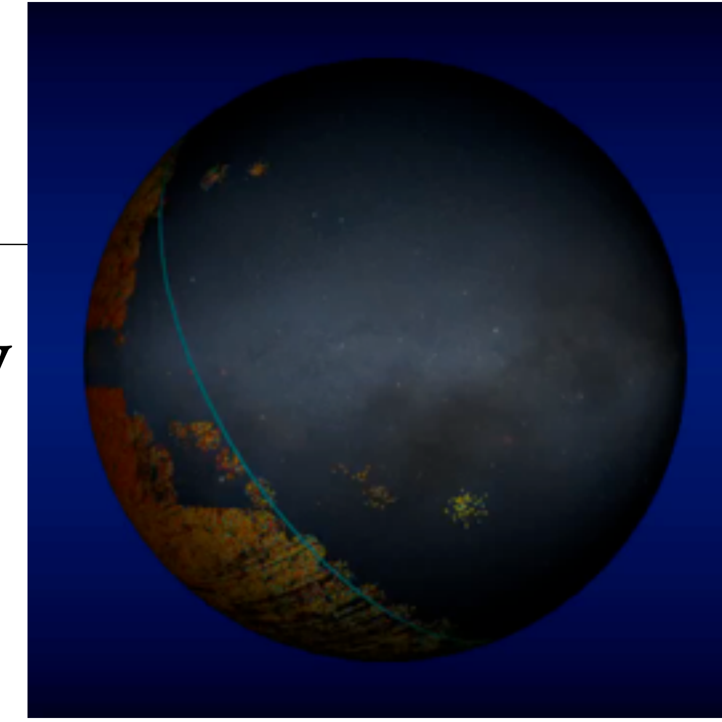
Matthias Steinmetz (AIP)

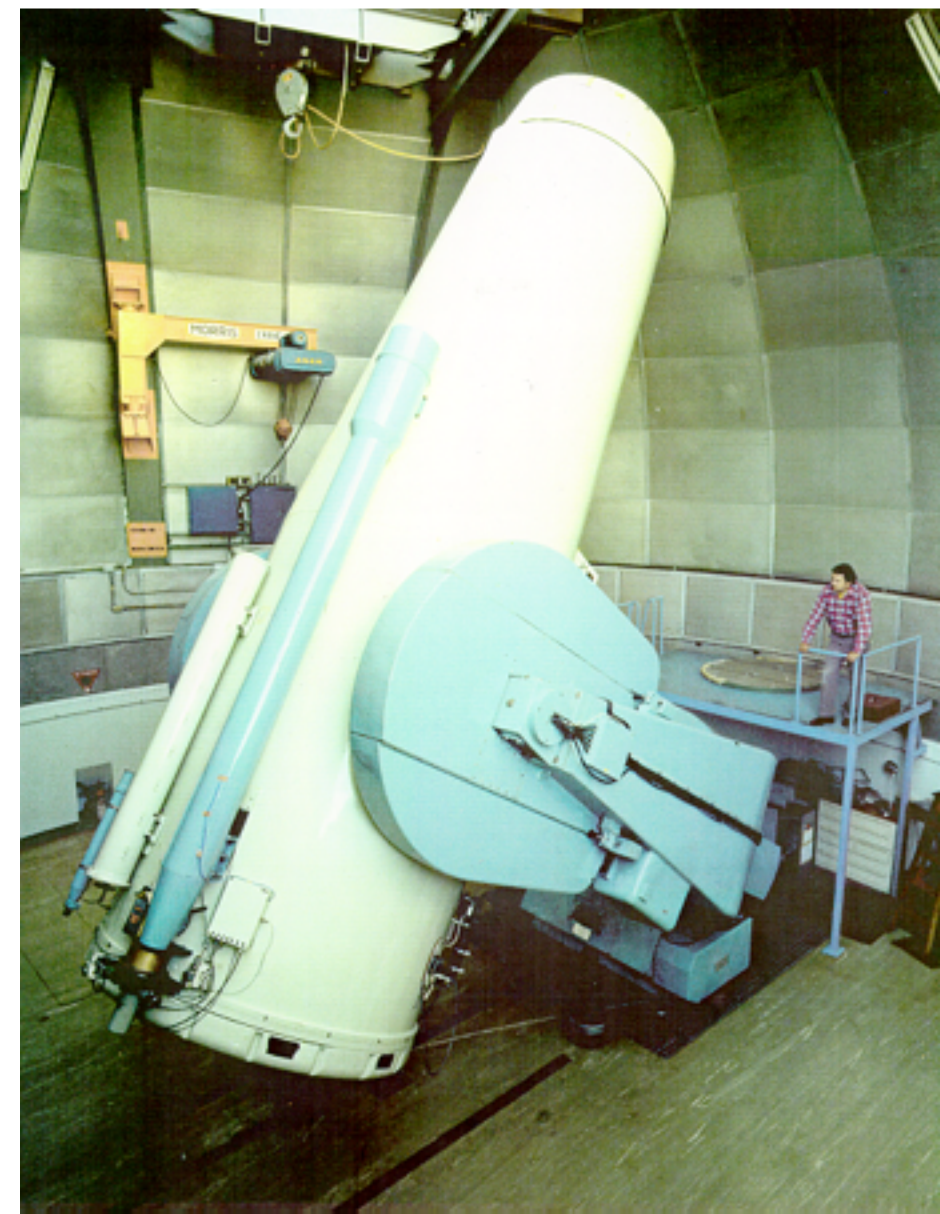
RAVE as a Gaia precursor: what to expect from the RVS?

KITP GalArcheo15 **Feb 24, 2015**

The RAVE Survey



- Spectroscopic high latitude survey of the MW
  - $9 < I < 13$
- GAIA spectral range and resolution
  - Ca triplet region (8400-8800Å), R_{eff}=7500
- 6dF at the 1.2m UKST in Australia
  - 100-120 fibres
  - 38 sqdeg FoV
- Scheduled operation: 4/2003 – 4/2013
  - 7 nights per lunation up to 8/2005
  - 25 nights per lunation since 8/2005
- 574,630 spectra for 483,330 stars
  - catalogue of 40000 active stars



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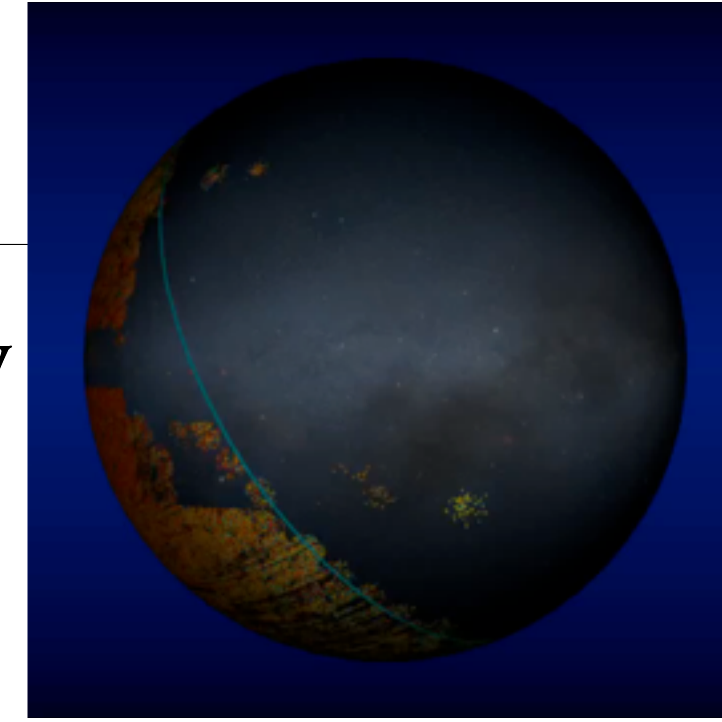

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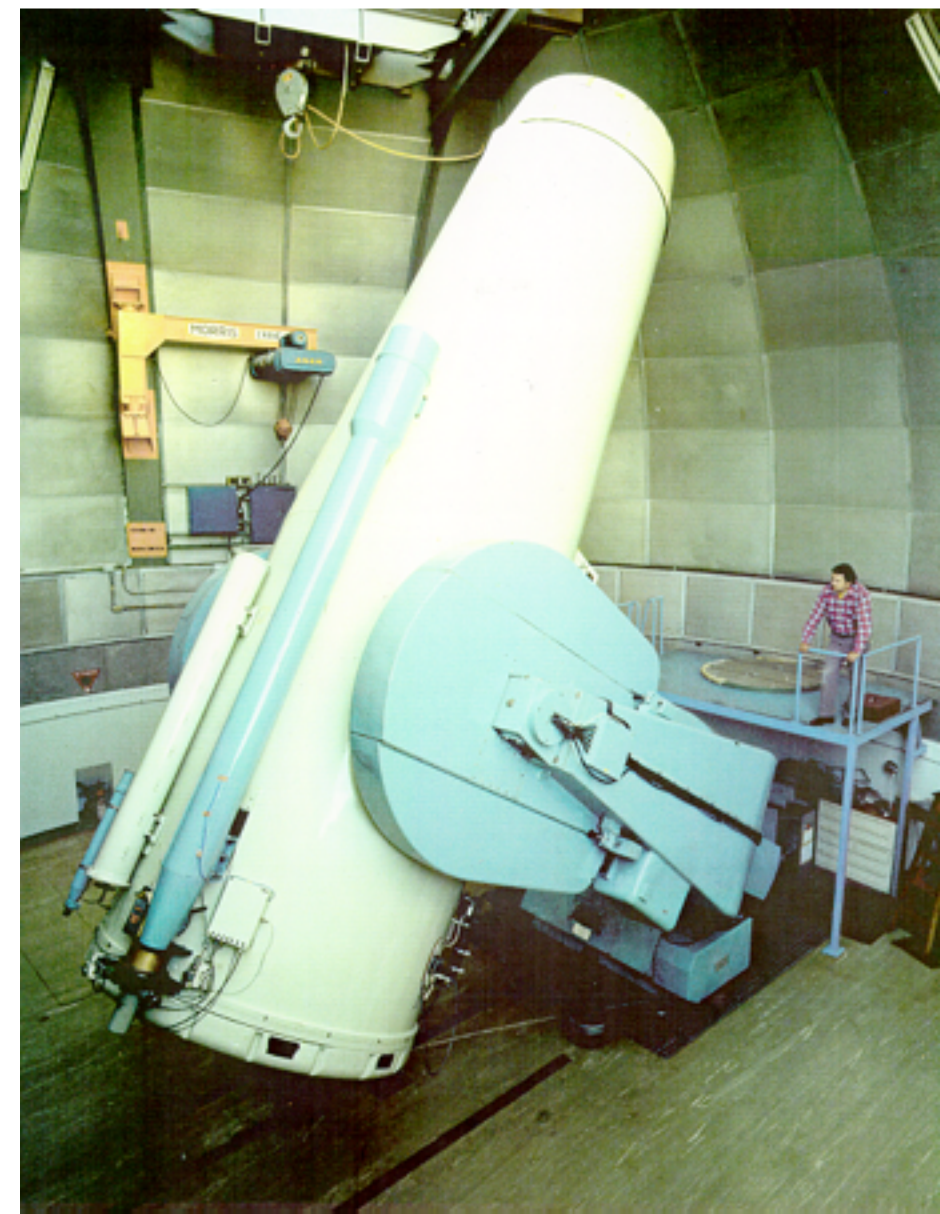

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  - complete to V=10.5 (0.3mas, 0.5mas/a)
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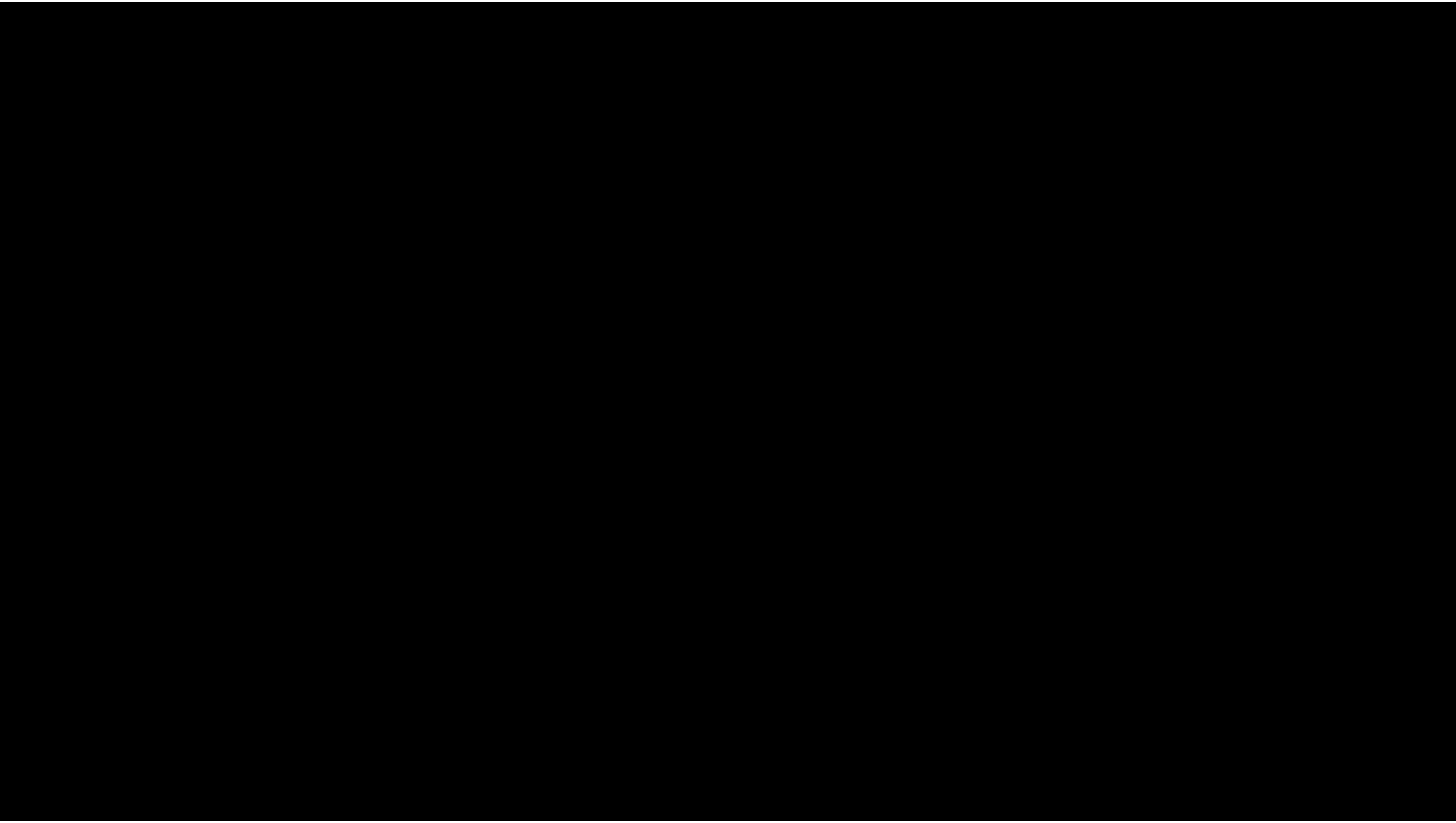
- DIVA was cancelled in 2004 owing to lack of global DLR funding

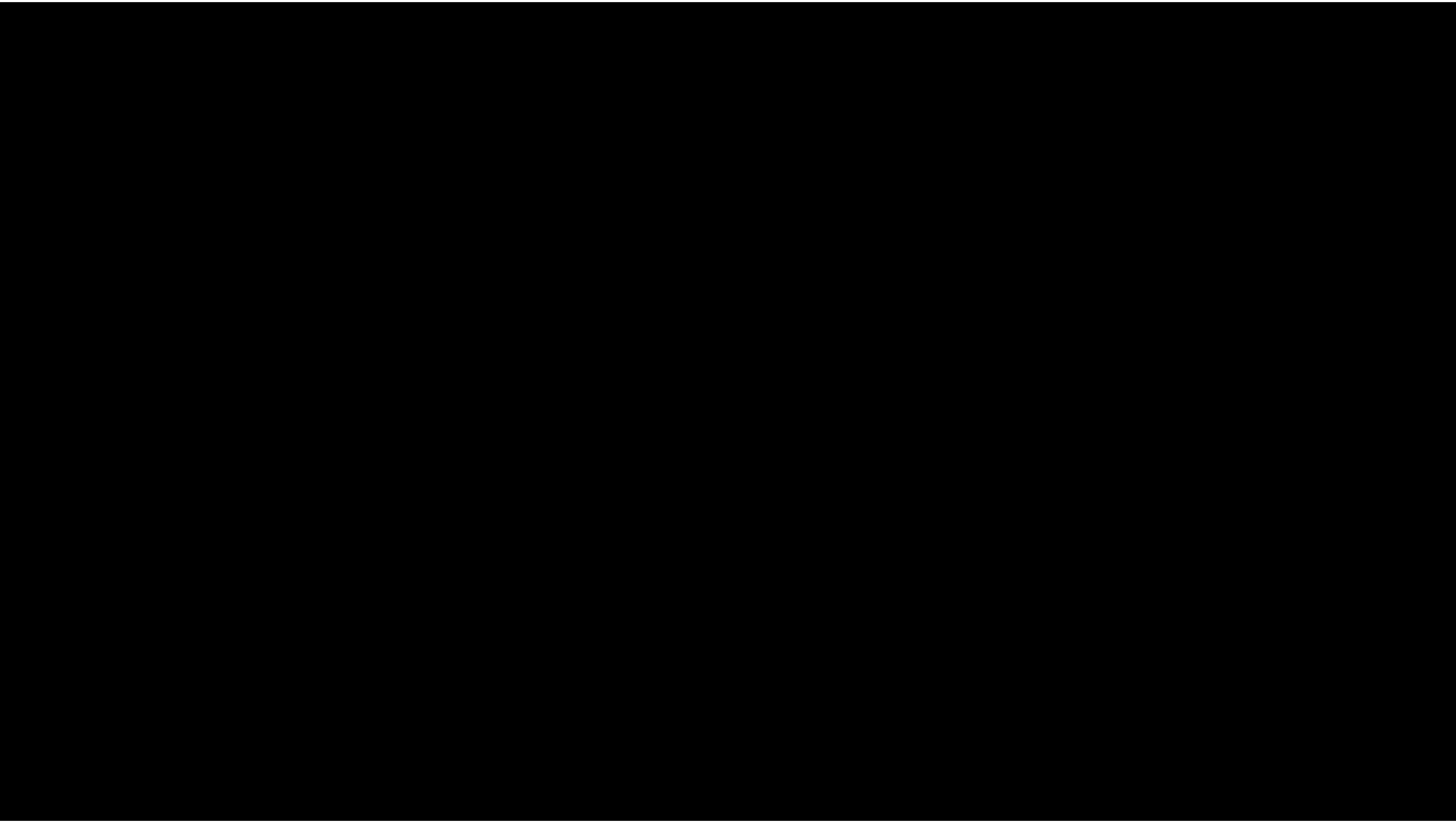
Systematic spectroscopic surveys 2004

Systematic spectroscopic surveys 2004

Systematic spectroscopic surveys 2014

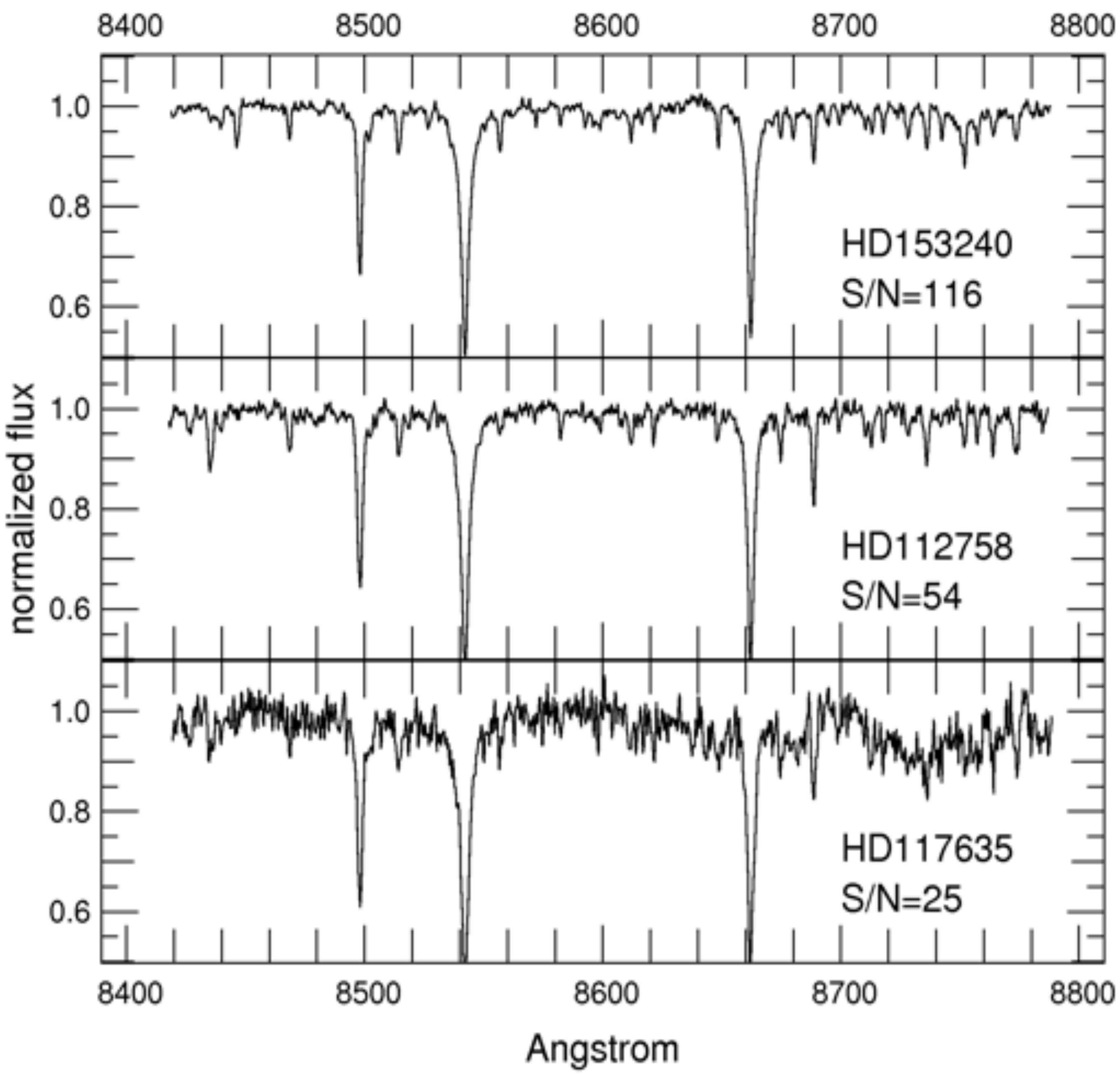


Systematic spectroscopic surveys 2014



Spectra

λ range: 8410-8795Å (Gaia wavelength range)
Resolution R=7500 at 8600Å; Dispersion = 0.4Å/pix



From the RAVE spectra we obtain:

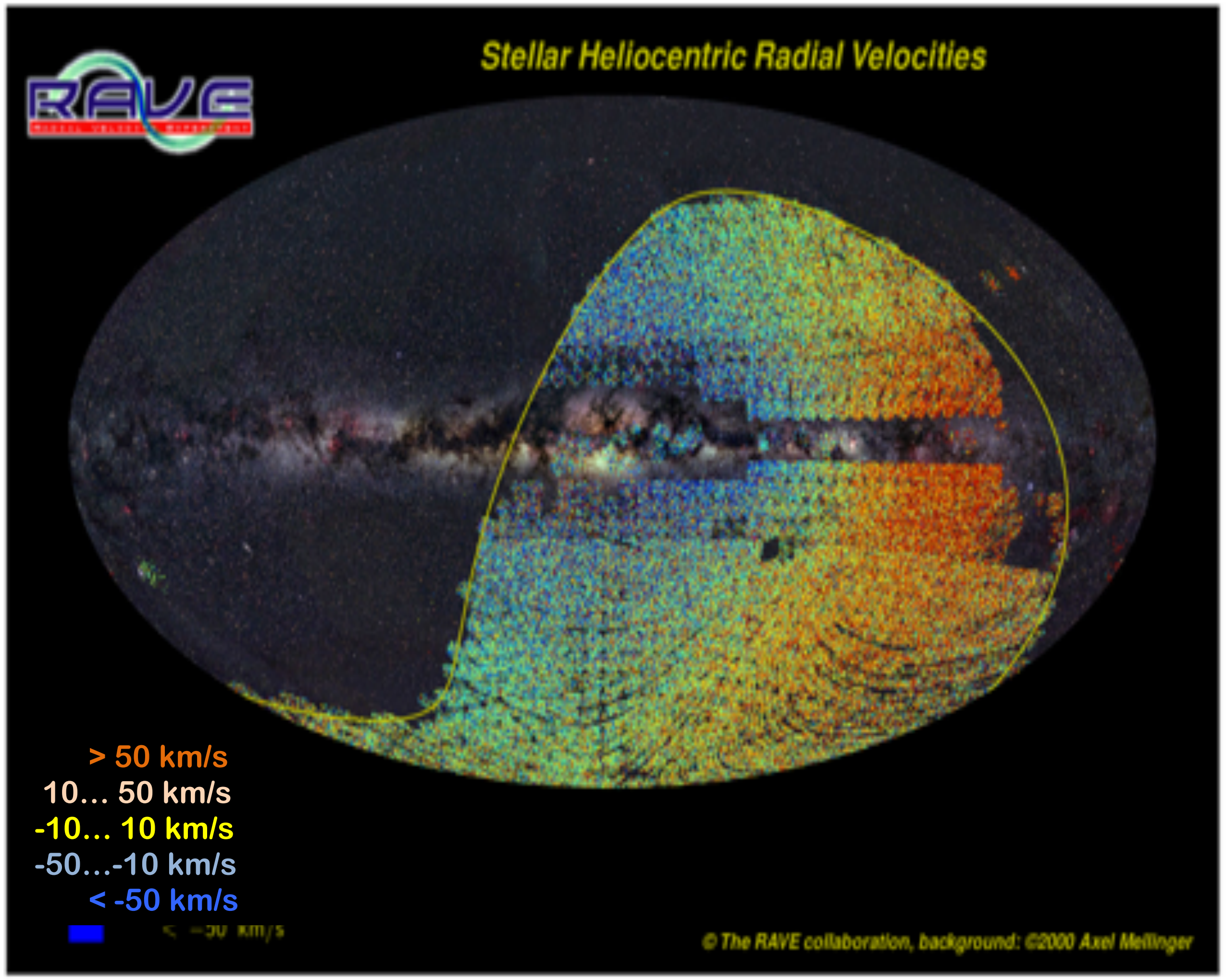
- radial velocities
- stellar parameters (effective temperature, gravity and metallicity)
- chemical abundances
- RAVE + photometry → distances

