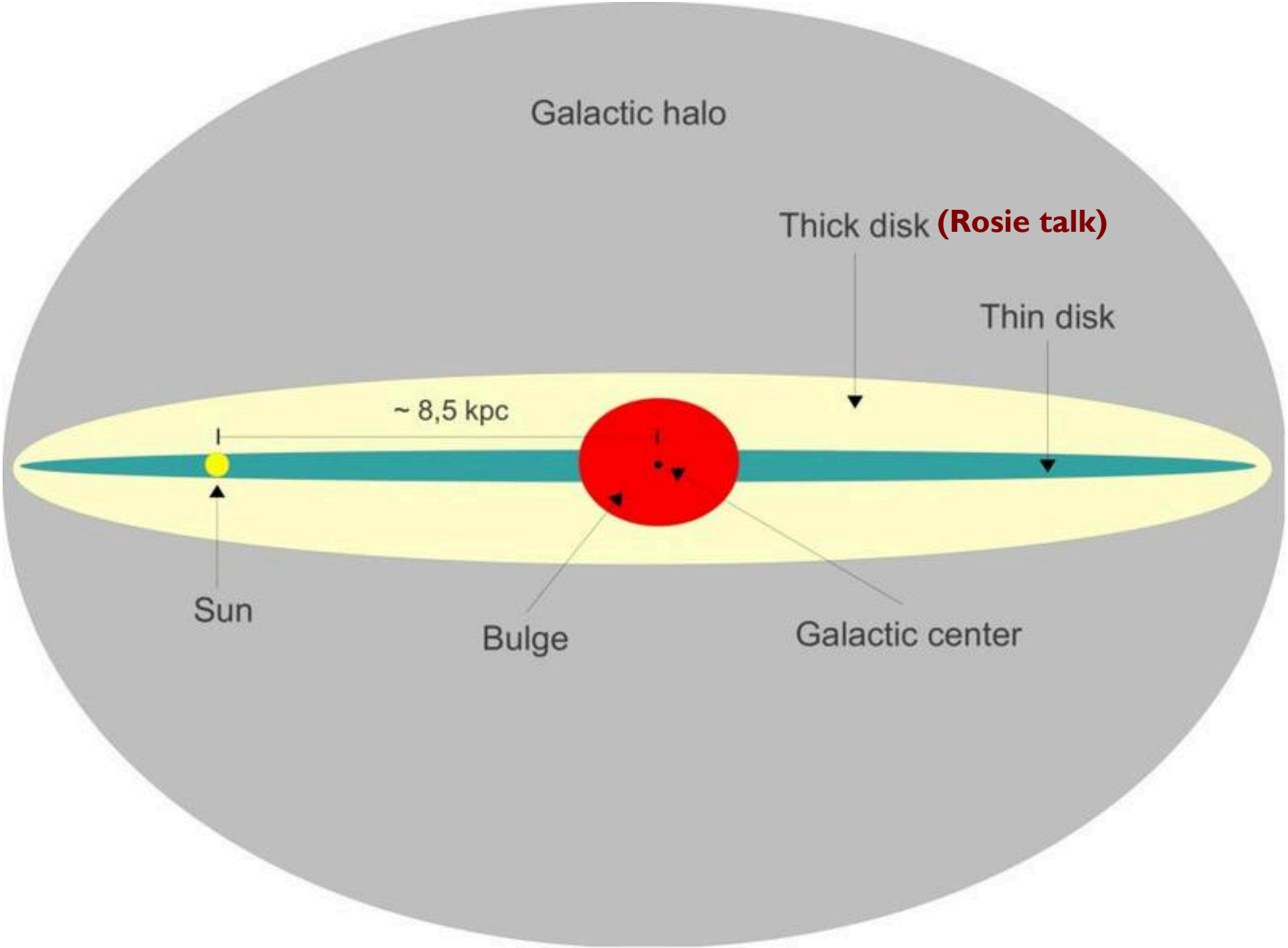
THE DISK OF THE MILKY WAY

Lowell Exponential Disks workshop

Giovanni Carraro, ESO Chile

Oct 8, 2014


Galactic halo
Thick disk (Rosie talk)
Thin disk
~ 8,5 kpc
Sun
Bulge
Galactic center


Galactic Longitide
0°
30°
330°
75,000 ly
15,000 ly
120°
240°
30,000 ly
150°
210°
180°
www.AstroPixels.com
©2012 F. Espenak

OUTLINE

- **Question I: Is there an ideal Spiral Structure tracer?**
  → **SPIRAL STRUCTURE OF THE MILKY WAY**

- **Question II: Do we have a *MODEL* of the MW?**
  → **THE OUTER DISK OF THE MILKY WAY**

~1952-4

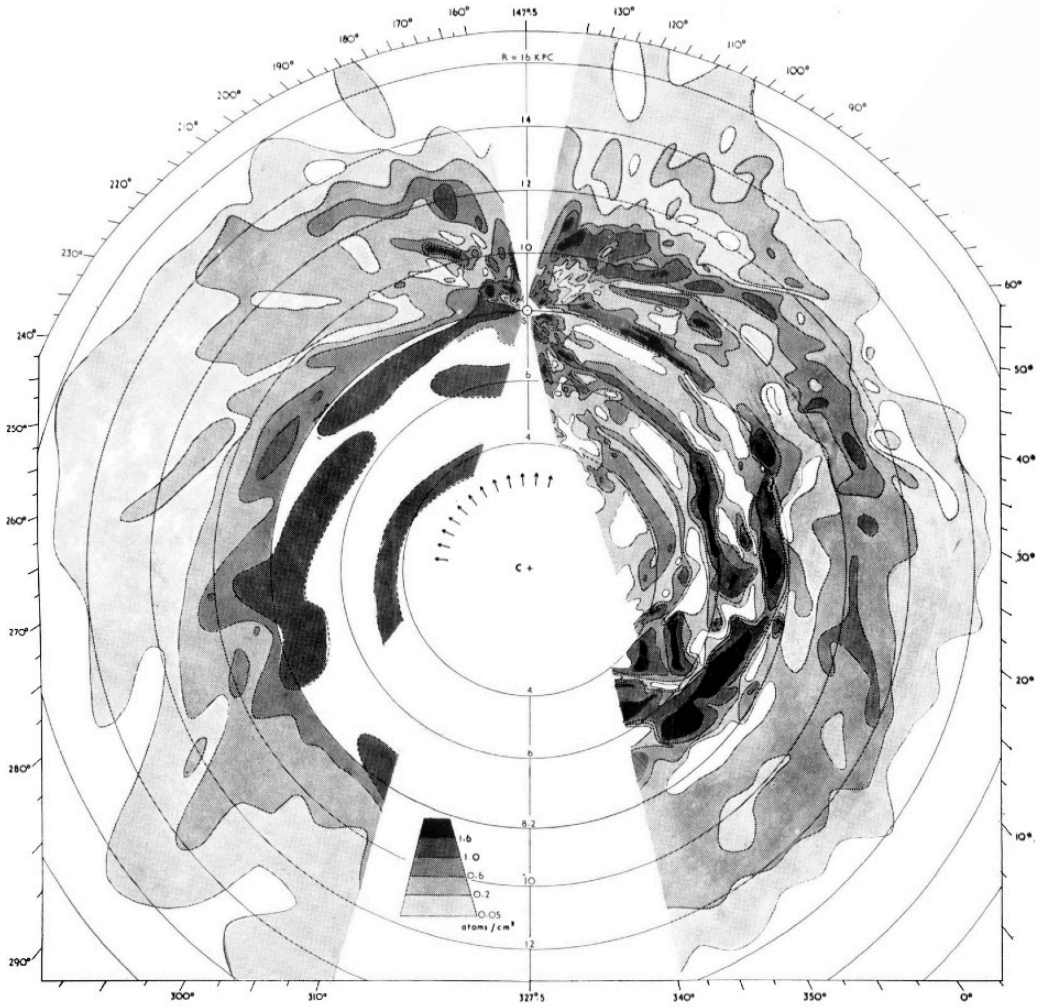
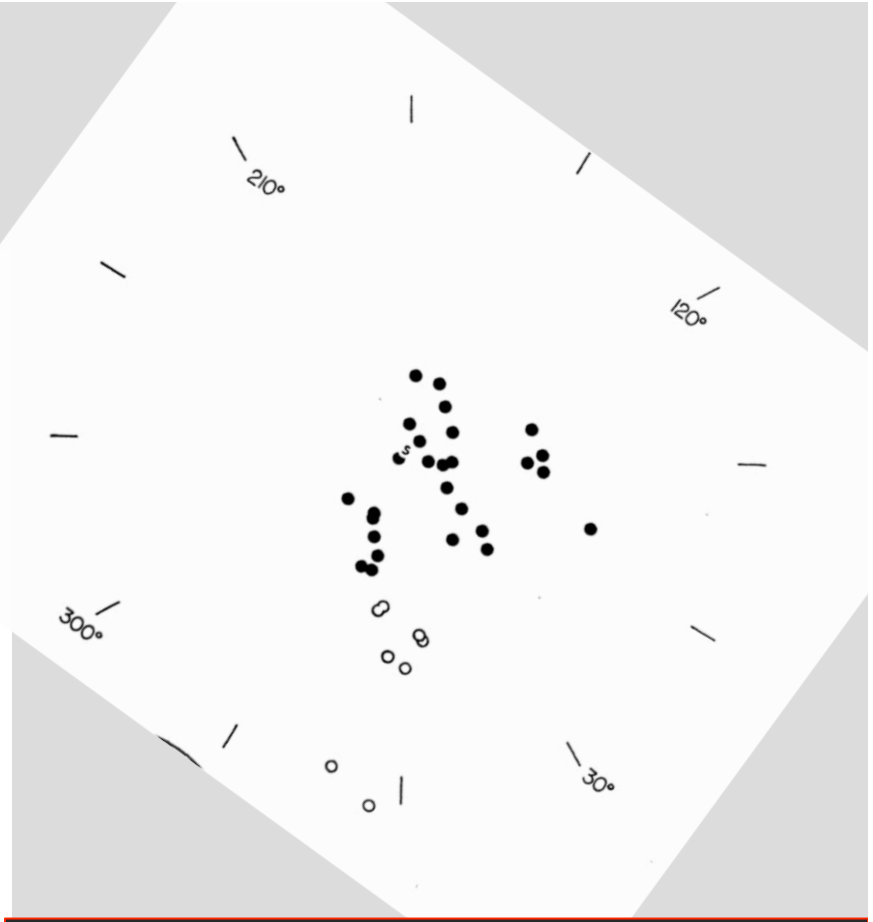


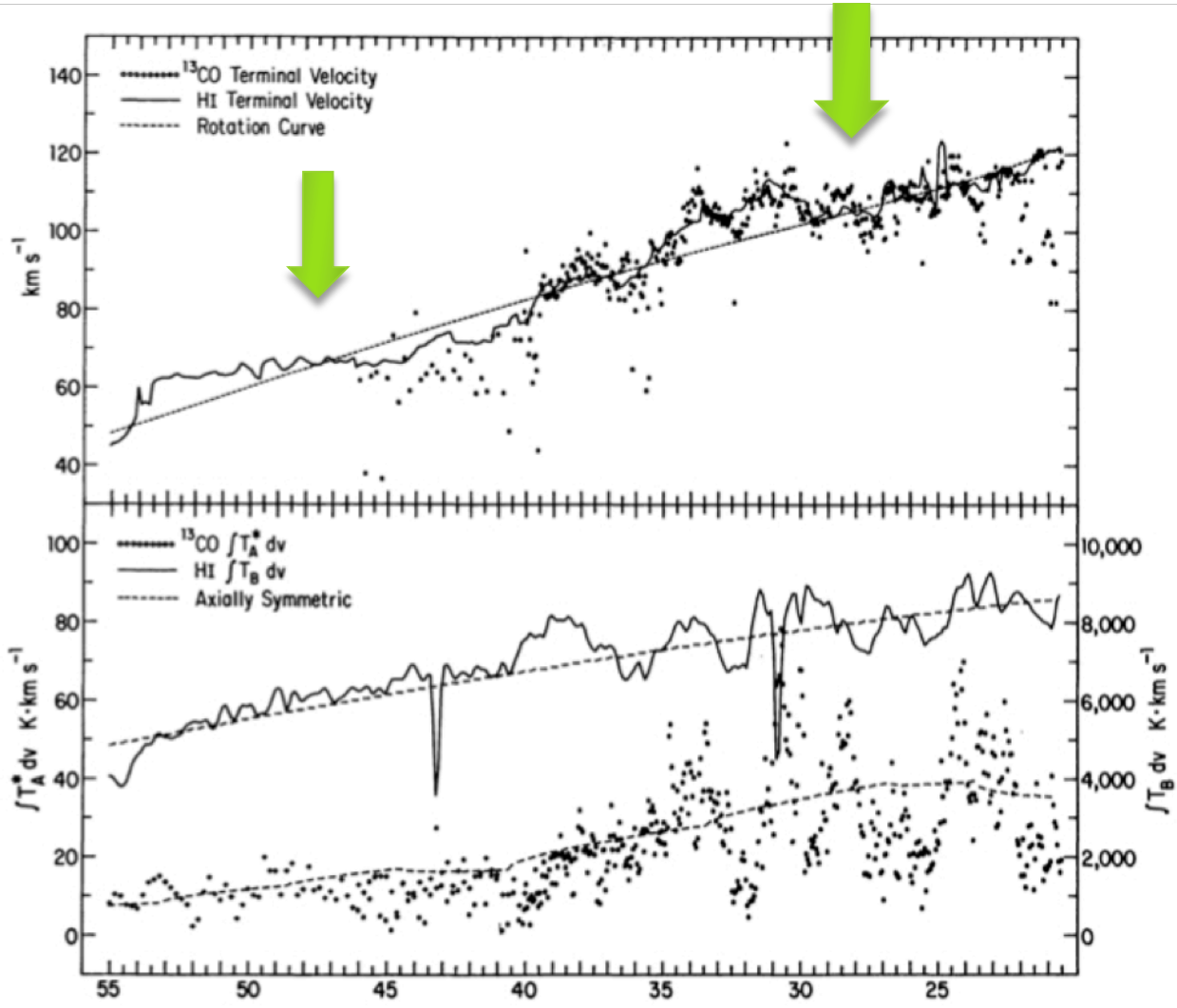
FIG. 4.—*Distribution of neutral hydrogen in the Galactic System. The maximum densities in the z-direction are projected on the galactic plane, and contours are drawn through the points.*



