The galactic thick disc:

What information will Gaia bring?

Georges Kordopatis
Institute of Astronomy, Cambridge

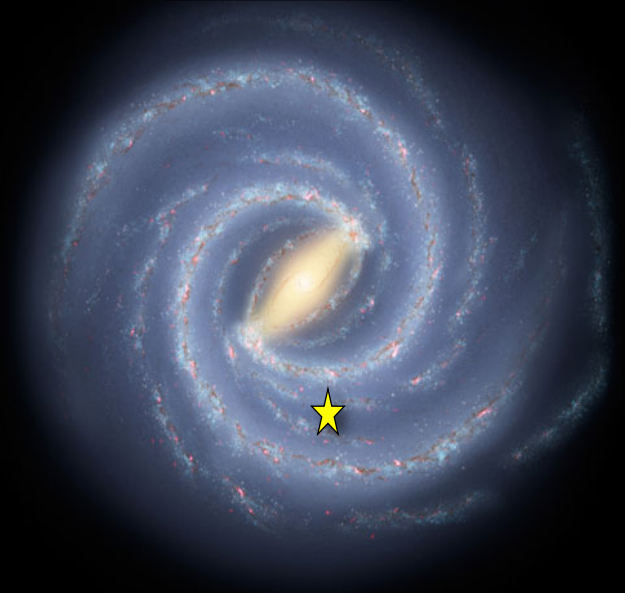
SF2A, Nice – Wednesday 6th June 2012

Outline

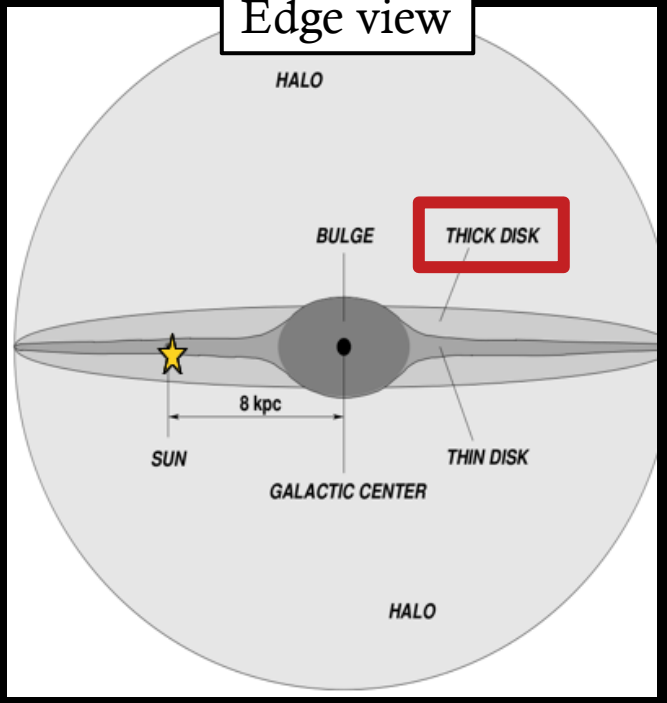
- Cosmological importance of the thick disc
  - Why are we interested in it?
- Commonly proposed formation scenarios for the thick discs
- Observations *vs* formation scenarios of the thick disc
  - Measuring the properties & the gradients with Gaia

The Milky Way galaxy

Top View



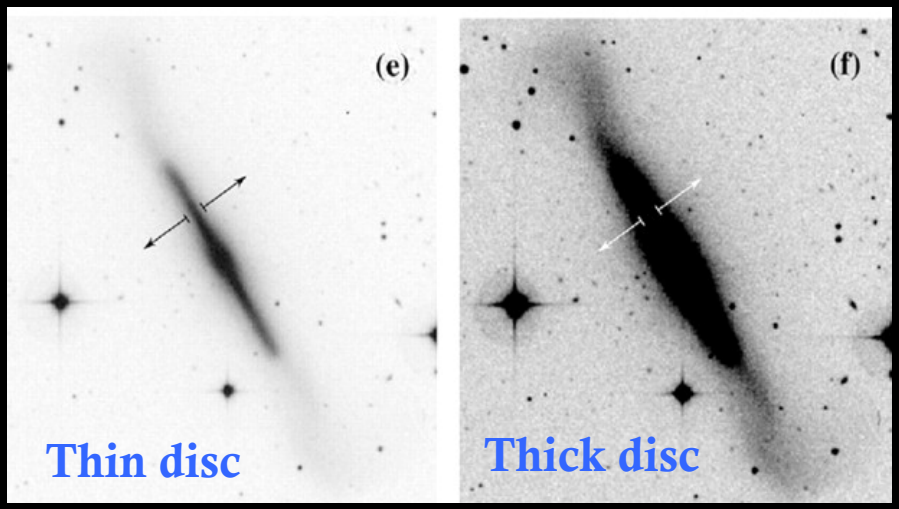
Edge view



Bulge: Old stars (~10 Gyr)
Thin disc: Young stars, gas rich, rotationally supported
Halo: Old stars (~11-13 Gyr), pressure supported, no gas

Thick disc: Existence suggested by Gilmore & Reid (1983)
Old stars (~10 Gyr)
Rotationally supported but hotter than the thin disc (lag ~ 40 km/s)
[M/H]~-0.5 dex, [α /Fe] enhancement

Galactic archaeology: thick disc



NGC 4762 Freeman & Bland-Hawthorn (2002)

Thick discs are ubiquitous in external disc galaxies *(Yoachim & Dalcanton 2006)*

- They are composed of old stars
- They have intermediate metallicity values
- Rotationally supported but hotter component than the thin disc

Valuable information on galaxy formation
➔ Snap frozen relic of the early galaxies

How was formed the thick disc of the Milky Way?

➔ Relation between the thick disc and the other components?
➔ How much different than the thin disc and the bulge ?

-Scale height & length? [M/H] ? Kinematics ? Vertical & radial gradients ?

Thick disc formation scenarios

Each of the scenarios succesfully represent the local properties of the thick disc but have different predictions far from the solar neighbourhood

- 3 big categories:
  1. Accretion of satellite galaxies
  2. Minor mergers
  3. Internal processes

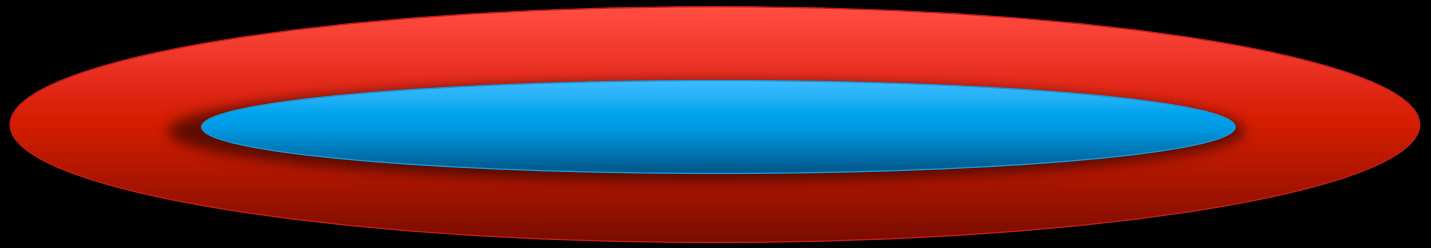
Thick disc formation mechanisms 1-2) Accretion scenarios

Thick disc different from thin disc (chemistry + kinematics)

- Abadi et al. (2003): dwarf galaxy deposing its stars in co-planar orbits

- Brook et al. (2004, 2005, 2007): Gas-rich merger

Thick disc formation mechanisms 1-2) Accretion scenarios

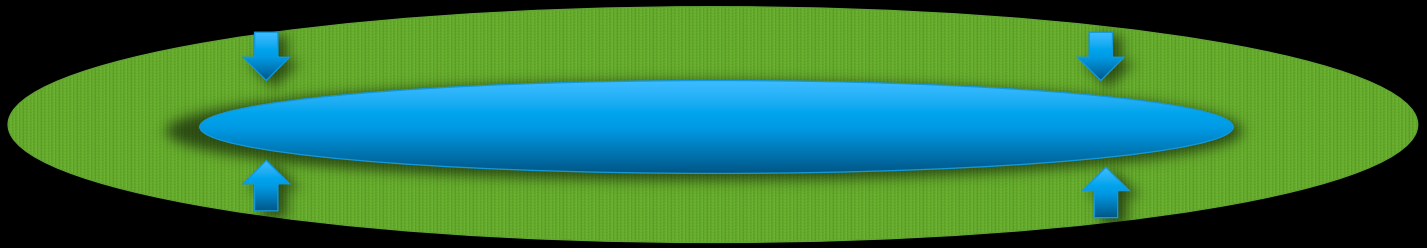


Thick disc different from thin disc (chemistry + kinematics)

- Abadi et al. (2003): dwarf galaxy deposing its stars in co-planar orbits
  - Homogeneous chemistry, depending on the accreted population
  - Rotational lag depending on the inclination angle
  - ➔ No vertical or radial gradients

