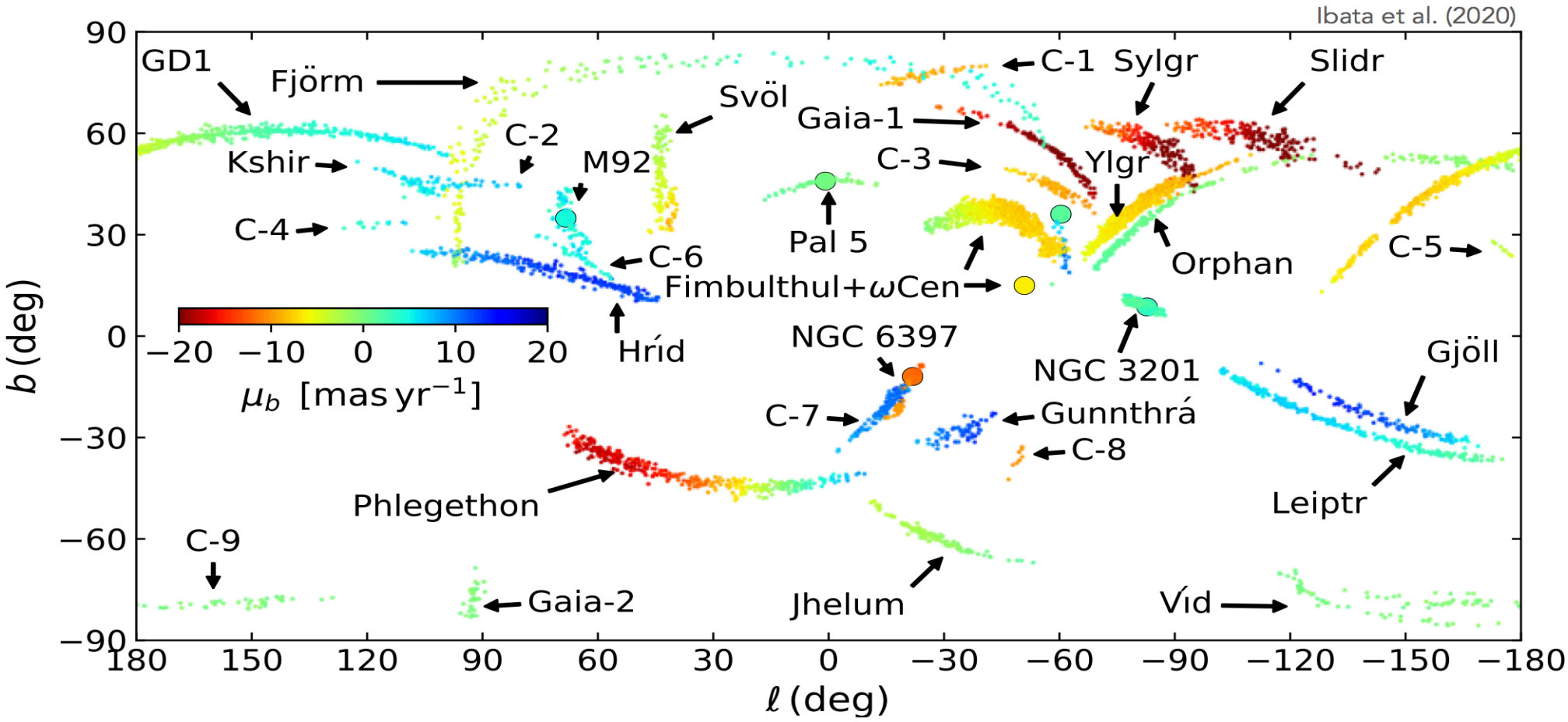


Helmi et al. 1999



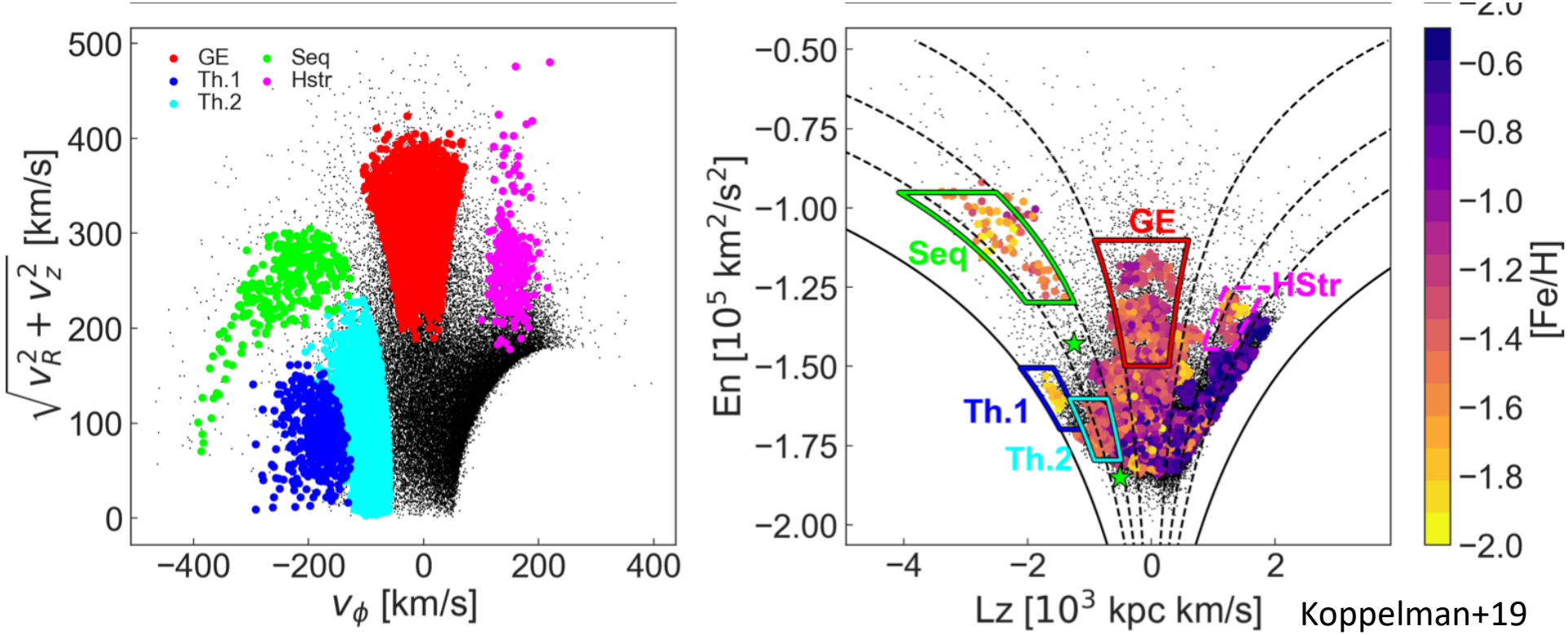
Fuhrmann et al. 2008 Hipparcos Distances

Gaia's harvest : stellar streams from Gaia 5/6D



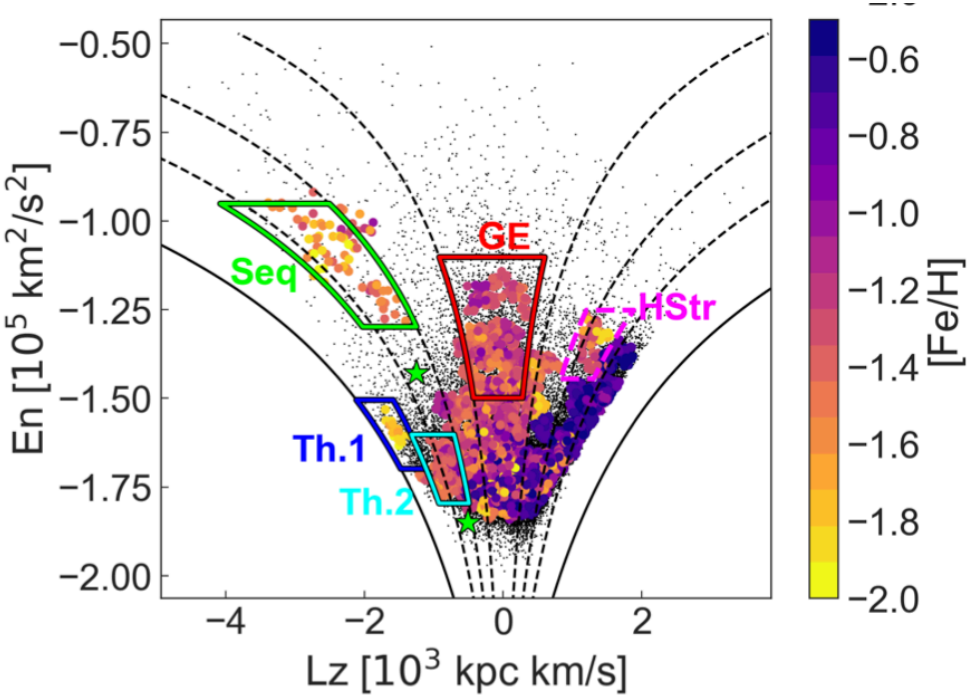
- Many streams discovered by Gaia using proper motions / phase-space, …
- Their shapes (orbits and densities) can be used to constrain the MW dark matter profile, clumpiness, …
- RVs and chemistry to turn candidate streams into stream + progenitor nature

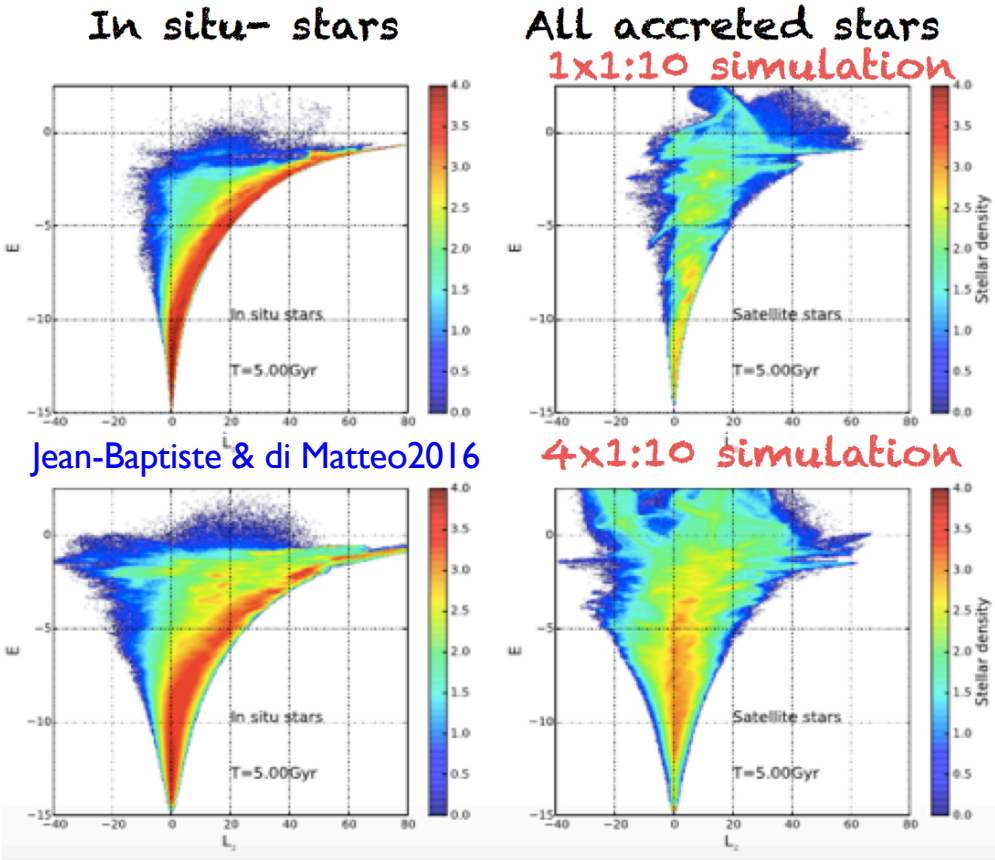
Gaia's harvest: Accretion history of the MW



- Phase-space searches for dissolved accretions

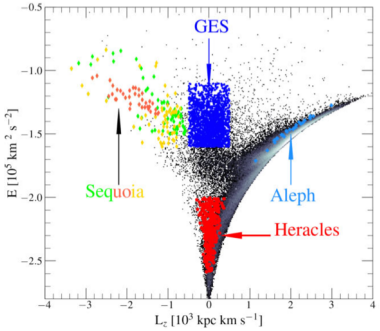
Gaia's harvest: Accretion history of the MW

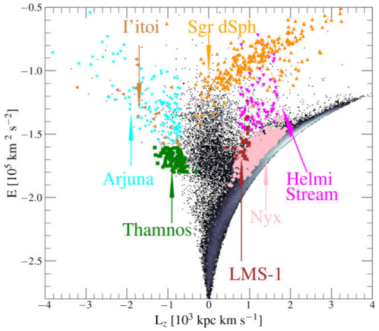


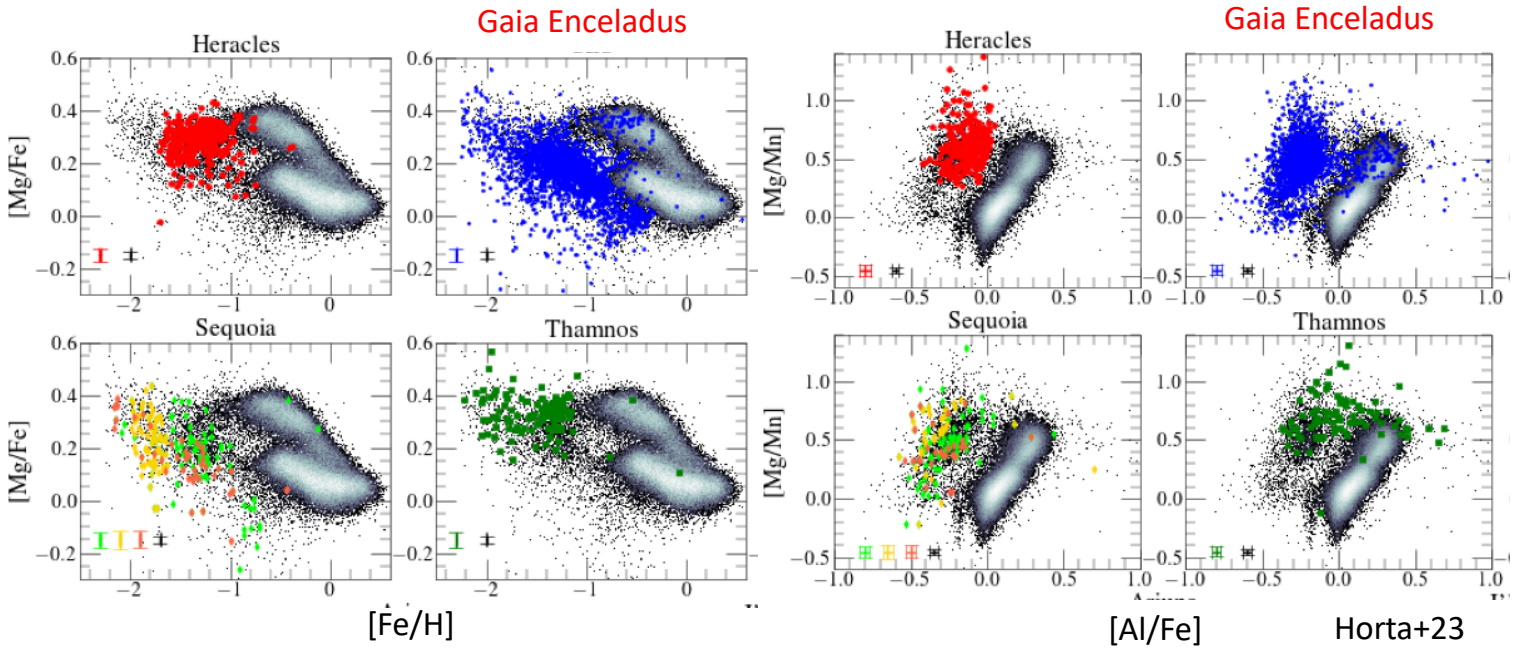


- Are quantities really conserved ? Accretions on pré-existing galaxy
  - Several accretions may overlap in phase-space / actions / E-Lz spaces
  - Overlaping clumps
  - Clumps may be responses of the existing in-situ disk populations

Gaia's harvest: Accretion history of the MW
using chemical evolution of the parent systems