4th public data release

Kordopatis et al. 2013

- Intermediate resolution (R~7500)
- 425 561 stars,
- 482 430 spectra

  (DR3: 77 461 stars)
- 9 < I < 12 mag



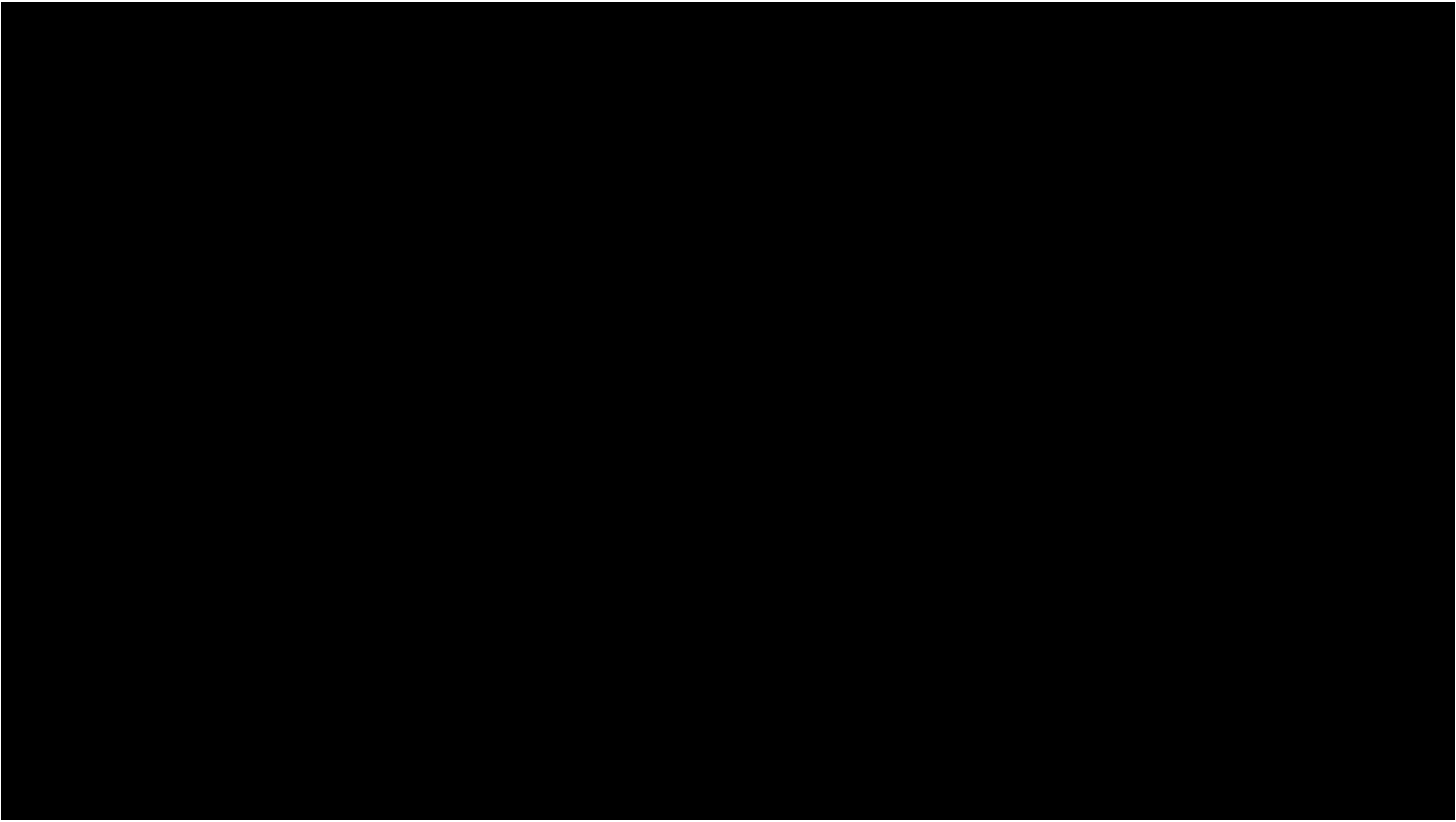
Database:

- ✓ Radial velocities
- ✓ Spectral morphological flags
- ✓ T_{eff}, logg, [M/H]
- ✓ *Mg, Al, Si, Ti, Ni, Fe*
- ✓ Line-of-sight Distances
- ✓ Photometry:

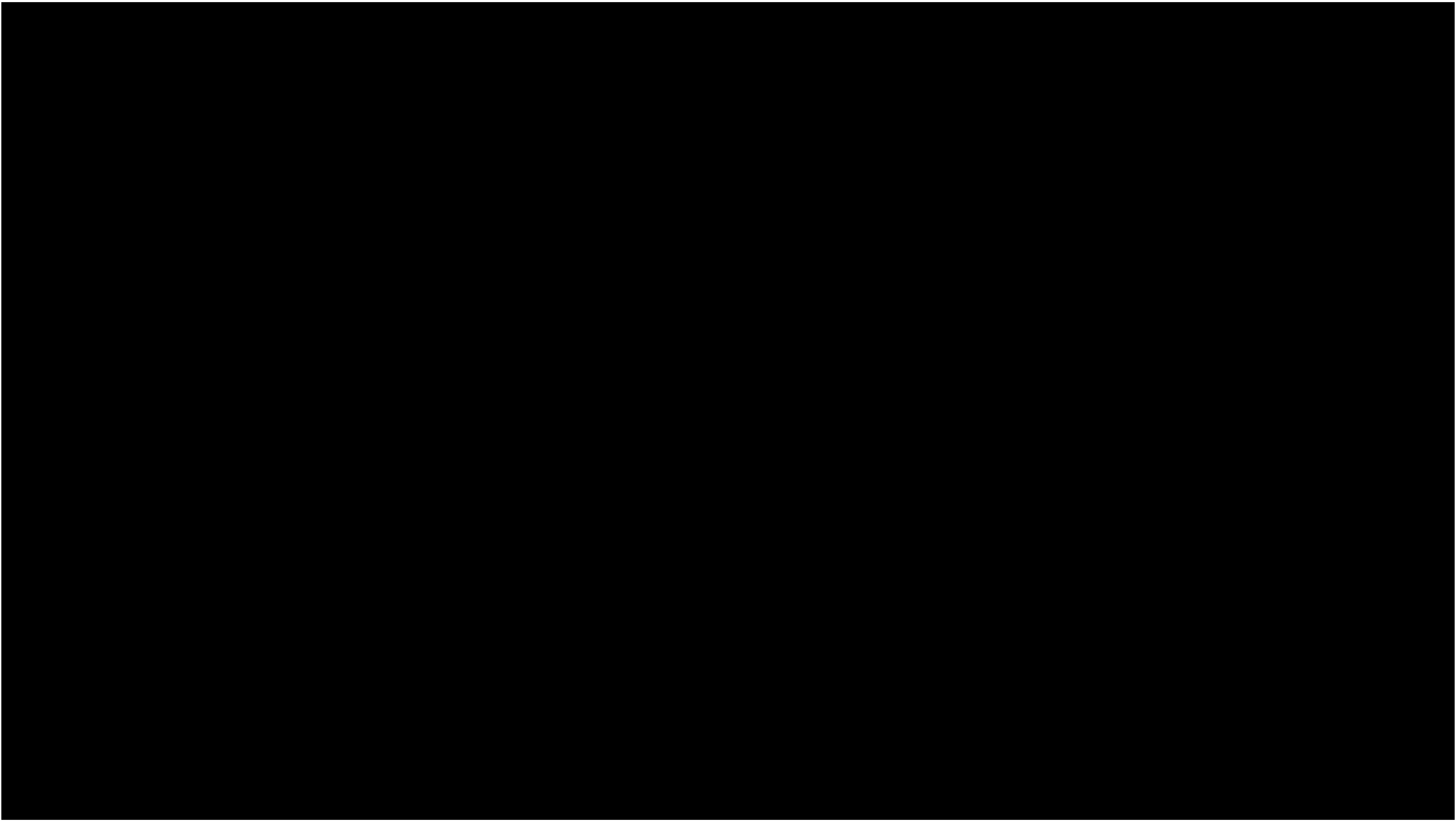
  DENIS, USNOB, 2MASS, APASS
- ✓ Proper motions:

  UCAC4, PPMX, PPMXL, Tycho-2, SPM4

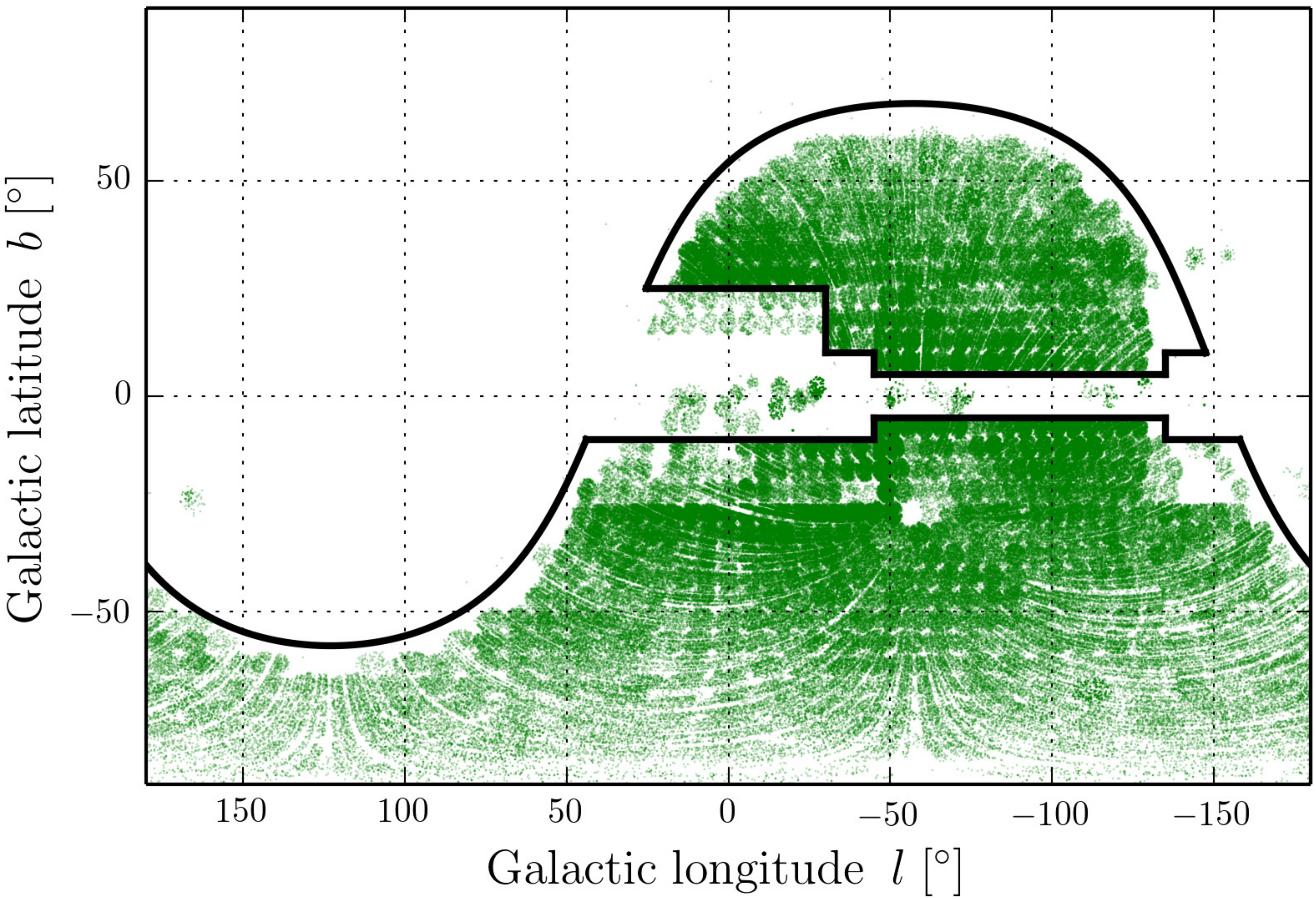
DR4



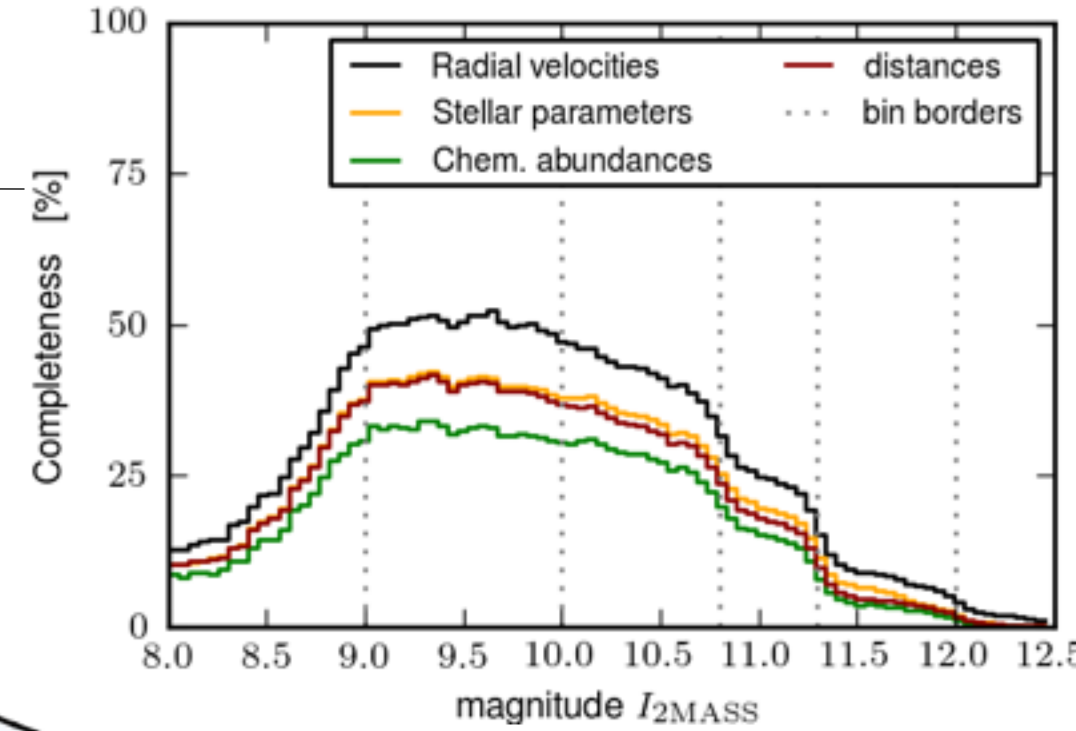
RAVE DR4

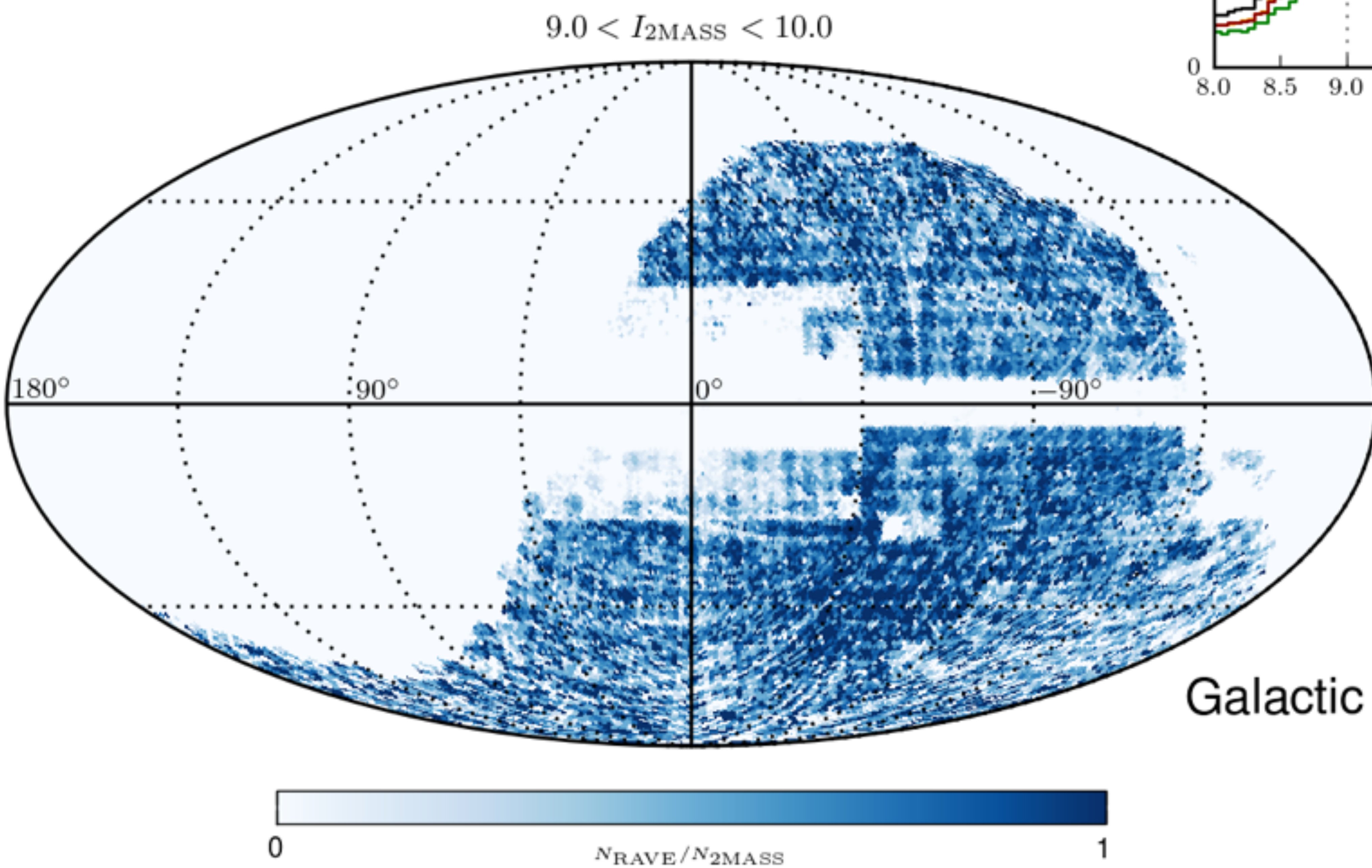


RAVE selection function: DR4 footprint



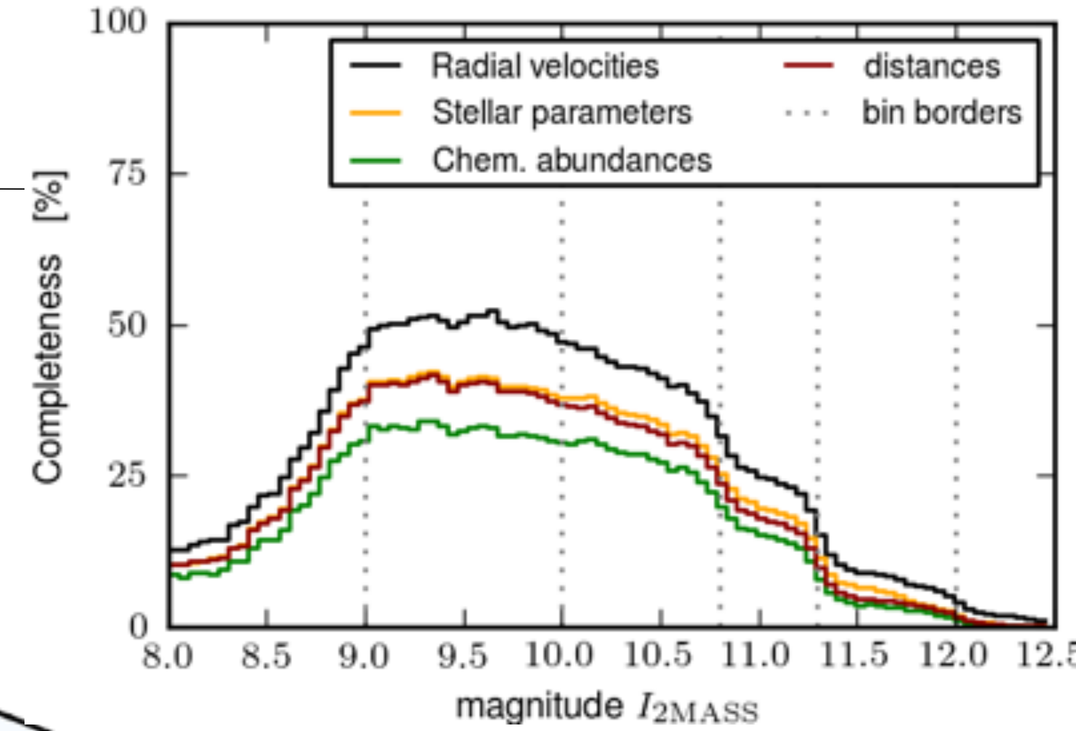
completeness

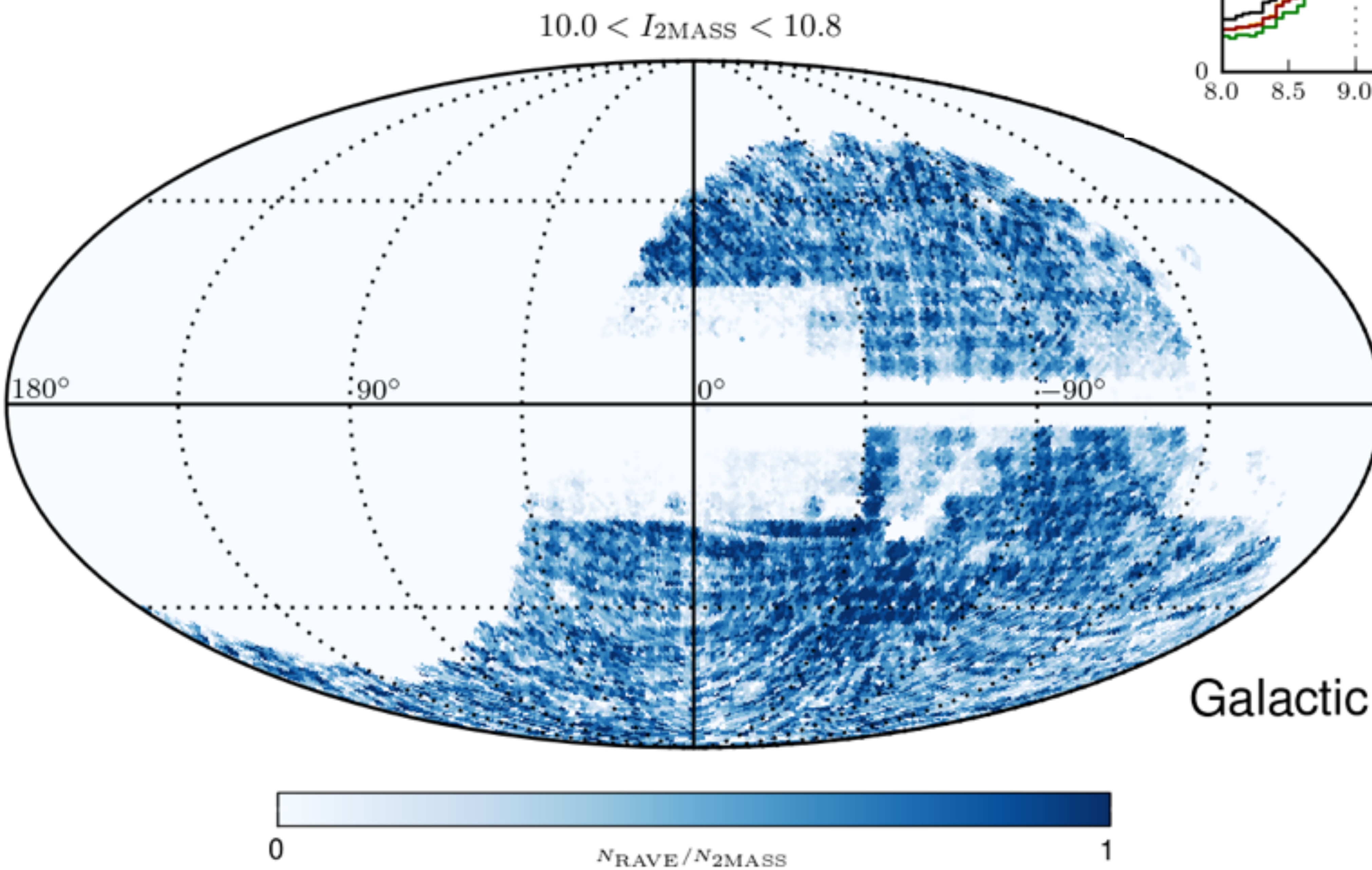




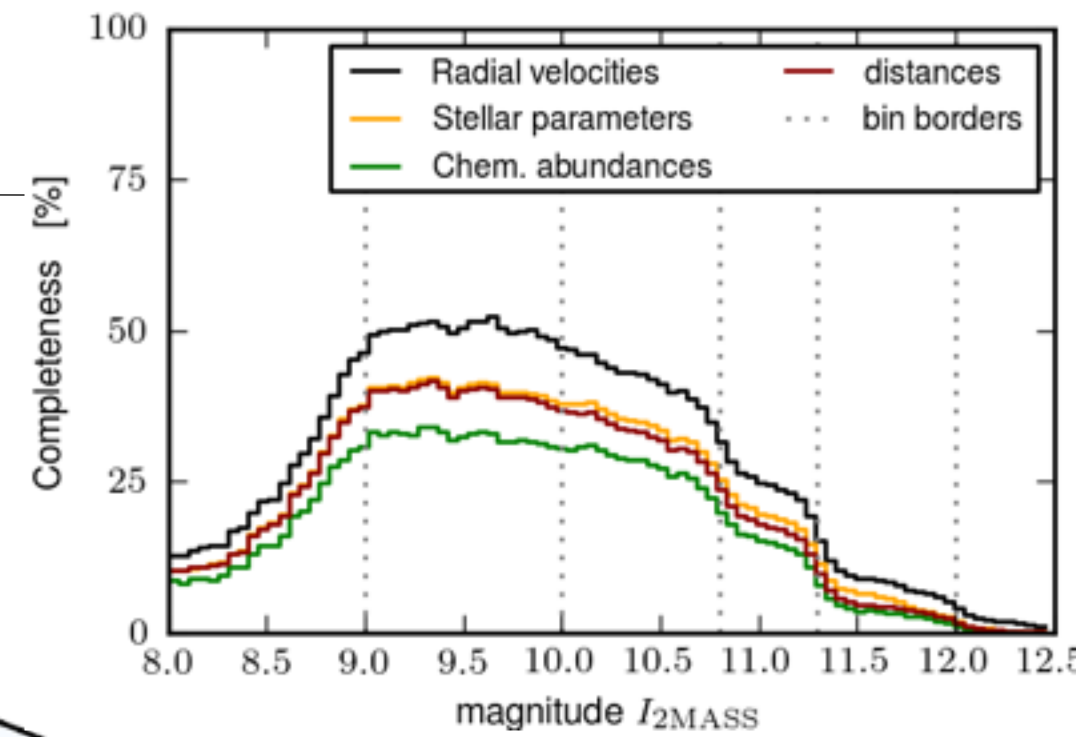
Galactic

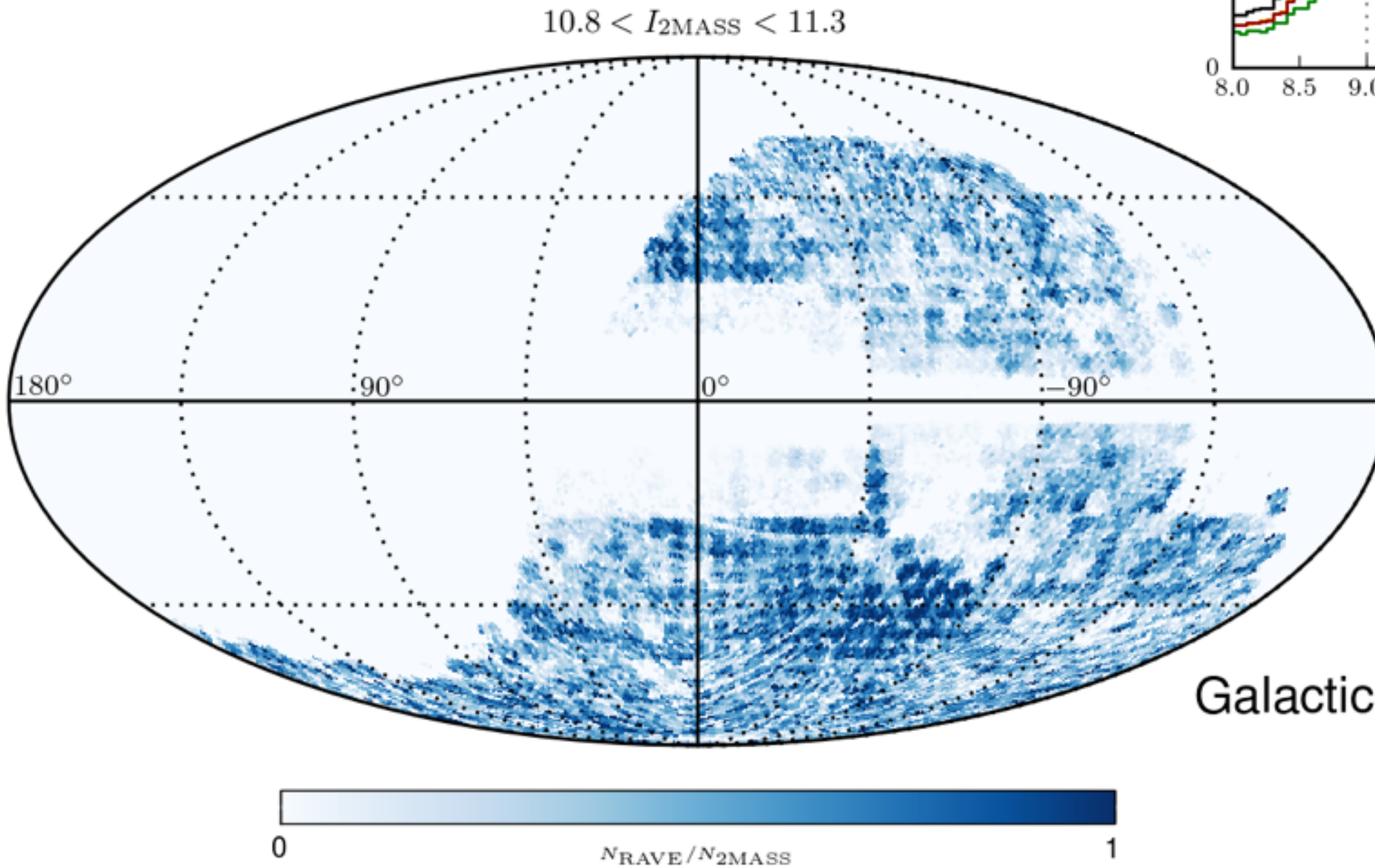
RAVE completeness





completeness





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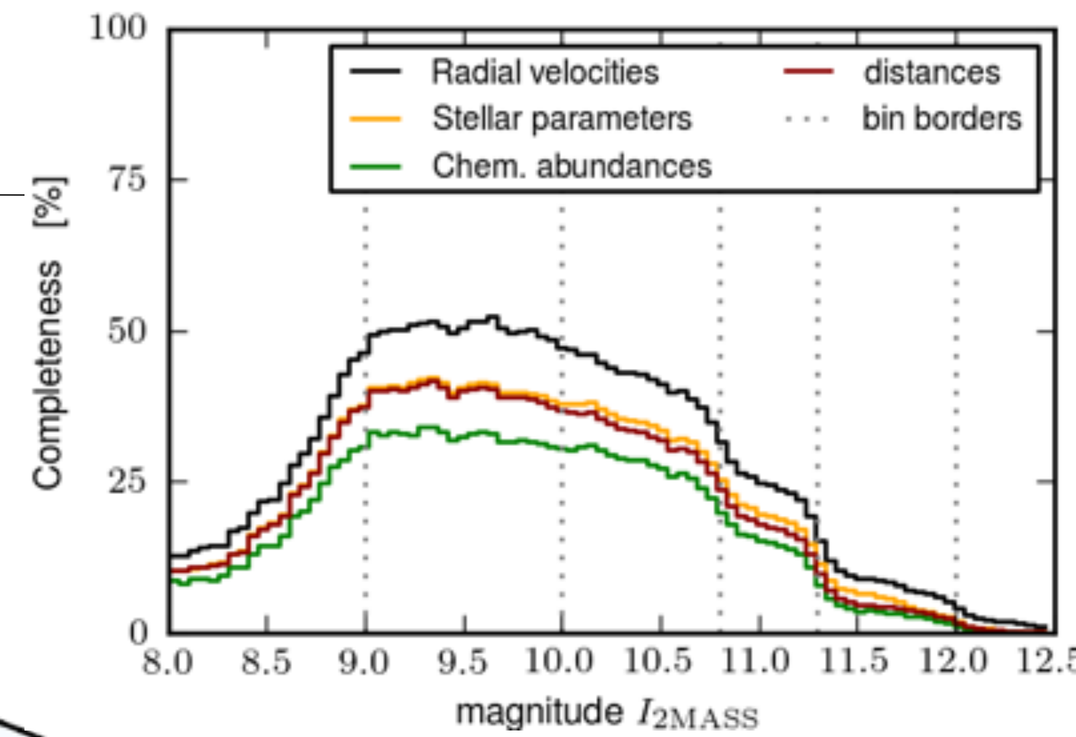
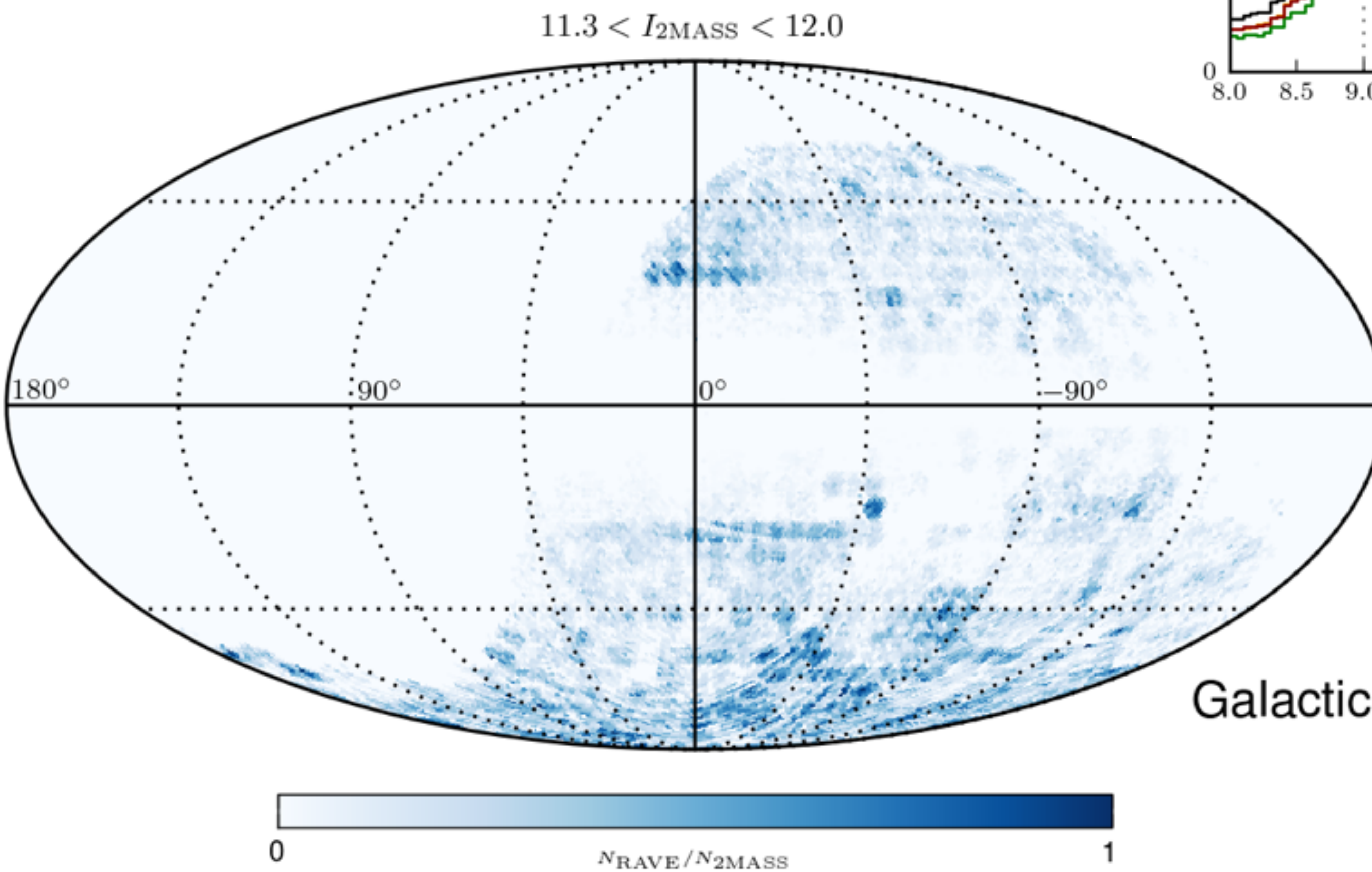
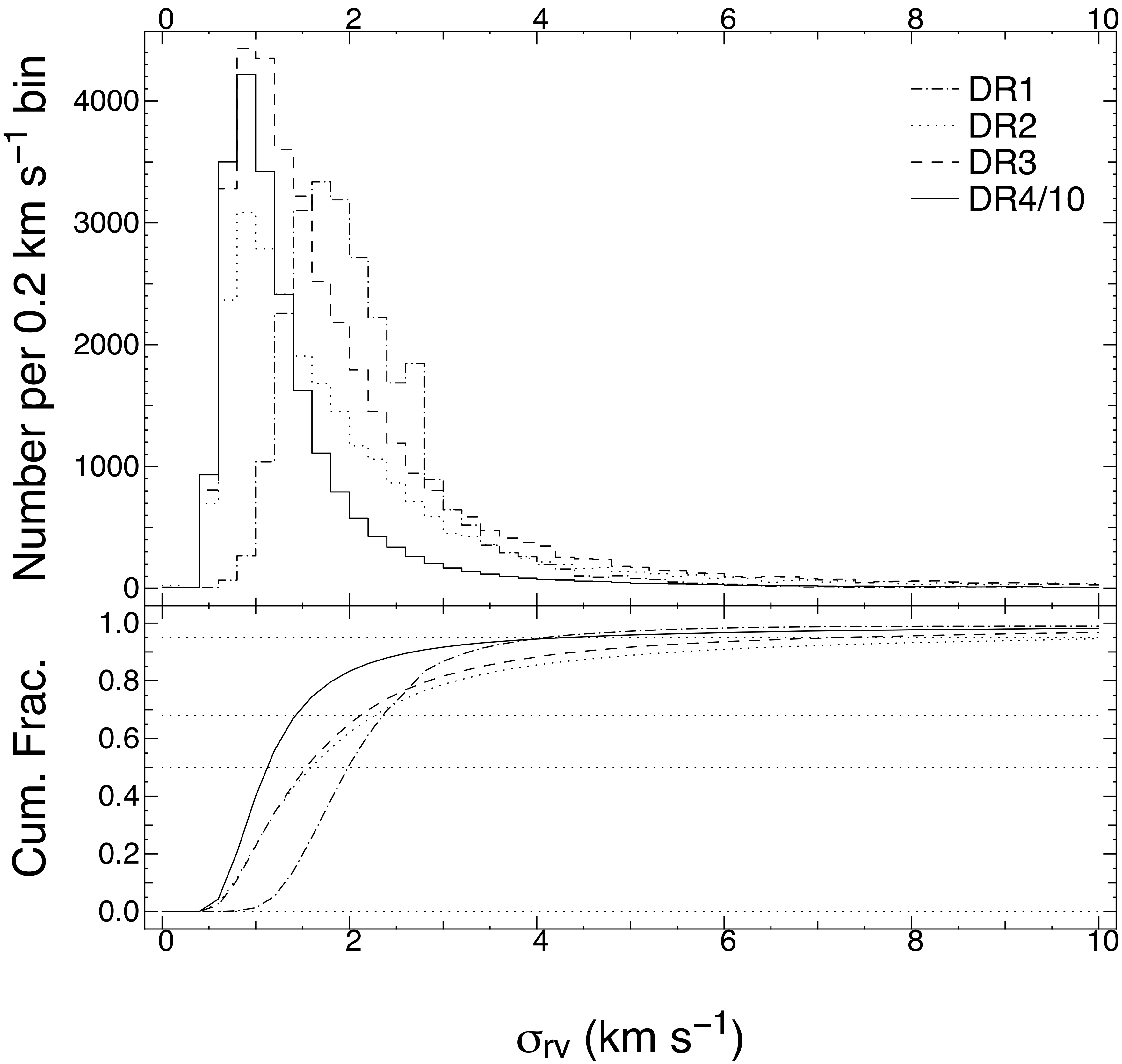




DR4 radial velocities

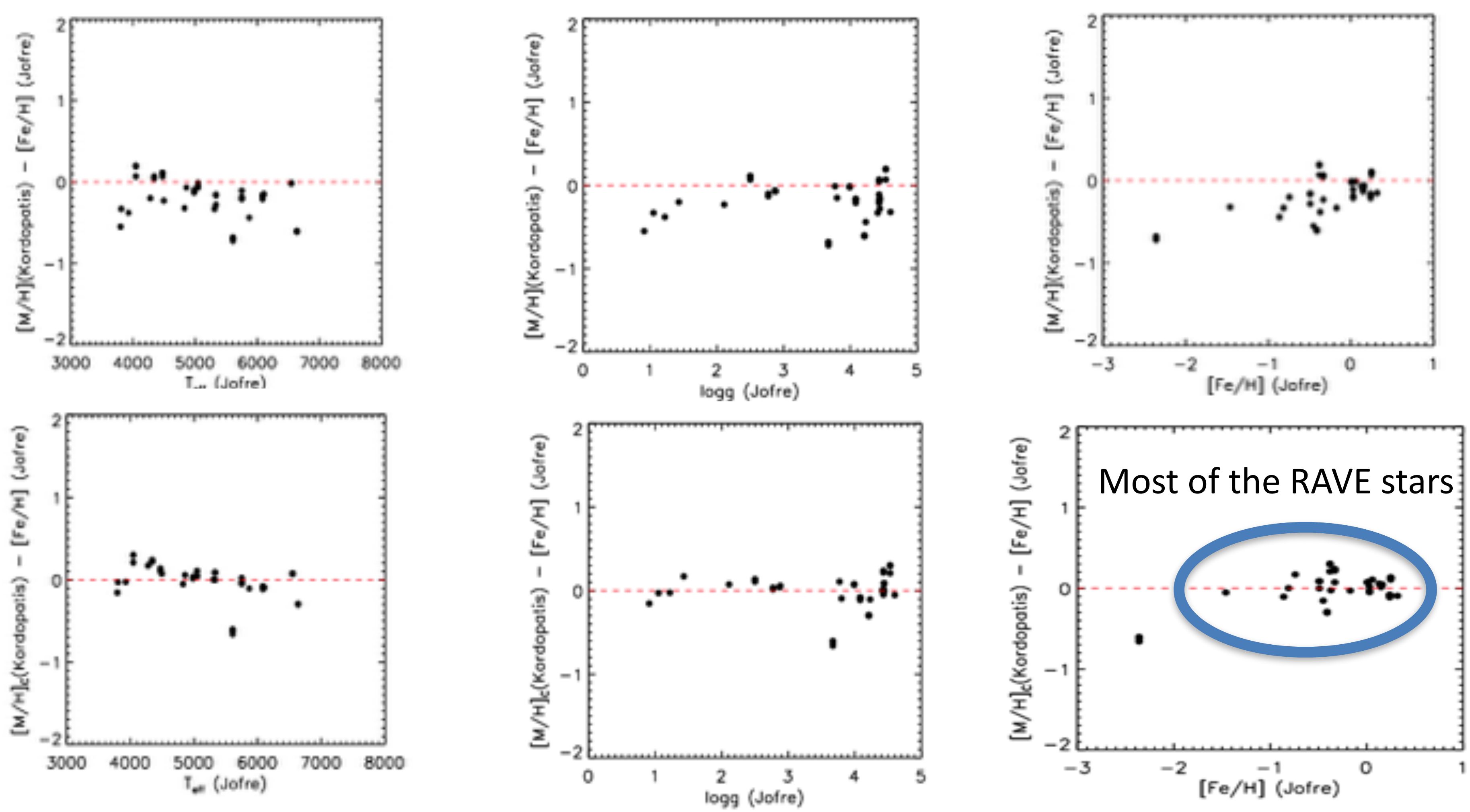


Benchmark stars (Jofre et al 2014)

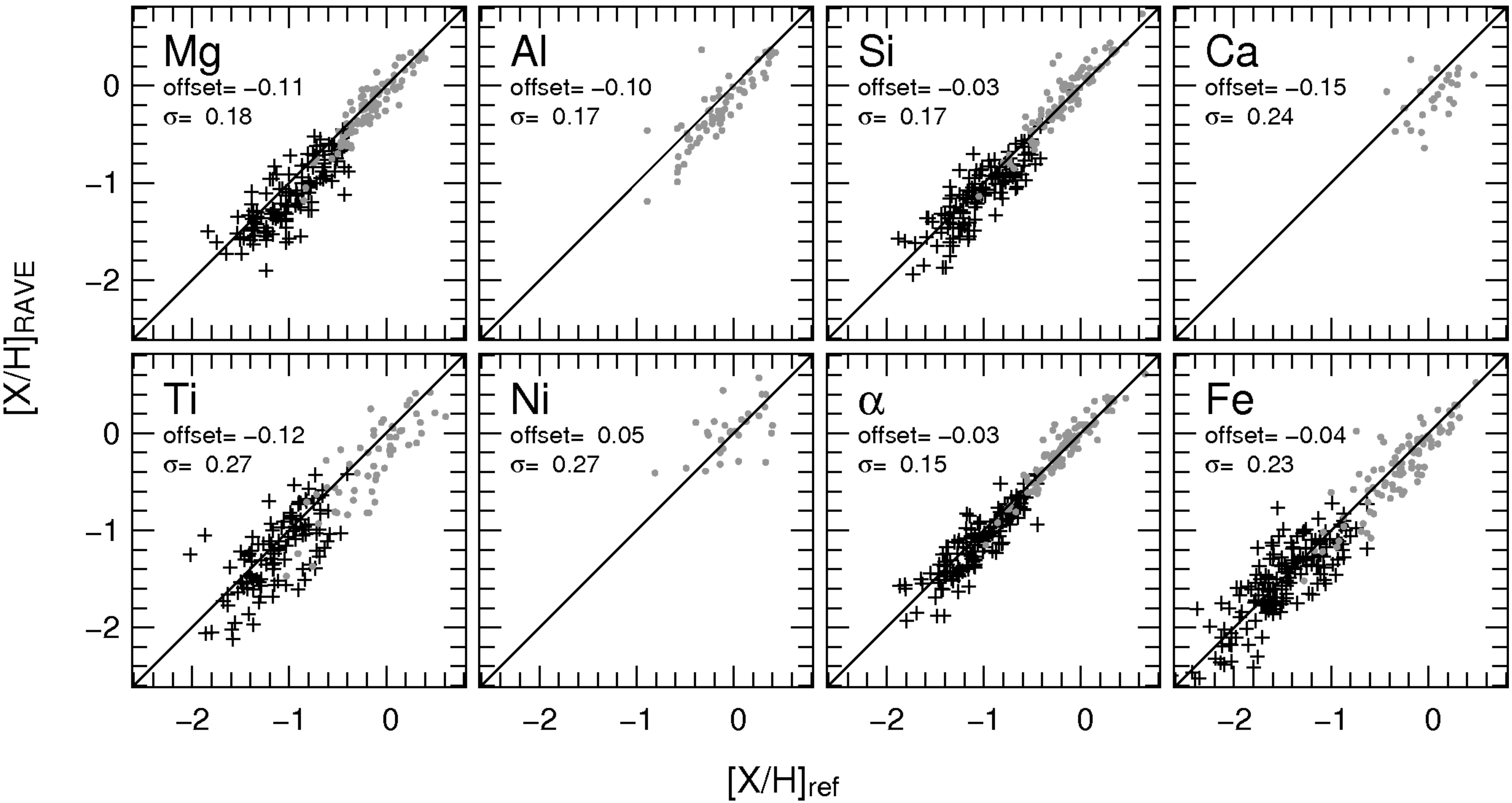
- Jofre et al. 2014 ~ 30 stars observed with ESPADON (R ~ 65 000) and NARVAL (R ~ 80 000) to be the standards for Gaia-ESO and Gaia:
  - Distances and angular diameter of the stars known.

uncalibrated

calibrated



DR4 stellar parameters



DR4 distances

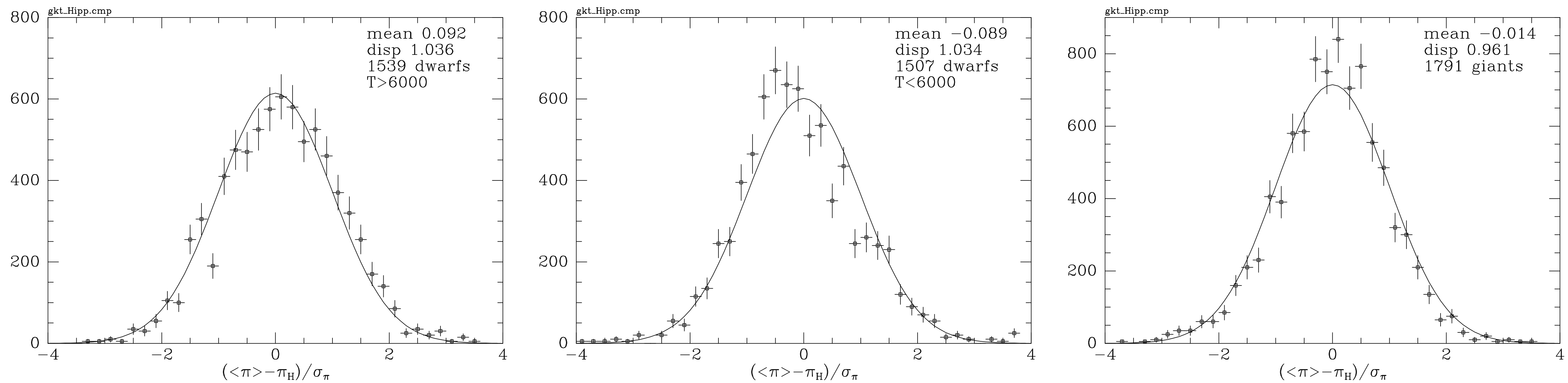


Figure 1. Histograms of the difference between the Hipparcos parallaxes and the expectation of the parallax from the spectrophotometry.

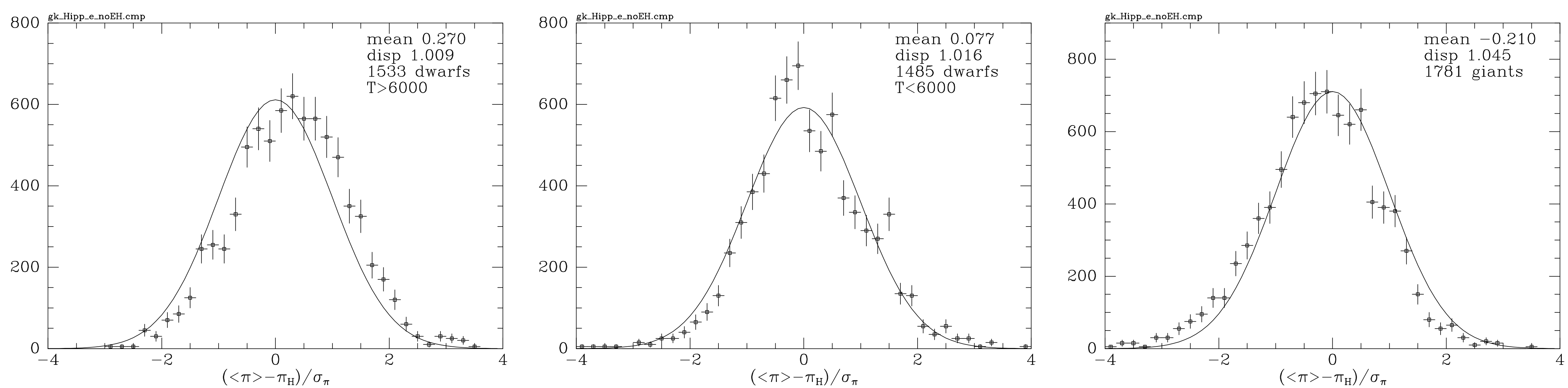


Figure 2. Histograms of the difference between the Hipparcos parallaxes and expectation of the parallax from the spectrophotometry when the extinction is assumed to be zero.