⇧

Yerkes, optical

⏎ **Leiden-Sydney, radio**



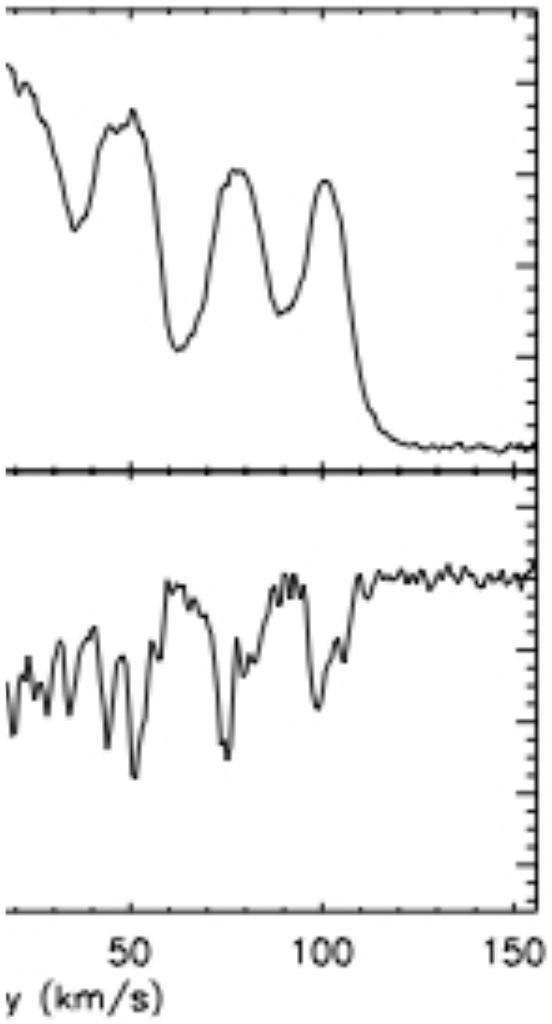
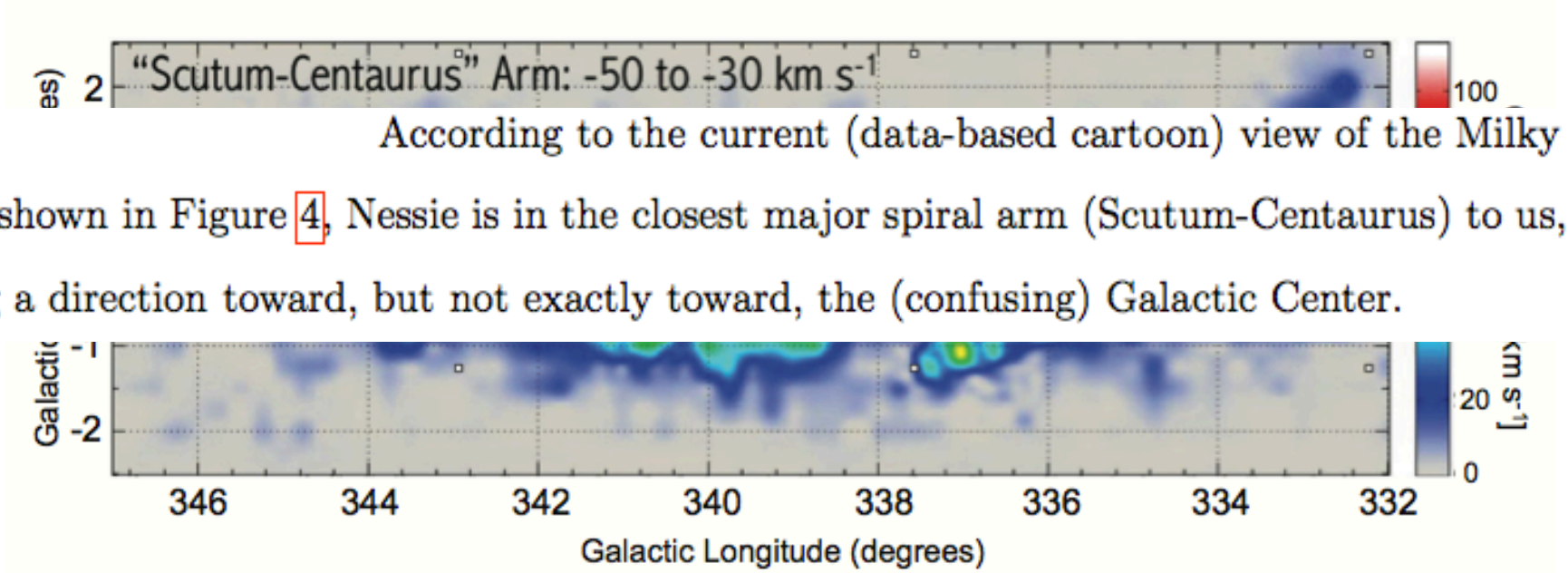


Figure 4. Upper panel: terminal velocities measured on HI (Westerhout 1976) and ^{13}CO (Liszt and Burton 1983) line profiles, and the maximum rotation velocity from Burton and Gordon's (1978) rotation curve. Lower panel: integrated intensities and the predictions of axisymmetric models. The HI model has constant density and temperature, the CO uses the usual intensity-abundance histogram derived from the data. The ^{13}CO data have been extended above 40° using scaled data of Burton and Gordon (1978).



The traditional ISM-based probes of the Milky Way's structure have been HI and CO. Emission in these tracers gives line intensity as a function of velocity, so the position-position-velocity data resulting from HI and CO observations can give three dimensional views of the Galaxy, if a rotation curve is used to translate line-of-sight velocity into a distance. Unfortunately, though, the Galaxy is filled with HI and CO, so it is very hard to disentangle features when they overlap in velocity along the line of sight

The Bones of the Milky Way, Goodman et al. 2014

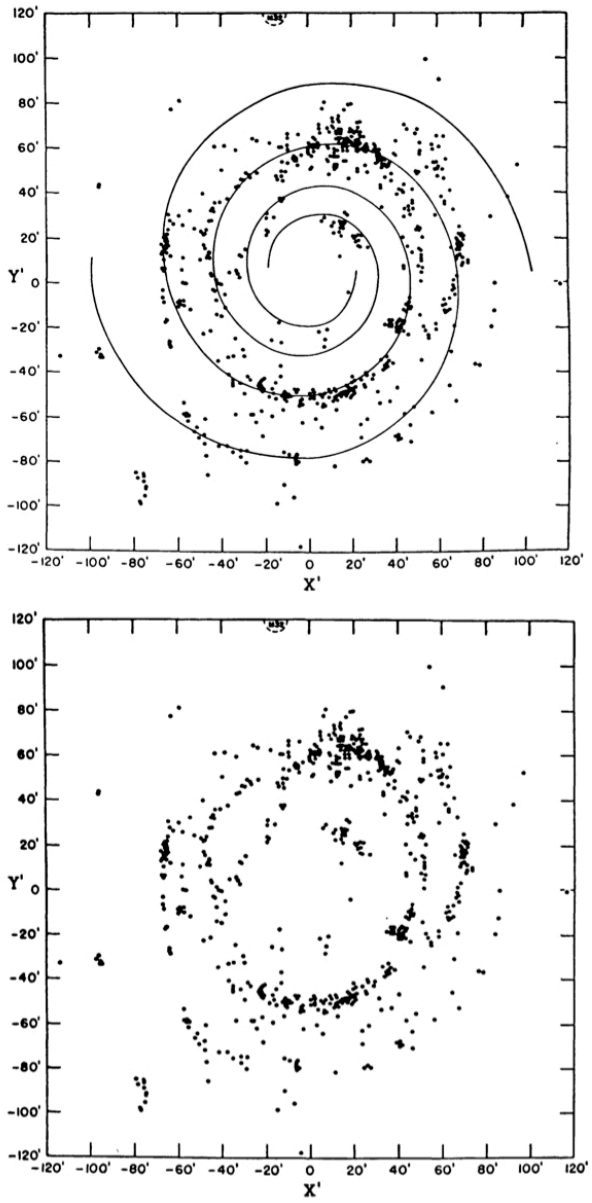
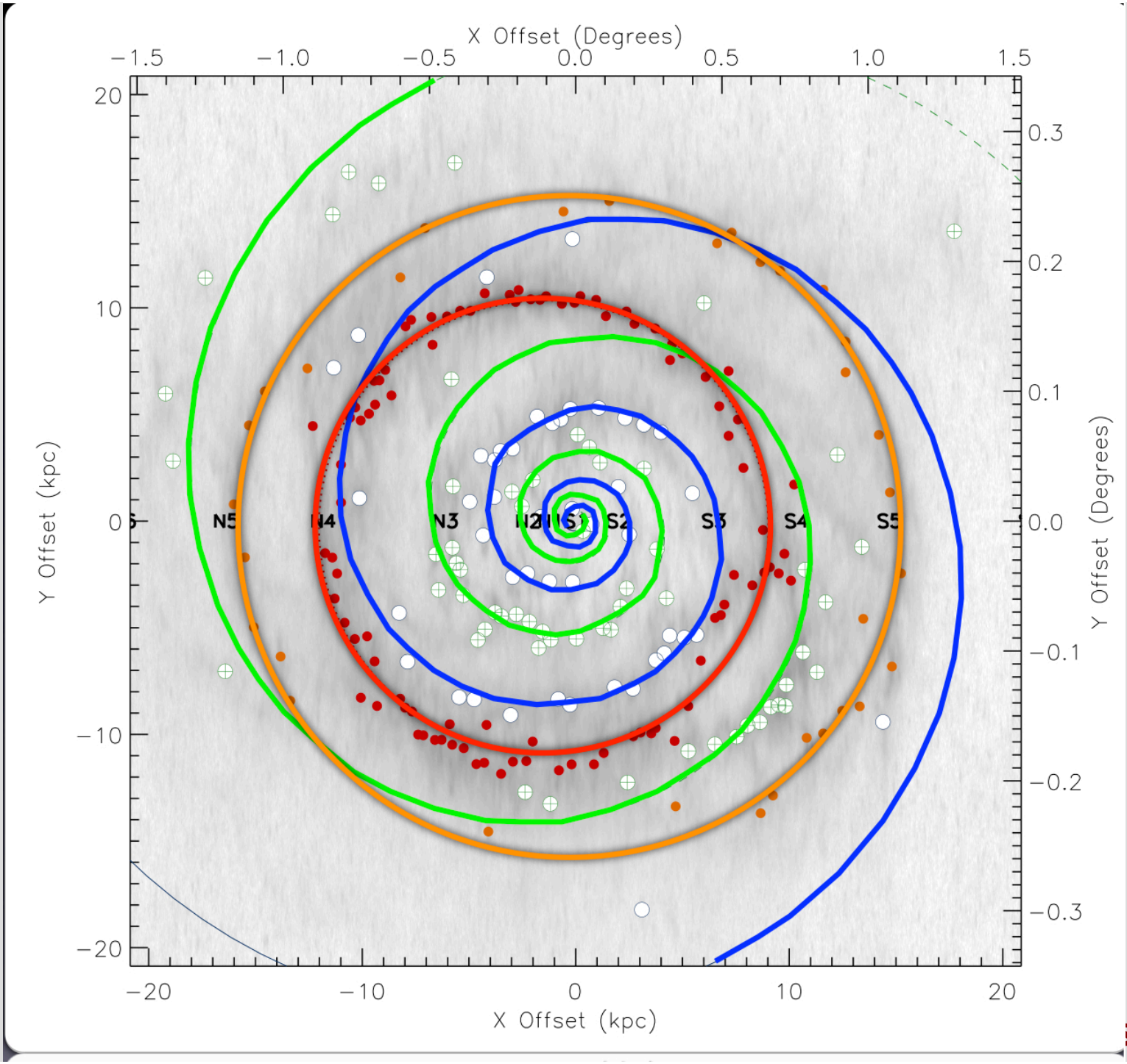


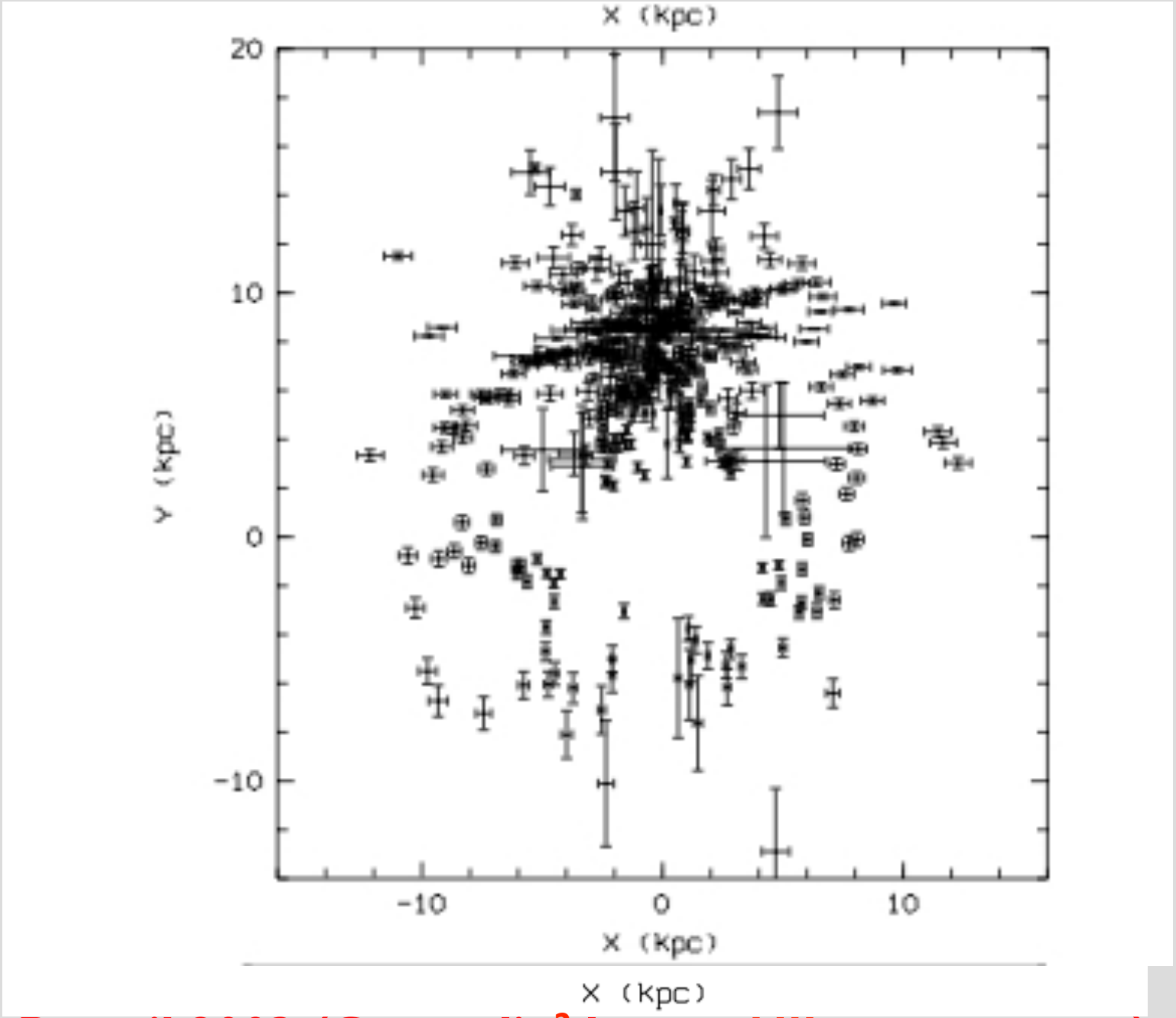
Figure 3. Deprojected positions of emission nebulae across the face of M31 (Figure 114 of Bok and Bok 1981), with and without a fitted logarithmic spiral. The Boks use this diagram to illustrate the difficulty of visual discrimination between spiral and ring distributions.

