MAPPING THE GALACTIC BULGE
with recent surveys

Manuela Zoccali
PUC Chile

The question: how did the Milky Way form?

bulge is old, massive component.

The clues:

- The bulge shape

  spheroid? triaxial? bar? boxy? peanut?

- The bulge age

  uniformly old? gradient? bar age?

- The bulge chemical content

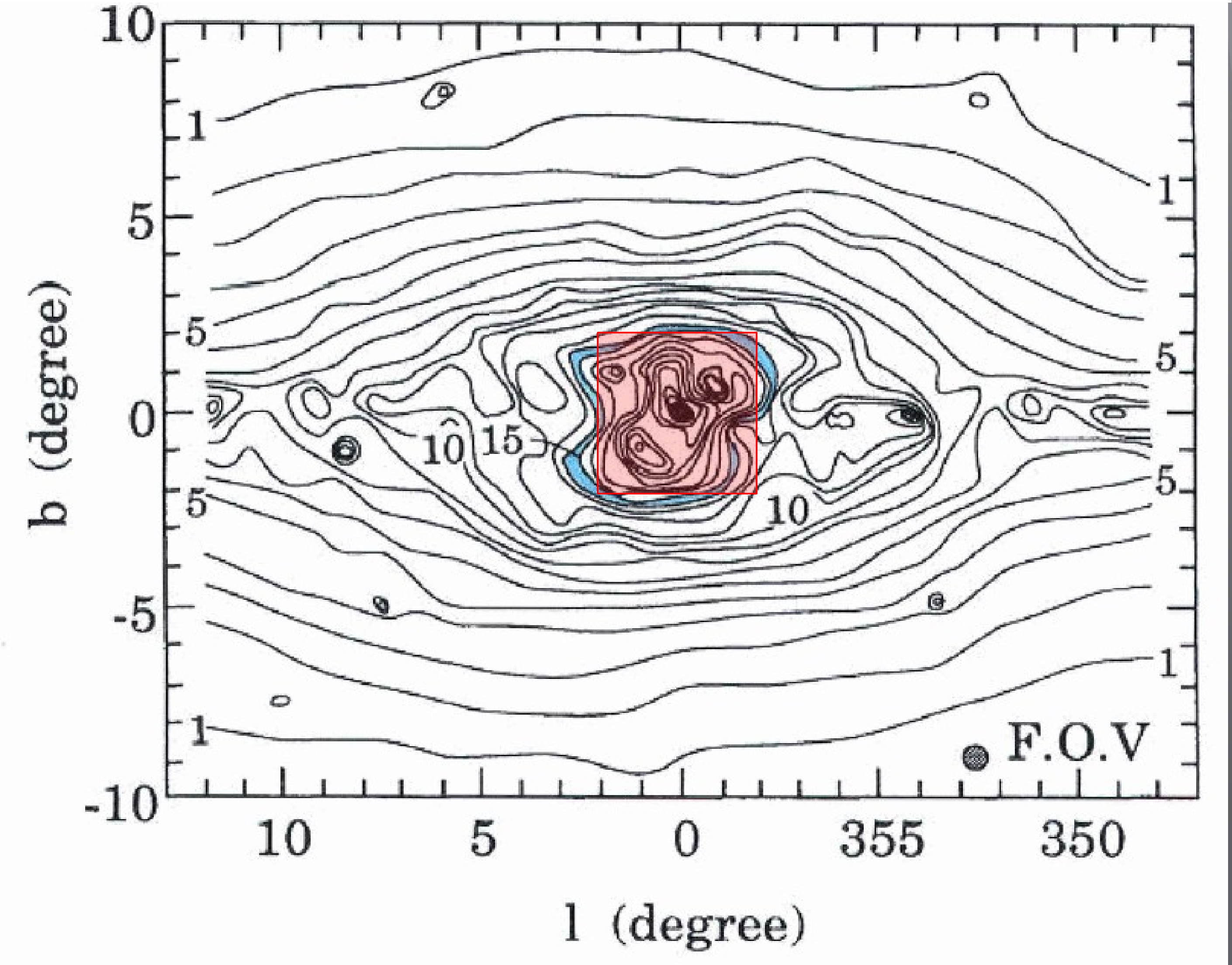
  metallicity distribution broad/narrow? closed box?
  vertical/radial metallicity gradient?
  element ratios? formation timescale
  comparison with inner/outer thin/thick disk

BULGE SHAPE First Ideas

1980s – Balloon Infrared maps of the Bulge

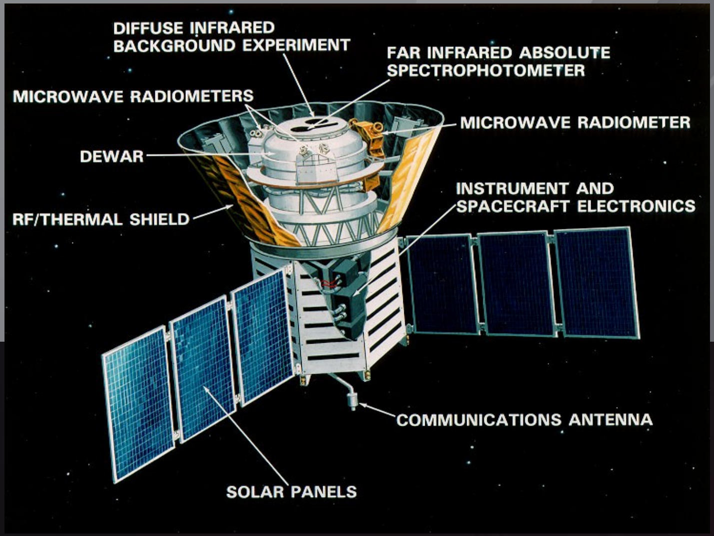
asymmetry in the contour map indicate a triaxial spheroid (bar)

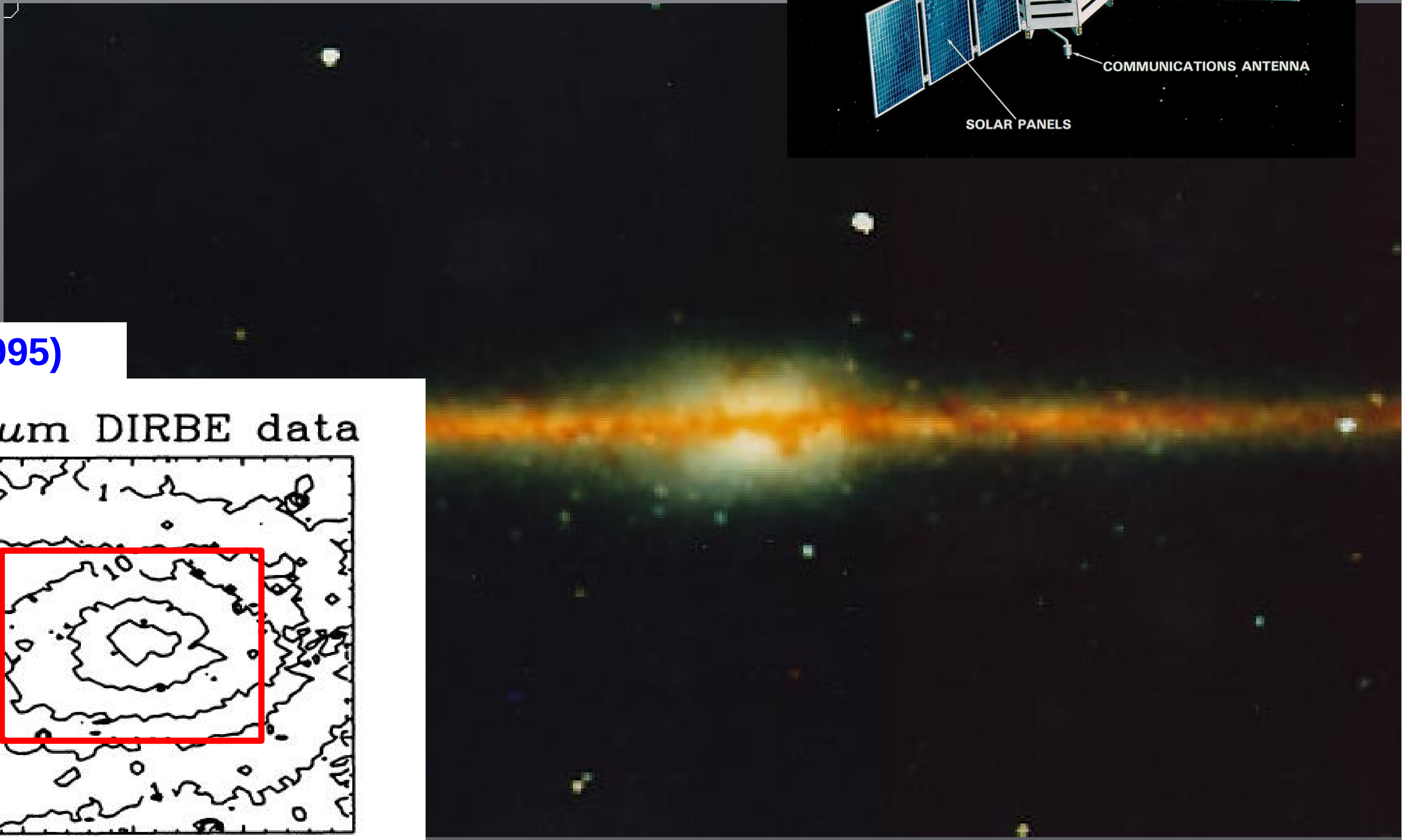
Blitz & Spergel (1991) on the 2.4μm map of Matsumoto et al.(1982)