RAVE DR4 vs Gaia

RAVE DR4

- R~7500
- 425 561 stars,
- 482 430 spectra

  (DR3: 77 461 stars)
- 9 < I< 12 mag

Gaia:

R~11 500 for bright targets

R~7 000 for faintest targets

Same λ coverage (CaII triplet)

~10^7 -- 10^8 targets with spectra

Database:

✓ Radial velocities

✓ Spectral morphological flags

✓ T_{eff}, logg, [M/H]

✓ Mg, *Al, Si, Ti, Ni, Fe*

✓ Line-of-sight Distances

✓ Photometry:

DENIS, USNOB, 2MASS, APASS

✓ Proper motions:

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Database:

✓ Radial velocities → same accuracy

✓ Spectral morphological flags → coming from CU

✓ T_{eff}, logg, [M/H] → same precision

✓ *Mg, Al, Si, Ti, Ni, Fe* → similar

✓ Line-of-sight Distances → **Parallaxes!**

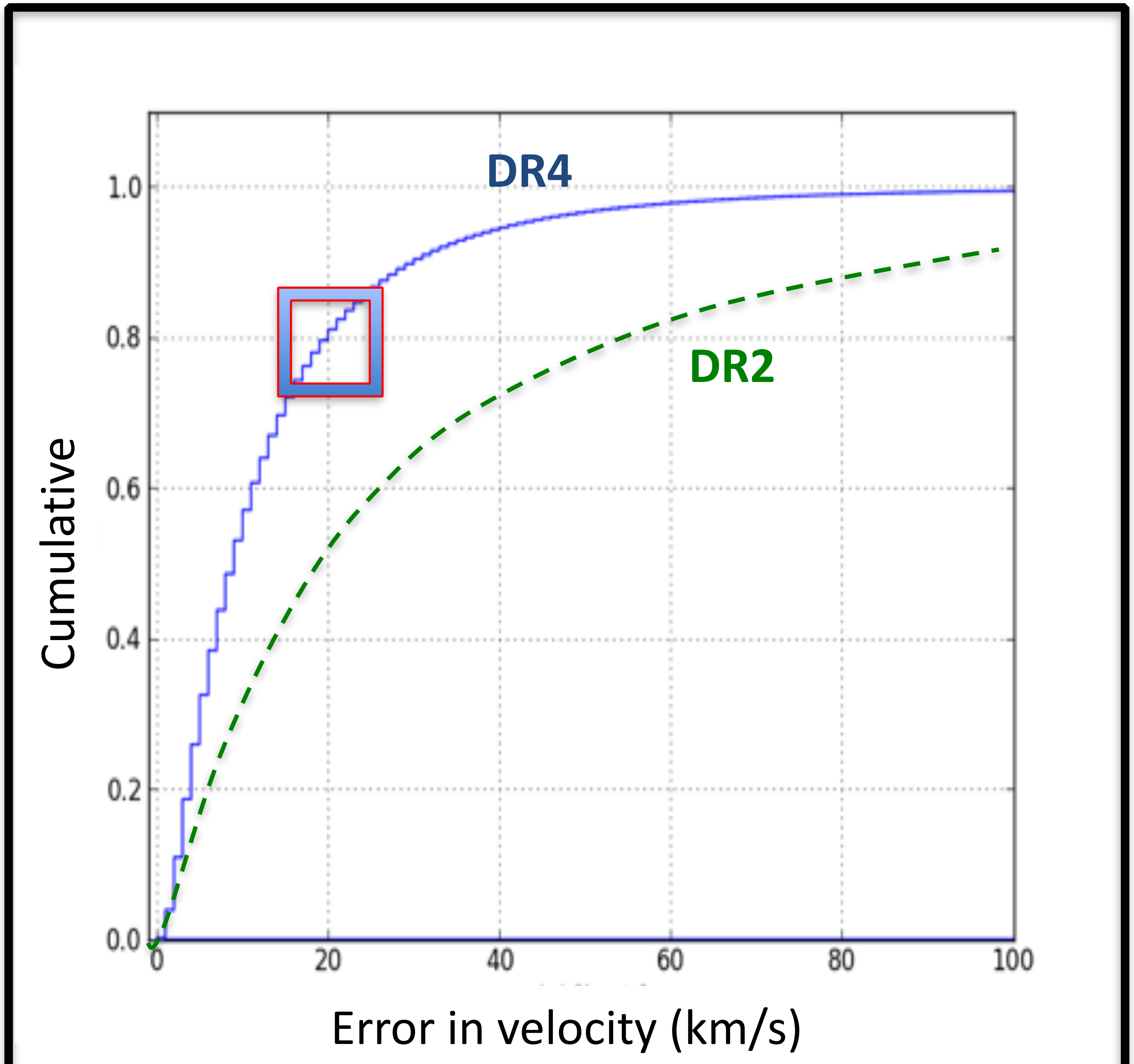
✓ Photometry: → blue/red photometer

DENIS, USNOB, 2MASS, APASS

✓ Proper motions: → **high precision!**

UCAC4, PPMX, PPMXL, Tycho-2, SPM4

RAVE's Galactic 3D velocity errors



Combination of:

Distance errors (<30%)

+Errors in RV

(95% of the stars $\Delta V_{rad} < 4$ km s^{-1})

+Errors in proper motions

(~3 mas yr^{-1})

RAVE: 80 % of the stars with $\Delta V < 20$ km s^{-1}

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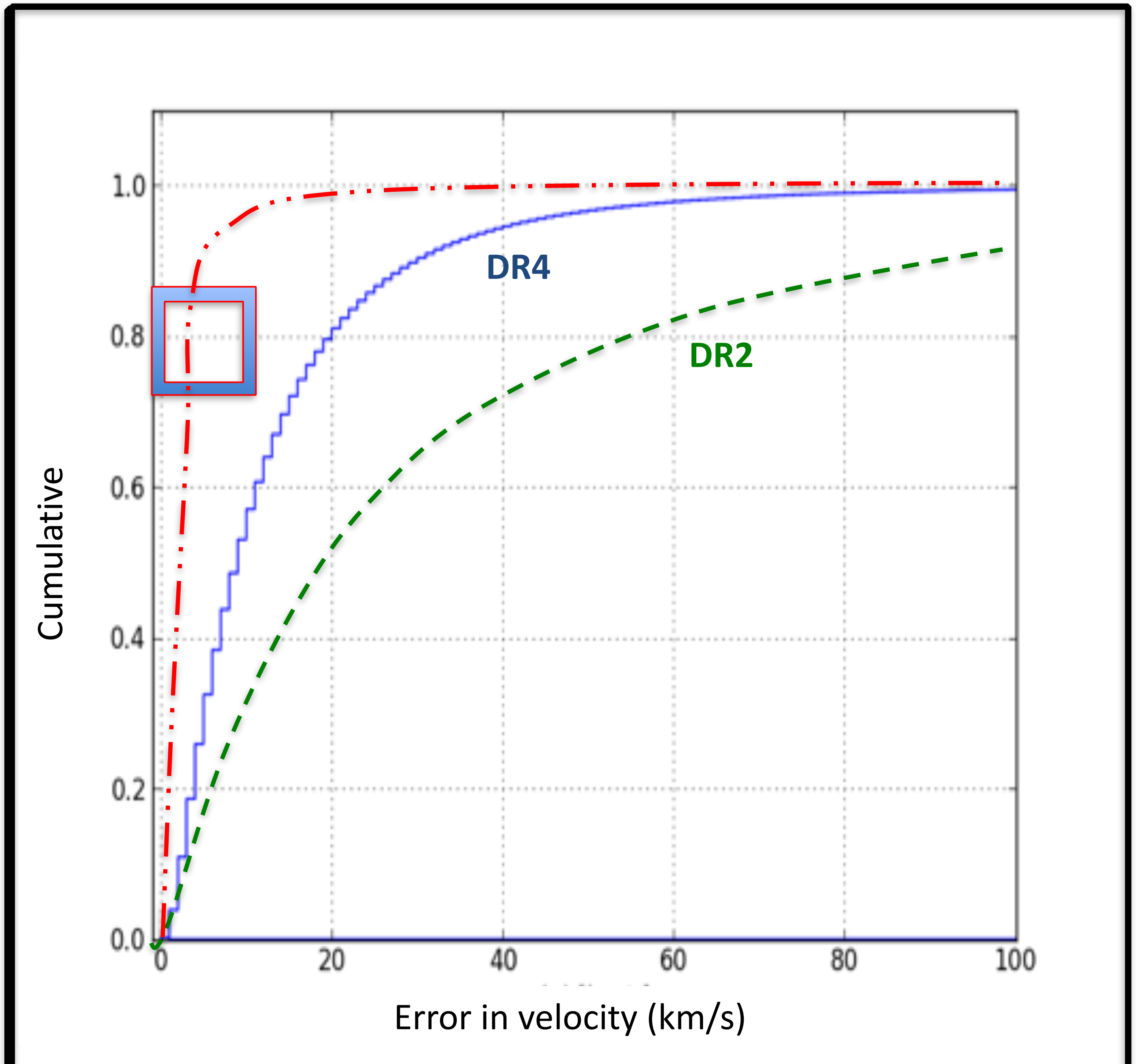


Combination of:

Distance errors ~~(<30%)~~ (<10%)

+Errors in RV

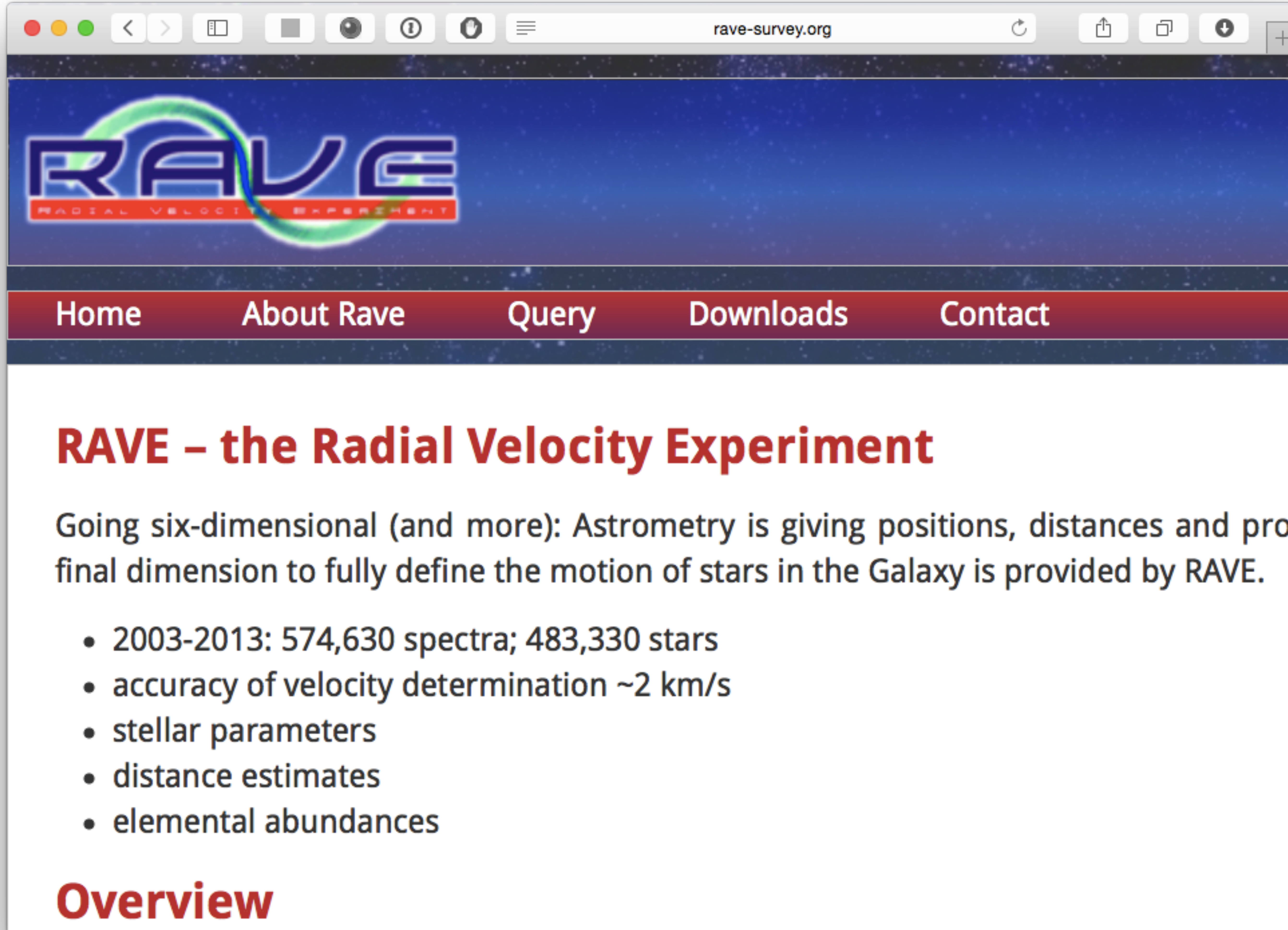
(95% of the stars $\Delta V_{rad} < 4$ km s^{-1})

+Errors in proper motions

~~(~3 mas yr^{-1})~~ 50 μas yr^{-1}

RAVE: 80 % of the stars with $\Delta V < 20$ km s^{-1}

Gaia: 80 % of the stars with $\Delta V < 5$ km s^{-1}


rave-survey.org
RADIAL VELOCITY EXPERIMENT
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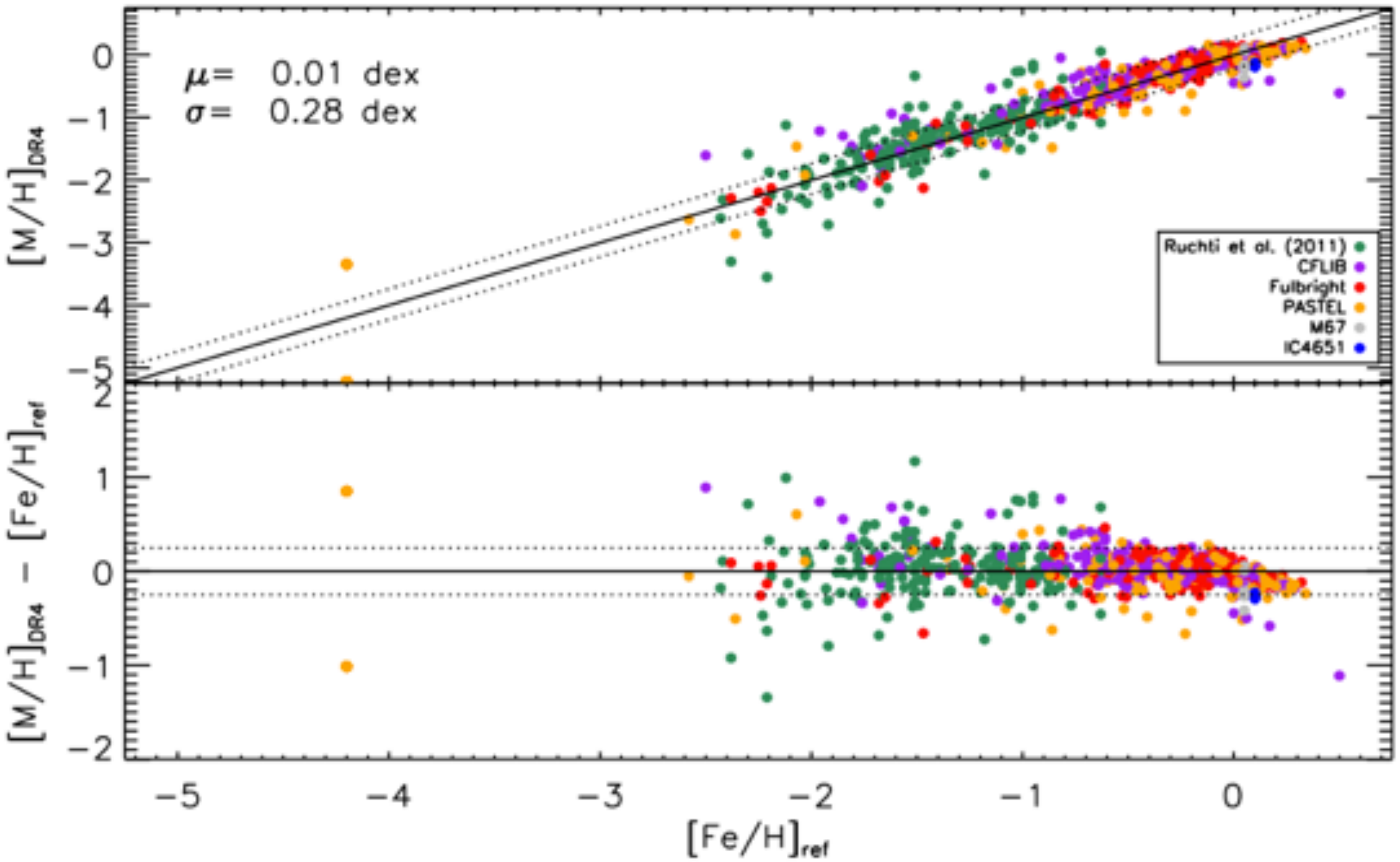
RAVE – the Radial Velocity Experiment
Going six-dimensional (and more): Astrometry is giving positions, distances and pro
final dimension to fully define the motion of stars in the Galaxy is provided by RAVE.
2003-2013: 574,630 spectra; 483,330 stars
accuracy of velocity determination ~2 km/s
stellar parameters
distance estimates
elemental abundances
Overview

Towards RAVE DR5

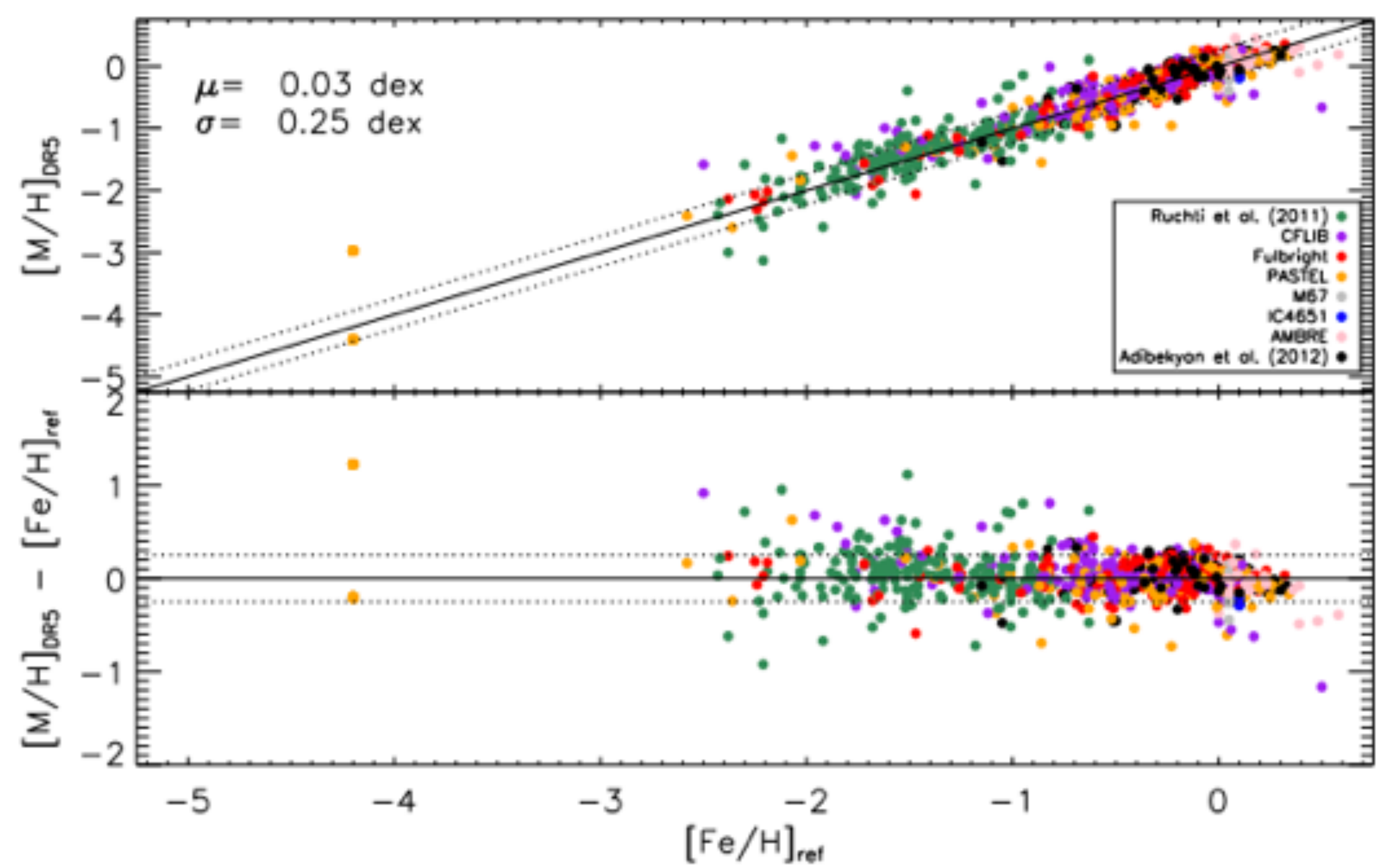
- new new data, but considerable number of „problematic“ fields could be recovered
- Revised temperature priors based on optical photometry (APASS)
- error handling, new abundances pipeline
- Revised calibration at the metal-rich end using GaiaESO benchmark stars (Joffre et al, 2014), HARPS (Adibekyan et al 2013) and FEROS (Worley et al 2012)
- the Cannon ...
- currently being explored: log g and ages from Kepler Astroseismology

