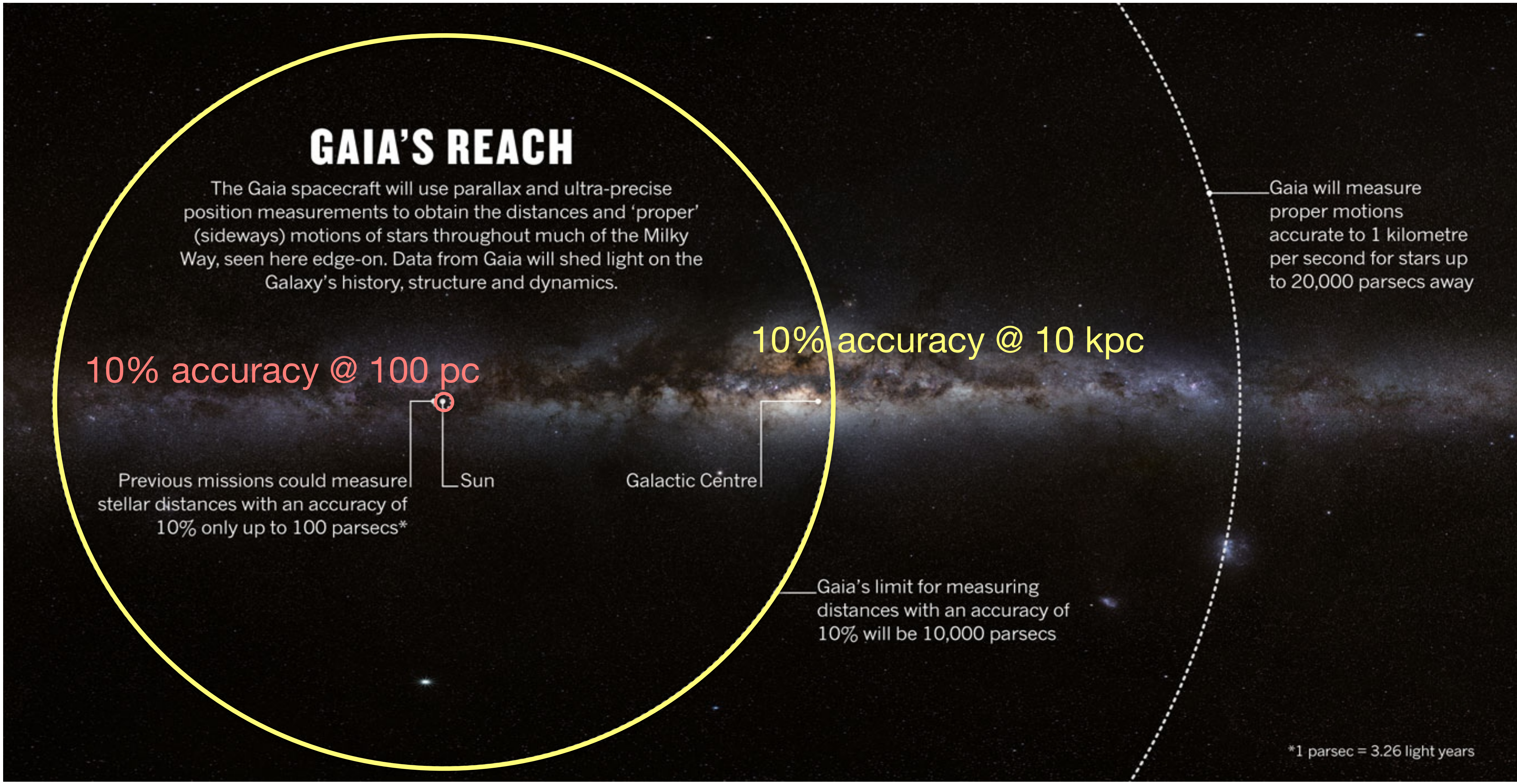
Ground-based follow up and their science cases

Sofia Feltzing
Lund Observatory

Gaia will "fix" the distances



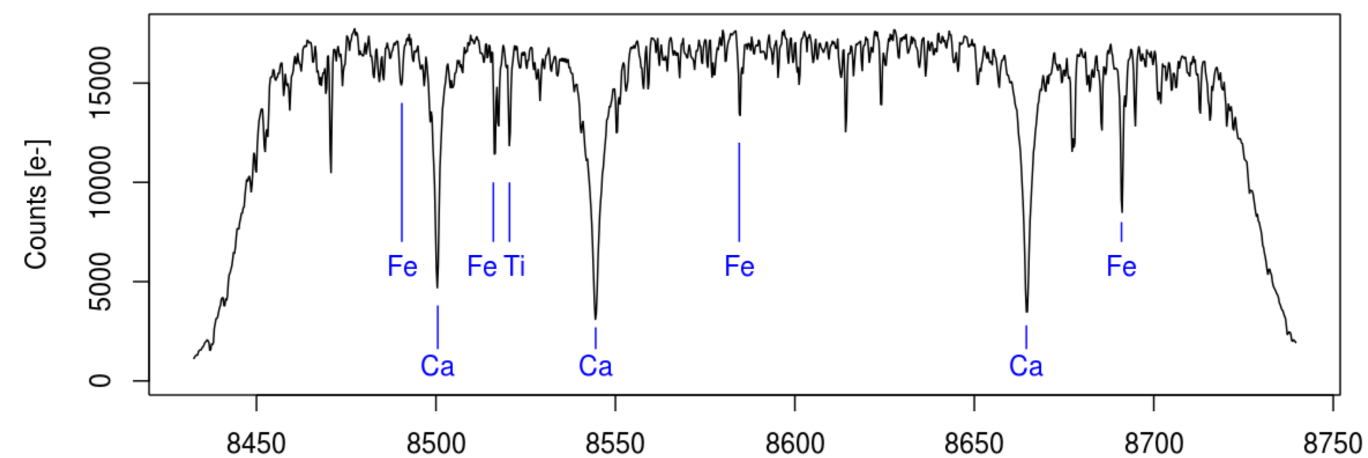
From A. Helmi @ ESO in 2020

Gaia's offerings

Spectral type	V [mag]	Vel. error [km s^{-1}]
B1V	7.5	1
	11.3	15
G2V	12.3	1
	15.2	15
K1III-MP (metal-poor)	12.8	1
	15.7	15

Need more (and longer) spectra at fainter magnitudes

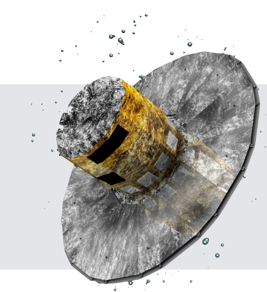
- RVs to ~15.5 (tip RGB in the Bulge)
- Abundances to ~12.5 (a sun at 300 pc)



http://www.cosmos.esa.int/web/gaia/science-performance

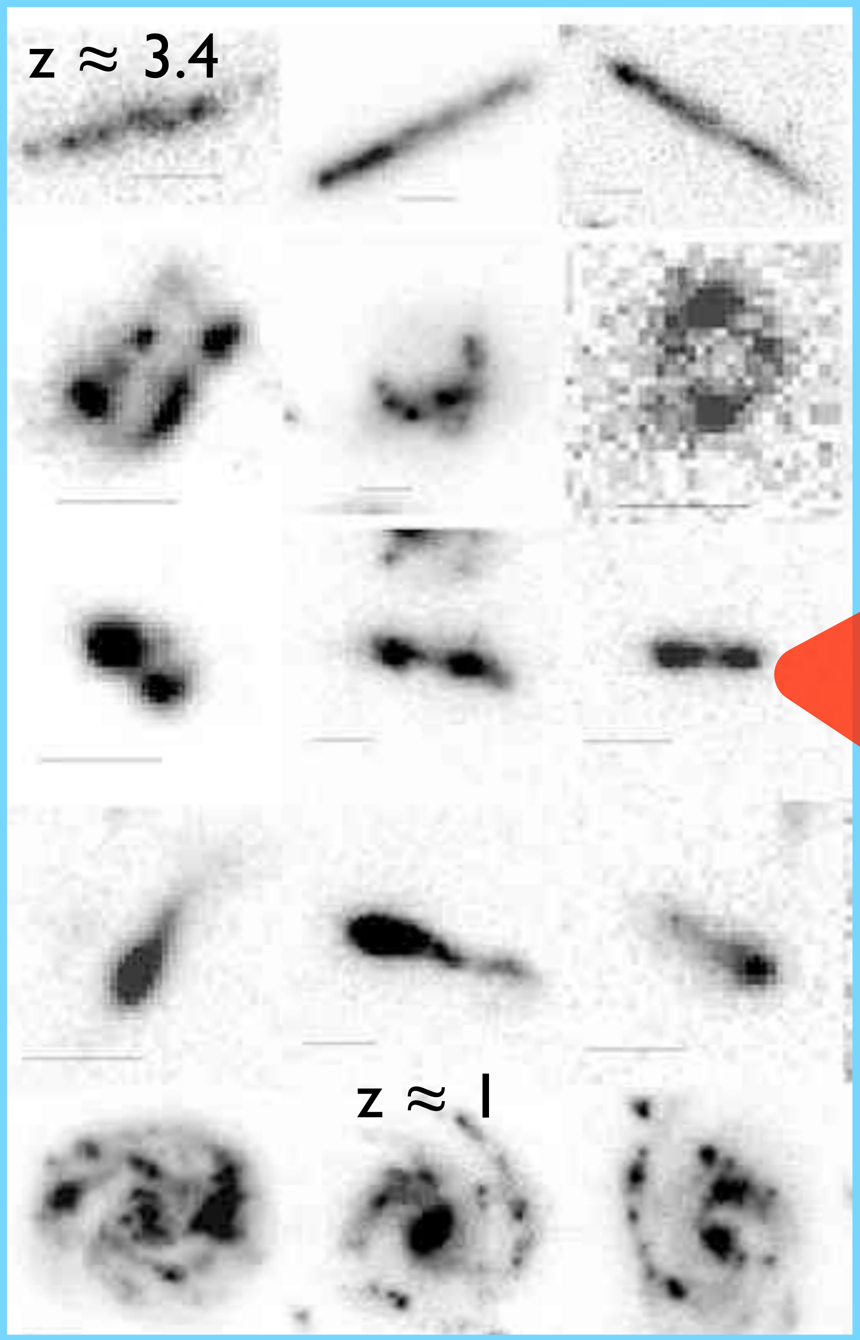
Recio-Blanco et al. 2016 A&A 585 A93

By ~2025

R (λ / Δλ)	λ-coverage	# stars	
> 2000	full UV-NIR	> 20 million	
> 5000	full UV-NIR	> 20 million	
	CaII NIR triplet	15% of all *Gaia* stars	
20 000	UV	~4-6 million	
20 000	NIR	~5 millions*	+ MOONS

