Rotational Behavior of Halo BHB Stars in the Milky Way

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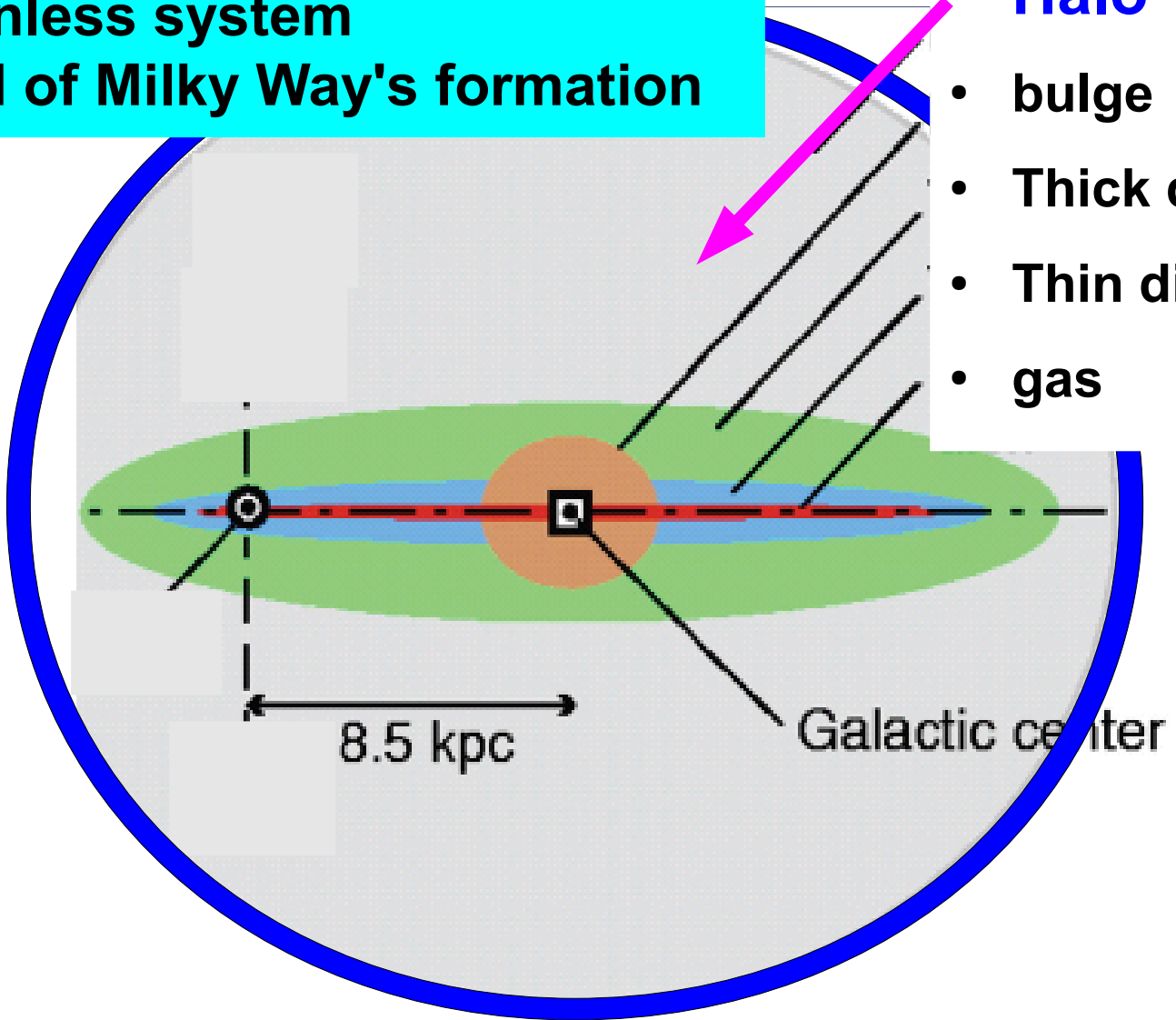
(3) Macquarie University, Australia

(4) INAF - Osservatorio Astronomico di Torino - Italy

□ Stellar halo as a tracer of Milky Way's formation

Halo: ・old
・collisionless system
⇒ fossil record of Milky Way's formation



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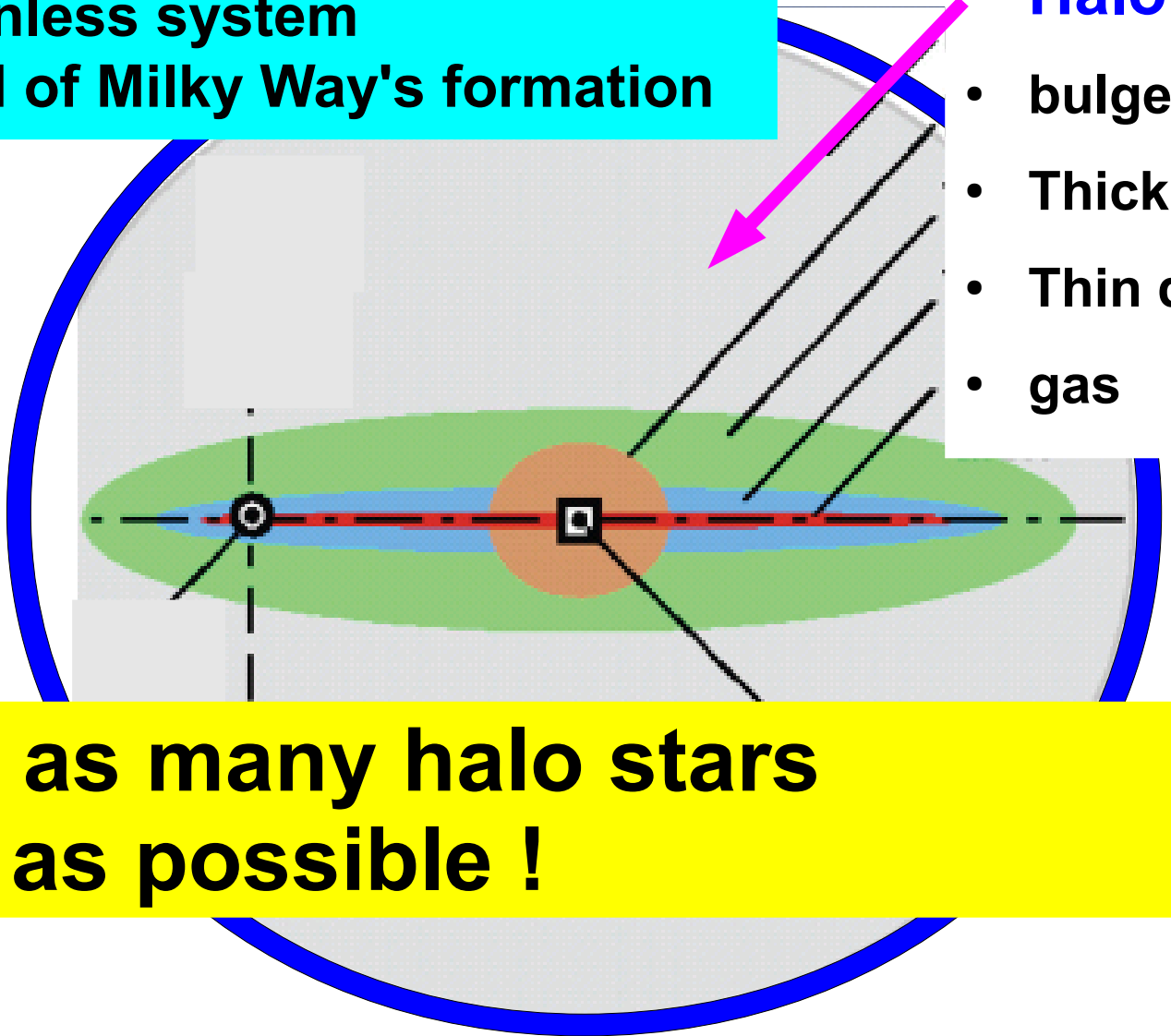
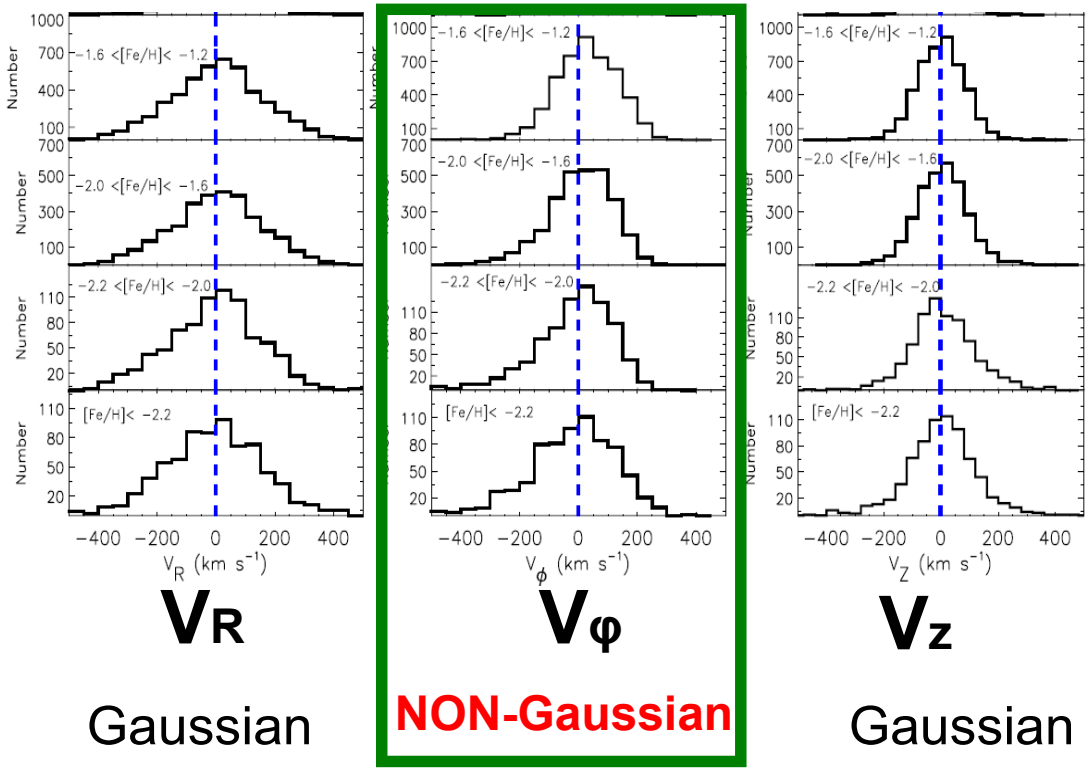