DR4 vs DR5 calibration

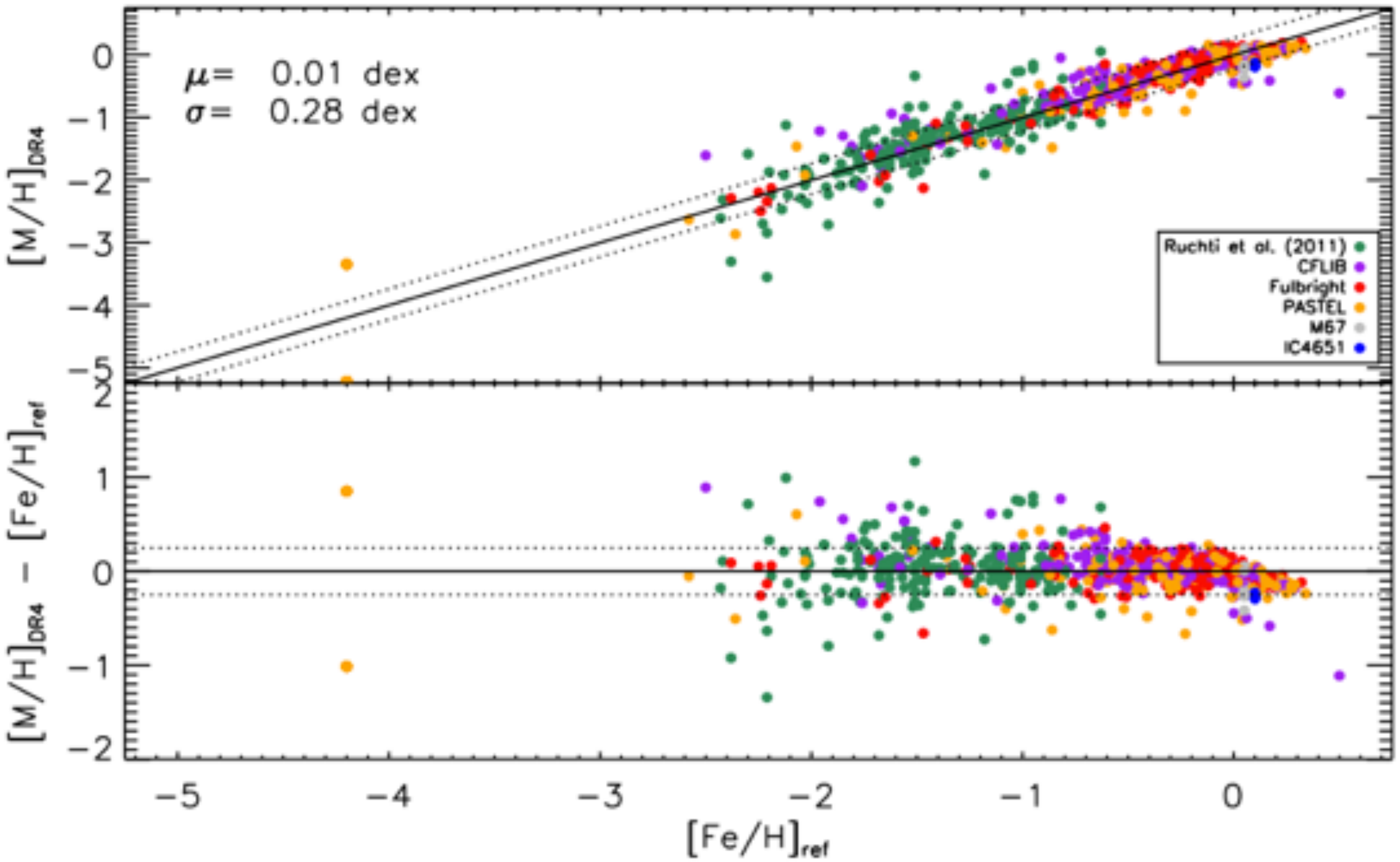


DR4

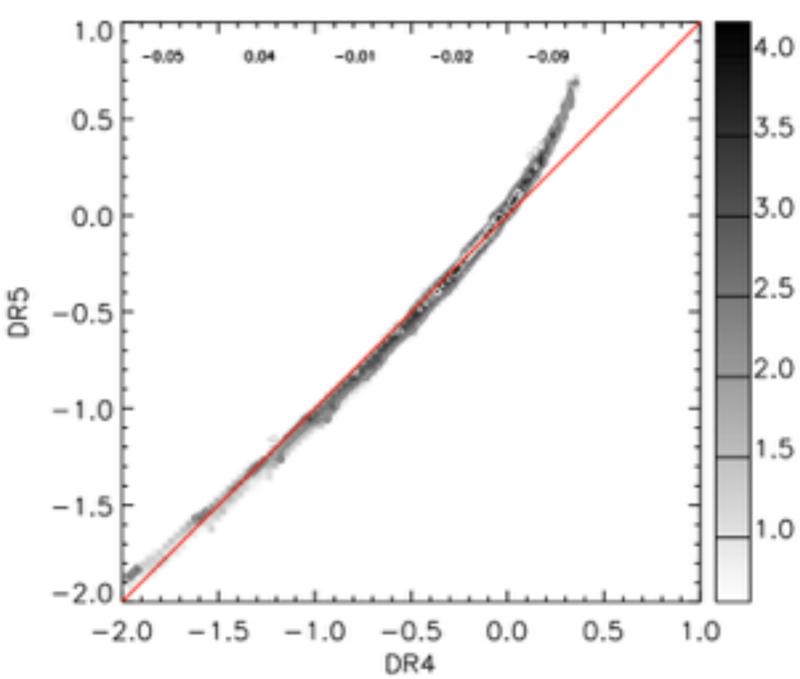
DR5



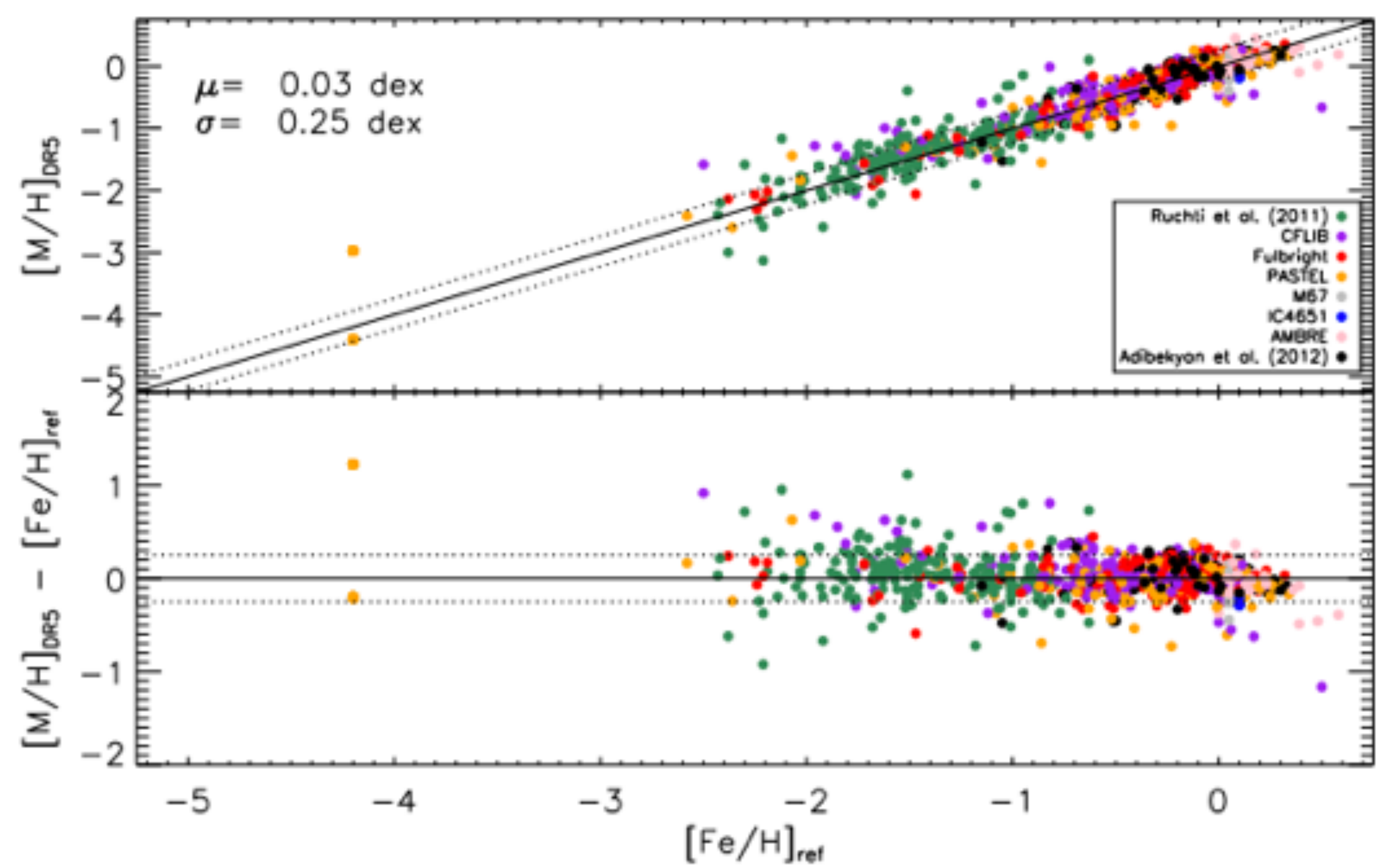
DR4 vs DR5 calibration



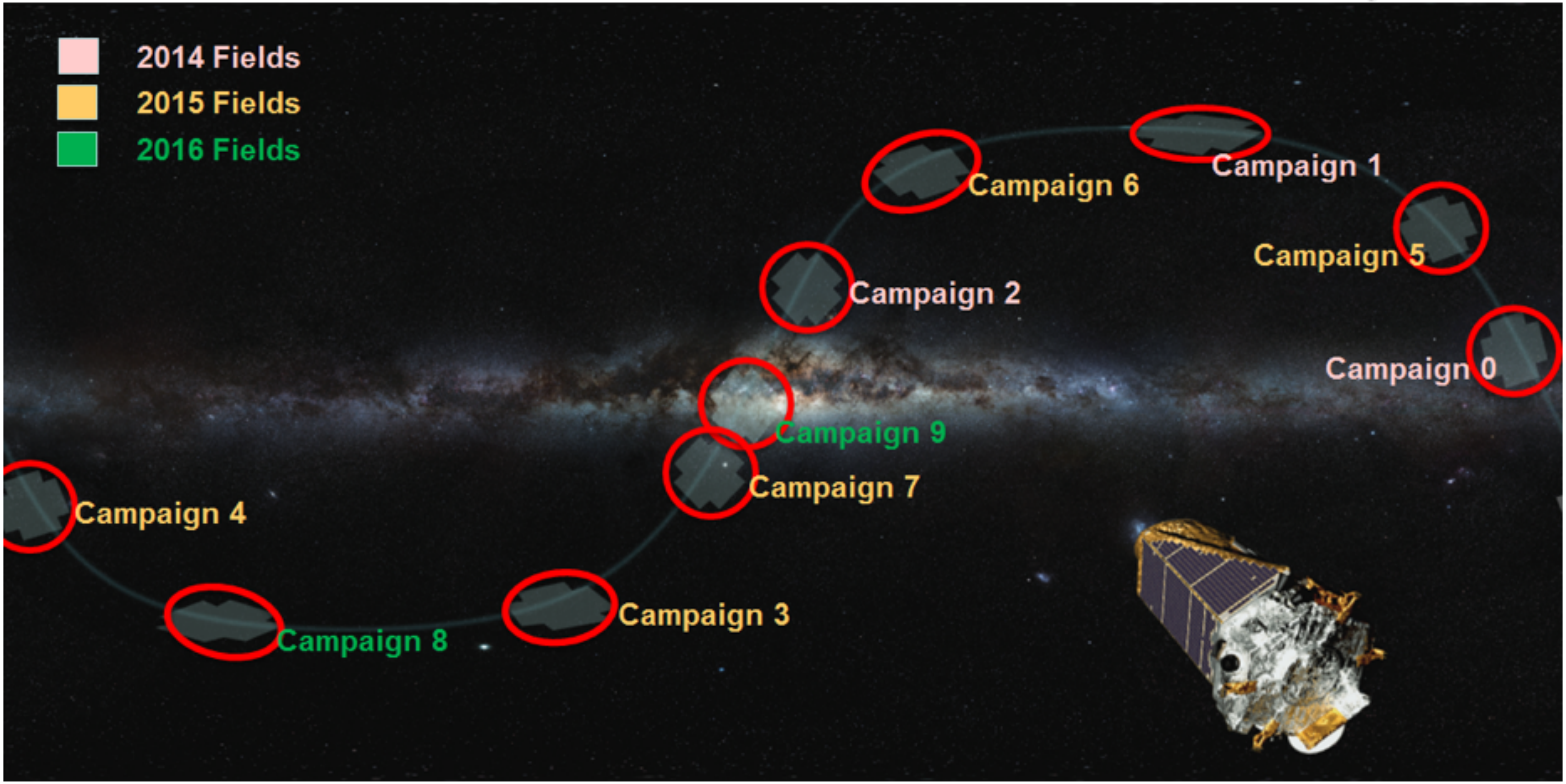
DR4



DR5



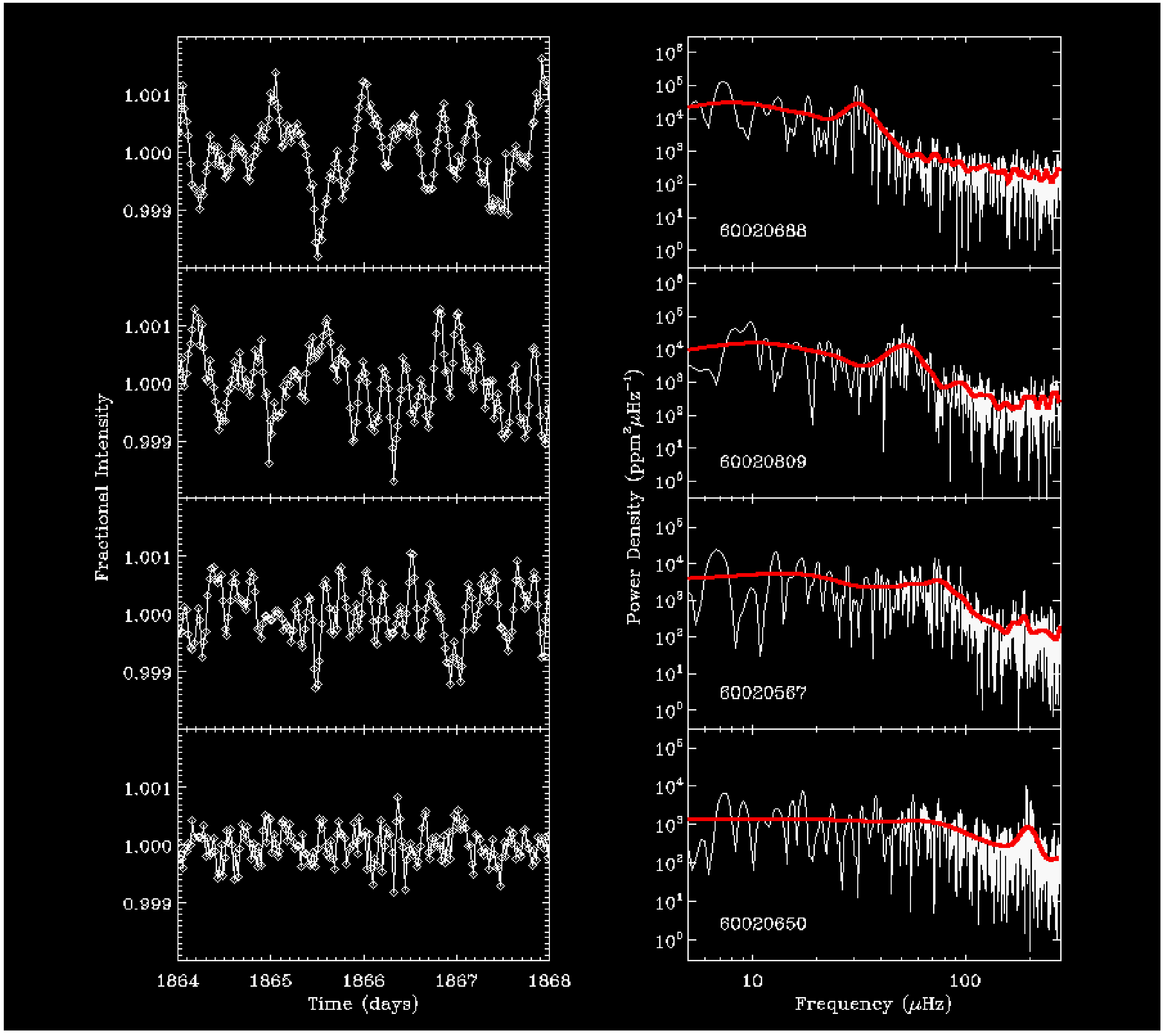
RAVE + astroseismology Kepler



Campaign	Rave Targets.	Giants
K2-Campaign 0	397	168
K2-Campaign 1	522	166
K2-Campaign 2	520	384

RAVE + astroseismology Kepler

- Oscillations in RAVE Red Giants have already been detected in K-2 campaign 0.
- Final light-curves and data for K2-campaign 1 will be available in January 2015.

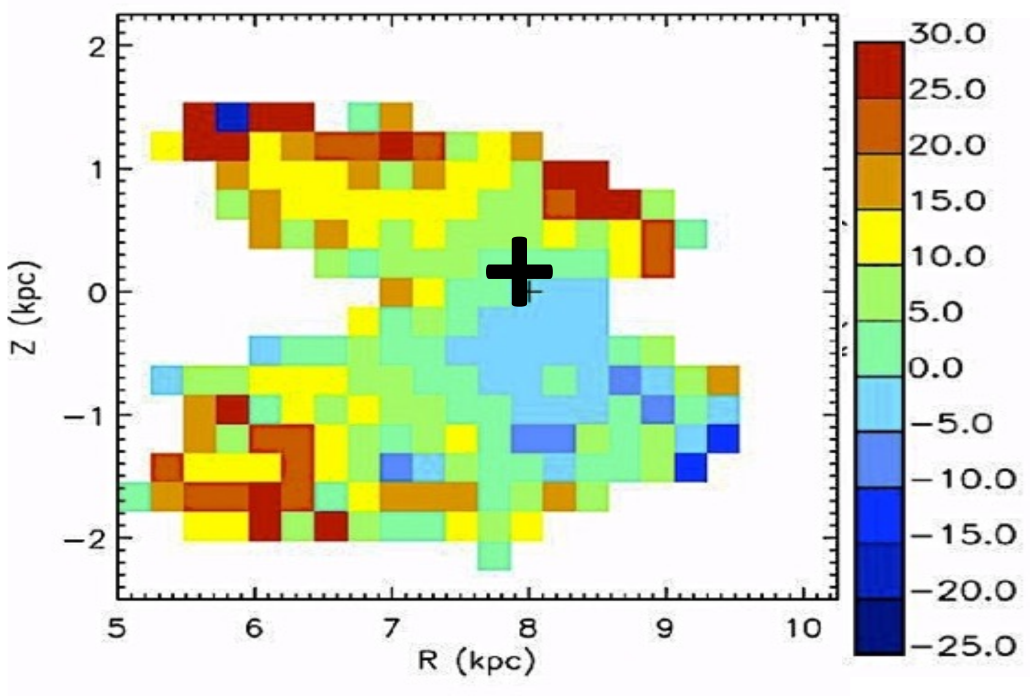


Valentini et al., in prep.

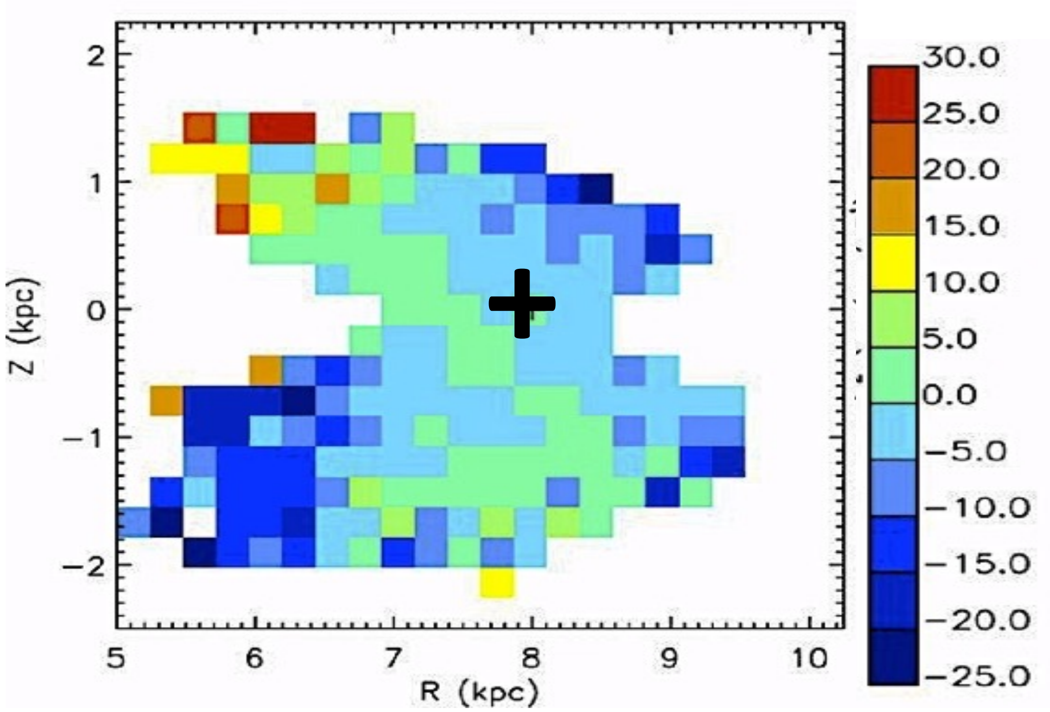
Some recent Applications

Velocity Maps

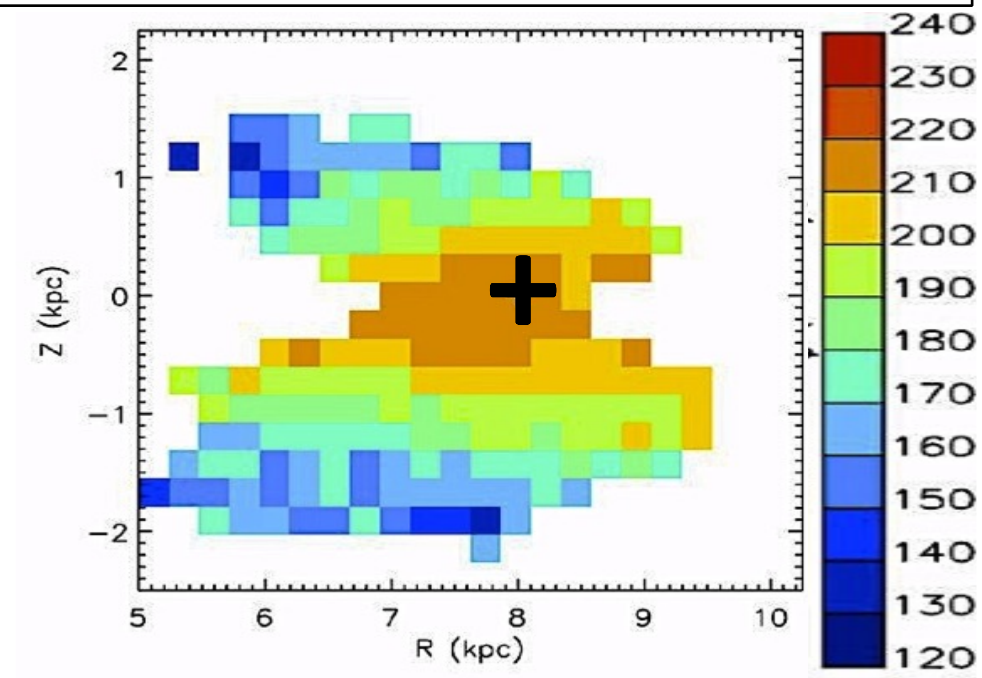
Galactocentric radial velocity



Galactocentric vertical velocity

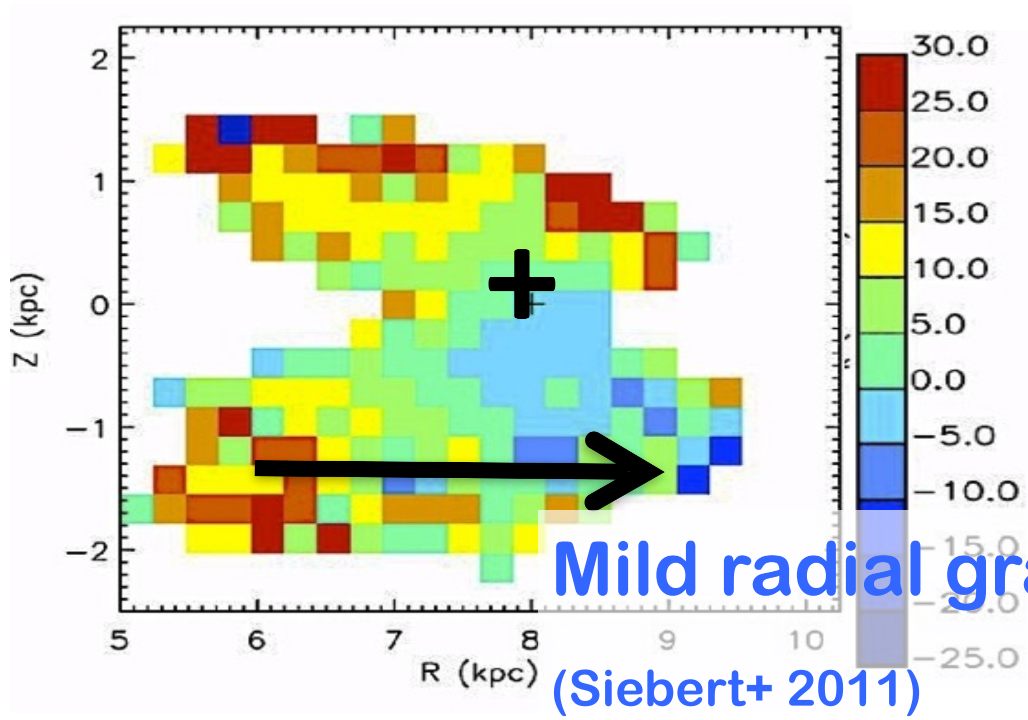


Galactocentric azimuthal velocity



Velocity Maps

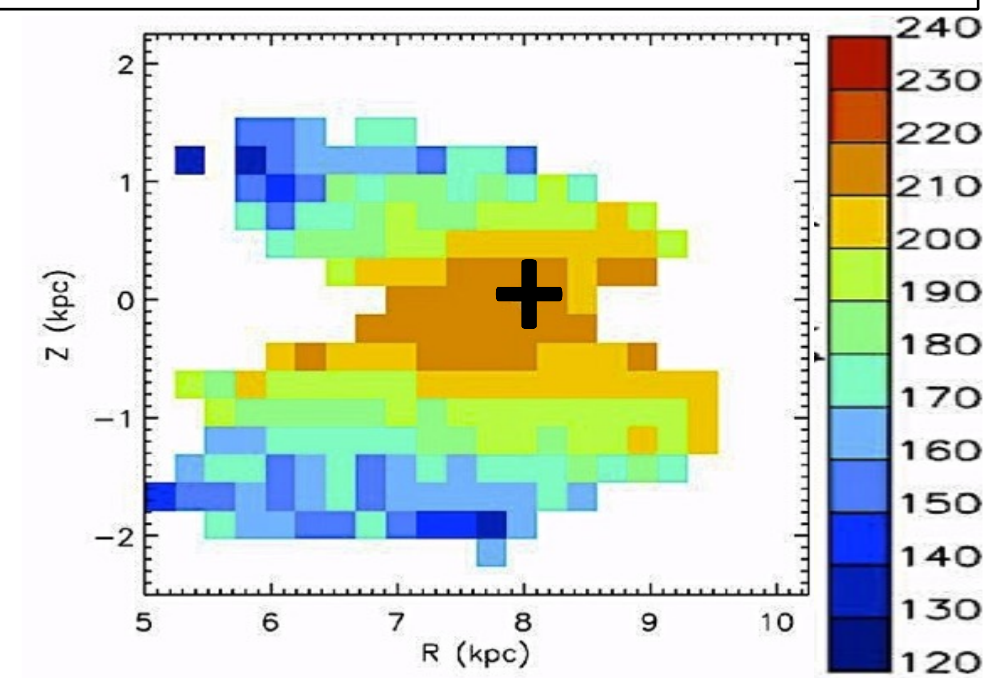
Galactocentric radial velocity



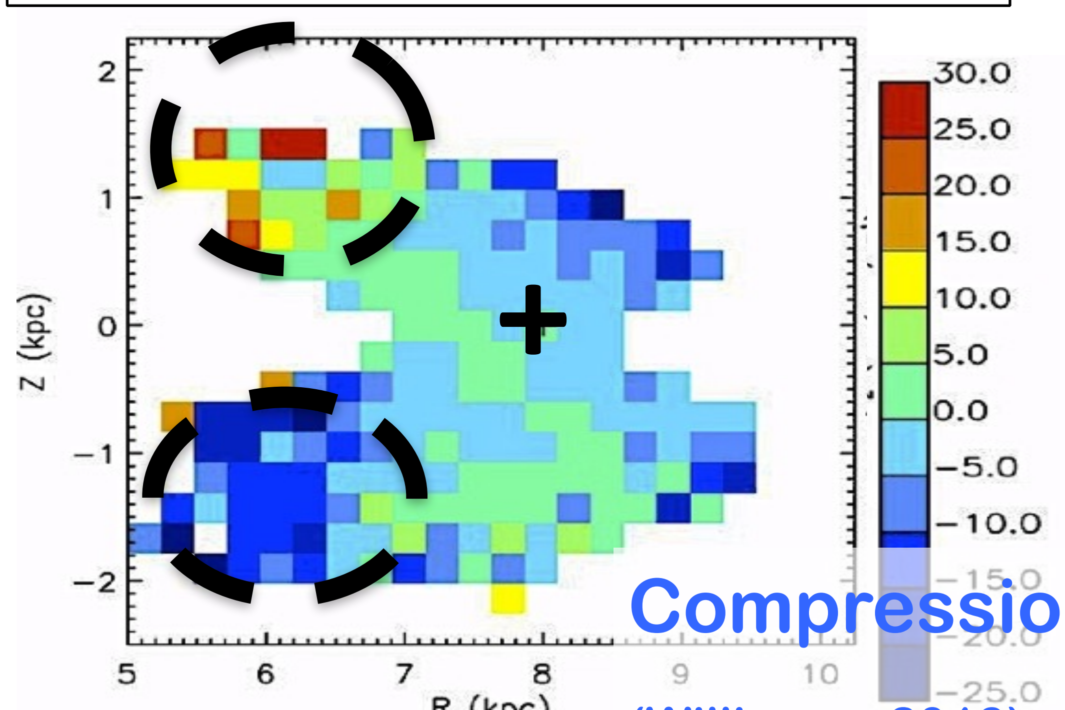
Mild radial gradient in V_R

(Siebert+ 2011)