*AS4/DISCO

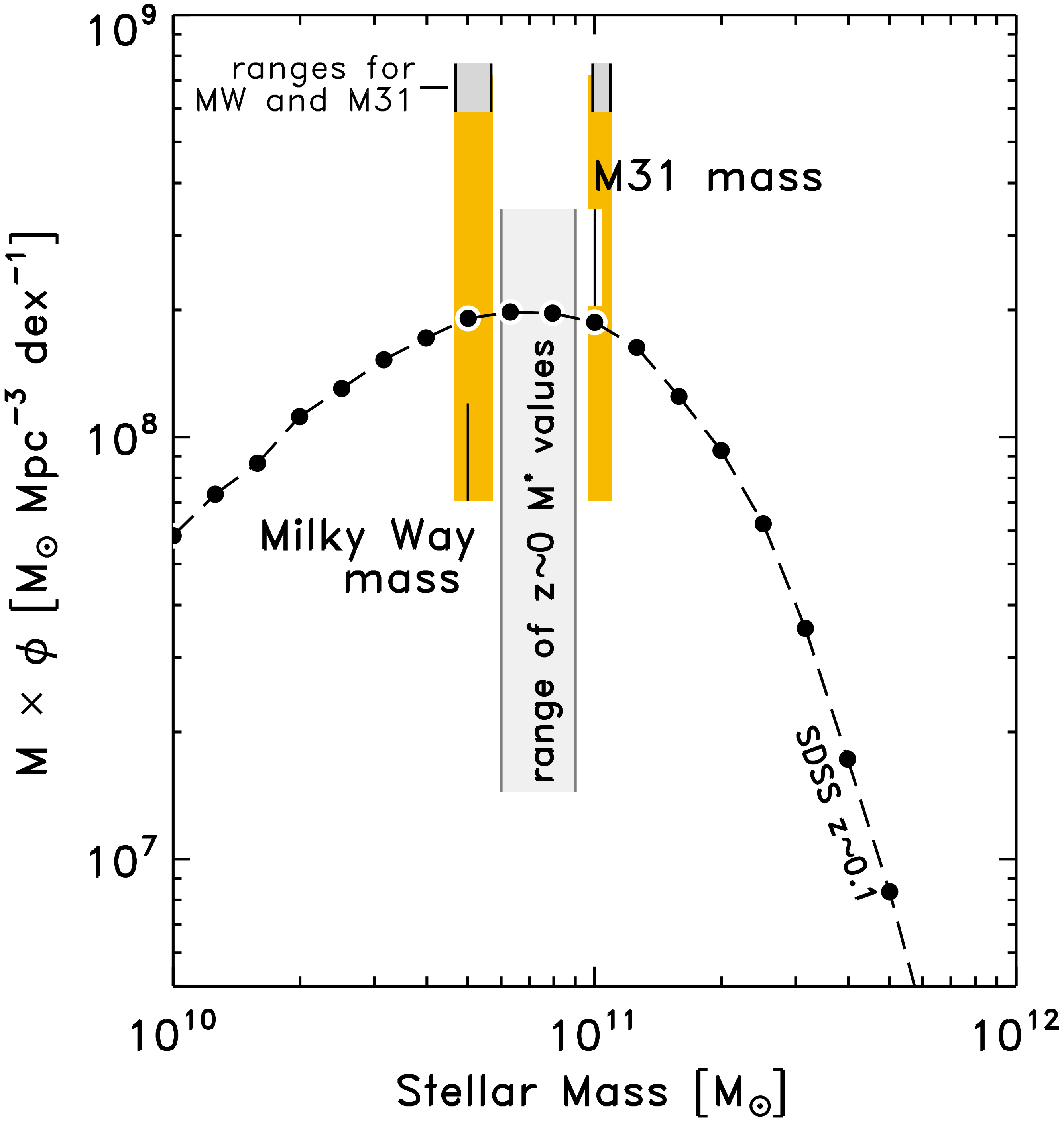
Why all this effort?



Age$_{Universe}$ ≈ 7 Gyr

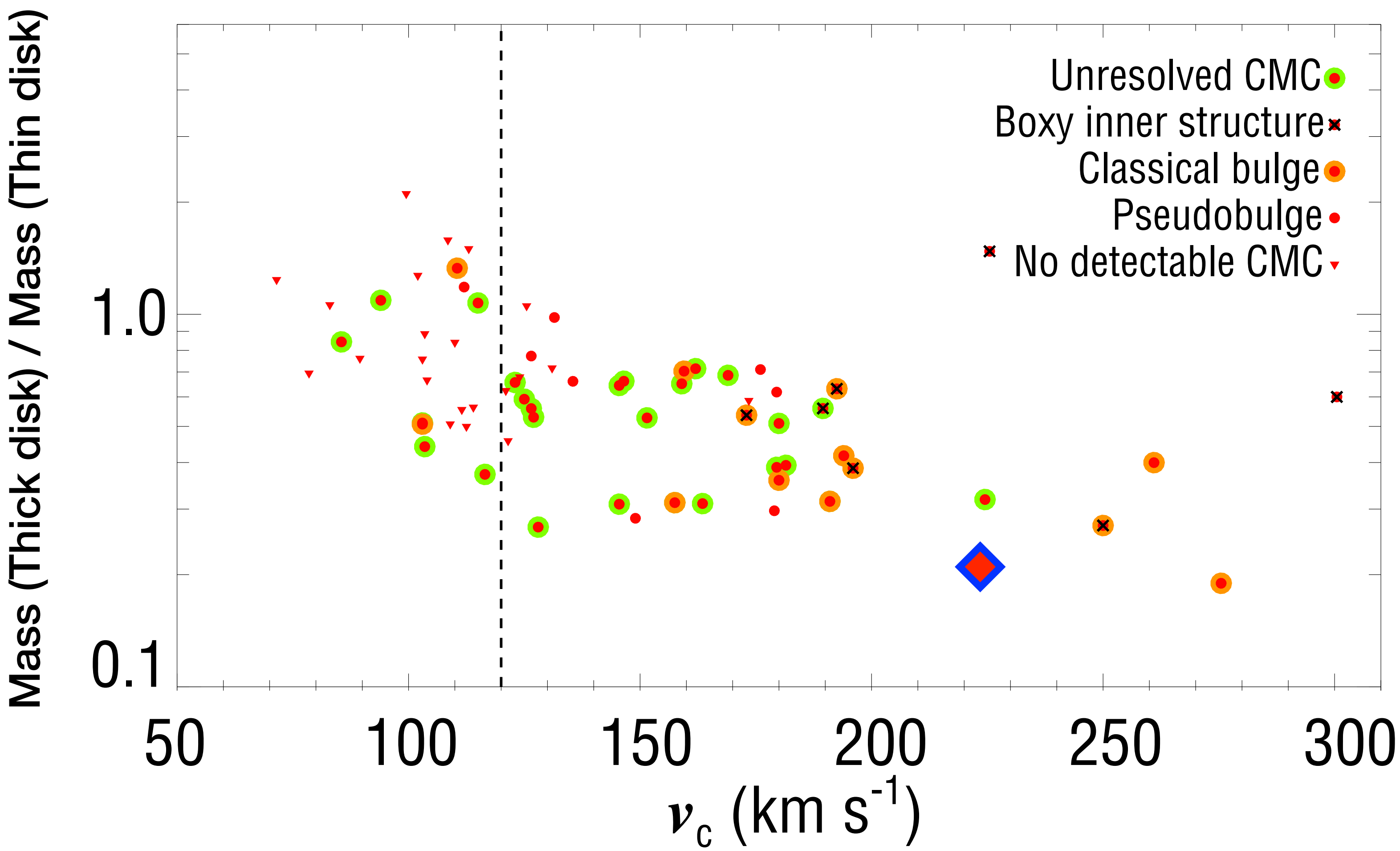
Elmegreen & Elmegreen (various)

MW and other galaxies



Papovich et al., 2015, ApJ 803 26

MW and other galaxies

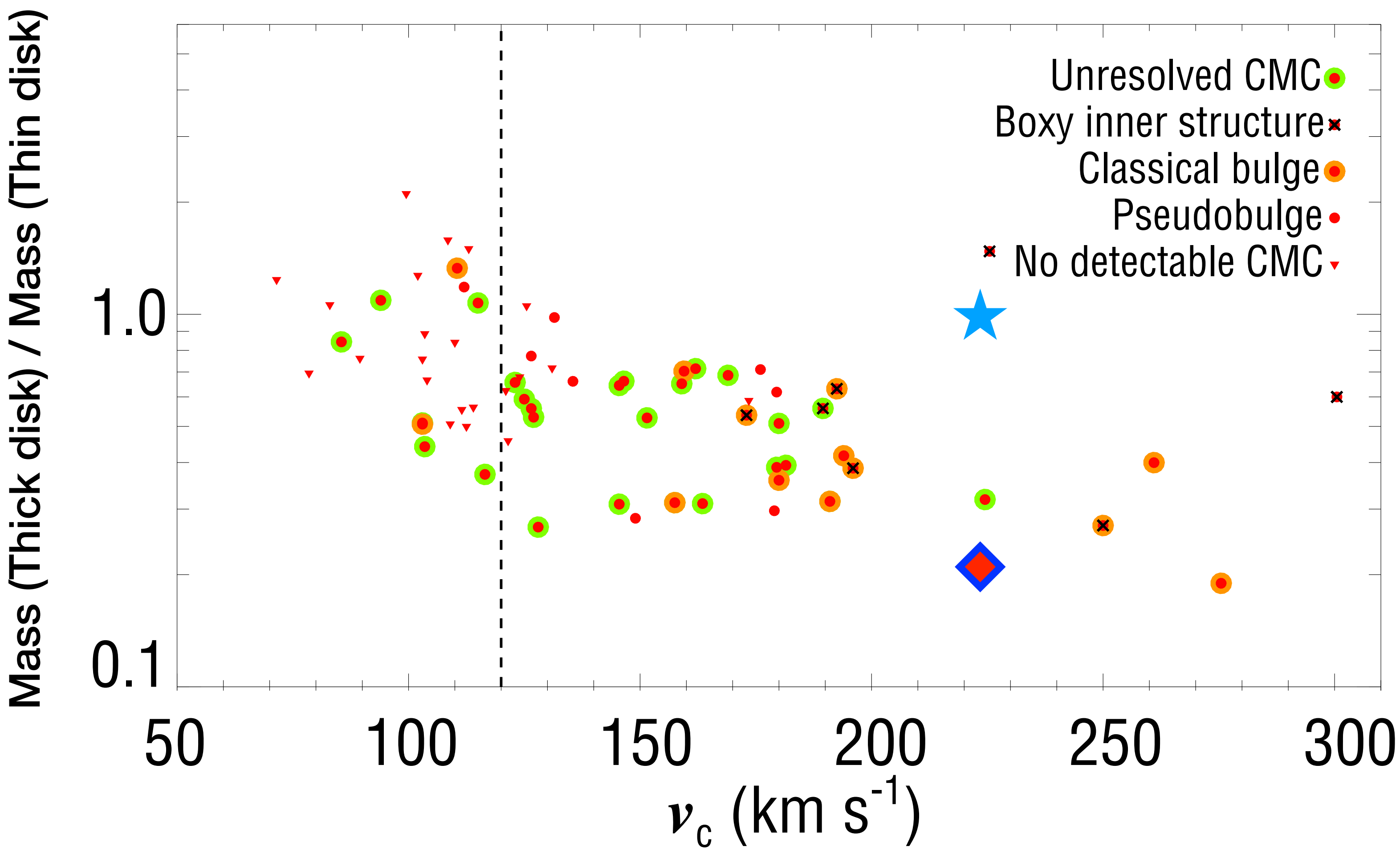


Milky Way
~0.2 @ 220 km/s

- Note - scale length of MW thick disk < thin disk
- In other galaxies not the case

Comerón et al., 2014, A&A <u>571</u> A58
Bland-Hawthorn & Gerhard, 2016, ARA&A 54, 529