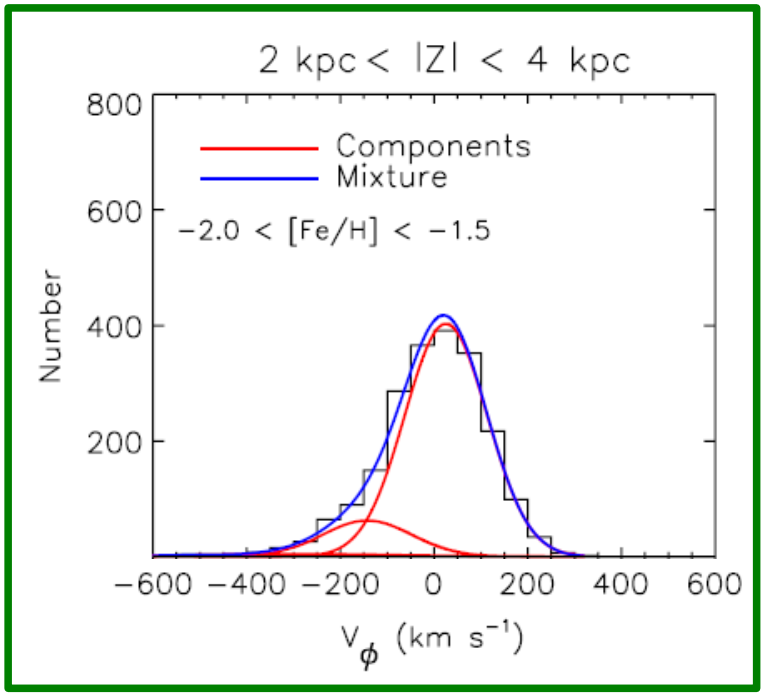
Gather as many halo stars as possible !

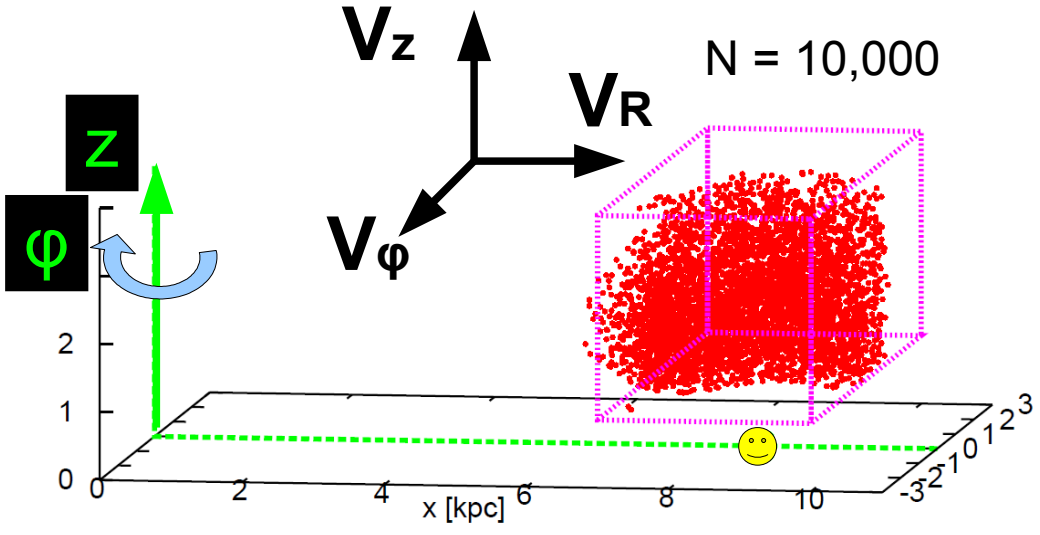
1. Introduction (2/4)