- Brook et al. (2004, 2005, 2007): Gas-rich merger

Thick disc formation mechanisms 1-2) Accretion scenarios

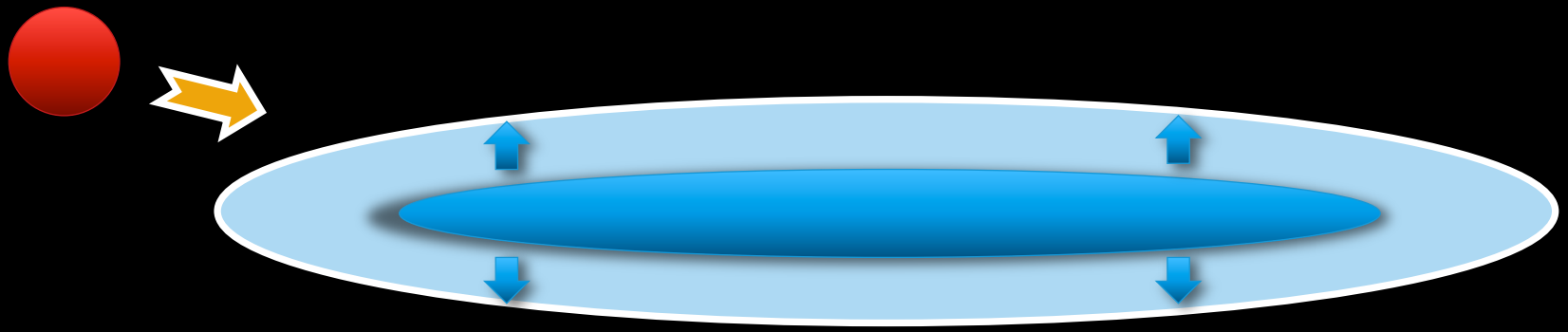


Thick disc different from thin disc (chemistry + kinematics)

- Abadi et al. (2003):
  - Homogeneous chemistry, depending on the accreted population
  - Rotational lag depending on the inclination angle
  - ➔ No vertical or radial gradients

- Brook et al. (2004, 2005, 2007): Gas-rich merger
  - Thick disc lag depending on distance above the plane
  - Vertical metallicity gradients depending on the collapse time

Thick disc formation mechanisms
3) Heating scenario



- Villalobos & Helmi (2008), Kazantzidis et al. (2008), Qu et al. (2011) …
  - Thick disc formed by dynamical heating of the thin disc + few extragalactic stars
  - Thick disc chemistry depending on the chemistry of the thin disc when created

➔ **Vertical/Radial gradients: *yes*, if the initial thin disc had any**

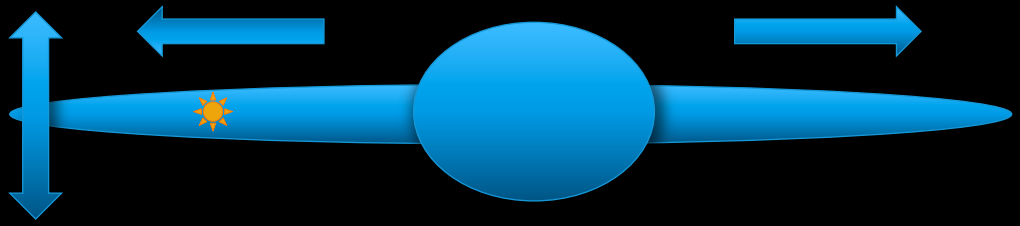
Thick disc formation mechanisms
4) Internal processes

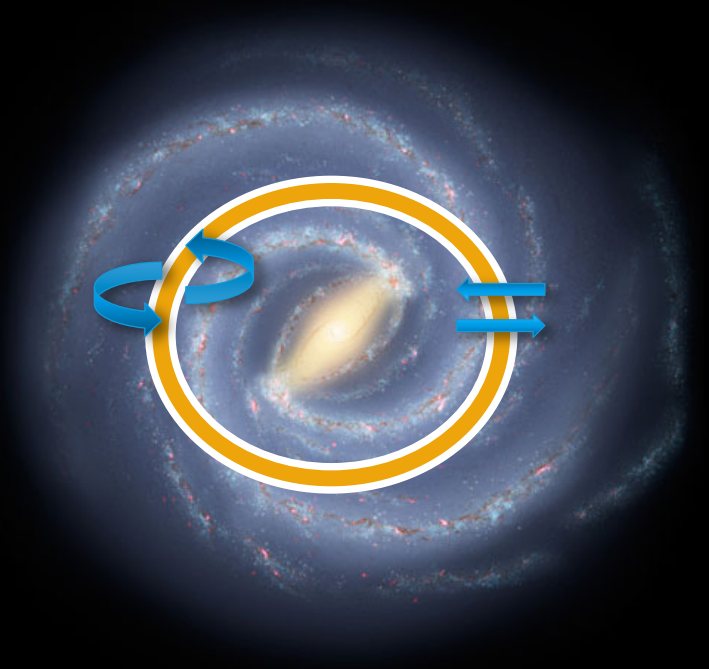
➔Radial migration of the stars:

e.g.: Sellwood & Binney (2002), Roskar et al. (2008), Schoenrich & Binney (2009a,b), Minchev & Famey (2010), Loebman et al. (2011)

Thick disc formed by internal processes: co-rotational resonances with the spiral arms

Radial migration





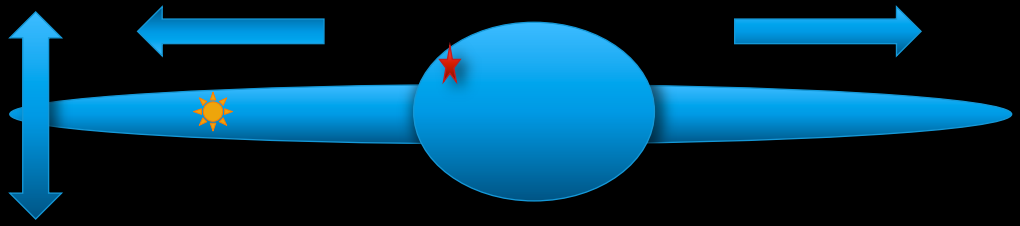
Thick disc formed by internal processes: co-rotational resonances with the spiral arms

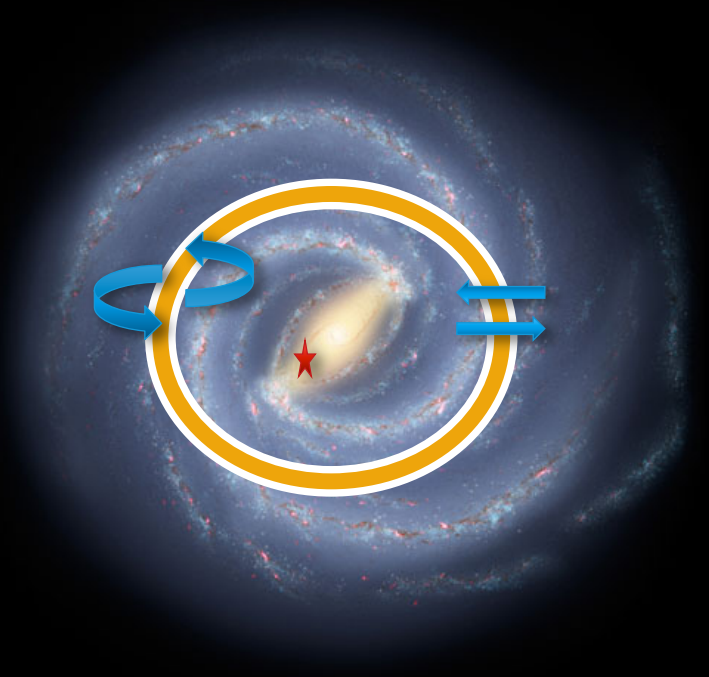
➔ Churning: circular orbits are maintained but change in angular momentum

➔ Blurring: eccentricity changes but angular momentum is the same

Predictions: No metallicity vs rotational velocity correlation if there is full mixing

Radial migration





Thick disc formed by internal processes: co-rotational resonances with the spiral arms

➔ Churning: circular orbits are maintained but change in angular momentum

➔ Blurring: eccentricity changes but angular momentum is the same

Predictions: No metallicity vs rotational velocity correlation if there is full mixing

Thick disc formation mechanisms

	Accretion scenario (Abadi et al.)	**Gas rich accretion** (Brook et al.)	**Dynamical heating** (Villalobos & Helmi)	**Radial migration** (Schonrich & Binney)
< [M/H] >	<[M/H]> of the satellite	<[M/H]> of the gas + gradient	<[M/H]> of the thin disc when heated (+ gradient ?)	Depending on the age and the origin
$<V_\varphi>$	Depending on the inclination angle	Inclination angle+ gradient	…	…
Eccentricity distribution	e~0.5	e~0.2 with tail	e~0.2 with tail + accreted stars on high e	e~0.2 without tail
$d[M/H]/dV_\varphi$	…	…	…	0

All the necessary information is contained in proper motions and the stellar spectra

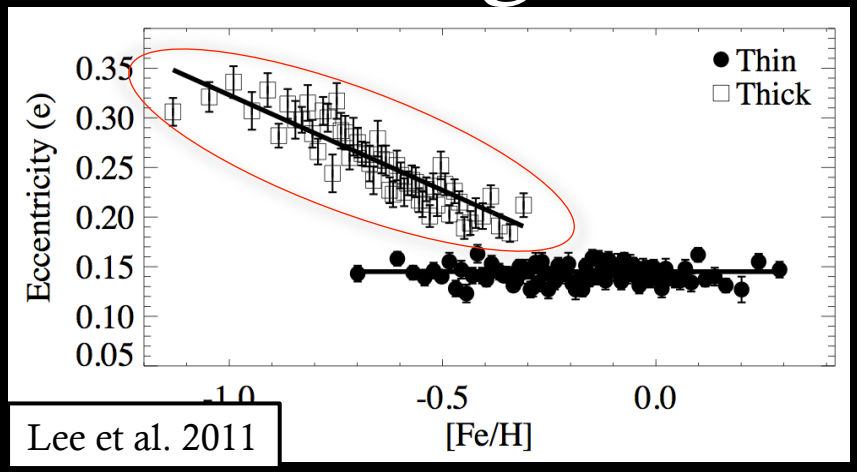
➔ **Gaia !**

The stellar spectroscopic surveys

Project	MOS	λ (nm)	R= λ / Δ λ	Telescope	N targets	Limiting mag.
RAVE	150	841-880	7 500	1.2m UK Schmidt	10^6	$9 < I < 12$
SEGUE & SEGUE-2	640	385-920	2 000	2.5 APO	2.4×10^5	$14 < g < 20$
LAMOST	4000	370-900	2 000	4m Xinglong Schmidt	2.5×10^6	$17 < g < 20$
HERMES[1]	400	375-950	28 000	3.9m AAT	1.2×10^6	V< 15
Gaia-ESO	130			8m UT2, VLT	10^5	14.5 <V< 19.5
4MOST[2]	1500	420-900	3 000 - 5 000	VLT	$> 7 \times 10^6$	
Gaia[3]	–	847-874	7 000 - 11 500	spatial	10^8	V<17
APOGEE	300	1600	20 000	2.5 APO	10^5	$H < 13$