Original Baade data for M31

Liszt 1985

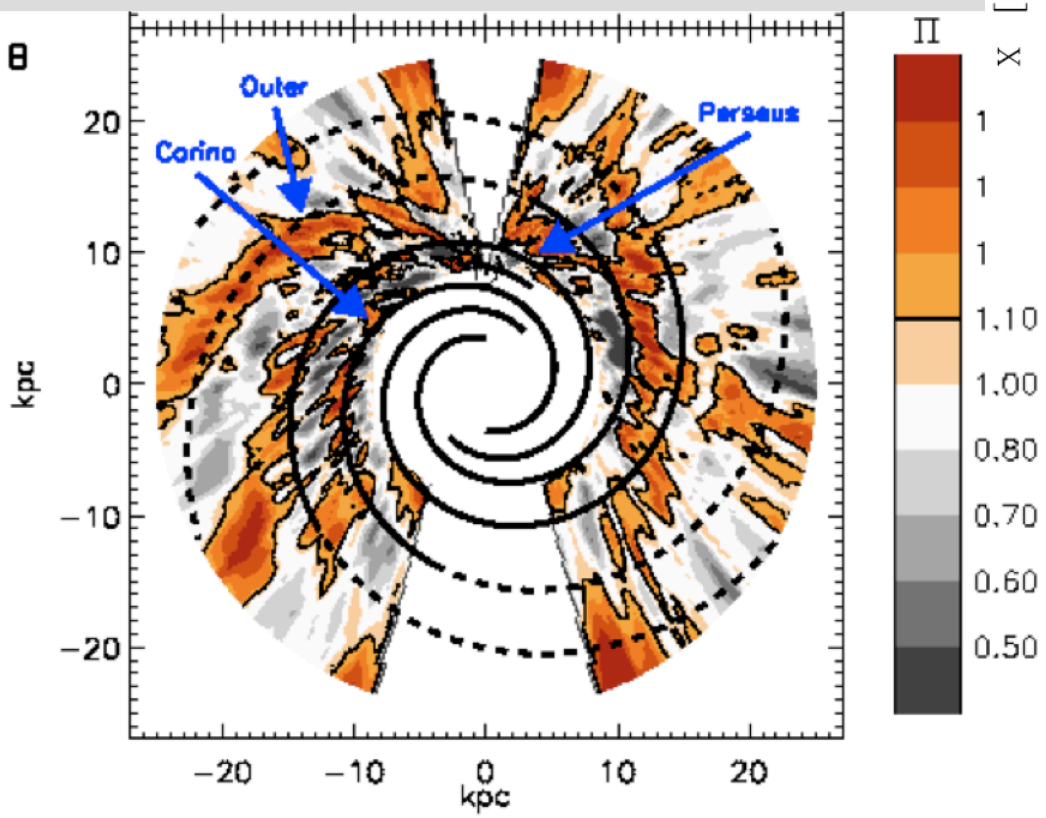

X Offset (Degrees)
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
20
10
0
−10
−20
0.3
0.2
0.1
0.0
−0.1
−0.2
−0.3
Y Offset (kpc)
Y Offset (Degrees)
N5
N4
N3
N2
N1
S1
S2
S3
S4
S5
−20
−10
0
10
20
X Offset (kpc)

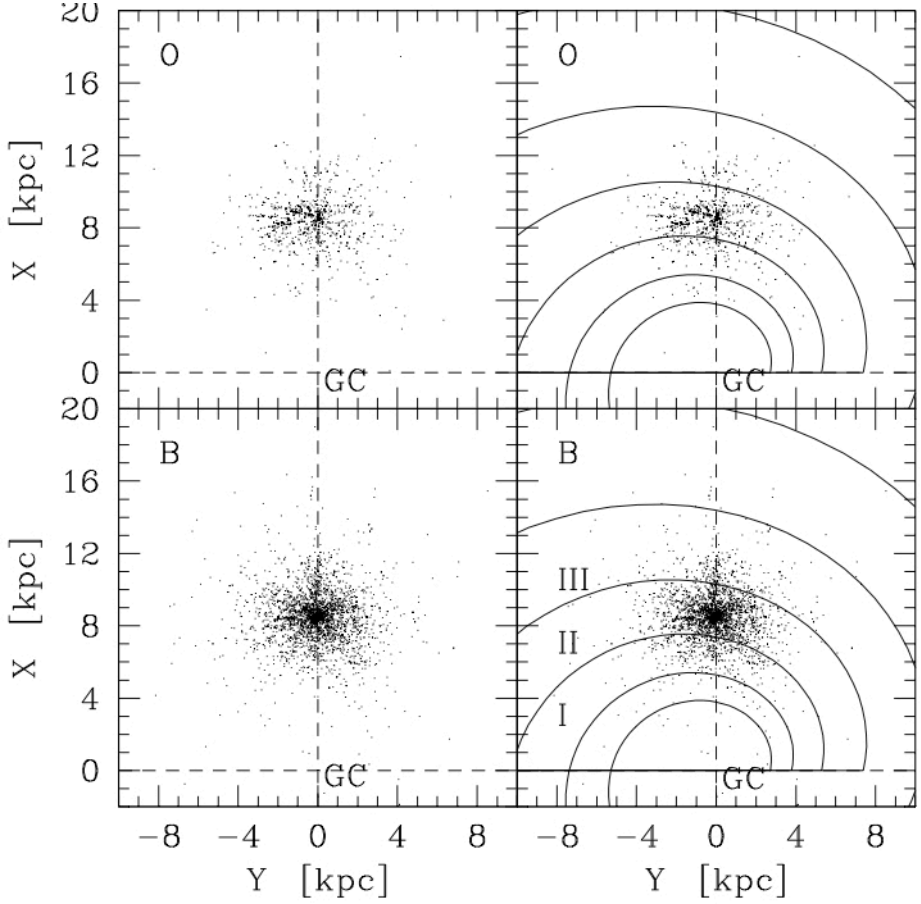
sults, 20



Russeil 2003 (Georgelin[2] legacy, *HII*, spectroscopy)