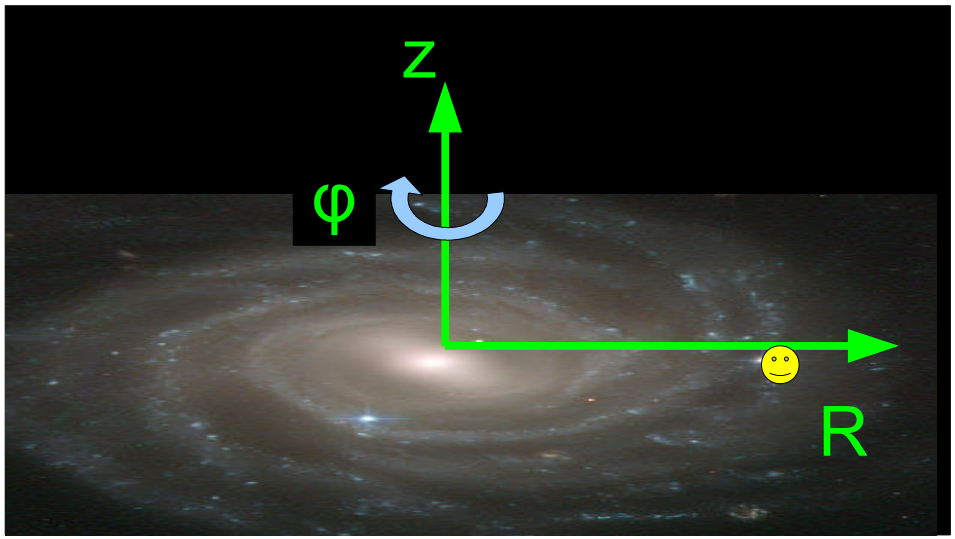
Carollo et al (2010) = SDSS

Two Stellar Haloes









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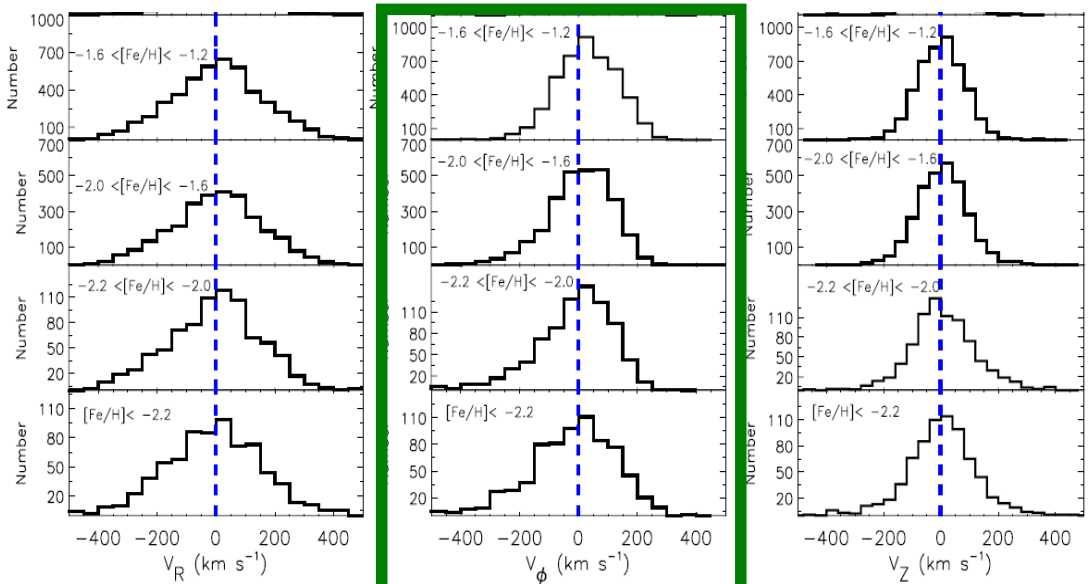
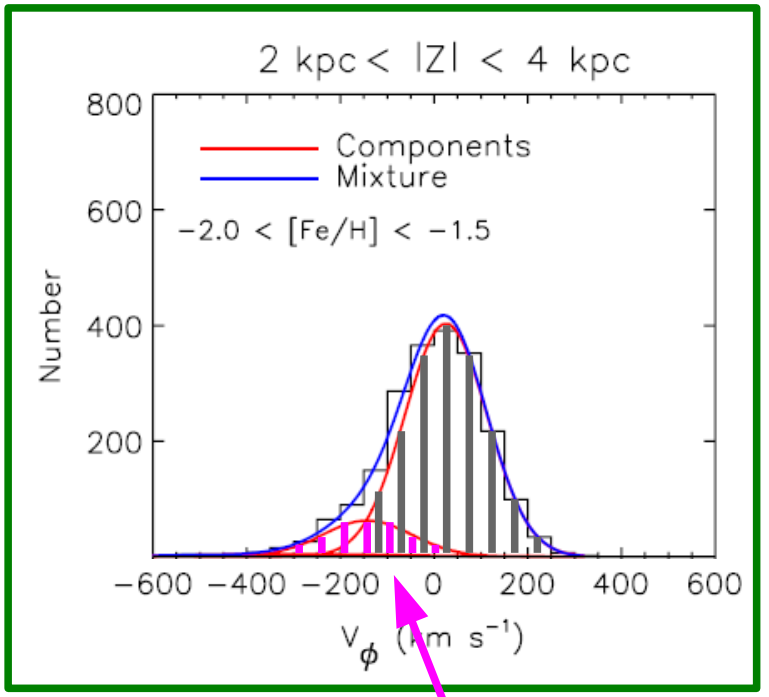
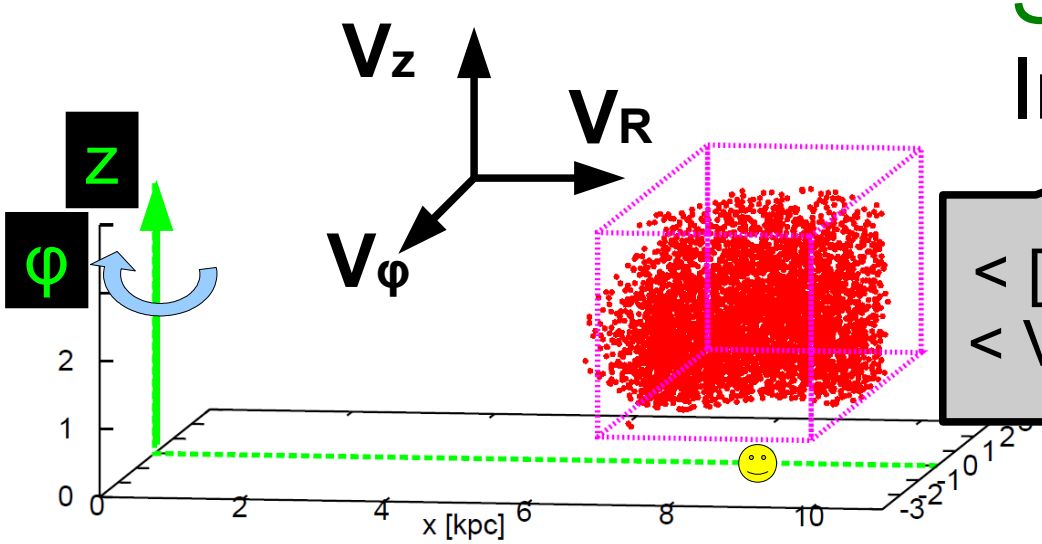


V_R V_φ V_z

NON-Gaussian



Stellar Halo = Inner Halo + Outer Halo



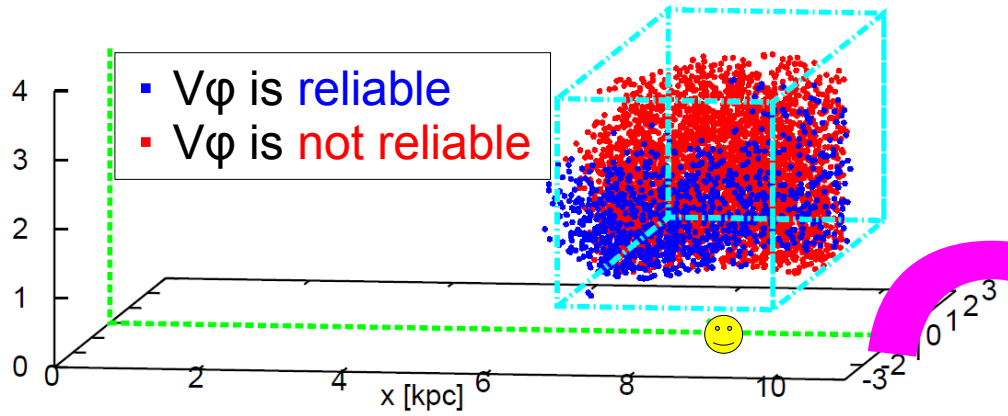
< [Fe/H] > = – 1.6
< Vφ > = 10 km/s

< [Fe/H] > = – 2.2
< Vφ > = – 80 km/s

~ 90 km/s difference in <Vφ>

Two Stellar Haloes

Schonrich et al. (2010)



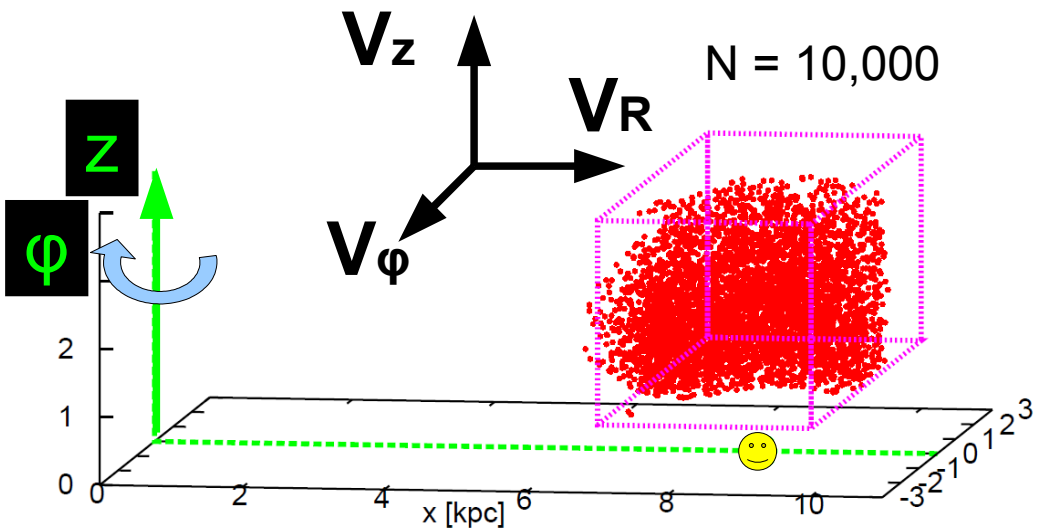
- Vφ is not reliable for most stars

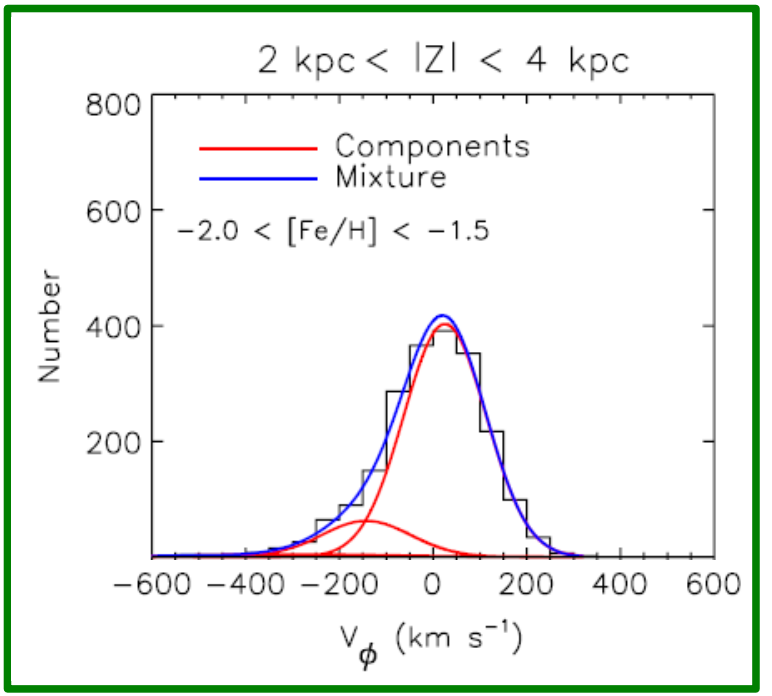
  ← poor precision of μ and d.

- **Non-Gaussianity** in Vφ-distribution is artificial !