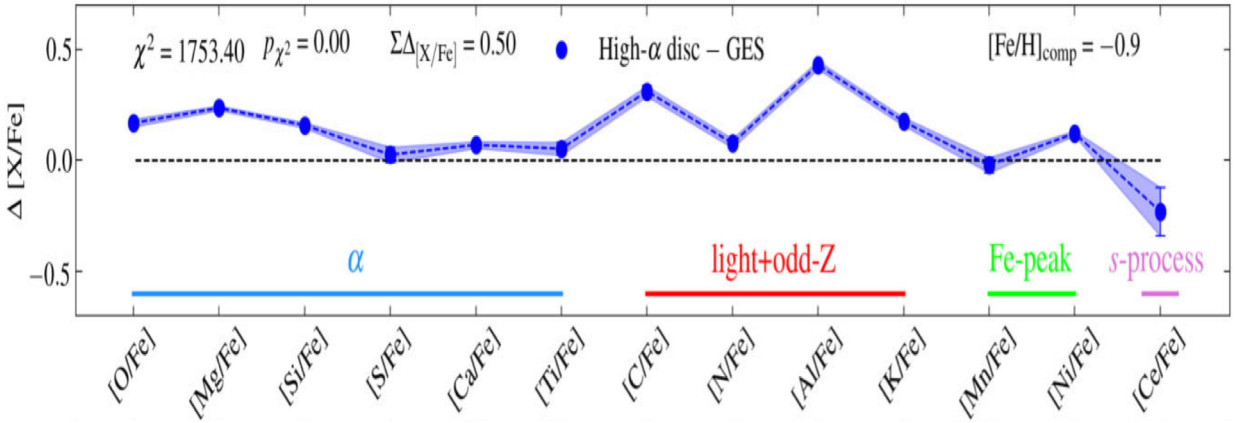




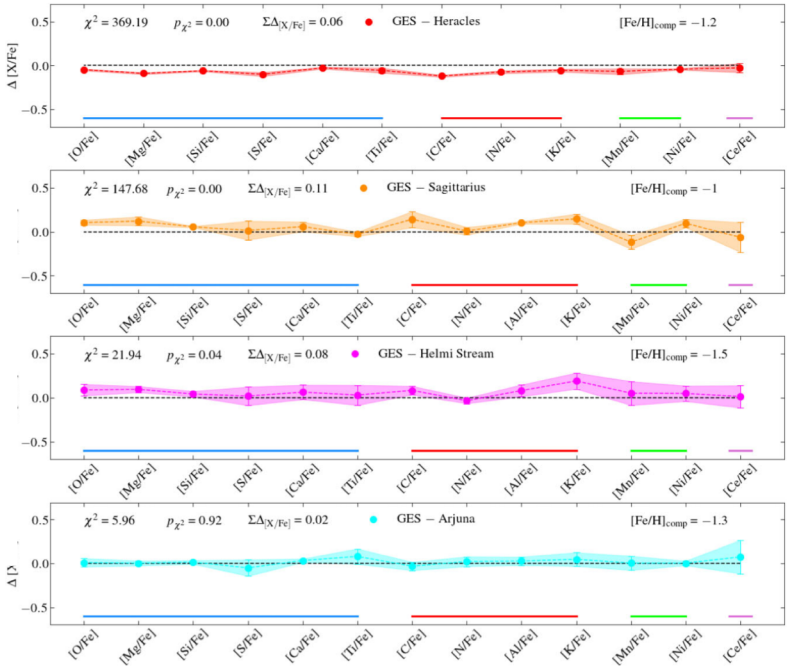


- Overlapping in phase-space → need chemistry to :
  - Relate several clumps
  - Separate out overlapping clumps
  - Characterize accretion progenitor

Gaia's harvest: Accretion history of the MW
using chemical patterns of the parent system



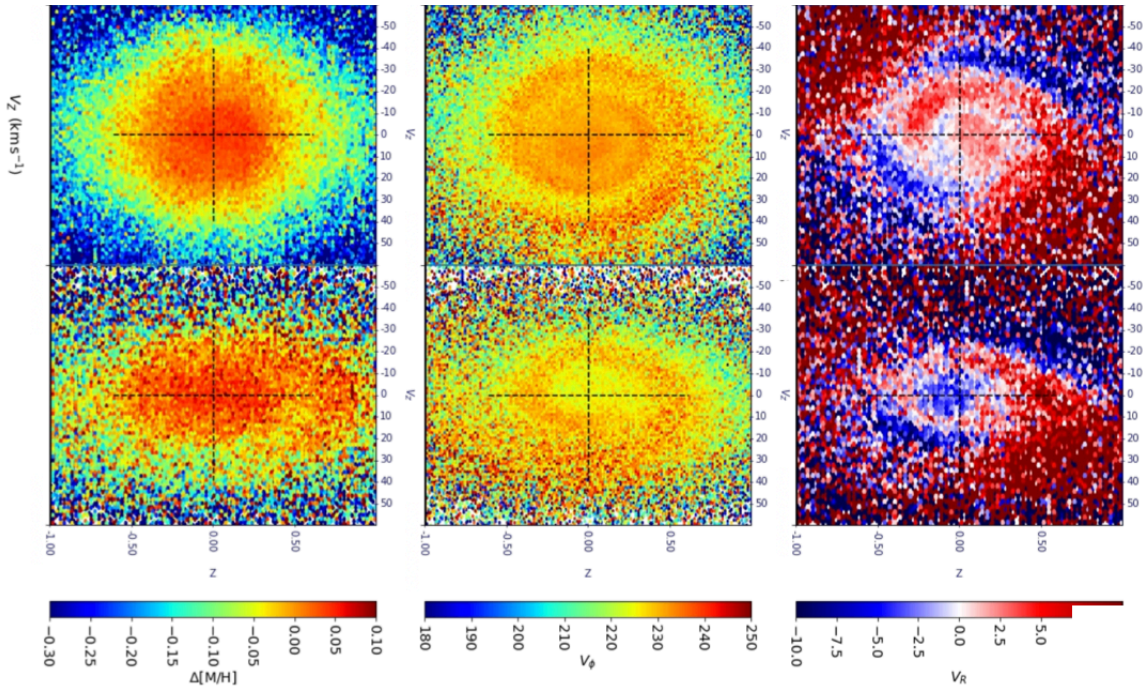
Horta+23



Signatures are weak: need *large samples of precise and homogeneous* abundances *of elements from many different channels*

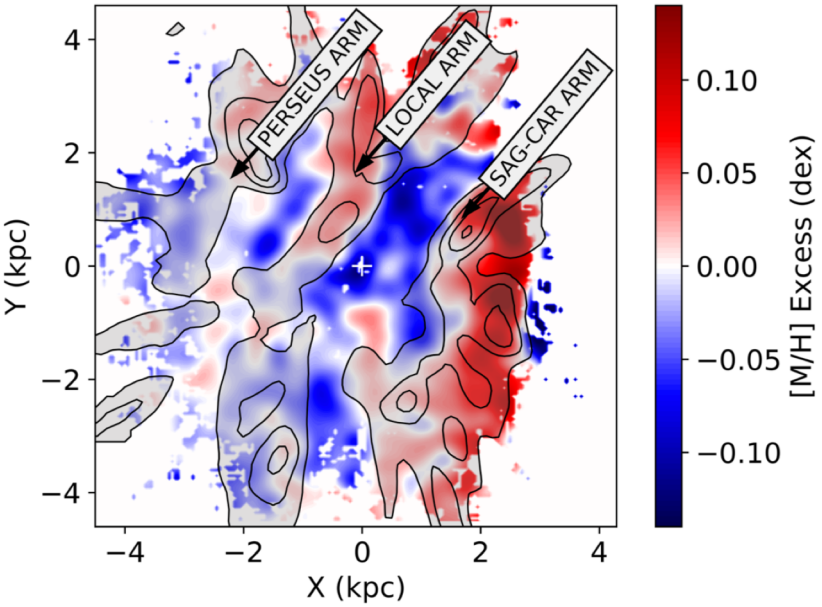
→ Need large surveys

Understanding the disc: non-axisymetries, not relaxed

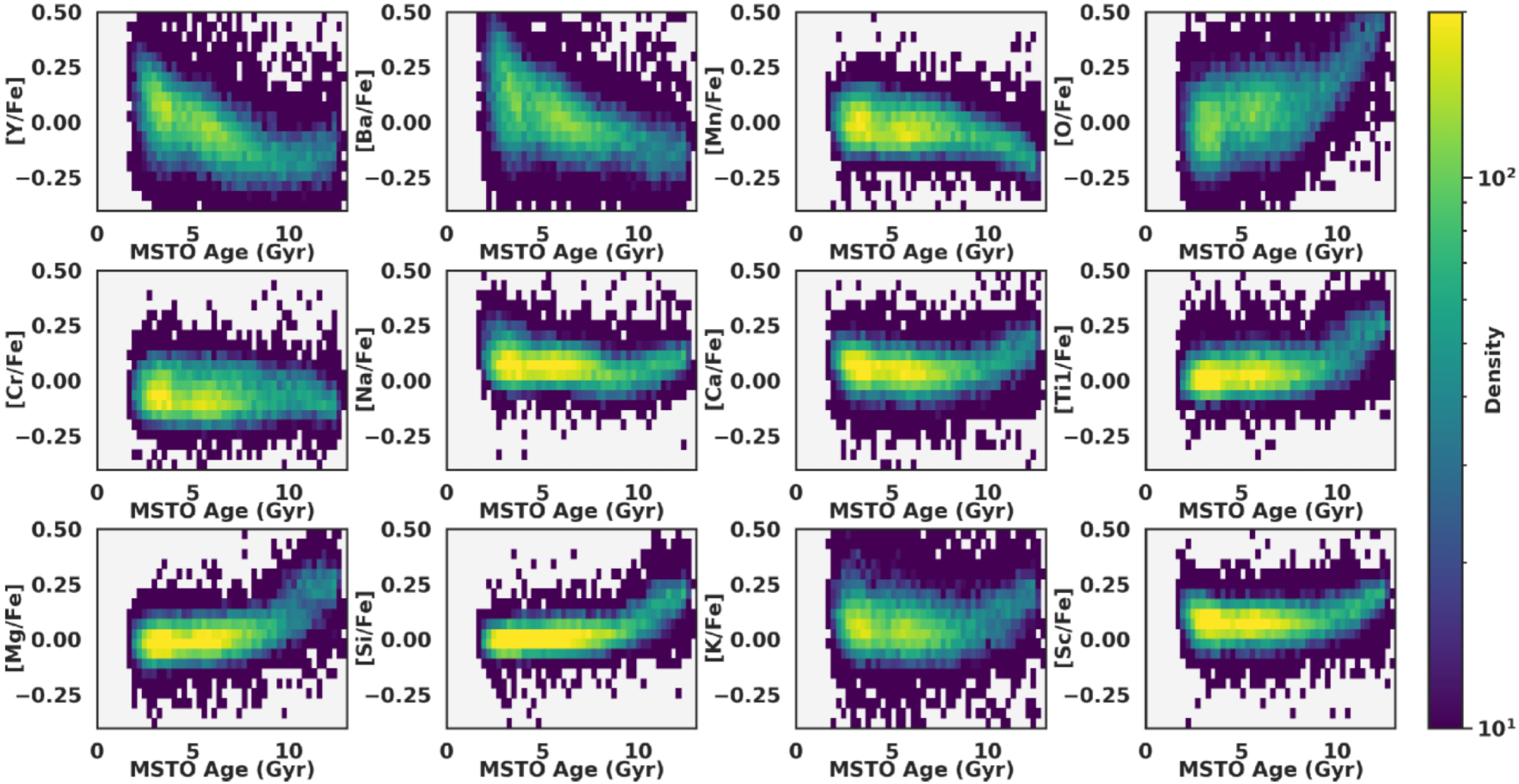


Antoja+ 2019, Recio-Blanco+ 2022

Poggio+ 2022; Barbillon+24 for Ca/Fe



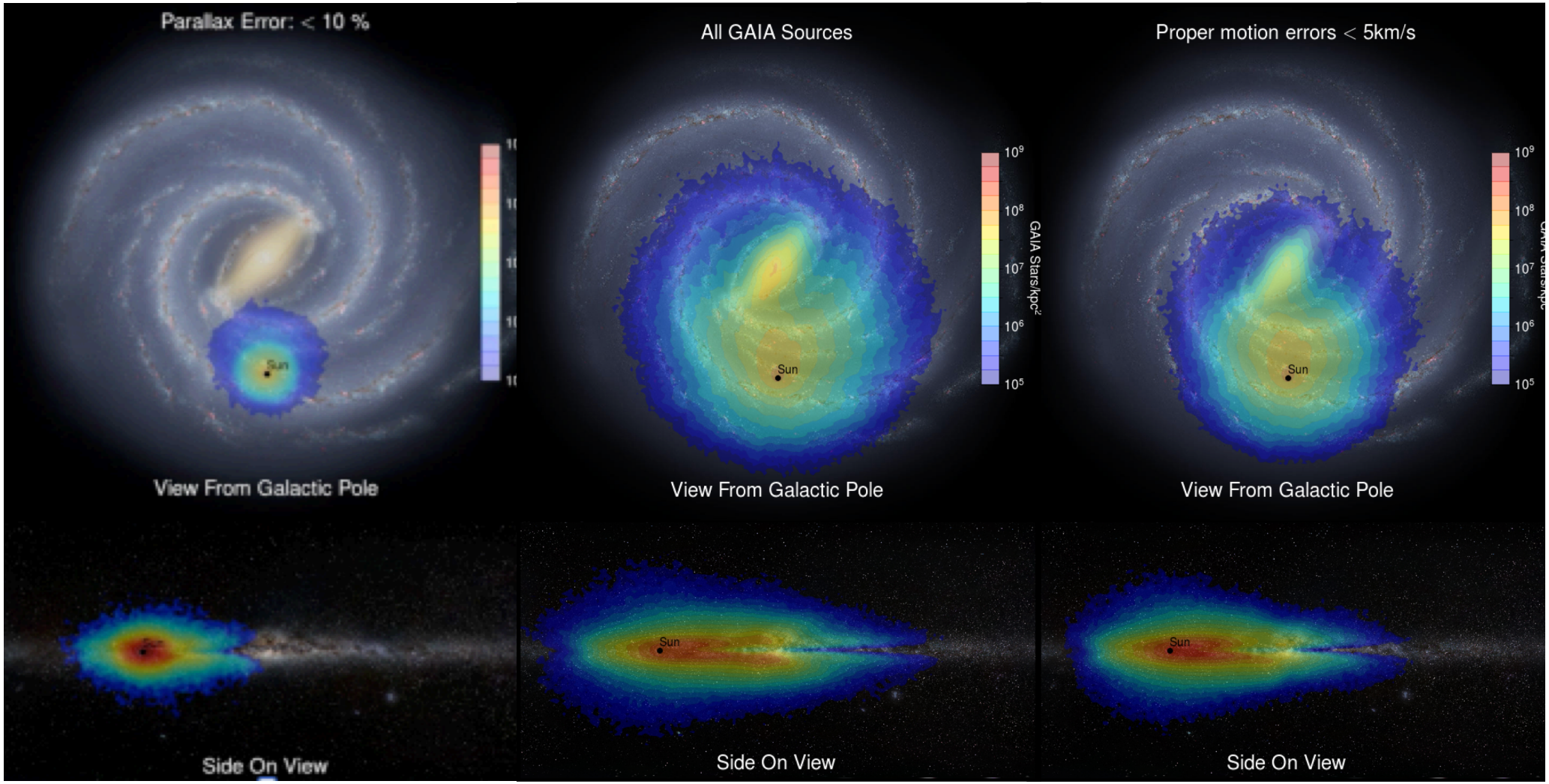
Chemical clocks



Hayden+22 (GALAH DR3)