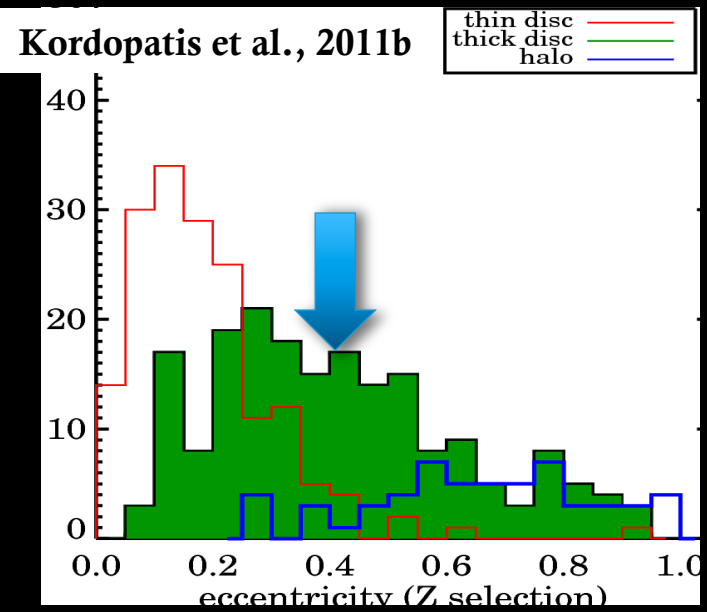
Gaia – RVS solar-like spectrum

What did the surveys recently tought us on the thick disc?



Lee et al. 2011

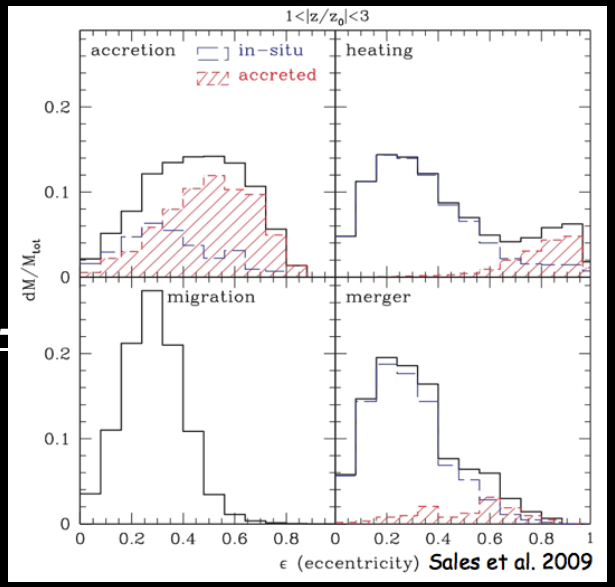
Thick disc is different both chemically and dynamically than the thin disc



Mean excentricity: ~0.3, with extented tail.

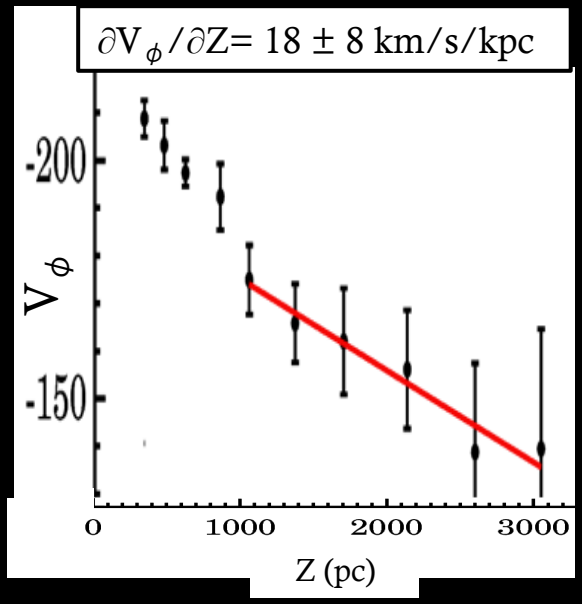
<u>Is Radial migration ruled - out?</u>

Theoretical eccentricities

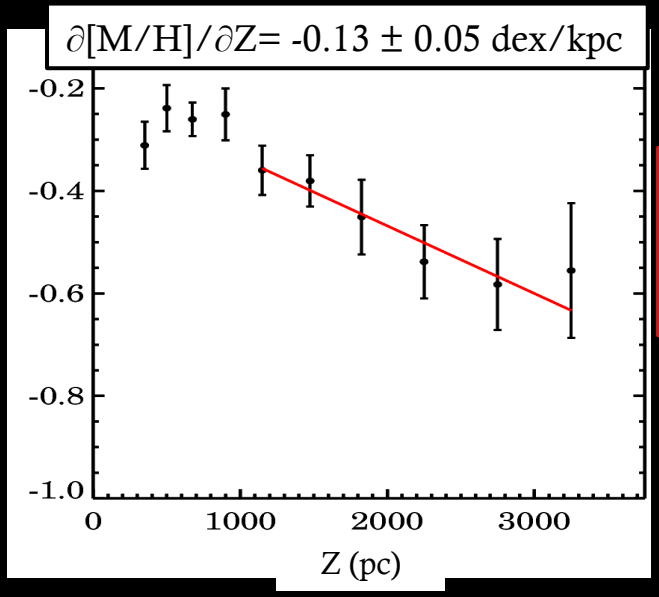


Vertical gradients

Orbital velocity



Metallicity



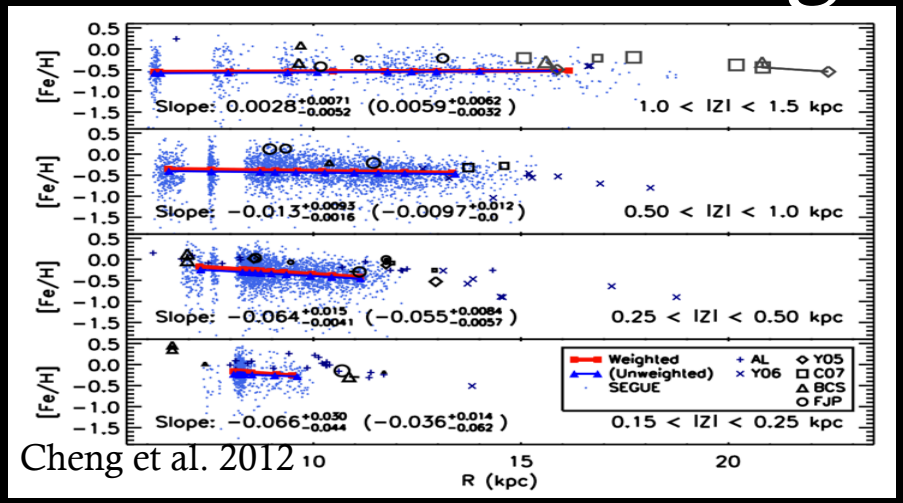
Rotational velocity correlated to metallicity:
$\partial V_\phi / \partial$[M/H]=-45±12 km/s/dex

Kordopatis et al., 535, A107

- Correlation between orbital velocity and metallicity for the thick disc is not predicted by radial migration in the case of a complete mixing

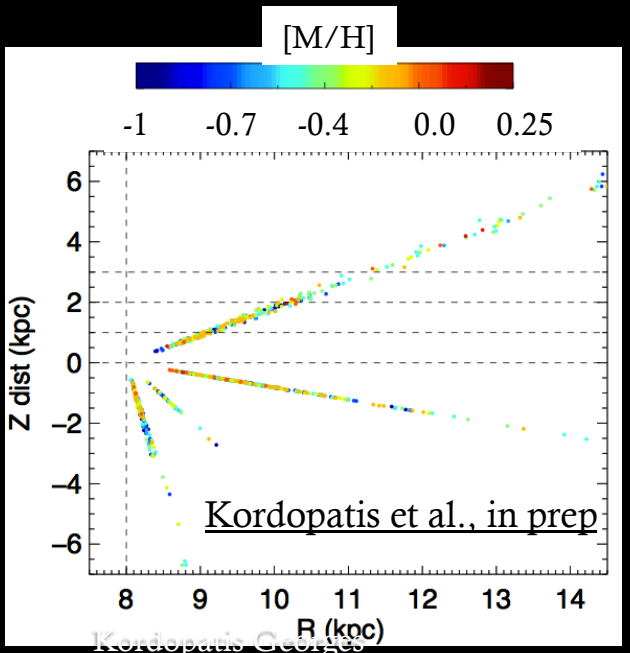
- Thick disc formed just by accretion is ruled out.

