The Structure of the Galactic discs

André Moitinho - SIM/U. Lisbon

Preamble

An early visionary

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ON THE ORIGIN OF THE FORMS AND THE PRESENT CONDITION OF SOME OF THE CLUSTERS OF STARS AND SEVERAL OF THE NEBULÆ.

By STEPHEN ALEXANDER,
PROFESSOR OF MATHEMATICS AND ASTRONOMY IN THE COLLEGE OF NEW JERSEY.

An early visionary

ASTRONOMI

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VOL. II. CAMBRIDGE

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The Milky Way — a Spiral.

The following coincidences are consistent with the supposition that the Milky Way and the stars within it together constitute a spiral with several (it may be *four*) branches, and a central (probably spheroidal) cluster; that which ought in such case to be observed being expressed in terms of that which has actually been seen.

If, then, the form of the Milky Way be really such as is here supposed, and our situation in the central cluster be, as it appears to be, "somewhat nearer to" the "northern surface,"* we should expect to find :—

S. Alexander, 1852

An early visionary

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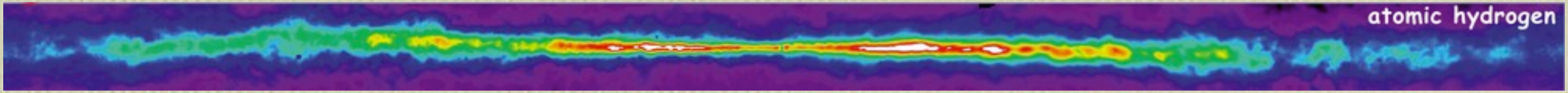
If, then, the form of the Milky Way be really such as is here supposed, and our situation in the central cluster be, as it appears to be, "somewhat nearer to" the "northern surface,"* we should expect to find :—

Interstellar extinction!

- **Central** role in studying disc structure
- Existence of ISM proved 78 years later.

Overview

The Discs

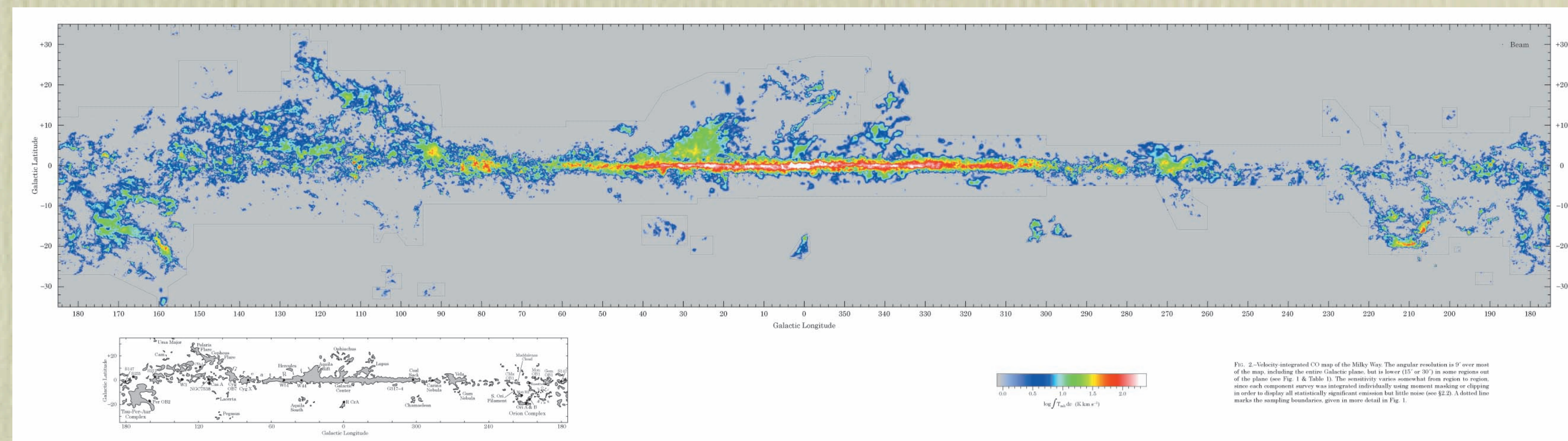


Structure

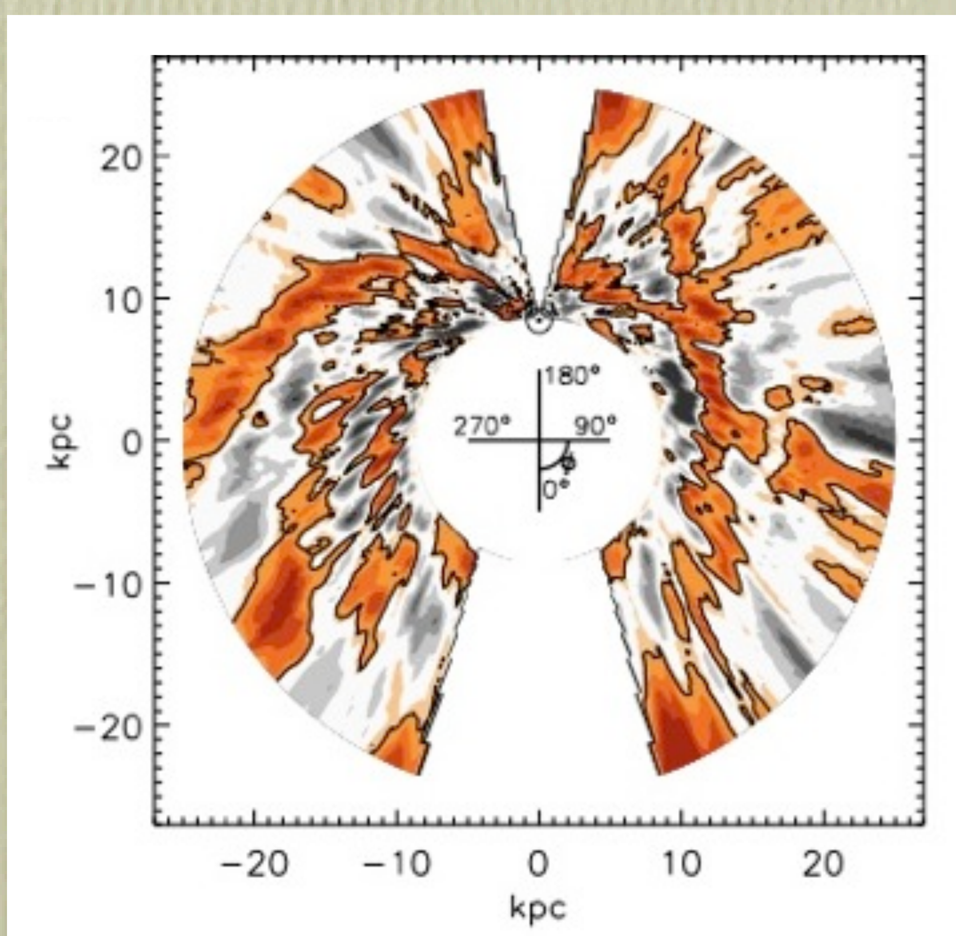
- Morphology
  - Scale heights
  - Scale lengths
  - Truncation?
  - Warp
  - Flare
  - Corrugations
- Features
  - Spirals
  - Bar(s)
  - Streams

Morphology

Overall appearance: Gas



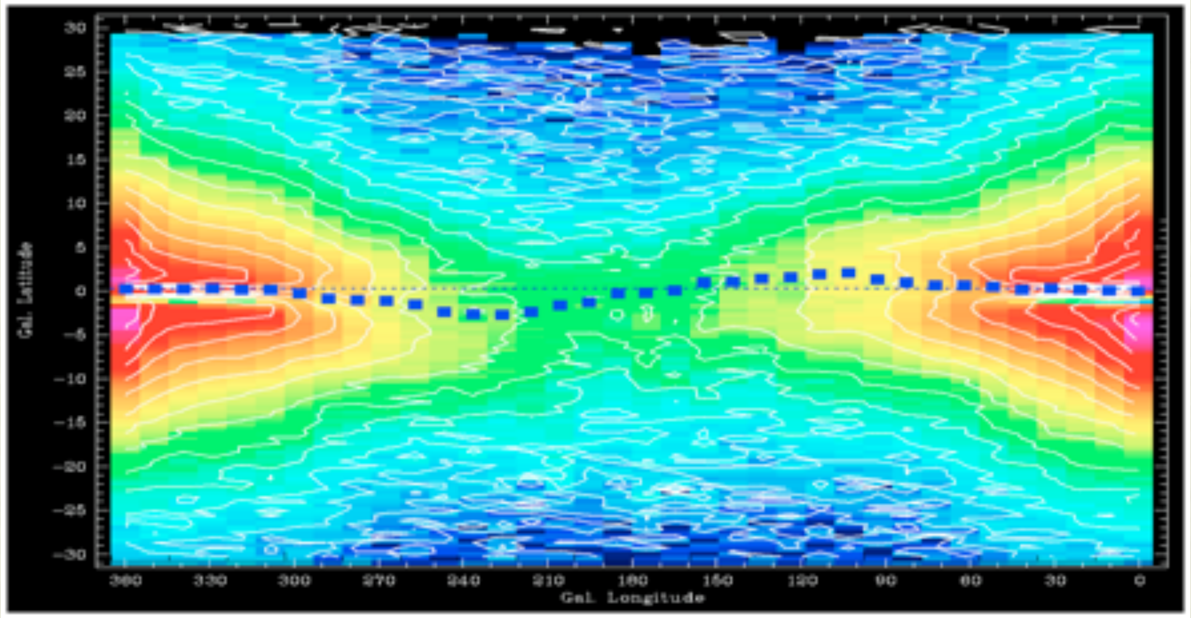
Dame et al. 2001



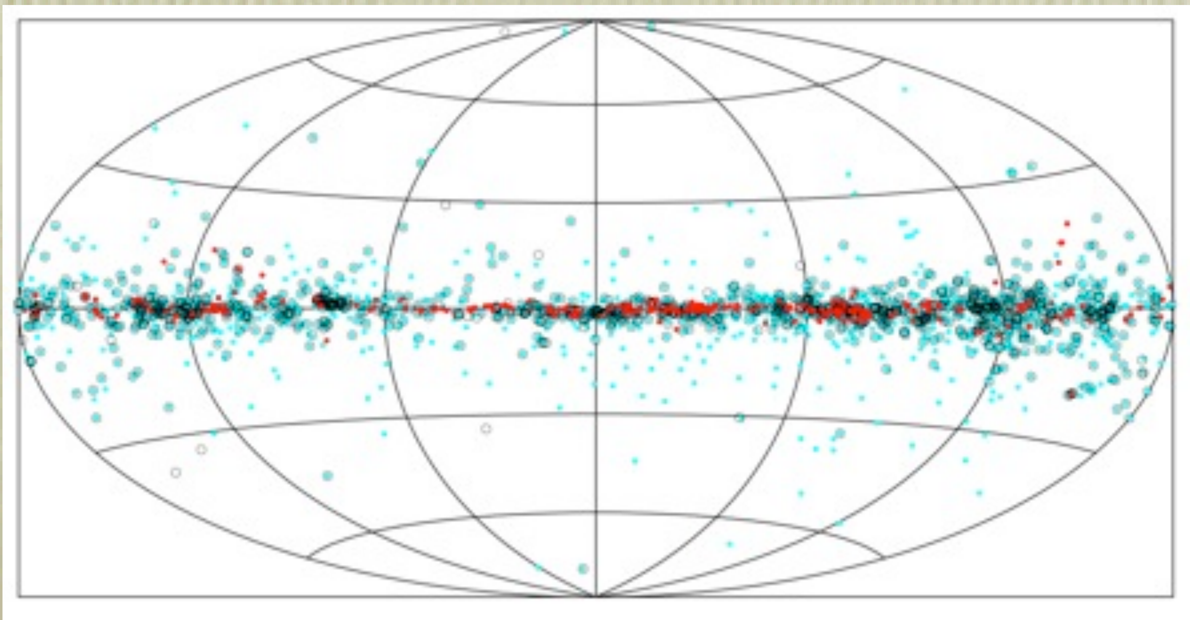
Levine et al. 2006

- HI: R> 25 kpc
- CO: Thin and fragmented

Overall appearance: Stars

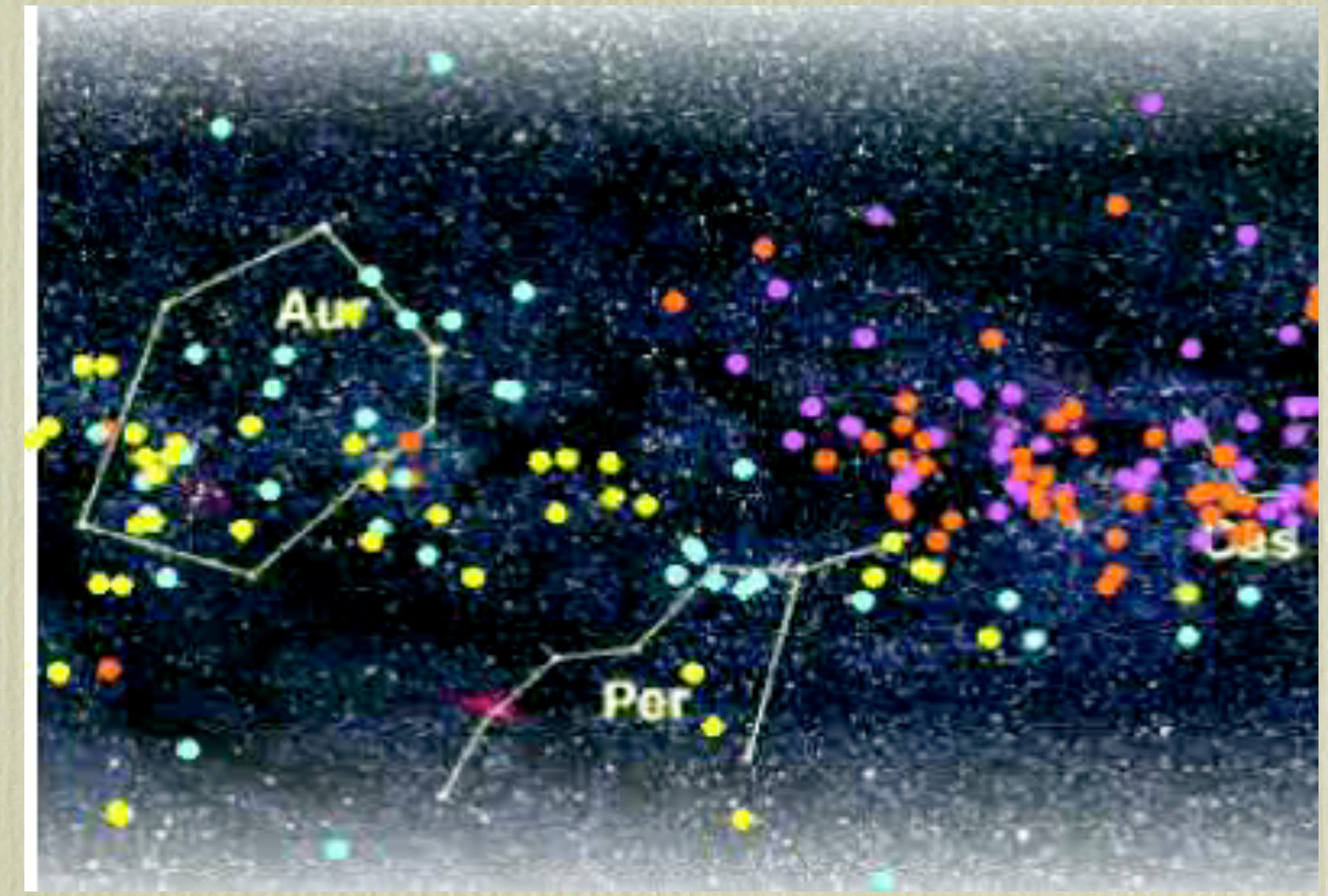


Momany et al. 2006



- Star counts
  - Pro: Infrared counts less affected by extinction
  - Pro: Statistics. There are lots
  - Con: Distances and reddenings not too precise.
  - Con: Interpretation often model dependent
- Clusters - Optical (& NIR)
  - Pro: Precise distances and ages. Unique chronometer over a wide time interval
  - Con: Very limited distance range (for the moment)

Selection effects



- Must really keep in mind that extinction will affect determination of Disc structural parameters when using optical observations:

  Cluster imaging, stellar spectroscopy, ...