(o) single halo (x) dual halo

Carollo et al (2010) = SDSS





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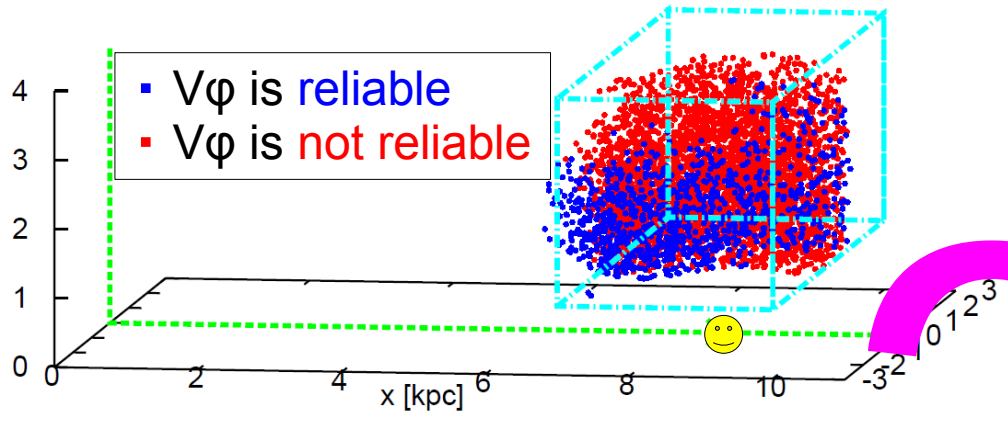

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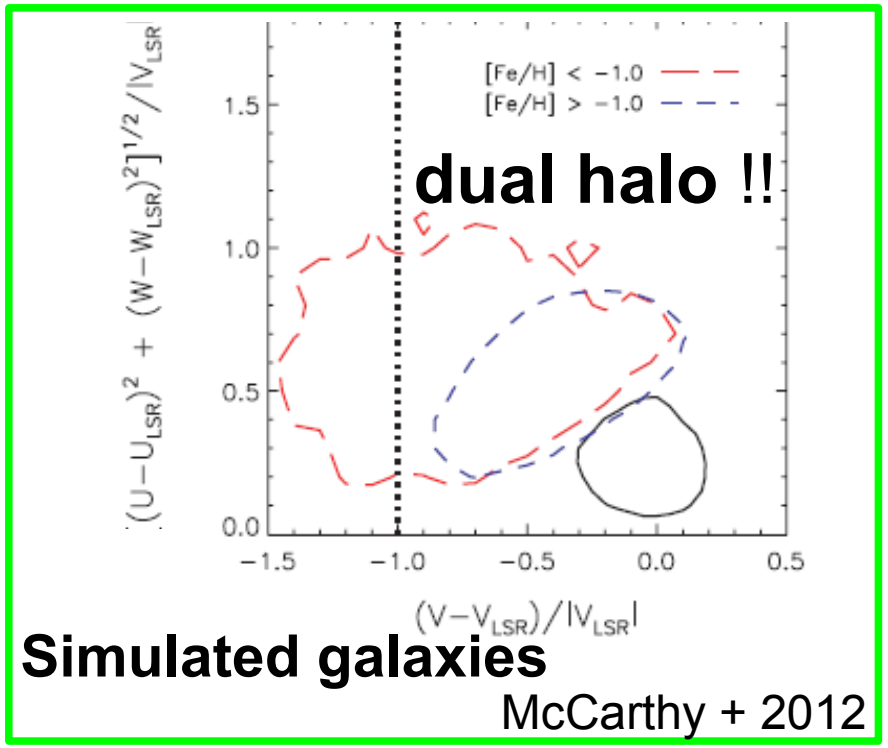
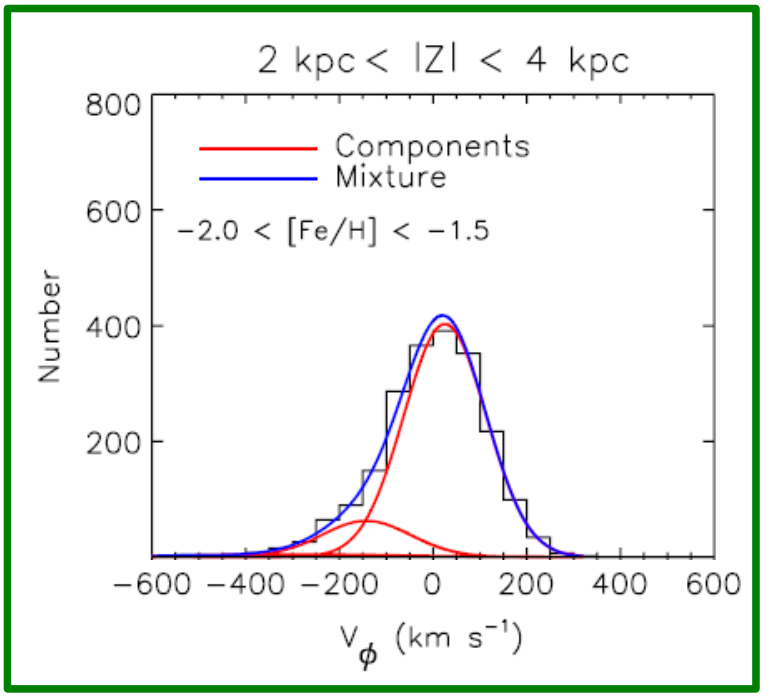


Simulated galaxies

McCarthy + 2012



1. Introduction (4/4)

Q. Given that tangential motion is not accurate.
How can we settle **single/dual halo** dispute ?

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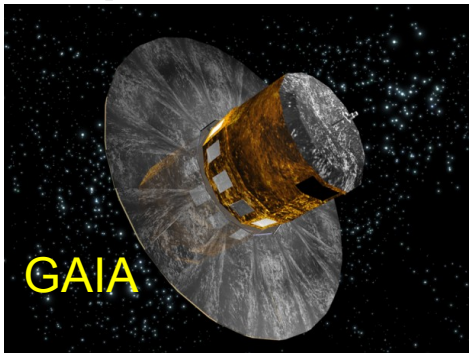
- [A1] Just wait for better data.
  - GAIA



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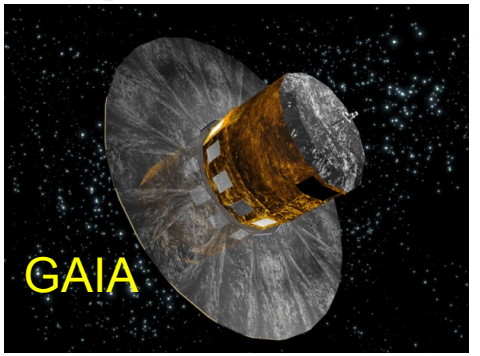


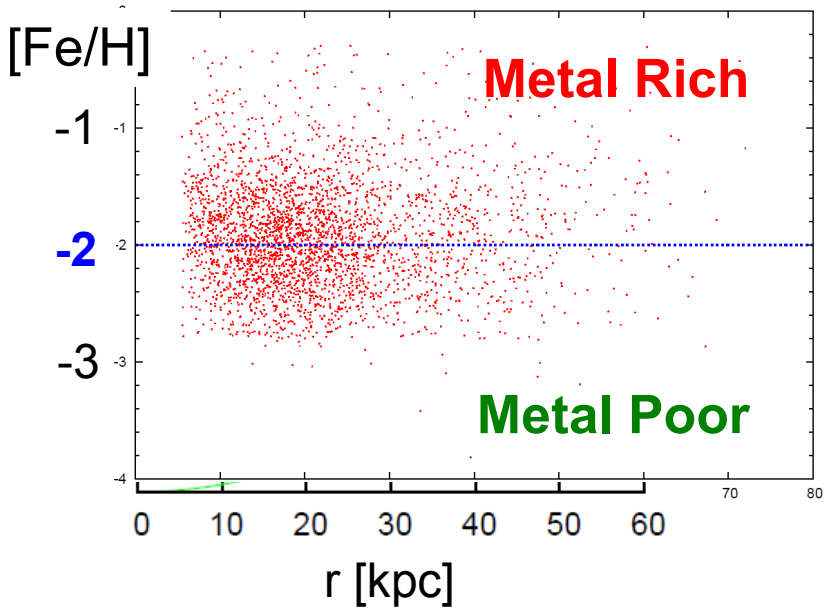
- [A1] Just wait for better data.
  - GAIA → first data release will be in 2015 (?)