Chemical properties towards the outer galactic radii

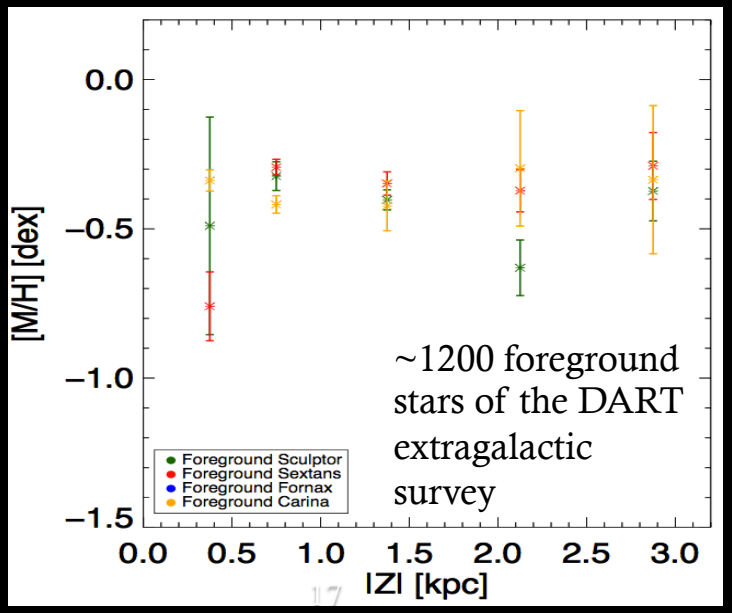


Cheng et al. 2012

Flat radial metallicity gradient at Z>1 kpc, Consistent with a <u>chemically homogeneous thick disc</u>



<u>Kordopatis et al., in prep</u>

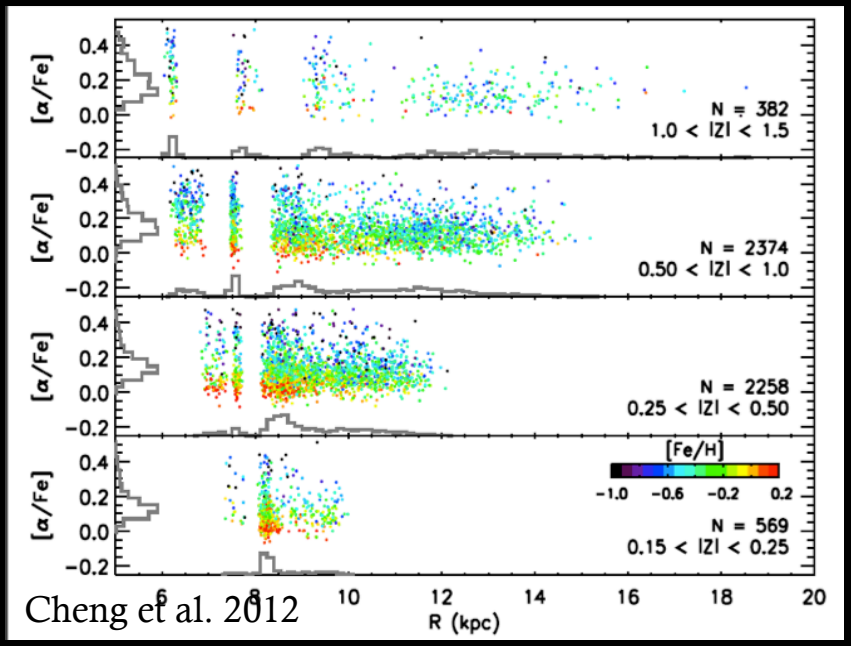


~1200 foreground stars of the DART extragalactic survey

Similar vertical gradients towards different directions

➔ **<u>Chemically homogeneous thick disc</u>**

Scale-length of the thick disc?



Cheng et al. 2012

Bensby et al. 2011 :
No thick disc (high [a/Fe] population)
Farther than 10 kpc.

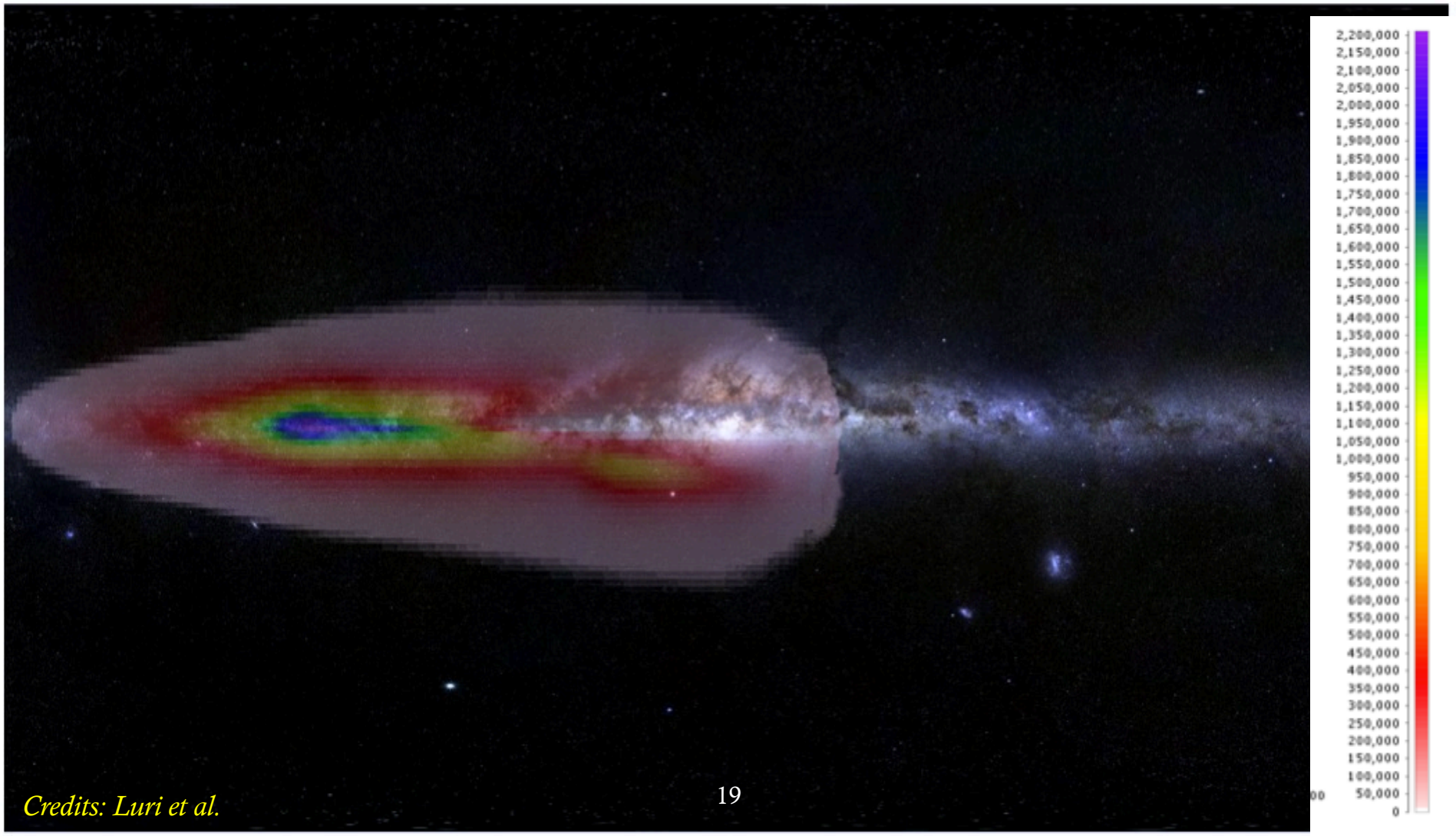
Confirmed by SEGUE? (Cheng et al. 2012)
L_{thin}~3.4 kpc, L_{thick}~1.8 kpc

➔ Poor statistics

Smaller scale-length compared to the thin disc
⇒ Incompatible with radial migration (?)
⇒ Compatible with a thick disc formed through a turbulent young thin disc

Bovy et al 2012: « *The thick disc of the Milky Way does not exist* »
➔ Mono-abundance populations of different scale-lengths (lots of debates)
➔ Not confirmed through a Jeans analysis (Kordopatis et al. 2011)