~2010



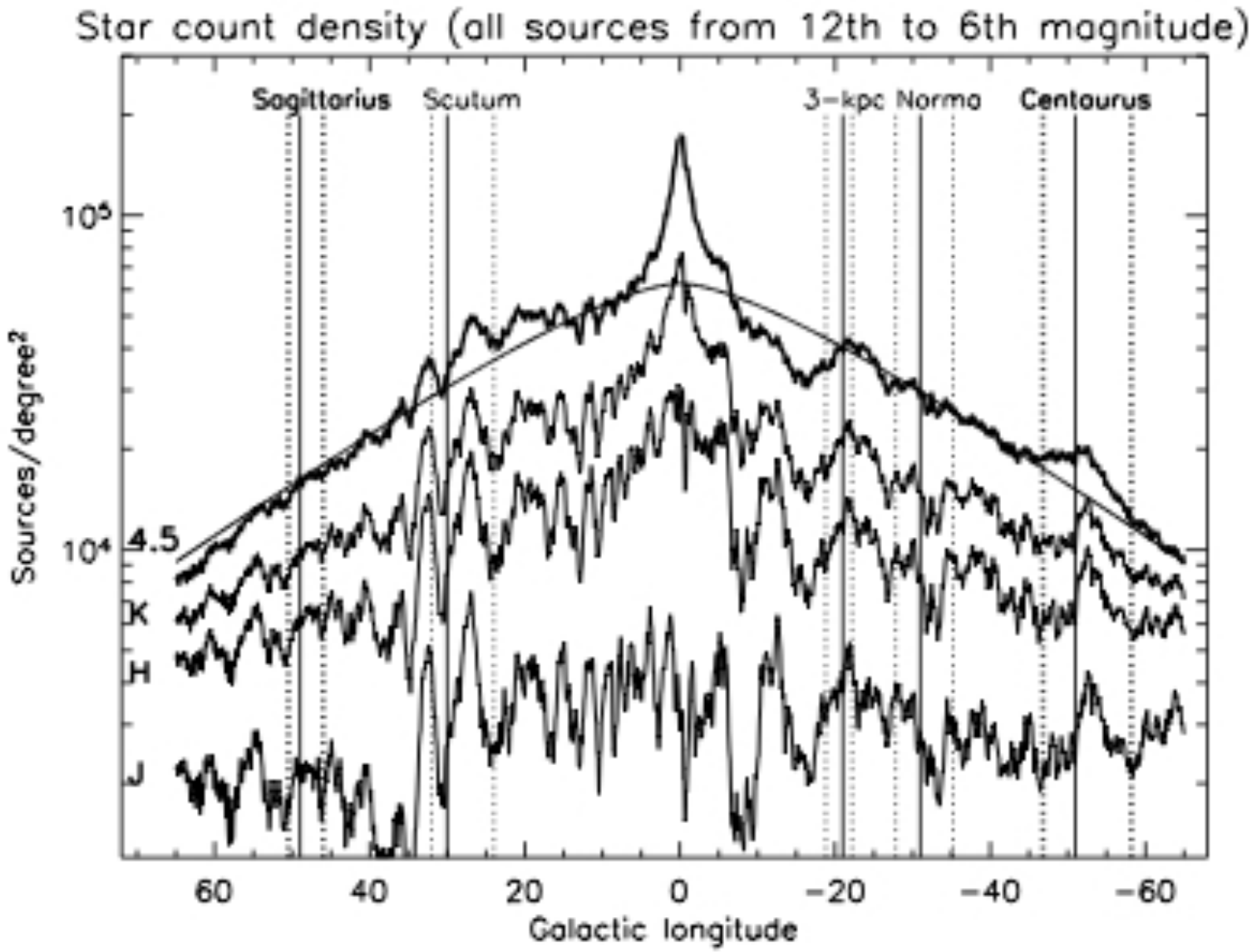


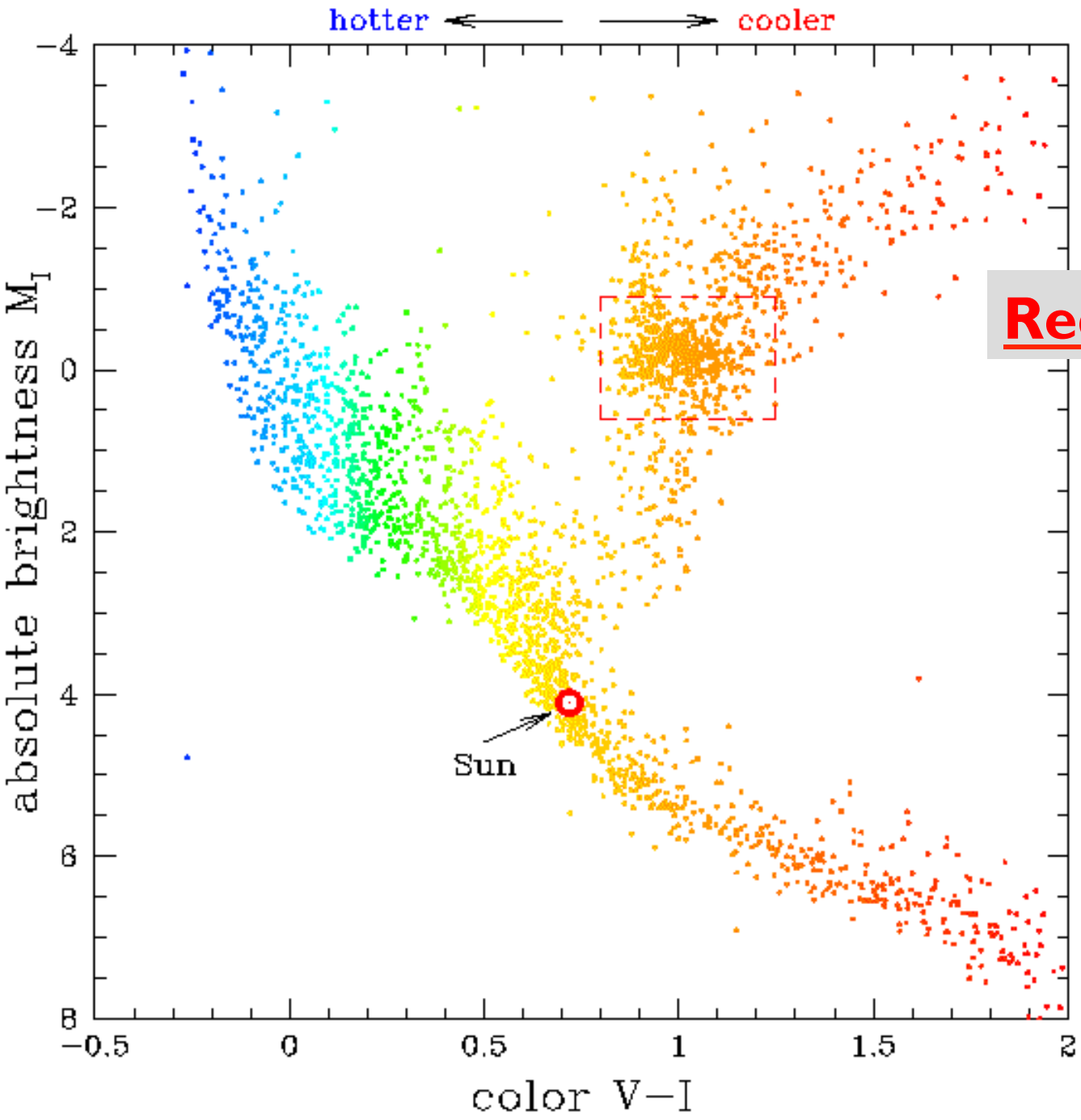
⇧

Reed, optical

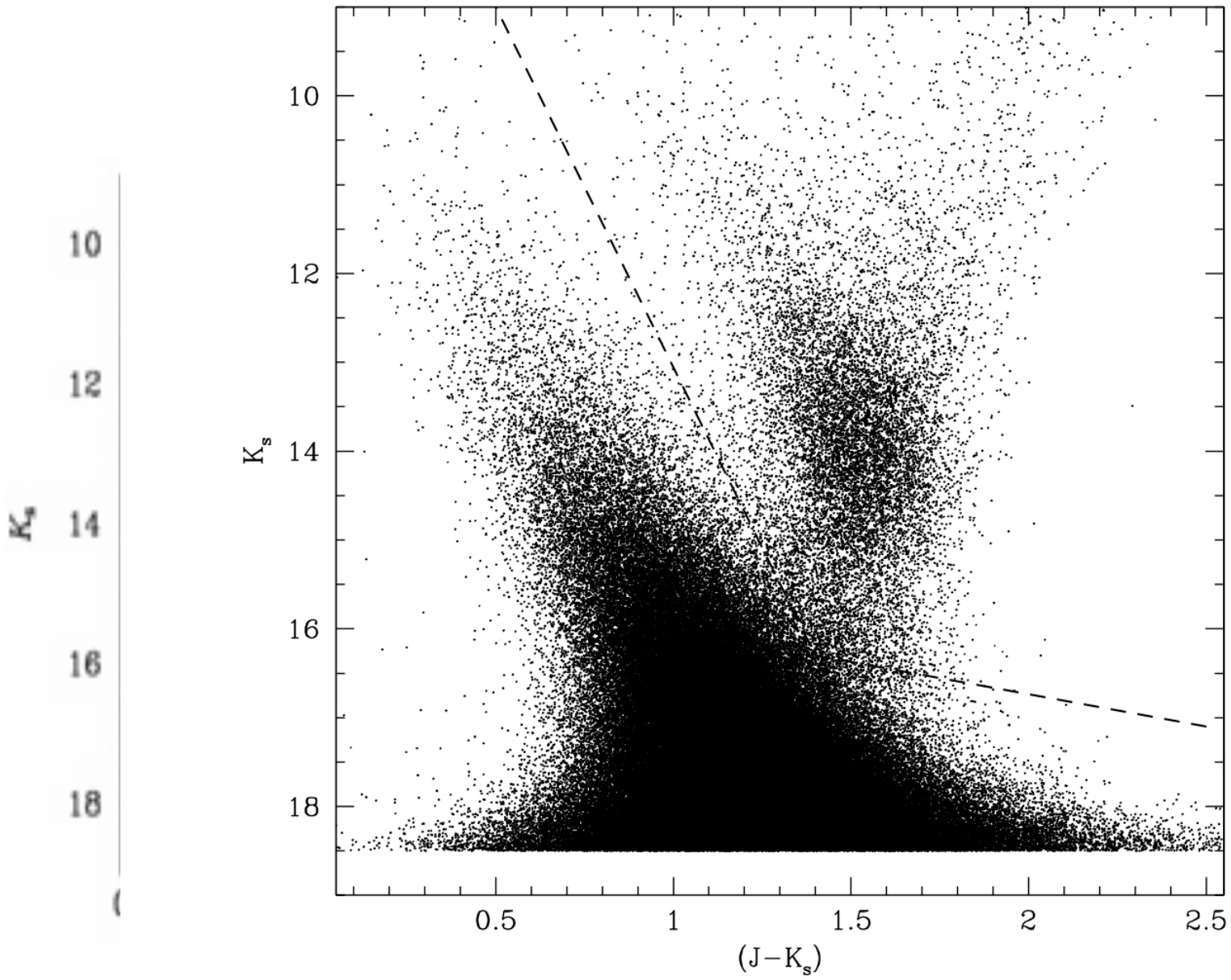
⏎ **Levine et al., radio**

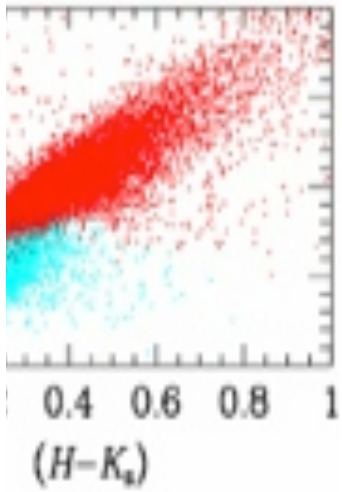
Churchwell et al. 2009

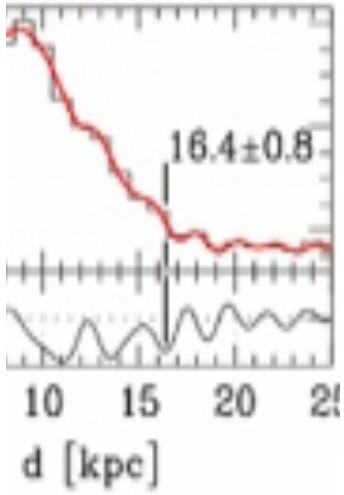




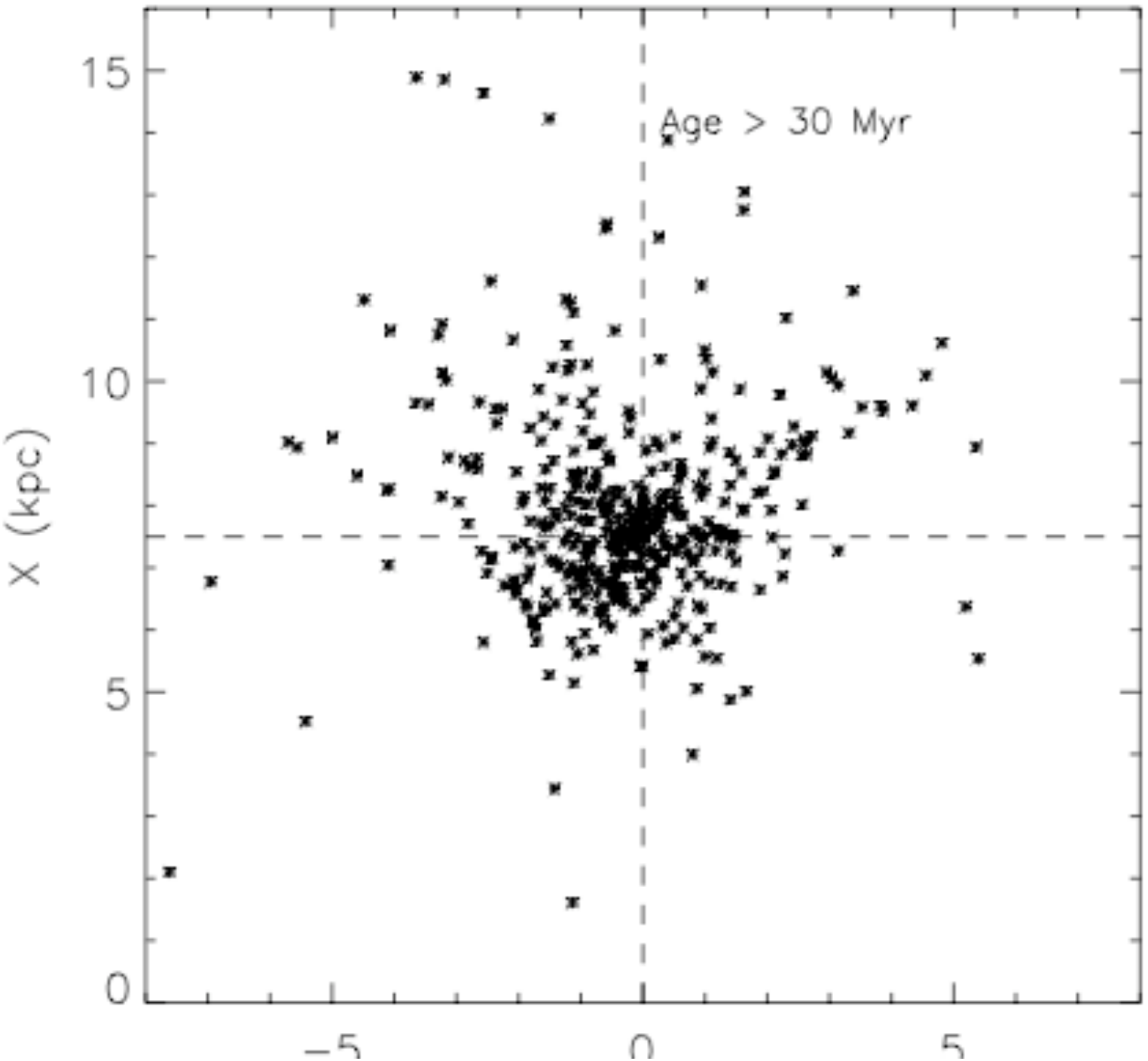
Red Clump Stars

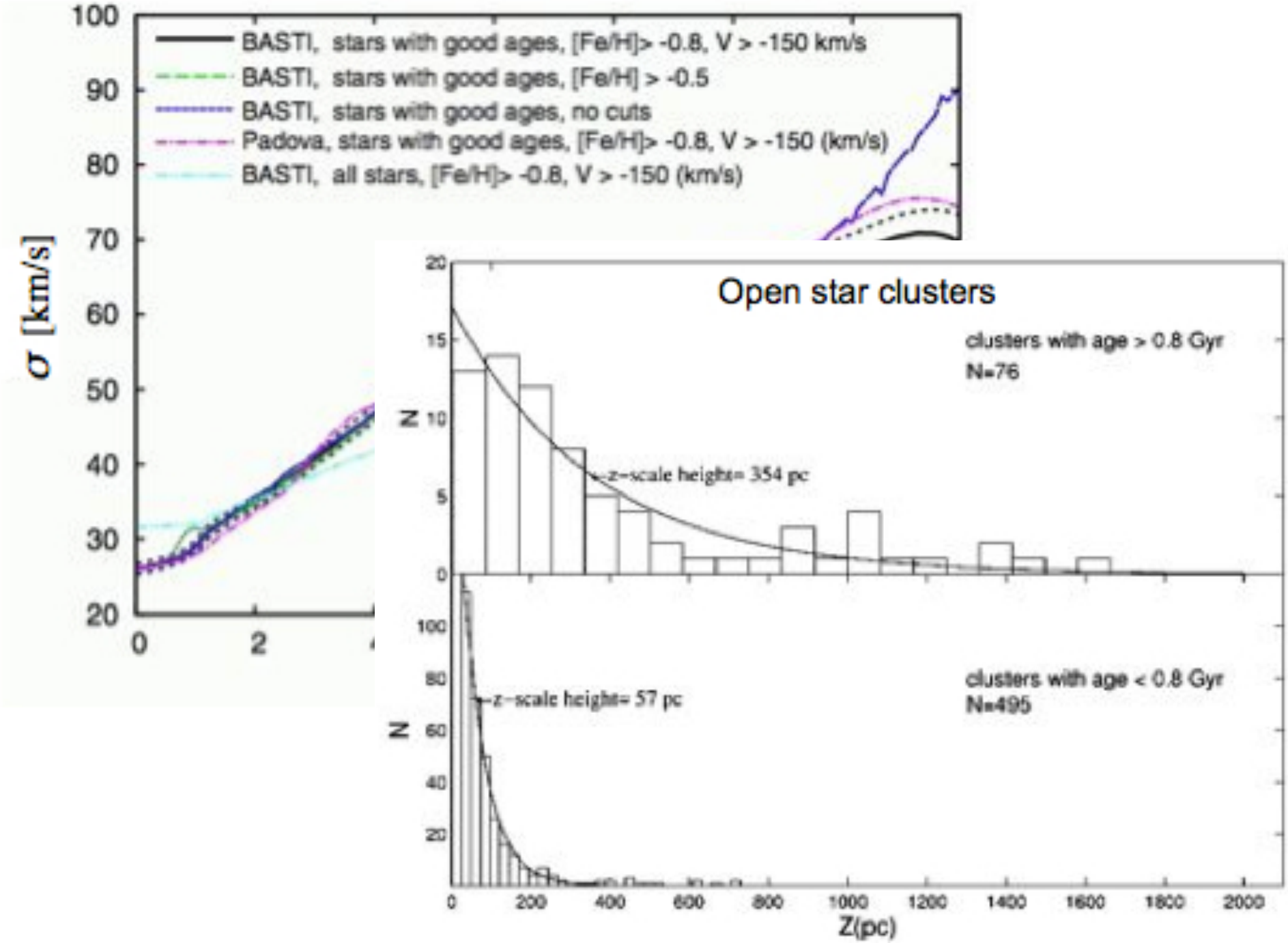


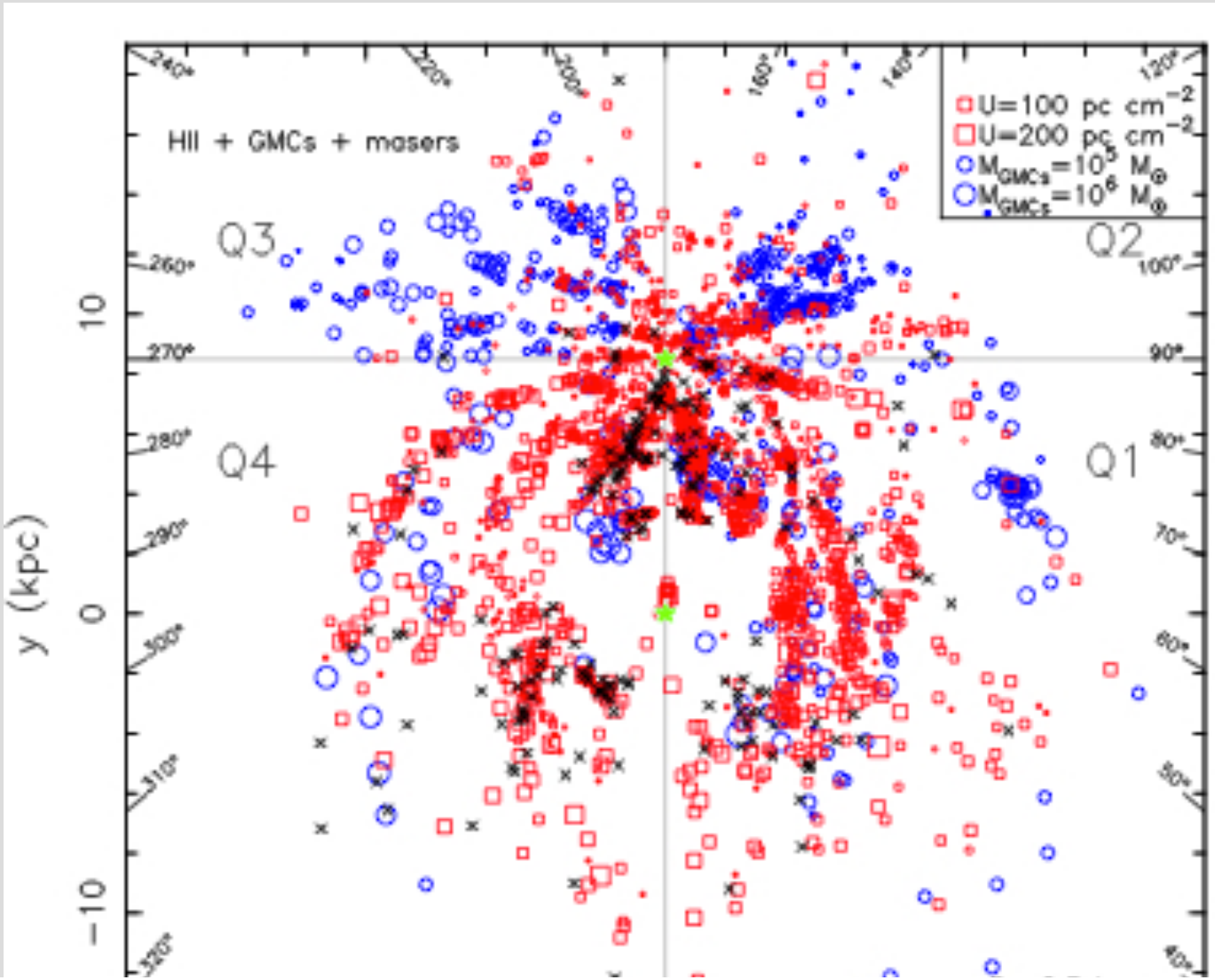




Handling contamination…….


Age > 30 Myr
X (kpc)
15
10
5
0
−5
0
5


BASTI, stars with good ages, [Fe/H]> -0.8, V > -150 km/s
BASTI, stars with good ages, [Fe/H] > -0.5
BASTI, stars with good ages, no cuts
Padova, stars with good ages, [Fe/H]> -0.8, V > -150 (km/s)
BASTI, all stars, [Fe/H]> -0.8, V > -150 (km/s)
σ [km/s]
Open star clusters