MW and other galaxies

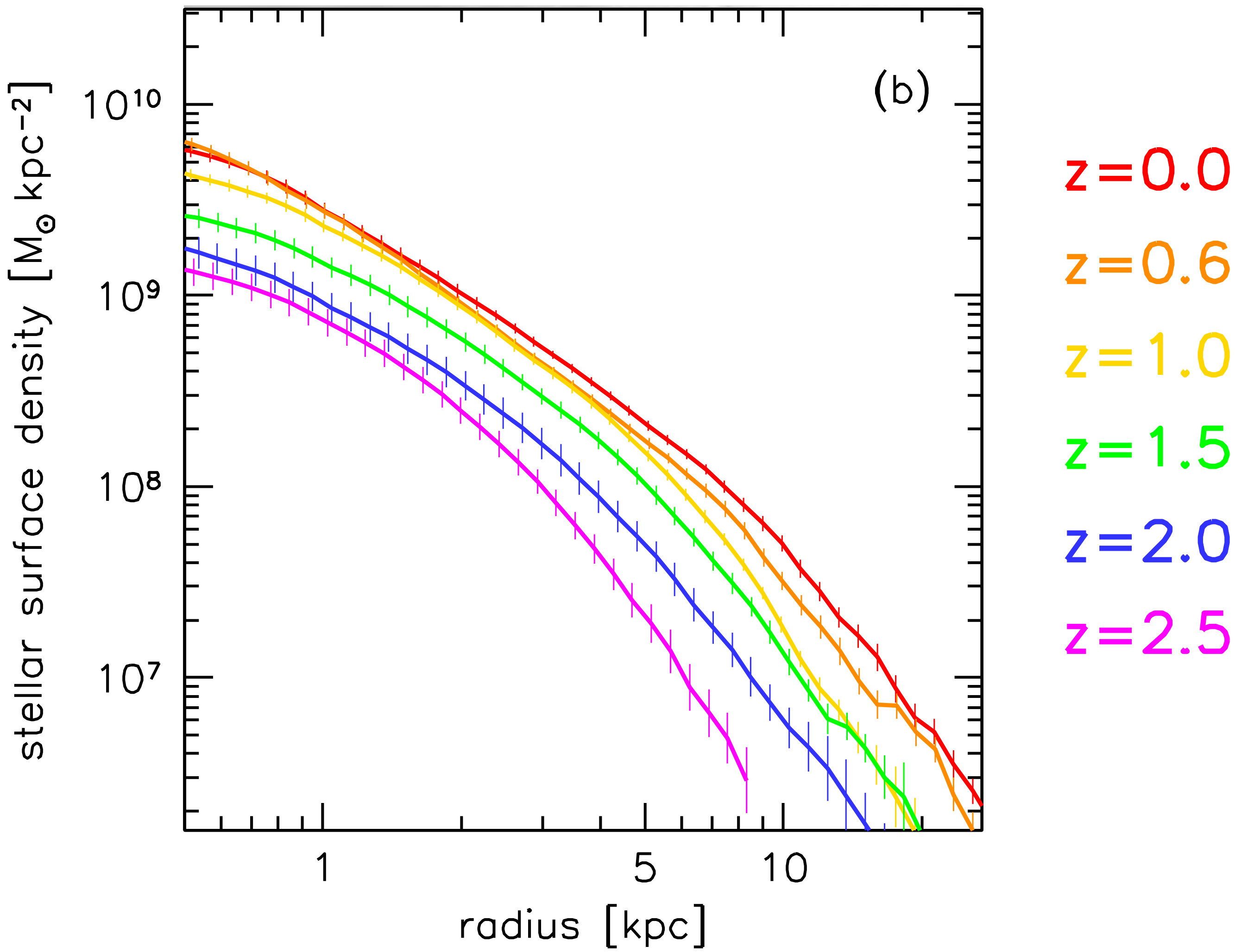


Milky Way
~1.0 @ 220 km/s

Milky Way
~0.2 @ 220 km/s

Snaith et al., 2014, ApJL, 781, L31

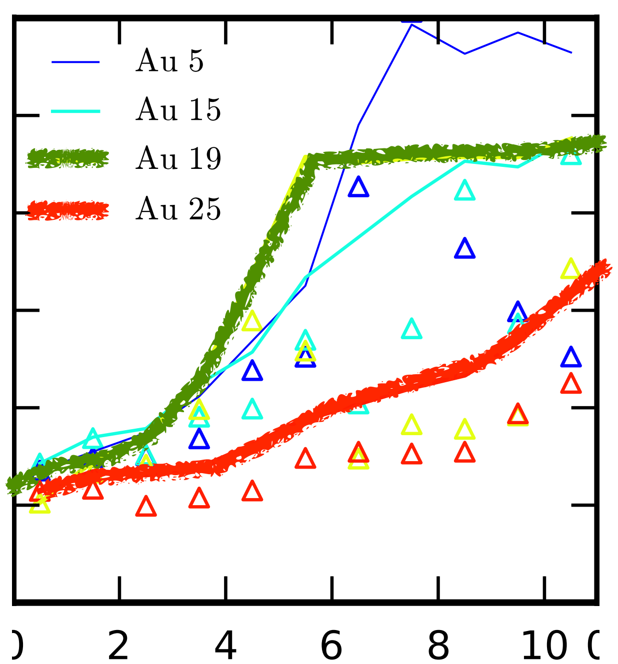
MW progenitors

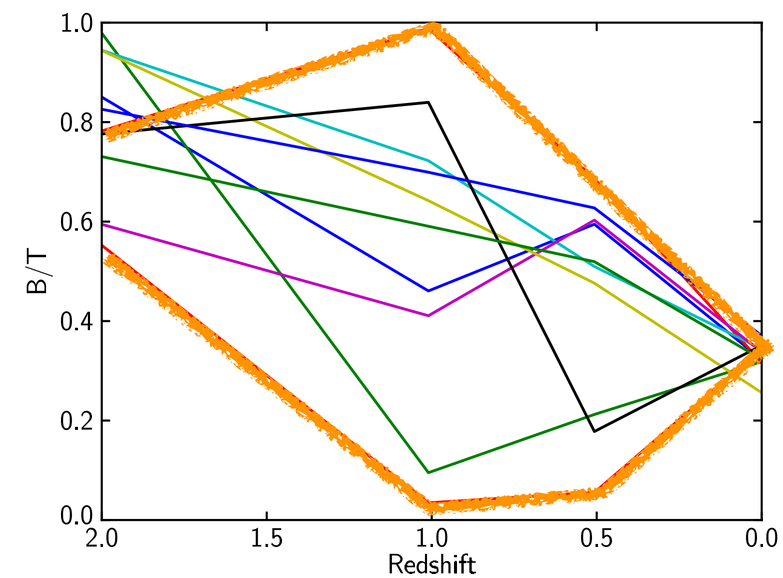


- More than half of the present-day mass was assembled in the 3 Gyrs between z = 2.5 and z = 1
- Build up of stellar mass at all radii until z ≈ 0.5

van Dokkum et al., 2013, ApJL 771 L35
Diemer et al. arXiv:1701.02308

Differing growth paths





Au19: Sharp increase when satellite hit. SFH shows stars accreted as well as formed in situ.

Au25: Slow, smooth build up of velocity dispersion. All stars formed in the galaxy and subsequently heated.

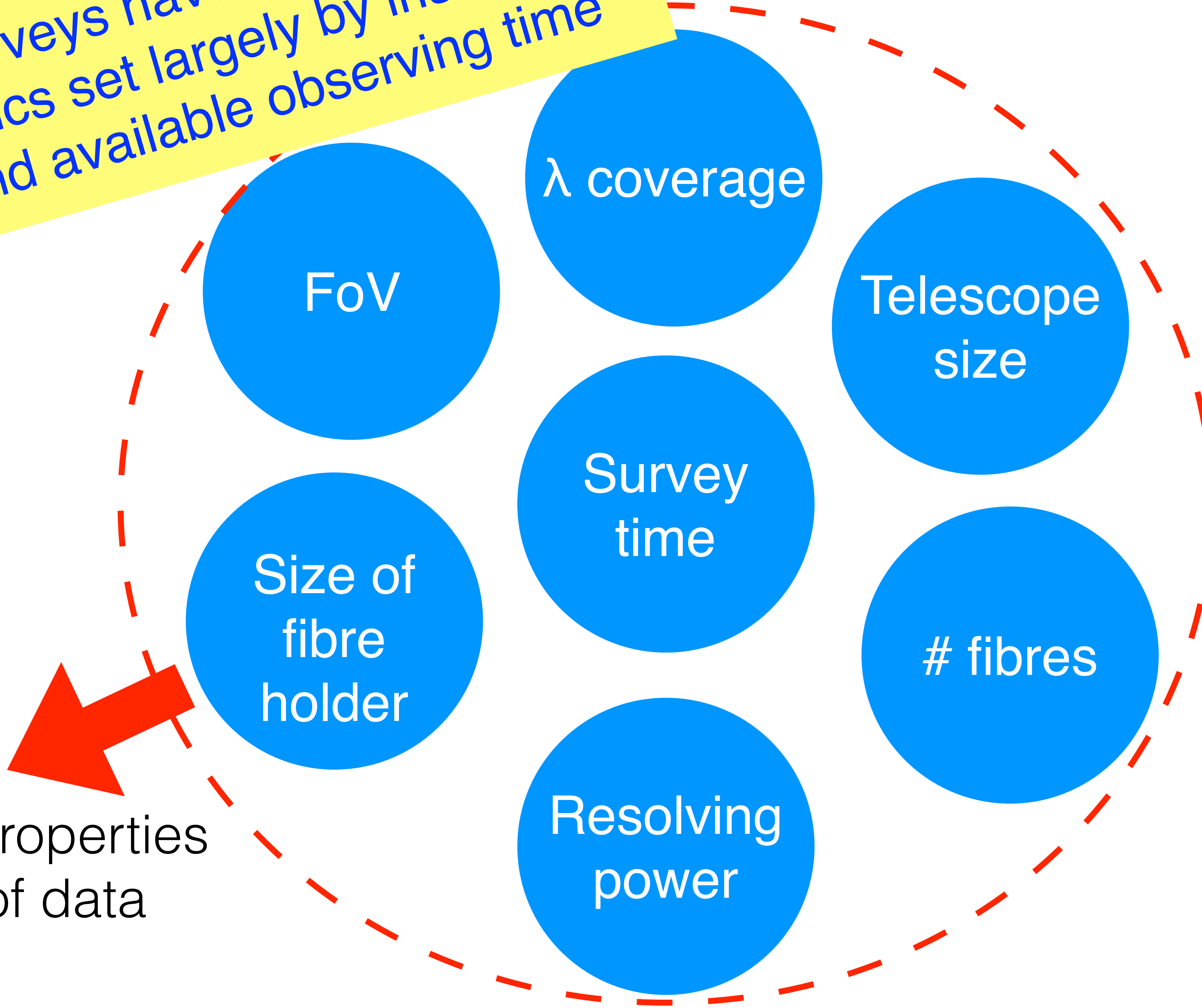
Two galaxies - at z=1 one is an elliptical the other a disc galaxy, at z=0 they have the same B/T.