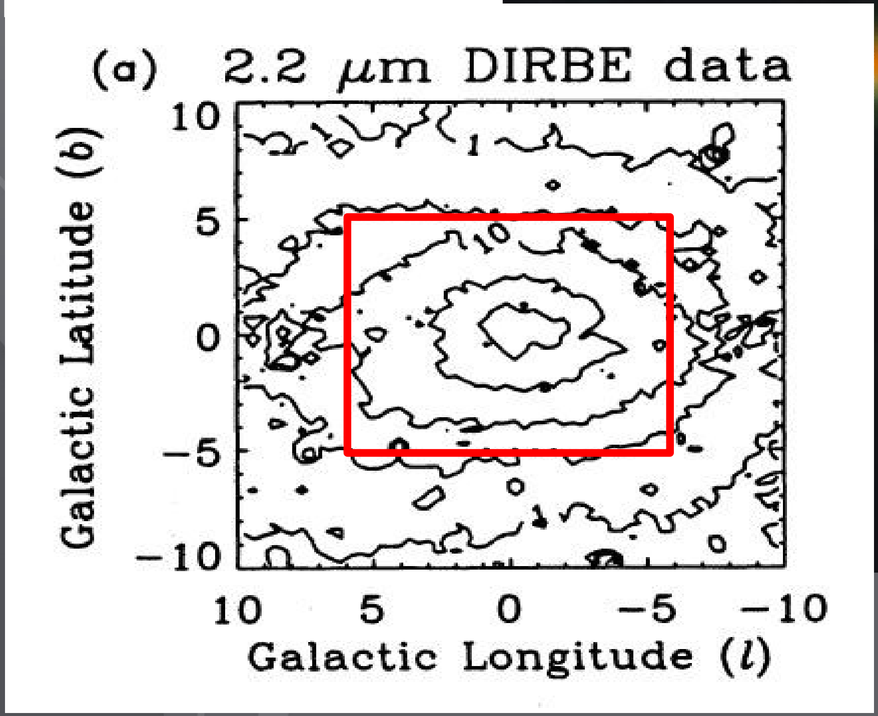
1990s – COBE Diffuse InfraRed Background Experiment

boxy bulge (=bar) confirmed



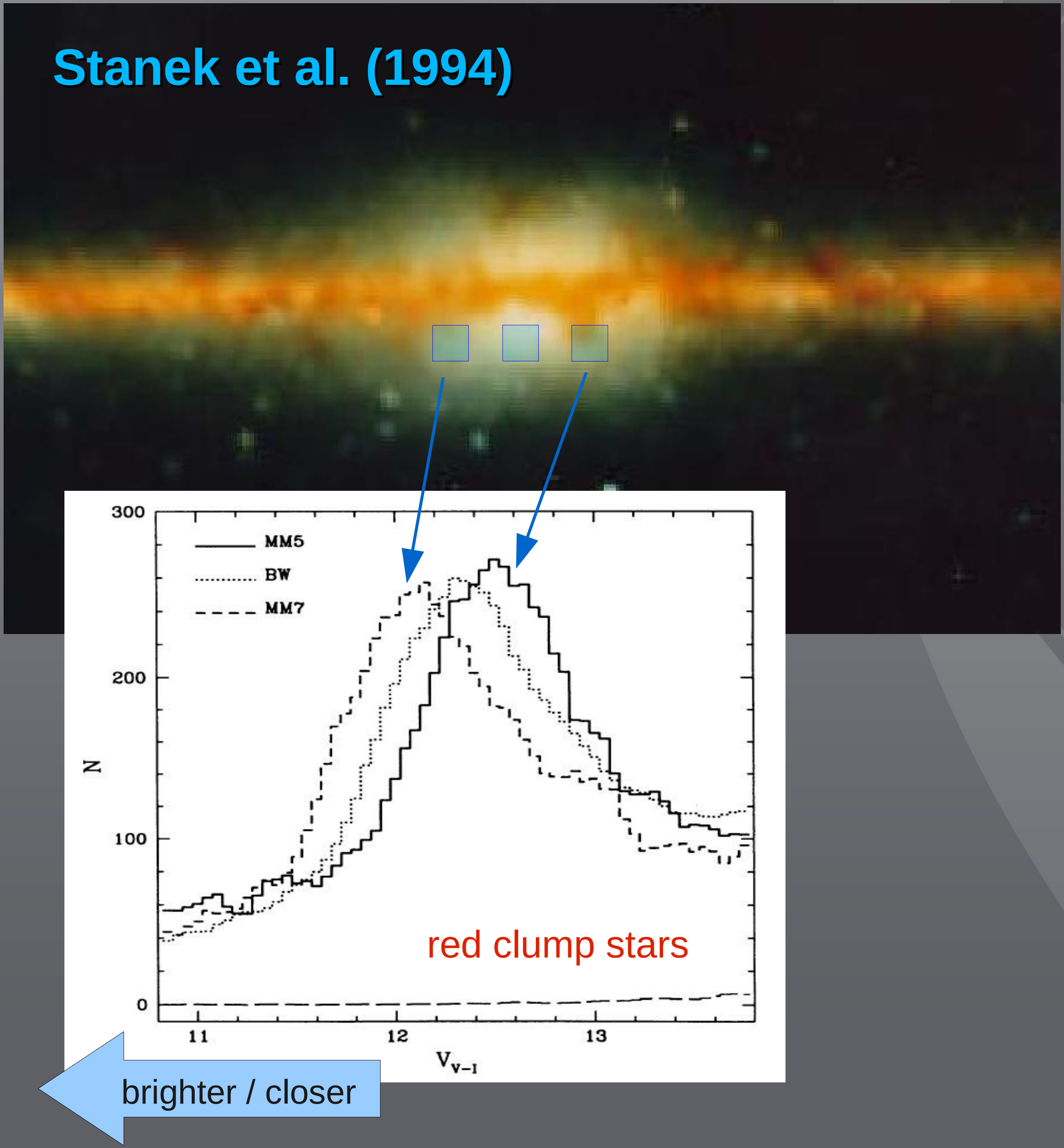


Dwek et al. (1995)



Further evidences of
a **Galactic bar**

Observational evidence:
stars at positive longitudes are brighter (closer) than those at negative longitudes.