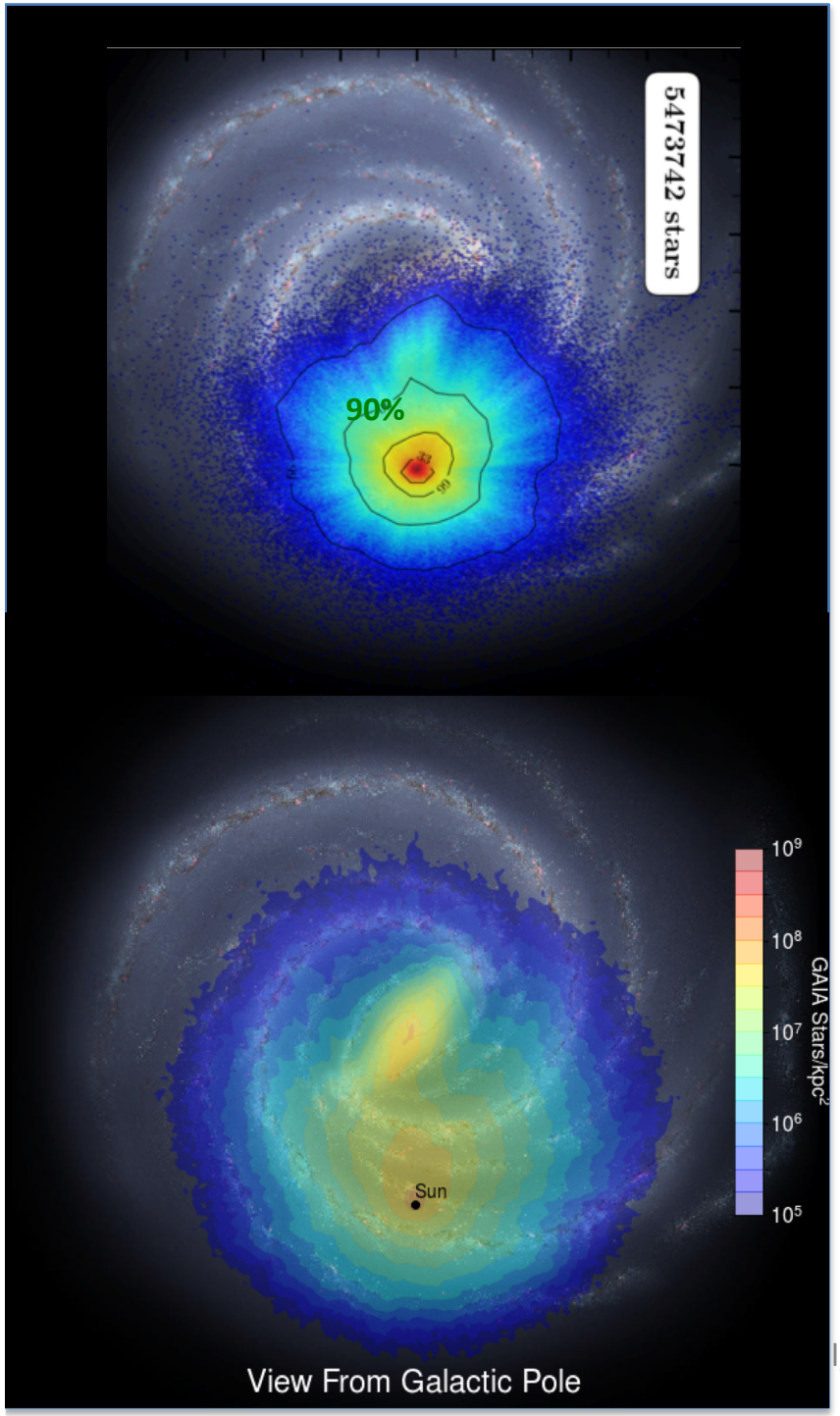
Synergies large spectro. Surveys – Gaia

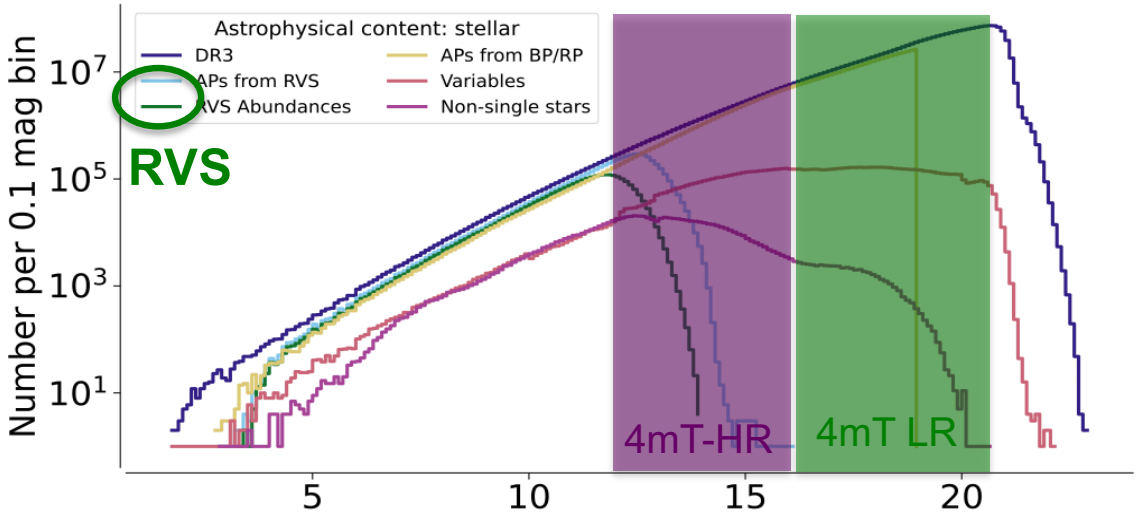
Movie and images cortesy of Chris Wegg (model-based)



Leave the Solar Neighborhood: spectro-photometric distances, turn exquisite proper motions in transverse velocities in larger volumes (where Gaia π not accurate enough)

RVS metallicities *Gaia Collab, Recio-Blanco+22*

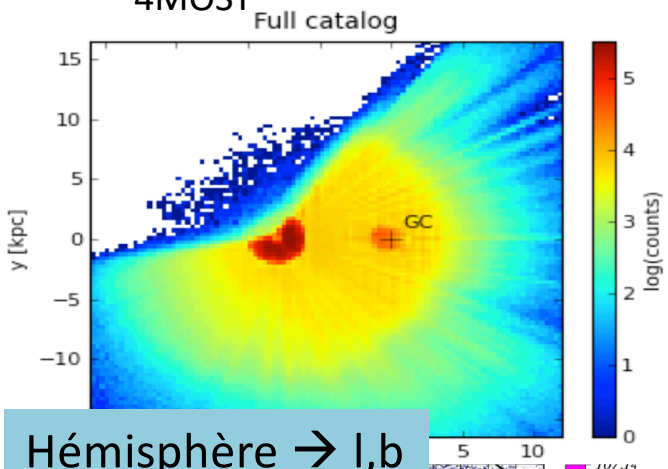




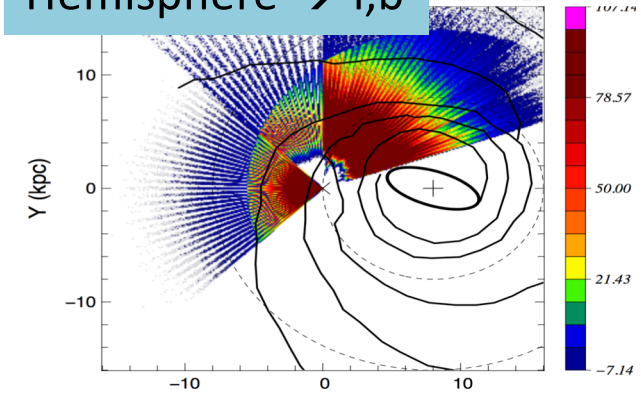
- *Leave the Solar Neighbourhood:* complement the Gaia catalogue with accurate Vr=Vlos (& metallicity) 15<G<21
- Enrich the Gaia catalogue with detailed chemistry beyond RVS