Grand et al. 2016 MNRAS <u>459</u> 199
Martig et al. 2012 ApJ <u>756</u> 26

Aim

Establishing present day make-up of the Milky Way

All surveys have their own characteristics set largely by instrument design and available observing time

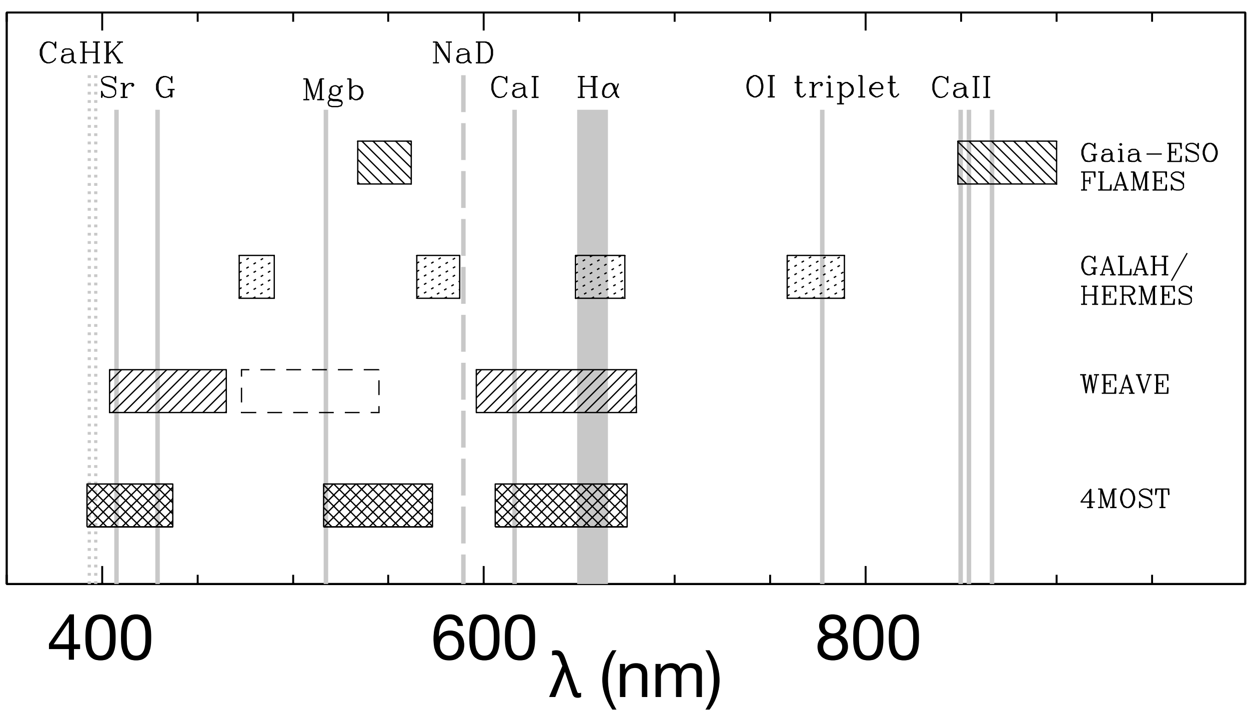


- # stars
- stellar properties
- quality of data

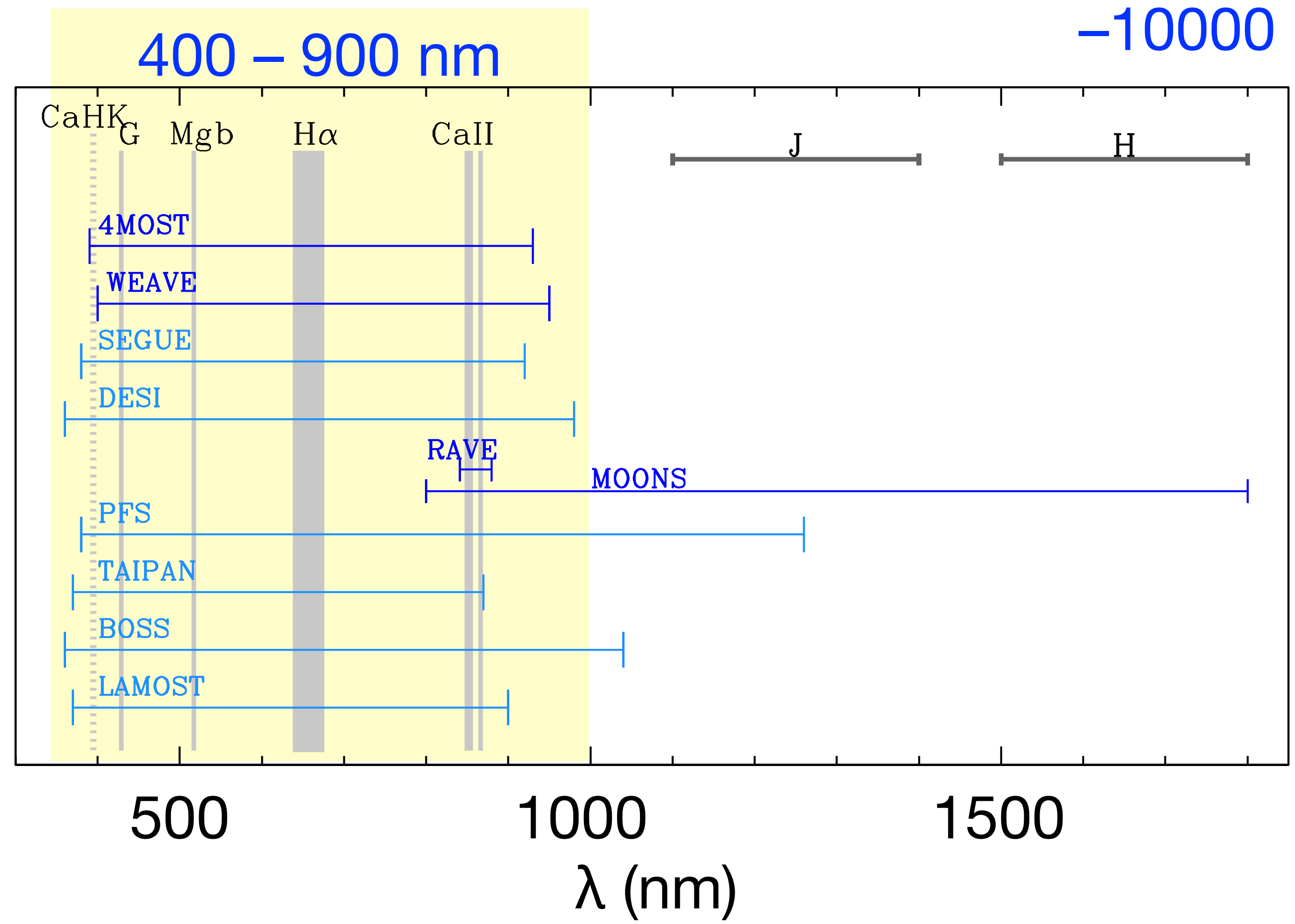
Wavelength coverage

R ~20 000

APOGEE, MOONS —>



R ~2000
–10000



4MOST:
Ructhi et al. 2016 MNRAS <u>461</u> 2174
Hansen et al. 2015 AN <u>336</u> 665

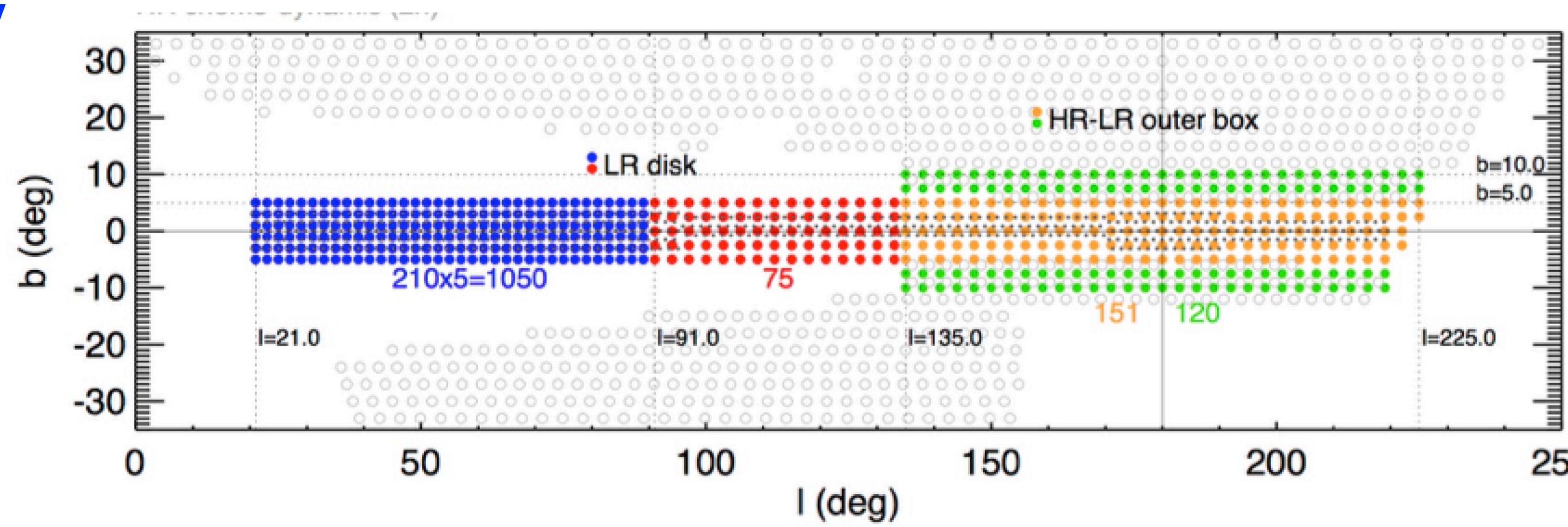
MOONS: 0.7-0.9, 1.17-1.26, 1.52-1.63 μm
APOGEE: 1.51 – 1.70 μm

www.ing.iac.es/weave/

- WEAVE GA survey facility will provide ~4 million stellar spectra
- 1000 fibres, pick and place positioner, closest separation ~60”, reconfiguration time ~1 h during observations with the other plate
- PDR completed 2013; system integration started in 2016; operations start 2018; 5 yr survey

WEAVE disk dynamics survey

- complementary to Gaia & 4MOST; competitive with APOGEE



- **Inner MW disk survey**
  - low resolution in 20° < *l* < 135° and |b|<6°
  - only red clump stars (ie also when *Gaia* π are bad you get distance)
  - detailed study of the effects of the bar and spiral arms on stellar dynamics in the inner Galaxy — understand secular evolution
- **Outer MW disk survey**
  - low resolution in 135° < *l* < 225° up to |b|~10° but for |b|>5° high resolution
  - effects of mergers and interactions of satellites or dark matter clumps on the disk becomes important in the outer disk
  - means flaring, corrugation waves, the presence of accretion debris, etc, at the interface between the thin, thick disk and the halo
  - interface between the disk and the halo is particularly important there, hence higher Galactic latitudes must be probed

Famaey et al. 2016 SF2A 281

de Jong et al. (SPIE 2016)
Walcher et al. (SPIE 2016)

https://www.4most.eu
PI: Roelof de Jong

- 4MOST survey facility will go on the VISTA telescope
- Low res: 1600 and High res 800 HR fibres, echidna positioner, reconfigure < 2min
- PDR passed in June 2016; FDR early 2018; operations start 2022
- 5+5 yr all-sky survey
- Consortium surveys (70% time first 5 yrs)
- ~15 million spectra for community proposals
- Still possible to join consortium

MPE
AAO
UNIVERSITY OF CAMBRIDGE
ASTRON
NOVA
LUND UNIVERSITY
AIP
Max-Planck-Institut für Astronomie Heidelberg
l'Observatoire de Paris GEPI
CRAL CENTRE DE RECHERCHE ASTROPHYSIQUE DE LYON
EPFL ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE
rijksuniversiteit groningen
UH
ZAH
Durham University
UPPSALA UNIVERSITET
Queen's University Belfast
University of Portsmouth
Lancaster University
University of Southampton
ESO

4MOST MW science in a nutshell

Helmi
Irwin
Christlieb

Chiappini
Minchev
Starkenburg
Bergemann
Bensby

Cioni

- **Near-field cosmology tests**
  - overall mass, extent and structure of the MW dark matter halo
  - the nature of dark matter from tidal stream properties
- **Characterising the major Milky Way components**
  - the formation of the Bulge and the link to the high Z universe
  - the potential, substructure and influence of the central bar
  - chemodynamical analysis of the thick & thin disks formation history
- **The Galactic Halo and beyond**
  - full chemodynamical analysis of the Magellanic Clouds
  - the properites of large scale streams (e.g. Sgr) in the Halo
  - probing the extent and properties of the stellar halo (e.g. RGBs, BHBs)
- **Extreme metal poor stars**
  - characterising early chemical evolution in the Halo and Bulge