- Distribution of cluster reddenings
  - Low extinction windows in the 3GQ and 4GQ (Carina)
  - Lacking: study of variations in Rv

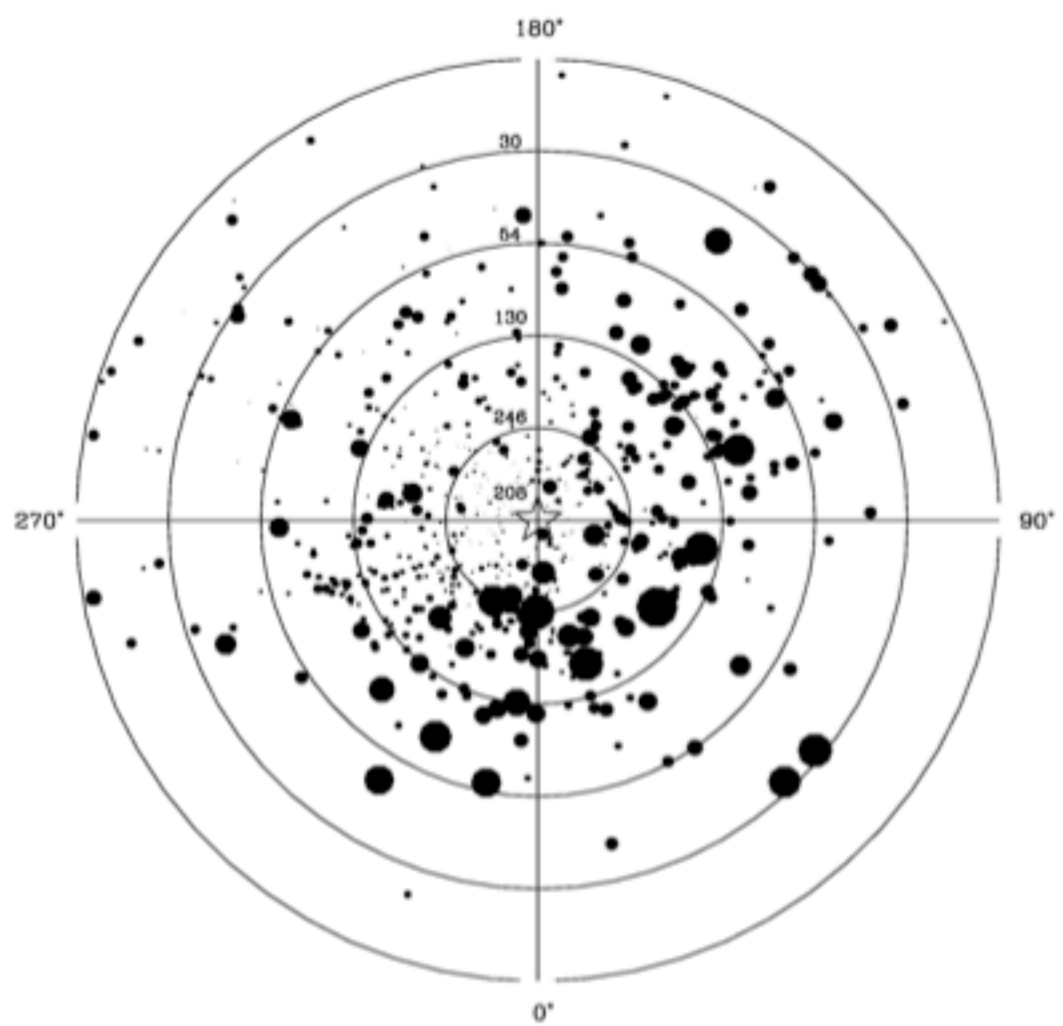
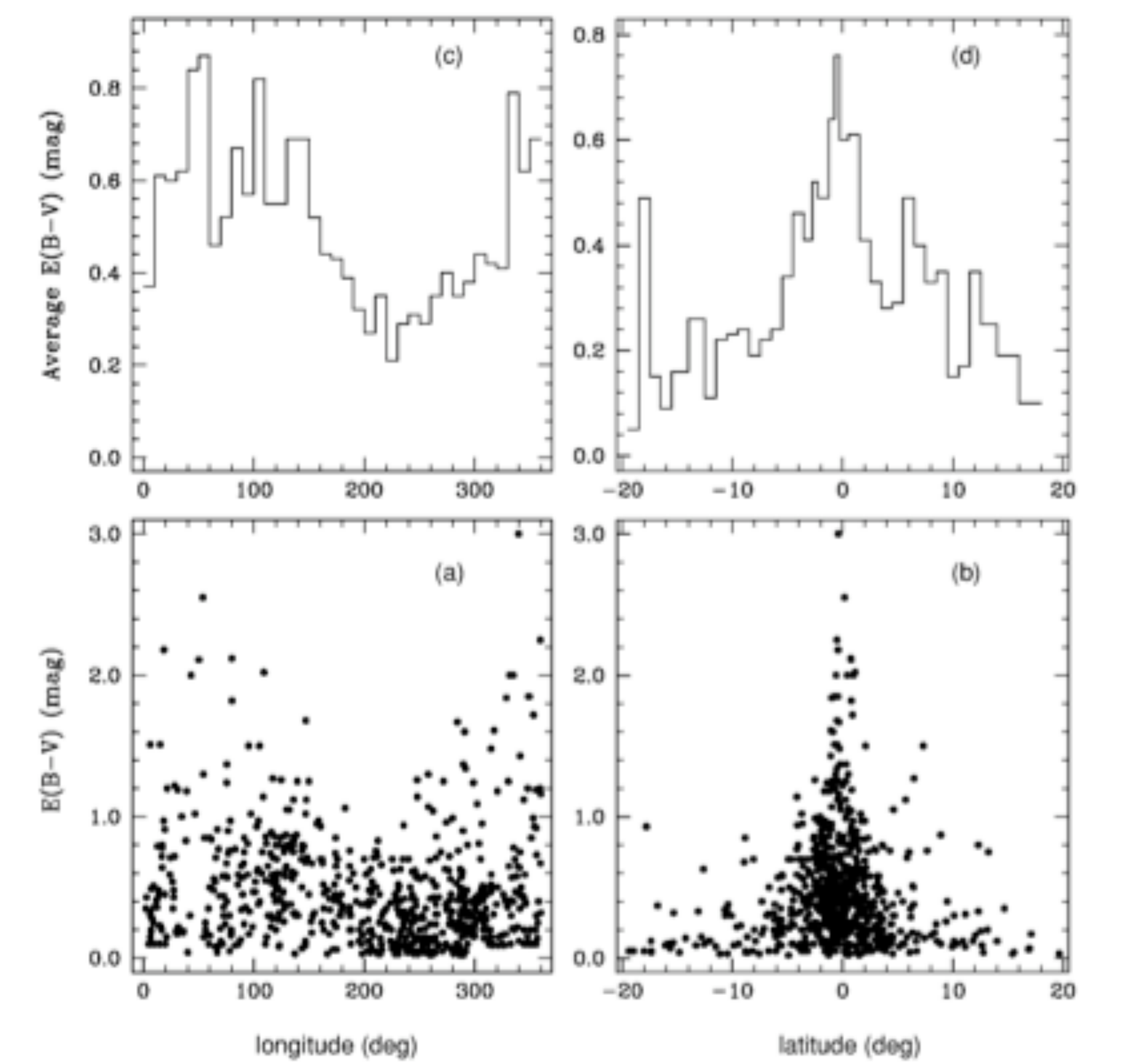
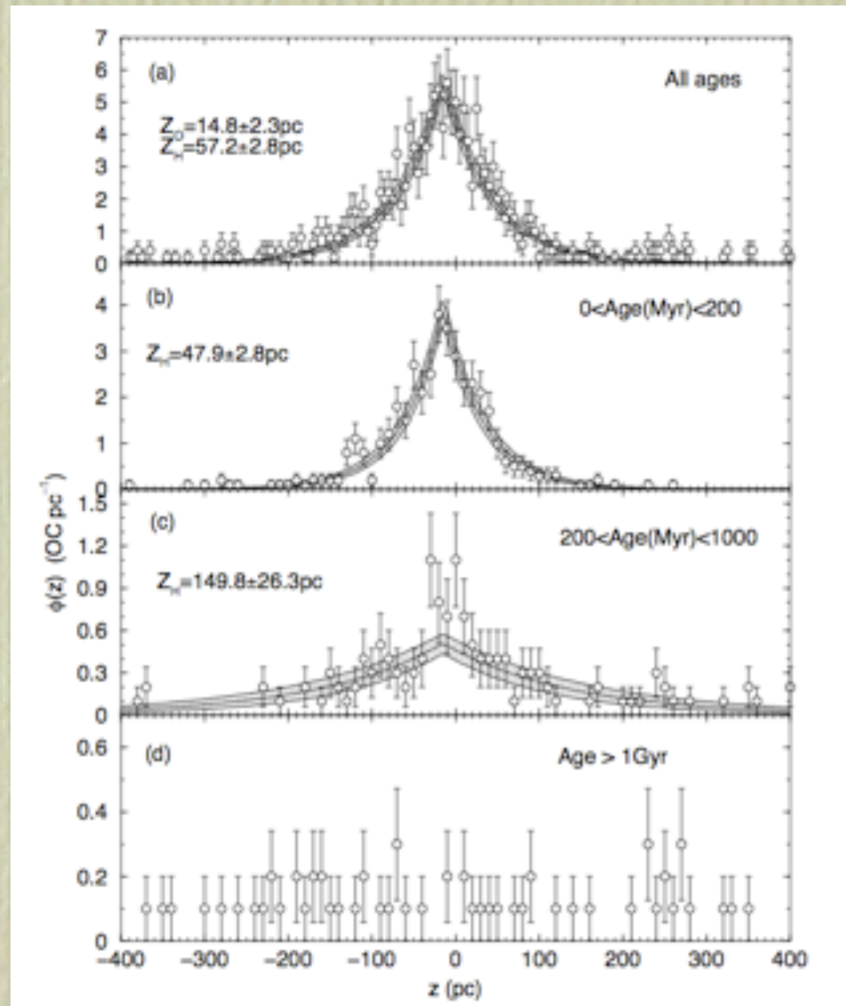


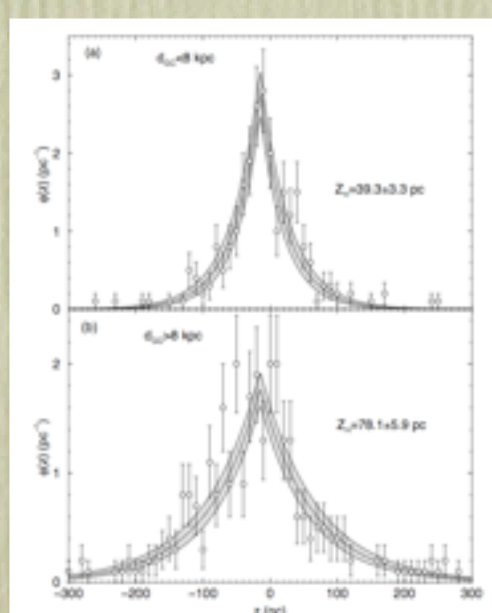
Figure 2. The distribution of open clusters as projected on the Galactic plane. Points are normalized to the extinction values such that the smallest and largest points denote $E(B-V) = 0.01$ and 2.55 mag, respectively. The position of Sun is shown by a star symbol at the centre. Five concentric circles at an equal distance of 1 kpc are drawn. The number of clusters in each distance bin are also given.



Joshi, 2005

Disc scale heights (SH)

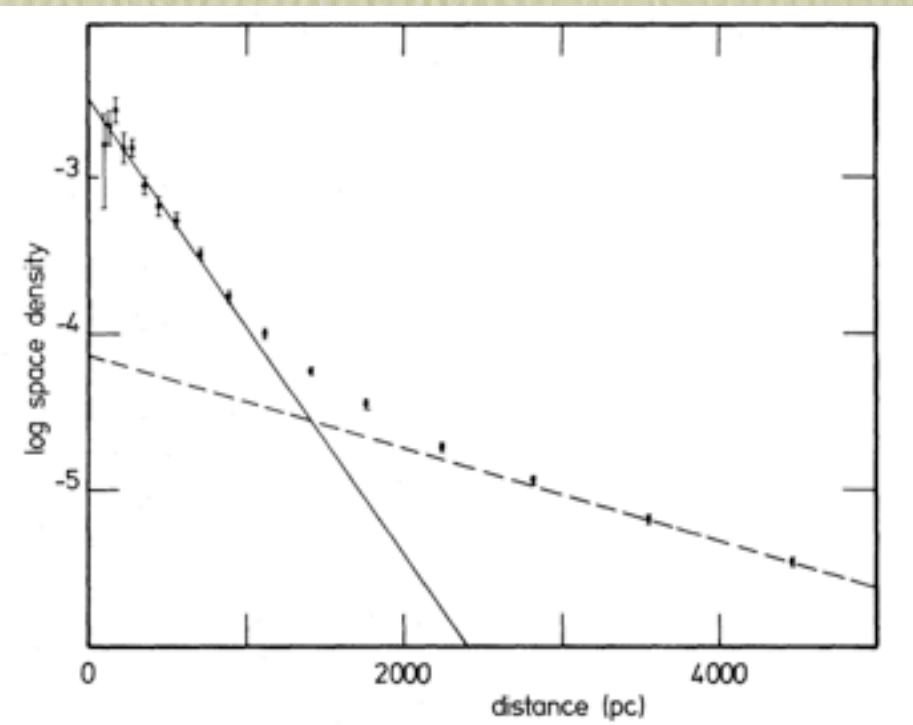




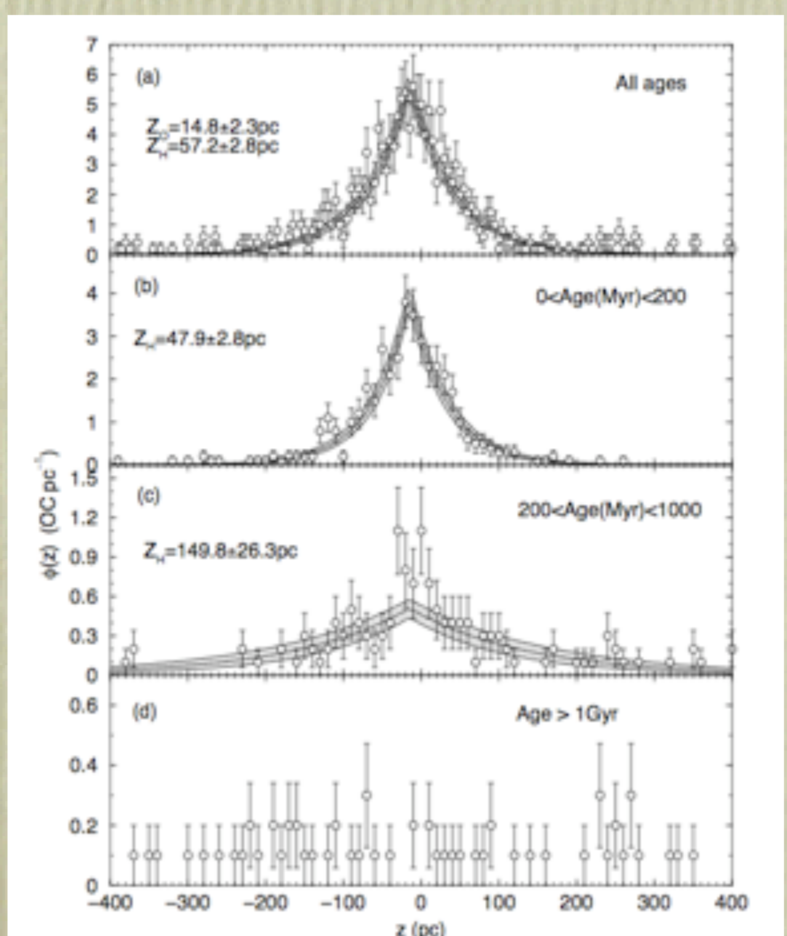
From Bonatto et al. 2006

- OB stars: 45 pc (Reed, 2000)
- Open clusters:
  - young: 47.9 pc
  - older: 149.8 pc
  - Young SH < Old SH
  - In SH < Out SH
  - Sun height ~15 pc (other studies 22 pc; 13-20 pc +/-4)
- HI: 140 pc
- Field stars: 300 pc

Disc scale heights (SH)



Gilmore & Reid 1983



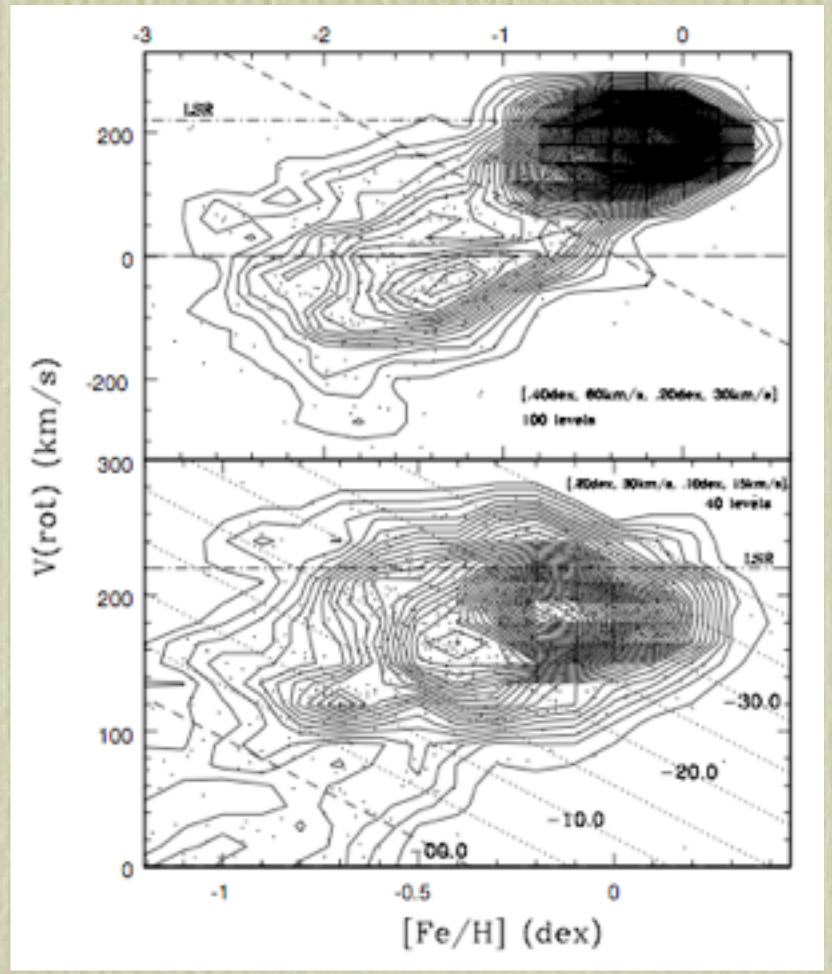
Bonatto et al. 2006

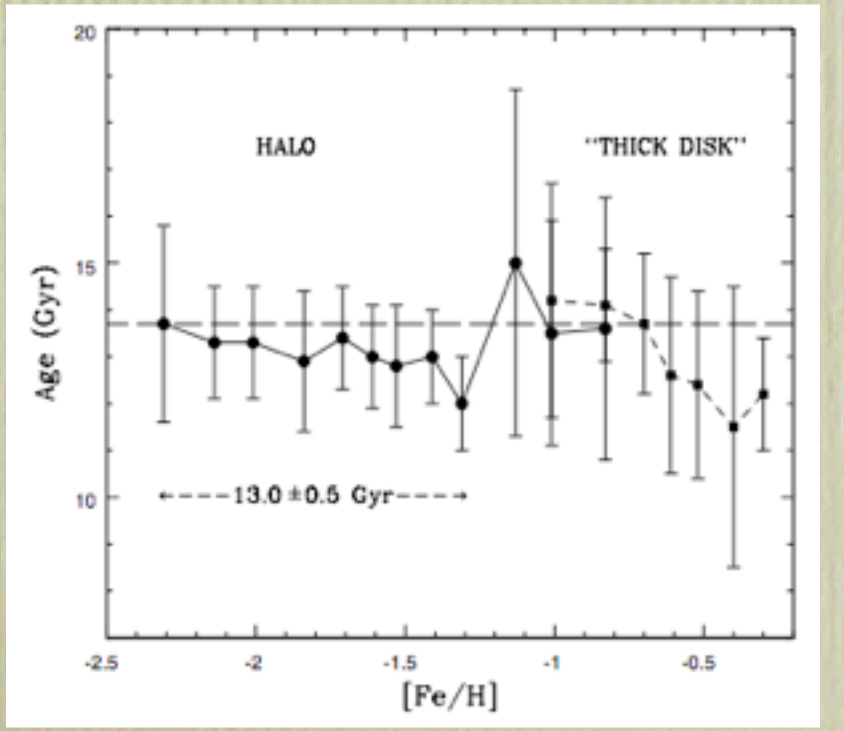
- Field stars
  - 300 pc - Thin Disc
  - 1350 pc - Thick Disc

(see Chang 2011, for a compilation)

- Cluster SH much smaller than stars (48-150 vs 300 pc)
  - Signature of original scale heights? (young vs old)
  - Heating of cluster orbits?
  - Signature of disruption close to plane?
  - If thick disk forms from OC popping (Kroupa 2002) then TD OCs should not exist (except if captured).