2000s – **GLIMPSE I, II, 3D**

3.6 4.5 5.8 8 µm

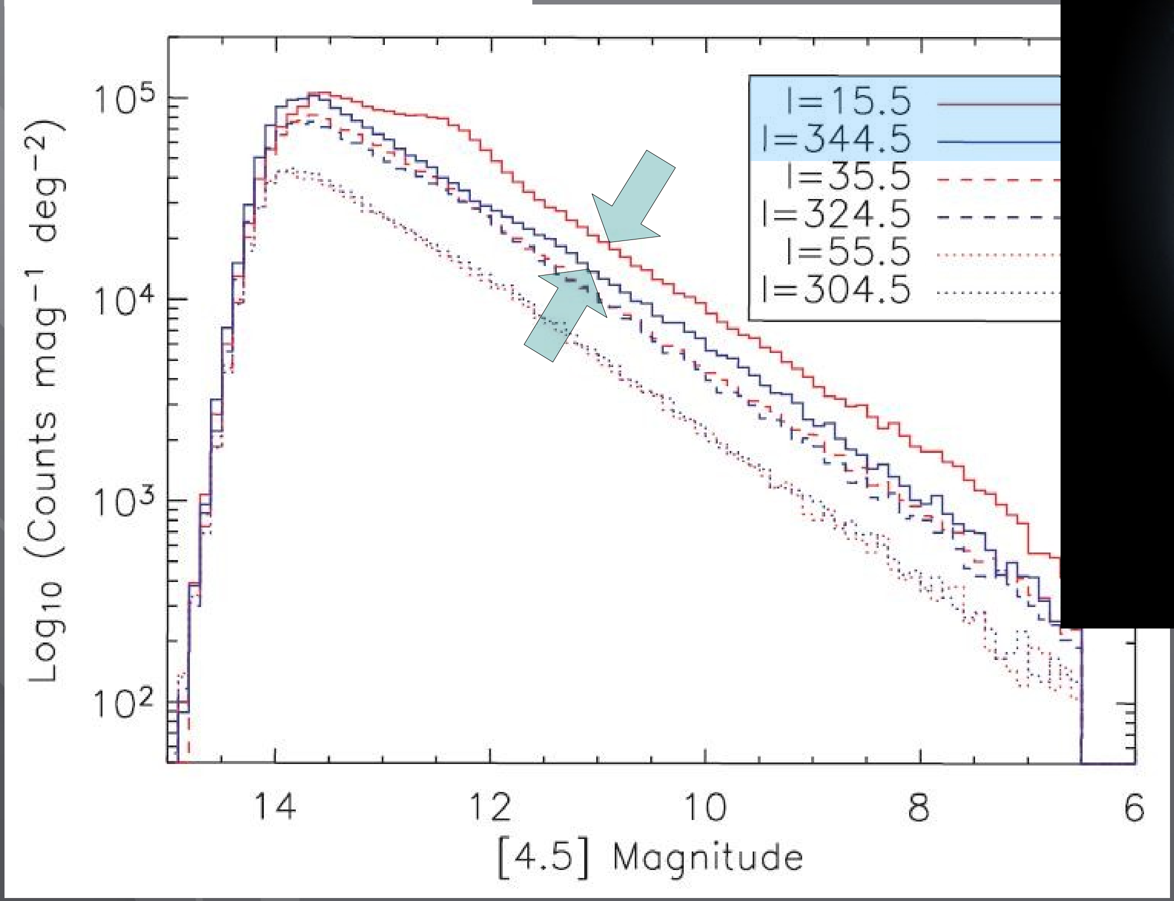
~ 2” resolution

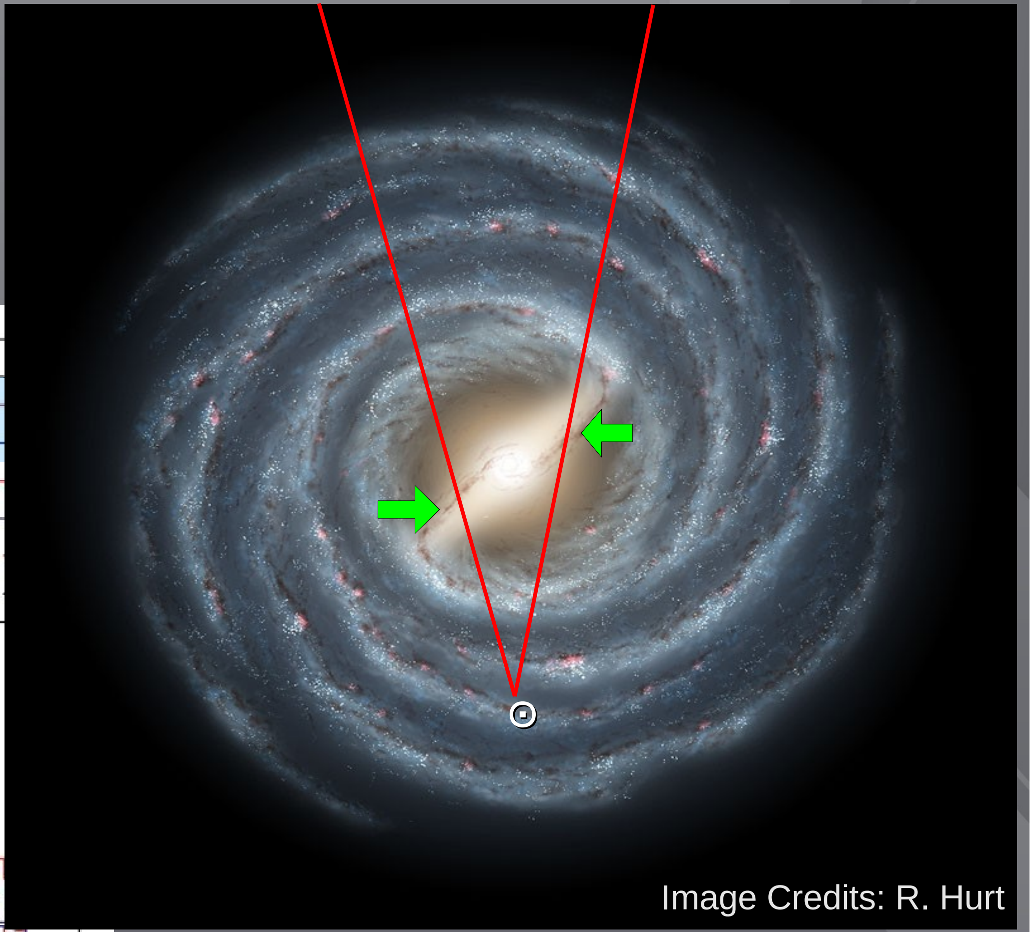
GLIMPSE 3D
~20,500,000 point sources

GLIMPSE I, II, 3D – The Galactic Bar

stars at positive longitudes are brighter (closer) than those at negative longitudes.