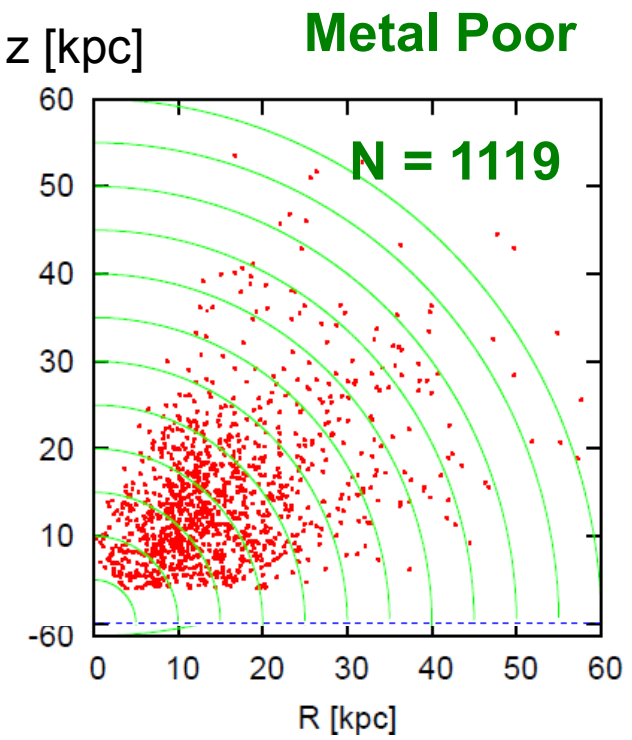
- [A2] Do <u>without</u> proper motion.
  - Independent analysis on <Vφ>,
    by using only line-of-sight velocity + distance .
  - (x) Vφ for each star
  - (o) Statistical estimate of <Vφ>

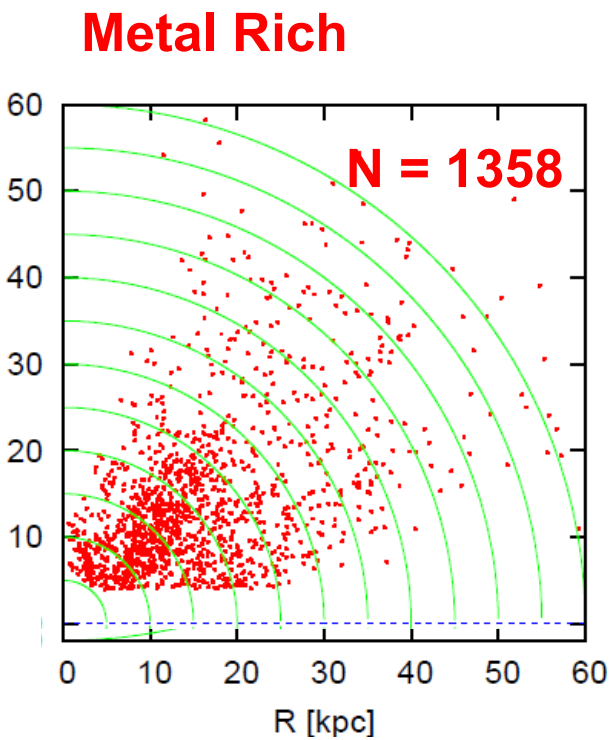
Goal: Does < Vφ > depend on [Fe/H] ?

Data outline

- **2,477** BHB stars from SDSS DR8 (Xue + 2011)
  - (1) Sgr-field is excluded.
  - (2) Minimum contamination from thick disk: **z > 4 kpc**
- Error
  - (line-of-sight velocity): **δ v = 5 km / s** << σ_los = 100 km/s
  - (distance): **δ d / d = 0.10**



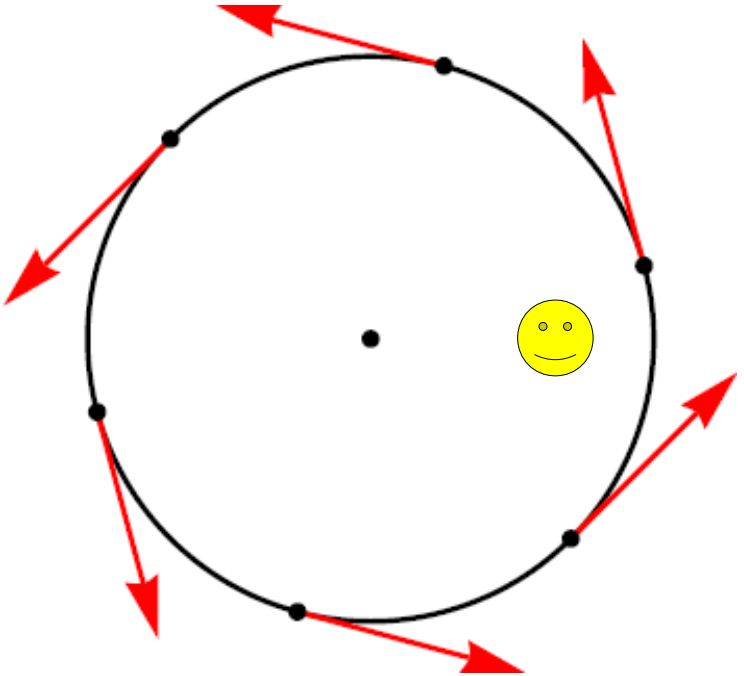




3. Analysis (1/3)

Basic idea: estimate of <Vφ>

- Ideal case [2D]
  - All stars rotate at < Vφ > . Observer is at rest.



Original work: Frenk & White (1980)

3. Analysis (2/3)

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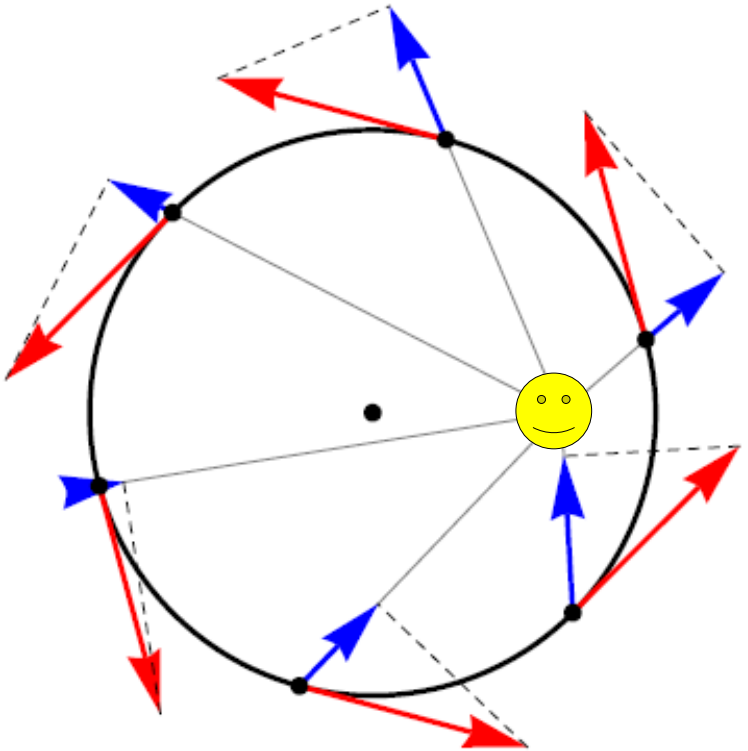

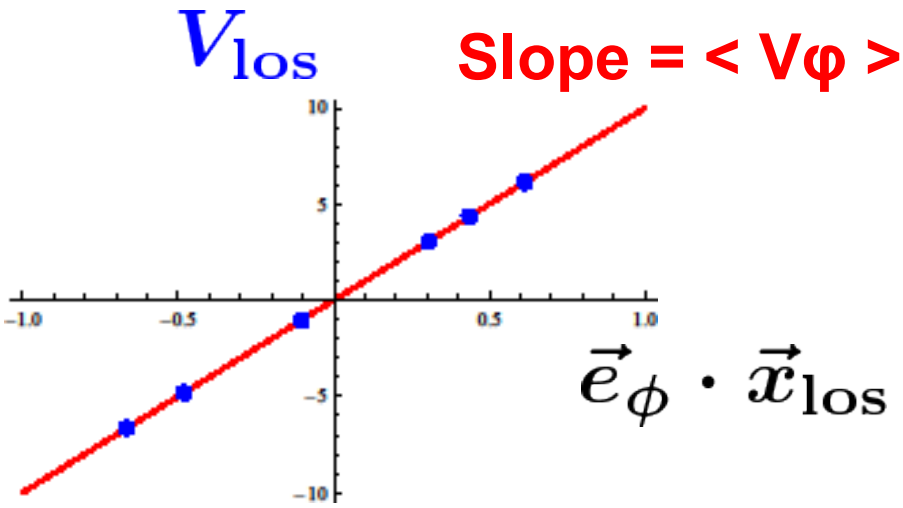

Vlos depends on the **direction** with respect to the Sun .