Galactocentric azimuthal velocity



Galactocentric vertical velocity



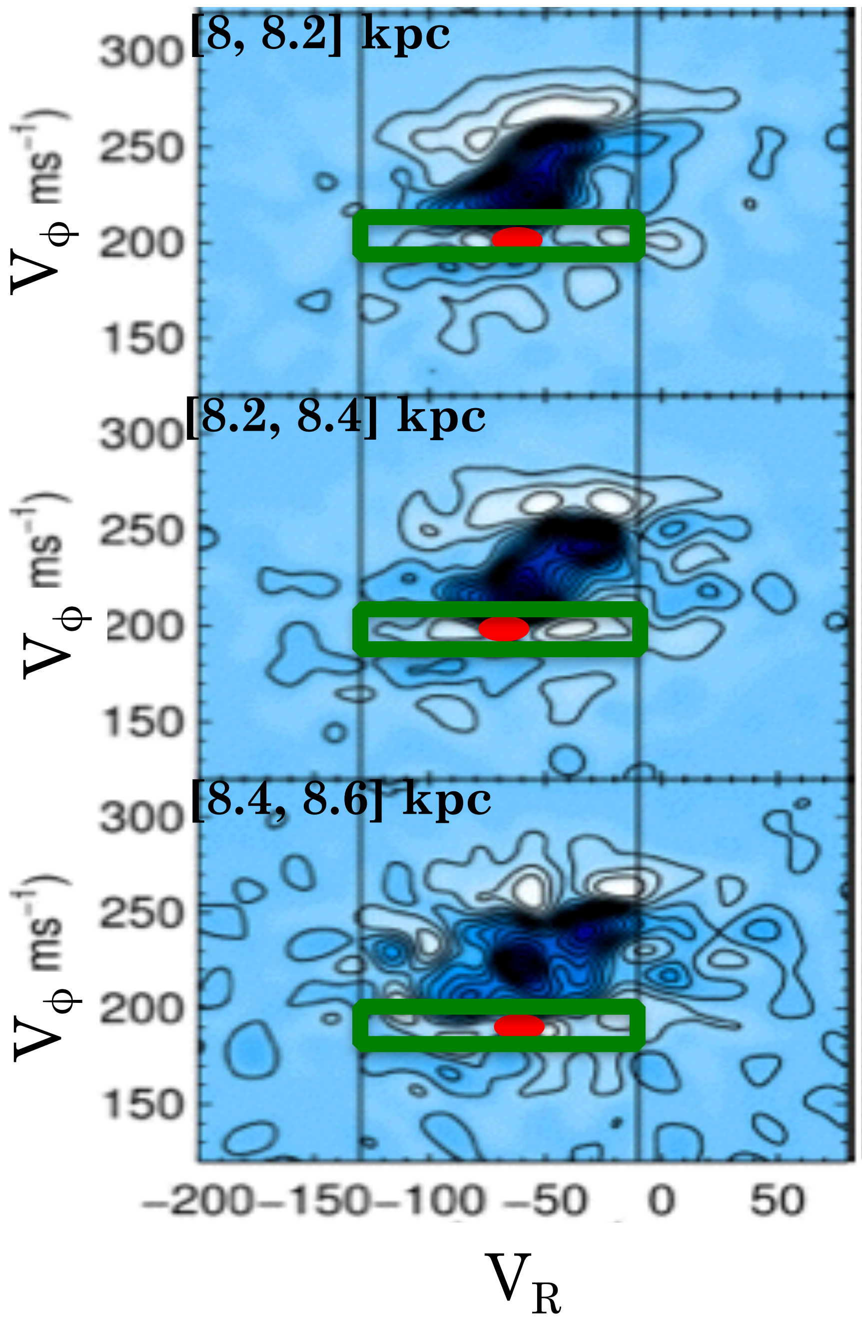
Compression-rarefaction pattern

(Williams+ 2013)

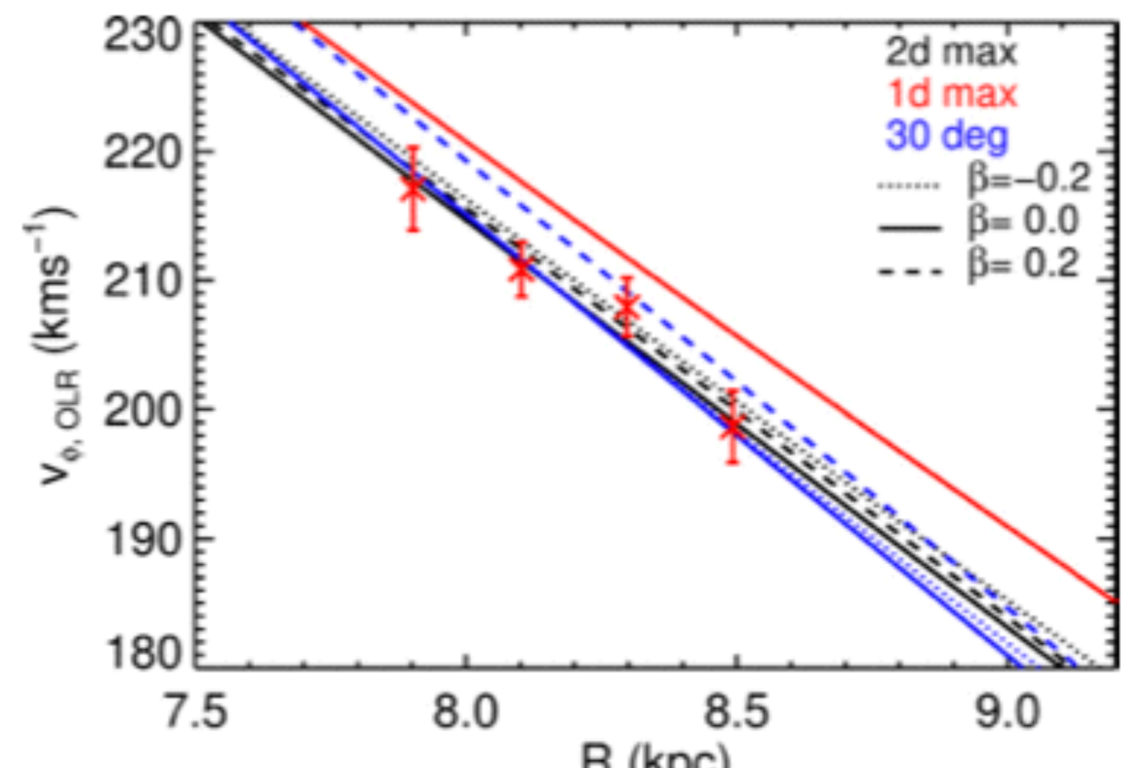
Galactic bar & Moving groups

Antoja+ 2014

Identification of the Hercules stream at different radii
Saddle point position ≈ f(pattern speed, orientation of the bar).



$$v_{\phi,\mathrm{OLR}}(R) \approx a\, v_0\,(R/R_0)^\beta\, \frac{1+\beta}{1-\beta}\left[1 - \frac{\Omega_b R}{v_0 (R/R_0)^\beta}\, \frac{1}{1+\sqrt{(1+\beta)/2}}\right] - (b + c\beta - 1)\, v_0\,(R/R_0)^\beta.$$



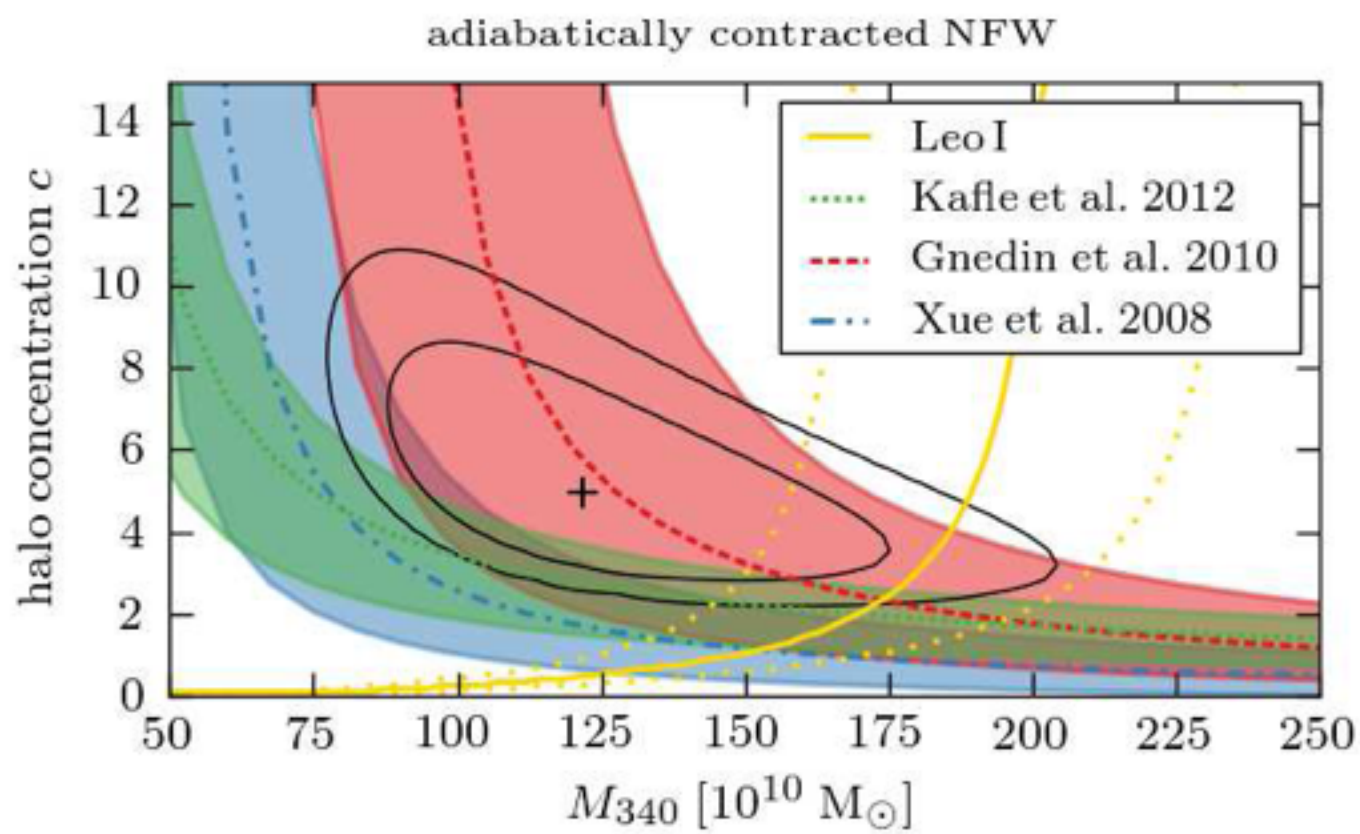
Bar's pattern speed:
$51 < \Omega_b < 56$ km s^{-1} kpc^{-1} for $10^o < \Phi_b < 45^o$

Escape speed of the Milky Way at the Solar Circle

- Leonard & Tremaine (1990):
  - consider distribution function f(E)
  - $f \rightarrow 0$ as $E \rightarrow \Phi(r_{vir}) \Rightarrow n(v) \propto (v_{esc}\text{-}v)^k$
- Consequently for line of sight:

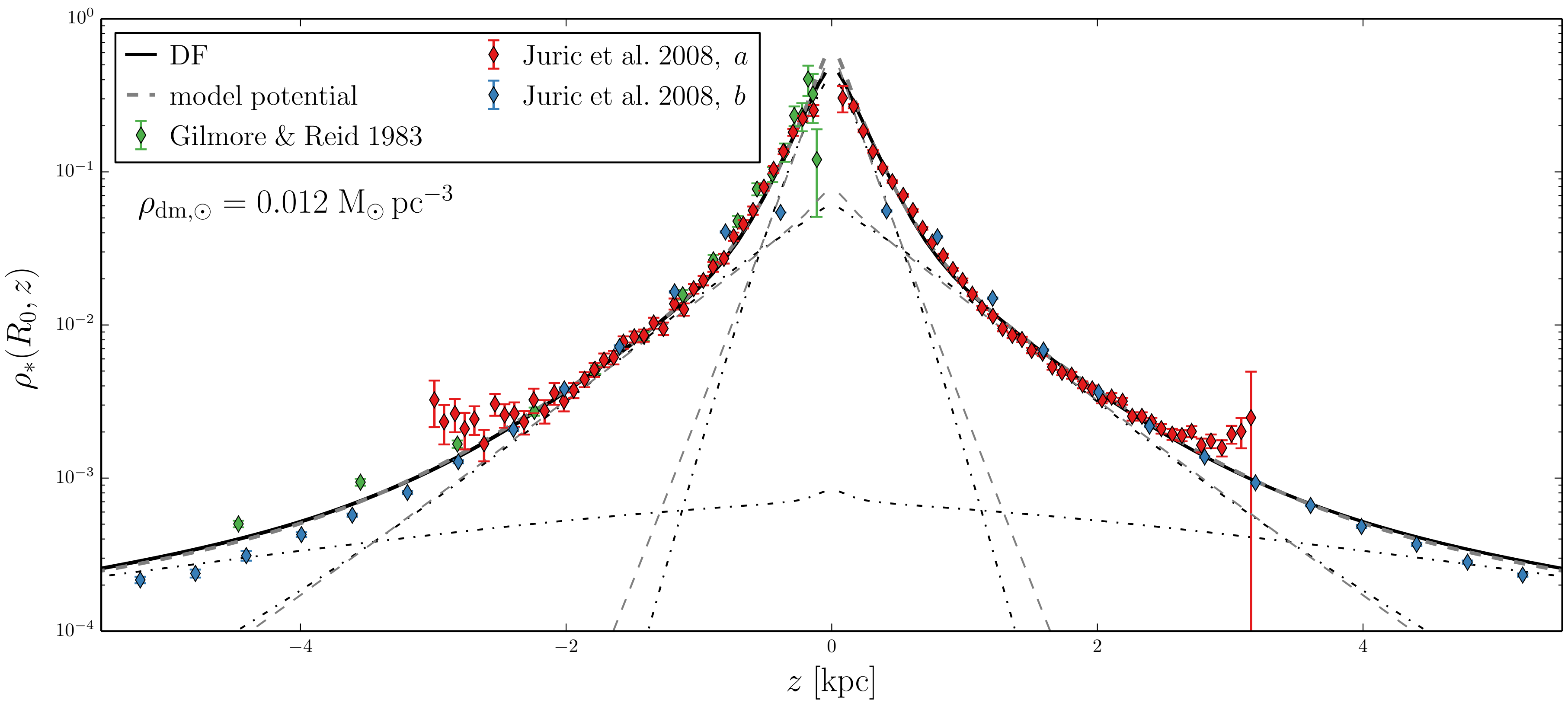
$$n(v_{||}) \propto (v_{esc} - v_{||})^{k+1}$$

- Dependence verified via cosmological simulations
- Measure distribution $n(v_{||})$ for high velocity stars with RAVE on counterrotating orbits
- Piffl et al (2014a):
  $493\text{km/s} < v_{esc} < 587\text{km/s}$
  $1.1{\times}10^{12}M_\odot < M_{200} < 2.1{\times}10^{12}M_\odot$

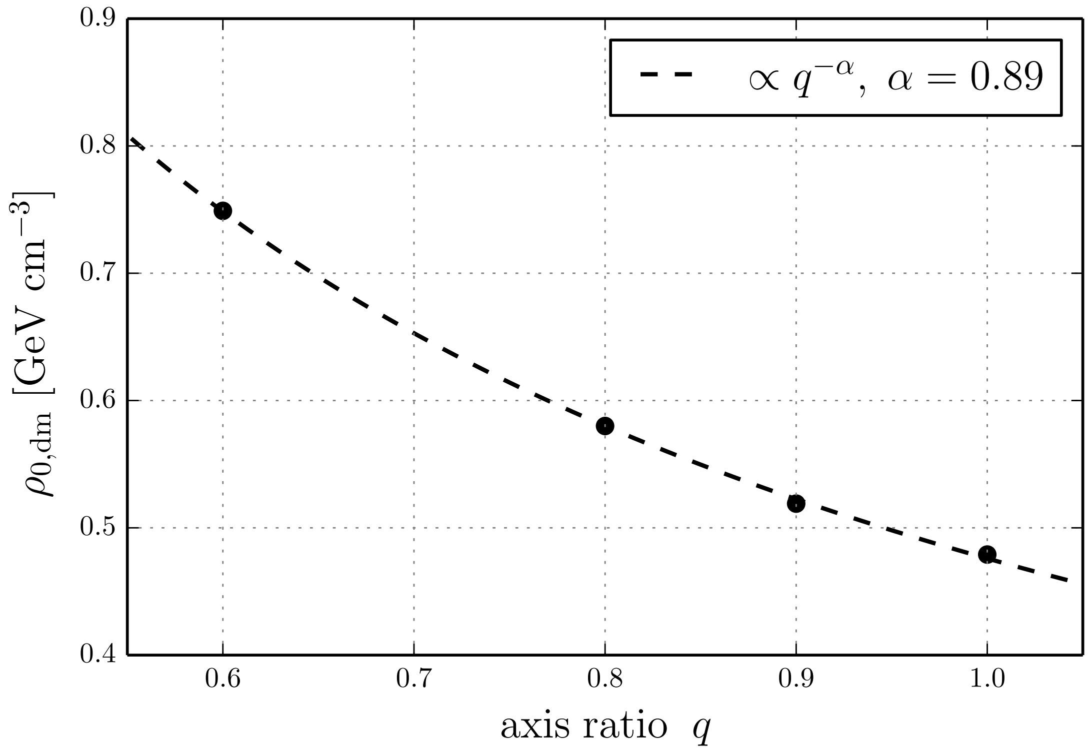


Dark mass in the solar neighborhood (Piffl et al 2014)

- Mass Model:
  - three exponential disks
  - flattened bulge
  - NFW dark matter halo
- Binney 2012 model for kinematics (incl. stellar halo)
- Model fit to vertical RAVE data



Results



Model potential parameters		
$\Sigma_{0,\mathrm{thin}}$	570.7	$\mathrm{M}_\odot\ \mathrm{pc}^{-2}$
$\Sigma_{0,\mathrm{thick}}$	251.0	$\mathrm{M}_\odot\ \mathrm{pc}^{-2}$
R_d	2.68	kpc
$z_{\mathrm{d,thin}}$	0.20	kpc
$z_{\mathrm{d,thick}}$	0.70	kpc
$\Sigma_{0,\mathrm{gas}}$	94.5	$\mathrm{M}_\odot\ \mathrm{pc}^{-2}$
$R_{\mathrm{d,gas}}$	5.36	kpc
$\rho_{0,\mathrm{dm}}$	0.01816	$\mathrm{M}_\odot\ \mathrm{pc}^{-3}$
$r_{0,\mathrm{dm}}$	14.4	kpc
DF parameters		
$\sigma_{r,\mathrm{thin}}$	33.9	$\mathrm{km\,s^{-1}}$
$\sigma_{z,\mathrm{thin}}$	24.9	$\mathrm{km\,s^{-1}}$
$R_{\sigma,r,\mathrm{thin}}$	9.0	kpc
$R_{\sigma,z,\mathrm{thin}}$	9.0	kpc
$\sigma_{r,\mathrm{thick}}$	50.5	$\mathrm{km\,s^{-1}}$
$\sigma_{z,\mathrm{thick}}$	48.7	$\mathrm{km\,s^{-1}}$
$R_{\sigma,r,\mathrm{thick}}$	12.9	kpc
$R_{\sigma,z,\mathrm{thick}}$	4.1	kpc
F_{thick}	0.460	
F_{halo}	0.026	

$$\varrho_{\mathrm{DM}} = 0.0126 \times q^{-0.89} \mathrm{M}_\odot\ \mathrm{pc}^{-3} \pm 10\%$$

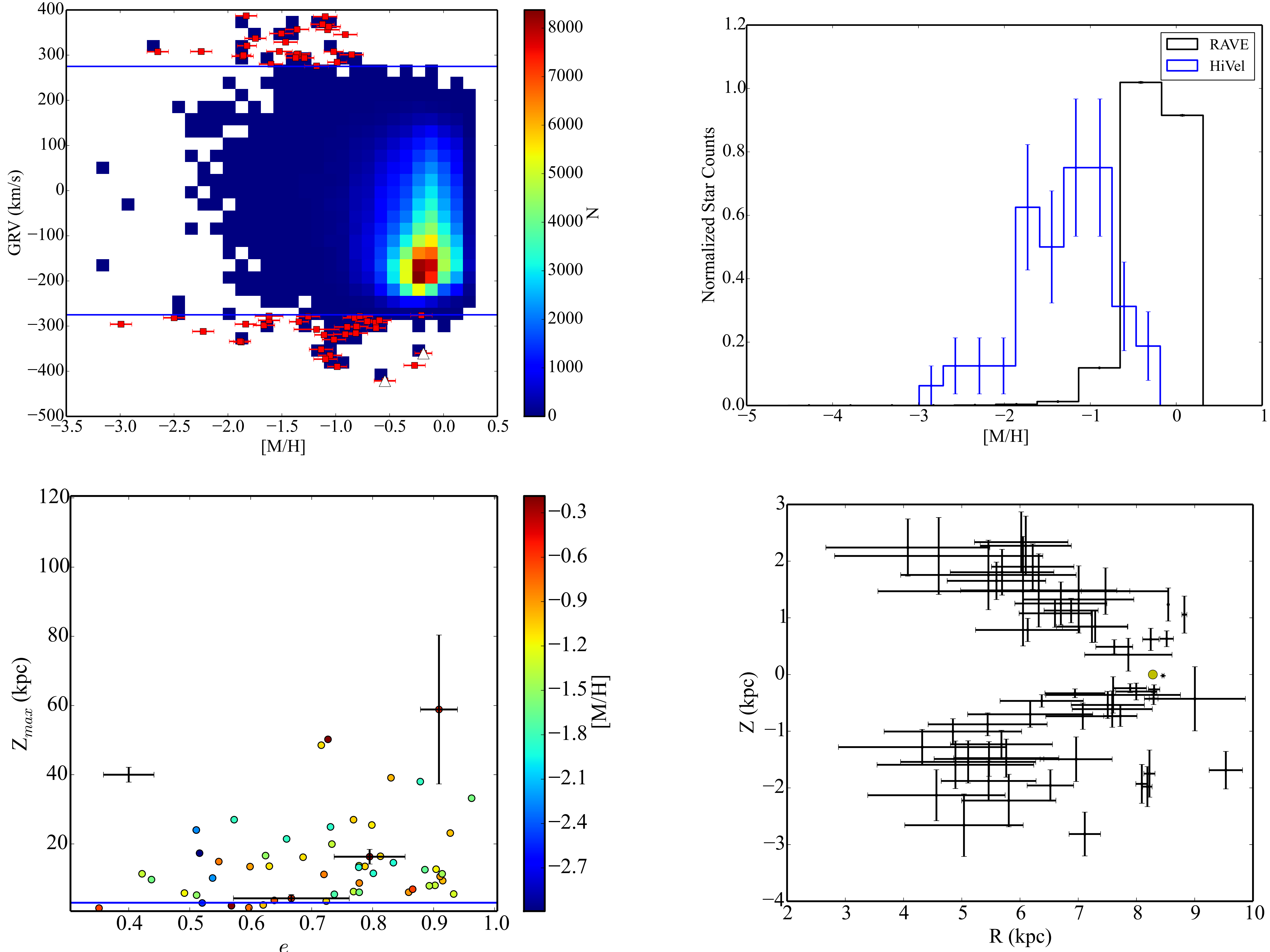
$$\Sigma_{\mathrm{DM}}(< 0.9\mathrm{kpc}) = (69 \pm 10)\ \mathrm{M}_\odot\ \mathrm{pc}^{-2}$$

$$M_{\mathrm{DM}}(< R_0) = (6.0 \pm 0.9) \times 10^{10}\ \mathrm{M}_\odot$$

$$M_{\mathrm{vir}} = (1.3 \pm 0.1) \times 10^{12}\ \mathrm{M}_\odot$$

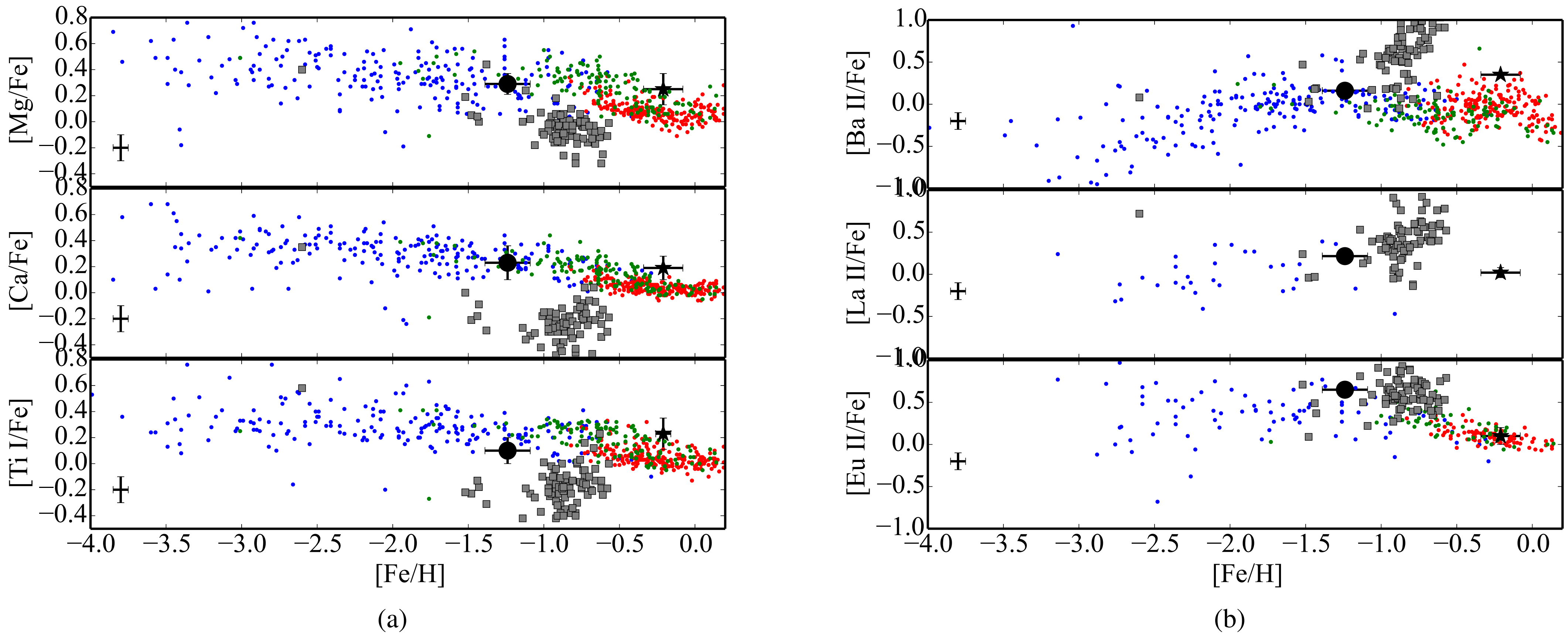
- 46% of the radial force at R_0 provided by baryons
- Bienamyé et al (2014): RAVE stars towards Galactic Pole, red clump distances: $\varrho_{\mathrm{DM}}(R=R_0, z=0) = 0.0143 \mathrm{M}_\odot \mathrm{pc}^{-3}$