Benjamin et al. (2005)

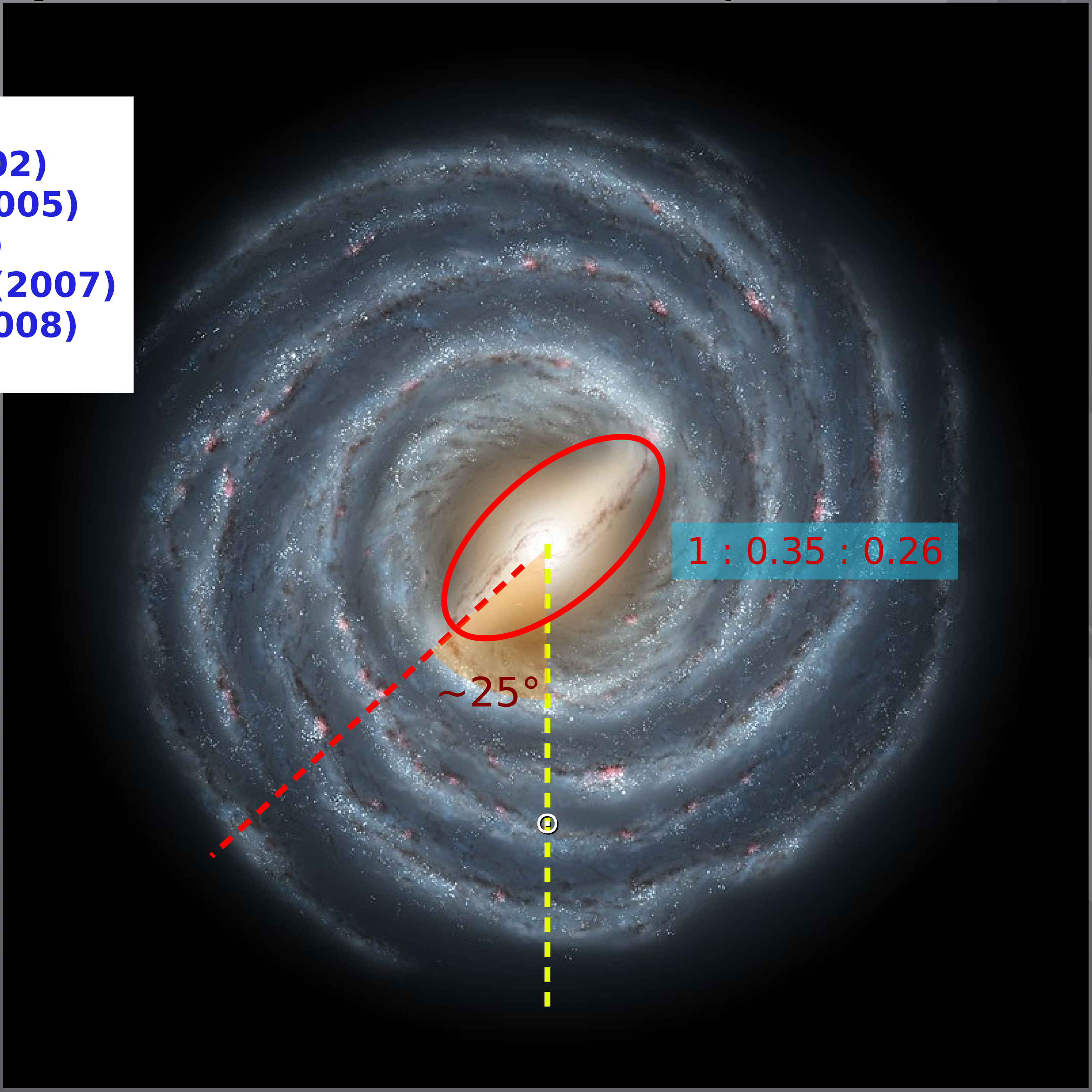




R_{bar}= 4.4±0.5 kpc ϕ_{bar}= 44°±10°

a convergence picture of the MW..... up to 2010

e.g.
Bissantz & Gerhard (2002)
Babusiaux & Gilmore (2005)
Rattenbury et al. (2007)
Lopez Corredoira et al. (2007)
Cabrera Lavers et al. (2008)
...