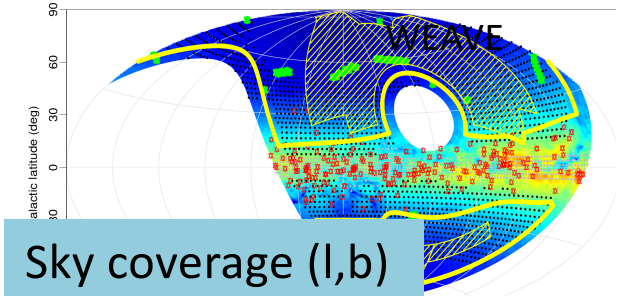
Surveys

4MOST

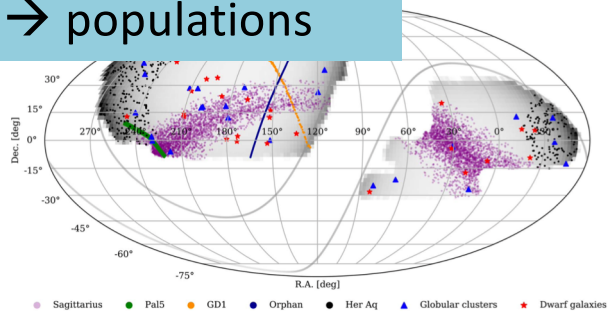


Hémisphère → l,b





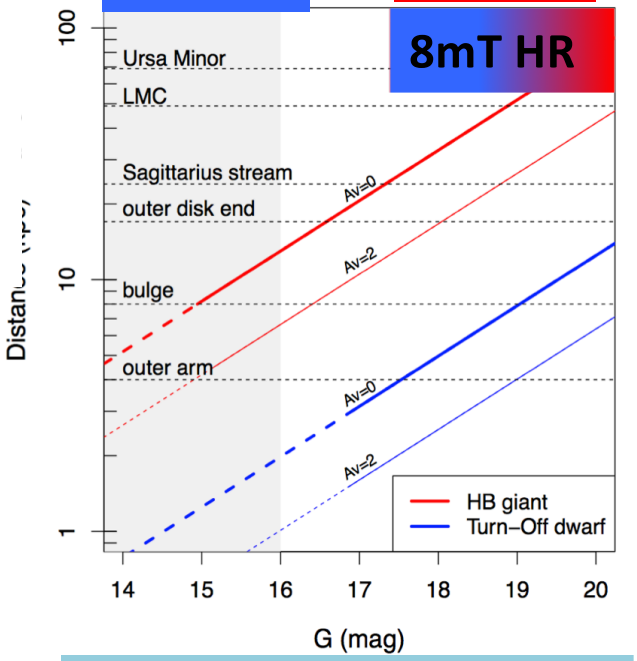
Sky coverage (l,b)
→ populations



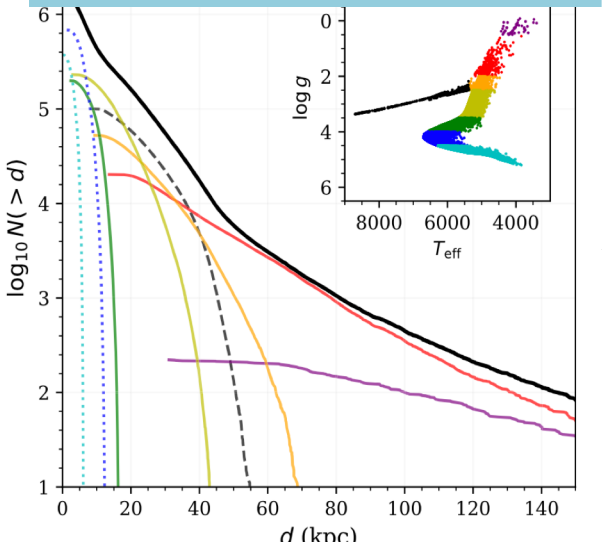
4mT HR

4mT LR

8mT HR



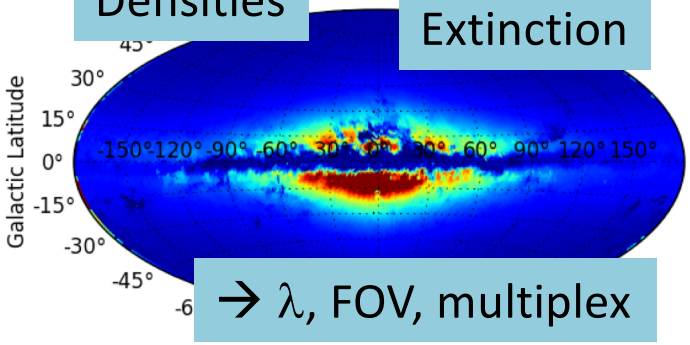
Depth, tracers → volume



Thick disc stars with V < 20

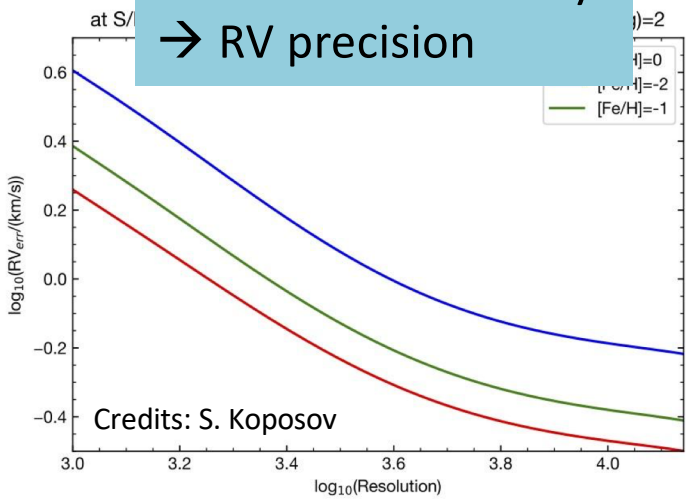
Densities

Extinction



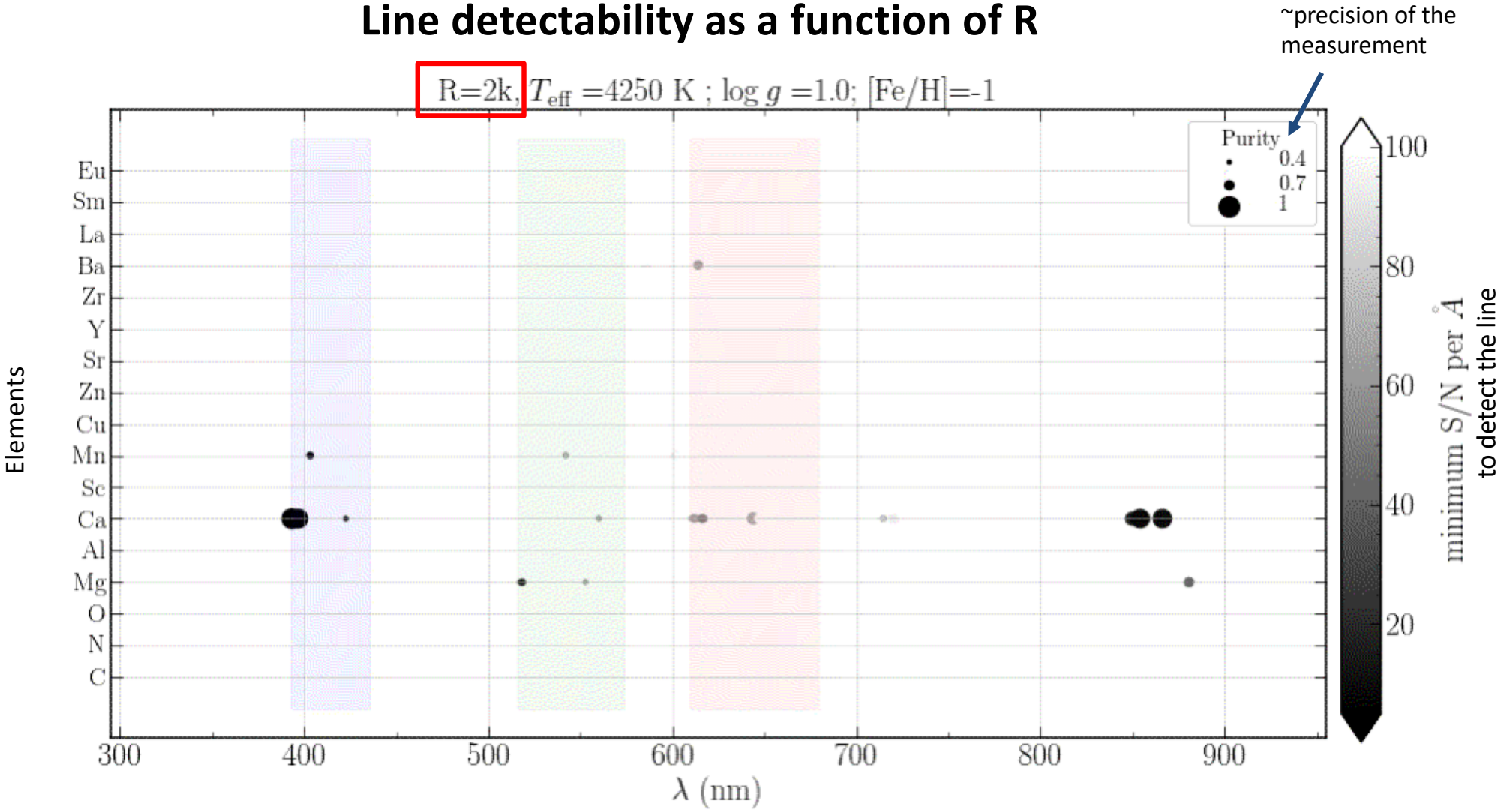
→ λ, FOV, multiplex

R, λ:
→ chemical precision
→ chemical diversity
→ RV precision



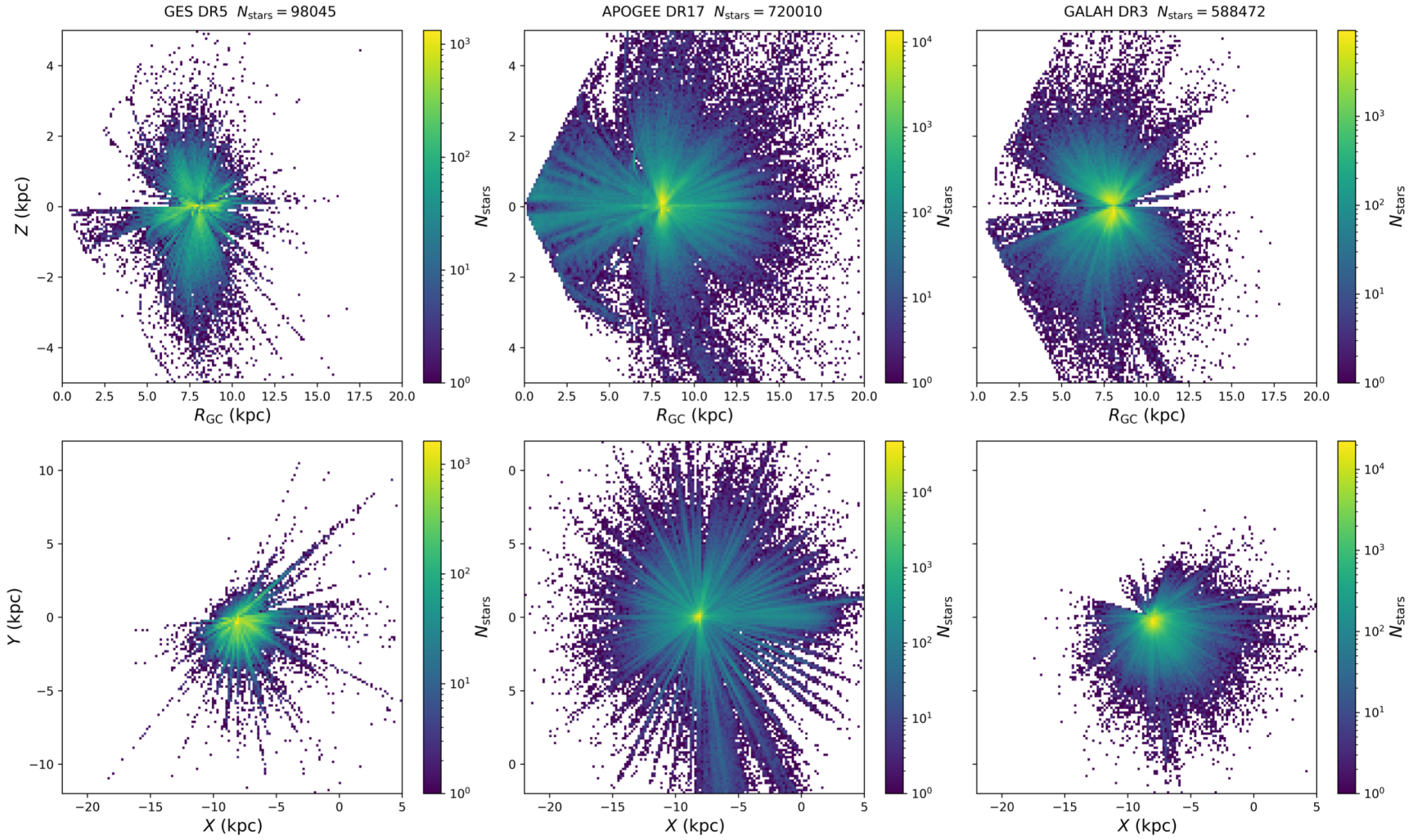
Total number of stars

Line detectability as a function of R

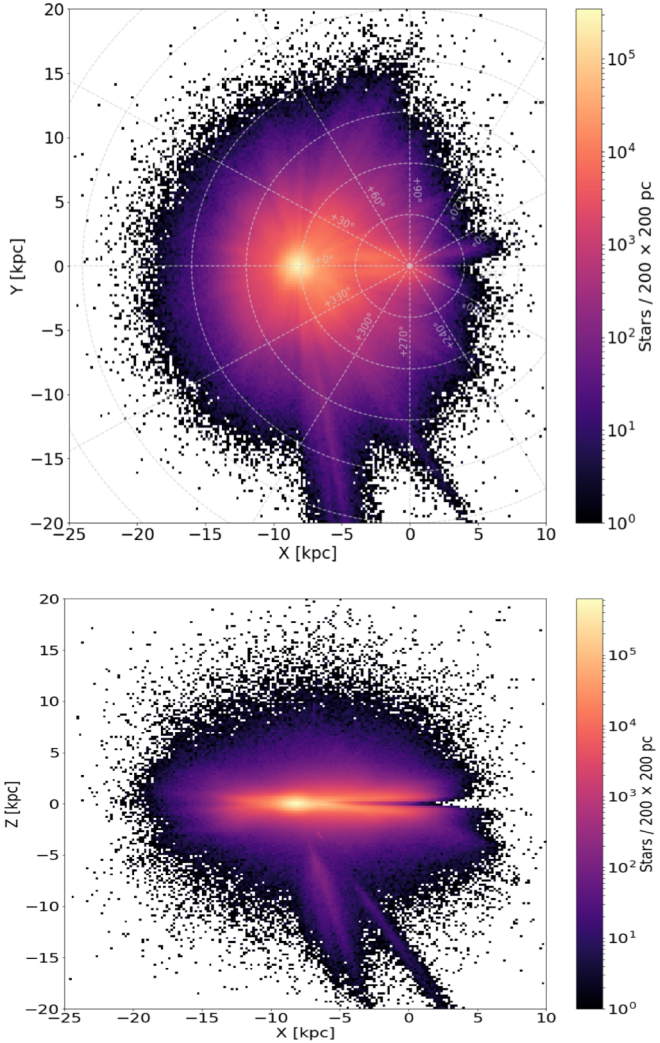


Kordopatis, Hill, Lind+22

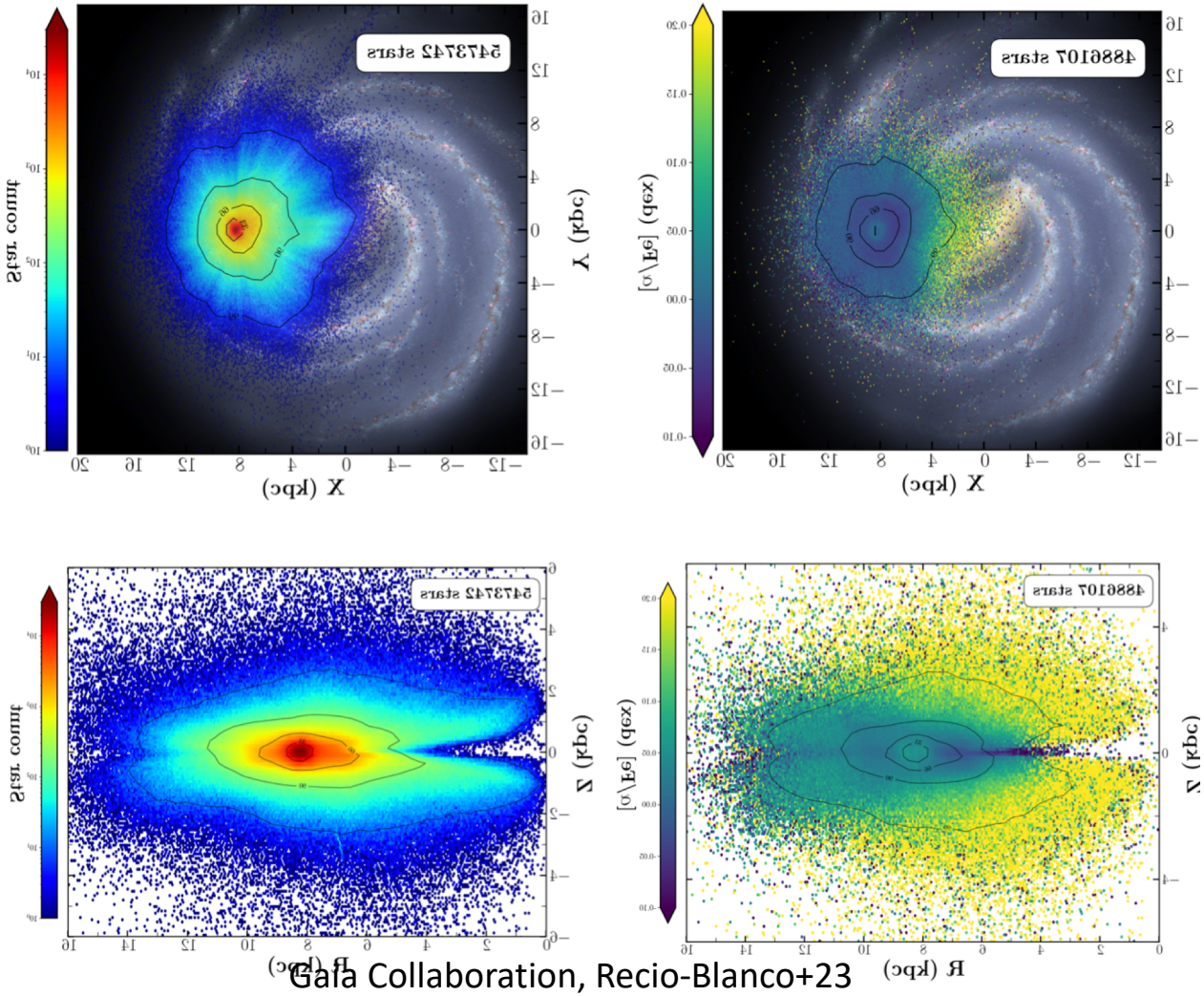
HR surveys today (R>=20,000)



Gaia RVS in DR3



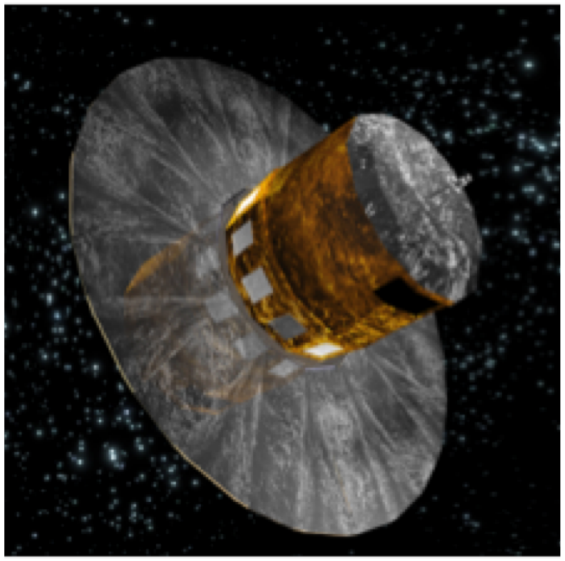
Gaia Collaboration, Katz+23

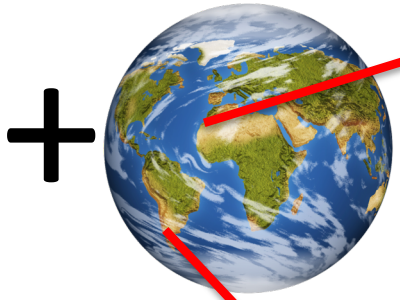


Gaia Collaboration, Recio-Blanco+23

Gaia DR4 : expect ~ 150 millions RV and « tens of millions » of metallicities (+ epoch RVS)

Large surveys (with chemistry information)
High resolution and high precision surveys are going to be crux for detailed chemistry
Lower resolution (high enough for at least basic chemistry) crux for the volume



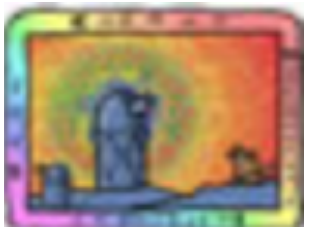


North

South

PFS SuMIRe

WEAVE



LAMOST Experiment for Galactic Understanding and Exploration

SDSS-V MW-mapper

APOGEE

MOONS Multi Object Optical and Near-infrared Spectrograph

4MOST

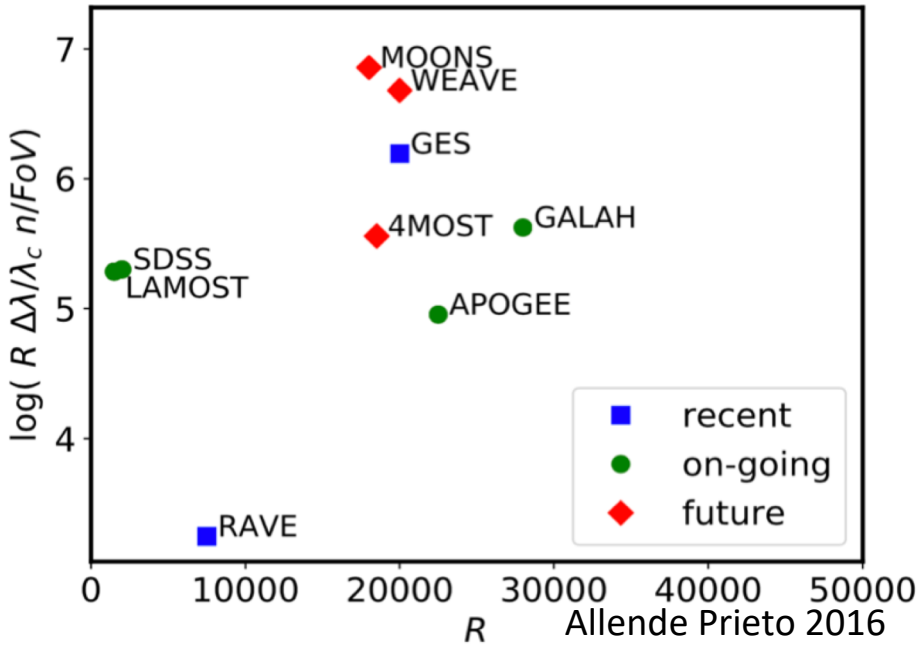
GALAH

GaiaESO

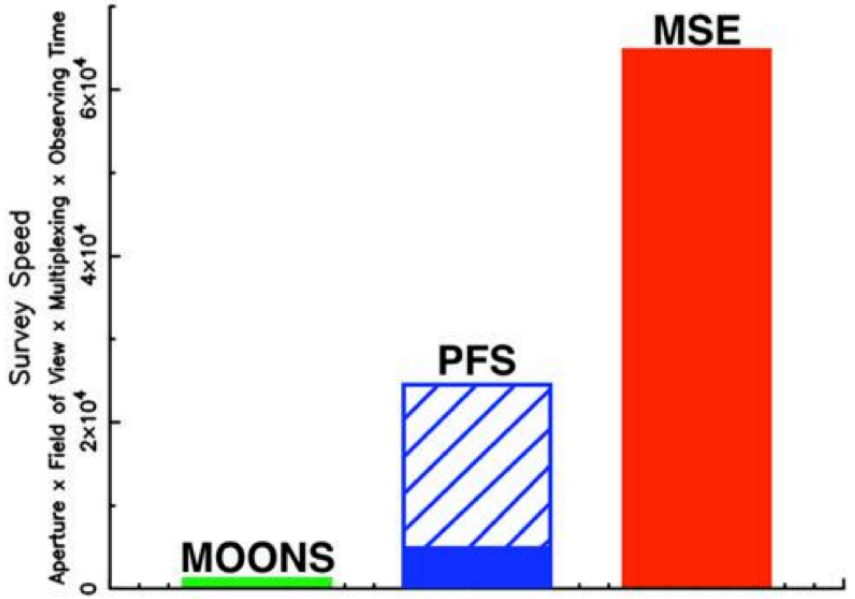
RAVE Radial Velocity Experiment

Looking at many millions of stars
In coming years…
DESI 8M; SDSS-V 5M; WEAVE 3-4M;
4MOST 20M; Gaia RVS 150M

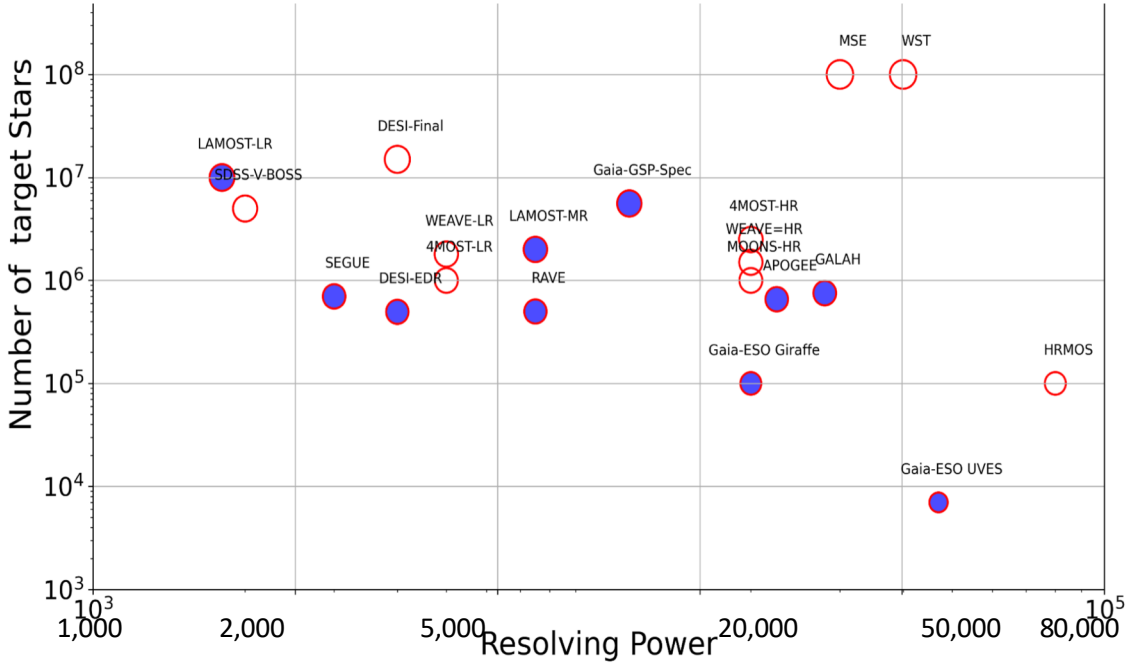
Many ways of representing survey *merits* …