4MOST Science Team, Feltzing et al 2017 arXiv:1708.08884

Some numbers

	Low resolution surveys	High resolution surveys
Halo	>1.8 million (goal 3) objects with **LRS** All halo giants with $15 < V < 20$ > 10 000 square degrees, contiguous	100 000 genuine halo stars with **HRS** (catalogue larger but contaminated) $12 < V < 16$ Sparse sample over 14 000 sq deg
	σ(RV) < 2 km/s to match Gaia's error in parallax	Defines blue arm of HRS in 4MOST 20 elements
Disk and bulge	>**15 million** (goal 20) objects with **low resolution spectra** $14 < V < 20$ Several sub-surveys to optimise science	Goal **4 million** stars with **high resolution spectra** $14 < V < 16$ Evenly distributed
	σ(RV) < 2 km/s to match Gaia's error in parallax precision ~0.1-0.2 dex	Defines green and red arm of HRS in 4MOST 20 elements precision ~0.03 dex (acc. 0.07 dex)

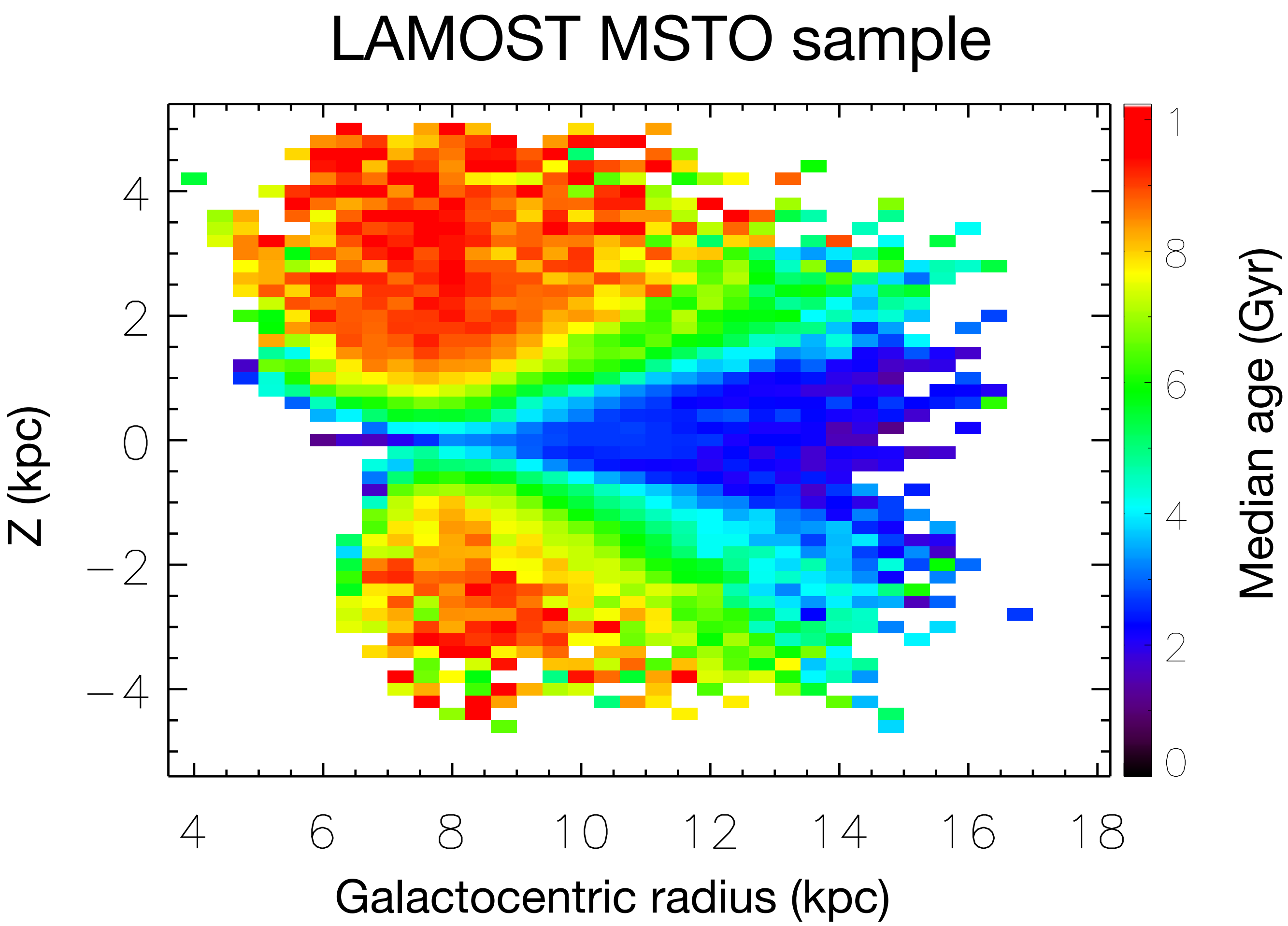
4MOST Science Team, Feltzing et al 2017 arXiv:1708.08884

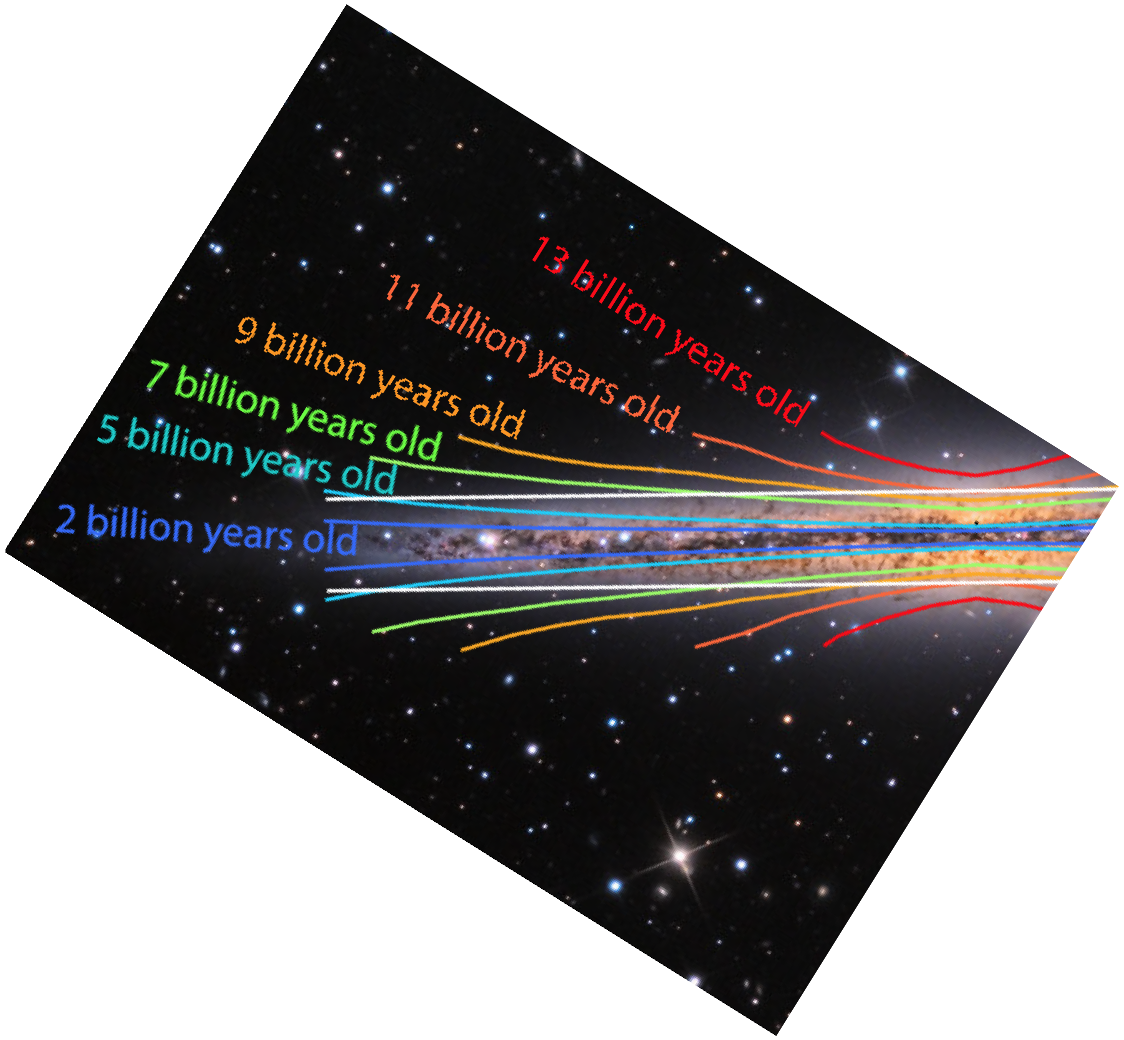
Worries

Things to consider before interpreting

First example

Selection function





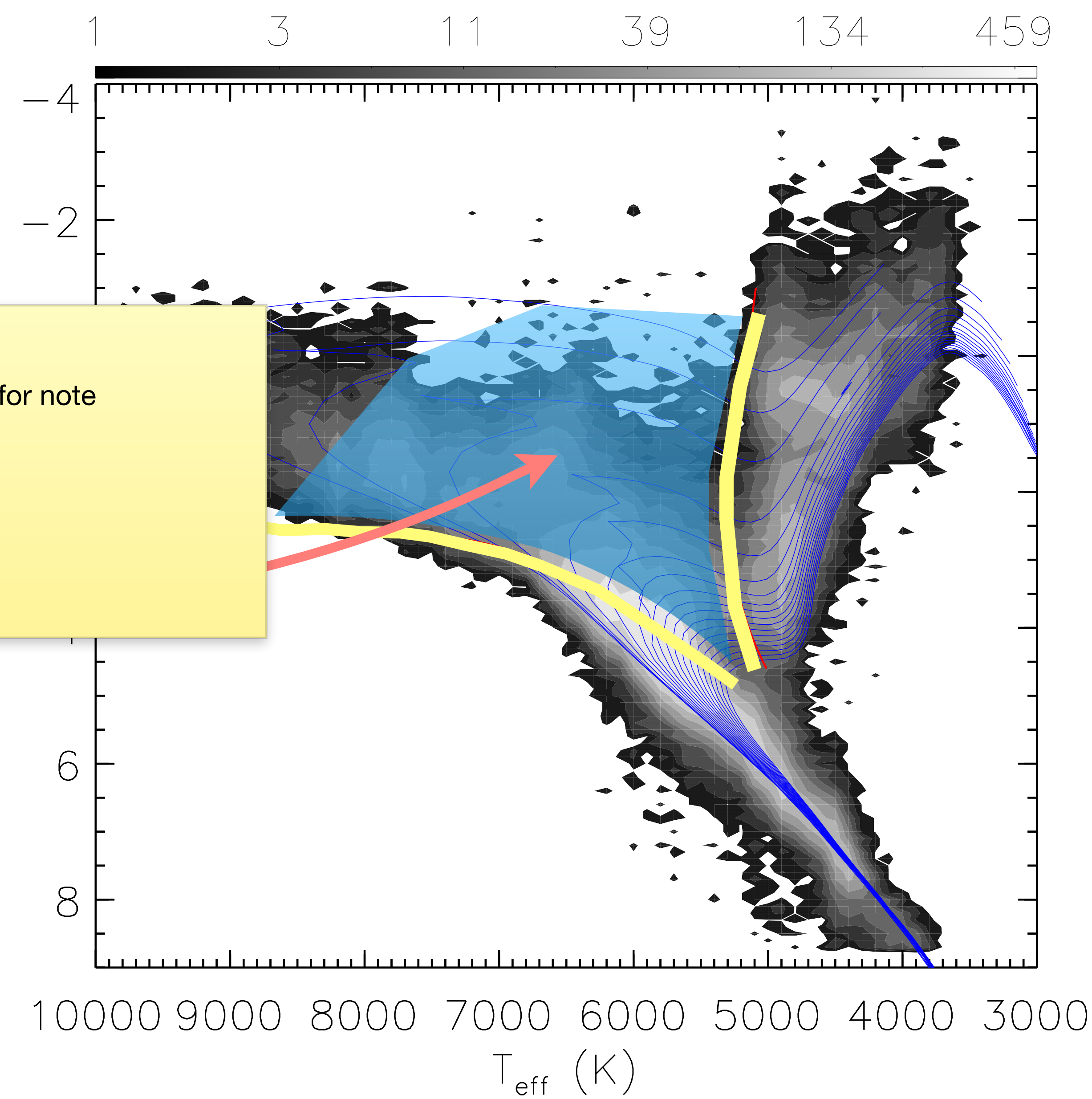
- Significant structure, including flaring
- Also seen in APOGEE data for giant stars
- Models can explain this flaring