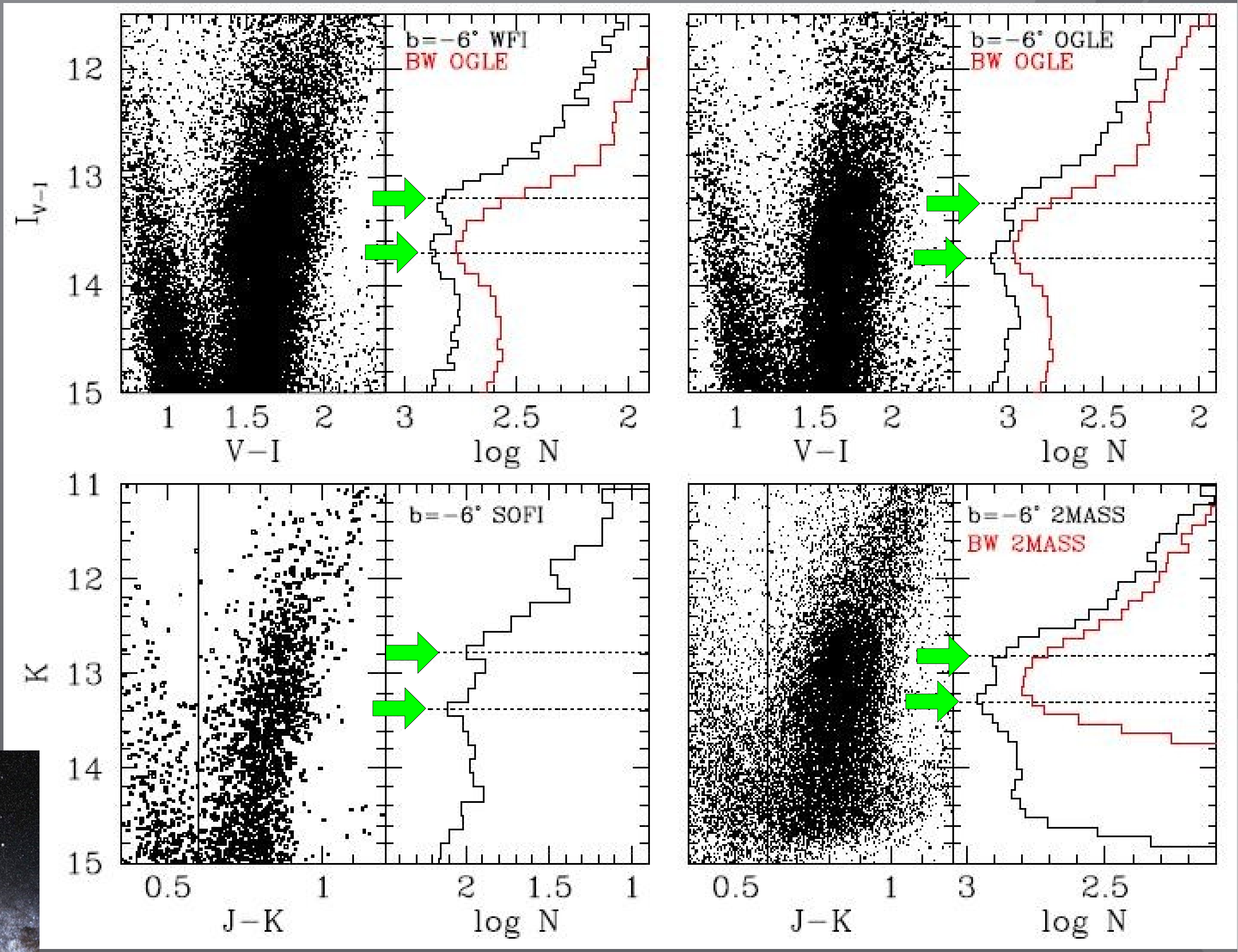
2010s – The X-shaped bulge

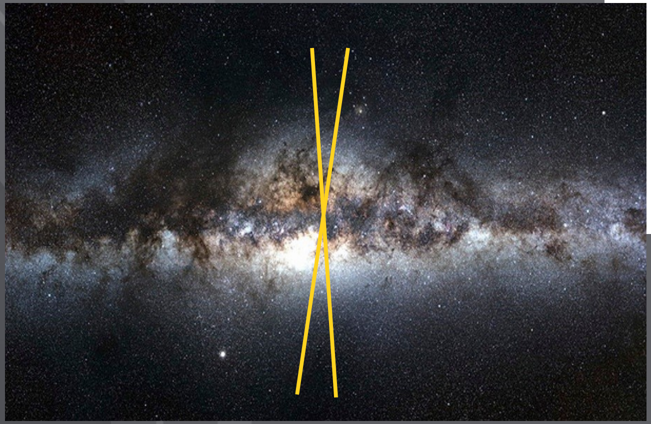
Nataf et al. 2010

McWilliam & Zoccali 2010

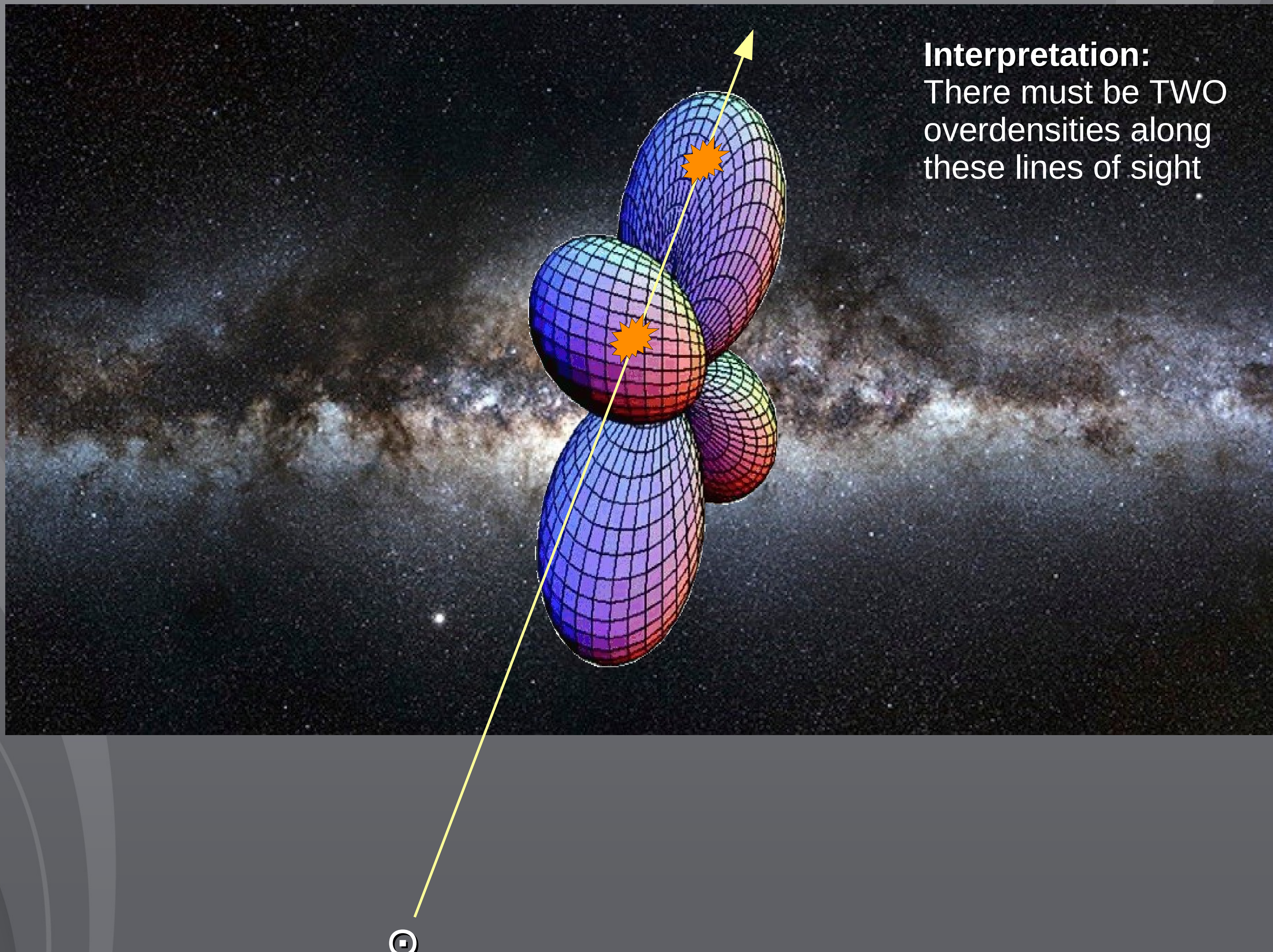
Saito et al. 2011

Observational evidence:
The bulge red clump splits in two, along the minor axis (l=0) and for |b|>5