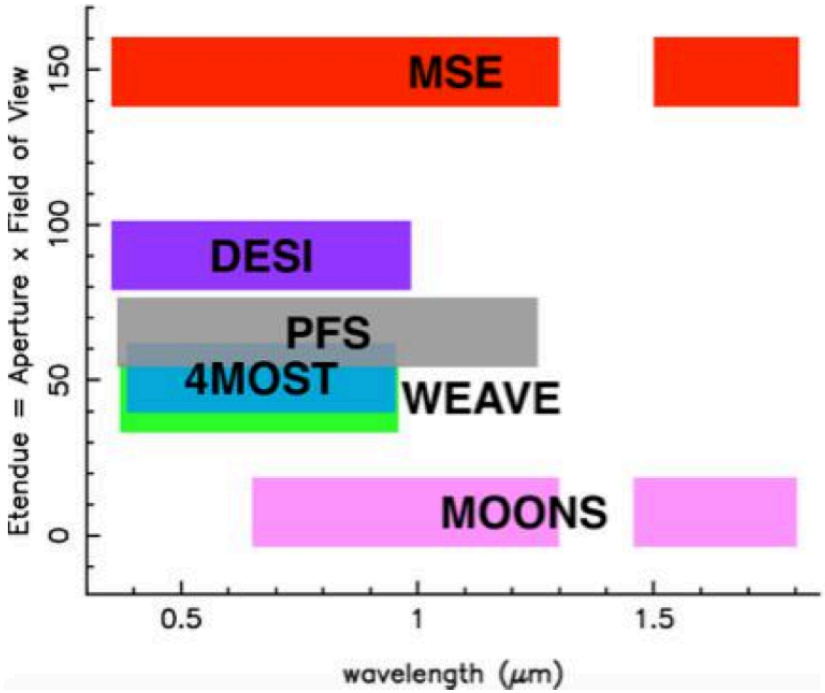
Allende Prieto 2016

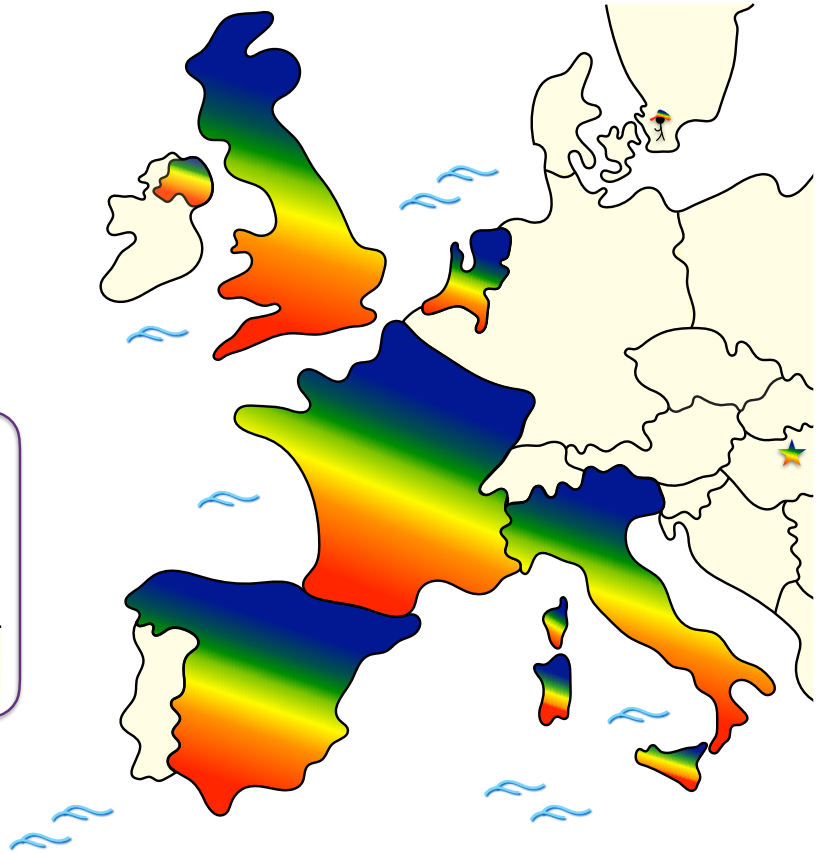


MSE science case



L. Magrini, Spectral Fidelity Workshop, 2023





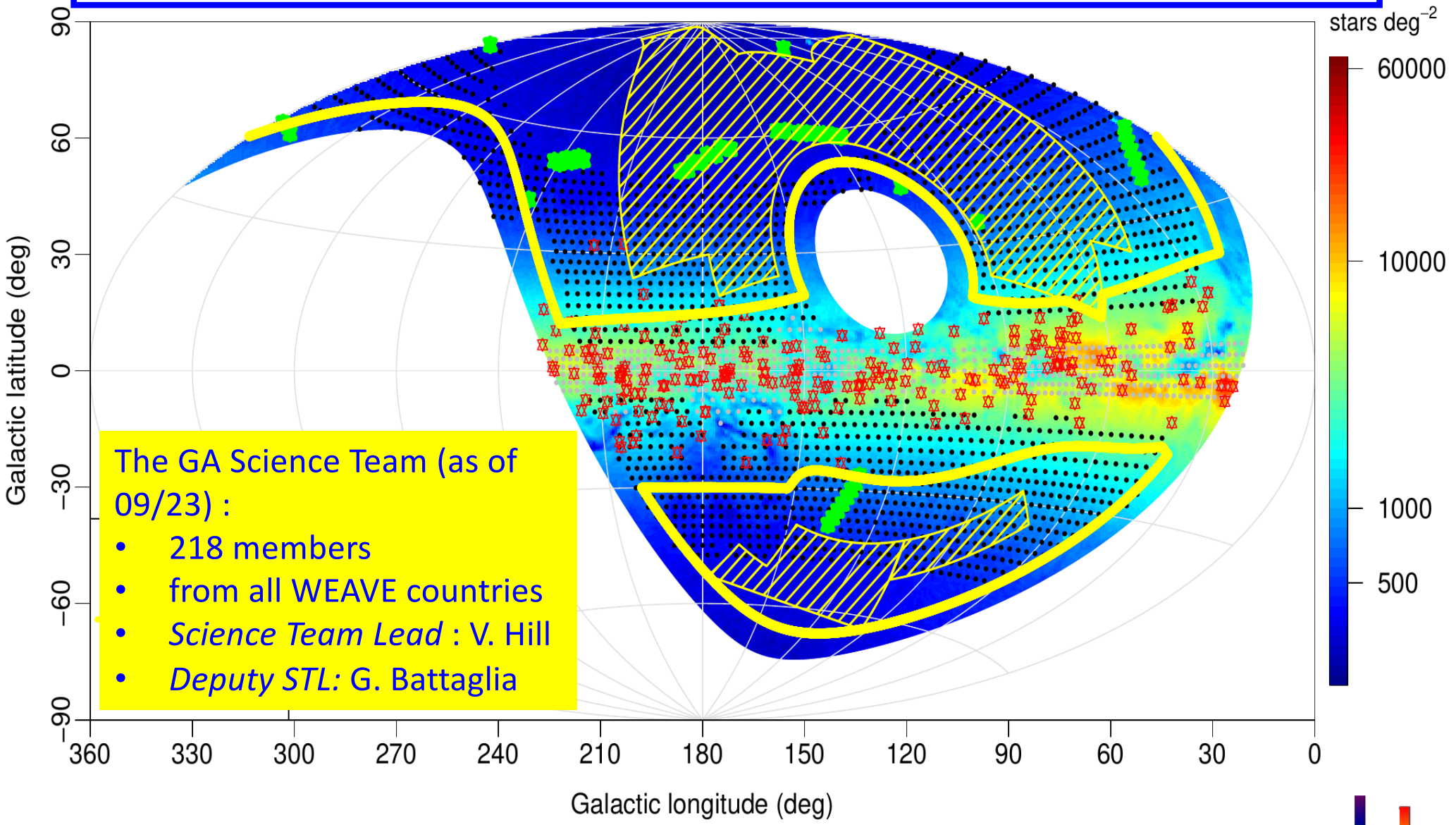
WEAVE Consortium Members | June 2016 | Shoko Jin

@WHT

WEAVE:

a wide field MOS in the North

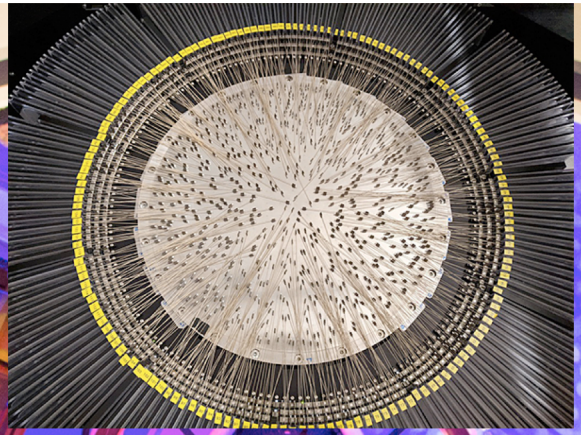
The WEAVE Galactic Archaeology surveys



The GA Science Team (as of 09/23) :

- 218 members
- from all WEAVE countries
- *Science Team Lead* : V. Hill
- *Deputy STL:* G. Battaglia

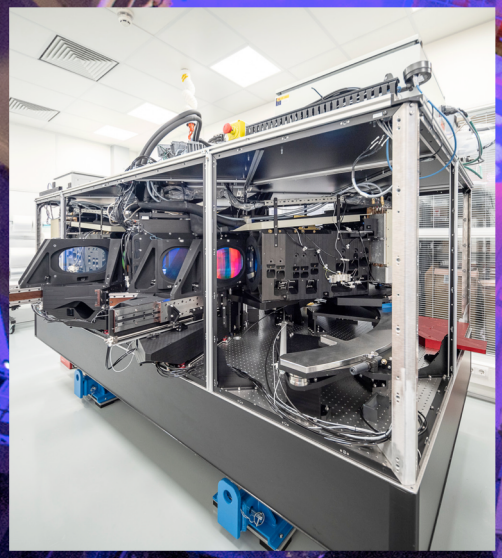

WEAVE
inauguration
30/11/2023
V. Hill, Paraty IAUS395, "Beatriz' fest"



WEAVE inauguration 30/11/2023

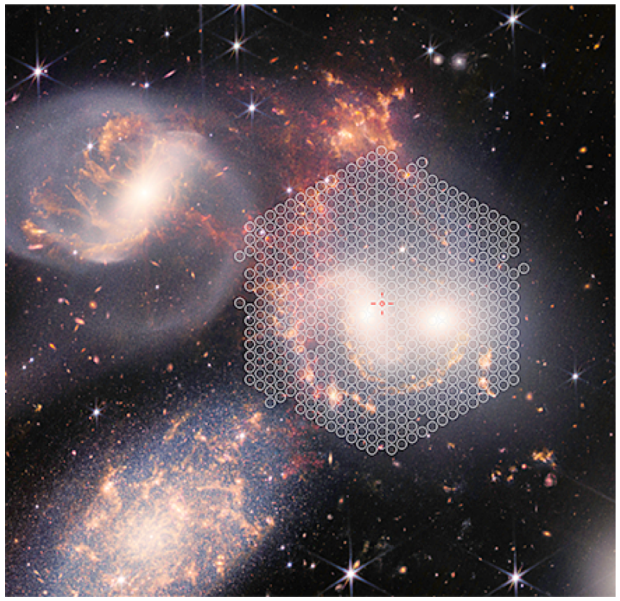
V. Hill, Paraty IAUS395, "Beatriz' fest"