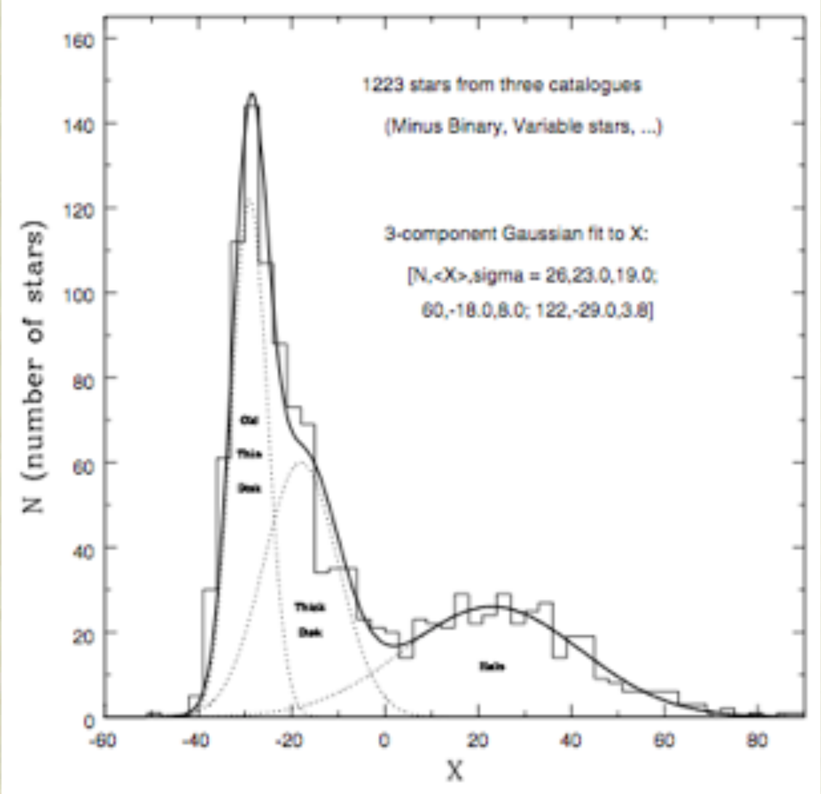
Thick Disc



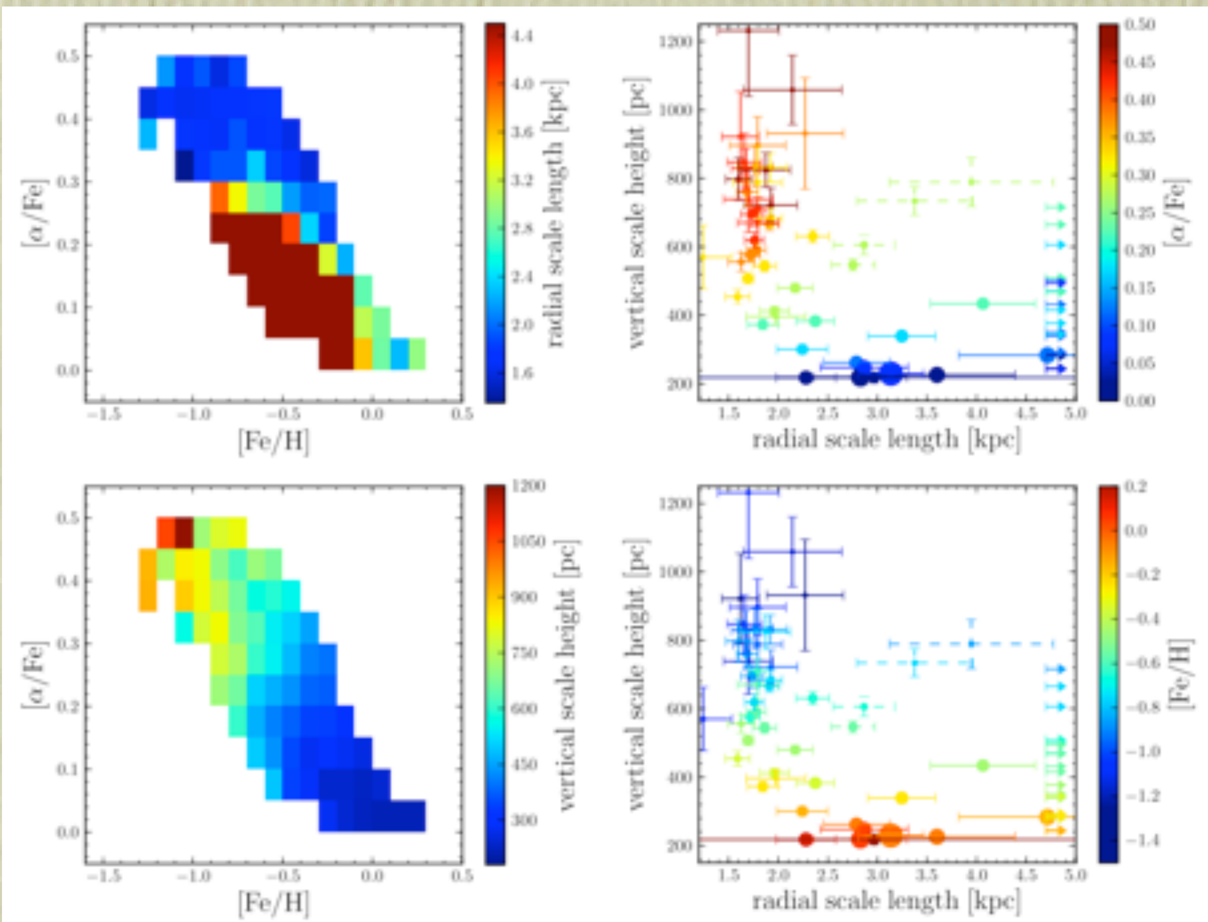


Schuster et al. 2006

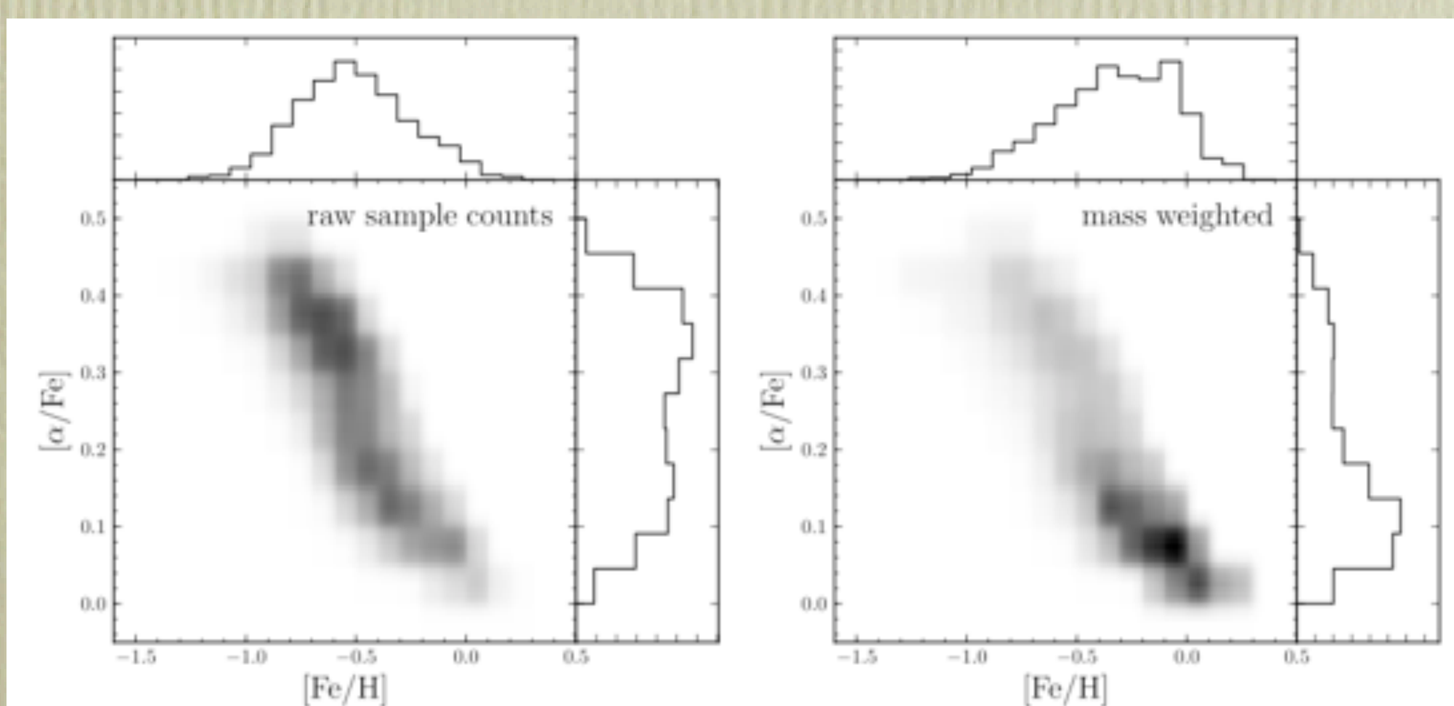
- Evidence for:
  - Different kinematics
  - Different abundances
  - Different ages
  - Substructure?



Thick Disc



Bovy et al. 2011

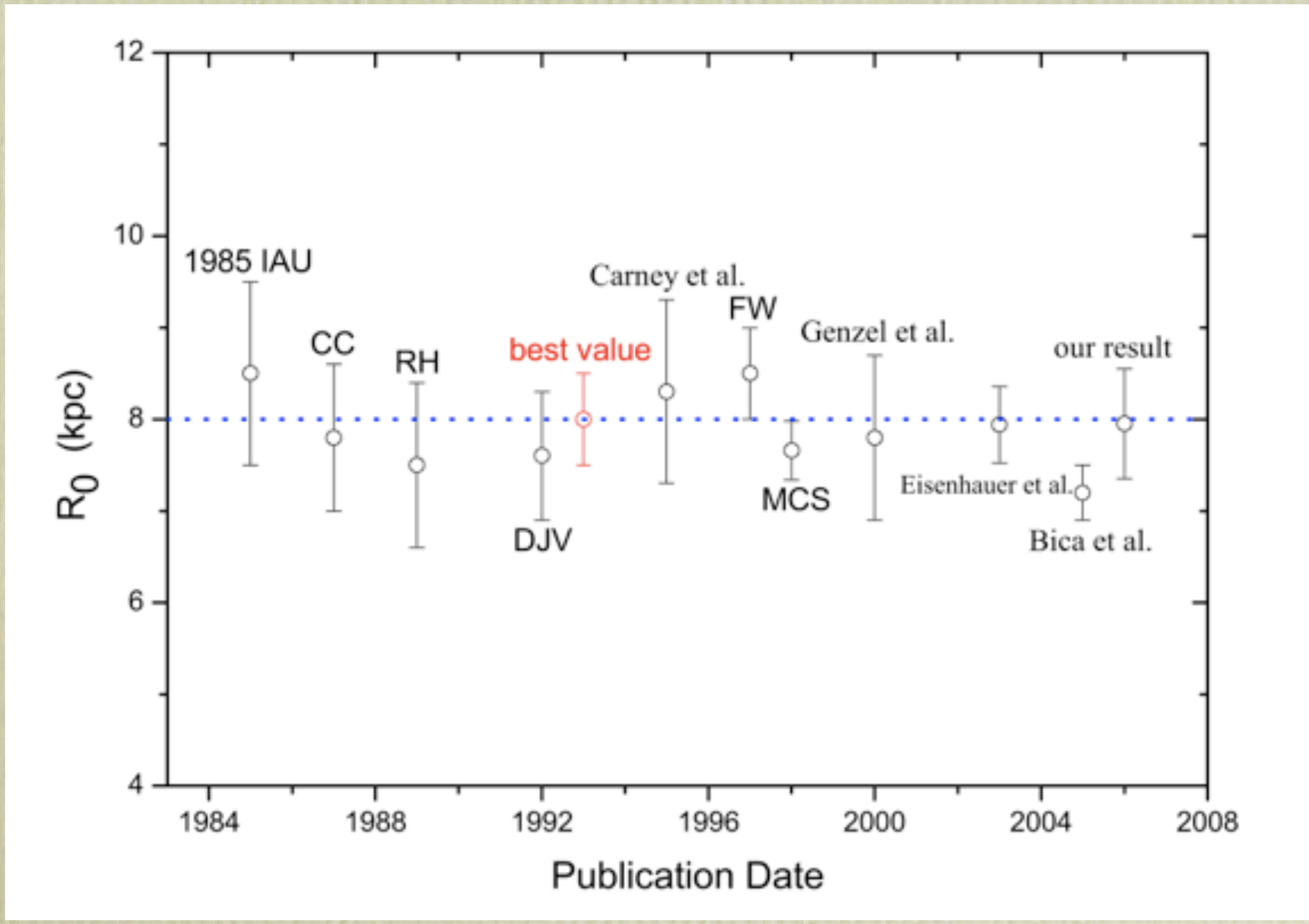


- However:
  - New claims that distribution of SH of mono abundance samples doesn't show a break
  - Bi-modality as a sample selection effect?
  - Have served as base for challenging thick disc as an independent structure

Bovy et al. 2012

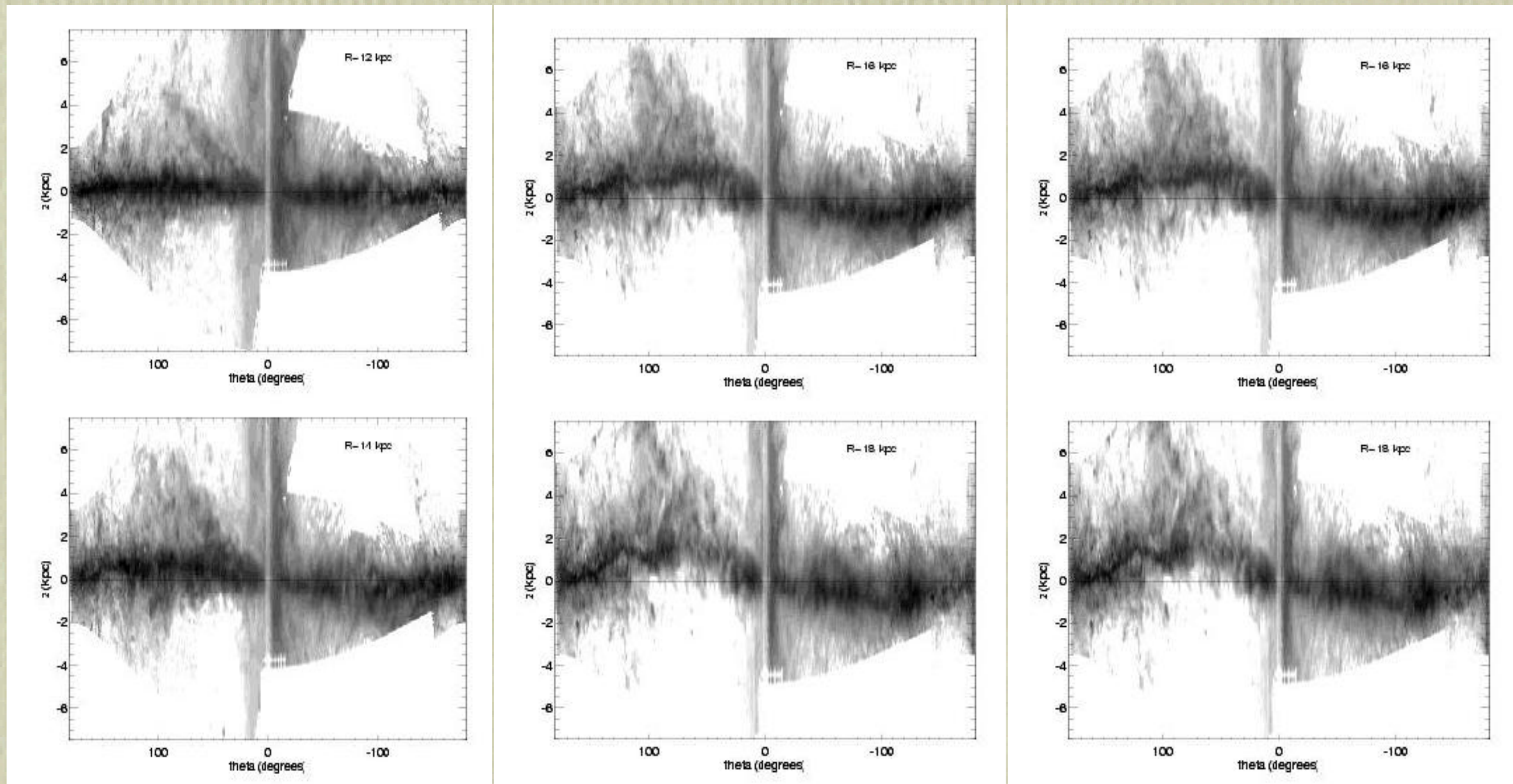
Distance to Galactic Center

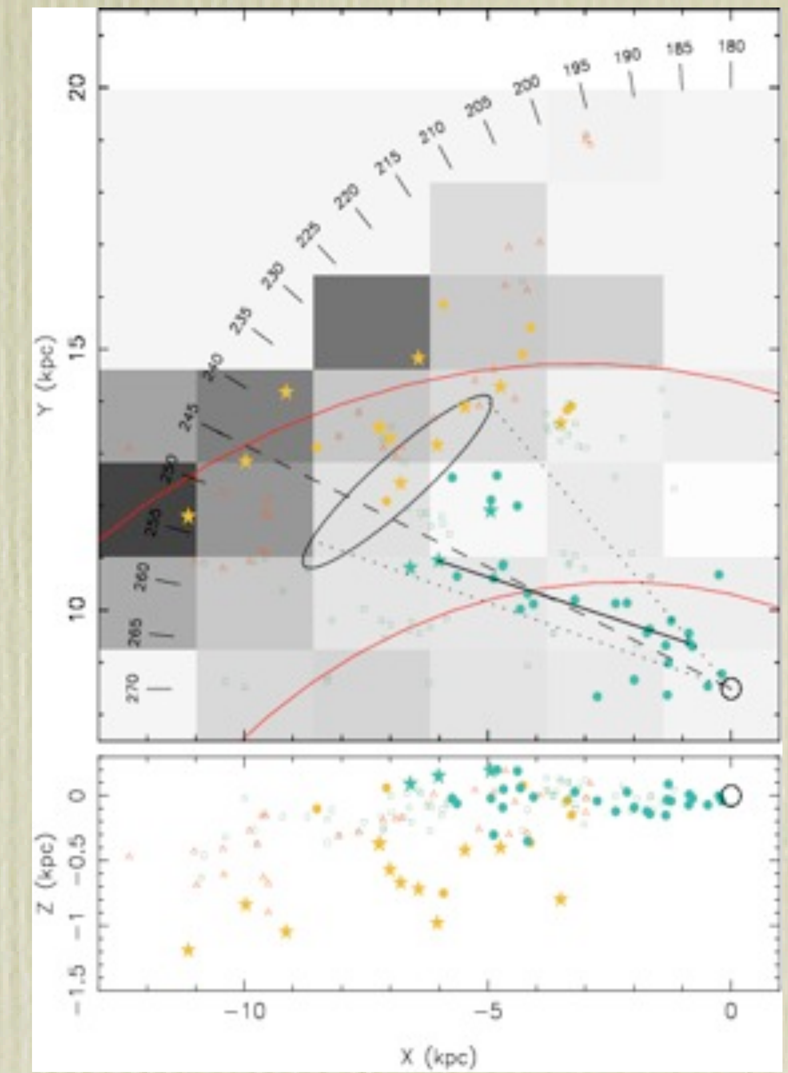
- Shen et al. (2007) from kinematics of 301 OCs < 3 kpc. Agreement with OB stars (7.95 vs 8.25 +/- 0.7 kpc).
- Meta study by Malkin (2012): 7.98±0.15 |stat ±0.20 |syst kpc