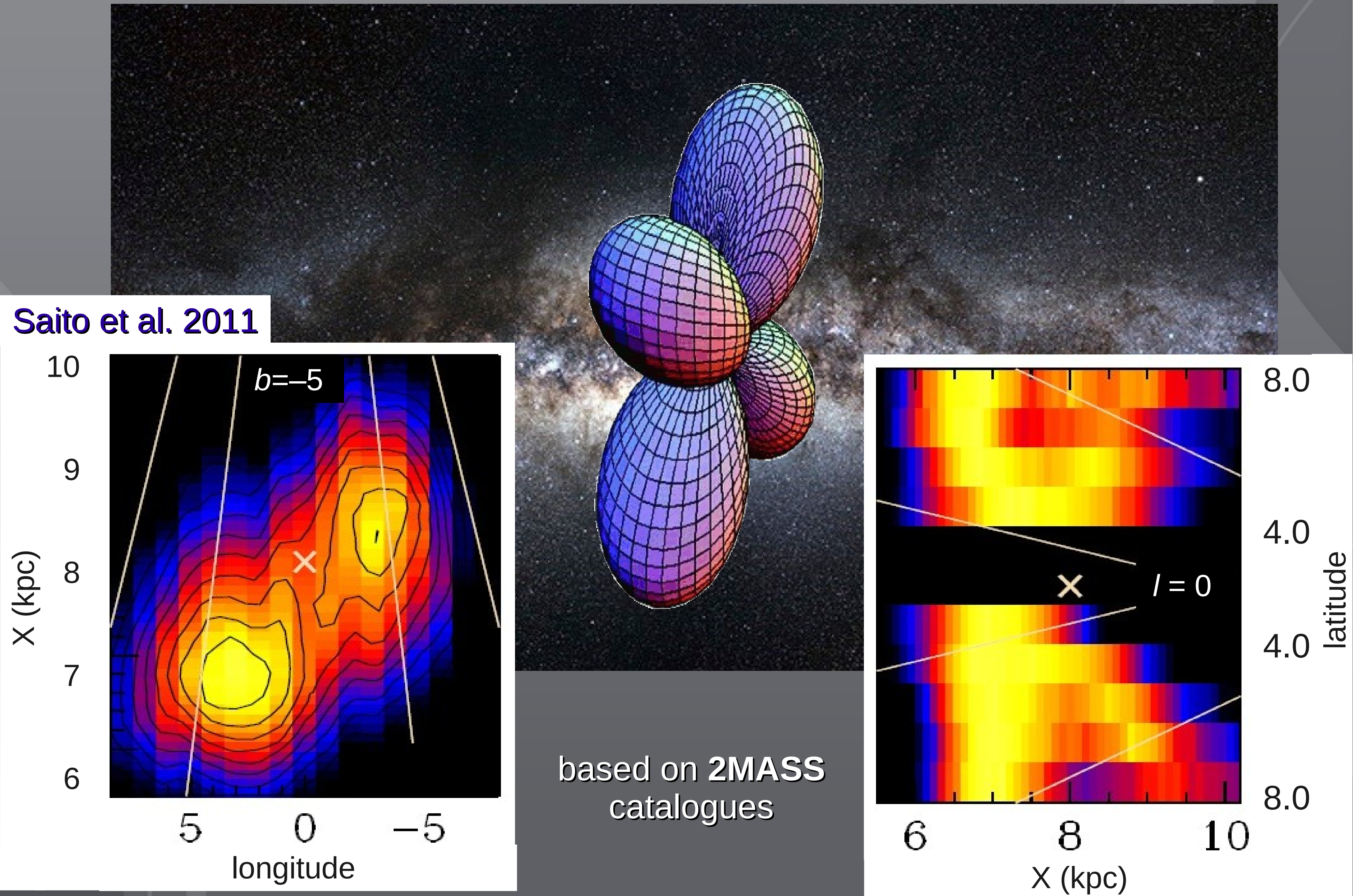




2010s – The X-shaped bulge

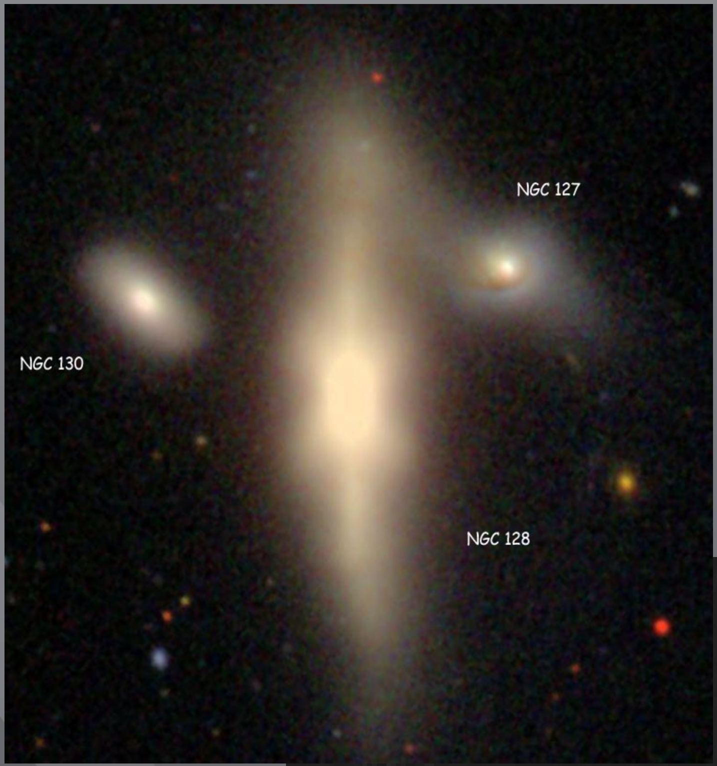


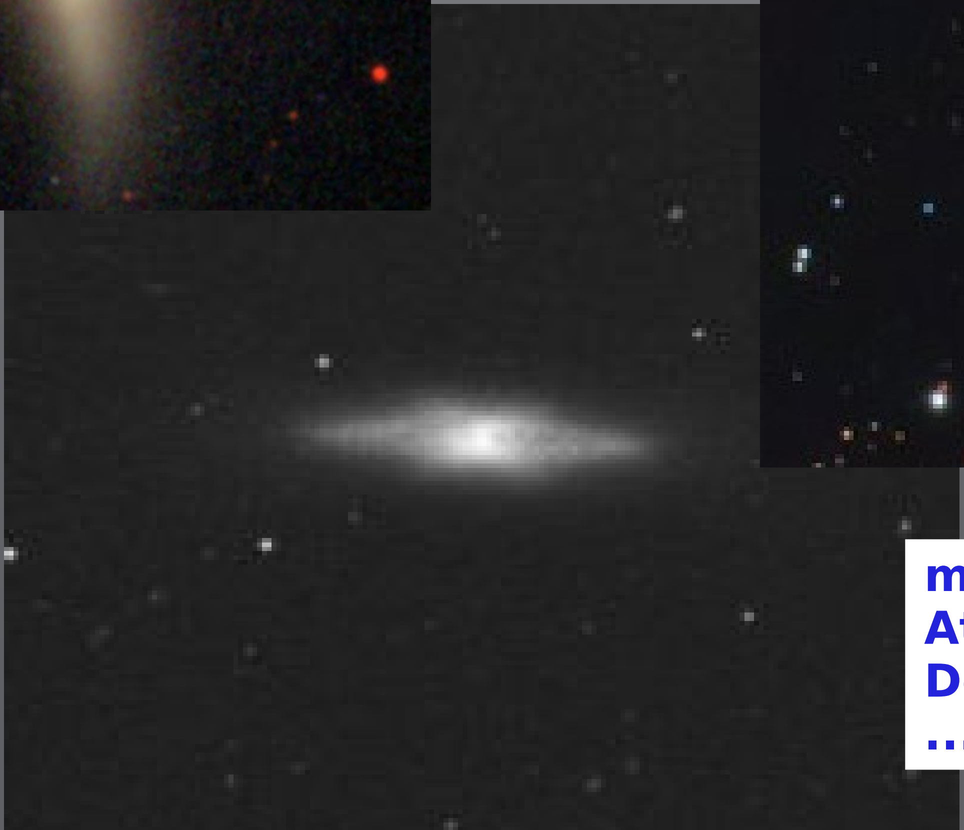
2010s – The X-shaped bulge



based on **2MASS** catalogues

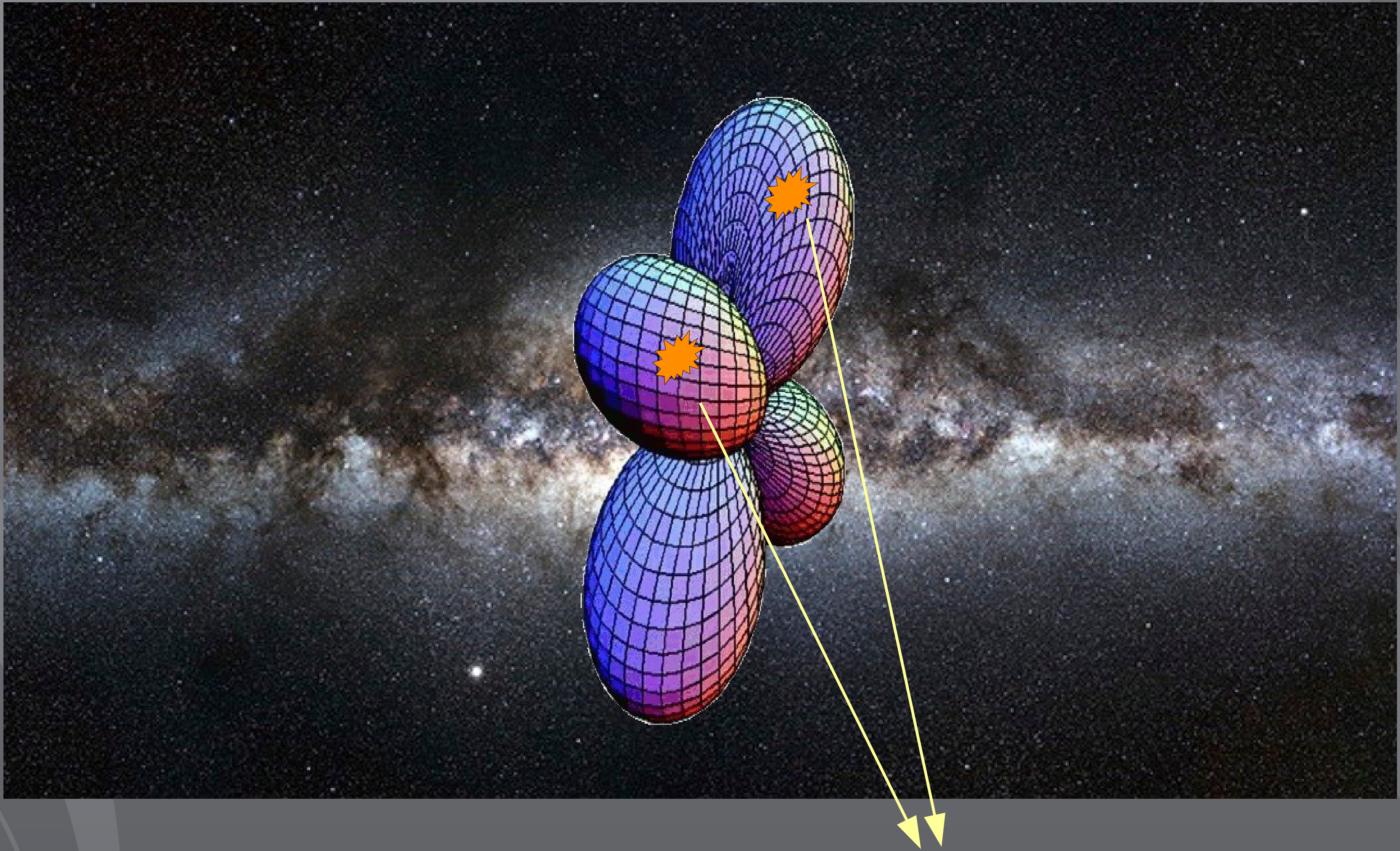
2010s – The X-shaped bulge





models by, e.g.,
Athanassoula (2005)
Debattista et al. (2006)
....