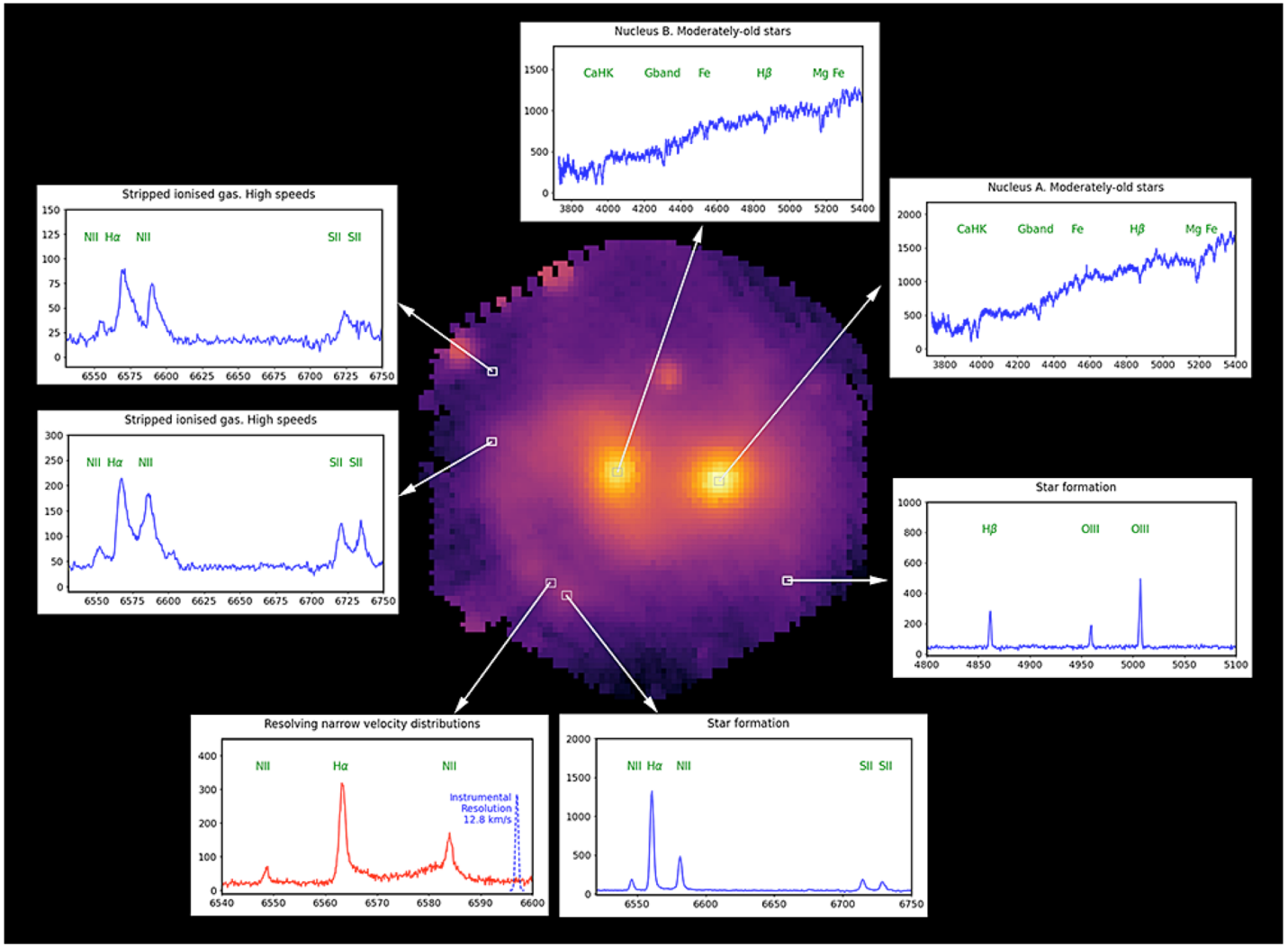
WEAVE
inauguration
30/11/2023



V. Hill, Paraty IAUS395, "Beatriz' fest"

WEAVE first light with the LIFU 12/2022

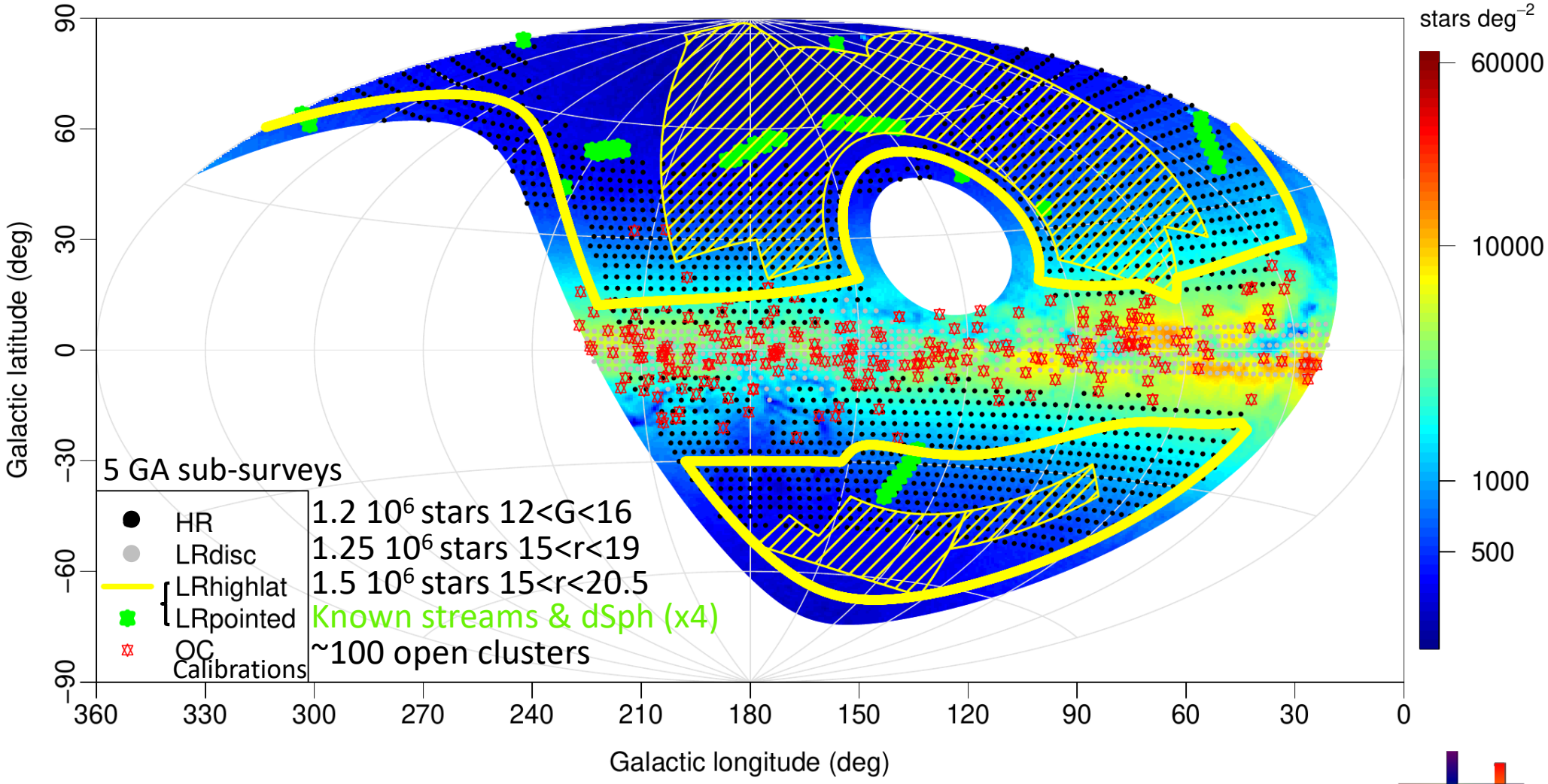




Building fast (and cheap)….

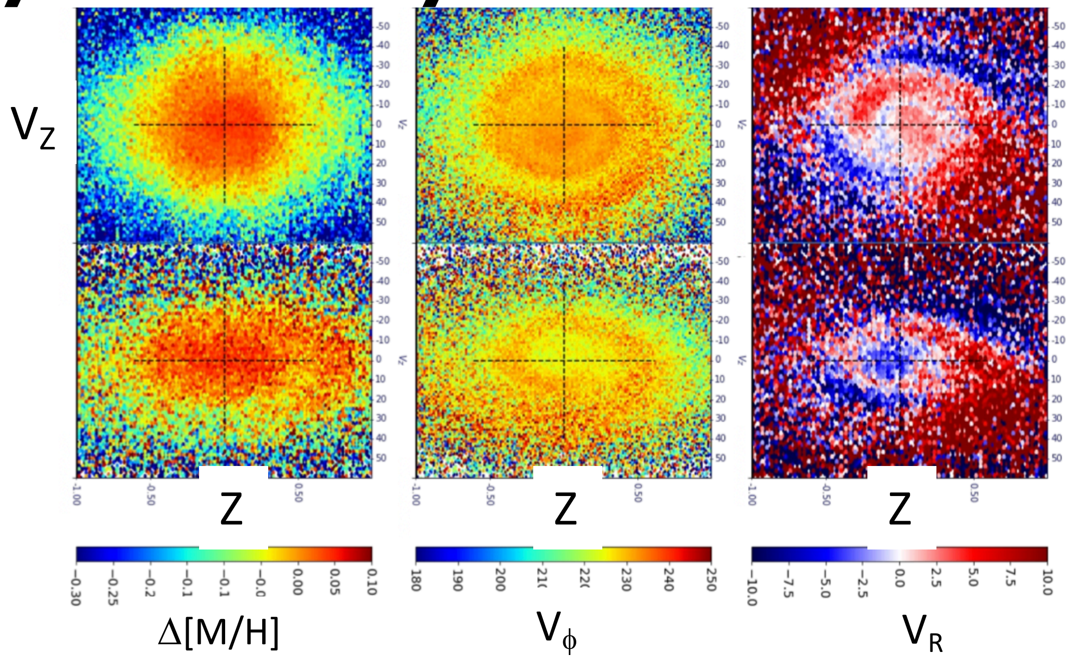
- WEAVE has no ground-braking new technologies, but ultimate pick and place; single spectrograph doing everything.
- MOS still not fully commissioned
  - Remaining issues with the SPECTRO:
    - optimisation of the IQ within spectrograph, under scrutiny and being solved by Tiger Team (from NOVA) and ING.
  - Remaining issues with the POS:
    - optimisation of positionning accuracy: now achieving positioning in spec (0.2-0.3”), configuration time still above whishes.
- Current schedule:
  - Science Verification of surveys Q2 2025
  - MOS surveys Q3 2025
  - Open Time (PI) programmes start at same time (30% of time)

WEAVE-GA surveys at glance

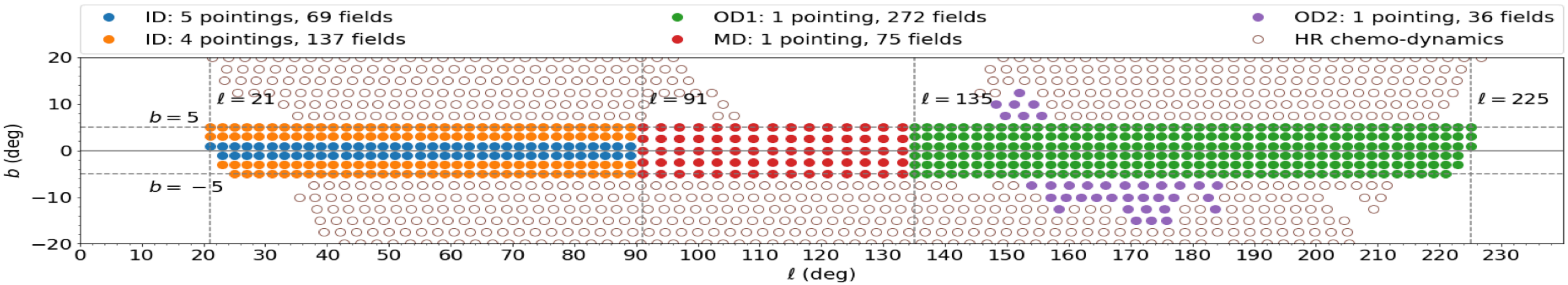


LR-Disc survey: disc dynamics

Discriminate fundamental aspects of galactic disc dynamics: moving groups, velocity elipsoid accross the disc ➔ probe non-axisymetric terms of the potential (bar, spiral arms). Implications for radial migration, dynamical processes in discs, disc response to accretions, etc.

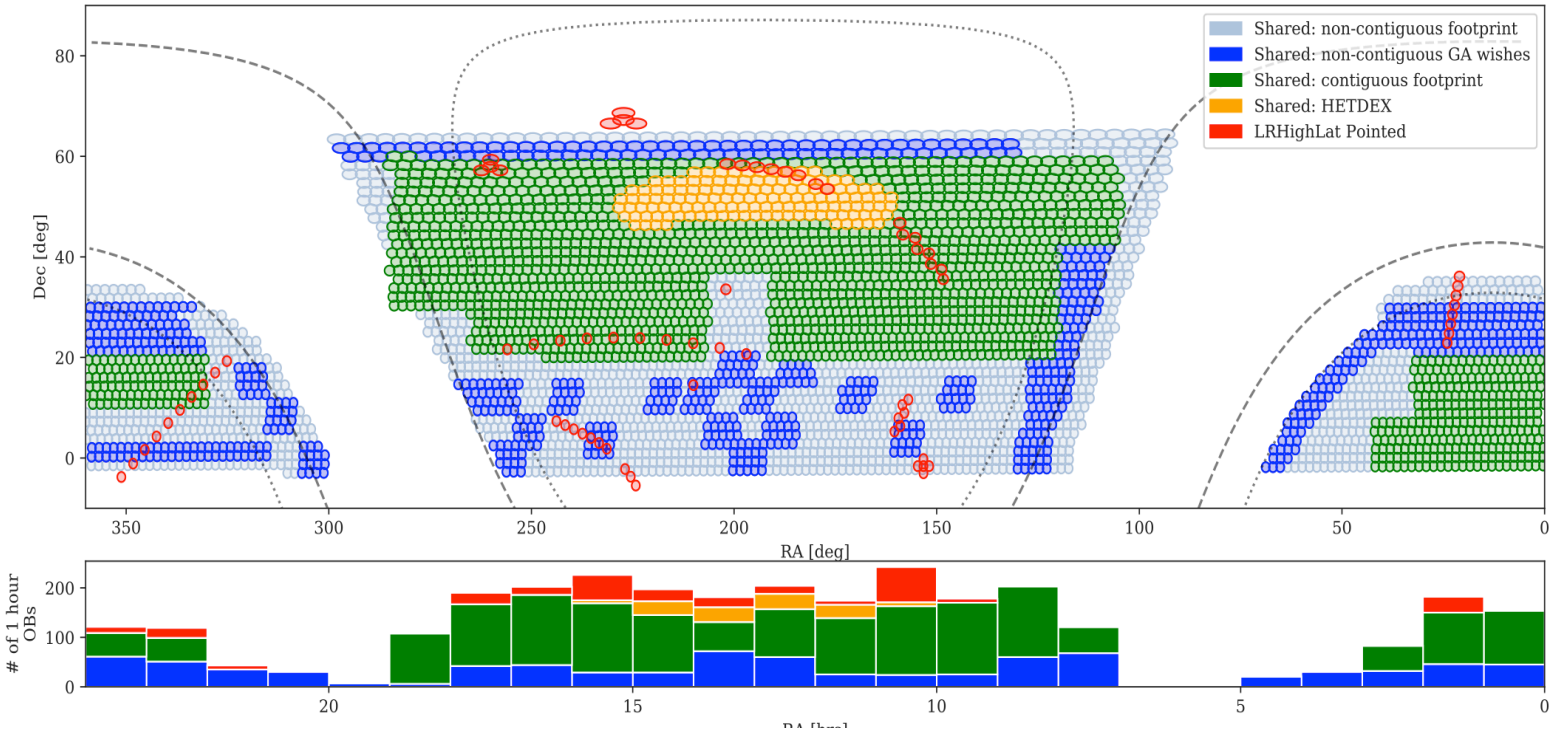


Antoja+ 2019, Recio-Blanco+ 2022



- For a total of ~1.1 10^6 stars
  - Red Clump stars in the inner disc (ID and MD) (colour-magnitude selected in PanSTARRS) to r<=19; Giants in the outer disc (Gaia M_G selected) to G<=18

High latitude LR survey: wide-area



Wide-area = Shared area = GA combined with cosmological surveys (LOFAR, QSOs) → footprint defined jointly, with dependencies on LOFAR LOTTS, JPAS, (Pristine) availability.

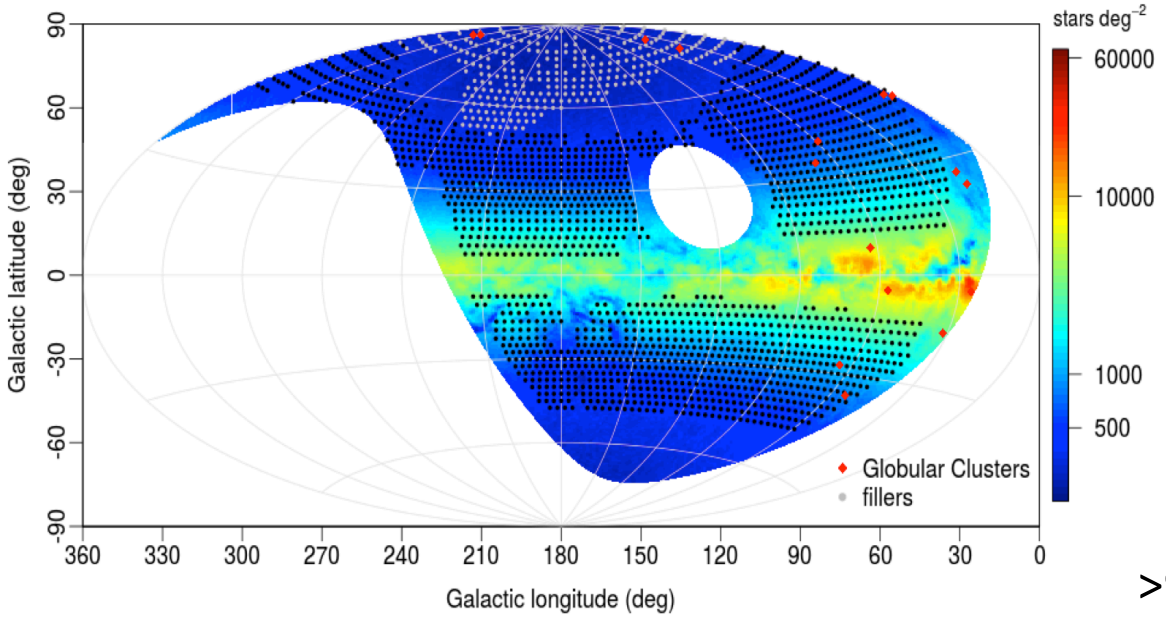
- 6000 (5yrs) to 8500 (7yrs) deg^2 with |b|>20-30°, down to r = 20-21
- Tracers: MSTO (colour-based) and giants (colours + Gaia π, ppm) + BHB, RRLyr, hypervelocity stars, EMP candidates (from Pristine + other sources), known streams & faint dwarf galaxies candidate members

Expected outcome

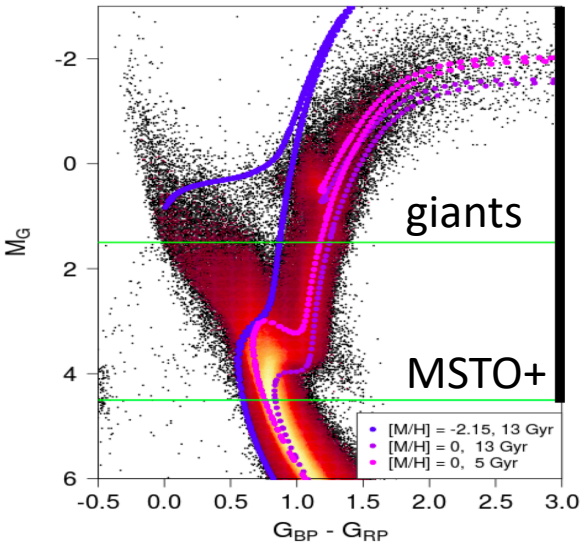
Halo: ~1-2.10^5 halo giants out to ~100kpc; ~3.5.10^5 halo MSTO out to ~30kpc; ~4.10^4 BHB/EMP candidates