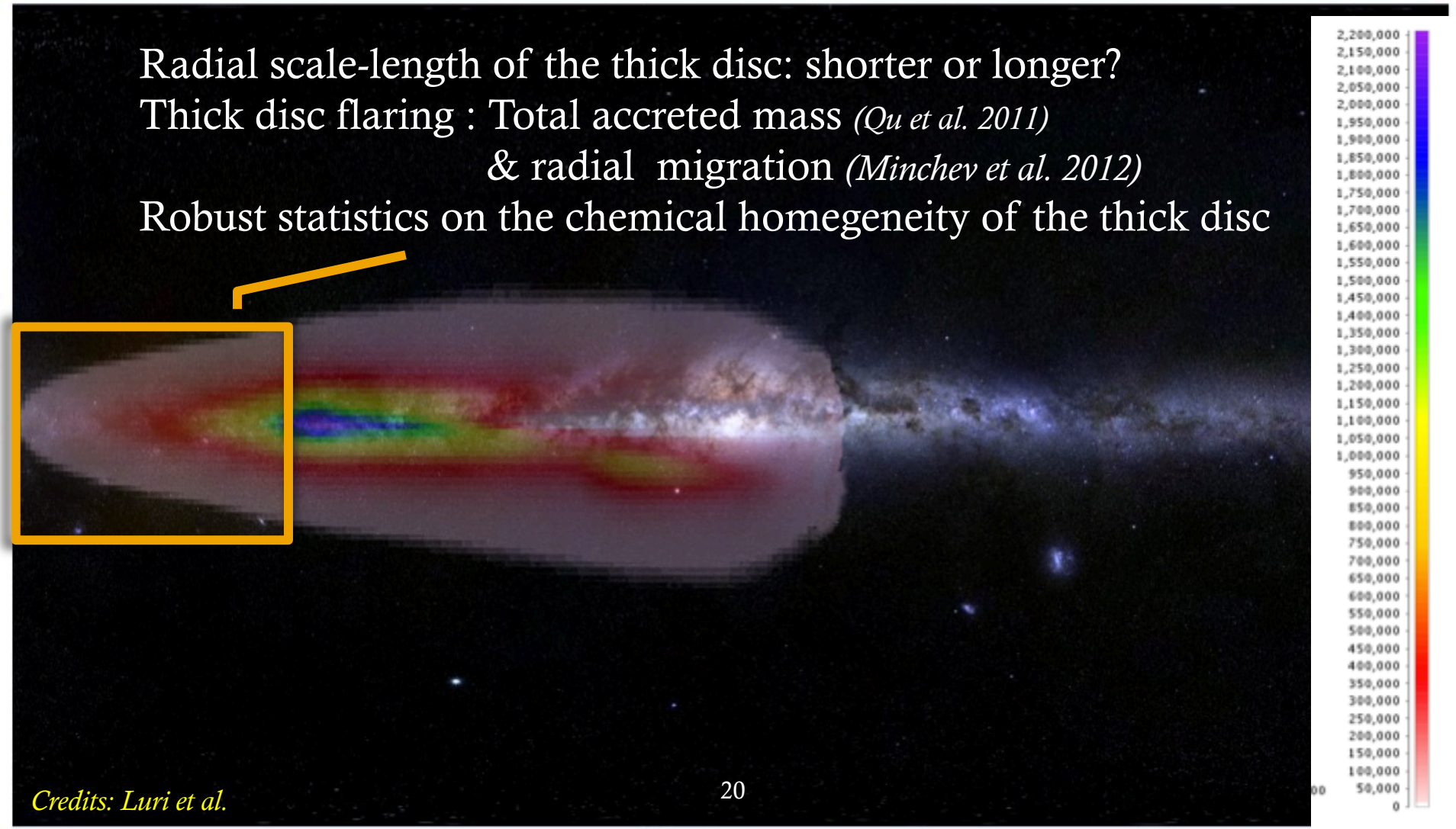
Beyond simple thin disc/ thick disc models? What will Gaia answer?



Credits: Luri et al.

Beyond simple thin disc/ thick disc models? What will Gaia answer?

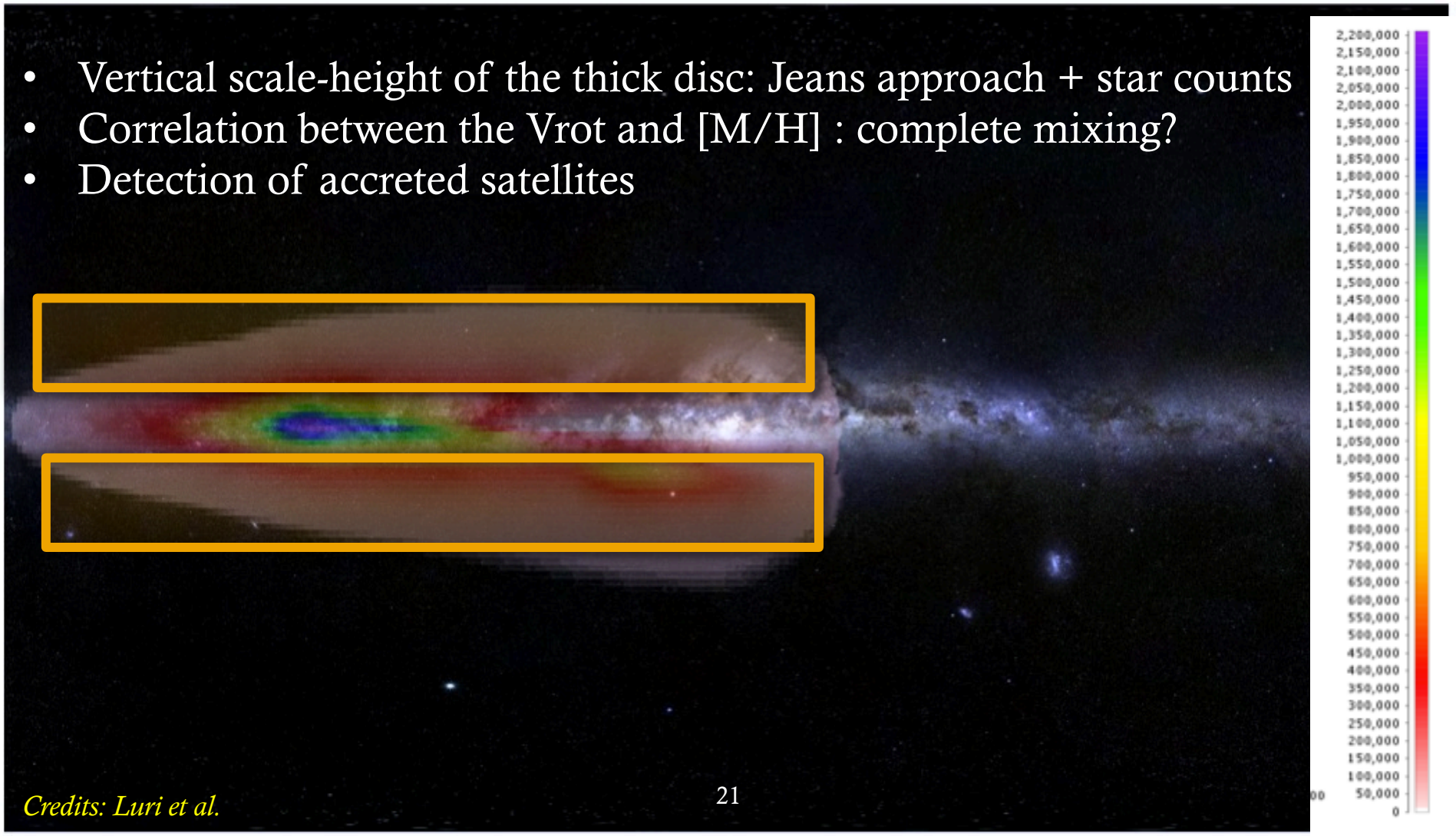
Radial scale-length of the thick disc: shorter or longer?
Thick disc flaring : Total accreted mass *(Qu et al. 2011)*
& radial migration *(Minchev et al. 2012)*
Robust statistics on the chemical homegeneity of the thick disc



Credits: Luri et al.

Beyond simple thin disc/ thick disc models? What will Gaia answer?

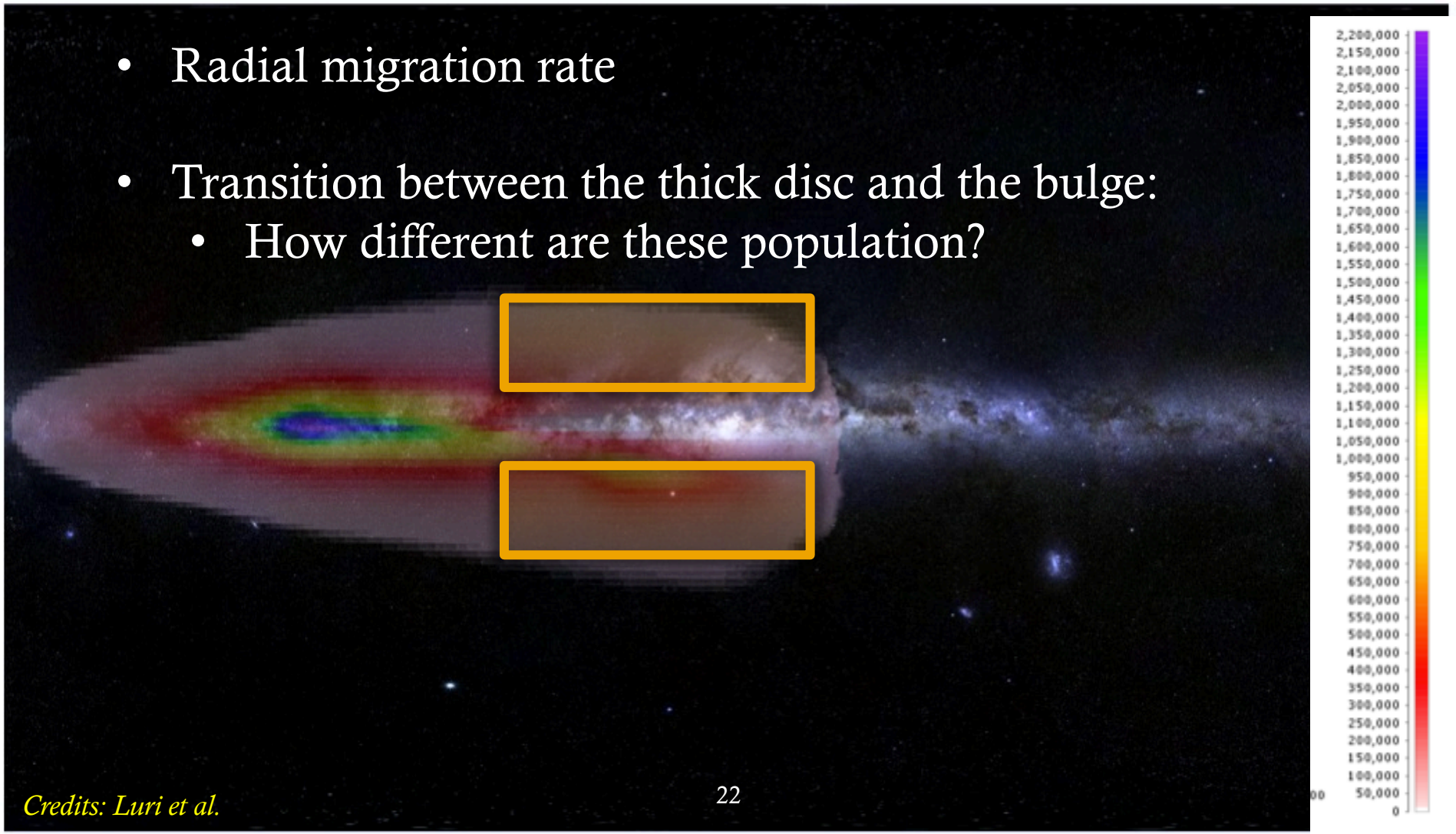
- Vertical scale-height of the thick disc: Jeans approach + star counts
- Correlation between the Vrot and [M/H] : complete mixing?
- Detection of accreted satellites



Credits: Luri et al.