2010s – The X-shaped bulge

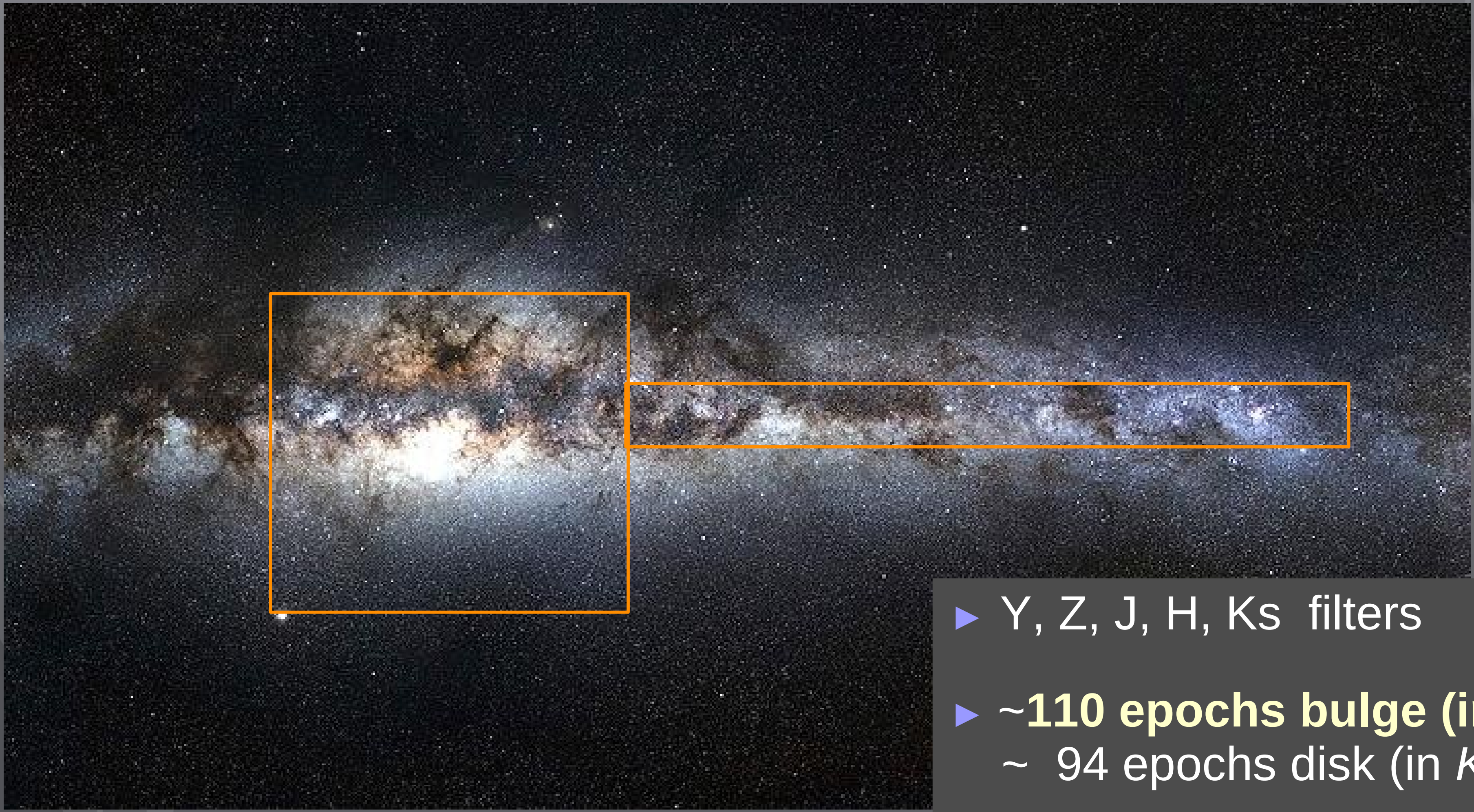


Kinematics? **De Propris et al. (2011)** found no difference in radial velocities of background and foreground arms of the X.

The *VISTA Variables in the Vía Láctea* survey

PIs: Minniti, Lucas

- **300 □° bulge**: –10° < l < +10° –10° < b < +5°
- **220 □° disk**: –65° < l < –10° –2° < b < +2°