Xiang et al. 2017 arXiv:1707.06236
Minchev 2017 arXiv:1701.07034

Selection function

- **LAMOST MSTO age-map**
  - several selection functions at play
  - LAMOST target selectic
    weather/fibre allocation
  - analysis of MSTO stars
    possible for certain (infe
    stellar parameters
  - How do you combine this to understand what the map actually is telling you?
- **All surveys need to carefully monitor and document their selection function(s)**

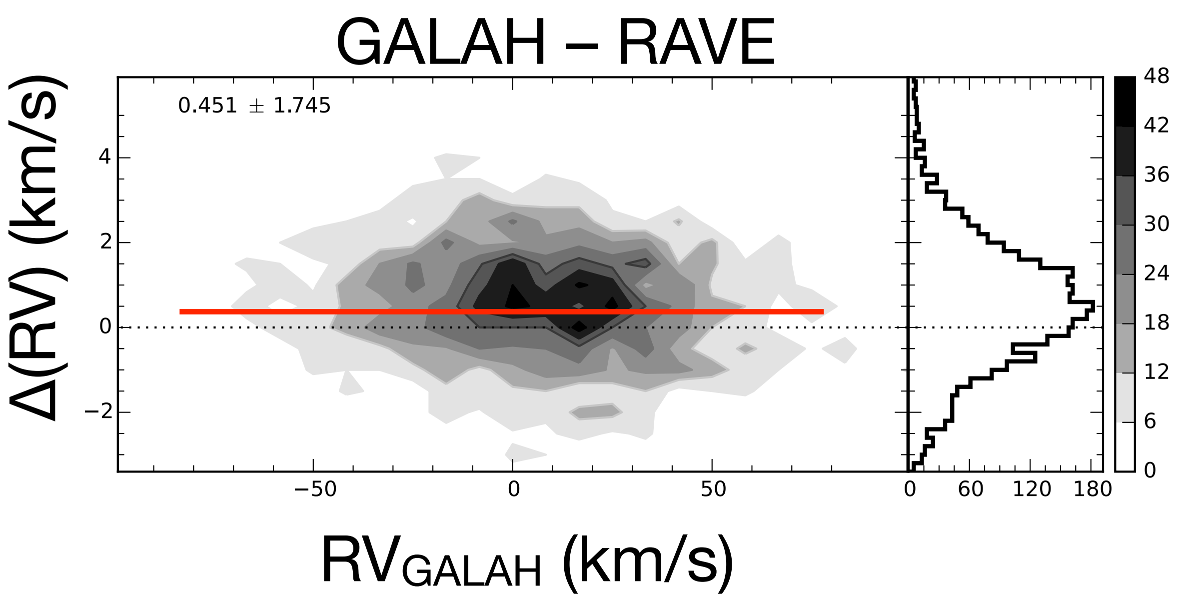
make black box like for note

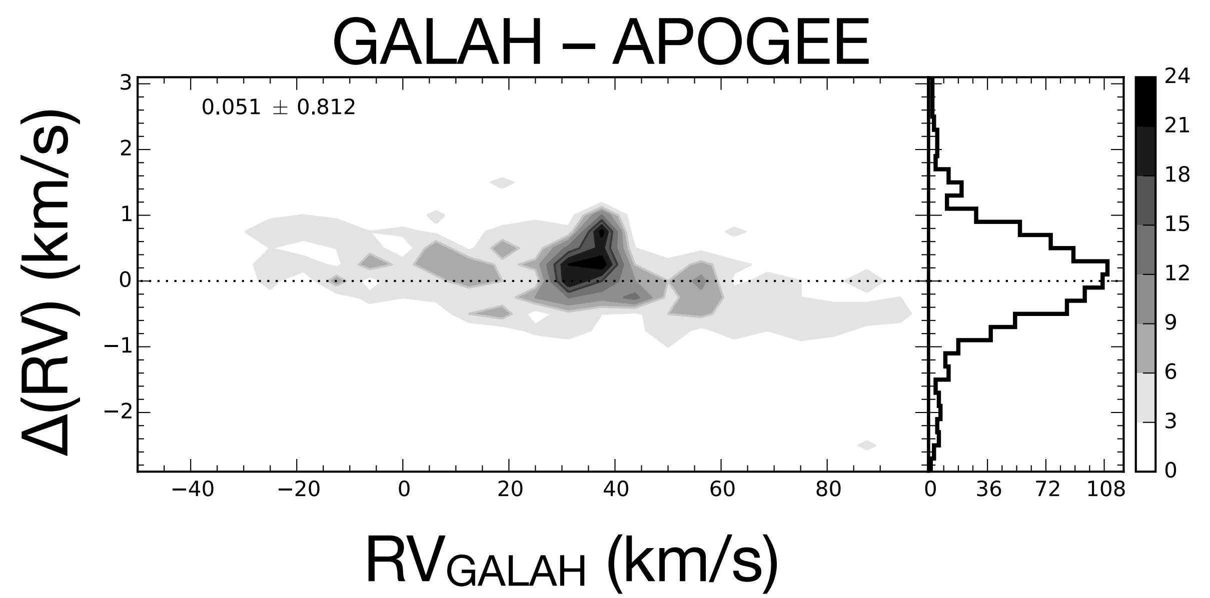


Xiang et al. 2017 arXiv:1707.06236

Second example

Precision & accuracy



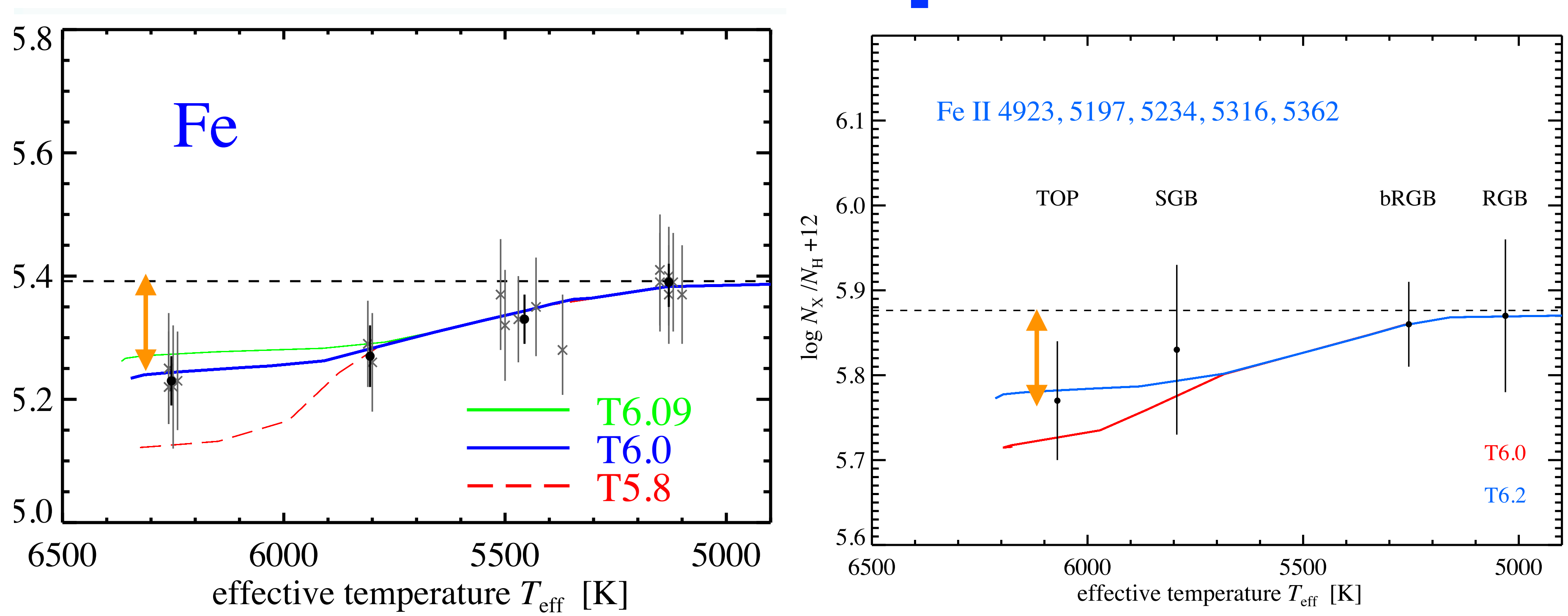


- Δ=0.45 km s^{-1} σ=1.75 km s^{-1} (GALAH-RAVE)
- Δ=0.05 km s^{-1} σ=0.81 km s^{-1} (GALAH-APOGEE)
- σRV ∝ R$^{-3/2}$ (—> 4.3 times as large error in RAVE as in GALAH)
- Median scatter in APOGEE single stars ~0.2 km s^{-1}
- Offsets always need to be understood
- For elemental abundances the situation will be more acute

Martell et al. 2017 MNRAS 465 3203

Third example

Diffusion changes abundance patterns

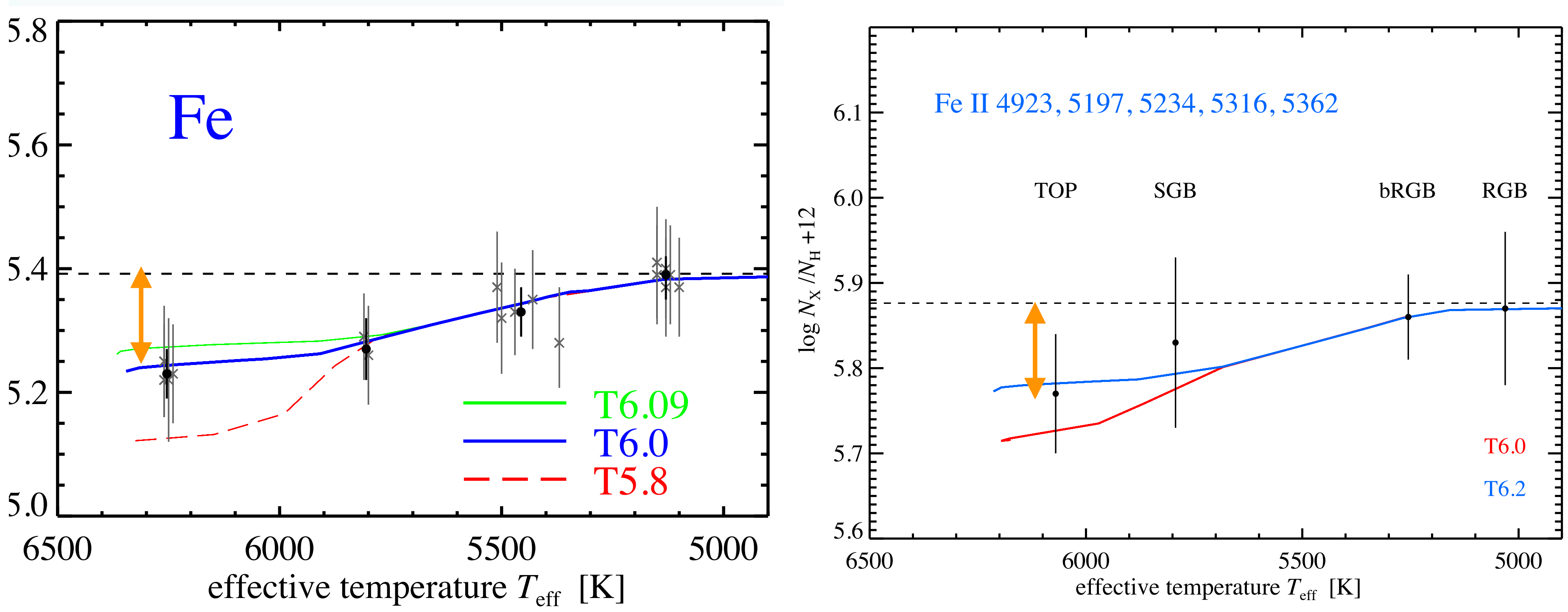


- Effects of stellar evolution.
- Evidence that selective diffusion occurs in stars at MS and TOP in globular clusters and M67.
- Up to 0.2 dex.