clusters with age > 0.8 Gyr
N=76
z-scale height= 354 pc
clusters with age < 0.8 Gyr
N=495
z-scale height= 57 pc
N
Z(pc)



The observed spiral structure of the Milky Way★

Hou & Han 2014

CONCLUSION # 1

Question 1: Is there an ideal Spiral Structure tracer?

HI and CO studies are loosing most of their original *impetus*, since associated uncertainties are more and more understood.

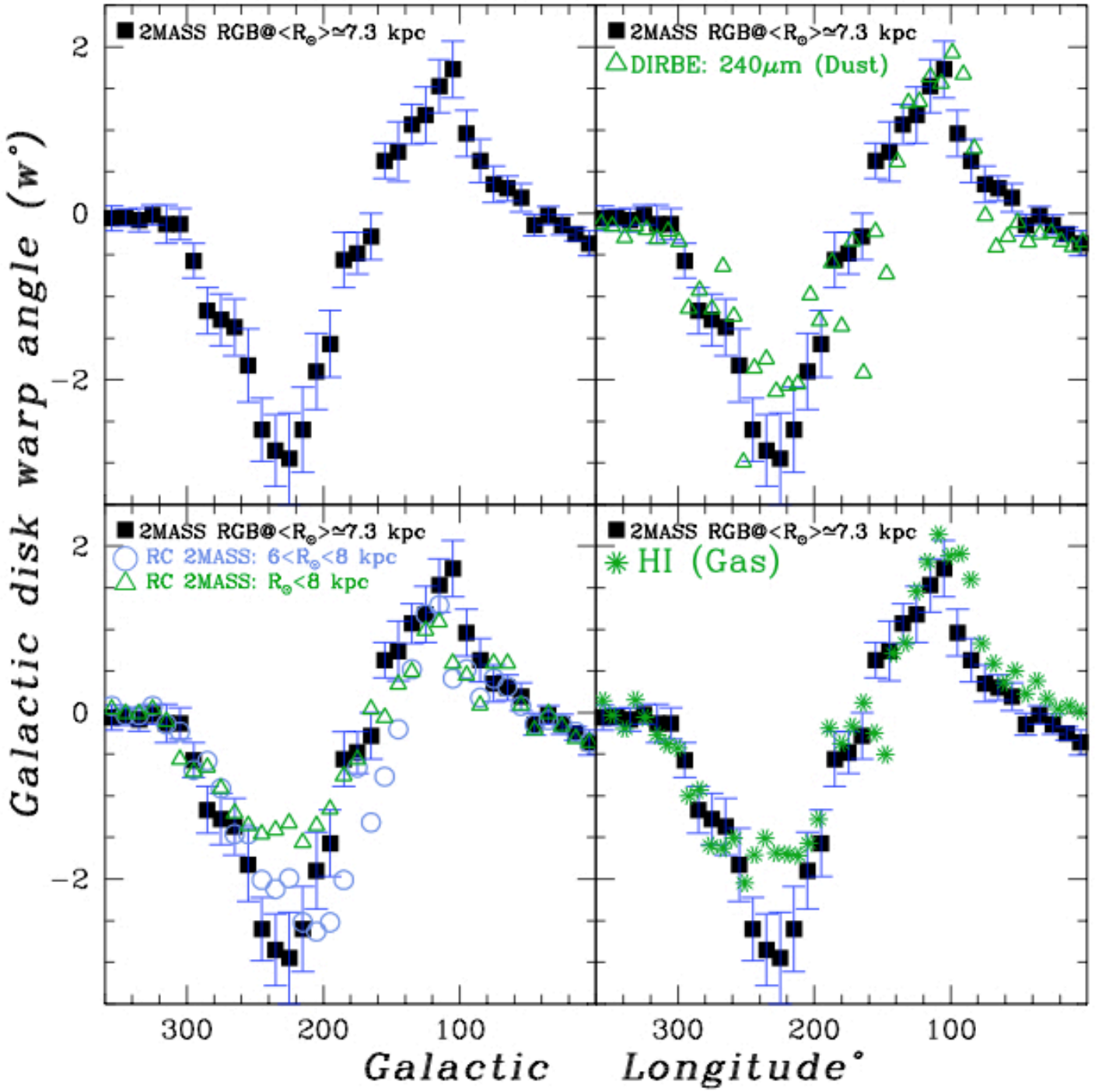
Star counts, star clusters, and masers are slowly re-gaining their role.

Still, we are very far from the solution of the MW spiral structure problem !

THE OUTER MILKY WAY DISK

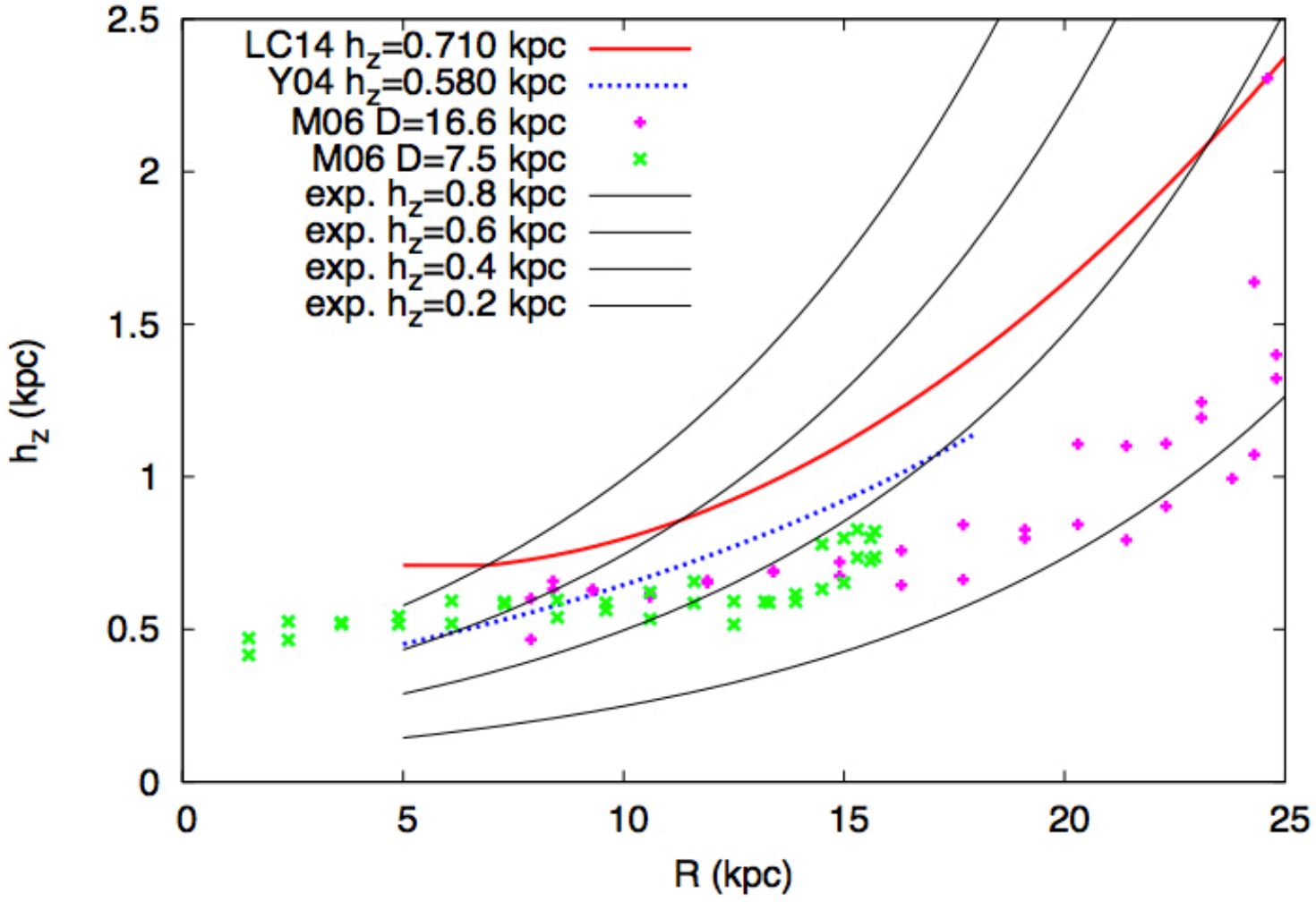
<u>Question II</u>: Do we have a *<u>MODEL</u>* of the MW?

Momany t al. 2006
Moitinho et al. 2006
Carney 1984



WARP !