stars in many directions → we can estimate **< Vφ >**

3. Analysis (3/3)

Basic idea: estimate of <Vφ>

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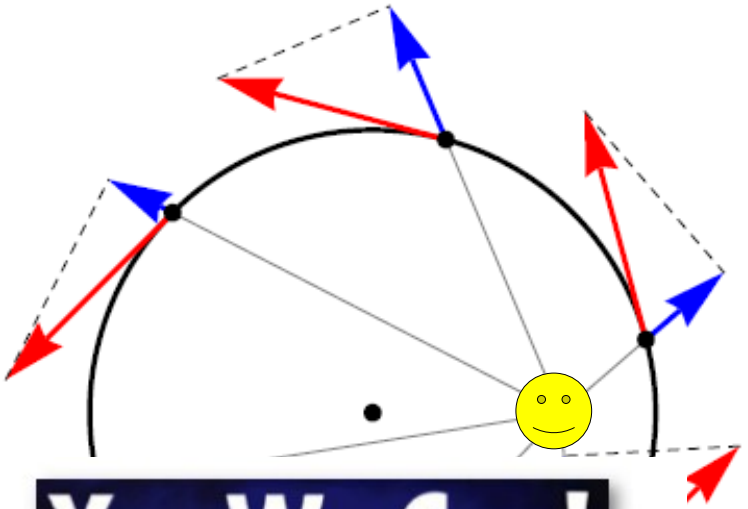
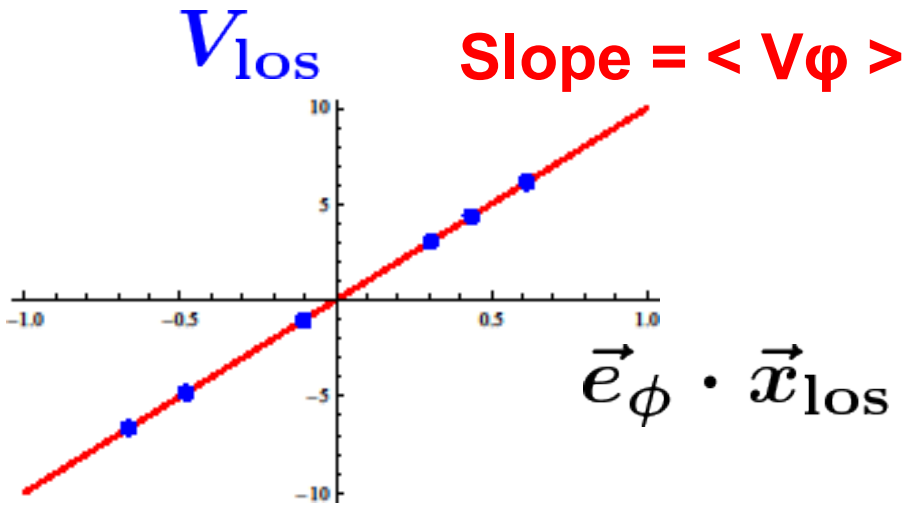
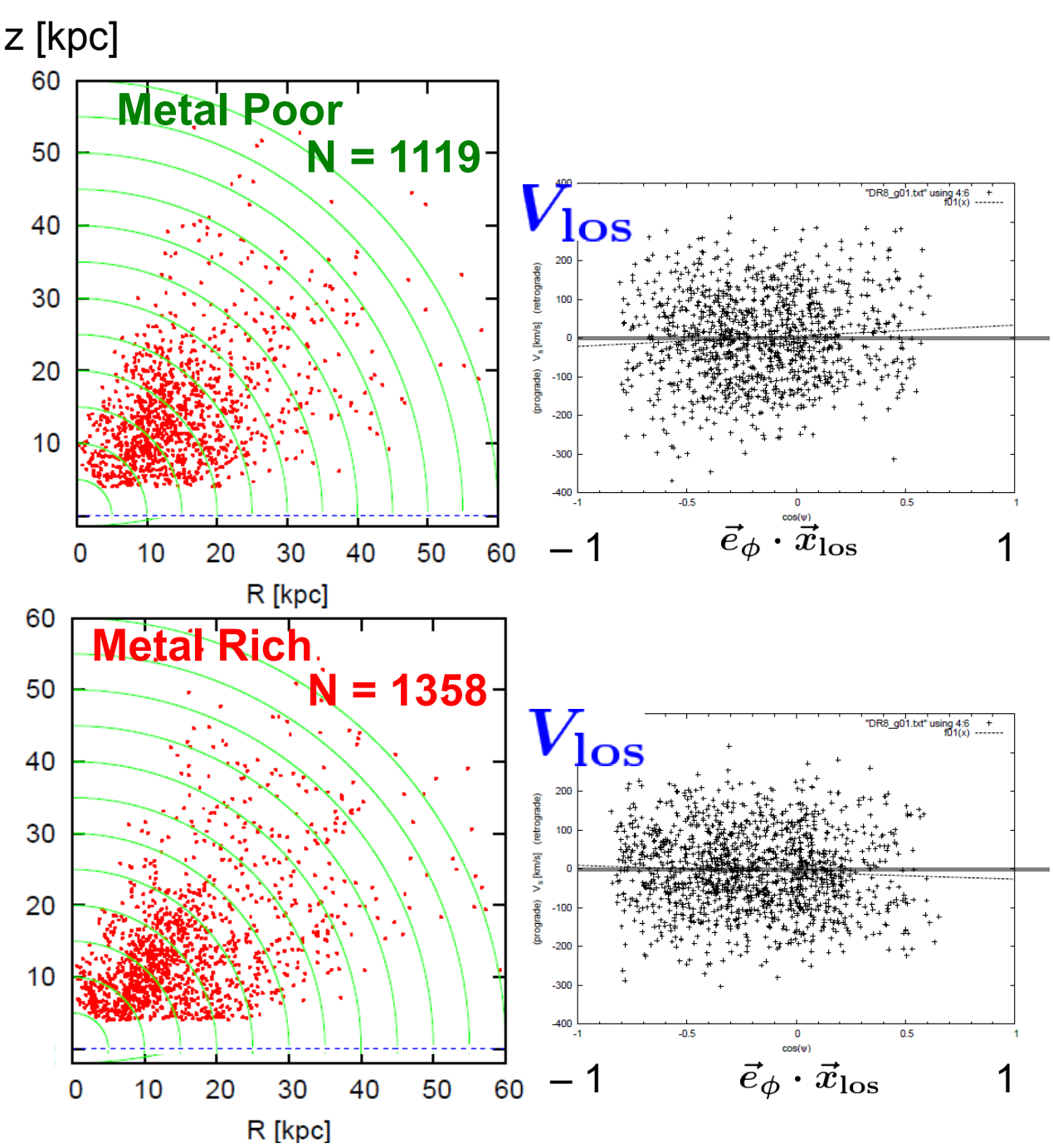
  - All stars rotate at < Vφ > . Observer is at rest.





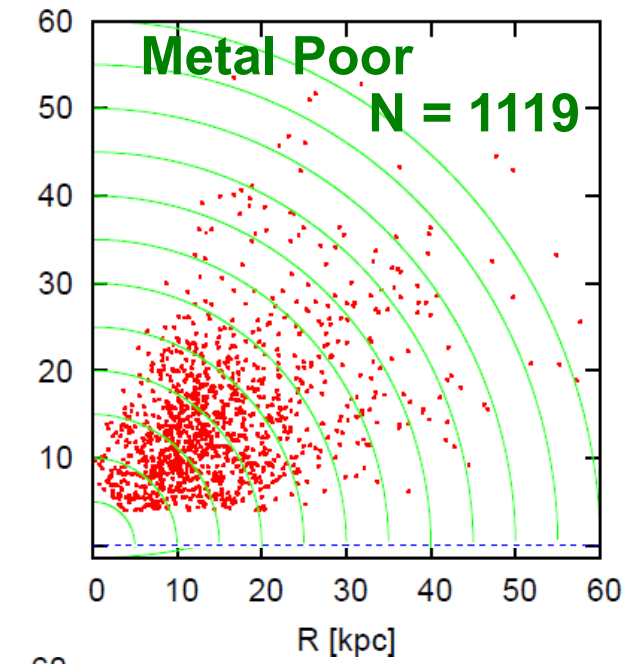
- Complications
  - 3D
  - Vφ = < Vφ > + (random motion)
  - Motion of observer

4. Results (1/2)

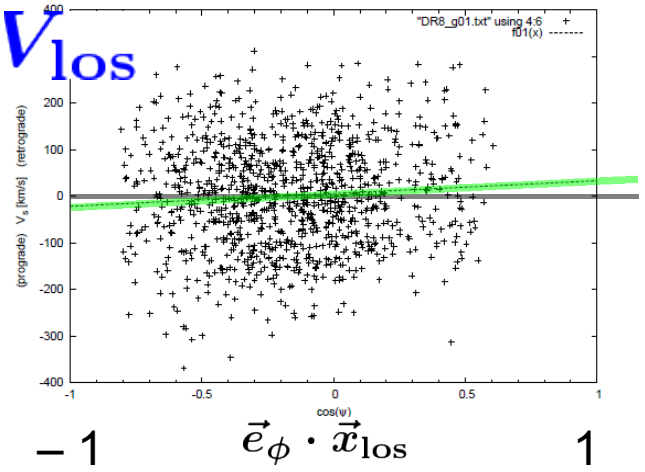

z [kpc]
Metal Poor
N = 1119
R [kpc]
V_{los}
(prograde) V_ϕ [km/s] (retrograde)
cos(ψ)
– 1
$\vec{e}_\phi \cdot \vec{x}_{los}$
1
Metal Rich
N = 1358
R [kpc]
V_{los}
(prograde) V_ϕ [km/s] (retrograde)
cos(ψ)
– 1
$\vec{e}_\phi \cdot \vec{x}_{los}$
1

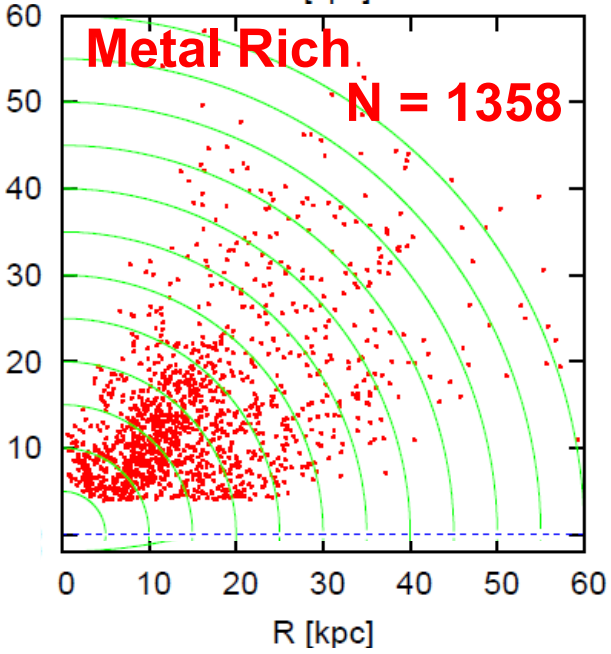
4. Results (1/2)

Metal-Poor stars rotates more slowly !!