Önehag et al. 2014 A&A 562 A102
Korn et al. 2007 ApJ 671 402
Gruyters et al. 2013 A&A 555 A31

Third example

Diffusion changes abundance patterns



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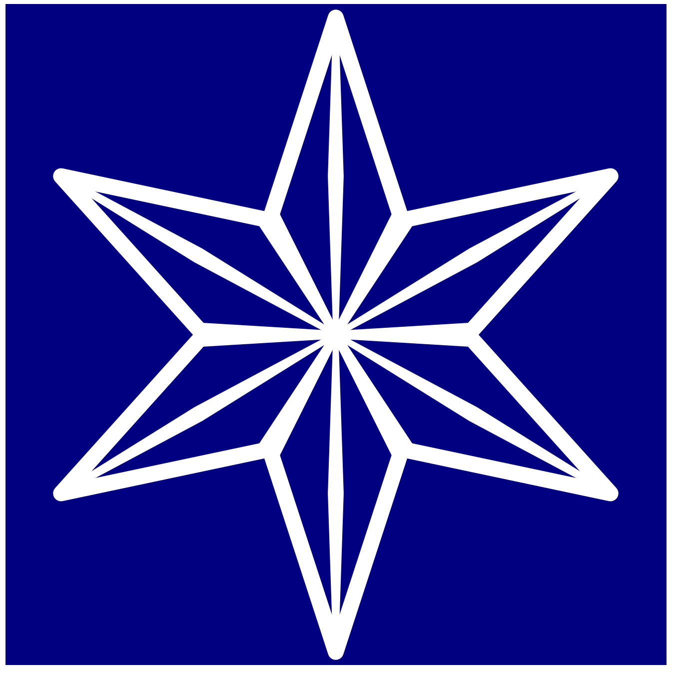
Önehag et al. 2014 A&A 562 A102
Korn et al. 2007 ApJ 671 402
Gruyters et al. 2013 A&A 555 A31

This is just one example - NLTE and 3D atmospheres

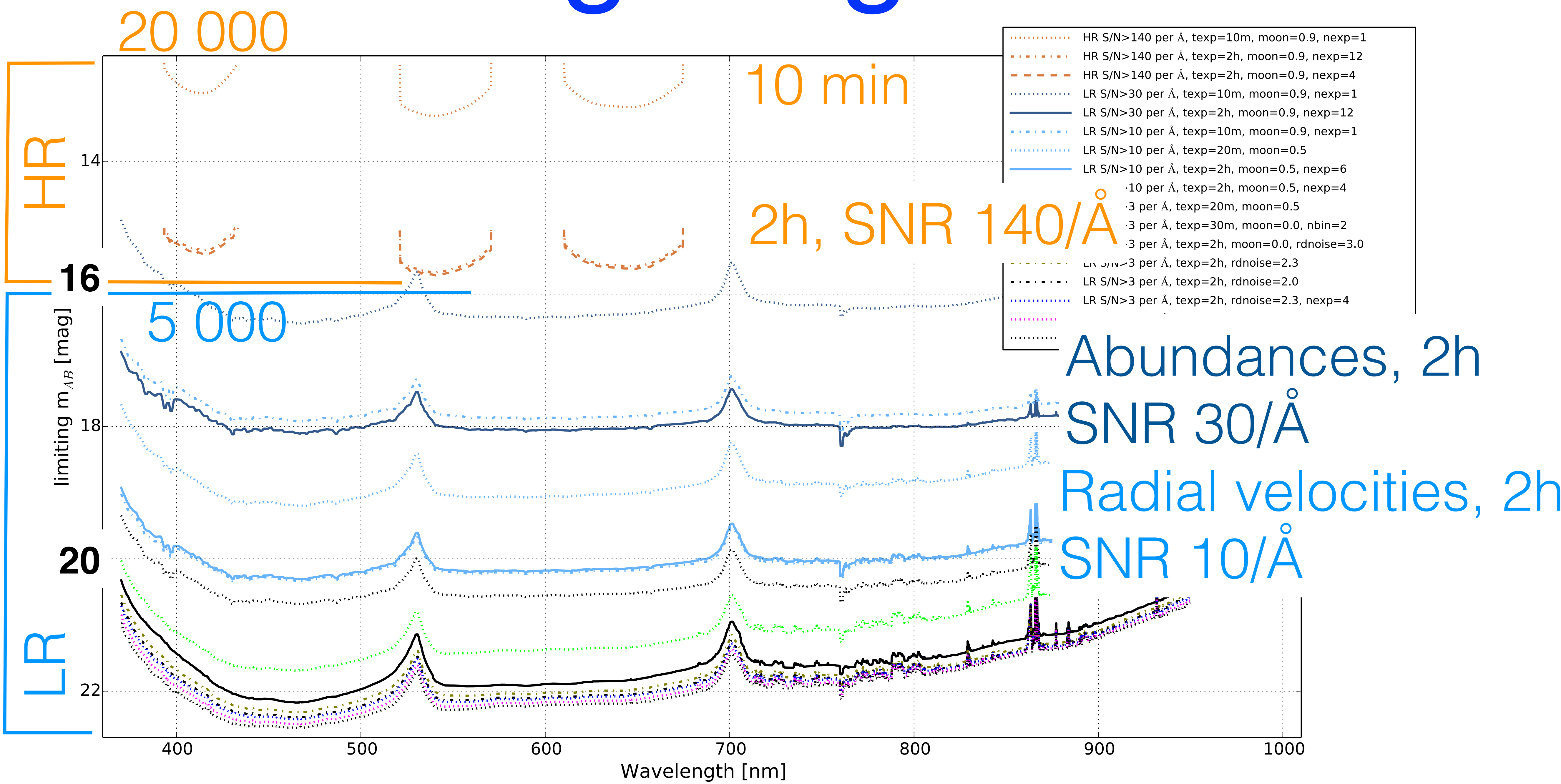
Summary

Need to construct this slide.
Venn diagram?
Any references?
Two Feltzing proceedings?

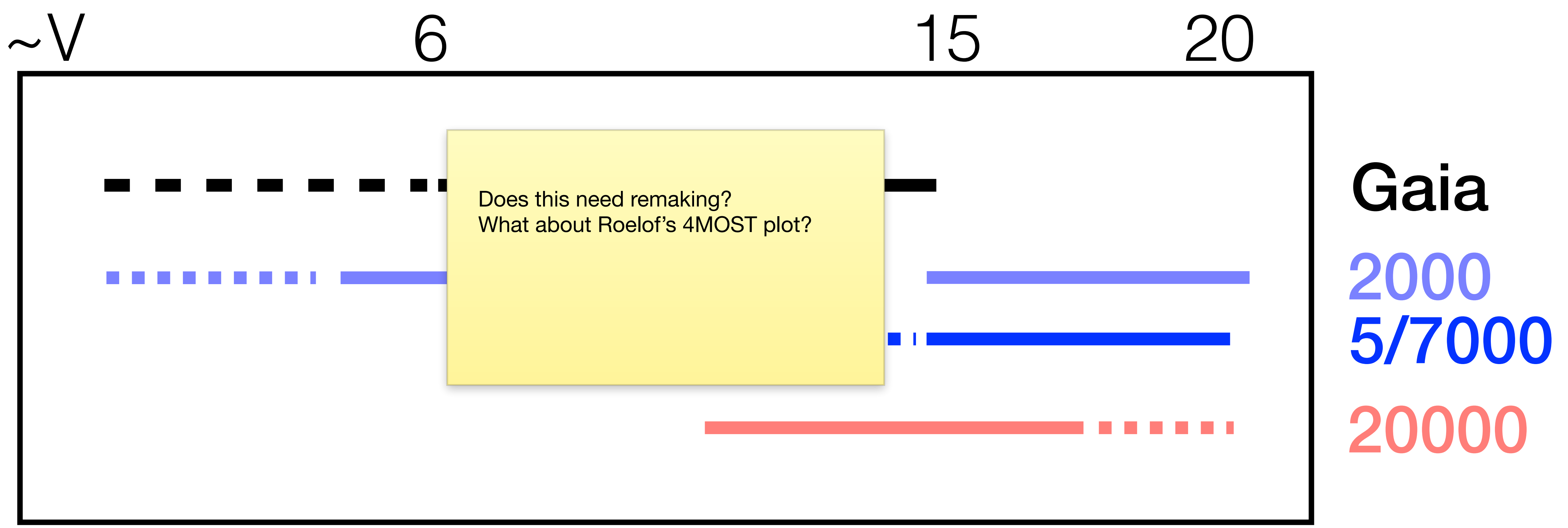
- Past, on-going and future surveys will provide spectra for 10s of millions of stars in the near future enabling exciting research
- The spectra will provide RVs and from them we can derive elemental abundances
- There are several challenges that need to be addressed:
  - Huge datasets requires “new” methods for abundance analysis, e.g. *Cannon*
  - Understanding the influence of the selection functions on the results is crucial
  - Many surveys = need to ensure all data are on the same scale to be able to combine the data for a deeper understanding of the Milky Way