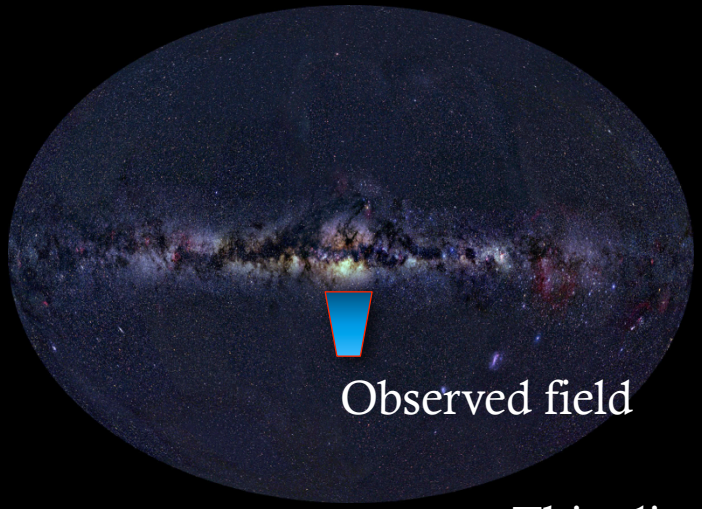
Beyond simple thin disc/ thick disc models? What will Gaia answer?

- Radial migration rate
- Transition between the thick disc and the bulge:
  - How different are these population?



Credits: Luri et al.

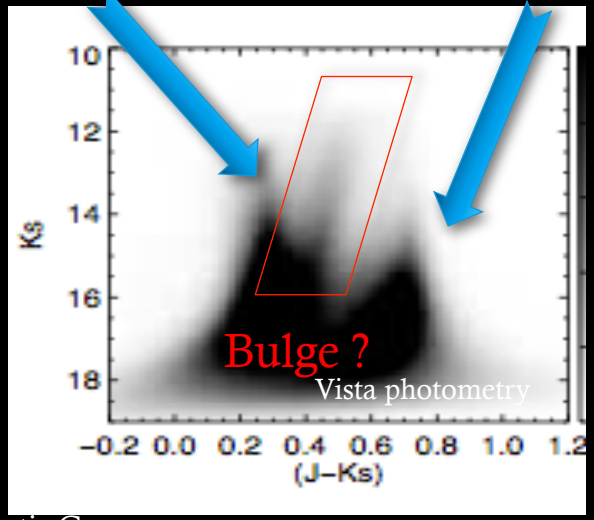
Estimating the importance of the radial migration



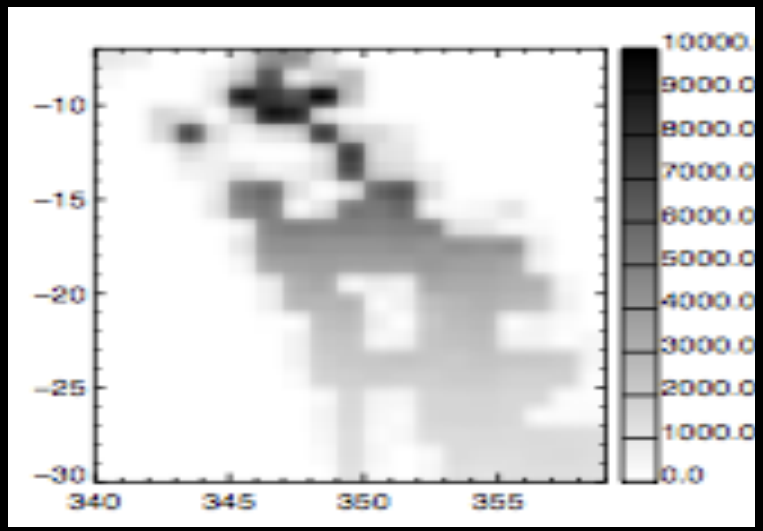
Kordopatis et al, 2012b (in prep.)

Thick disc

Thin disc



Star count of the selected population




Merci de votre attention

Beyond simple thin disc/ thick disc models? What will Gaia answer?

- **Radial gradients?**

=> Lots of statistics at the outer radii of the MW

- **Mono abundance populations with different scale-heights? Vertical transition between the discs?**
- **Radial scale-lenghts of the thick disc?**

⇒ Bensby et al 2012, Cheng et al. 2012, Kordopatis et al, en prep.

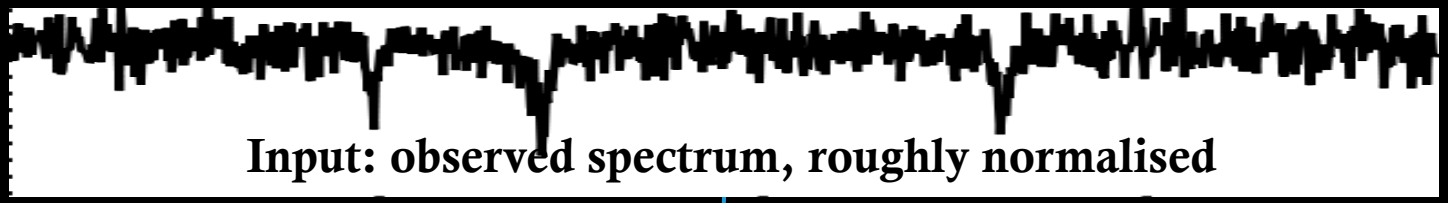
Disc Flaring: Total accreted mass (et al. 2011)

Detection of accreted satellites (in the velocity space) ?

Conclusions

- Thick disc formed in a LCDM context:
  - Accretion does happen, and has an effect on the morphology of the discs
- Outer galactic radii:
  - Total mass accreted, scale-length of the thick disc
- Inner radii:
  - Relation with the bulge => importance of the radial migration

Pipeline (see also Friday's talk)



Input: observed spectrum, roughly normalised

DEGAS with a rough estimate of the S/N

Application of DEGAS according to the new S/N estimate

Re-normalisations and new S/N estimates

Final normalised spectra and final S/N estimates

MATISSE — S/N > 35

DEGAS — S/N < 35

Result: Output synthetic spectrum: T_{eff}, log g, [M/H]

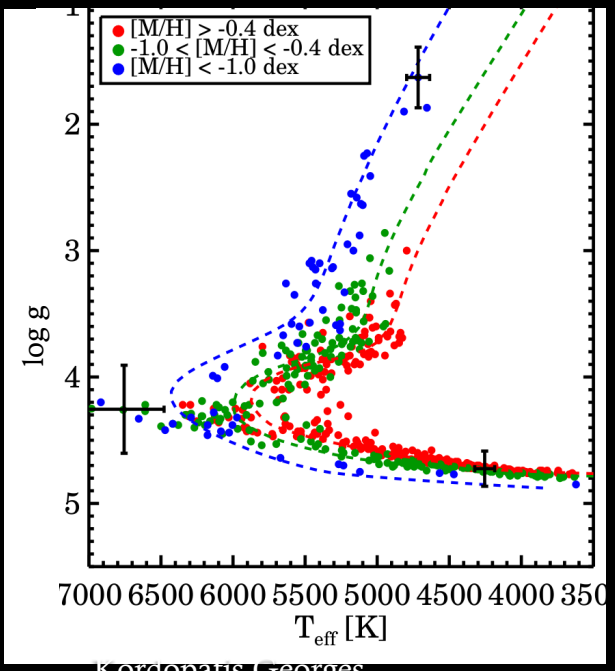
Kordopatis et al. 2011, A&A, 535, A106

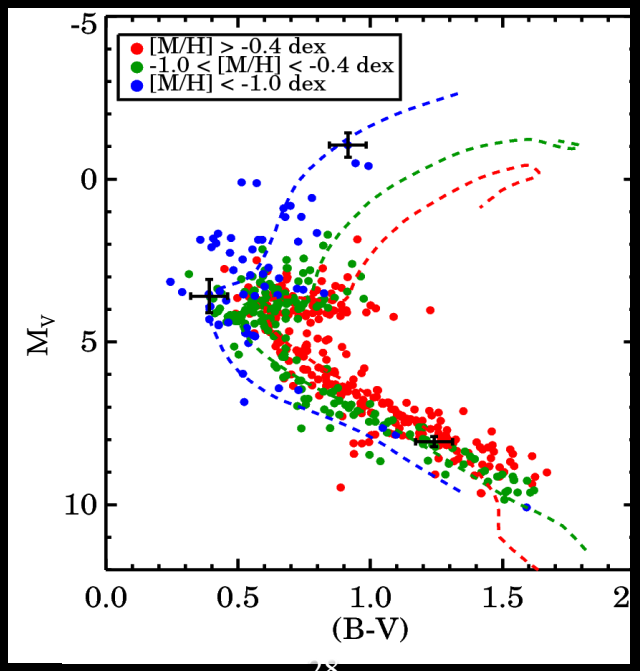
Chemical & kinematic characterization of the thick disc