Thick disc: ~6x10^5 stars

HR baseline survey



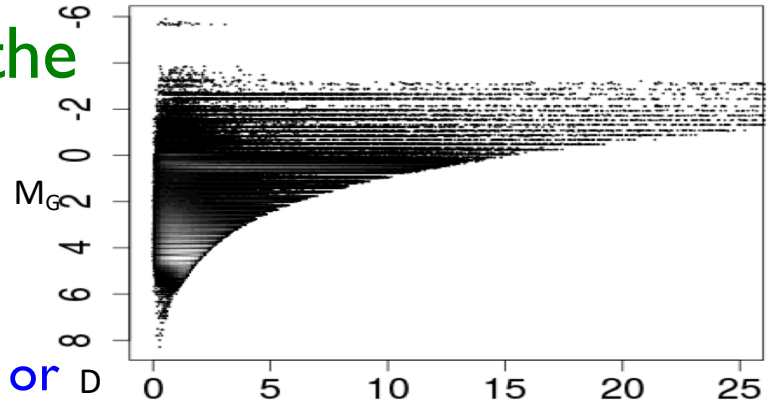
Targets selected from Gaia DR3 M_G



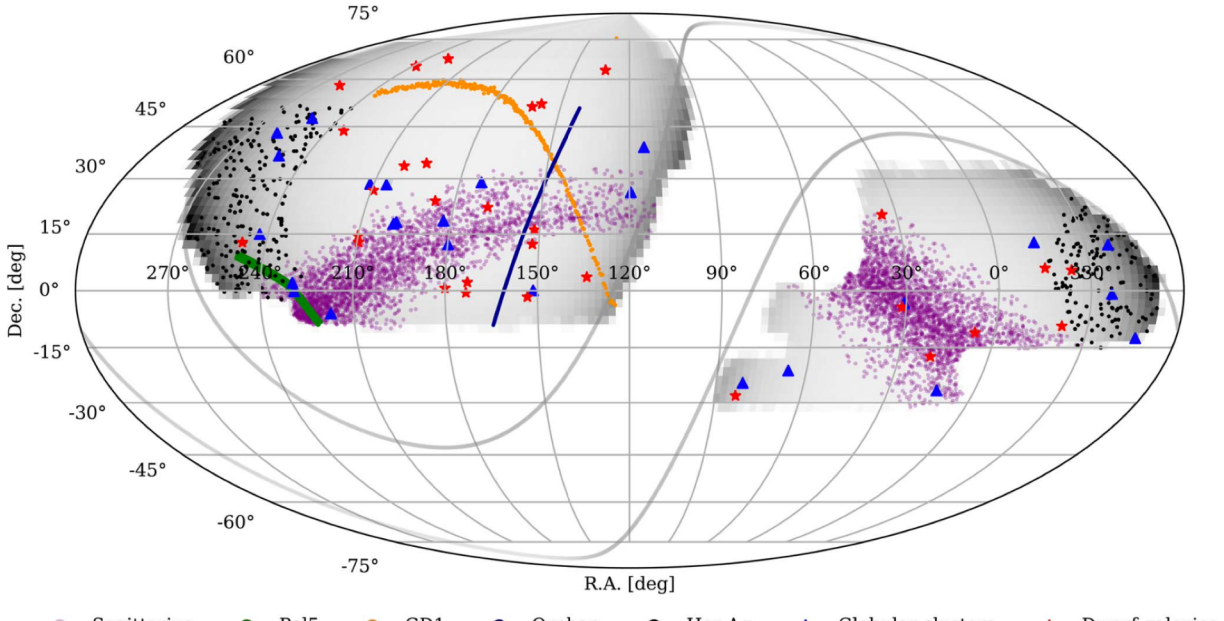
Baseline: A_0<1.0 & M_G<4.5 & G<16. Lower priority (used at high |b|): allow M_G<6 & G<17.

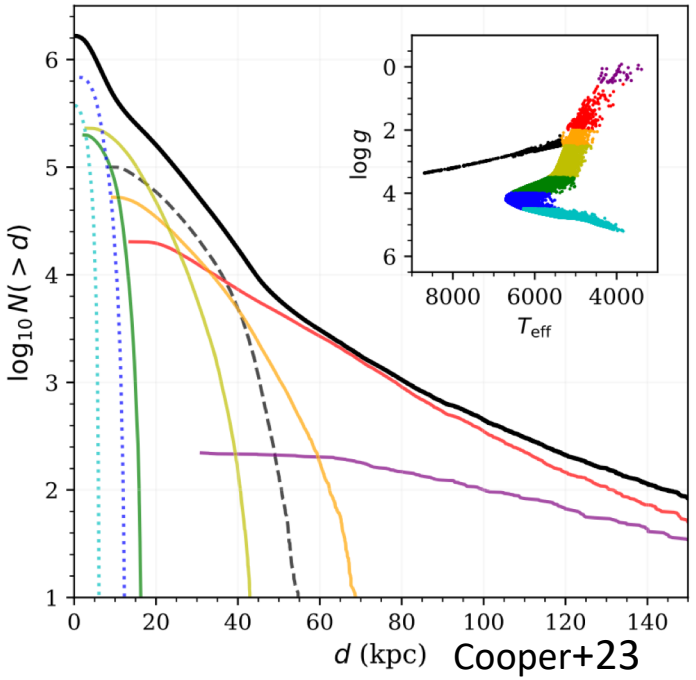
>90% of WEAVE GA-HR have σ_π/π<20%

- ~10^6 MSTO + SG out to 1-2kpc stars
- >2.10^5 giants reaching out through the thick disc
- Incl. ~10^5 halo candidates (mostly giants), with higher priority for
  - Stars with hot kinematics (evaluated in 5 or 6D)
  - Metal-poor giant candidates ([Fe/H]<-1.5, from Pristine, Martin+23 and other sources

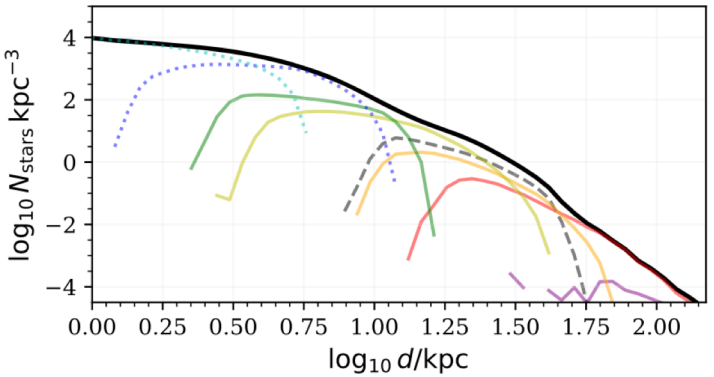


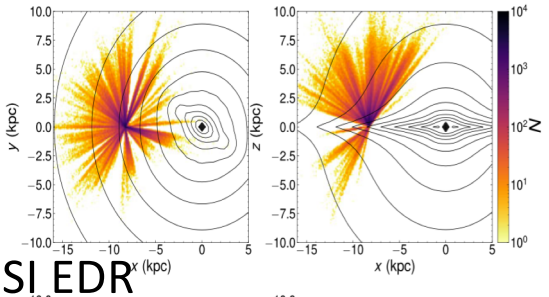
The DESI MW Survey



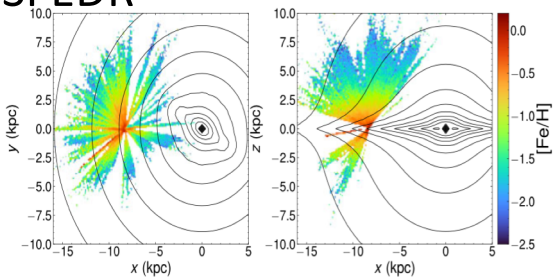


Cooper+23





DESI EDR



Koposov+24

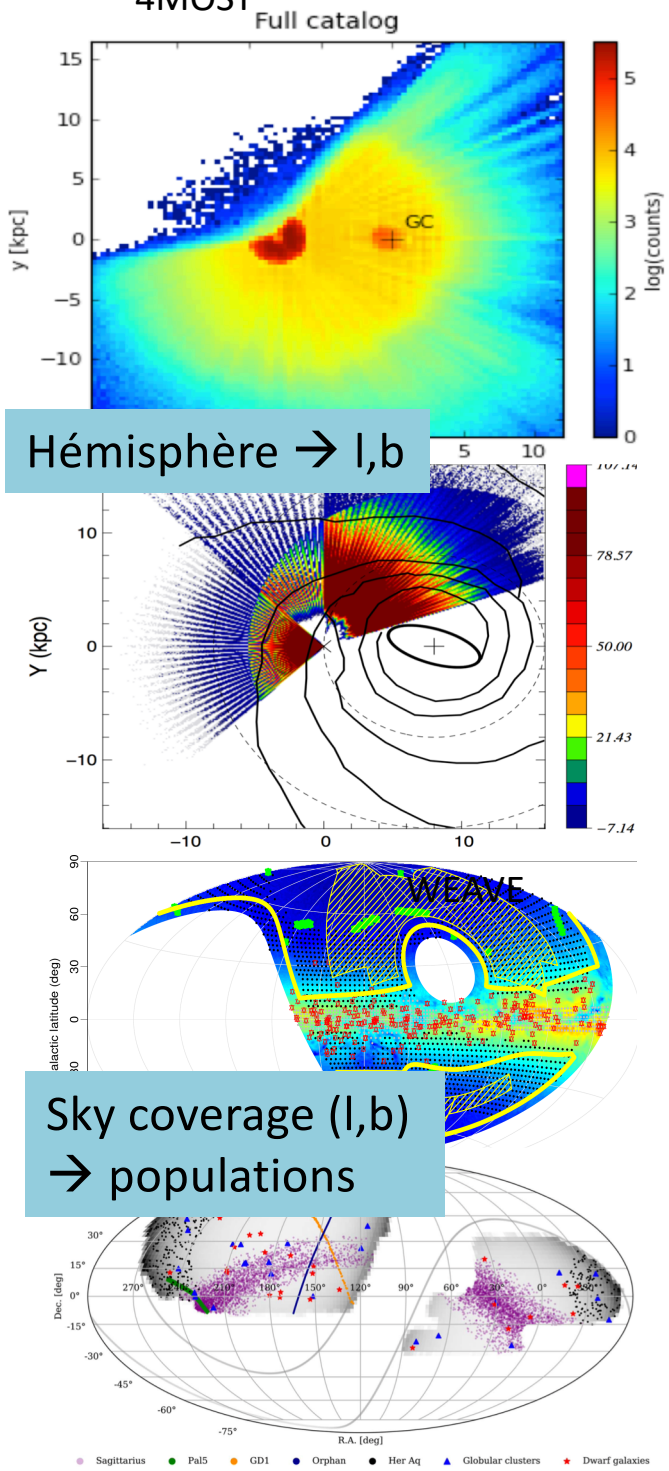
MWS: flux-limited sample of ~7 million stellar spectra, to a magnitude limit r<~19 over 5 yr, and much more if extended by 5-10 more yr.

→ EDR out, DR1 in ~1yr.

V. Hill, Paraty IAUS395, "Beatriz' fest"

Synergies

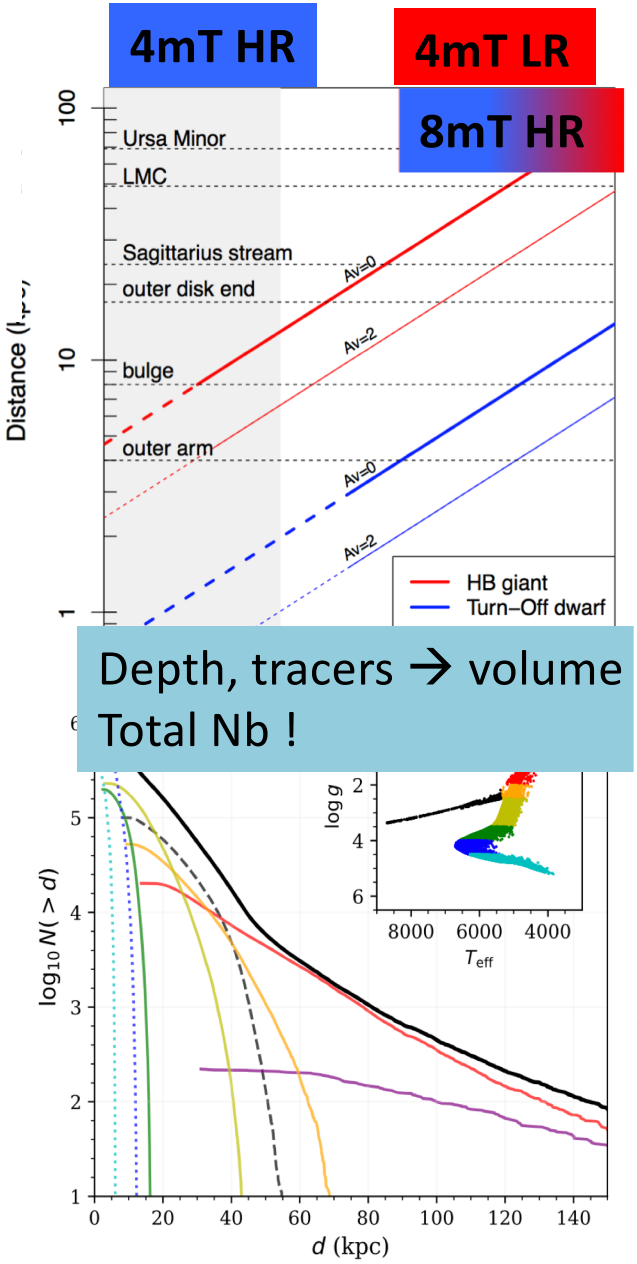
4MOST



Hémisphère → l,b

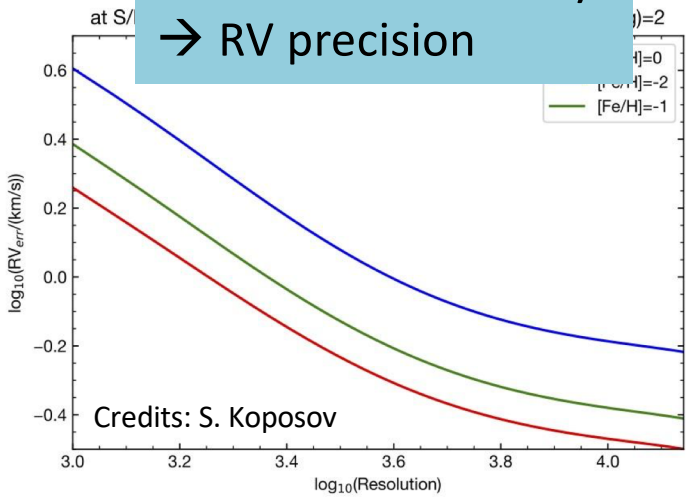
Sky coverage (l,b)
→ populations

SDSS-V
MW-mapper

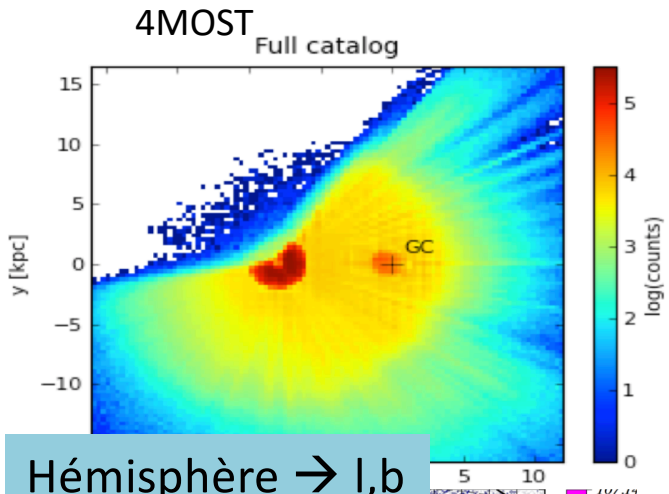


Depth, tracers → volume
Total Nb !