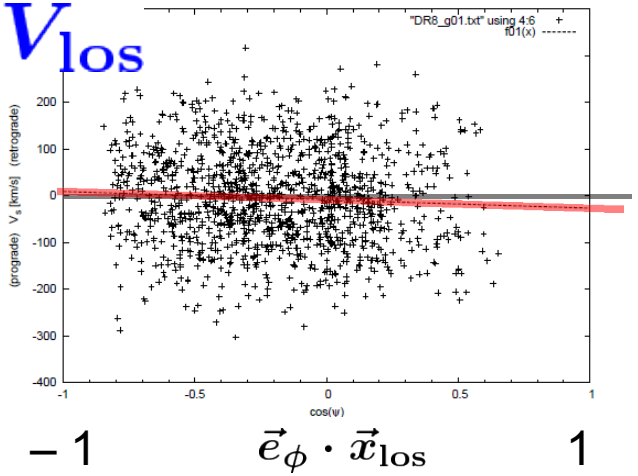


$$< V_\phi >= -27 \pm 11 \text{ km/s}$$





$$+18 \pm 8 \text{ km/s}$$



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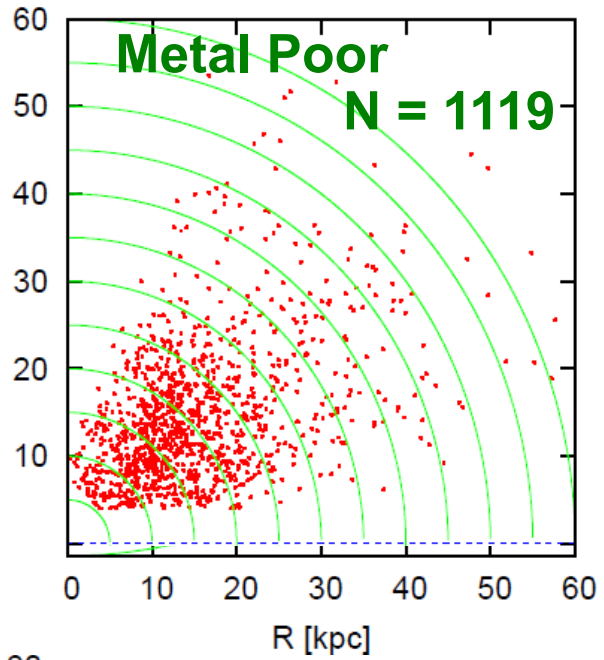

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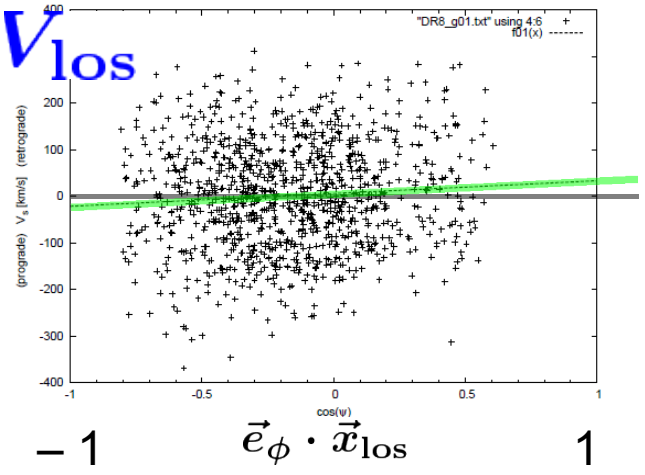

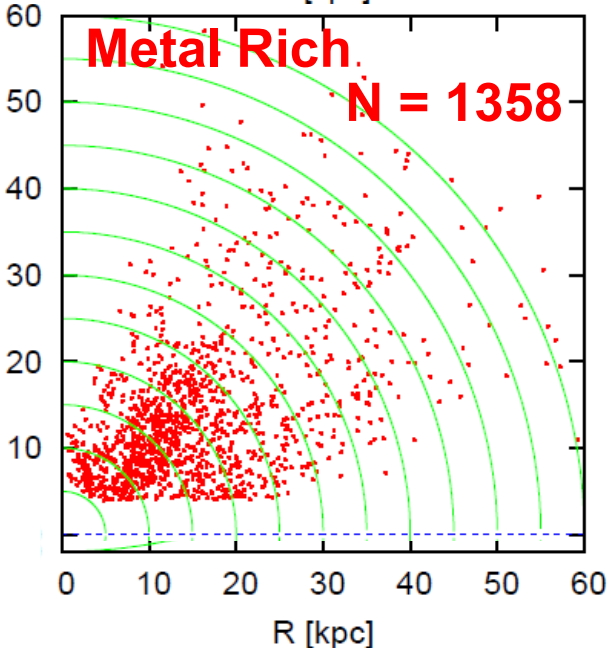

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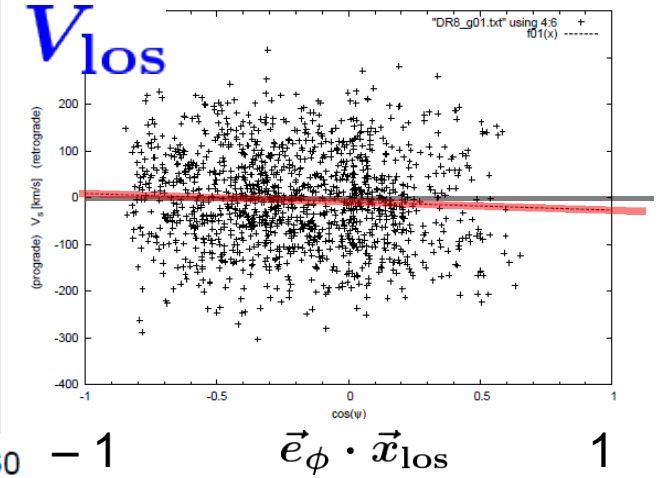
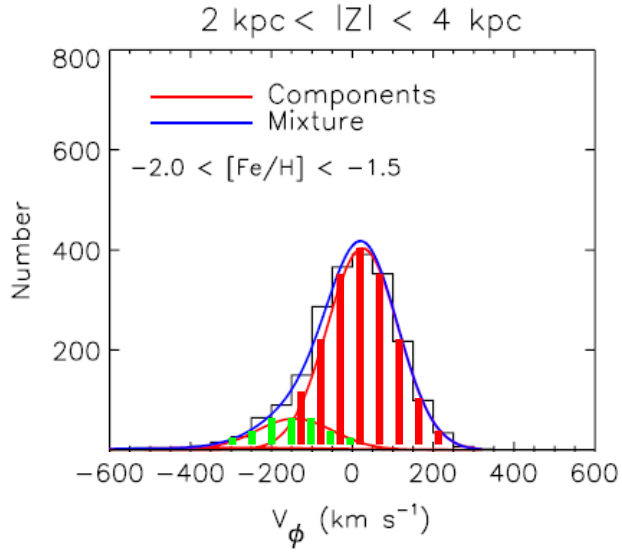


Carollo et al (2010)

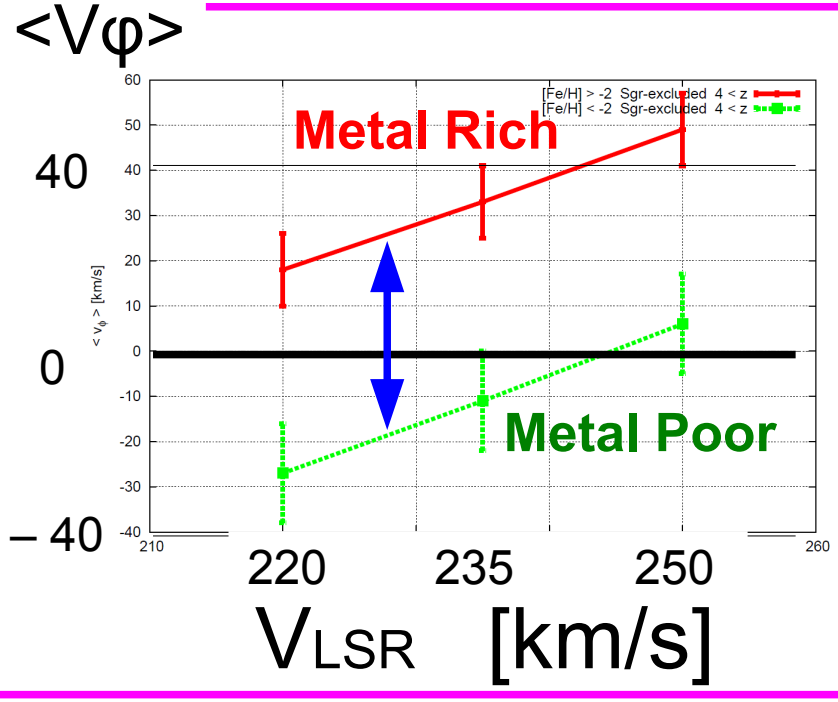
(cf) Outer Halo
< [Fe/H] > = – 2.2
< Vφ > = – 80 km/s