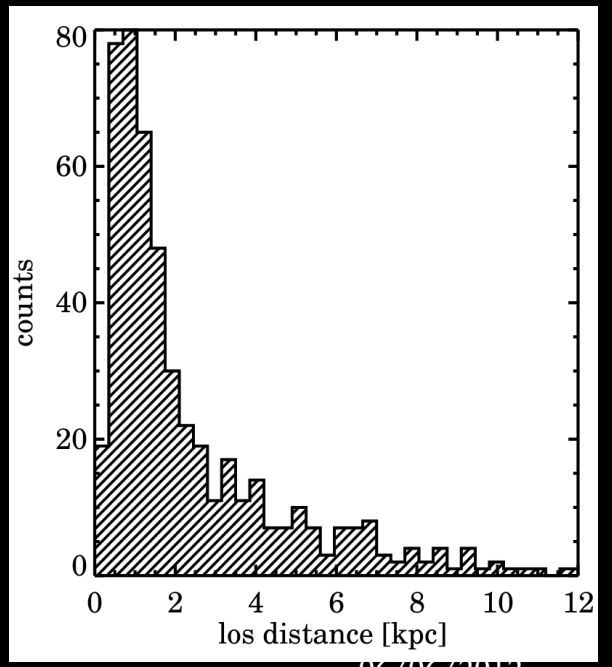
V_{rad}
(cross-correlation)
T_{eff} + log g + [M/H]
(This work: MATISSE + DEGAS)
+
V mag ; (B-V) (Ojha et al. 1996)

l, *b*
+
Distances
(Yonsei-Yale isochrones)
+
V_{rad}, μ_l, μ_b

Positions
Velocities
Eccentricities

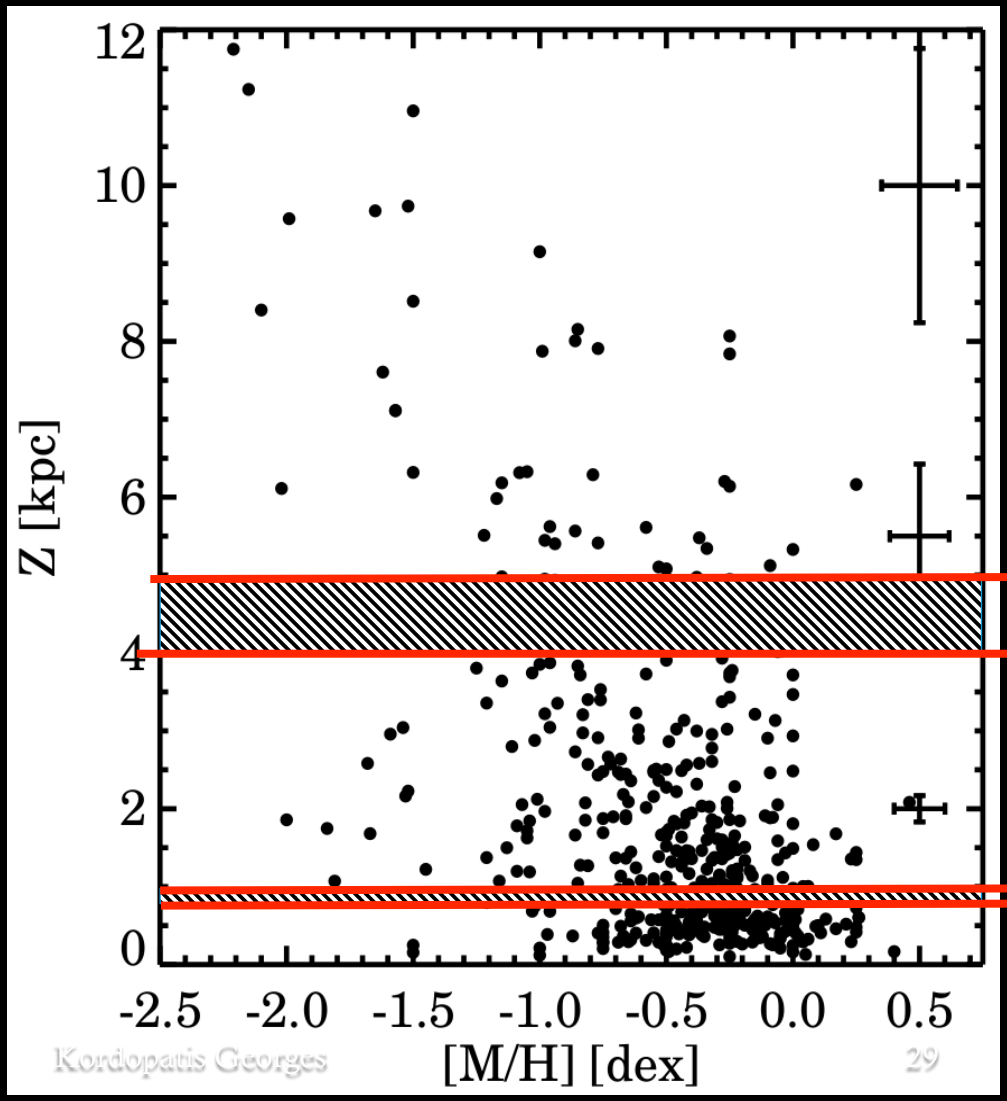






Kordopatis et al.,A&A 535, A107

Selection of the galactic components



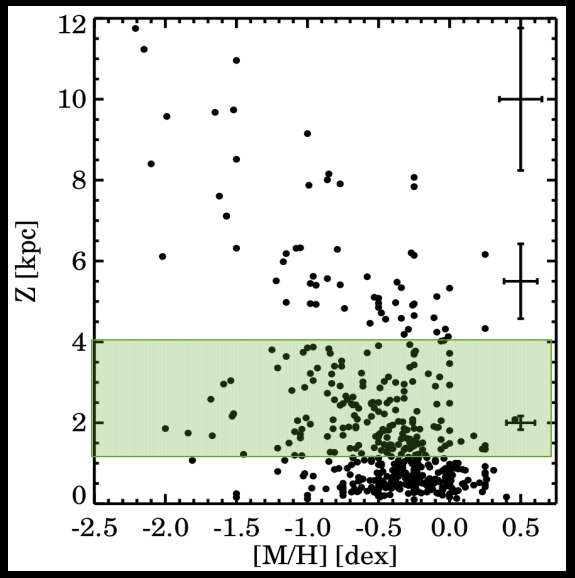
~ Halo: Z > 5 kpc

~ Thick disc: 1 < Z < 4 kpc

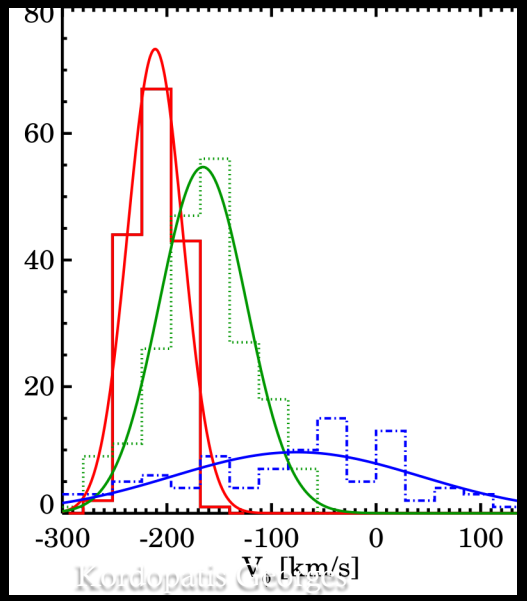
~ Thin disc: Z < 800 pc

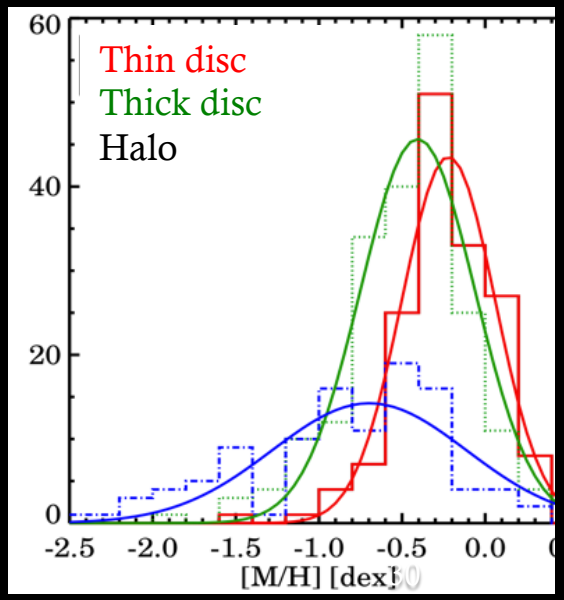
Kordopatis et al., A&A, 535, A107

06/06/2012



	Velocity dispersions			
	Lag (km/s)	σ_R (km/s)	σ_ϕ (km/s)	σ_Z (km/s)	[M/H] (dex)
Thin disc	16±1	43±2	32±1	25±1	-0.27±0.02
Thick disc	53±1	70±6	55±4	51±3	-0.48±0.02
Halo	173±1	223±39	142±28	158±34	-0.92±0.06