Shen et al. 2007

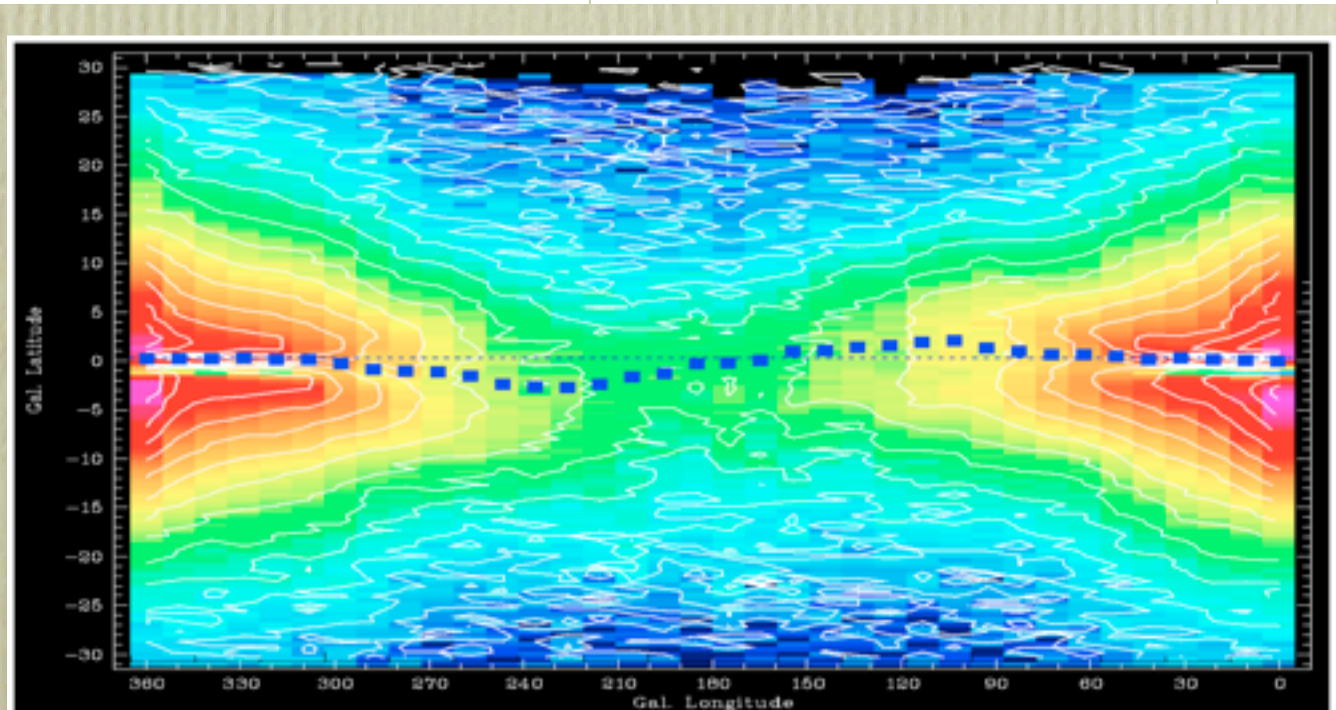
Warp and Flare





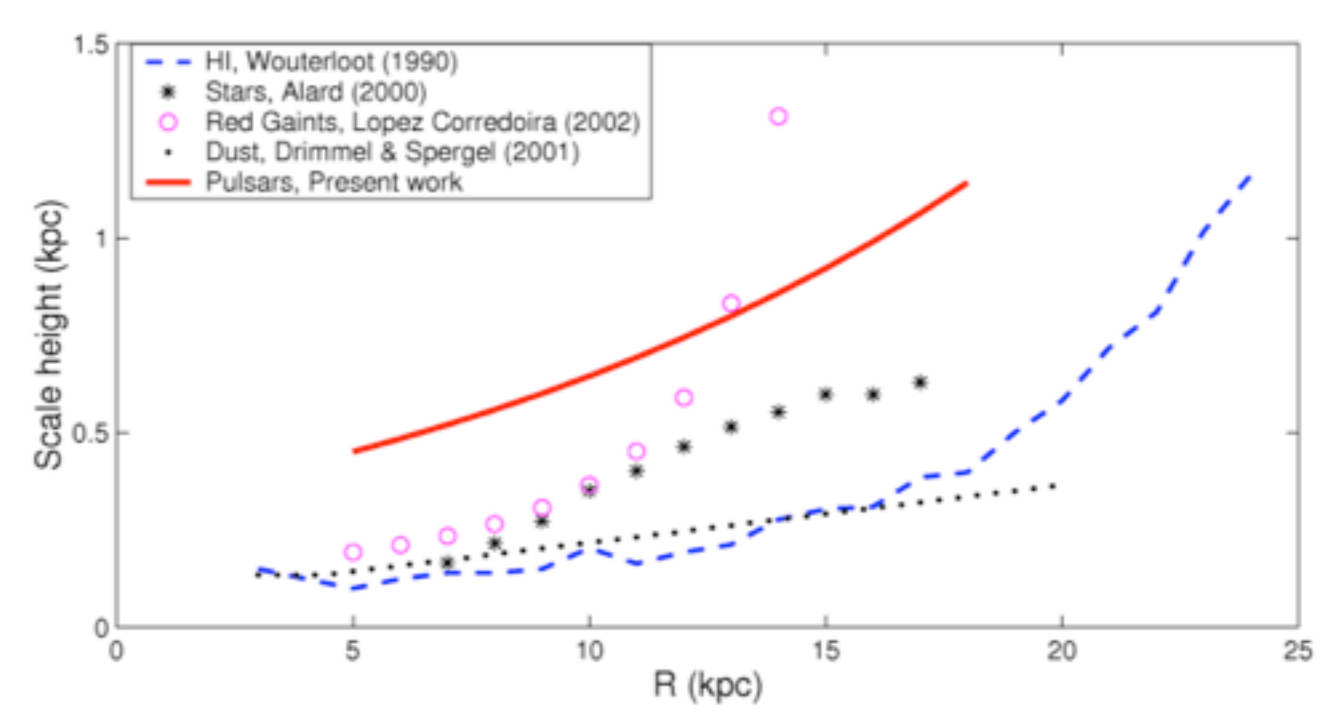
Voskes 1999

Moitinho et al. 2006

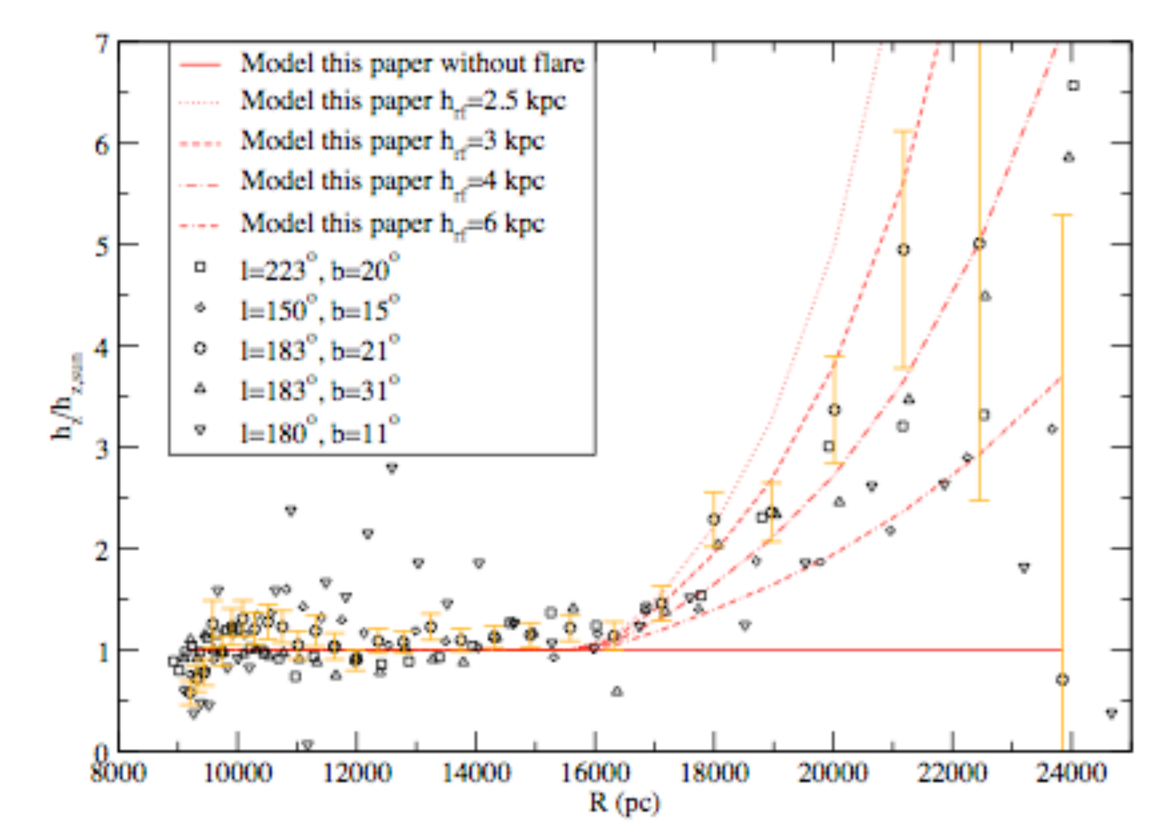


Momany et al. 2006

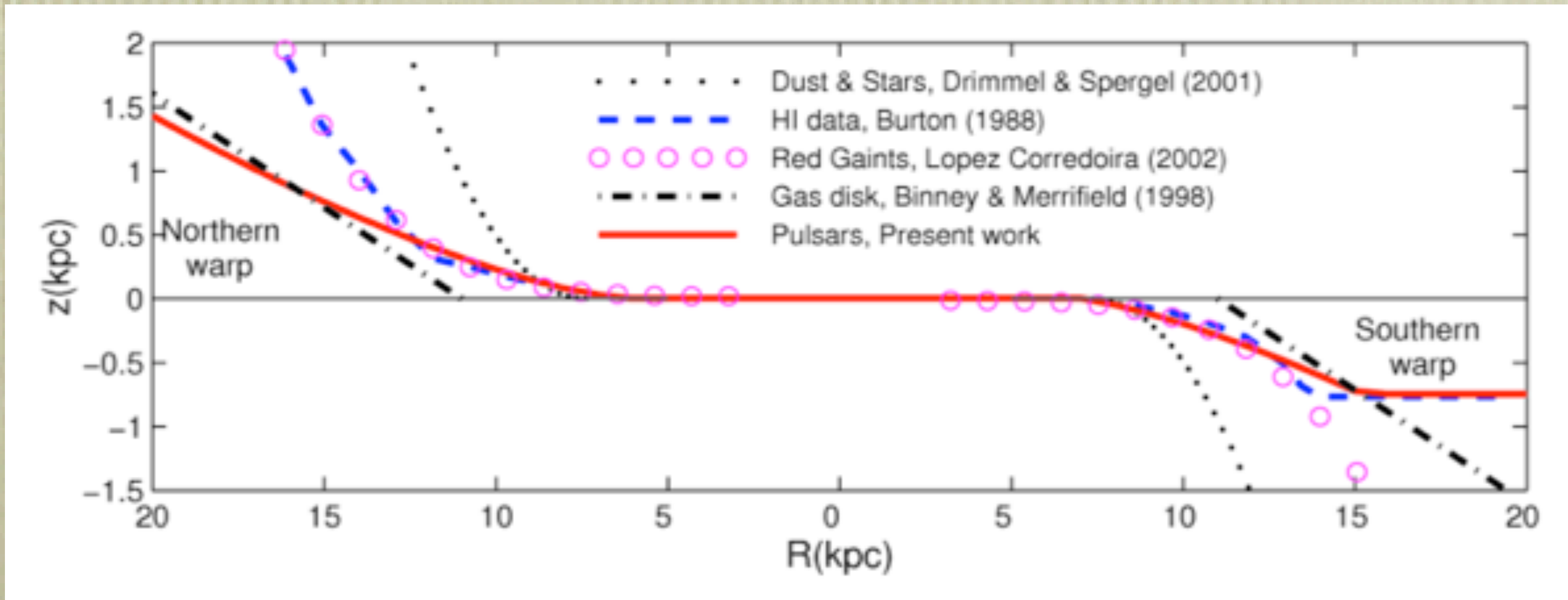
Warp & Flare



Yousifov 2004

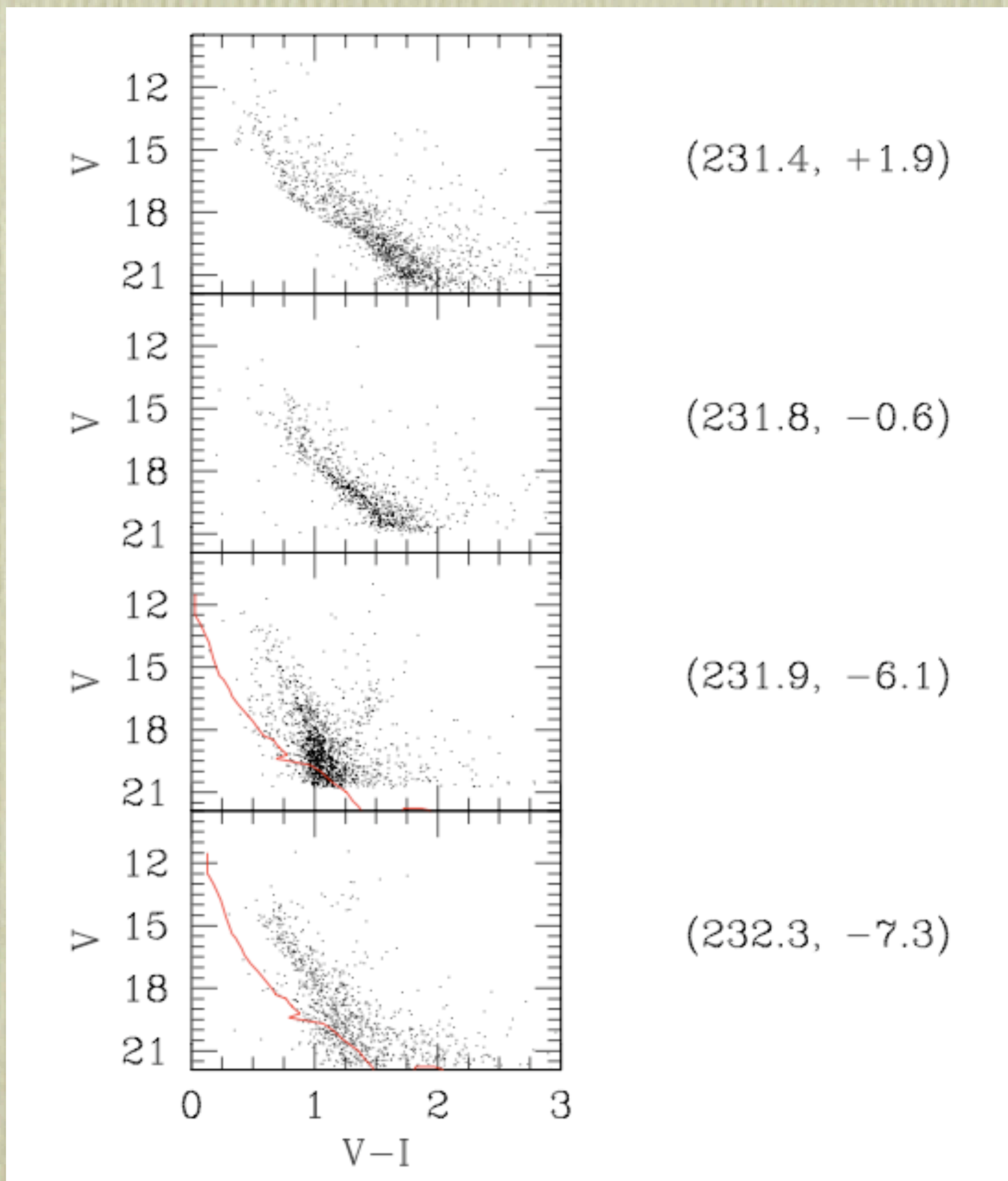


Hammersley & López-Corredoira. 2011

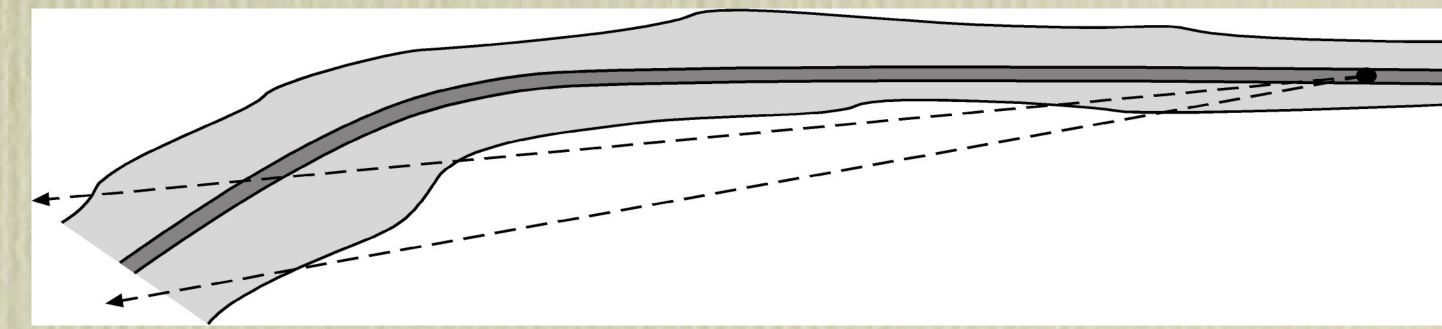


- Disc is not truncated at RGC ~ 12.5-15 kpc
- Illusion caused by the Warp and Flare