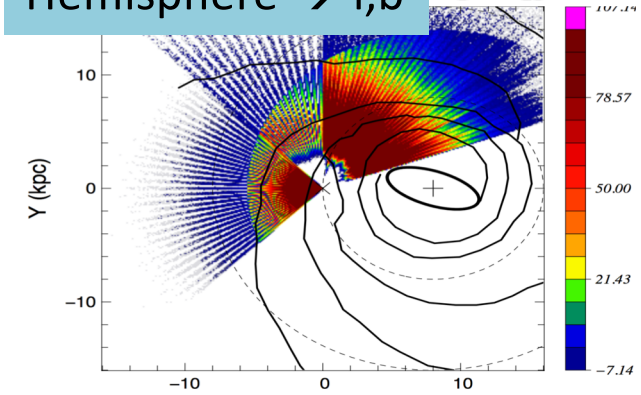
R, λ:
→ chemical precision
→ chemical diversity
→ RV precision

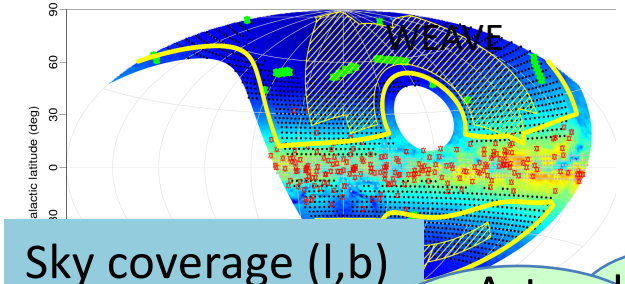


Synergies

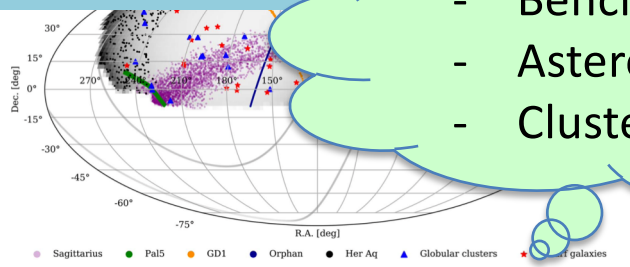


Hémisphère → l,b

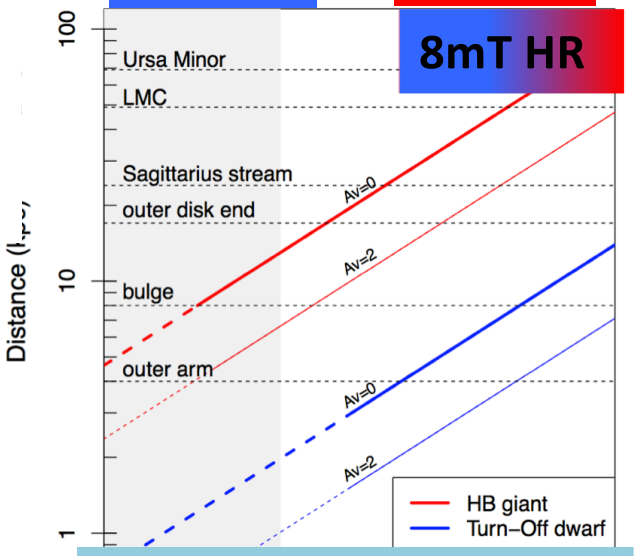




Sky coverage (l,b)
→ populations

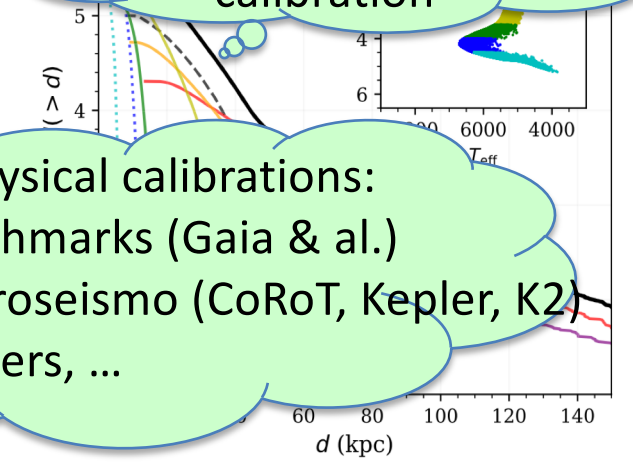


4mT HR
4mT LR
8mT HR



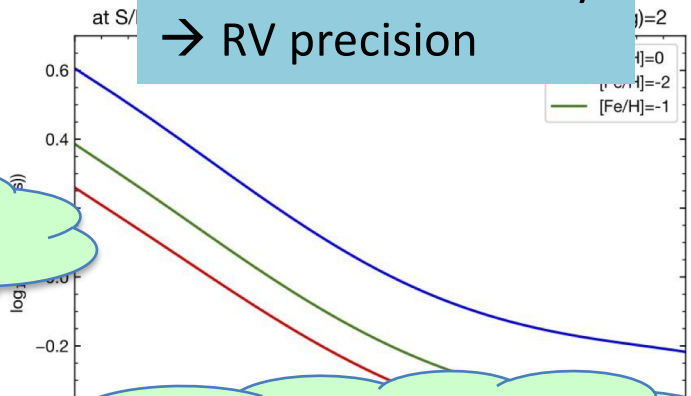
Depth, tracers → volume

Survey overlap for cross-calibration



Astrophysical calibrations:
- Benchmarks (Gaia & al.)
- Asteroseismo (CoRoT, Kepler, K2)
- Clusters, …

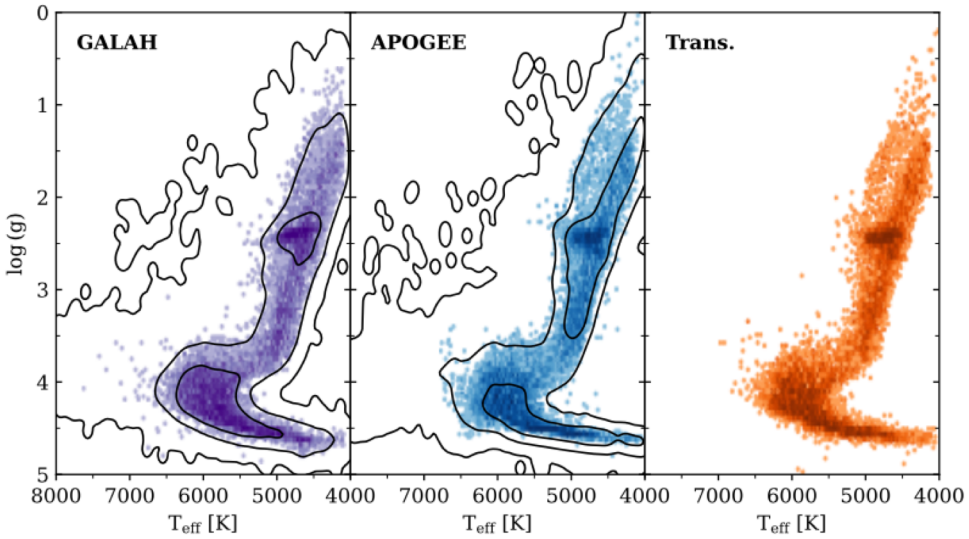
R, λ:
→ chemical precision
→ chemical diversity
→ RV precision

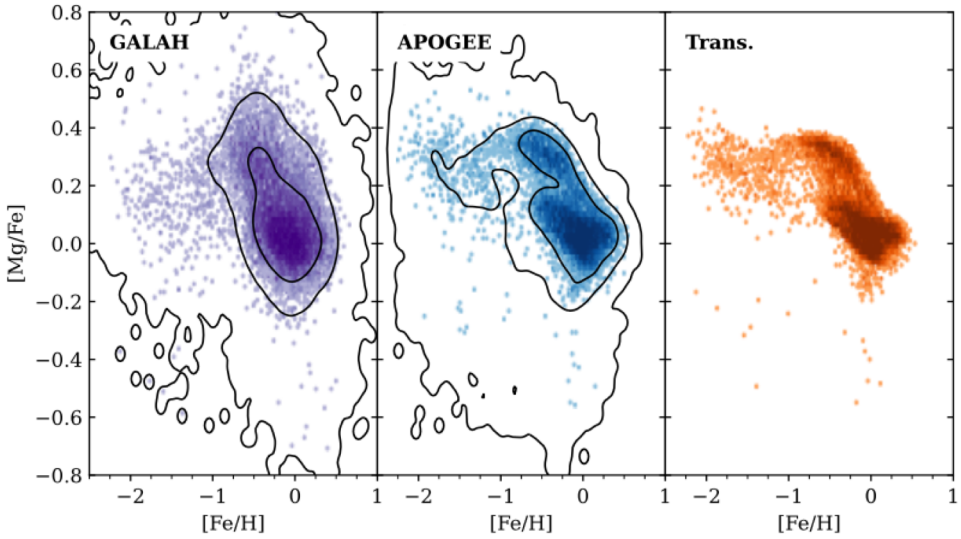


Spectro analysis methods

Data mining methods

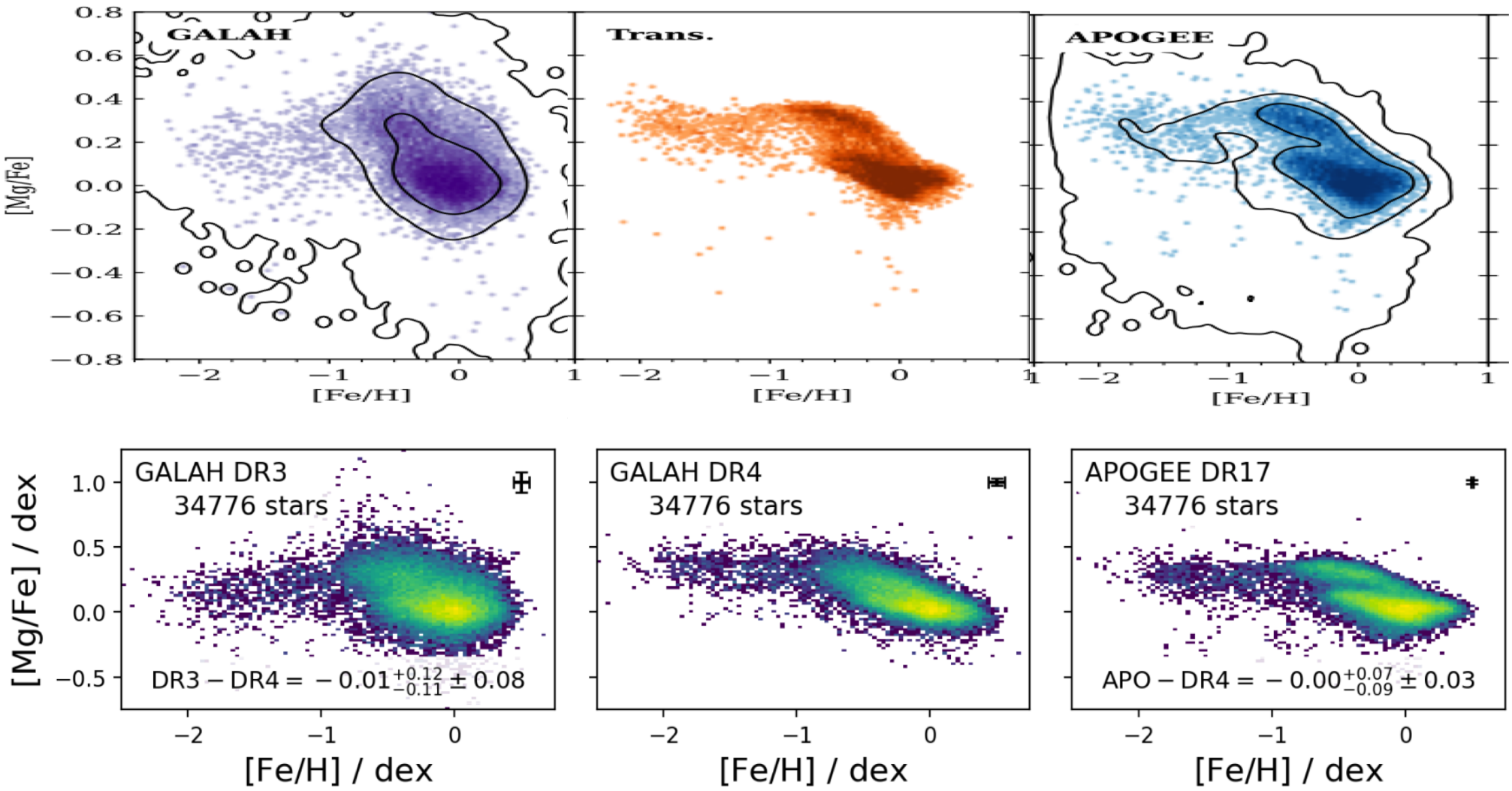
Homogenizing survey results





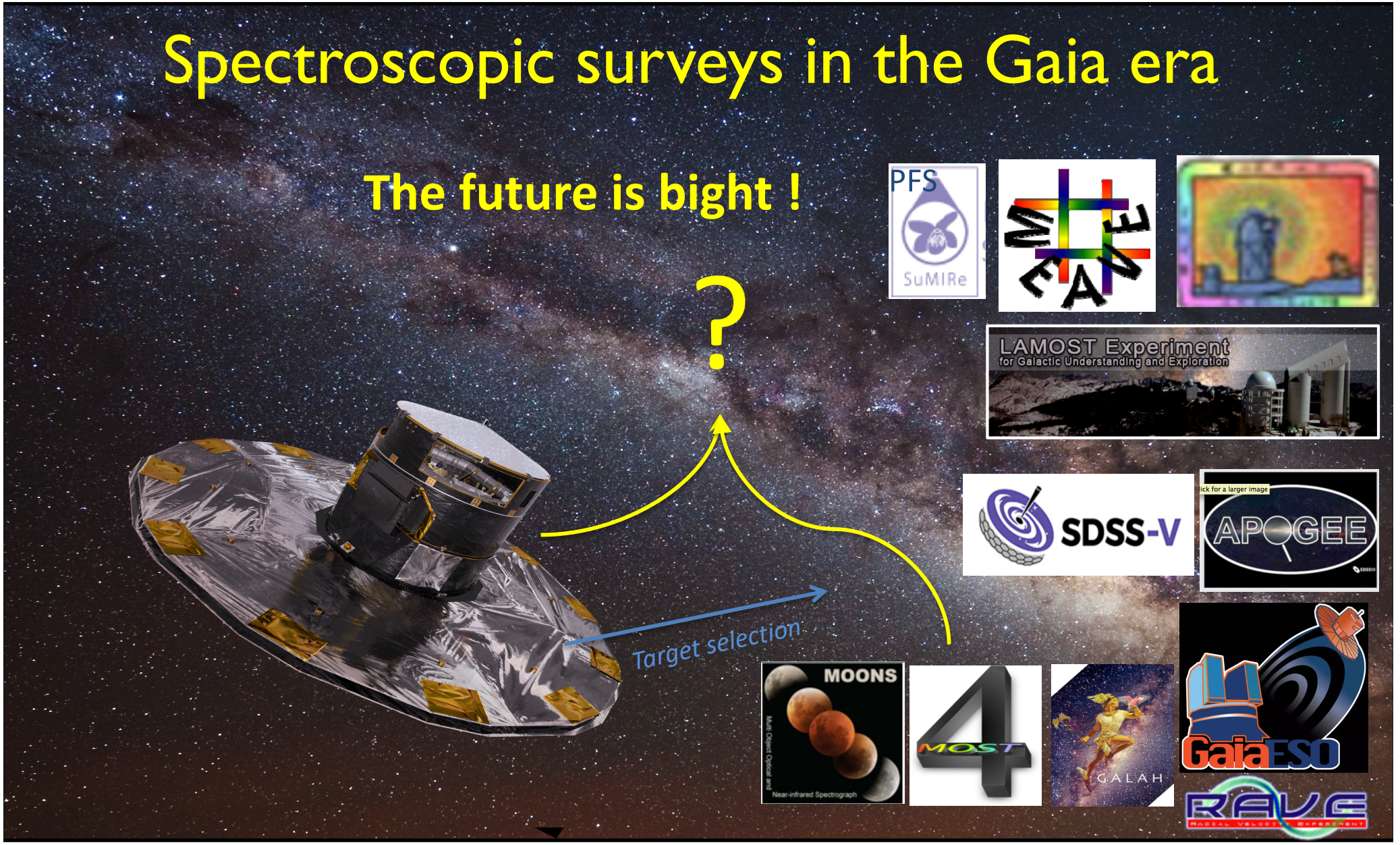
Thomas et al. 2024

- Transferring *labels* from one survey to another:
  - Using the spectra: eg. using TheCannon Nandakumar+22, Barun-Das+24
  - Using labels: eg. SpectroTranslator (Thomas+24, neural networks), Gran in prep. (), Pancino+24 (photometric)
- Classical polynomial relations (eg. Tsantakis+ for RVs), Bayesian inference methods (eg. Worley+24 on the GES highly heterogeneous and incomplete dataset)



- Feature enhancements in ML (NN or others)
- Fate of (astrophysical) outliers ?
- Label or physical quantities ?

Spectroscopic surveys in the Gaia era



Summary of Completed and Ongoing Stellar Spectroscopic Surveys with $\gtrsim 10^5$ Targets, Discussed in Section 2

Survey	$N_{star}/10^6$	Mag. Range	R	λ (Å)	Release	Reference
DESI MWS	7.2[a]	$16 < r < 20$	2500–5000	3600–9900	…	…
SEGUE I	0.2	$16 < r < 20$	1850–2200	3800–9200	DR17	Yanny et al. (2009)
SEGUE II	0.1	$16 < r < 20$	1850–2200	3800–9200	DR17	Rockosi et al. (2022)
LAMOST LRS	1.8[b]	$16 < G < 18$[c]	≈1800	3700–9000	DR8	Luo et al. (2015)
	5.0[d]	$10 < G < 16$	≈1800	3700–9000	DR8	Luo et al. (2015)
LAMOST MRS	1.1	$10 < G < 15$	≈7500	4900–6800	DR8	Luo et al. (2015)
RAVE	0.5	$9 < I < 12$	7500	8410–8795	DR6	Steinmetz et al. (2020b)
Gaia RVS	33[e]	$G < 14$	11,500	8450–8720	DR3	Katz et al. (2022)
Gaia-ESO	0.1	$17 < r < 18$	20,000	3700–9500	DR5	Gilmore et al. (2012)
GALAH	0.6	$9 < V < 14$	20,000–50,000	4718–7890[f]	DR3	Buder et al. (2021)
APOGEE	0.7	$10 < G < 17$	22,500	15,140–16,960	DR17	Majewski et al. (2017)
H3	0.3	$15 < r < 18$	32,000	5150–5300	…	Conroy et al. (2019)