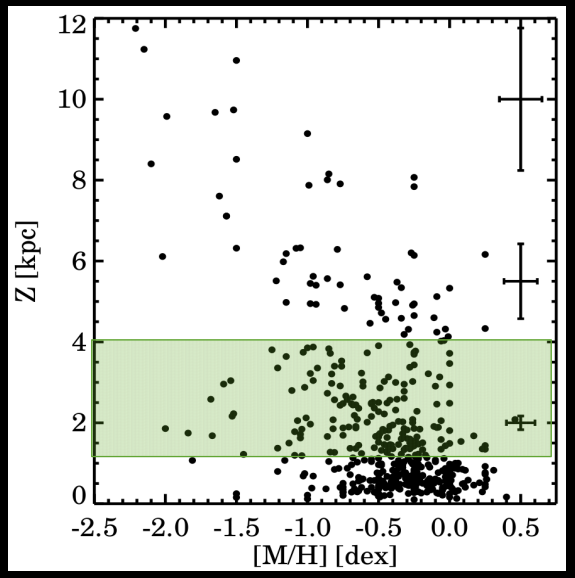
Thick disc:

➔ [M/H] similar to the canonical disc

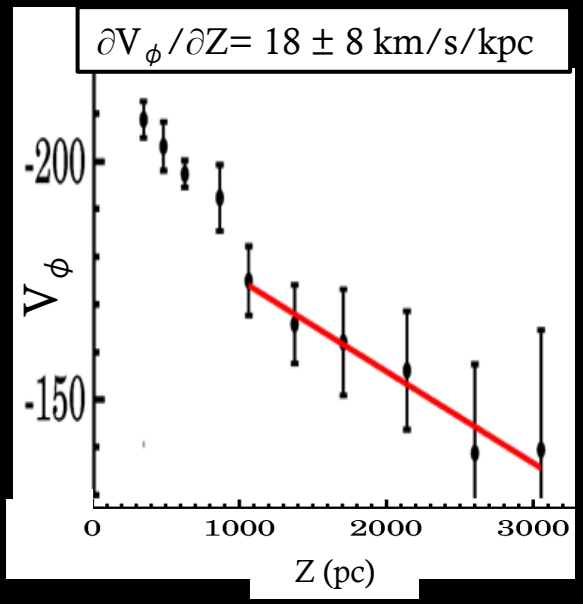
➔ Kinematics similar to the canonical disc

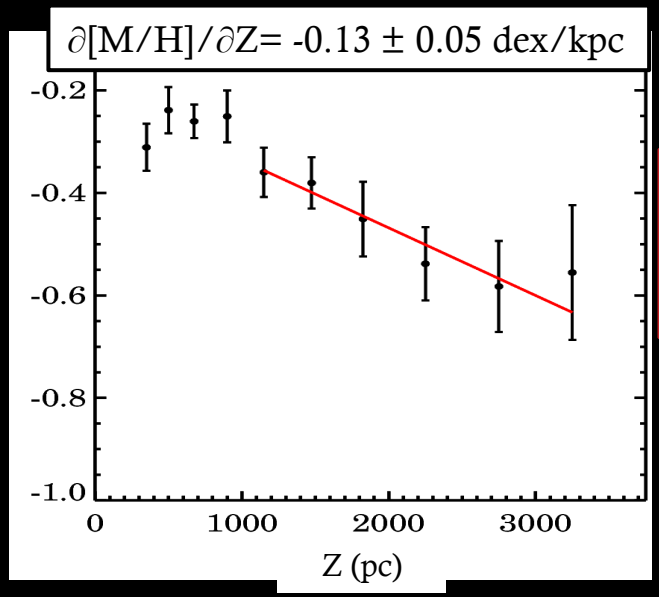
Thick disc far from the solar neighborhood has similar properties as the local one

06/06/2012



	Velocity dispersions			
	Lag (km/s)	σ_R (km/s)	σ_ϕ (km/s)	σ_Z (km/s)	[M/H] (dex)
Thin disc	16±1	43±2	32±1	25±1	-0.27±0.02
Thick disc	53±1	70±6	55±4	51±3	-0.48±0.02
Halo	173±1	223±39	142±28	158±34	-0.92±0.06

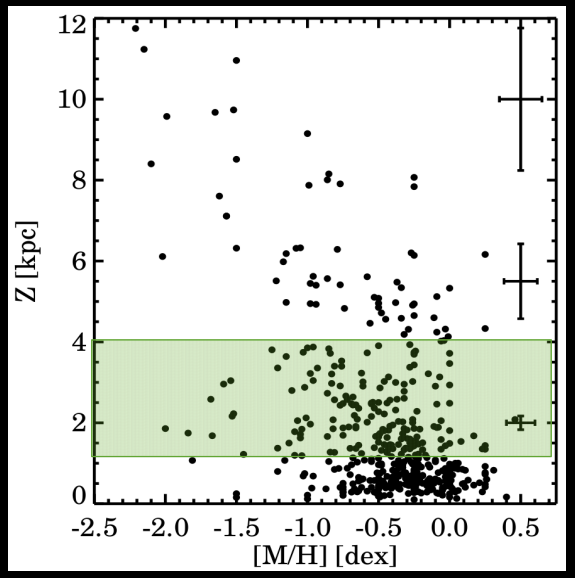




Rotational velocity correlated to metallicity:
$\partial V_\phi / \partial$[M/H]=-45±12 km/s/dex

Kordopatis et al., 535, A107

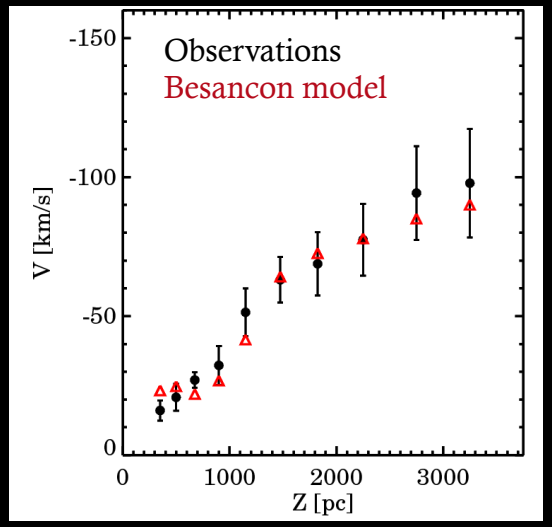
➔ Are these gradients intrinsic to the thick disc?



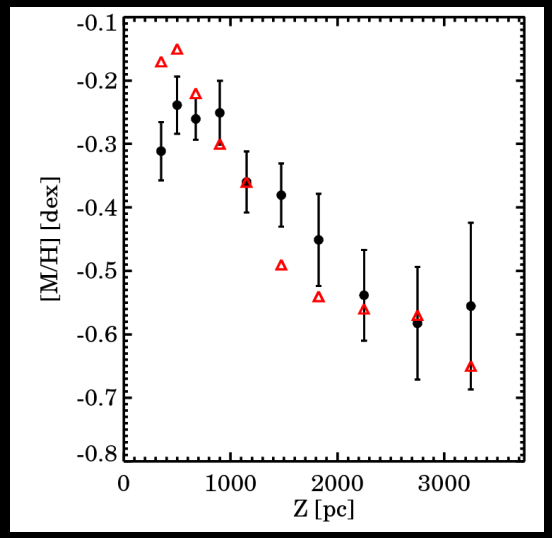
	Velocity dispersions			
	Lag (km/s)	σ_R (km/s)	σ_ϕ (km/s)	σ_Z (km/s)	[M/H] (dex)
Thin disc	16±1	43±2	32±1	25±1	-0.27±0.02
Thick disc	53±1	70±6	55±4	51±3	-0.48±0.02
Halo	173±1	223±39	142±28	158±34	-0.92±0.06

Comparison with the Besancon* model: (Robin et al. 2003)

* Modified means for the thick disc



Cartesian V-velocity



➔ Gradients can be explained as a smooth transition between the galactic components

Scale heights & lengths

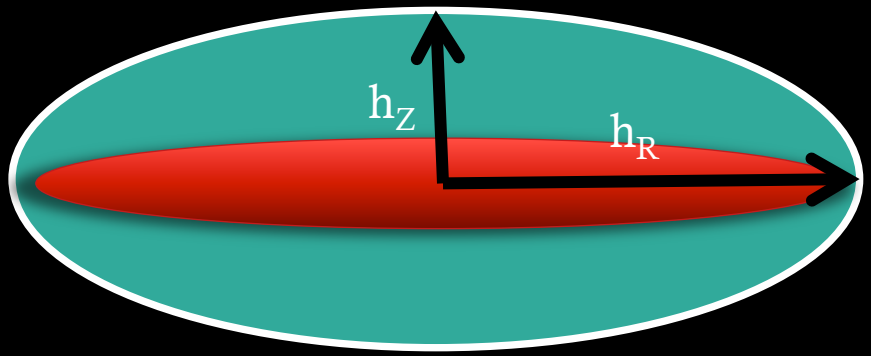
Jeans equations*:

$$\frac{\sigma^2_{V_\phi}}{\sigma^2_{V_r}} - 2 + \frac{2r}{h_r} - \frac{v_c^2 - \overline{v_\phi}^2}{\sigma^2_{V_r}} + \frac{\sigma^2_{V_Z}}{\sigma^2_{V_r}} = 0 \quad \& \quad \frac{\partial ln\sigma^2_{V_Z}}{\partial Z} - \frac{1}{h_Z} + \frac{K_Z}{\sigma^2_{V_Z}} = 0$$

* We assume $\rho(Z) \sim \exp(-Z/h_Z)$

Thin disc: $h_R = 2.9 \pm 0.2$ kpc
$h_Z = 216 \pm 13$ pc

(see Juric et al. 2008)



Thick disc: $h_R = 3.4 \pm 0.7$ kpc
$h_Z = 694 \pm 45$ pc

No metallicity dependence

➔ No evidence of accreted satellite relics *(≠ Gilmore et al. 2002)*
➔ In disagreement with pure migration mechanisms *(≠ Schoenrich & Binney 2009, Bovy et al. 2011)*