Kalberla+ 2014; Carraro+2010, 2014; Anderson+ 2014; Lopez-Corredoira and Molgo 2014; Feast+2014; Momany+2006

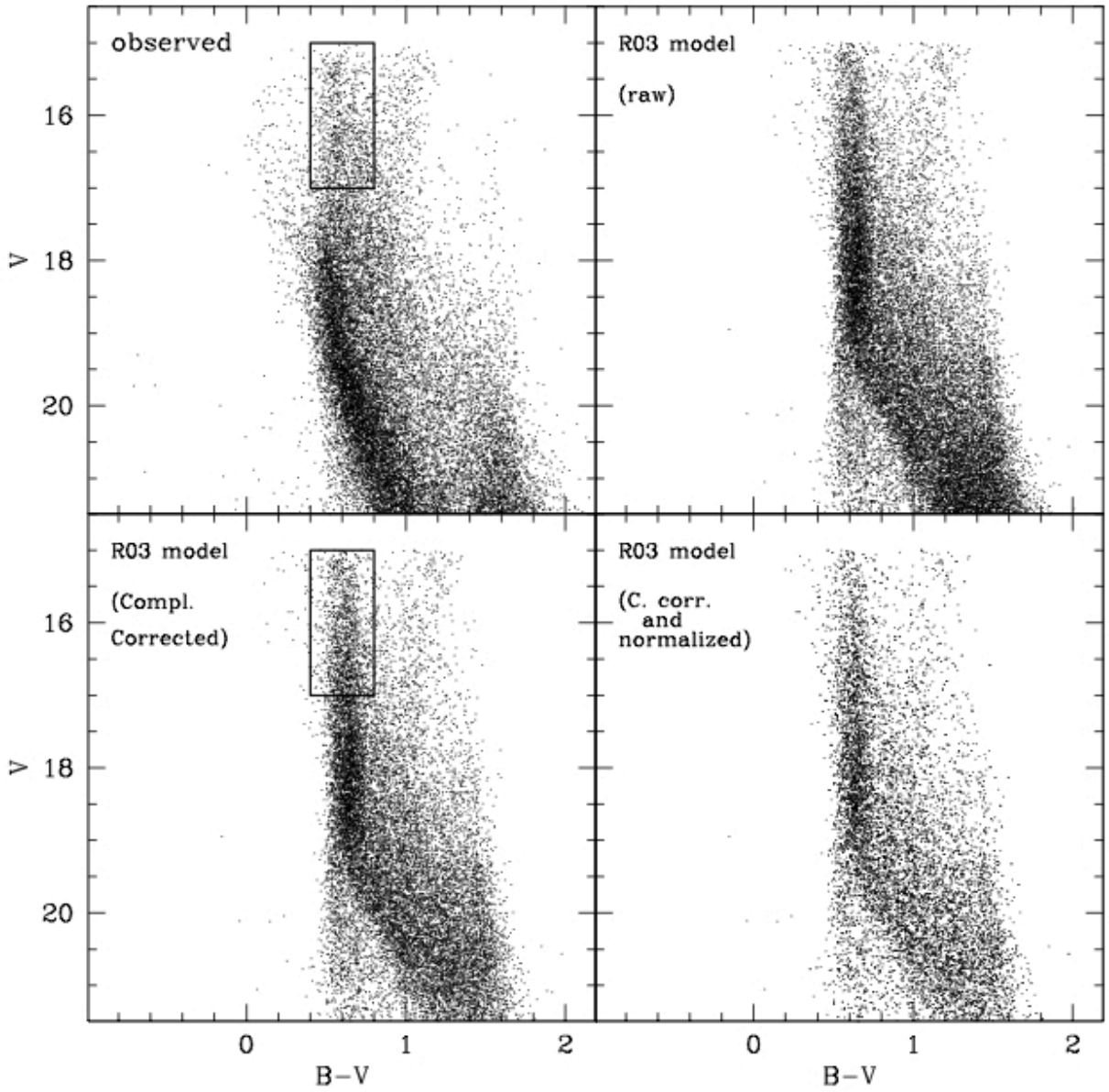


FLARE !

CANIS MAJOR

l = 244

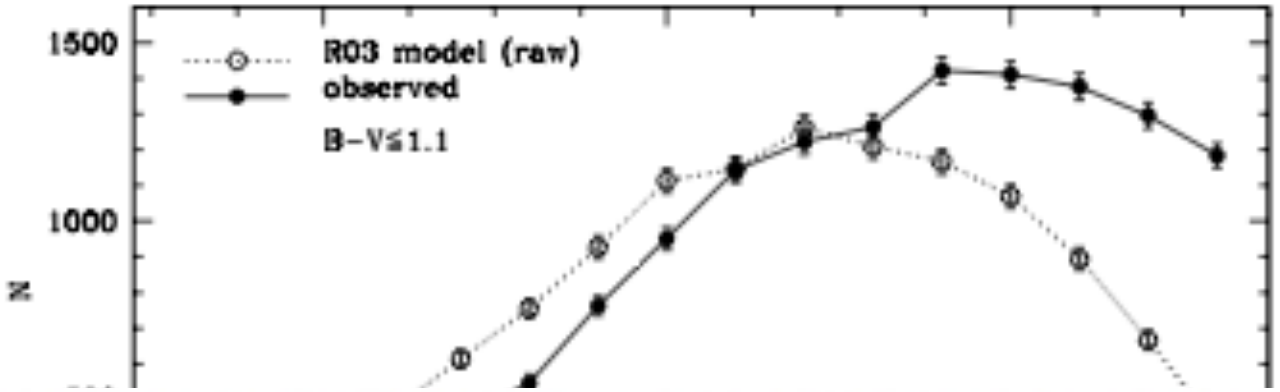
b=-8



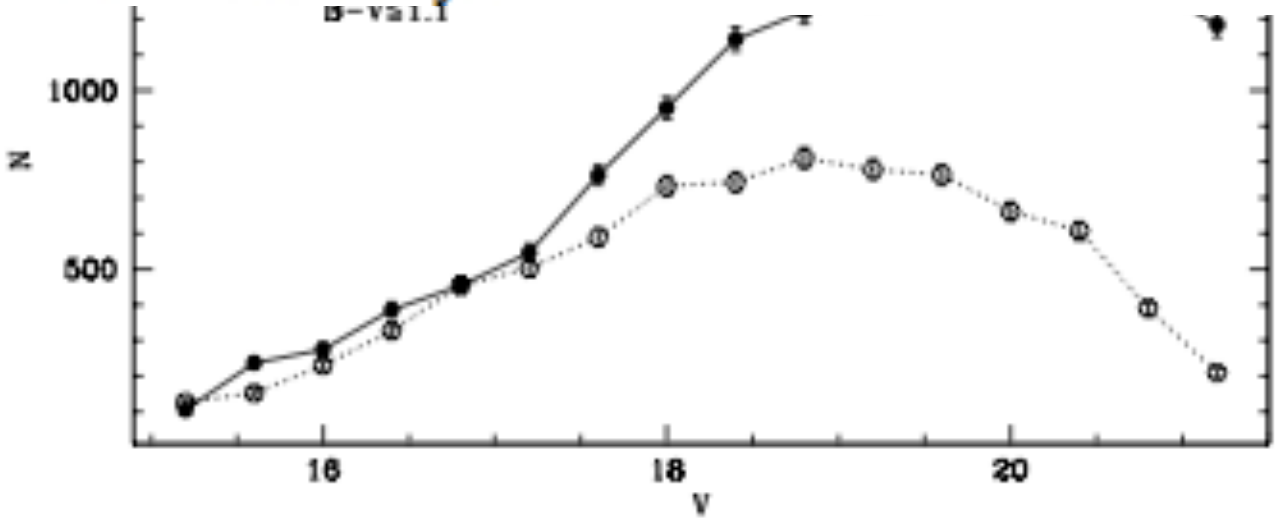
Bellazzini et al. 2004
Martin et al. 2004

Figure 3. Comparison with the observed CMD of F-*XMM* (upper left-hand panel) and the synthetic CMD from the Galactic model by R03. Upper right-hand panel: raw synthetic CMD. Lower left-hand panel: synthetic CMD corrected for incompleteness. Lower right-hand panel: synthetic CMD corrected for incompleteness and normalized to have the same number of stars as the observed CMD in the selection box plotted in CMDs on the left-hand panels.

CANIS MAJOR

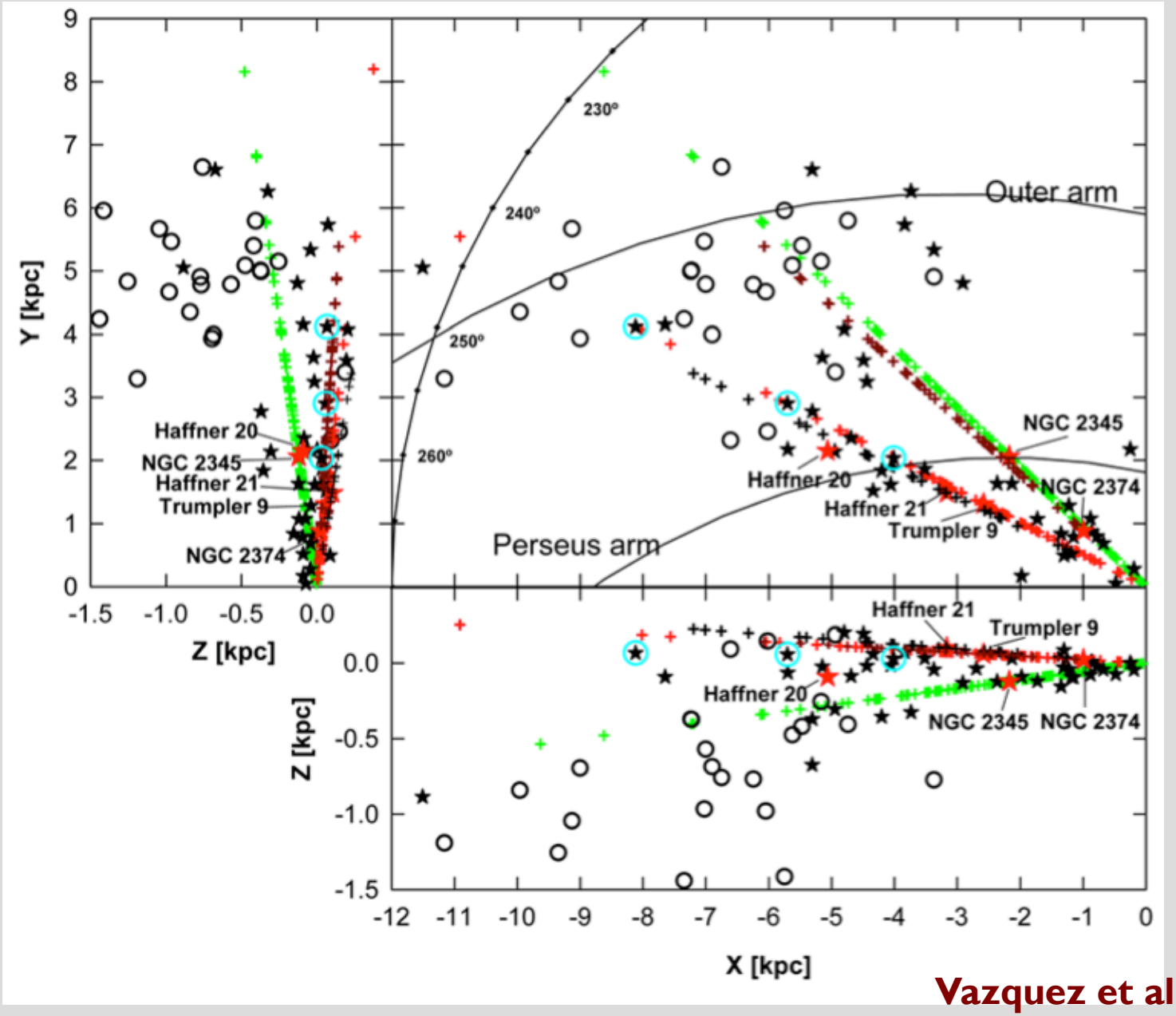


From the above comparisons we conclude that in the F-*XMM* there is indeed a conspicuous stellar population that is not comprised in the R03 Galactic model. We identify this population with the newly discovered CMa stellar system



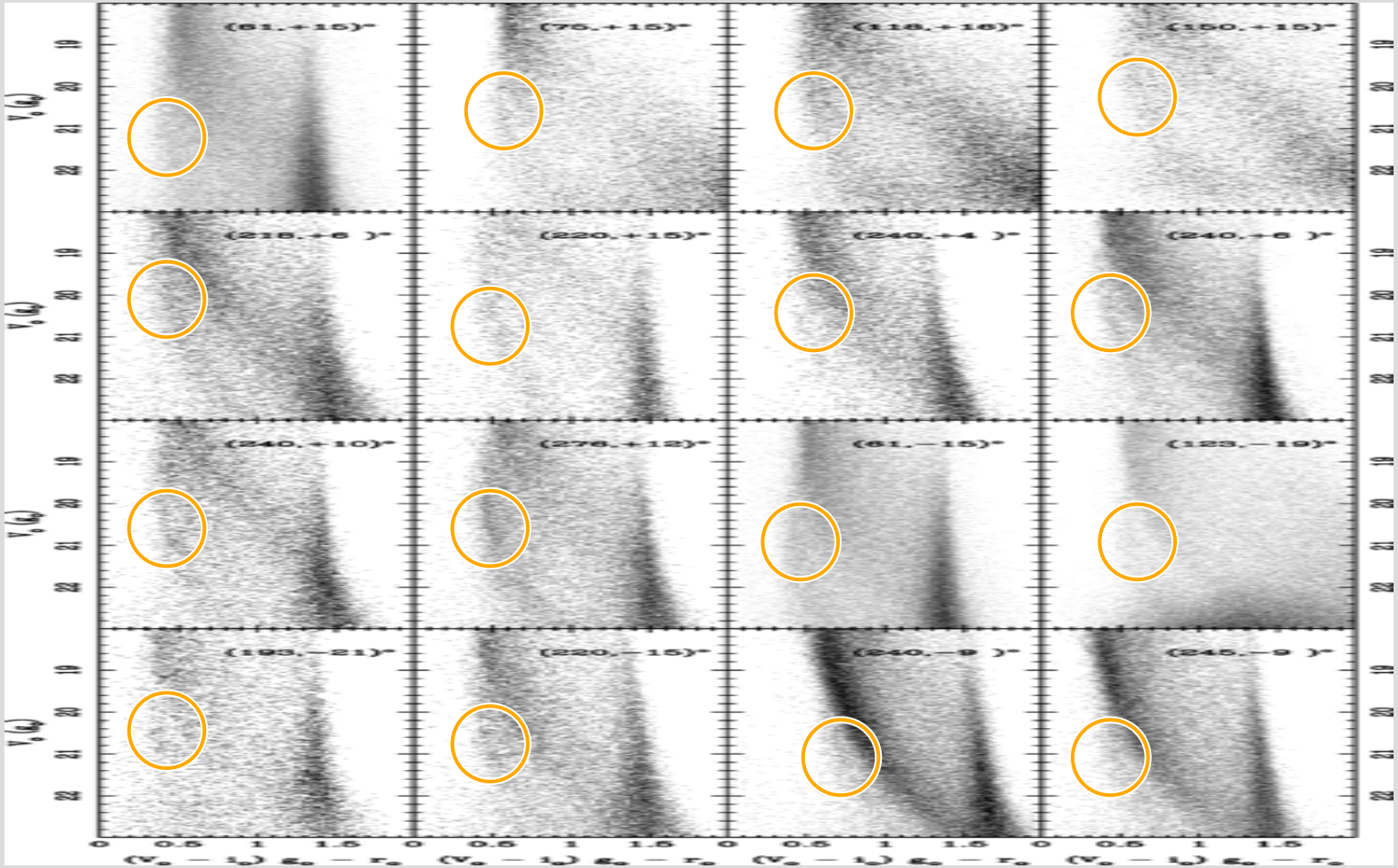
Bellazzini et al. 2004
Martin et al. 2004