High velocity stars in RAVE



Hawkins et al., 2015

Hyper velocity stars in RAVE



Follow-up Hires spectroscopy of two HVS candidates and comparison to Venn et al (2004)

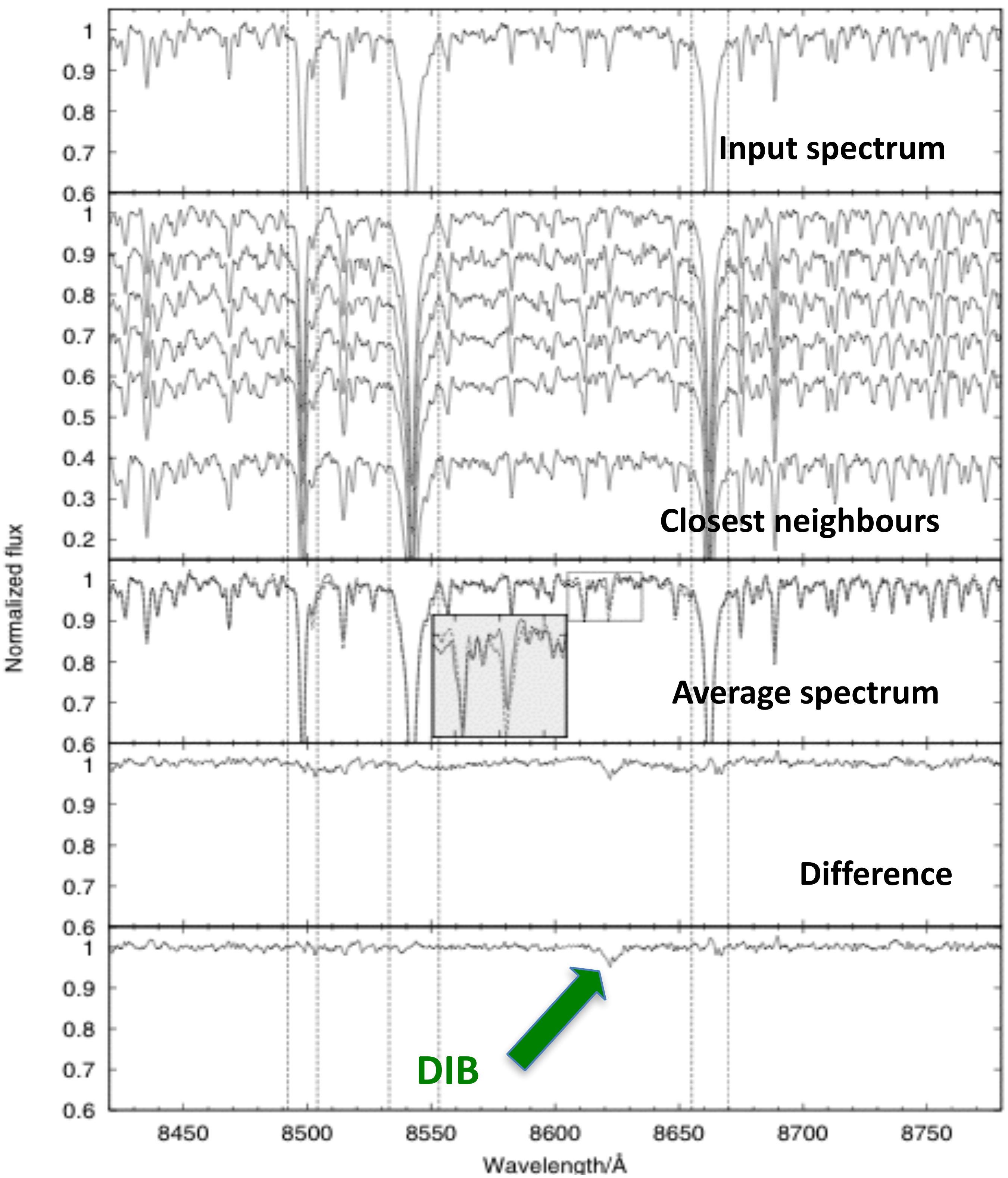
- J154401.1-162451 is chemically consistent with the halo field population or a massive dwarf galaxy
- J221759.1-051149 is chemically consistent with the Galactic thick disk ⇒ must be ejected

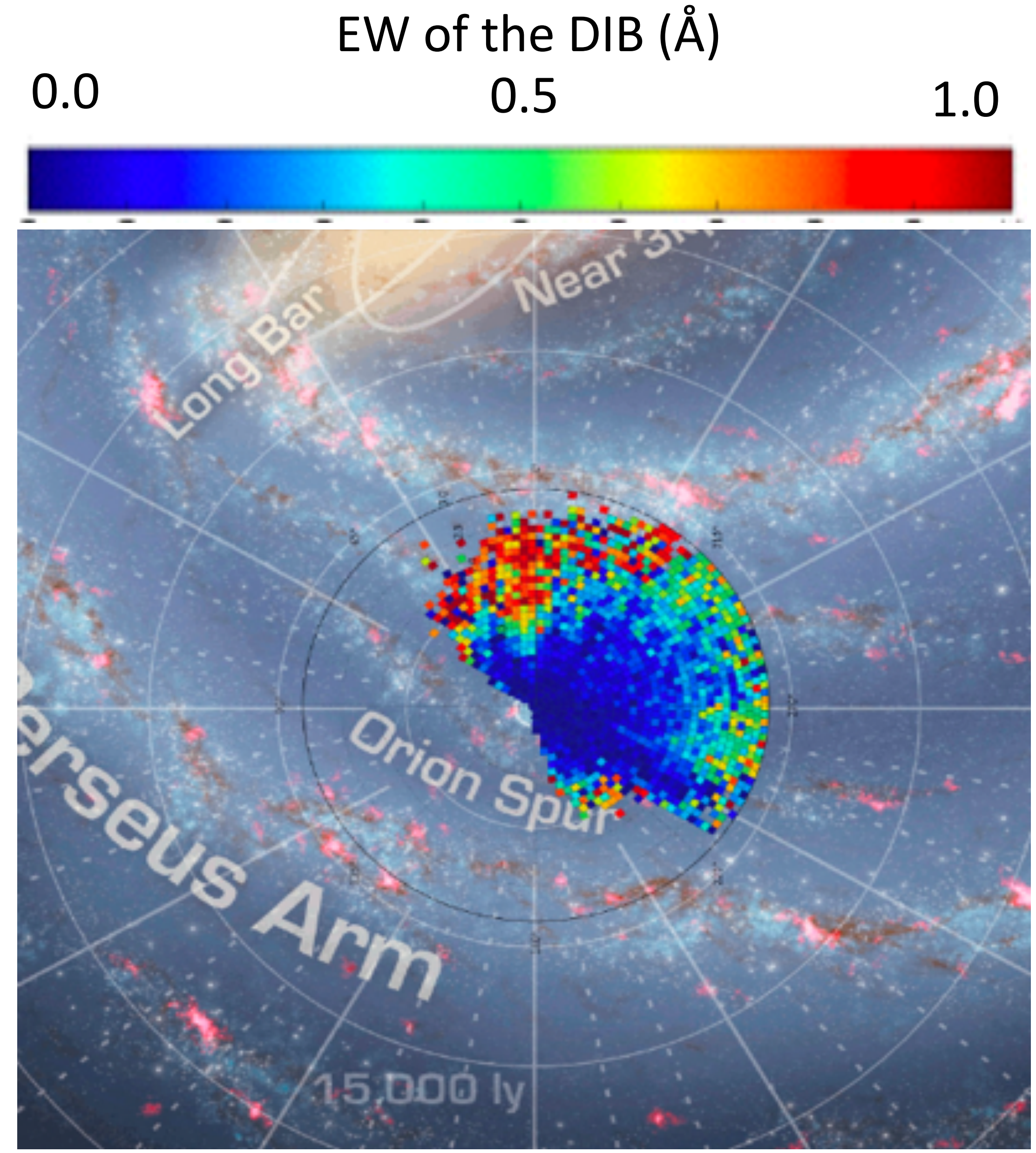
Hawkins et al., 2015

Interstellar matter

Kos+ 2013, 2014

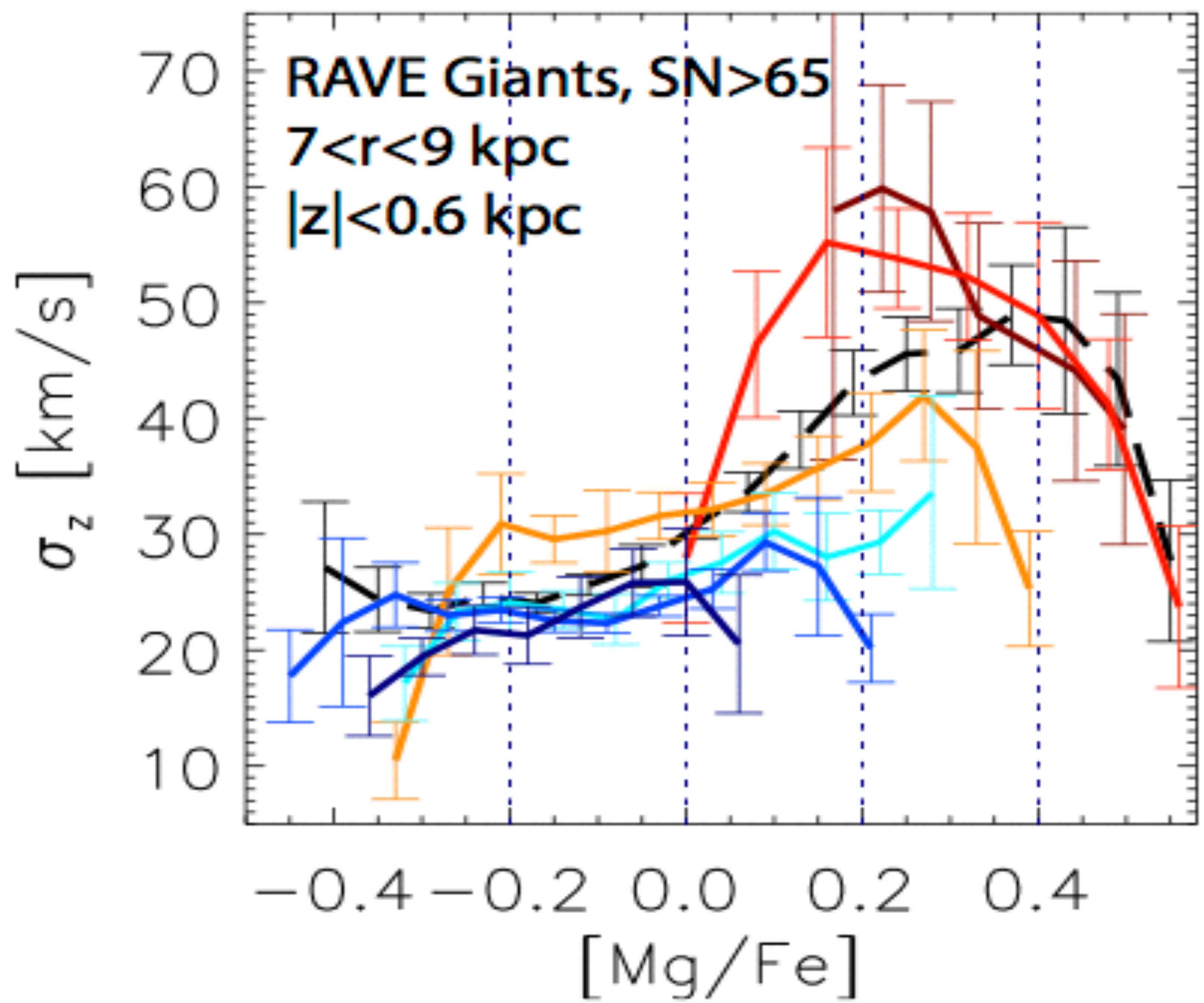
Mapping
of the Diffuse Interstellar Band





Signatures for a violent origin?

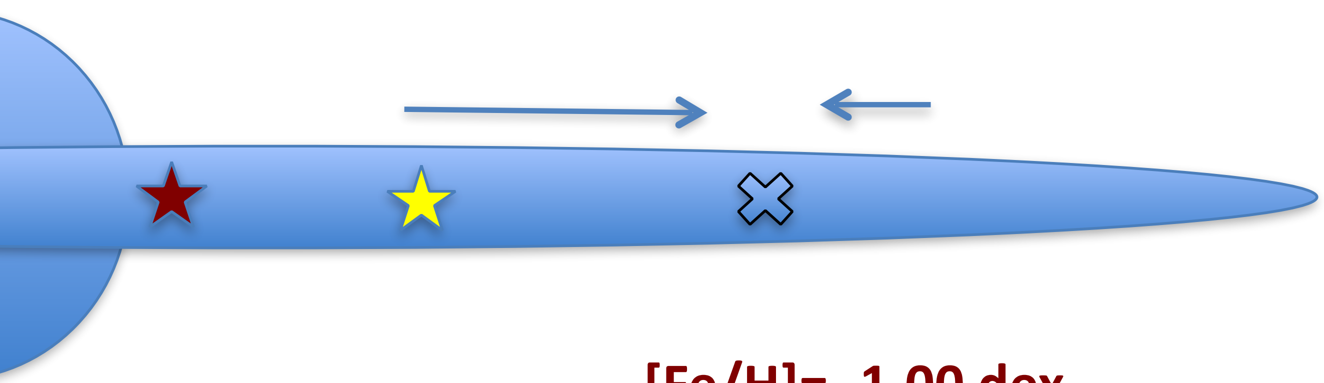
Minchev+ 2014



[Fe/H]= -1.00 dex
[Fe/H]= -0.80 dex
[Fe/H]= -0.45 dex
[Fe/H]= -0.30 dex
[Fe/H]= -0.17 dex
[Fe/H]= -0.04 dex

Signatures for a violent origin?

Minchev+ 2014



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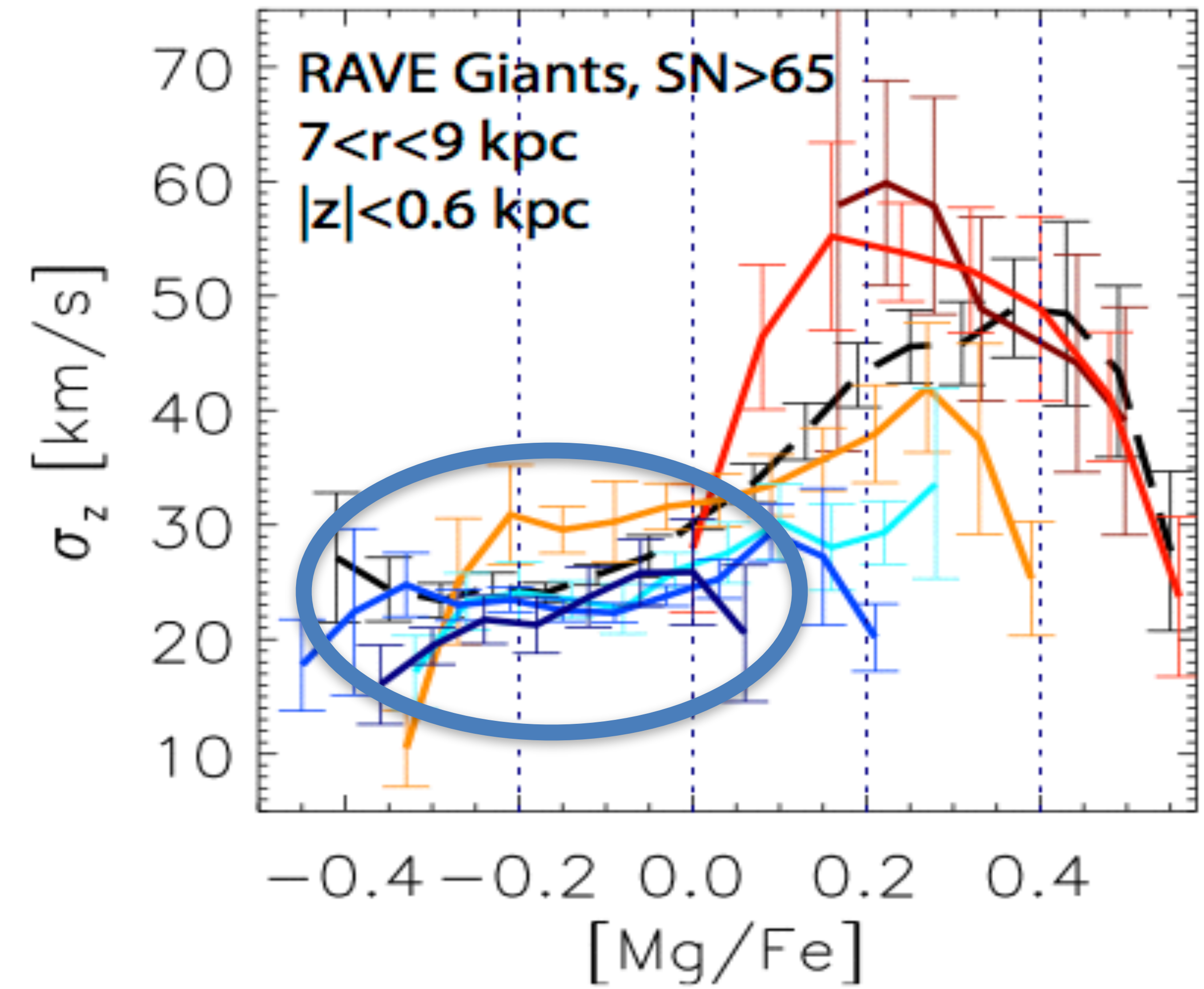
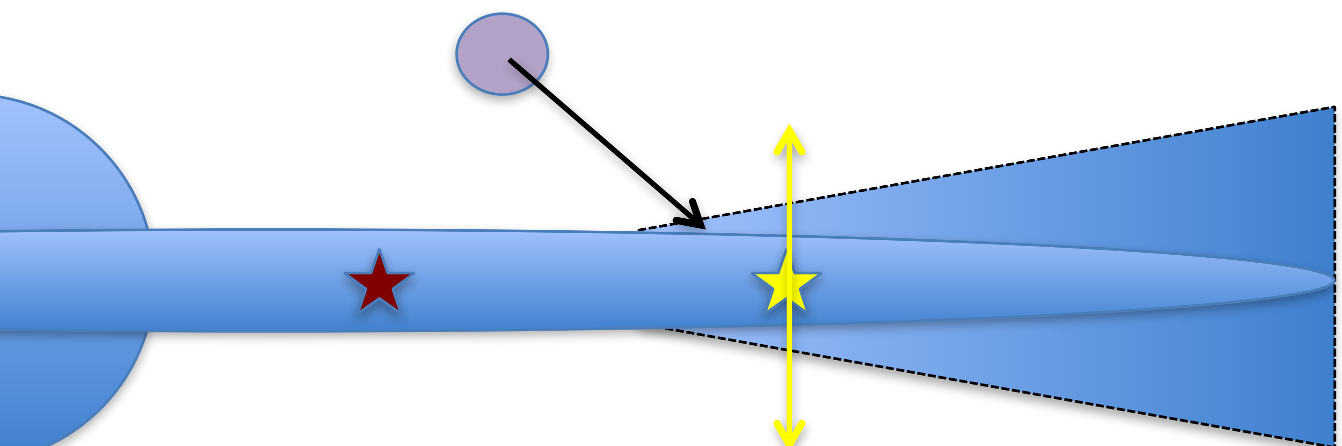
[Fe/H]= -0.17 dex
[Fe/H]= -0.04 dex



1 - Normal disc evolution:
Stars migrate and gain random energy (kinematically hotter)

Signatures for a violent origin?