Seeing the Milky Way face-on



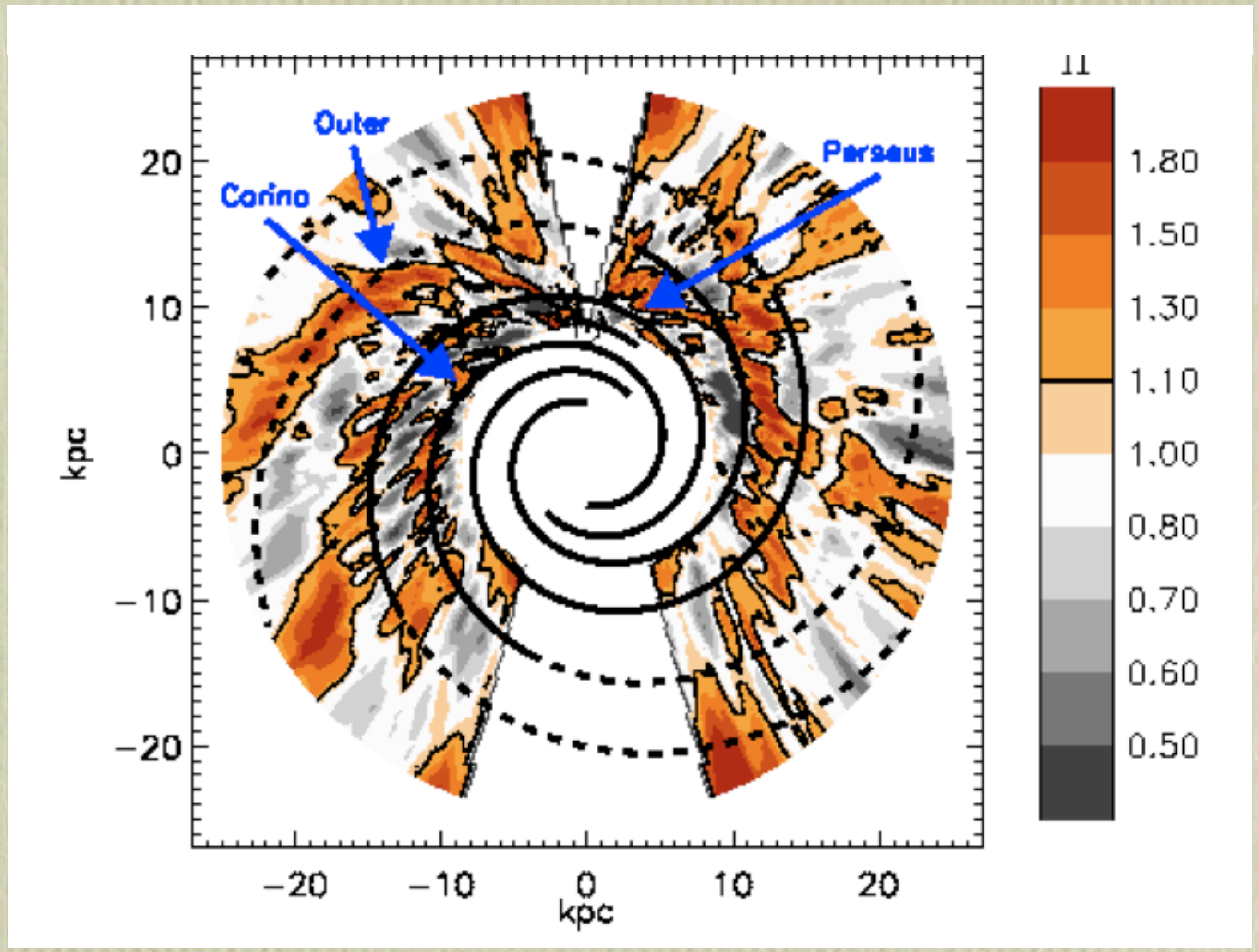
Carraro et al. 2007



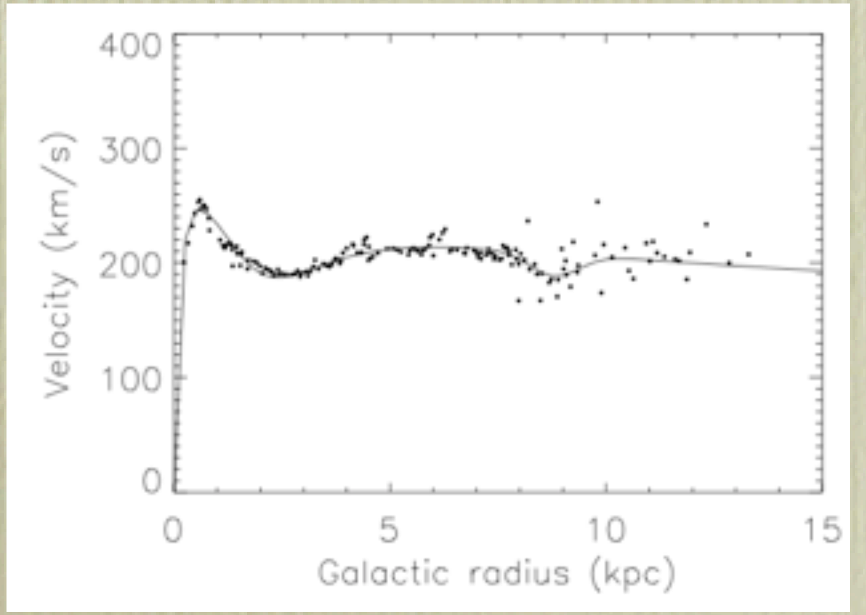
- Photometric signature of the old metal-poor disc population (Thick Disc)
- Not all fields show TD hump

Spiral Structure

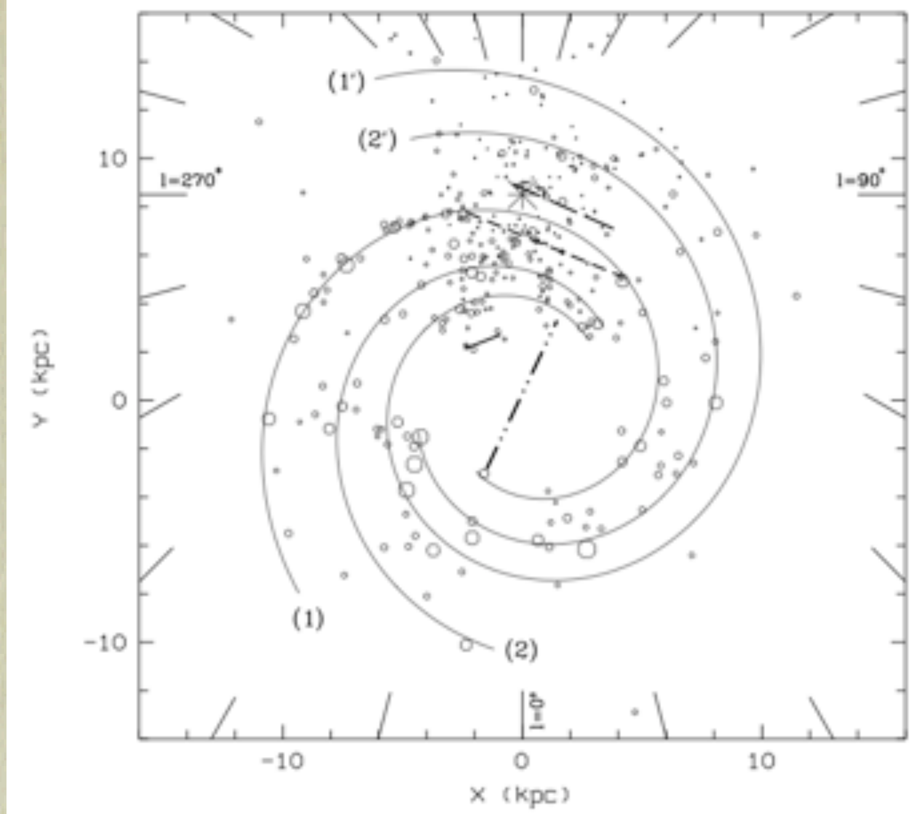
Hi, YOCs, SFR



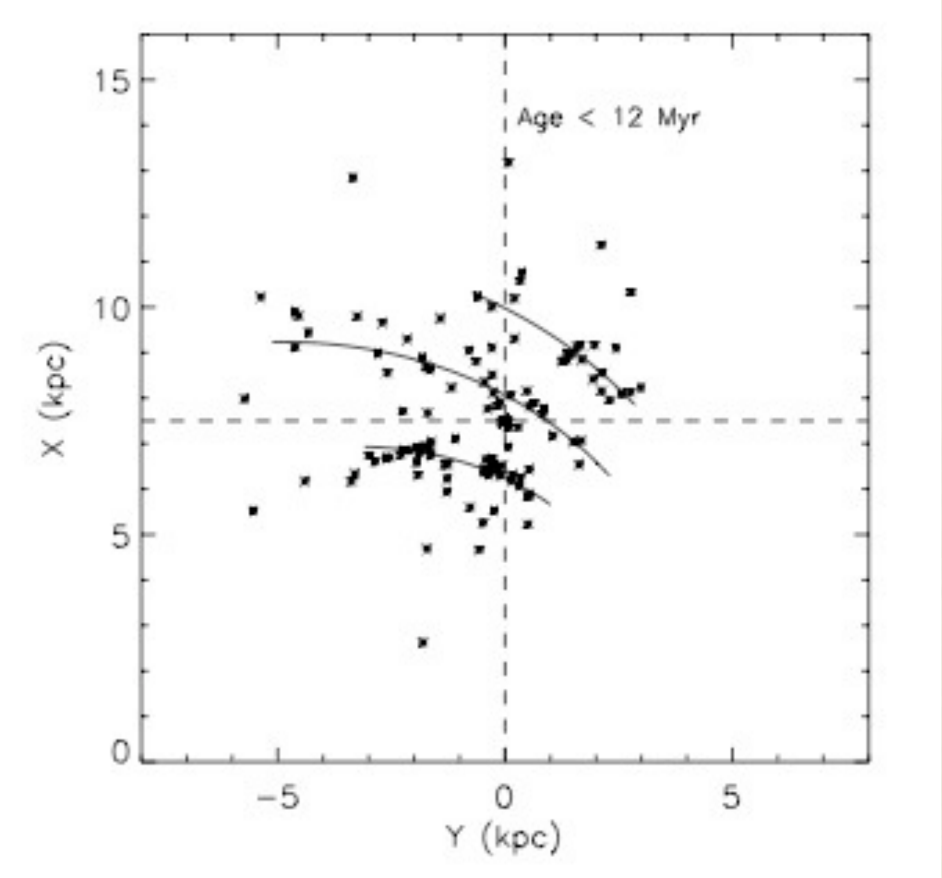
Levine et al 2006



Amôres et al. 2009

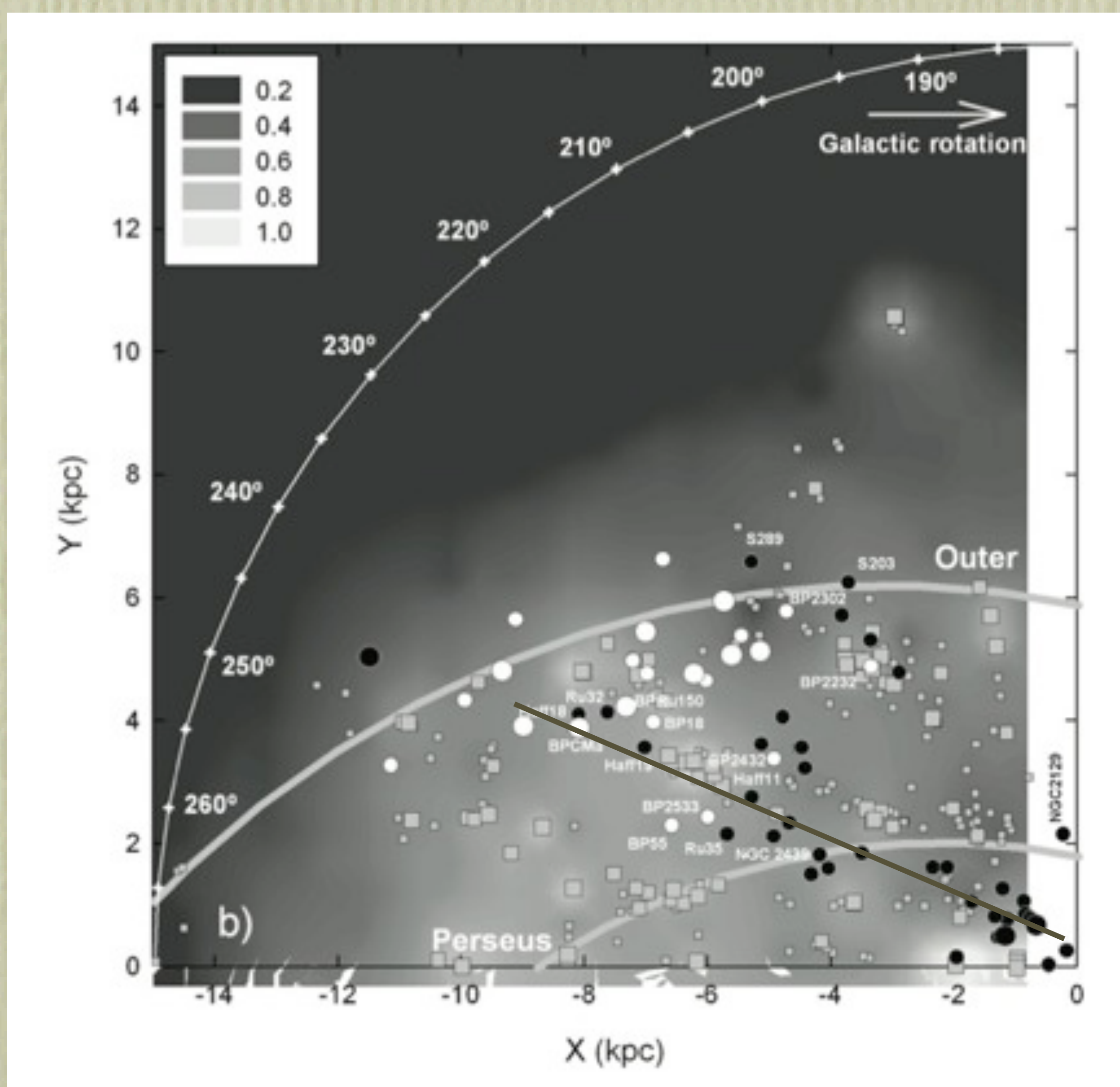


Russeil 2003



Dias & Lépine 2005

- Perseus not traced by YOCs in the 3GQ (but, some YOCs in the right place in the 4GQ)
- Norma-Cygnus defined over the 3GQ up to 20 kpc RGC
- The Local arm reaches the Norma arm