CANIS MAJOR



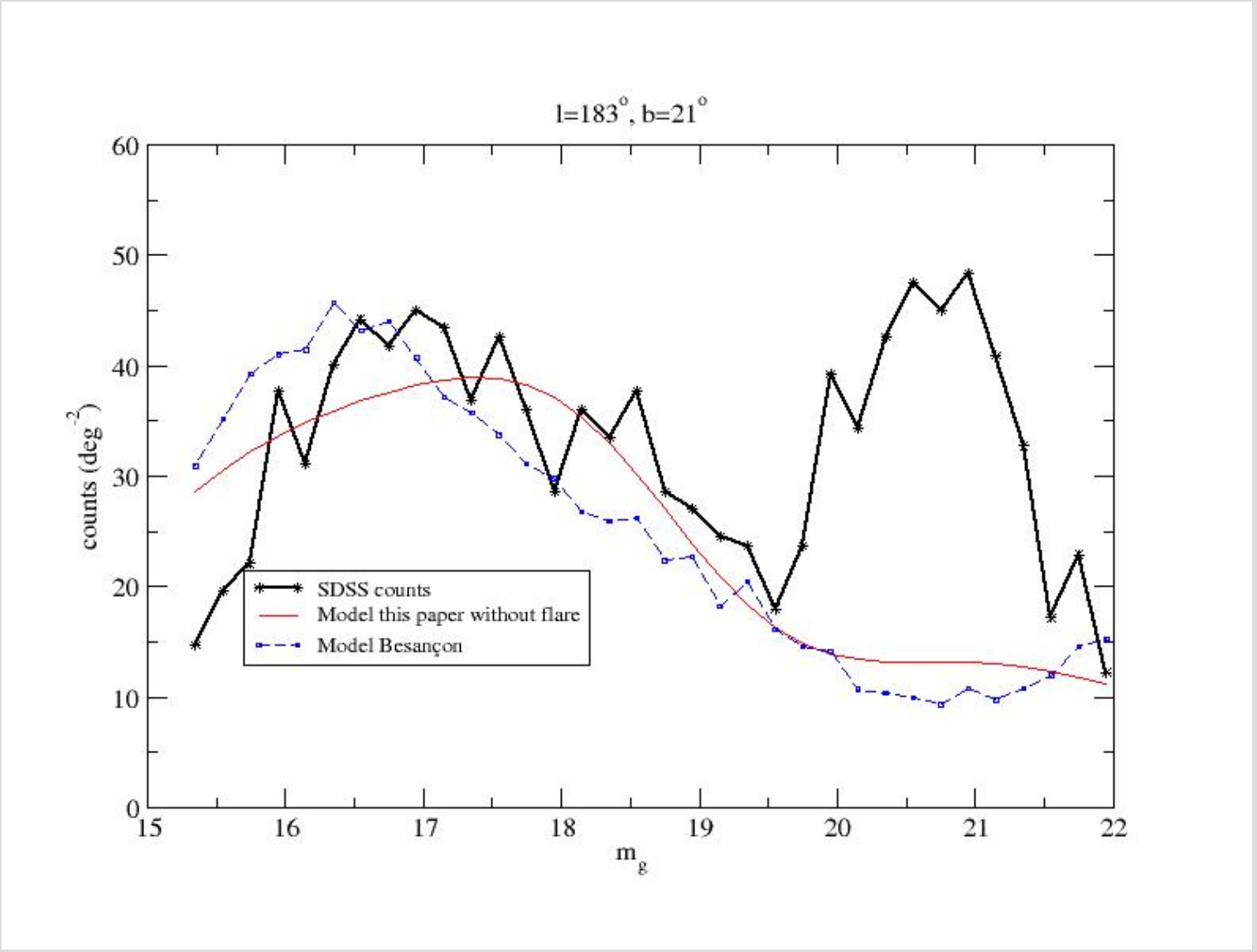
Vazquez et al. 2008

MONOCEROS RING



Conn et al. (2008)

MONOCEROS RING



Lopez-Corredoira et al. 2012, Carraro et al. 2014

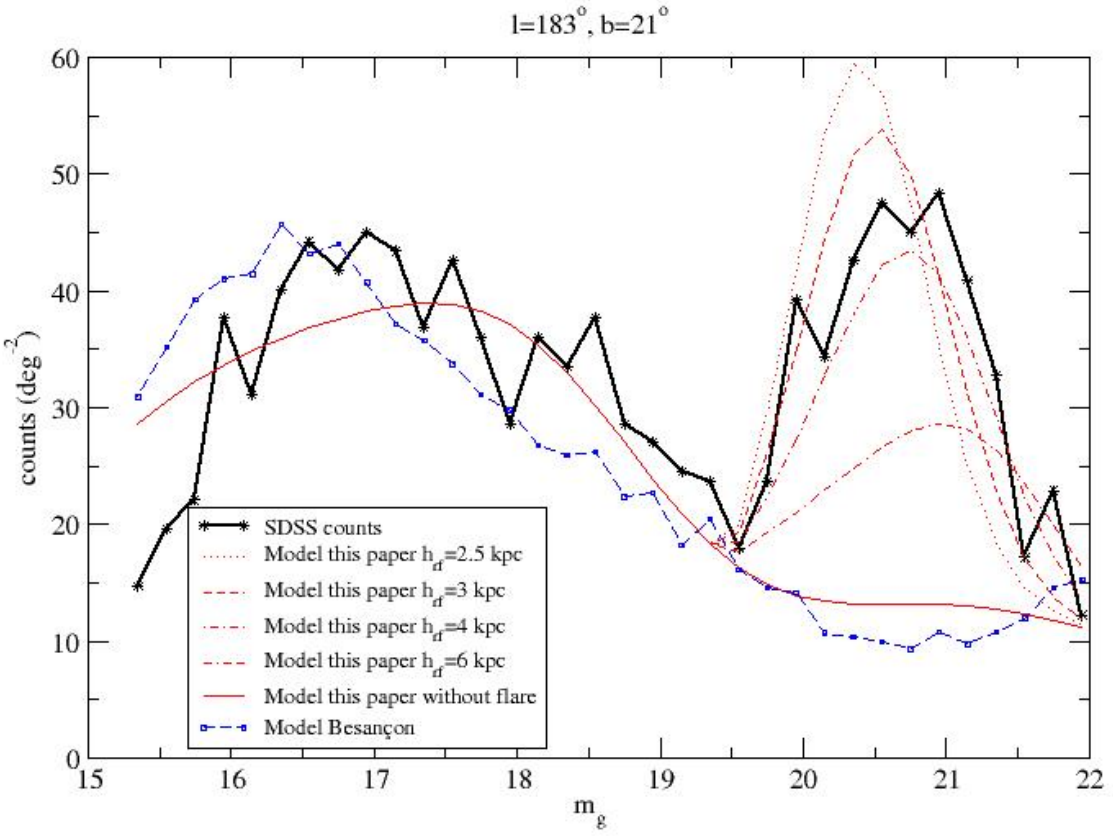
MONOCEROS RING

A thin+thick disc with each component:

$\rho(R,z) = \rho_{sun}\, h_{z,sun}/h_z(R)\, e^{((-R+Rsun)/hR)}\, e^{-|z|/hz(R)}$

flared at R>16 kpc:

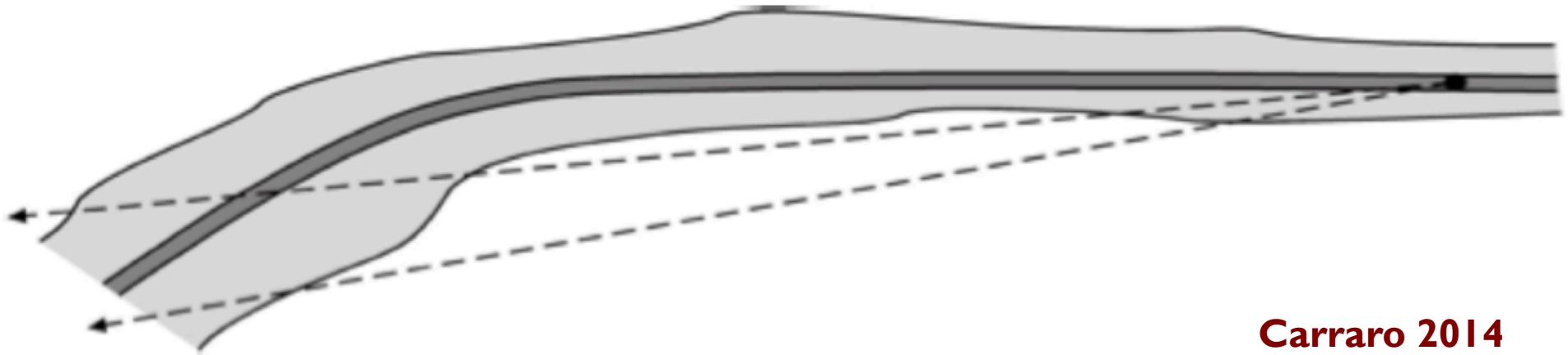
$h_z(R) = h_z(R_{sun})\, e^{(R-16\ kpc)/hrf}$



Lopez-Corredoira et al. 2012

DISK BREAK/CUT-OFF/TRUNCATION

The Besancon model has hard-coded a cut-off of the disk at 14 kpc from the Galactic Center;



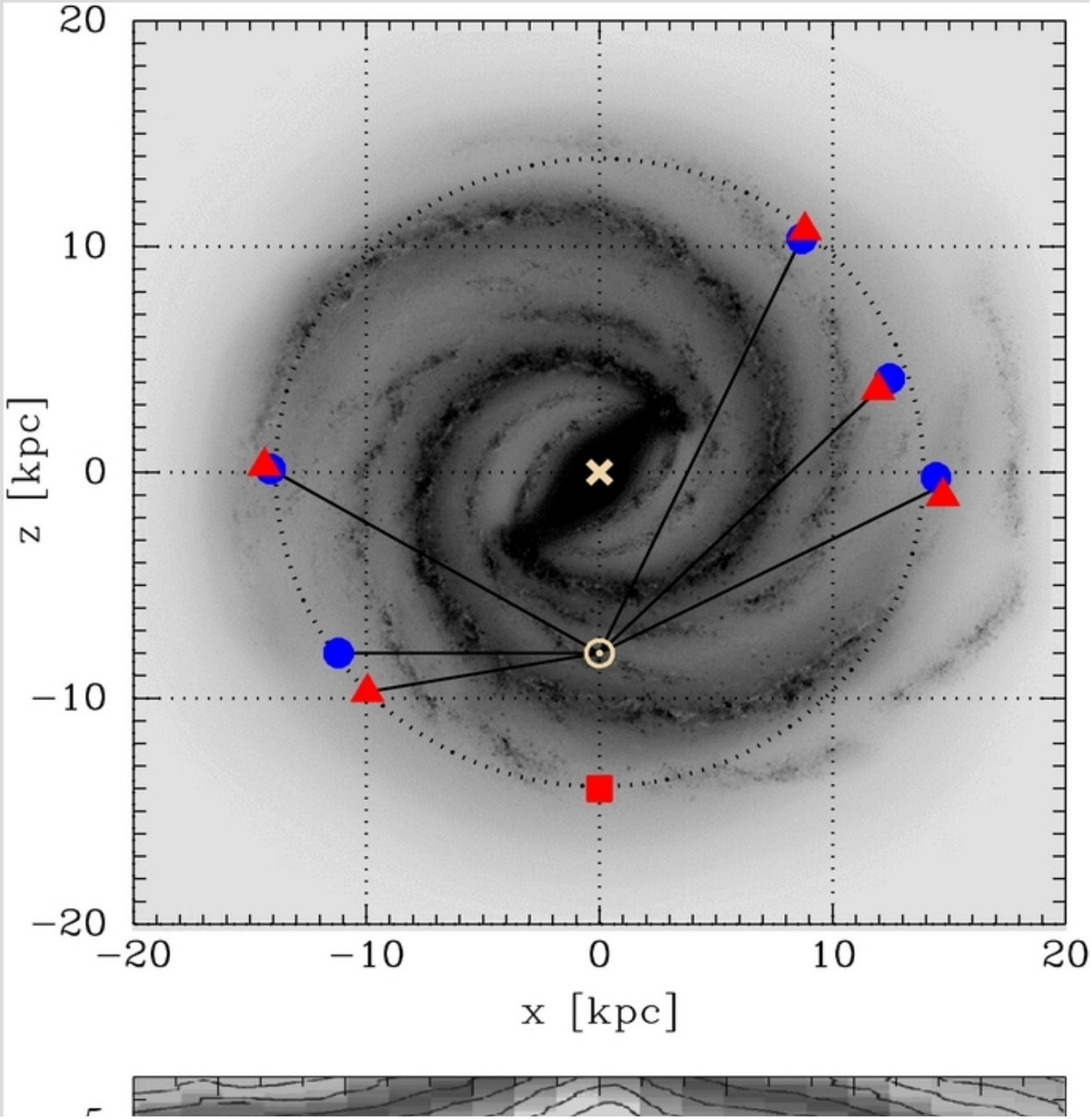
Carraro 2014

DISK BREAK/CUT-OFF/TRUNCATION

-Minniti et al. 2012

-Robin et al. 1992

-Sale et al. 2010



DISK BREAK/CUT-OFF/TRUNCATION

Robin et al. 1992

F/G stars

EDGE at 14 kpc !!