Minchev+ 2014



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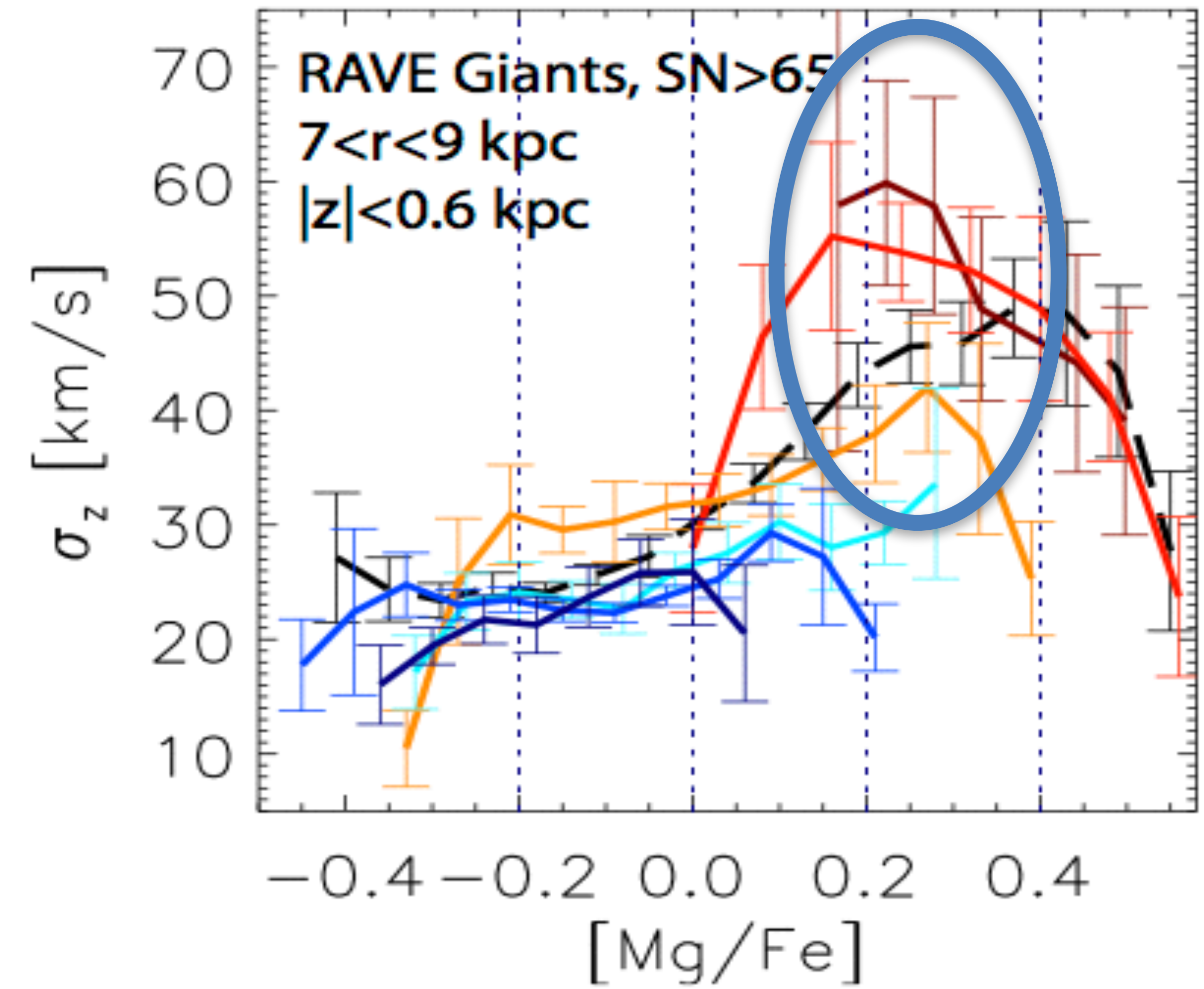
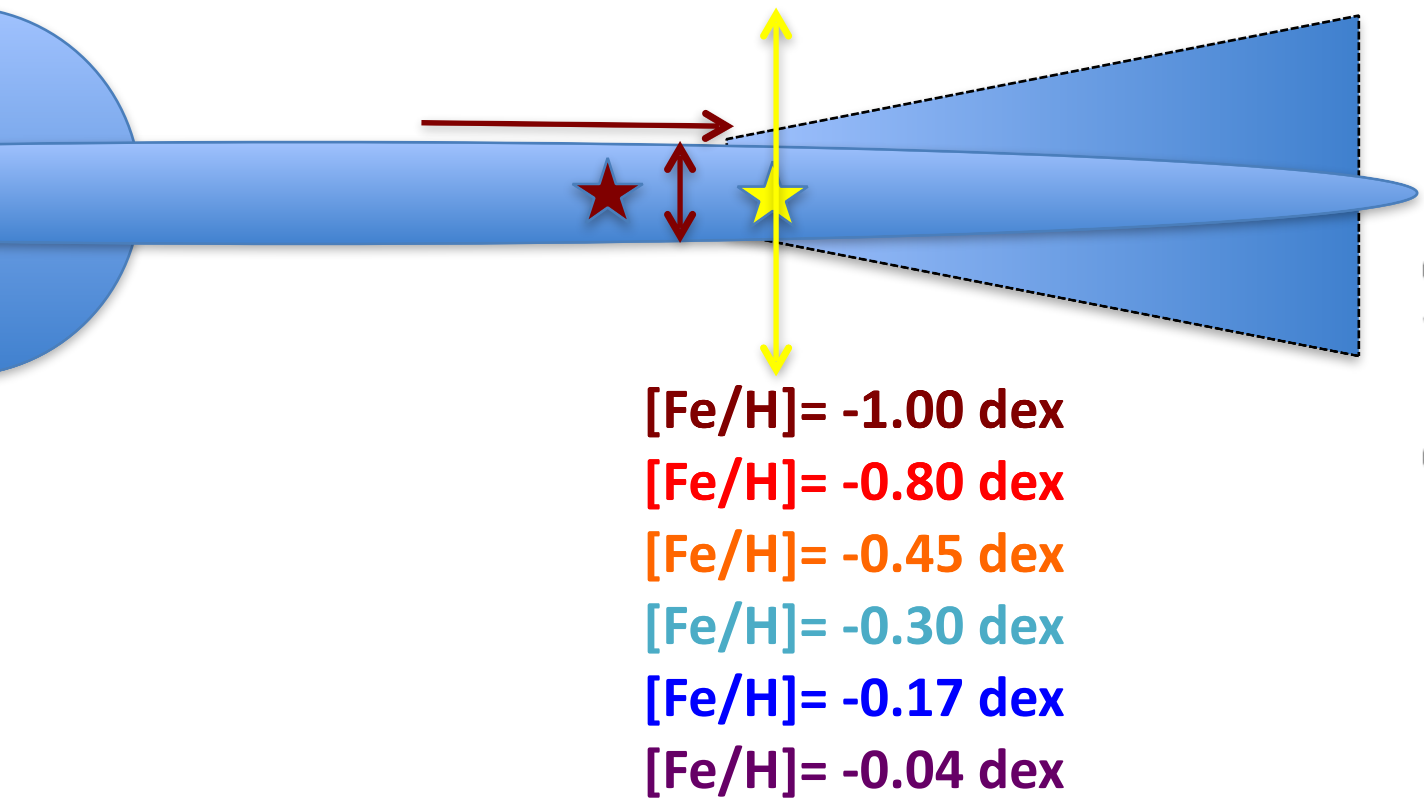
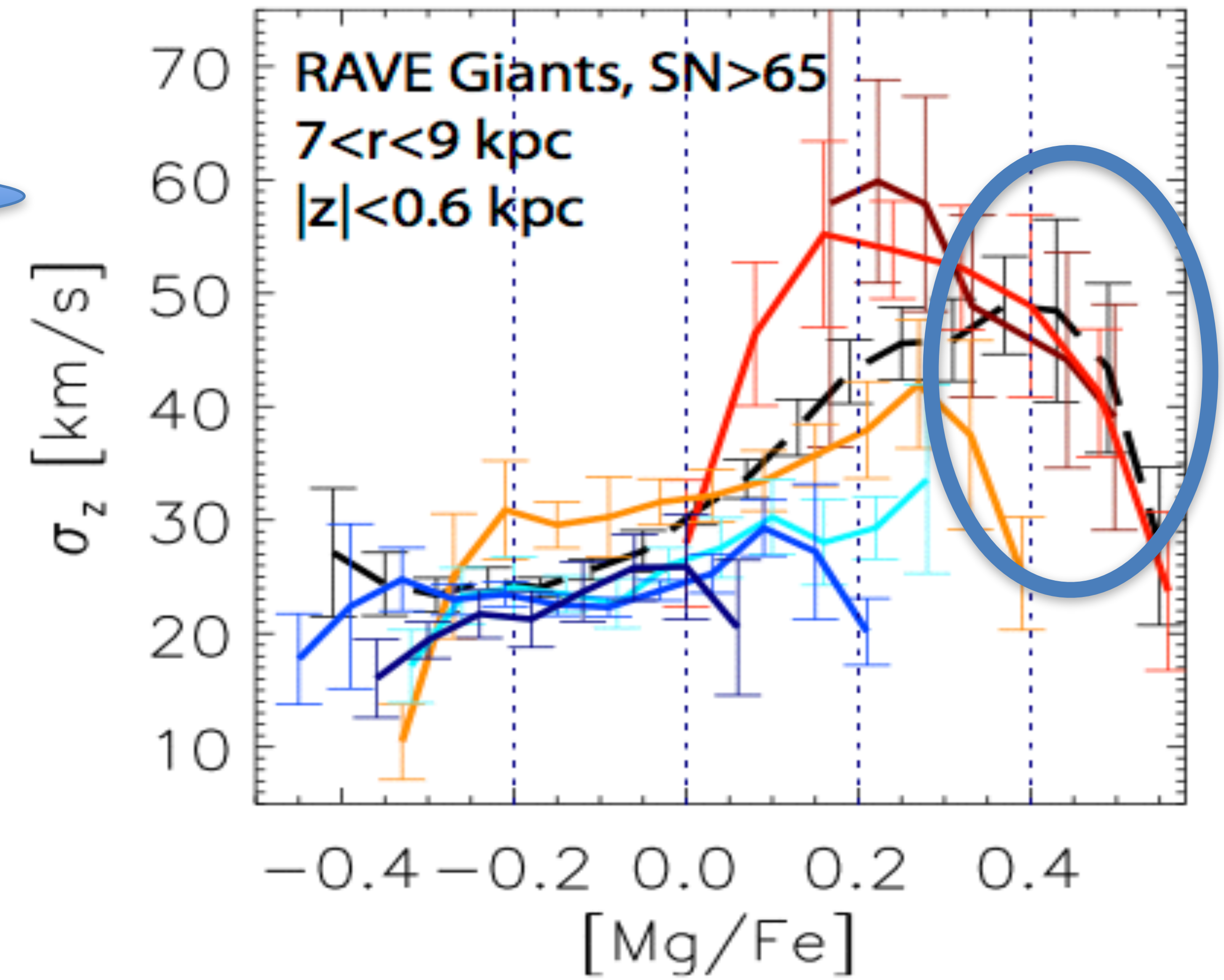


2- Massive merger at [Mg/Fe]~0.3 dex:
Stars gain a vertical velocity dispersion and cannot migrate as efficiently as before because they spend less time on the plane

Signatures for a violent origin?

Minchev+ 2014

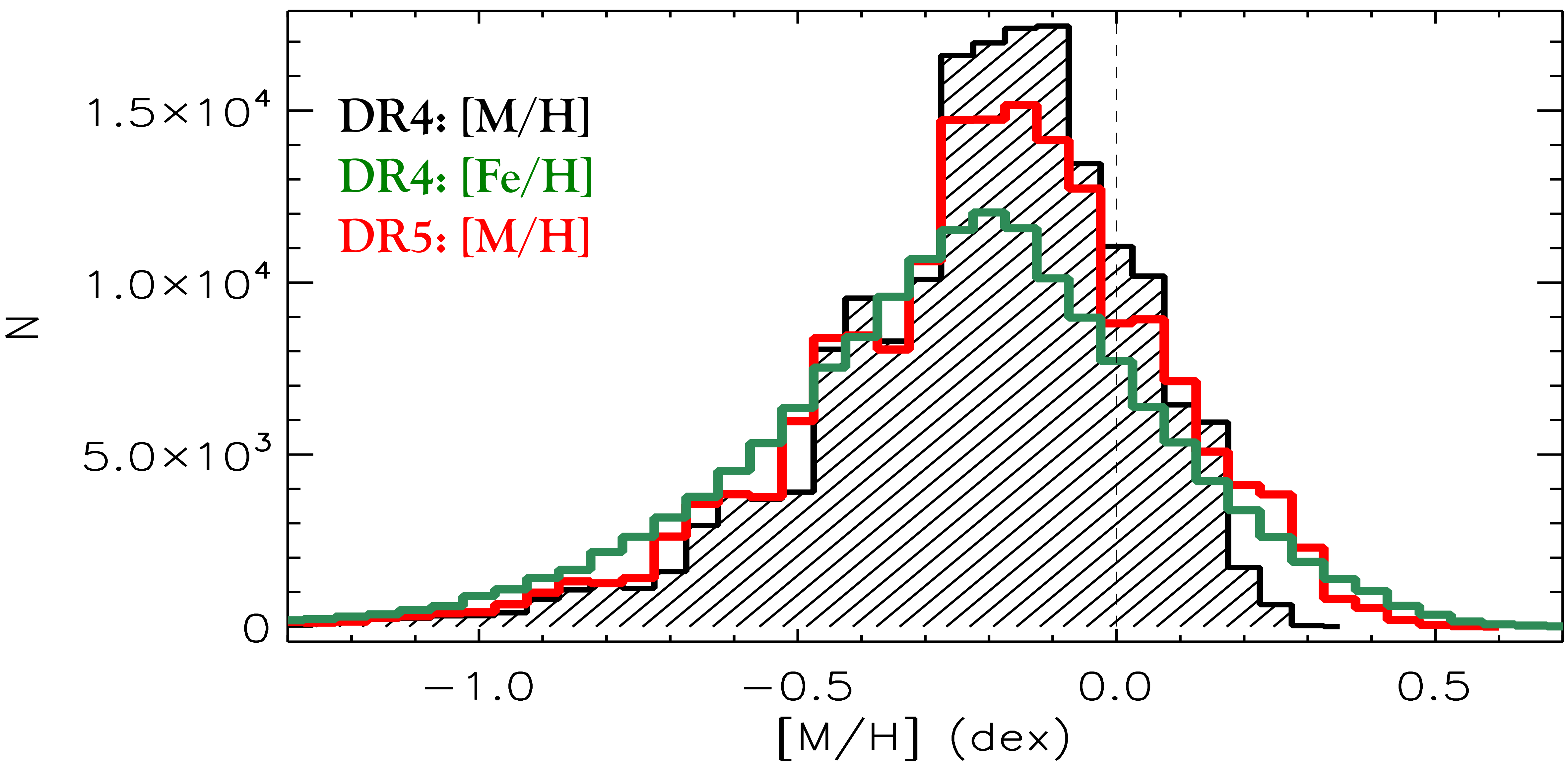




3- Older stars from small guiding radii migrate

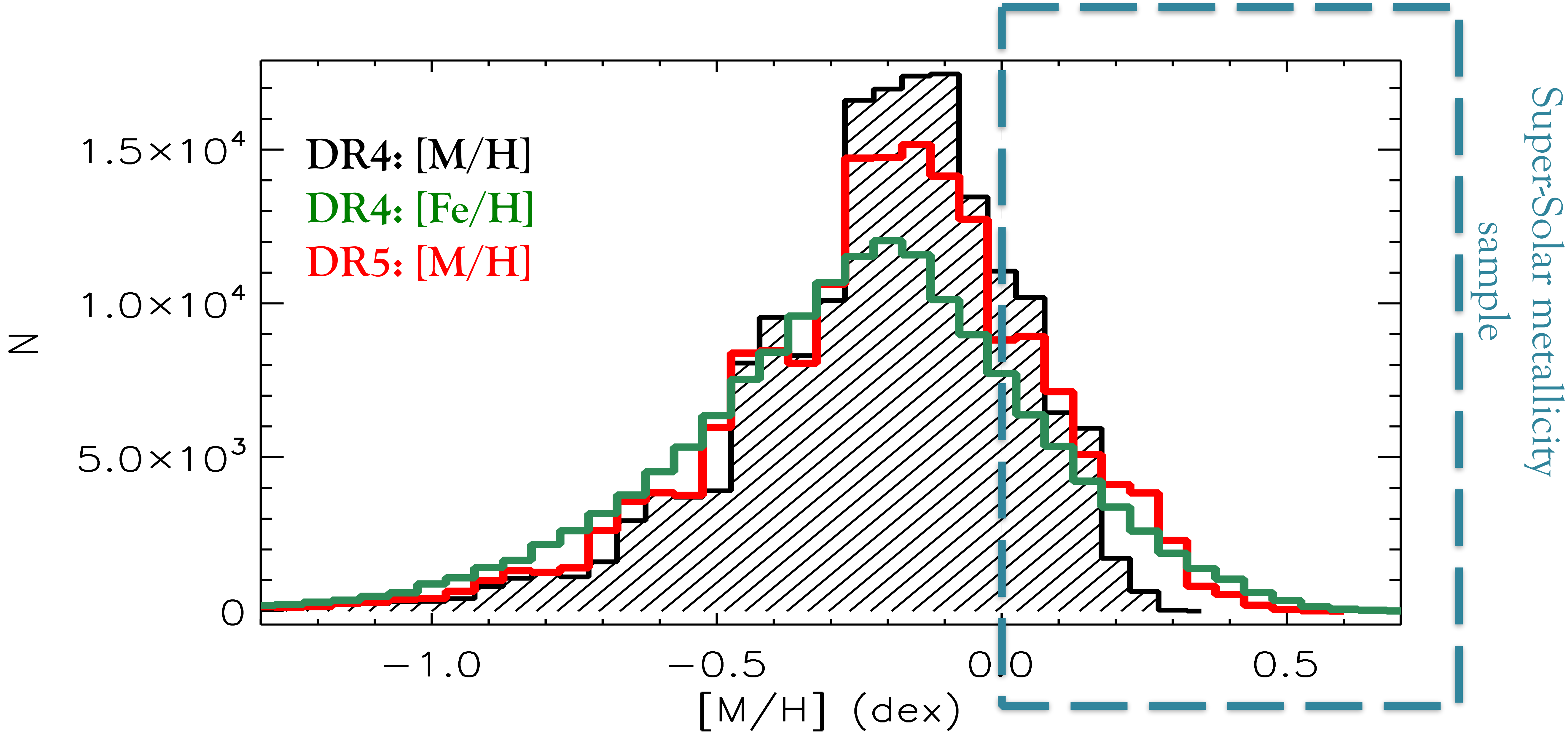
Stars with smaller guiding radii migrate to the Solar neighbourhood, having cooler kinematics than the locally born stars

Recalibration of the metal-rich end



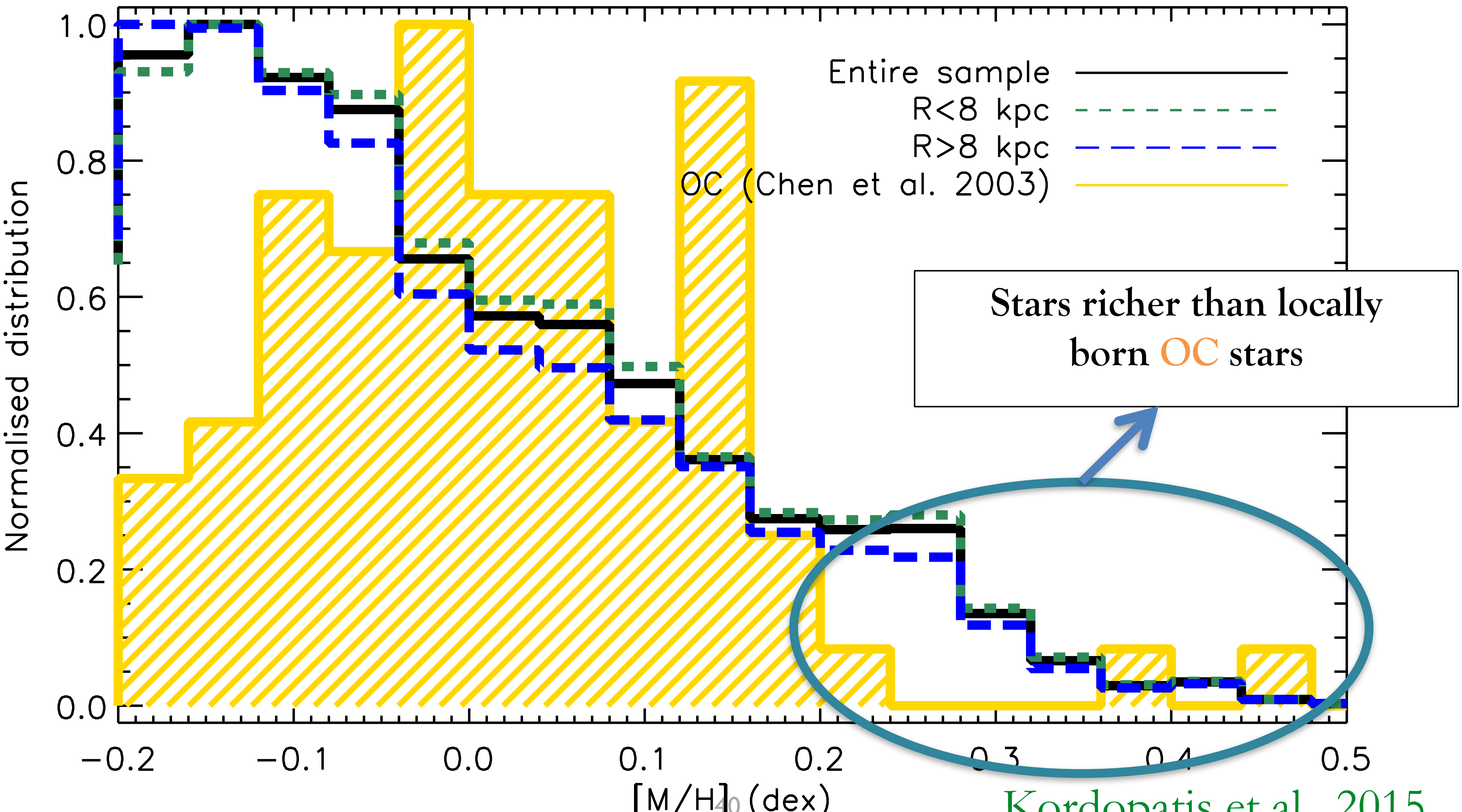
Kordopatis et al., 2015

Recalibration of the metal-rich end



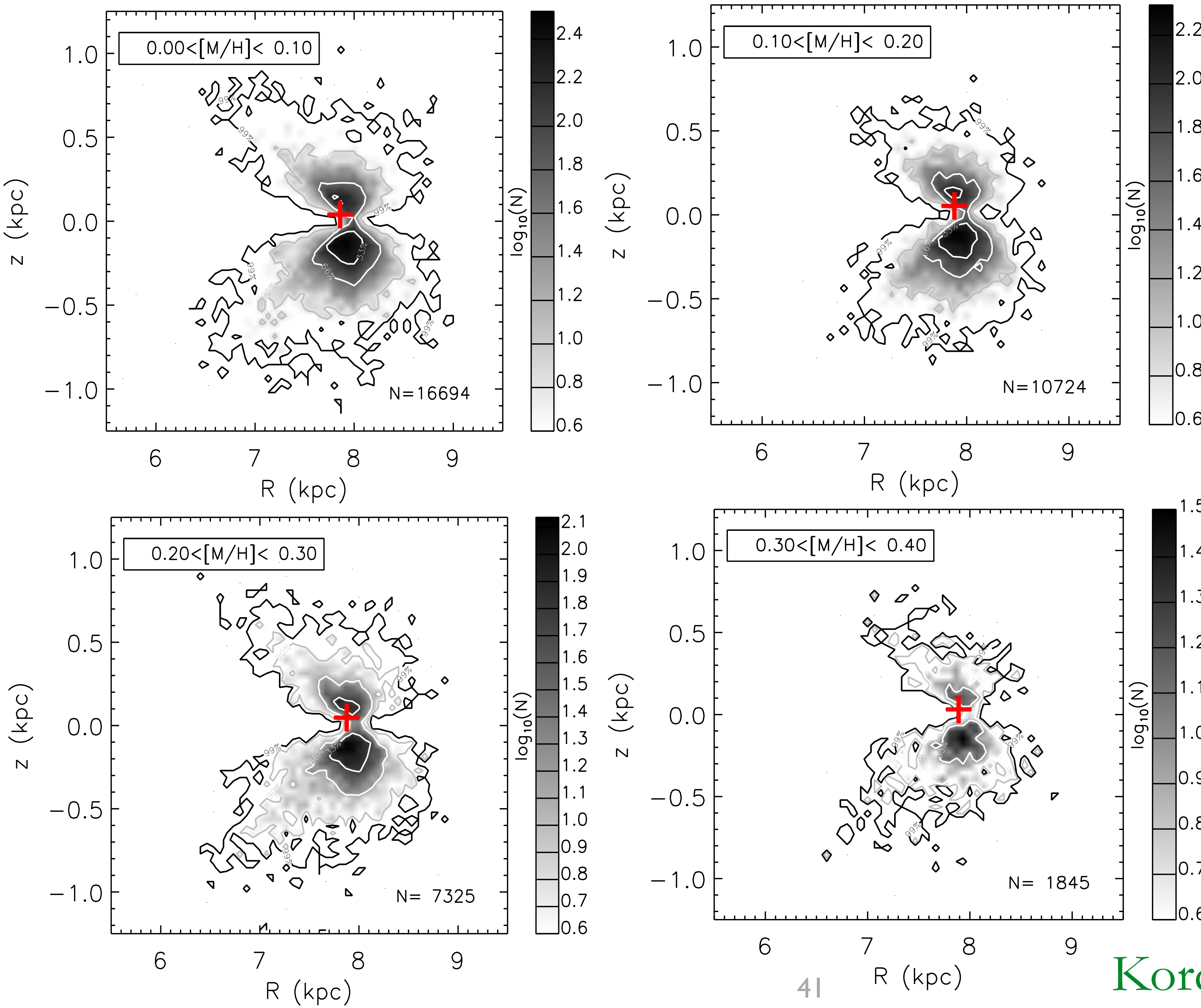
Kordopatis et al., 2015

Metallicity distribution function



Kordopatis et al., 2015

Super-Solar metallicity stars



Stars mainly located close to the plane.

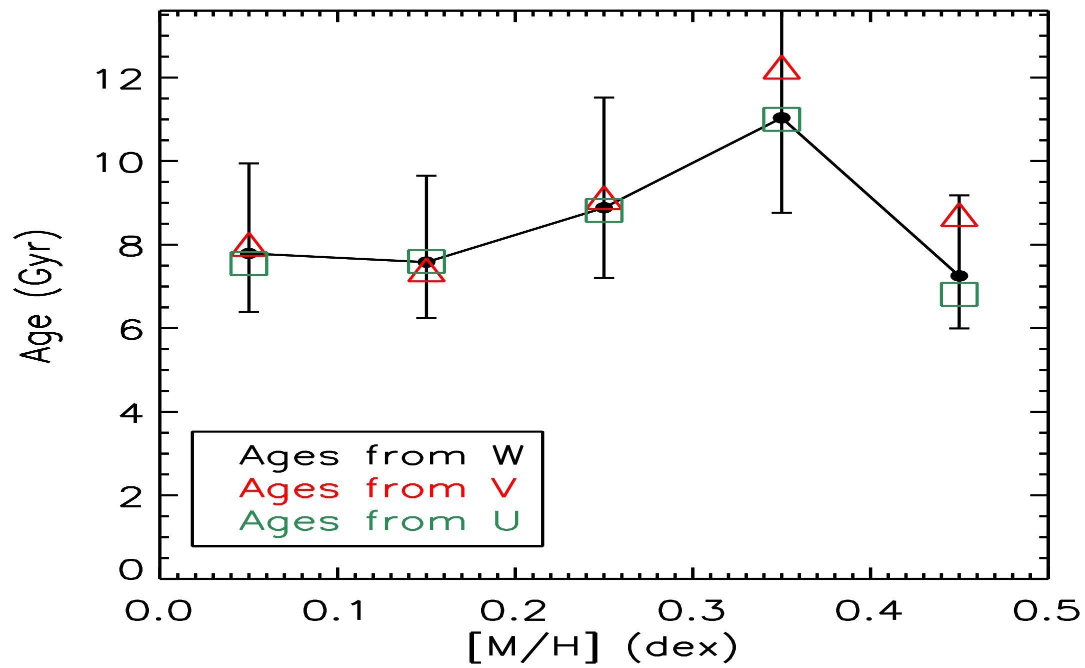
But also:

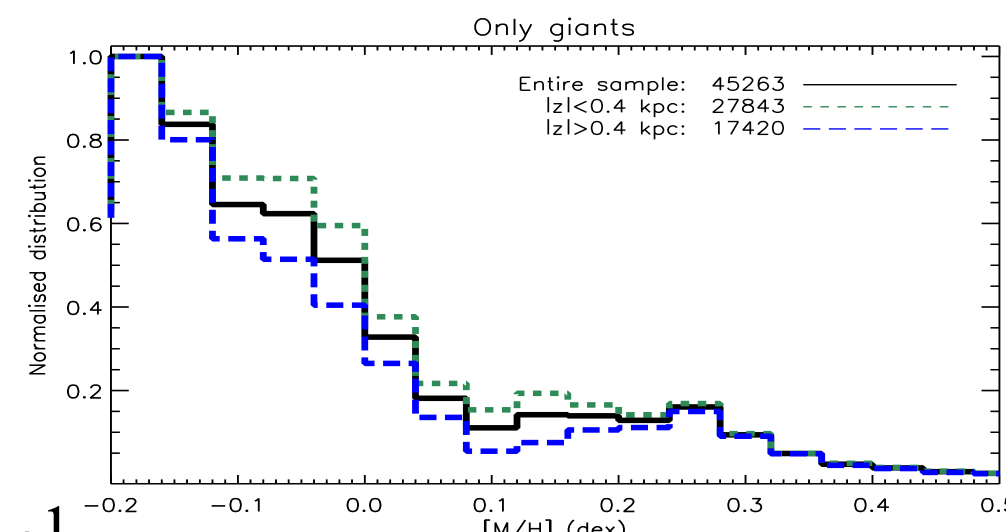
Fair amount of stars with 0.4 < z < 1 kpc

Kordopatis et al., 2015

Metal rich stars in RAVE

- Super Metal-rich giants in RAVE have a “flat” MDF from 0.1 < [M/H]< 0.35 dex
- no dwarfs above 0.25 dex
- Stars formed well inside R_0 (bar/bulge region?)
- Located up to ~1 kpc from the plane
- Same distribution inner and outer Galaxy
- Circular orbits:
  - Stars scattered through co-rotational resonances with the spiral arms
  - Spirals in the MW are strong, with large spiral structure





Summary

- RAVE survey: more than 574,000 spectra taken
  - Radial velocities (1km/s)
  - Stellar parameters
  - Distances
  - Abundances
- Local escape speed: low Milky Way DM halo mass confirmed
- Clear correlation between chemical and kinematical signatures in the disk(s)
- Detection of large-scale asymmetries of the velocity field in the solar neighborhood
  - Apparent asymmetry above vs below the plan (wave?)
- Metal-rich end from stars that were radially migrated from the inner disk
- Next major step: Gaia & 4MOST