Limiting magnitudes



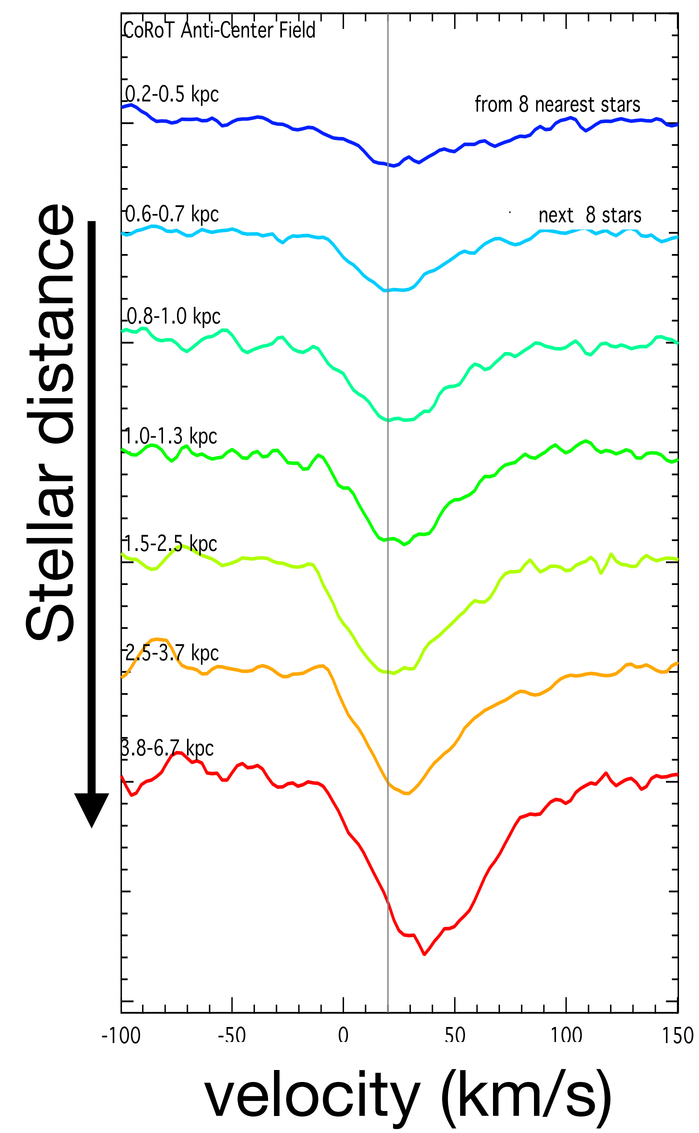
Rough comp. of depths



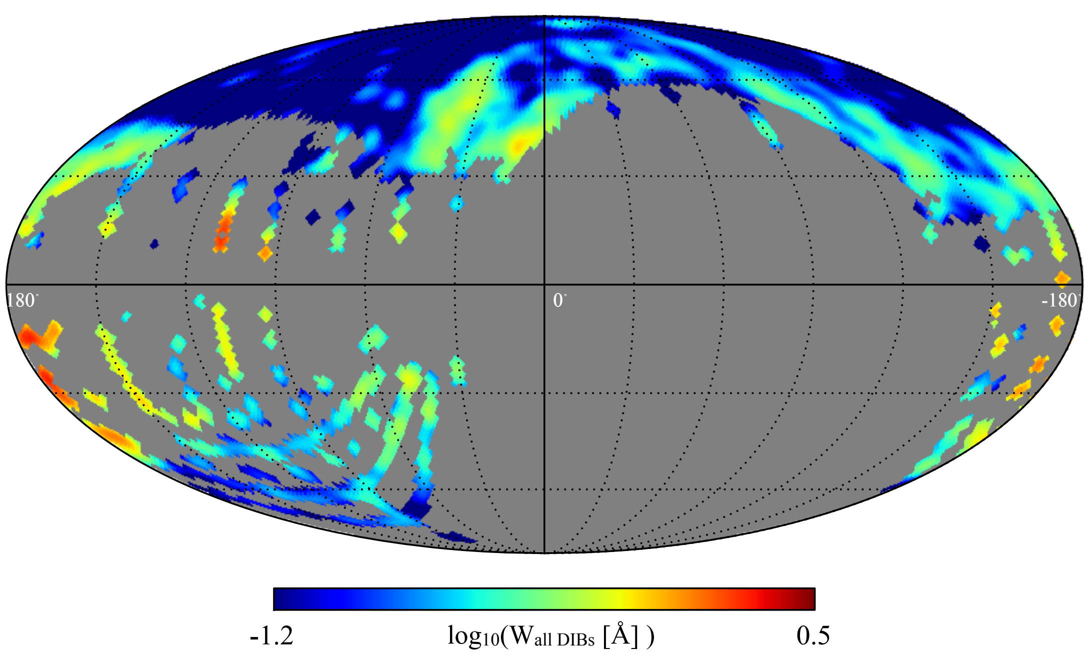
Diffuse interstellar bands in spectroscopic surveys

- DIBs - weak but numerous absorption lines seen in spectra of background stars
- allows to reconstruct absorption sites along the line of sight
- radial velocity shift can constrain placement of multiple clouds along each line of sight
- picked up in LAMOST spectra w Cannon

Gaia-ESO



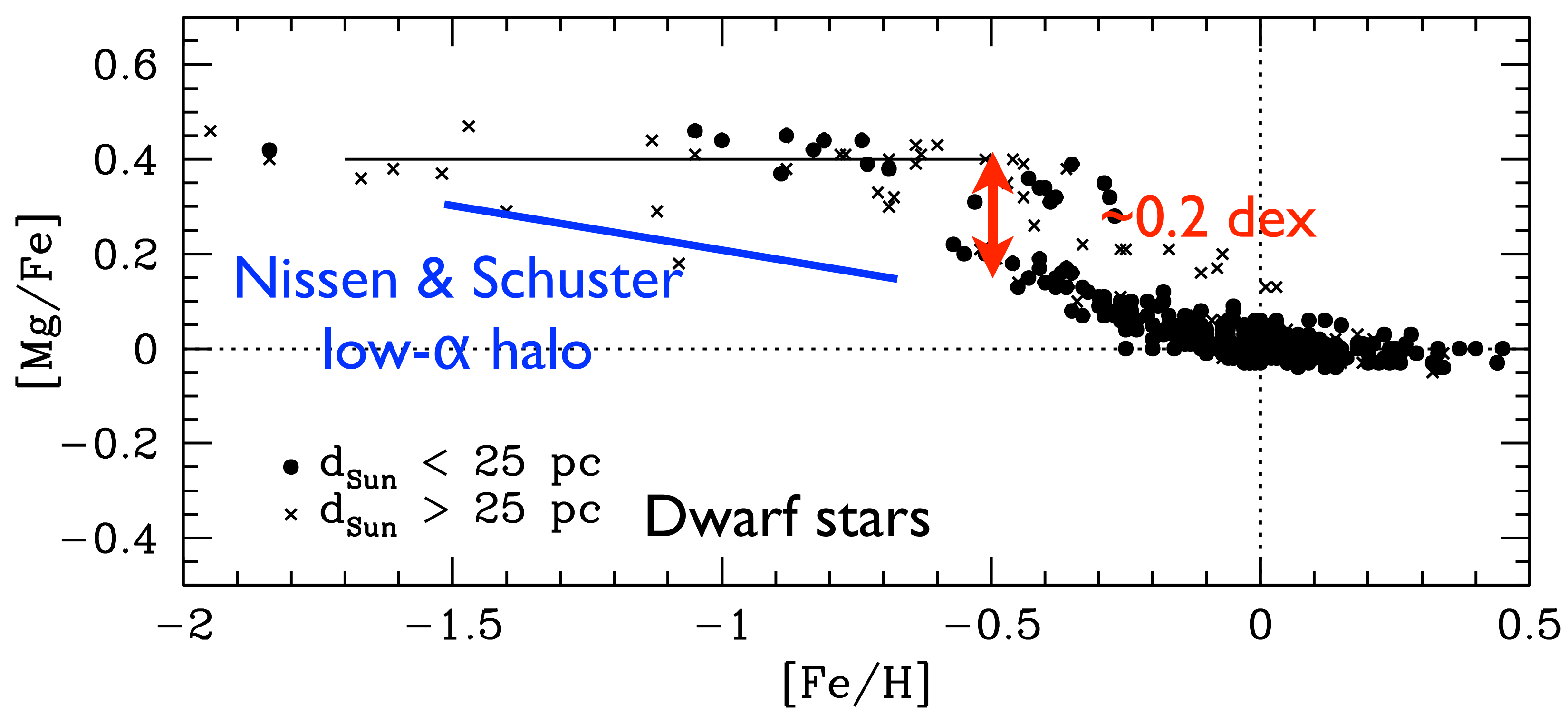
SDSS DIBs absorption map



Zwitter & Kos 2016 Mem. S.A.It. Vol. 86 541
Puspitarini et al. 2015A&A 573 A35
Lan et al. 2015 MNRAS 452 3629
Ho et al. 2017 ApJ 836 5

Precision required

Example of typical high precision/accuracy data.



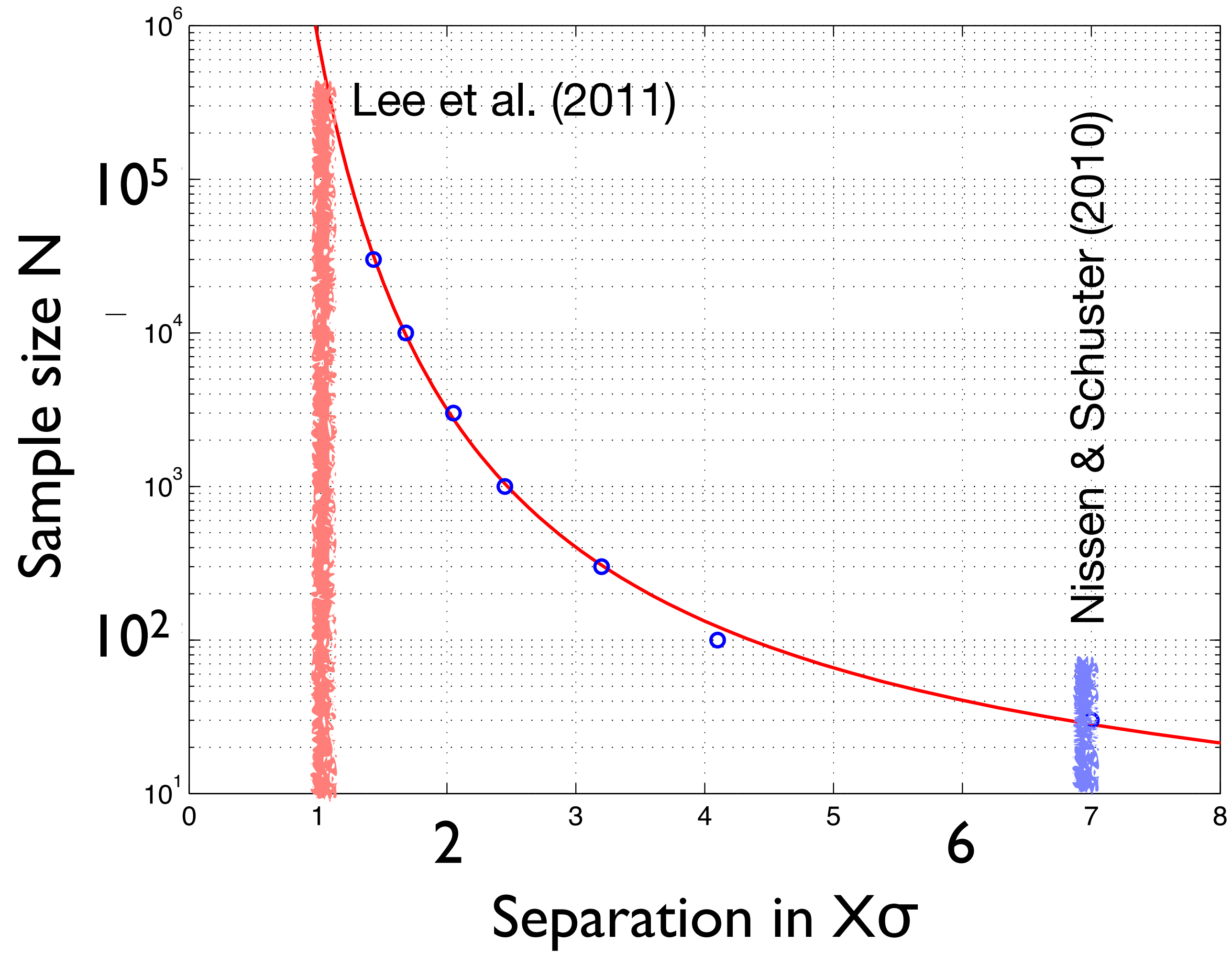
4MOST 2h exposure shall give:

– LR RVs at V=20 (SNR=10/Å)

– HR abundances at V=15.5 (SNR=140/Å)

Plot based on data from Klaus Furhmann's studies (priv. comm.)

Sheer number do not beat low precision



× volume to cover
ages
dynamics
…

→ # stars in your survey

- Both measure a gap of 0.2 dex
- One needs < 100 stars, the other >100 000 stars

Lindegren & Feltzing 2013 A&A 553 A94