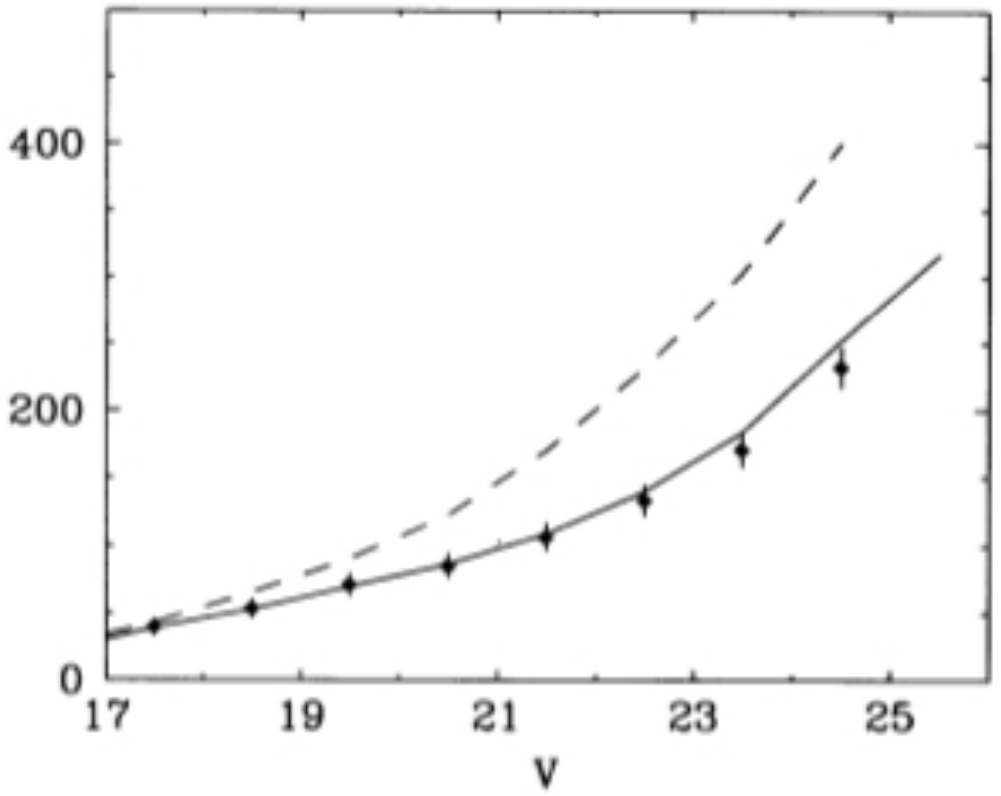


FIG. 2.—*V* star counts to magnitude 25 in the anticenter direction. *Diamonds:* Observed counts with 1 σ error bars (Poisson noise only). *Dashed line:* Predicted counts assuming no cutoff in the radial distribution of stars. *Solid line:* Predicted counts assuming a cutoff at 5.5 kpc from the Sun.

DISK BREAK/CUT-OFF/TRUNCATION

Sale et

A star

IPHAS

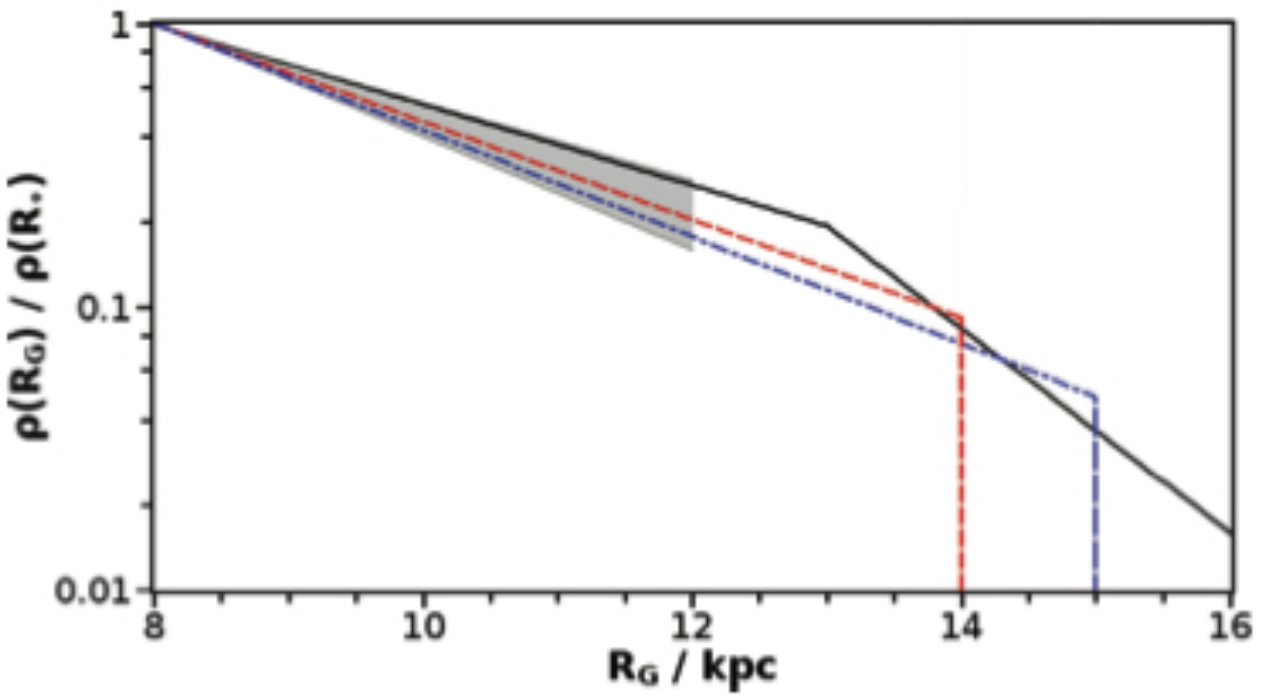
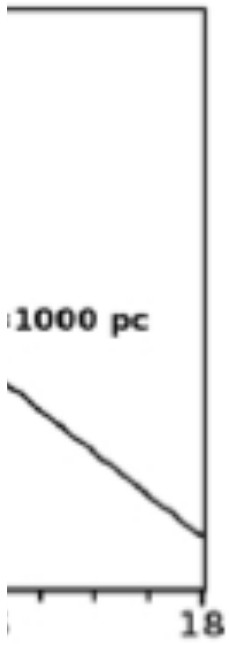


Figure 8. The best-fitting radial density profile derived in this study is shown in black. For comparison, the profiles of Robin et al. (1992) (red dashed line) and Ruphy et al. (1996) (blue dot–dashed line) are also shown, whilst the grey region indicates the inner scalelength found by Jurić et al. (2008). Note that the high Galactic latitude of the SDSS observations employed by Jurić et al. (2008) prevents them from observing features far beyond the Solar Circle and so they cannot observe the truncation of the disc. All profiles on this plot have been normalized to the density at the Solar Circle.

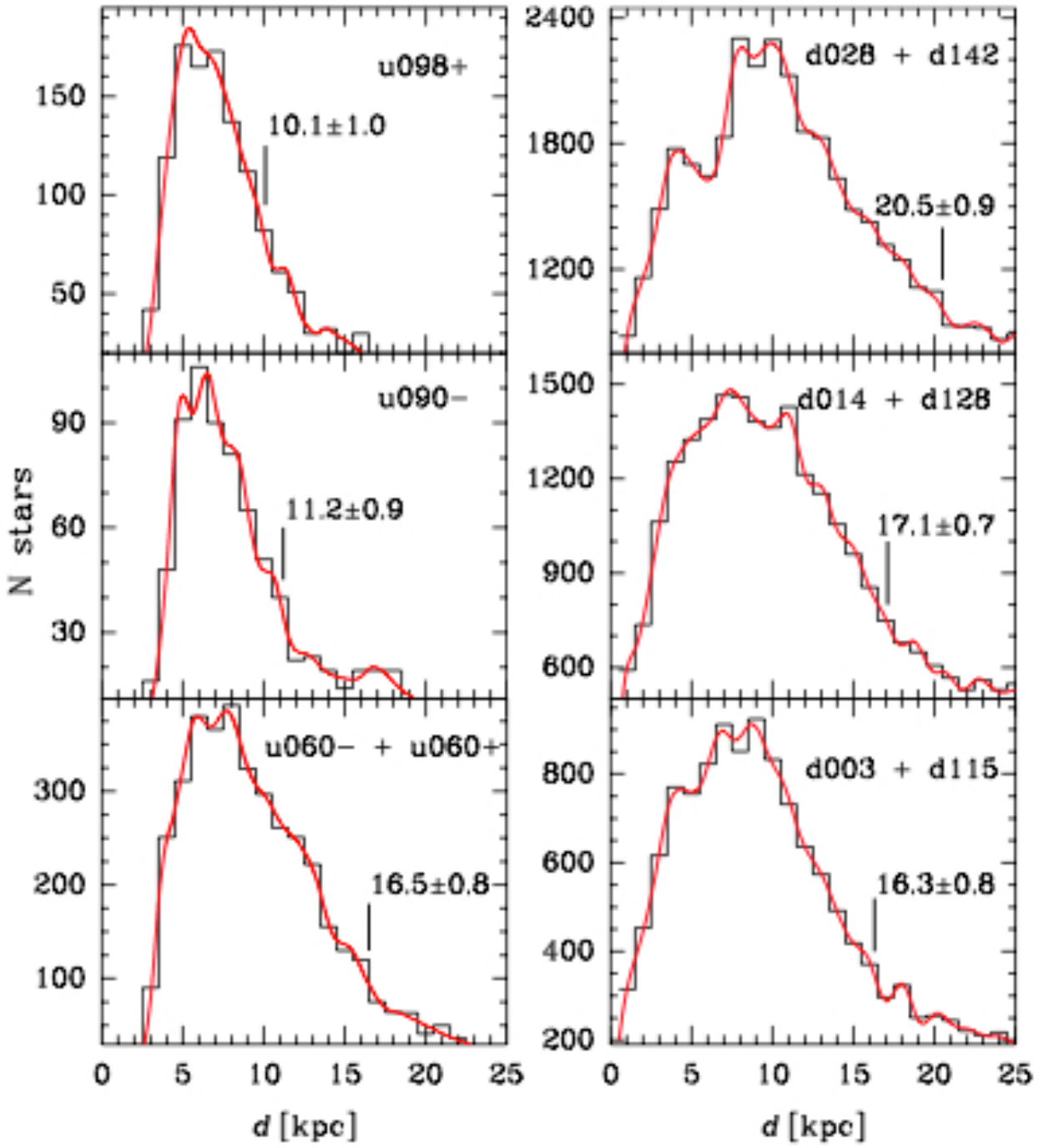


employed in
scalelength,
= 14 kpc, as

Minniti et al 2012

Red clump stars

VVV (IR)



CONCLUSION # II :

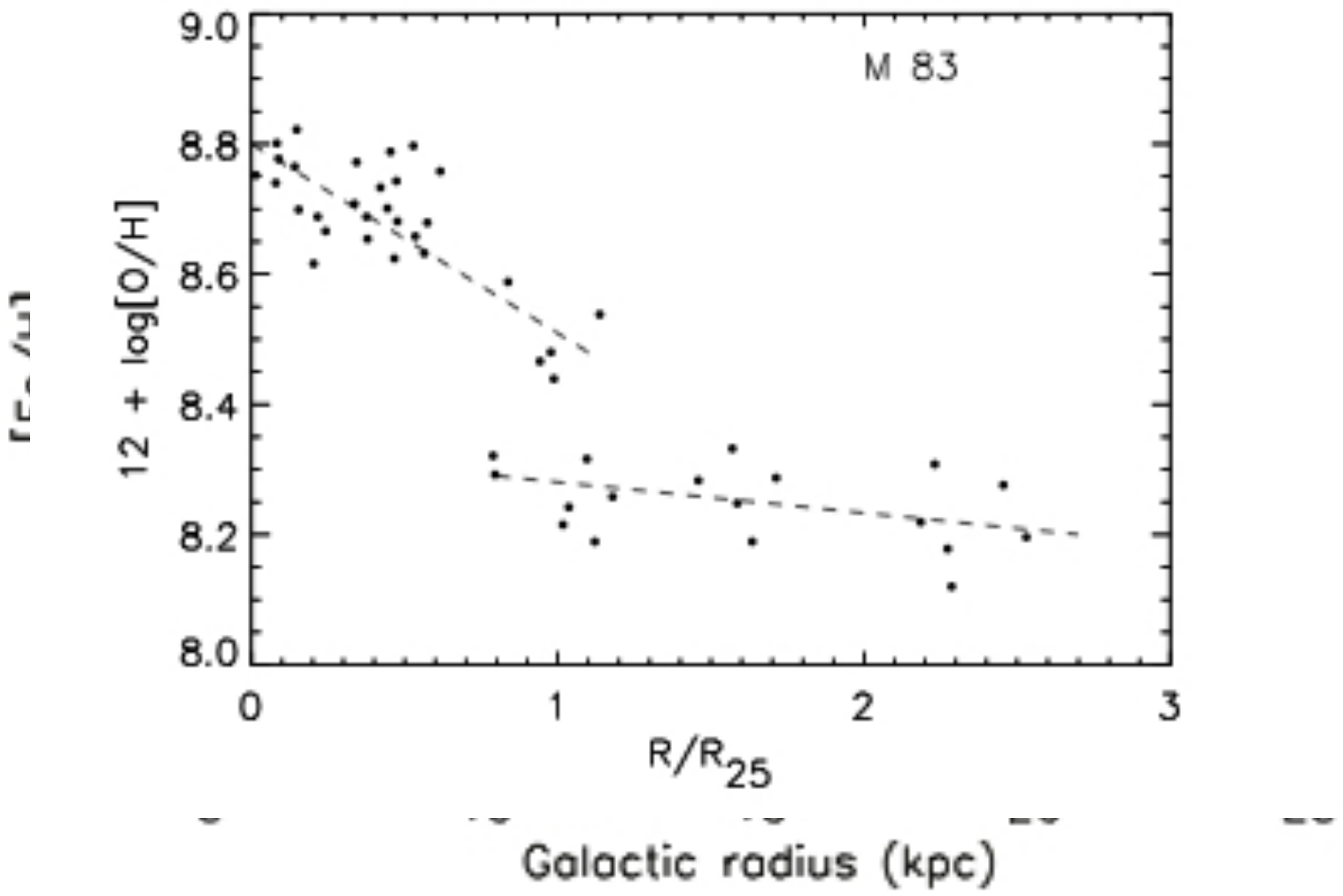
Actual models for the Galactic disk must be used with care if we want to predict the stellar populations in the disk and plan future surveys.

One has to avoid the very inner regions of the disk, where the models *by definition* do not work.

Extrapolations from model results should be taken *cum grano salis*, and conclusions from them deeply pondered.

The MW disk break, if confirmed, occurs at about the same starting location of the warp/flare…… --→ See Benjamin talk

Question II: Do we have a *MODEL* of the MW?



Lepine+ 2011, Magrini+2009,Carraro+2007,Bresolin+2009