(cf) Inner Halo
< [Fe/H] > = – 1.6
< Vφ > = +10 km/s



4. Results (1/2)

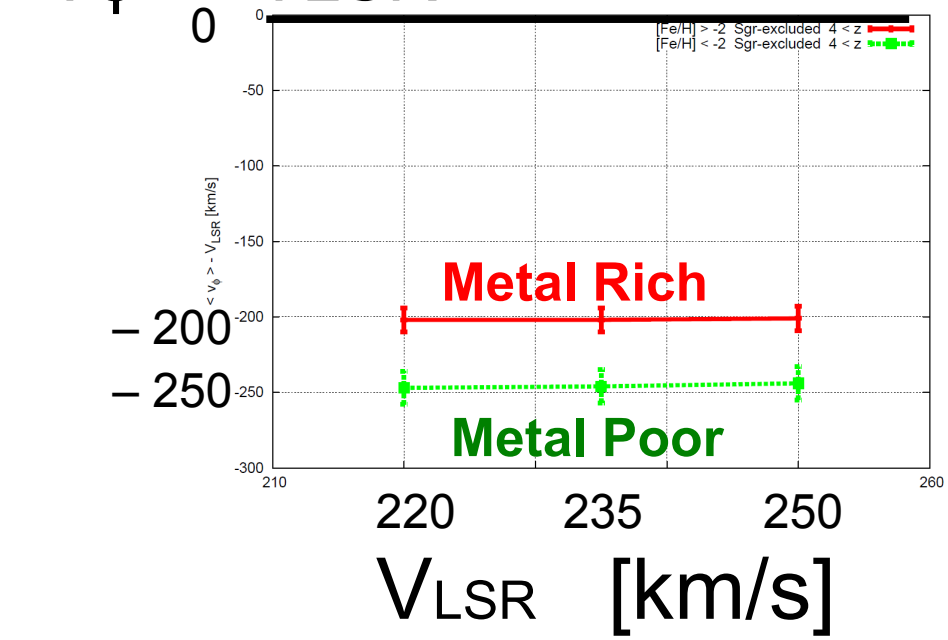
Rotational Lag with respect to LSR



- MR stars rotates 50 km/s faster than MP stars do.

  cf.) Carollo et al. (2010)

  → 90 km/s



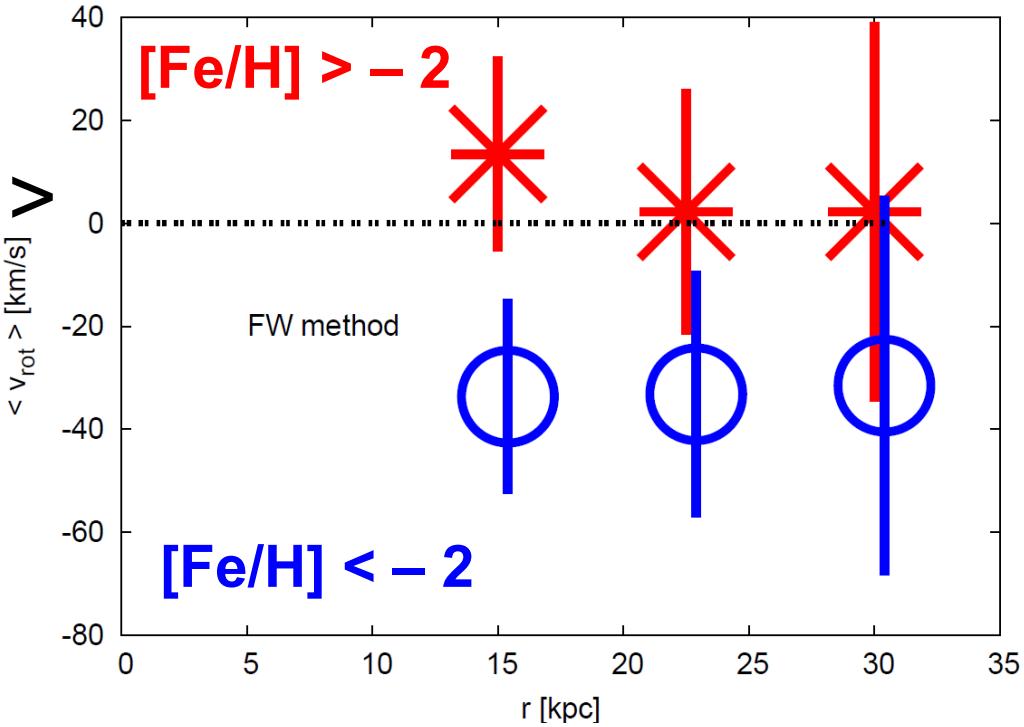
- Rotational Lag wrt LSR:
  - MR : – 200 km/s (+/– 8)
  - MP : – 250 km/s (+/–11)

  cf.) Carollo et al. (2010)
  - MR comp. : – 210 km/s (+/– 7)
  - MP comp. : – 300 km/s (+/–13)

Mean Rotation Curve

- Velocity shear exists for subsamples with
  - 10 < r < 20 kpc
  - 15 < r < 30 kpc
  - 20 < r < 40 kpc
- LSR = 220 km/s
- Rsun = 8.5 kpc
- Error bars are estimated from Monte Carlo simulation.

< Vrot >



Galactocentric distance

- Metal-rich sample: consistent with no net rotation.
- Clear rotational lag of metal-poor sample at r < 20 kpc.

If LSR = 250 km/s, then...

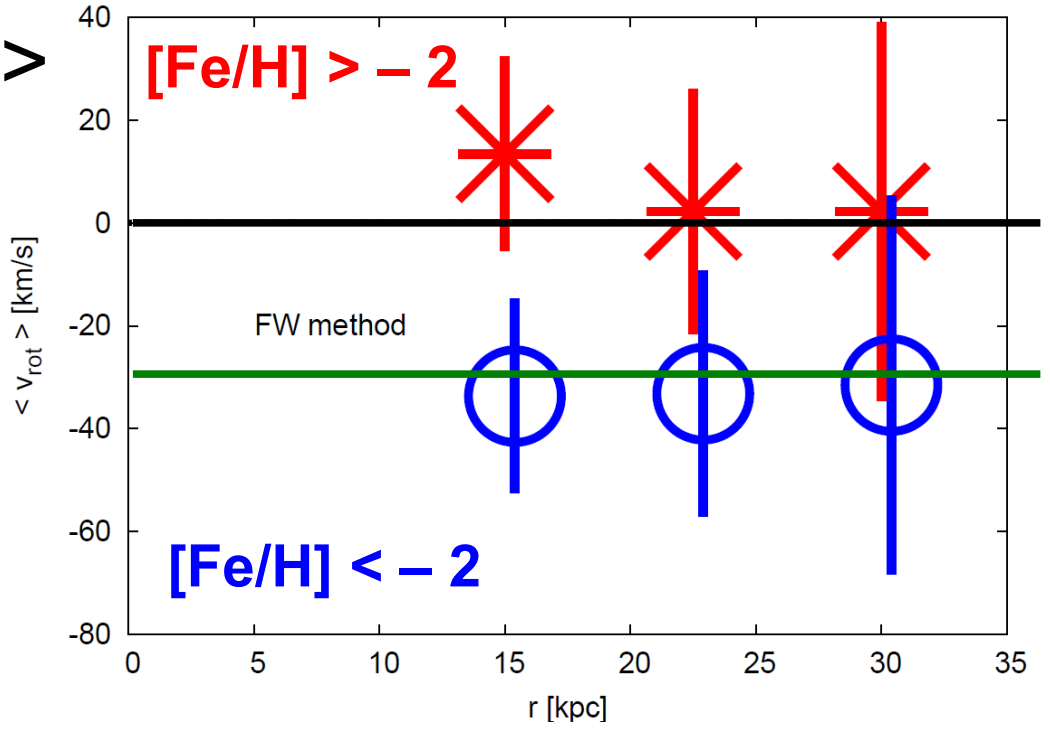
- (e.g.) Reid & Blunthaler (2004)
  - 8 years of VLBA observation of Sgr A*

- Metal-poor sample shows no net rotation,
- While metal-rich sample shows prograde motion.

< Vrot >

LSR = 220 km/s

LSR = 250 km/s



Galactocentric distance

5. Summary + Future Plan

- The mean rotation of BHB stars supports dual halo concept.
- If we assume LSR=220 km/s, we obtain

  $< V\varphi > = -27 \pm 11$ km/s for [Fe/H] < – 2.0

  $< V\varphi > = +18 \pm 8$ km/s for [Fe/H] > – 2.0
- This rotational shear of metal-rich & -poor sample is eminent at r < 20 kpc.

- We plan to extend this work, using ~40,000 F turn-off stars form SDSS DR8.

  → Not only <Vφ>, but also 3-dimensional velocity dispersion can be obtained from line-of-sight velocity + distance info.