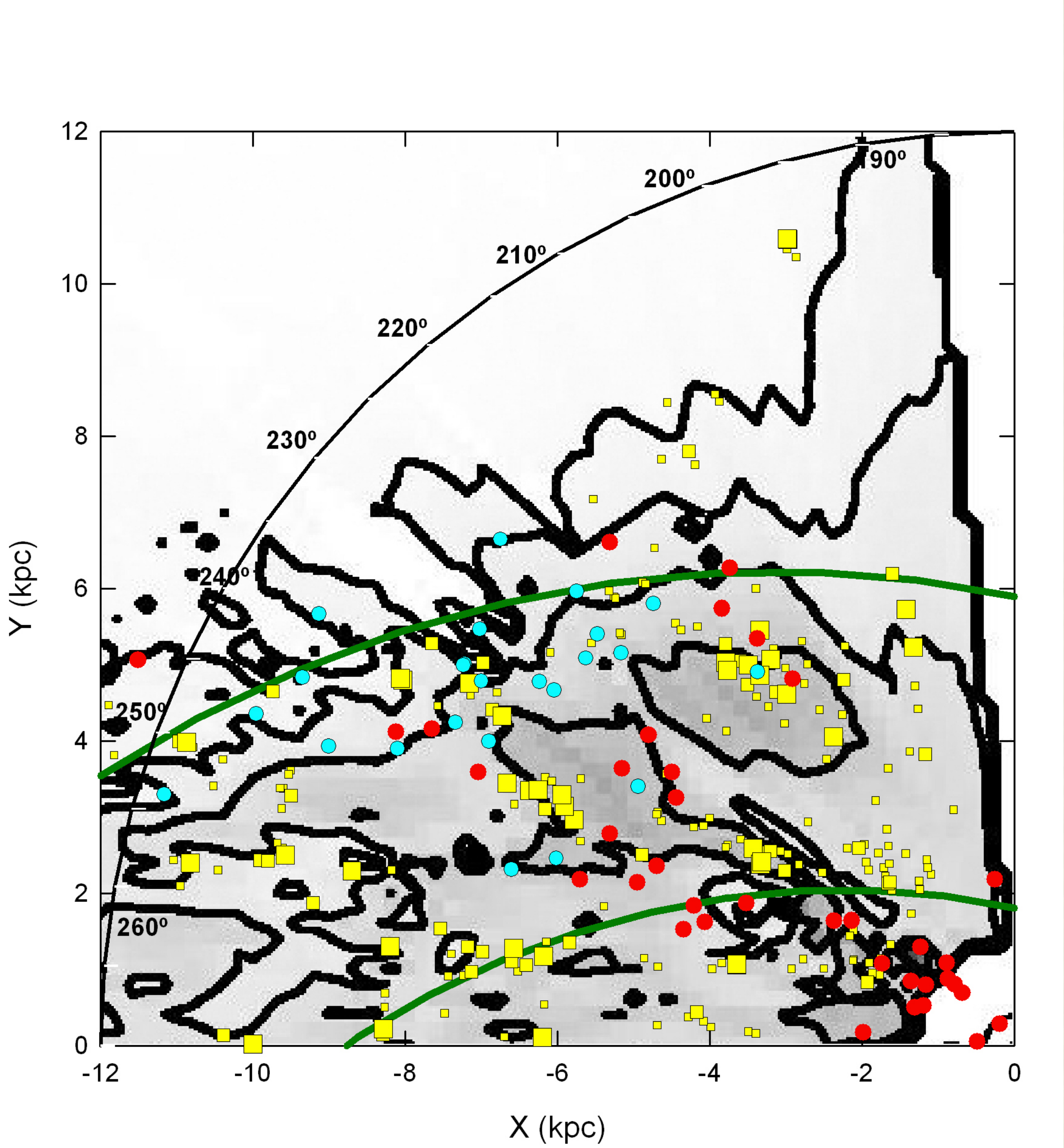


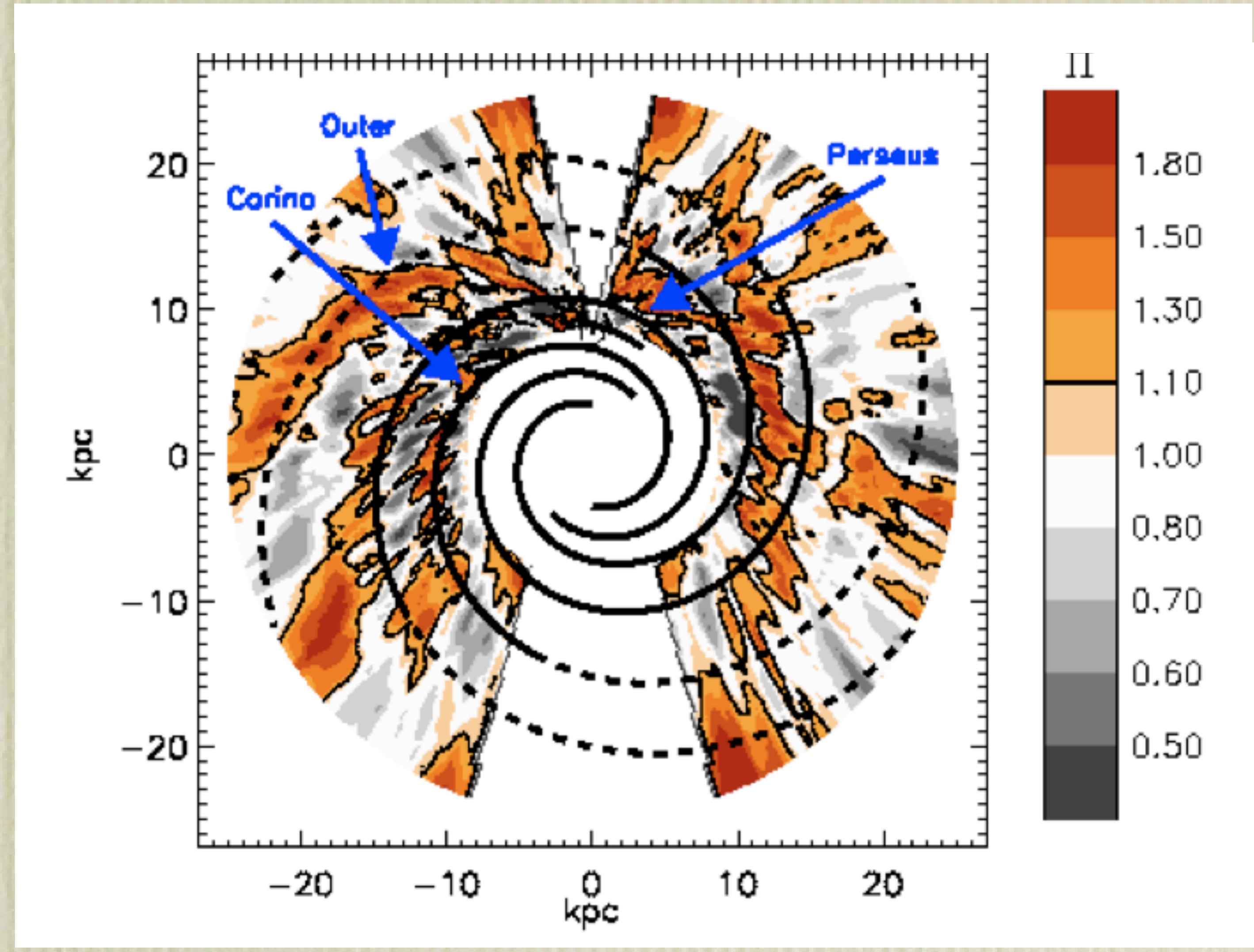
Vázquez et al 2008

M74

The Local/Orion arm

- HI structure is real and also traced by YOCs and BPs

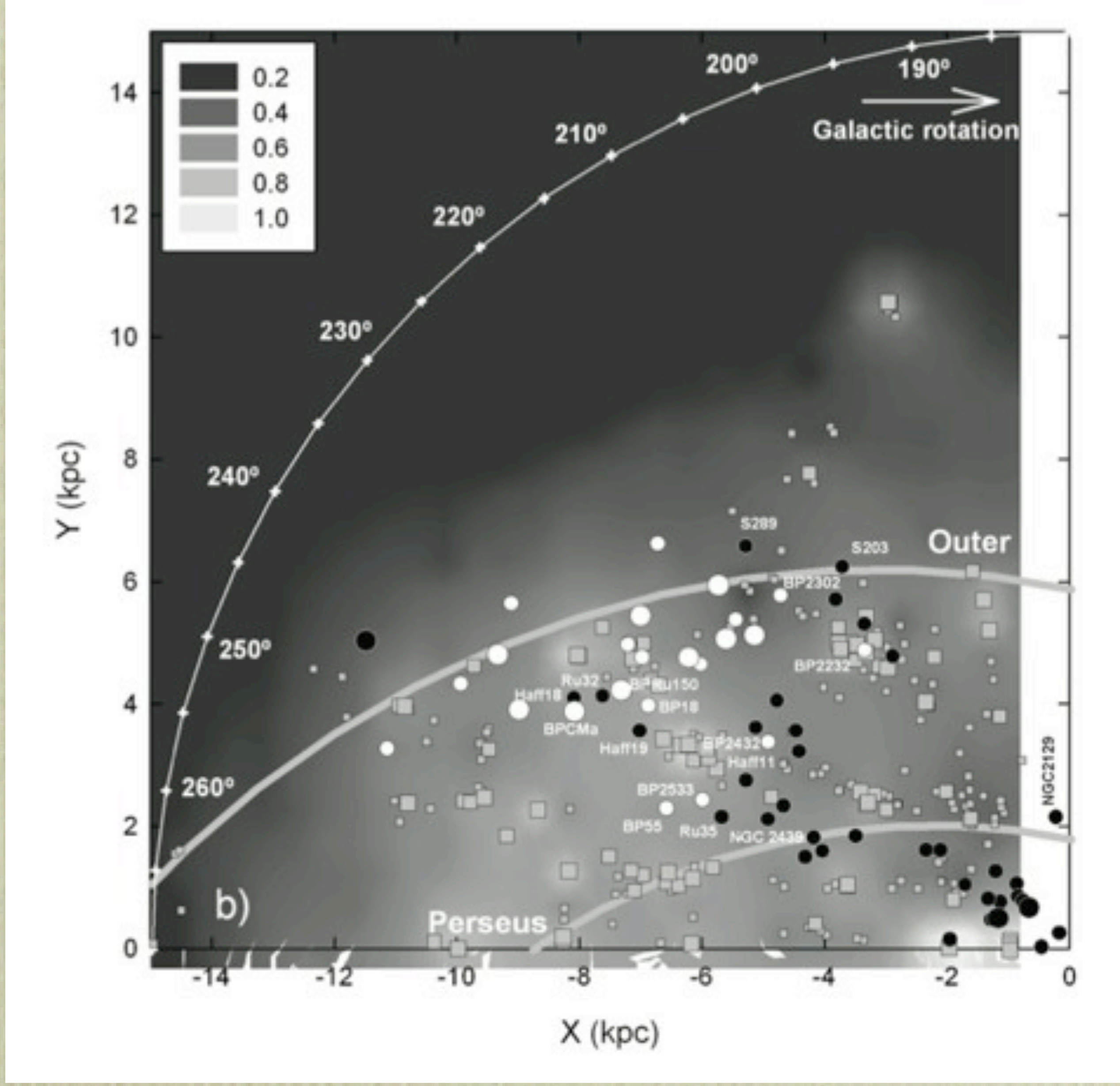




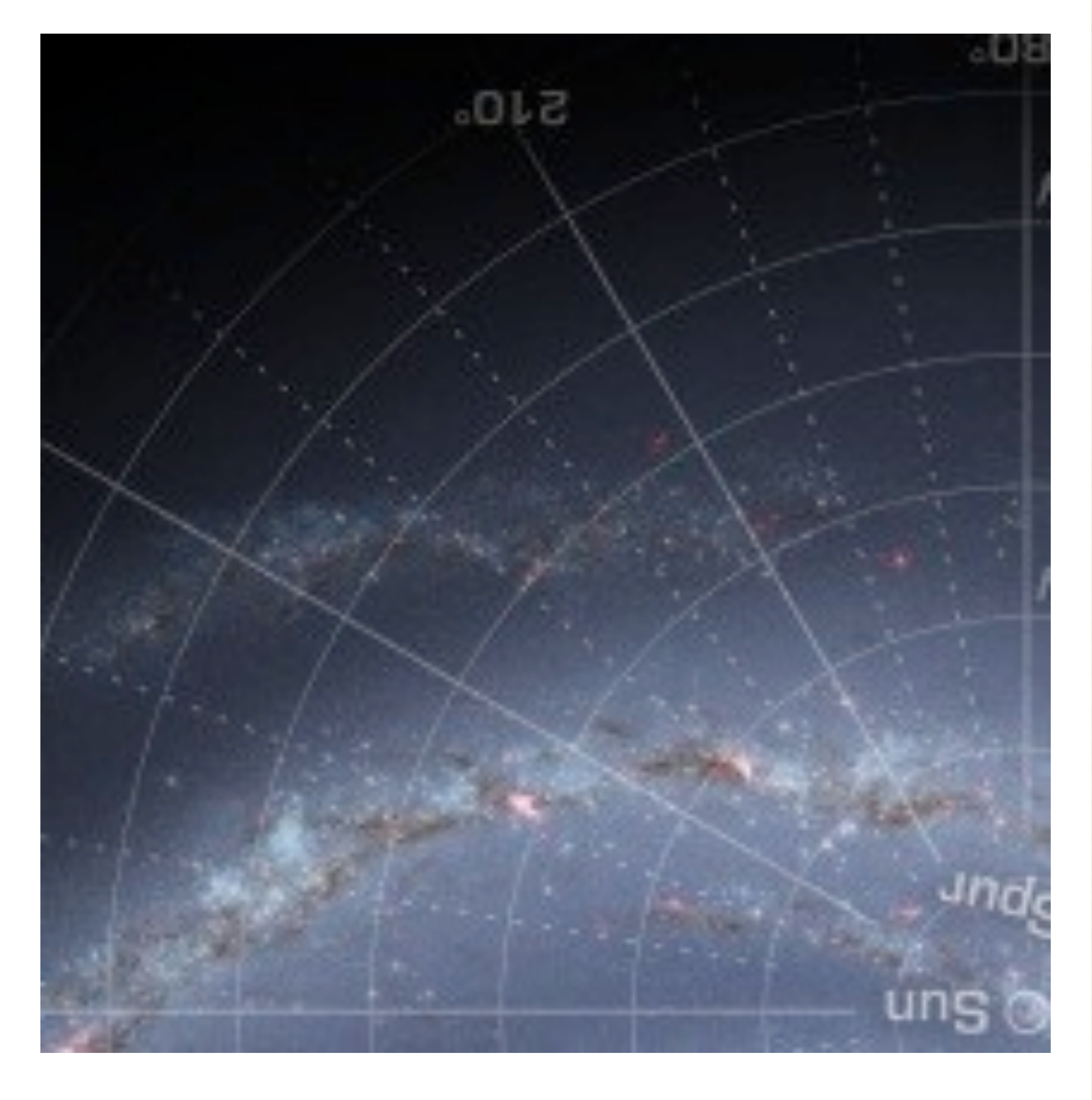
Levine et al 2006

Nakanishi & Sofue 2003

GLIMPSE extrapolation does not agree with stellar data in the 3GQ



Vázquez et al 2008



Credit: R. Hurt 2008

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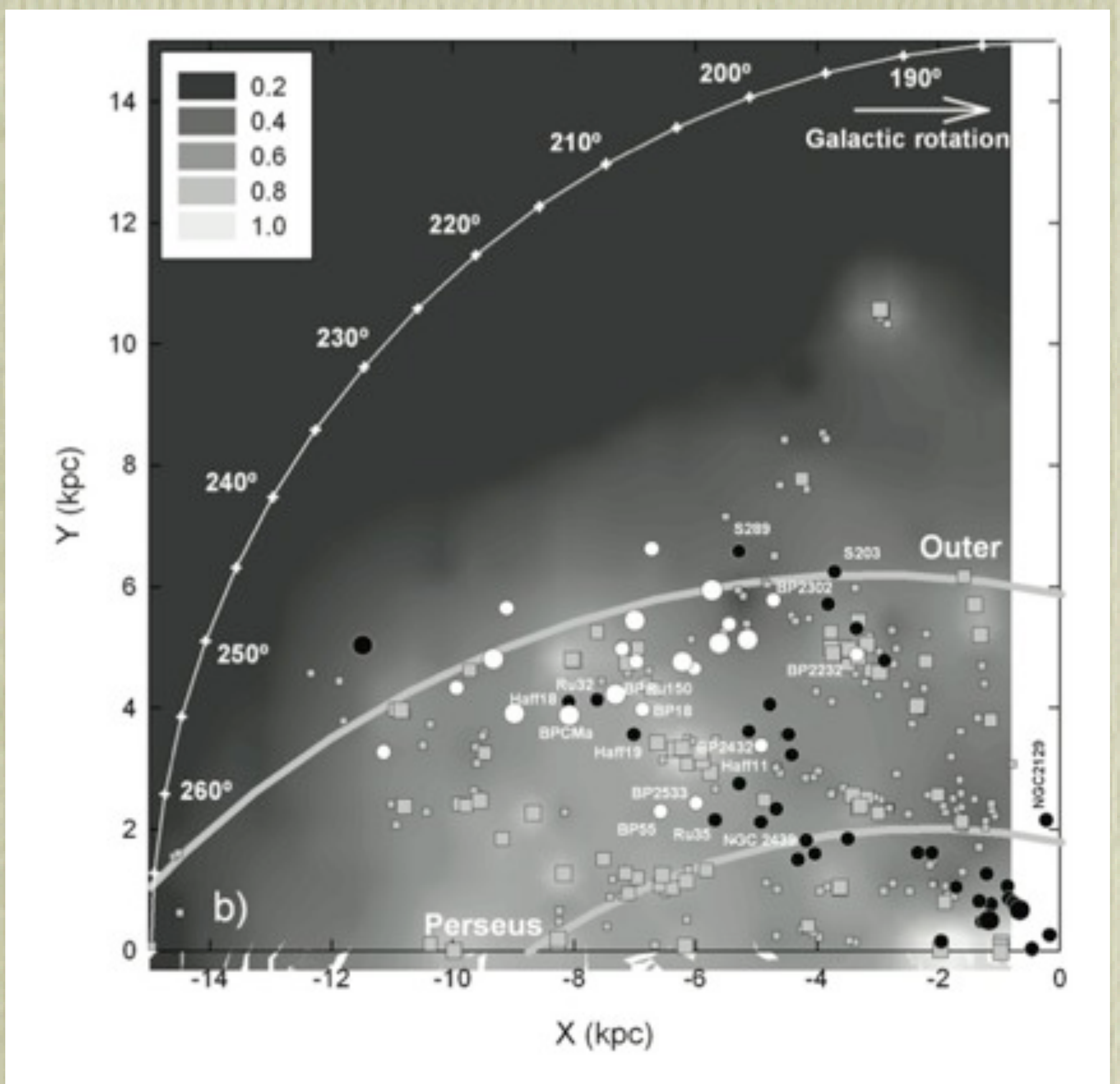
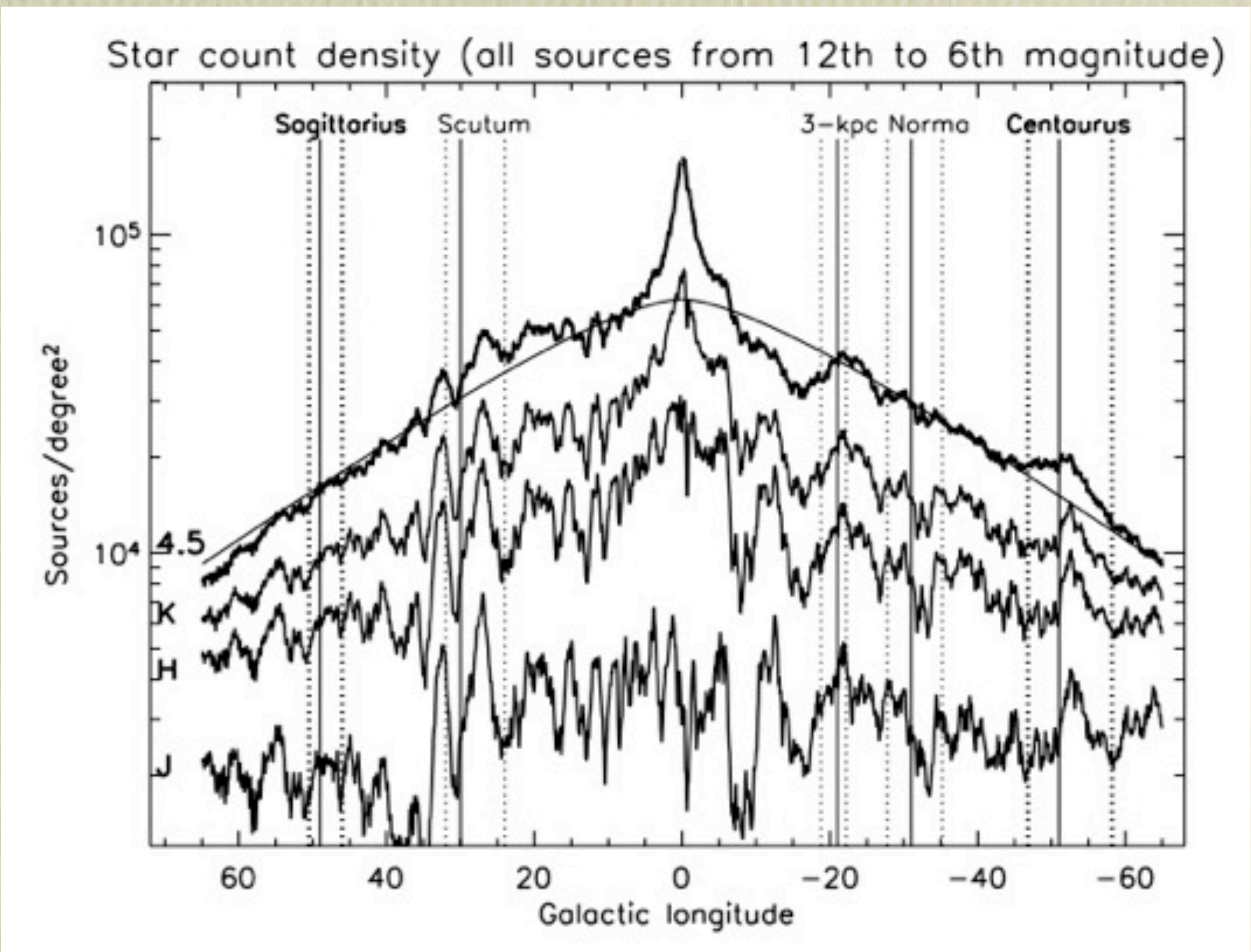


Vázquez et al 2008

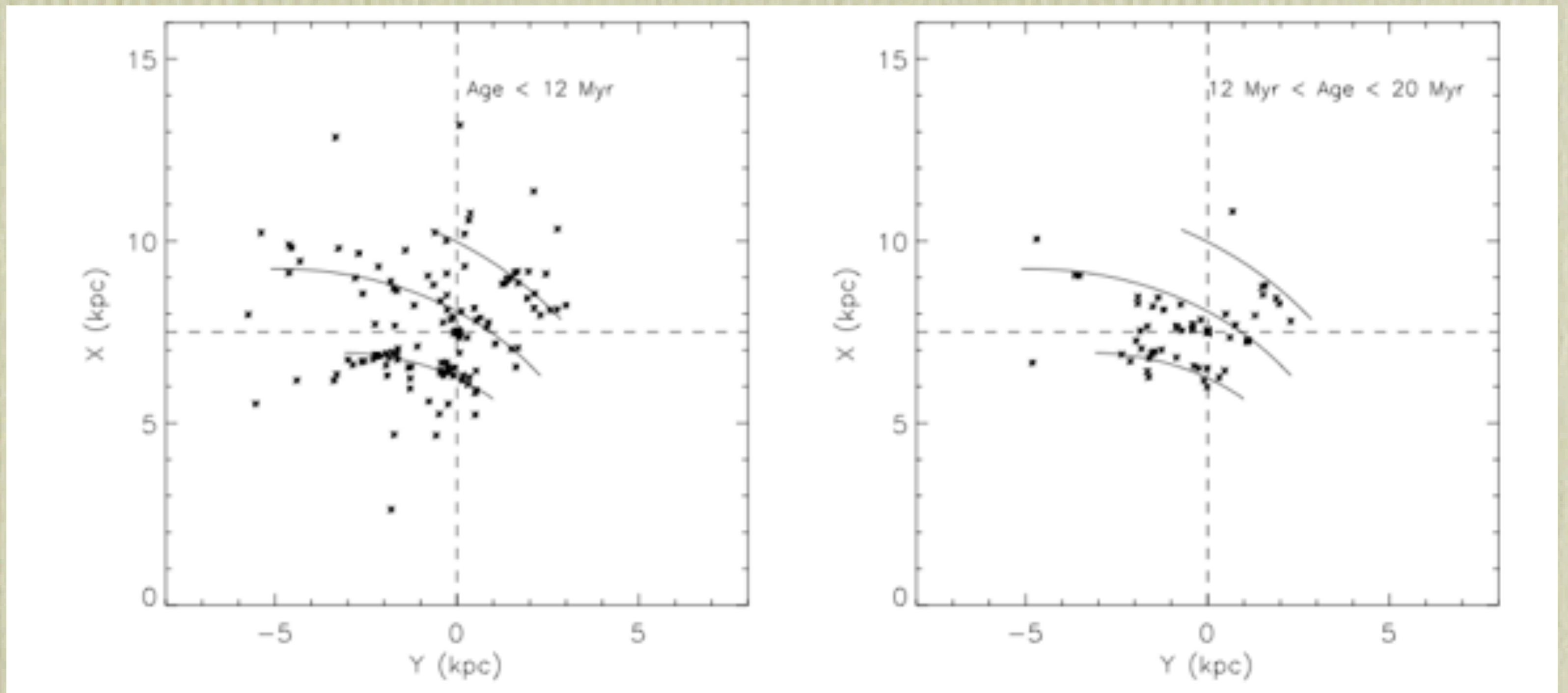


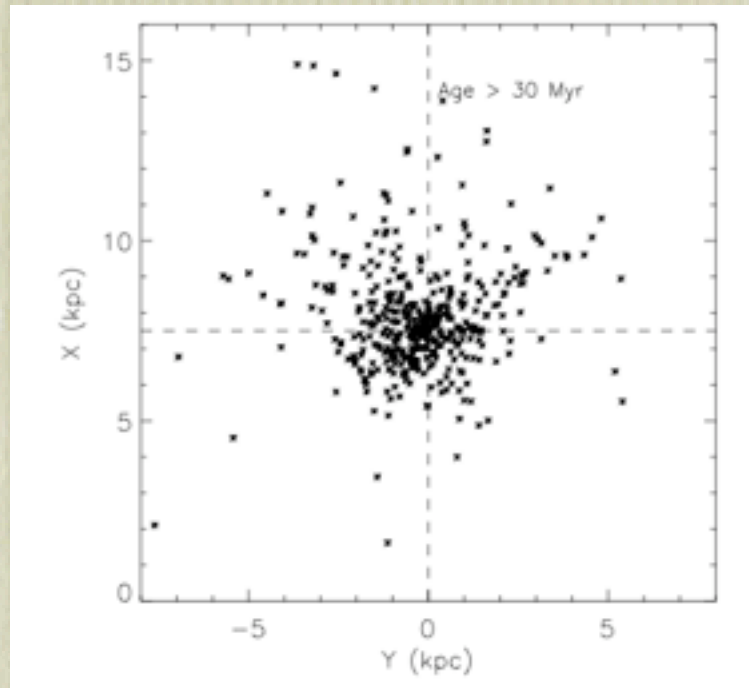
Churchwell et al 2009

- GLIMPSE is confined to the inner Galaxy

Spiral arms

- Young open clusters
- Leave arms between 20-30 Myr

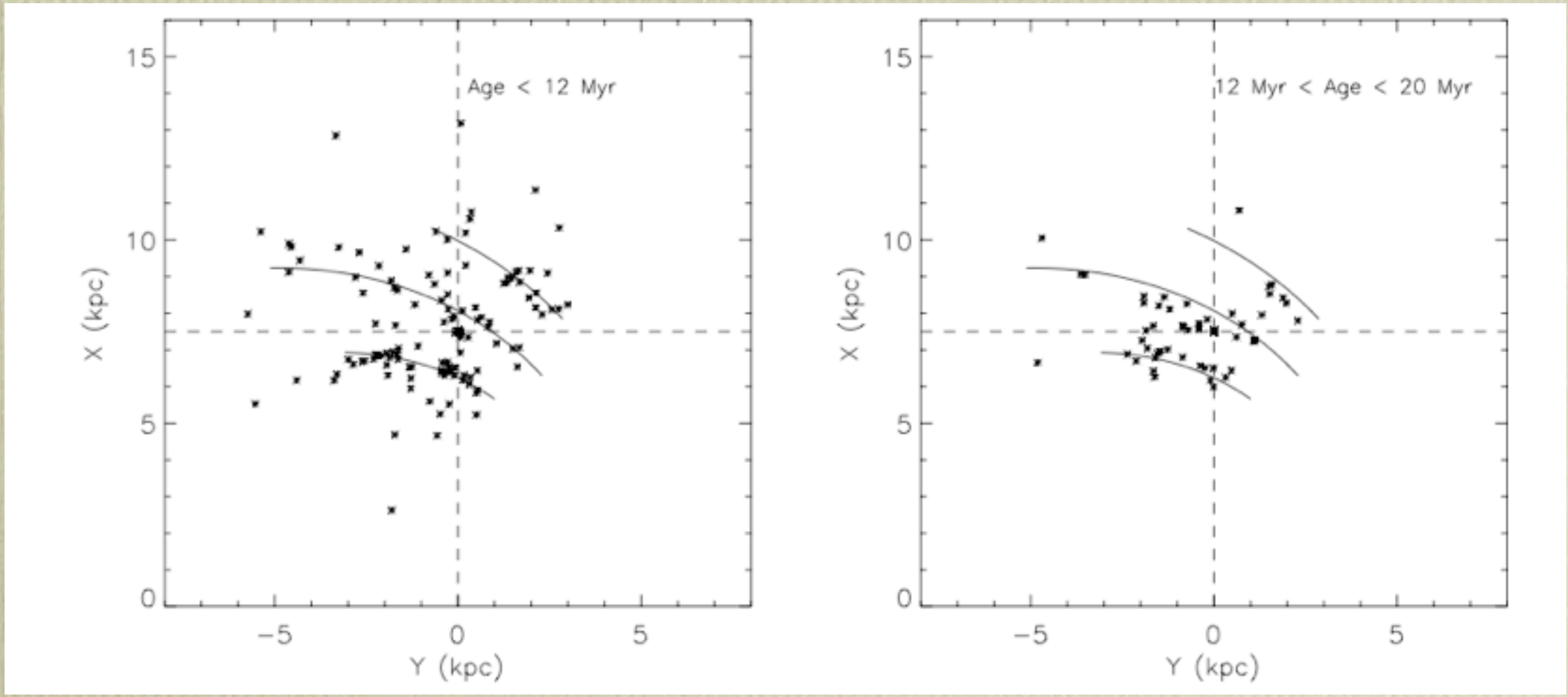




Dias & Lépine 2005

Pattern speed of Spiral Arms

- Comparison of “arms” defined by different age groups
  - Direct and doesn’t rely of rotation curve



Dias & Lépine 2005

Pattern speed of Spiral Arms

- Direct integration of orbits
  - Relies of rotation curve
  - btw, still lacking a proper Rotation Curve from OCs (APOGEE..)

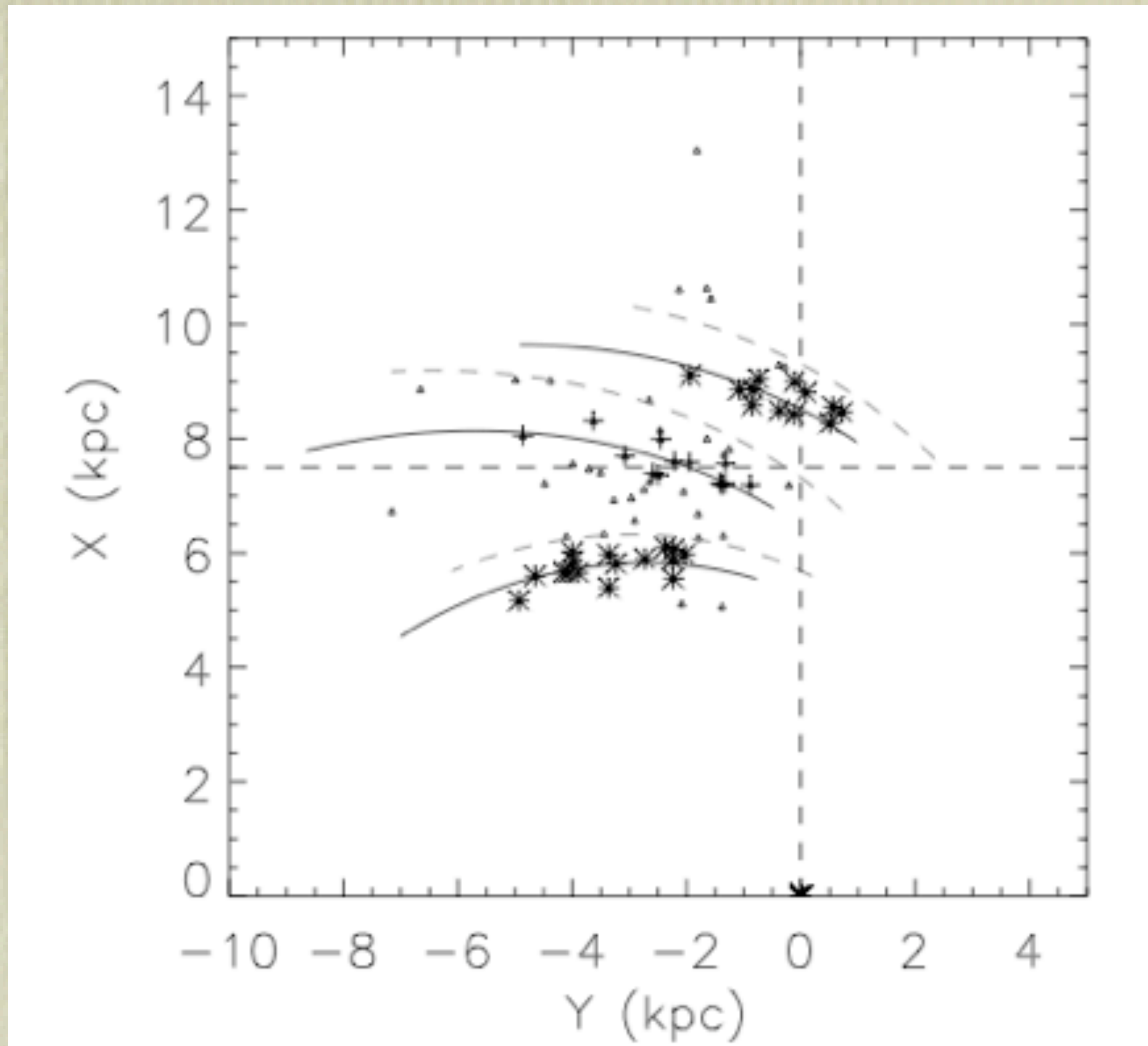
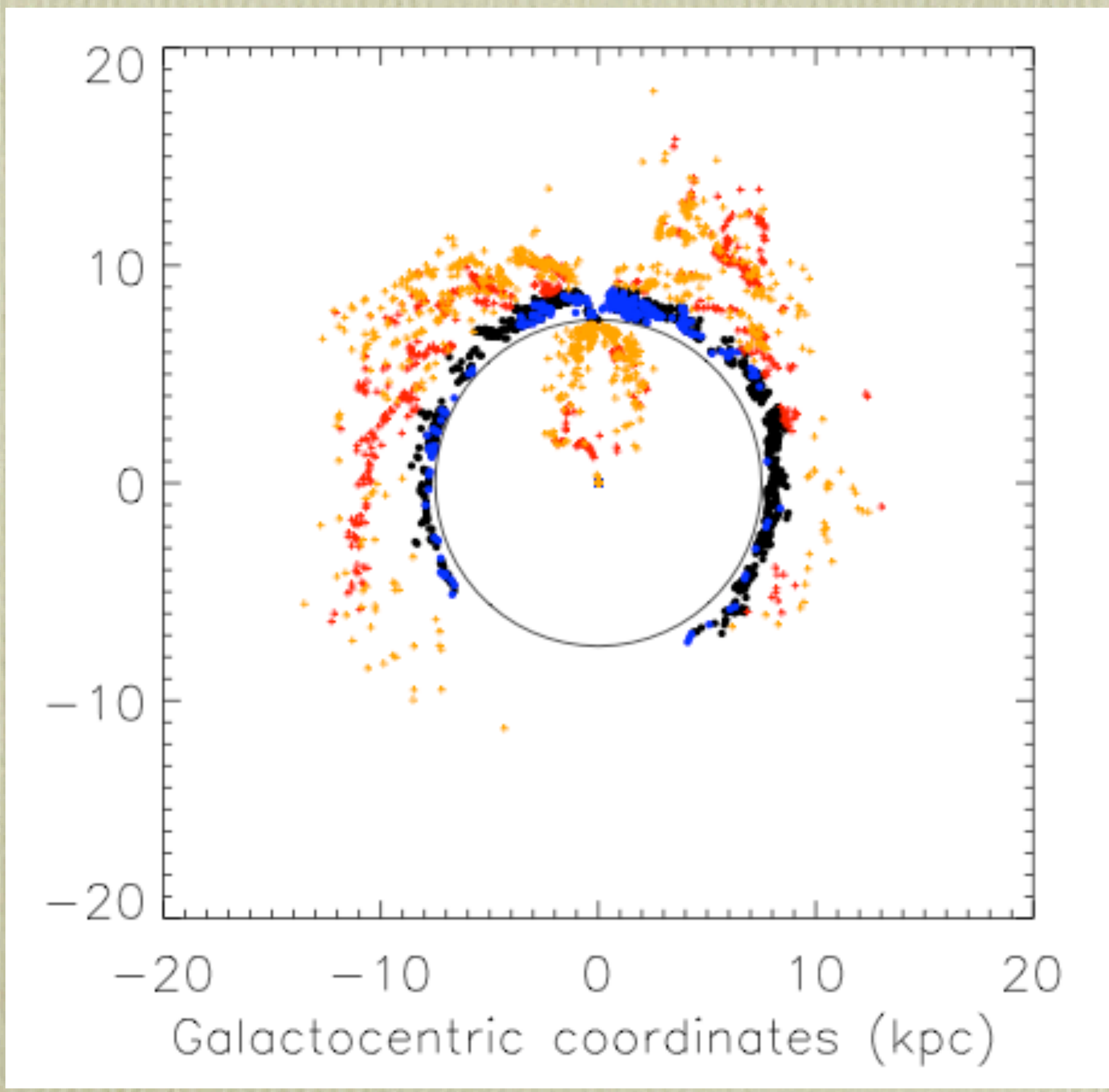


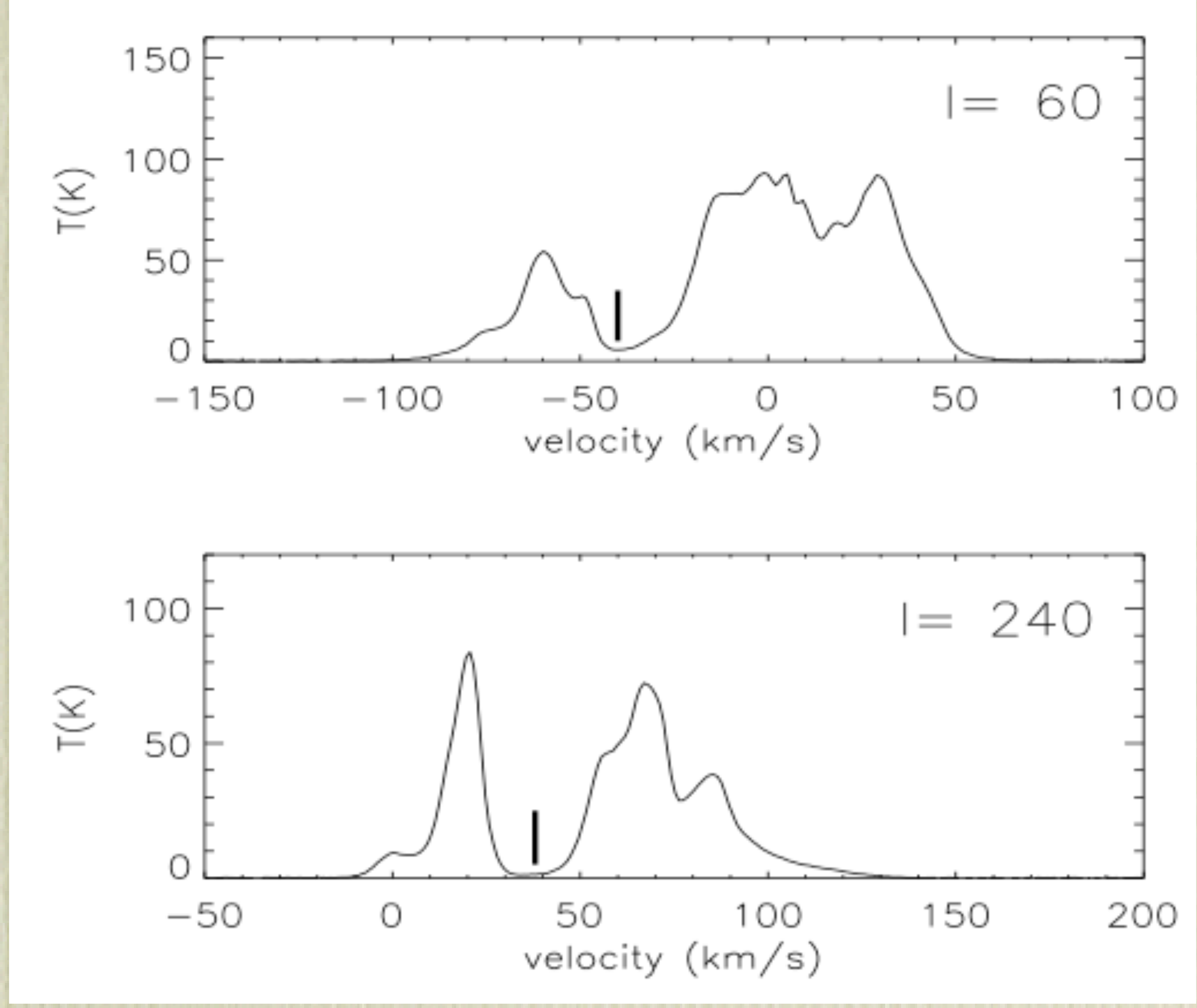
FIG. 4.—Birthplaces of the clusters with ages in the range 9–15 Myr (average 11.6 Myr) in the Galactic plane, obtained by direct rotation with a flat rotation curve with a velocity of 210 km s^{-1}. The dashed lines were fitted to a younger sample, not shown, with ages in the range 5–8 Myr (average 6.2 Myr); the solid lines are the same arms of the dashed line, rotated by 8° around the Galactic center. This angle is the best fit to the sample displayed. Different symbols have been used to indicate clusters belonging to each arm, or those more than 0.5 kpc from any arm (*small triangles*).

Dias & Lépine 2005

Corotation Gap

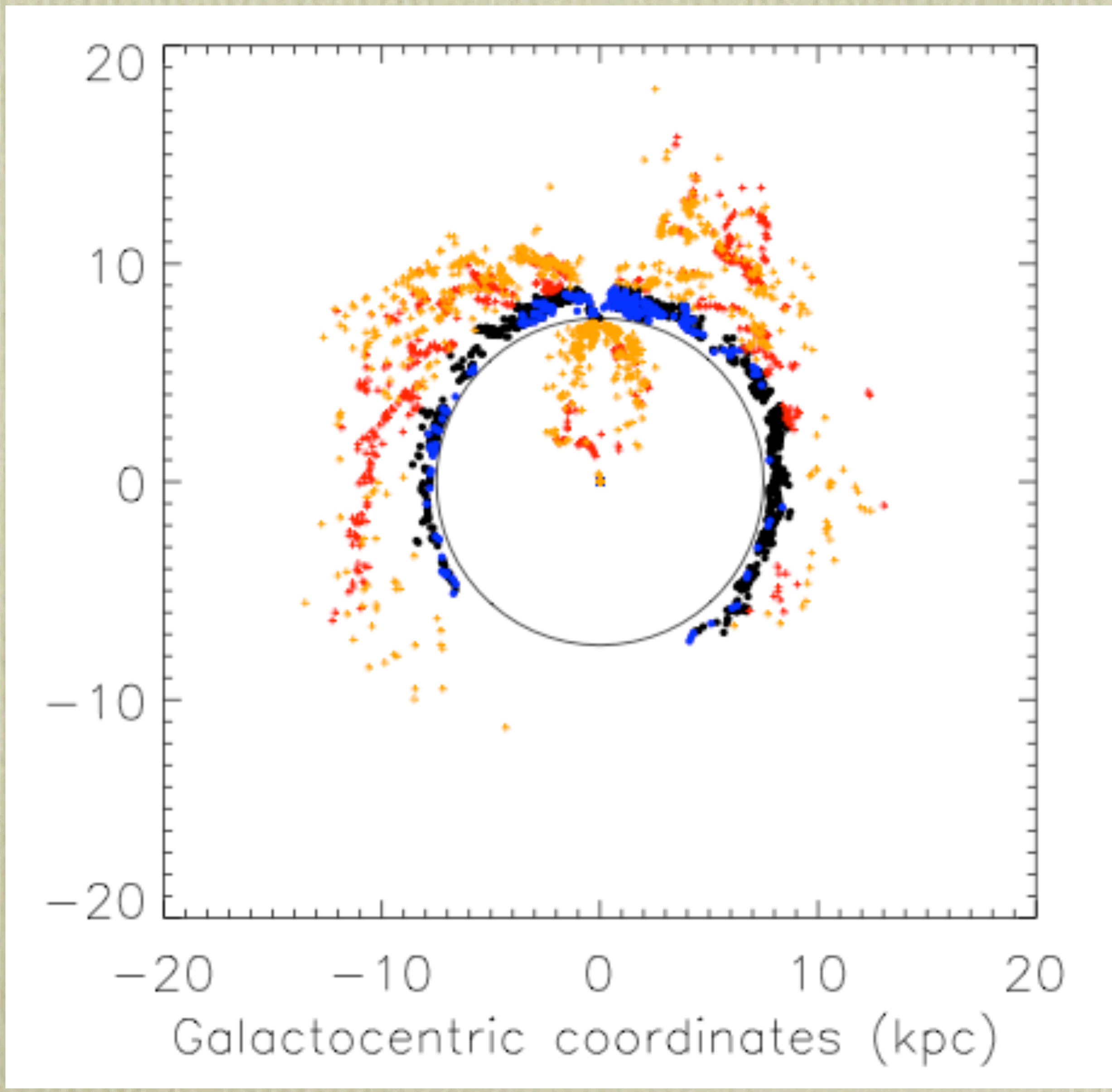


Amôres et al. 2009

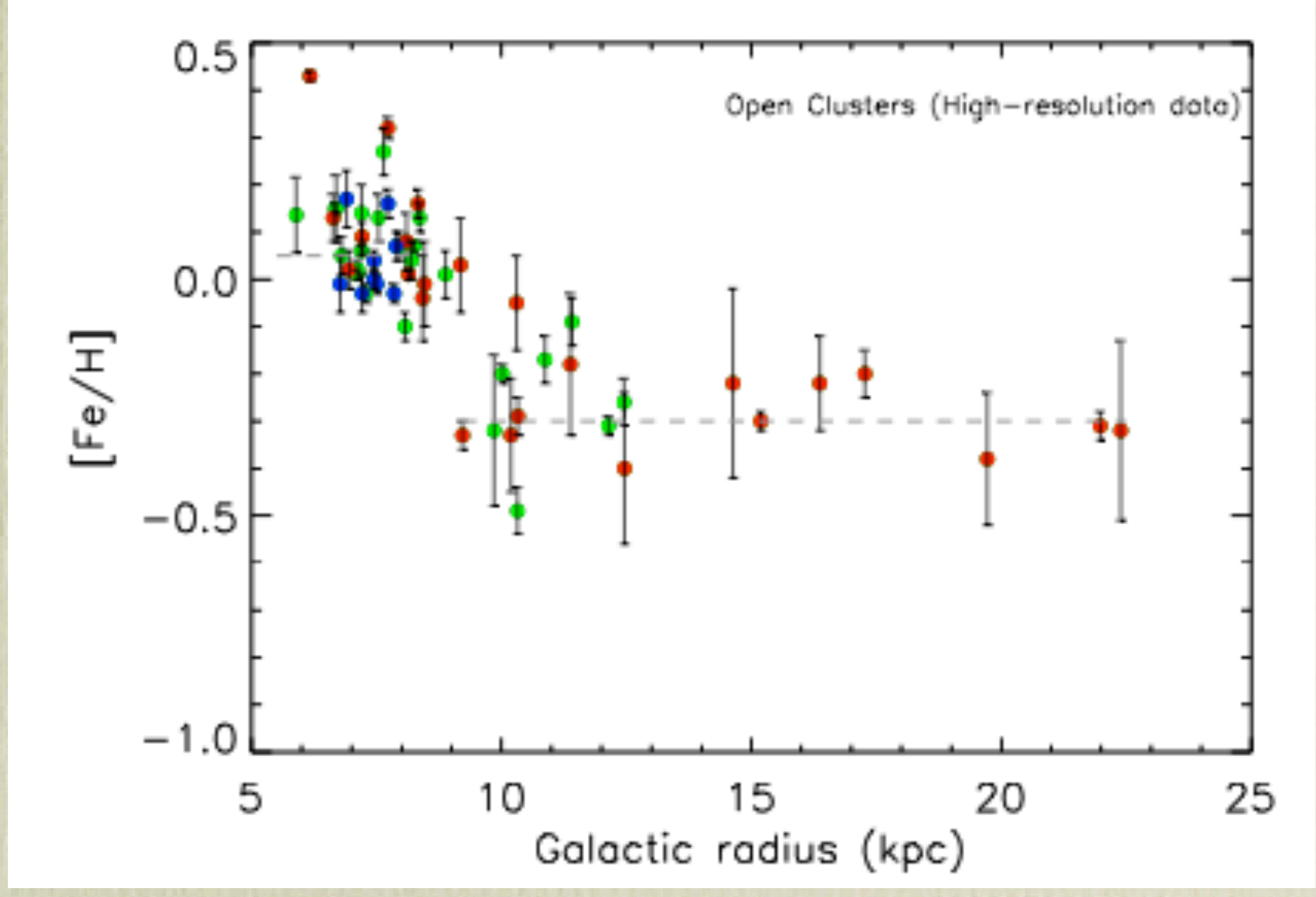


- Here RGC=7.5 kpc
- Rc= 8.3 kpc

Corotation Gap



Amôres et al. 2009

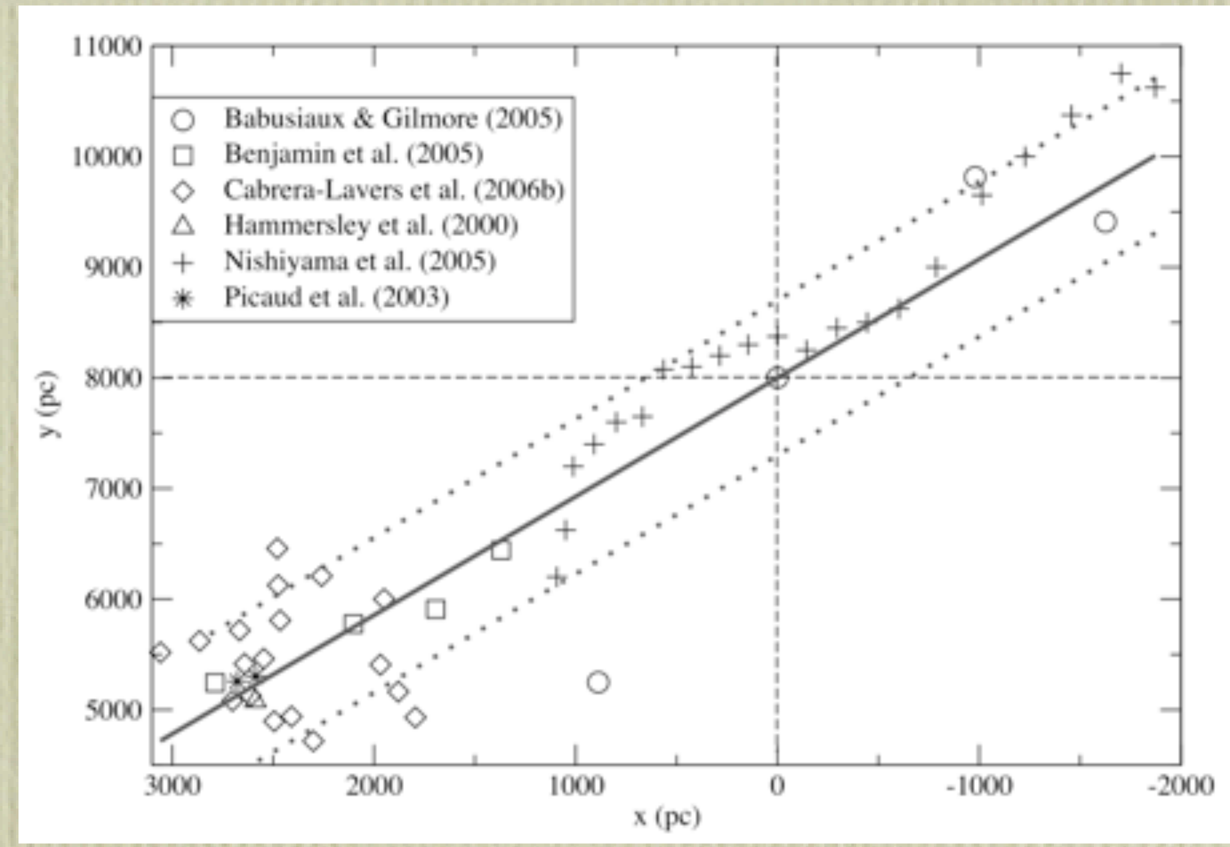


Lépine et al. 2011

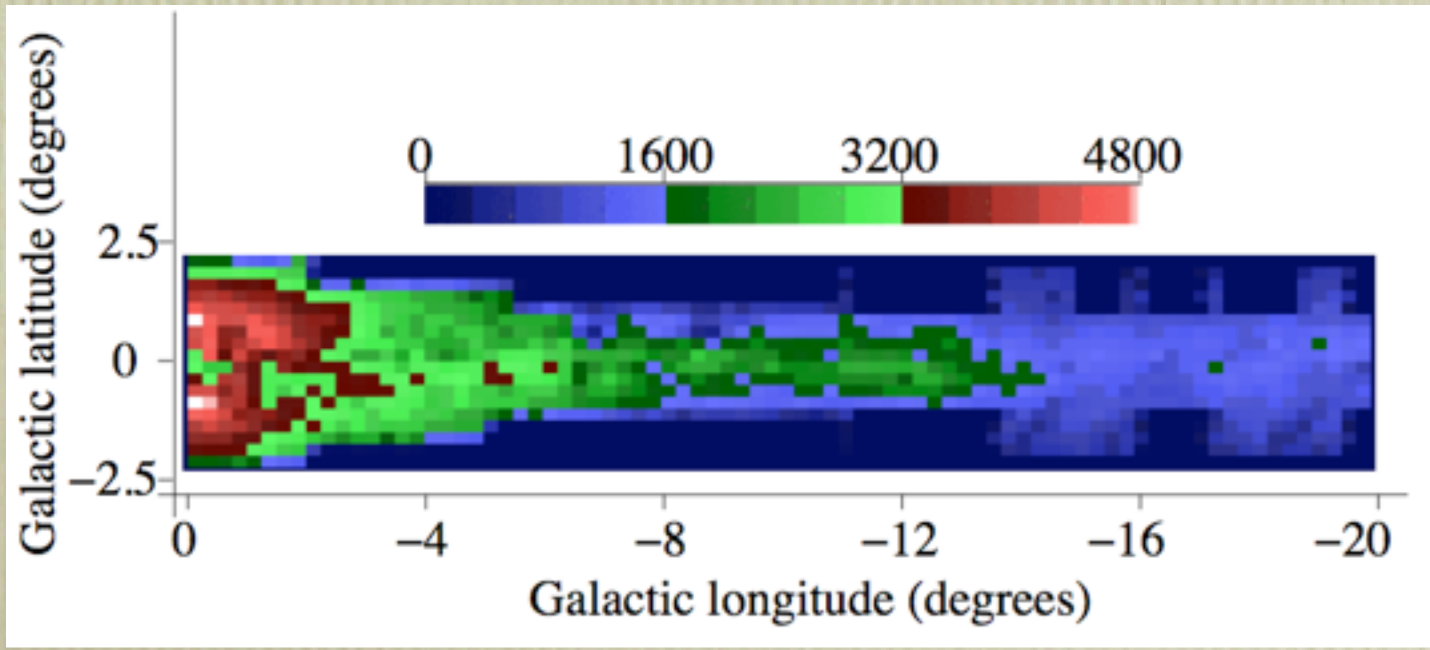
- Hints at persistent pattern: Building a 0.3dex "gradient step" takes > 3Gyr

Bar

Lopez-Corredoira et al. 2007



- Star counts. GLIMPSE + 2MASS
  - 7.8 kpc x 1.2 kpc x 0.2 kpc
  - Inclination 43°



- GLIMPSE + VVV
  - Confirm previous results

Amôres et al. 2012

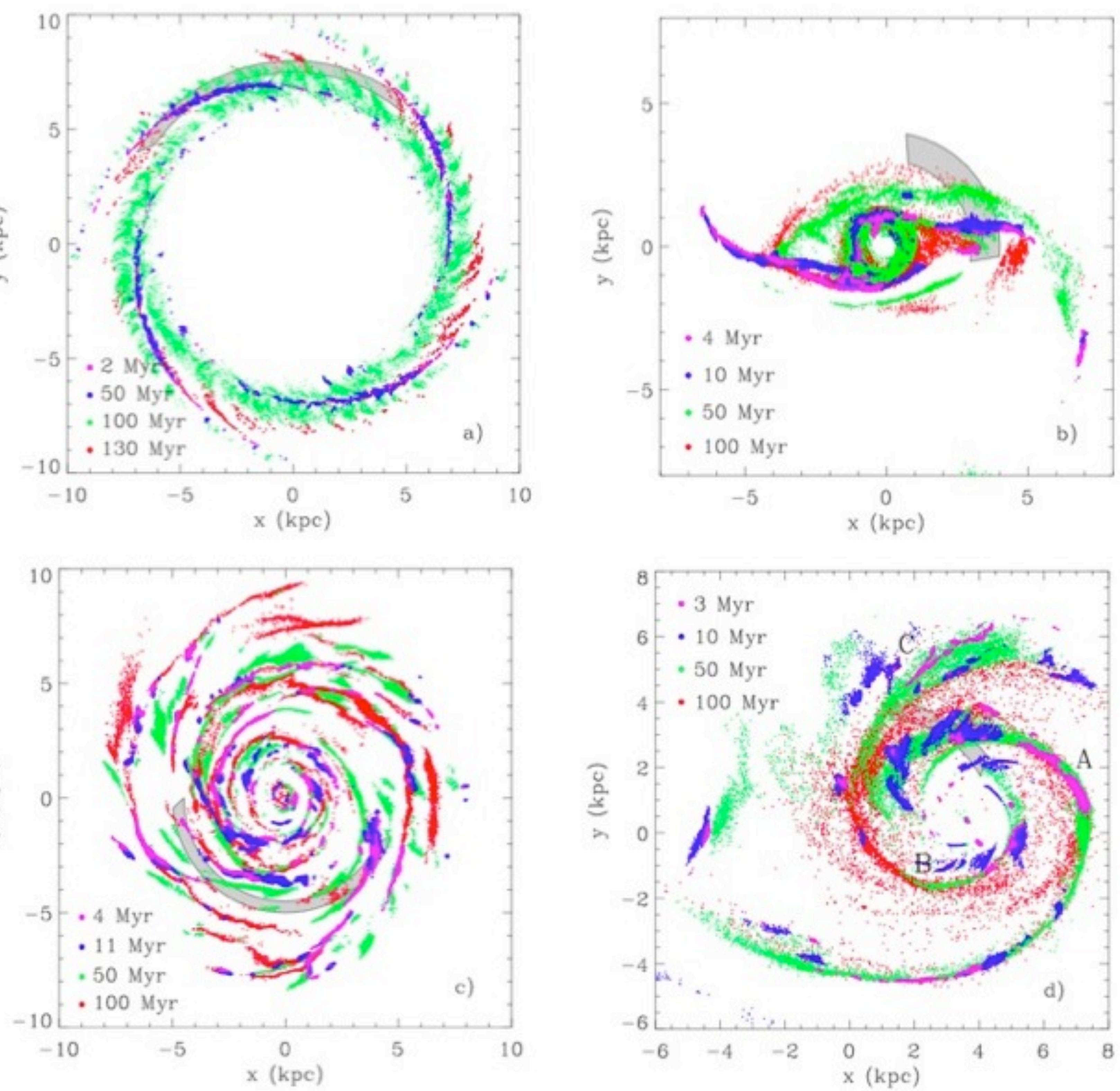


Figure 2. For the galaxy models representing (a) a spiral with a fixed pattern speed, (b) a barred galaxy, (c) a flocculent spiral, and (d) a tidally induced spiral at the times shown in Fig. 1, we show here the estimated positions of star clusters of various ages. The galaxies with a relatively constant pattern speed (the fixed spiral (a) and the bar (b)) contain younger stars in the spiral arms or bar, with older (100 Myr) stars downstream in the interarm regions. The distribution of stellar clusters is more complicated in the flocculent (c) and tidally induced spirals (d). For the flocculent galaxy, each segment of a spiral arm tends to contain clusters of a similar age. In contrast, the tidally induced spiral generally shows a complex and somewhat incoherent distribution. The grey regions show sections across spiral arms which are used to produce the 1D plots showing the distribution of clusters of a given age versus distance across the arm (measured as an angle θ) and shown in Fig. 4. These are discussed in Section 7.

Dobs & Pringle. 2010

- SPH simulations
  - Specific qualitatively different predictions
  - Dating is essential
- Work to do:
  - Simulations don't include "real" stars yet
  - More cluster measurements, specially NIR

Incidentally, if you are looking for a good problem, the exact details of how the arms are formed and what determines the shapes of these galaxies has not been worked out.

-R.P. Feynman

The Feynman lectures on physics, vol. 1, 1963