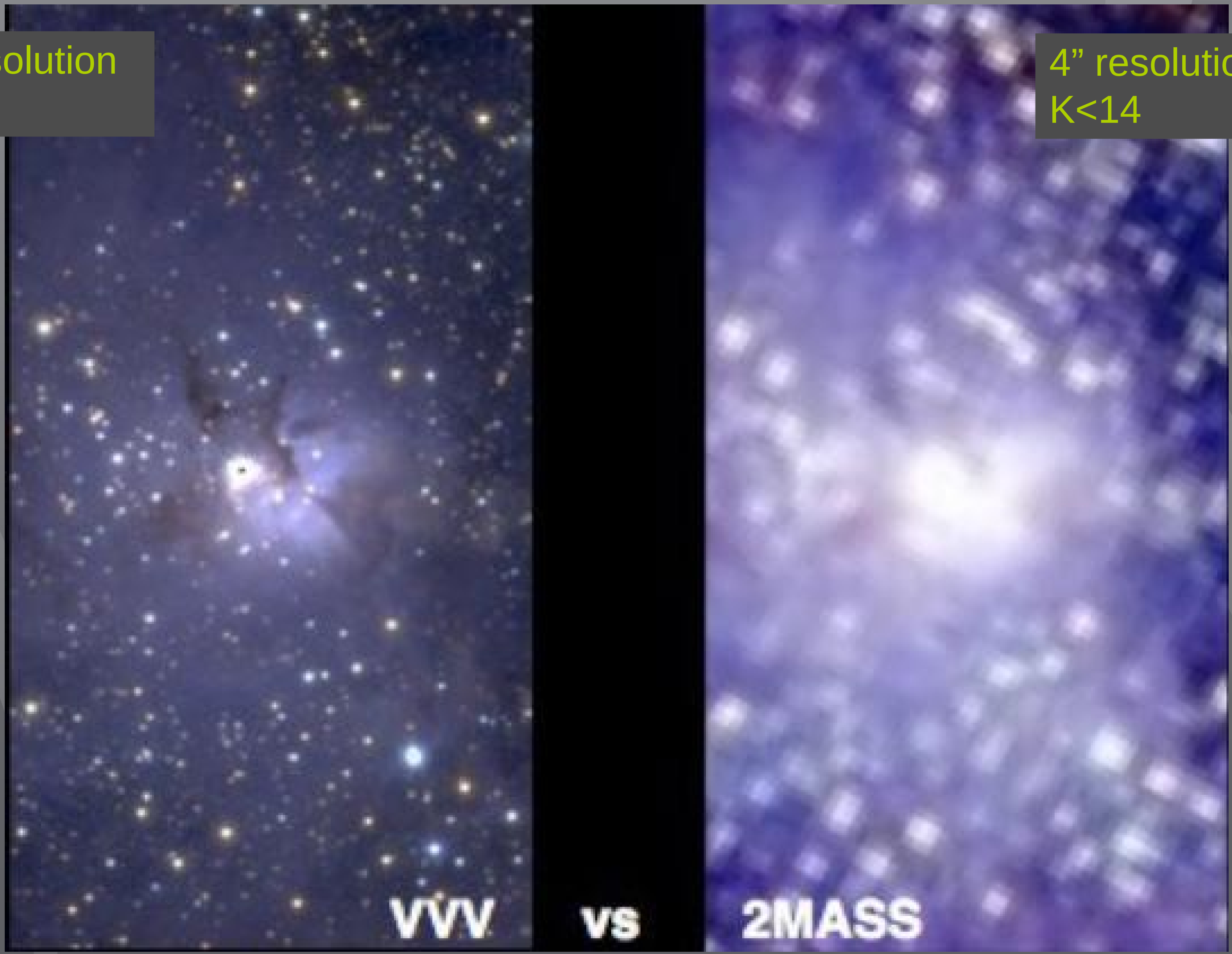


- Y, Z, J, H, Ks filters
- ~**110 epochs bulge (in *Ks*)**
  ~ 94 epochs disk (in *Ks*)

The VVV *vs* 2MASS

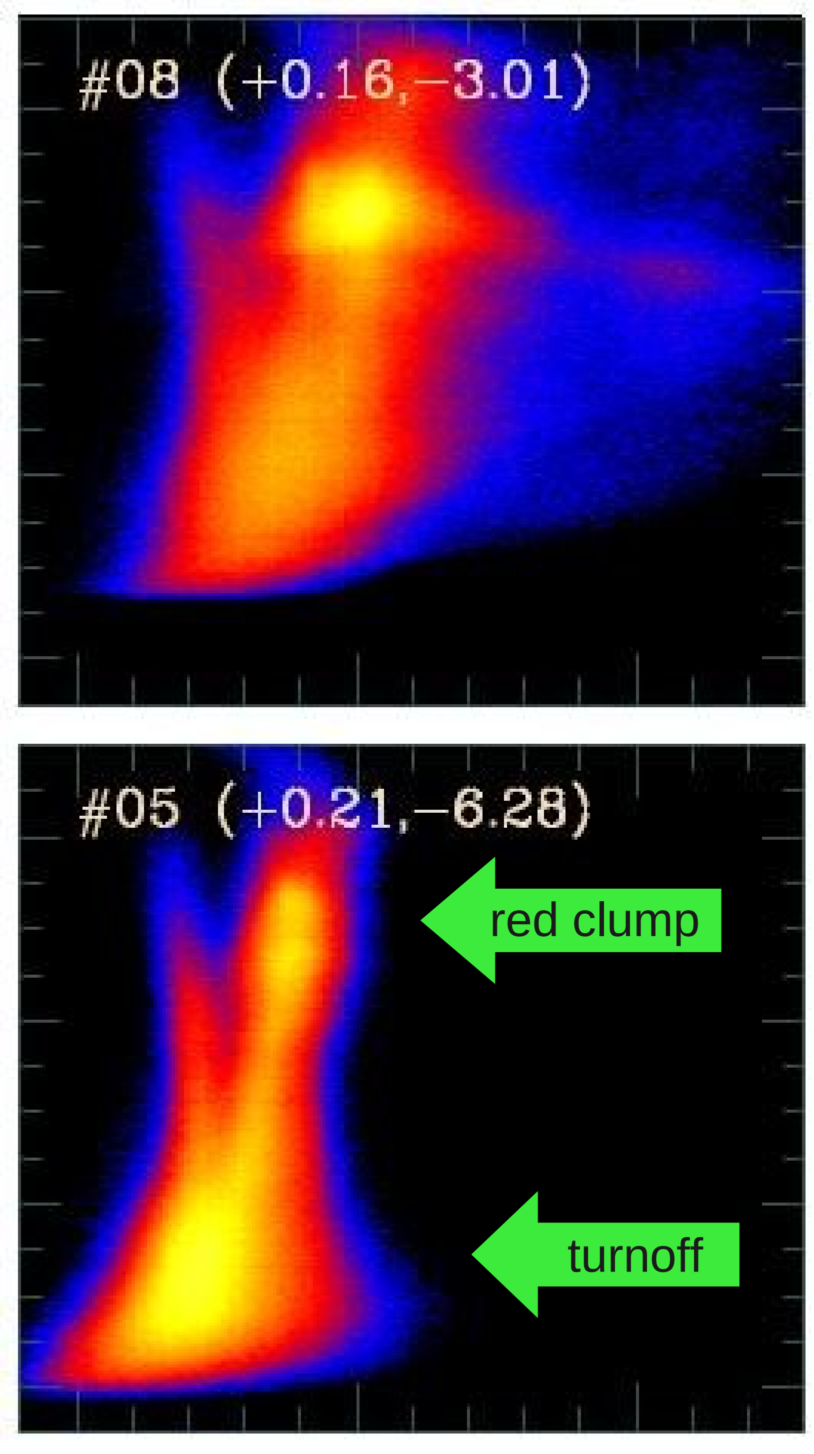
0.5” resolution
K<18

4” resolution
K<14



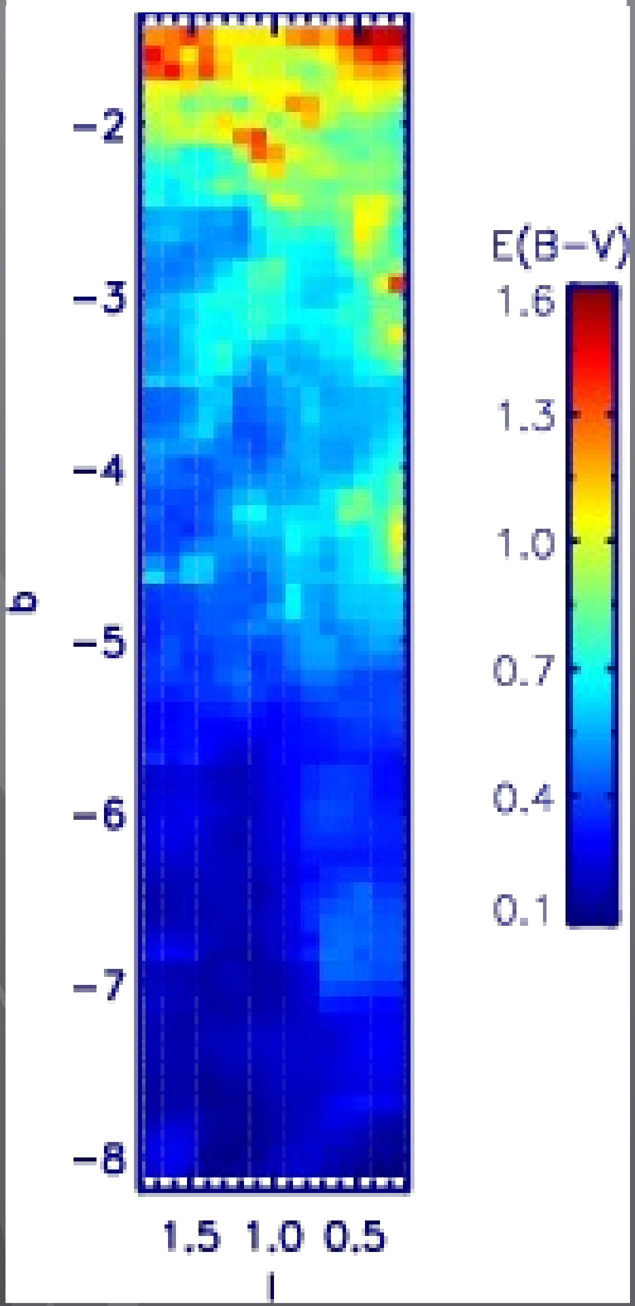
100 Million star CMD

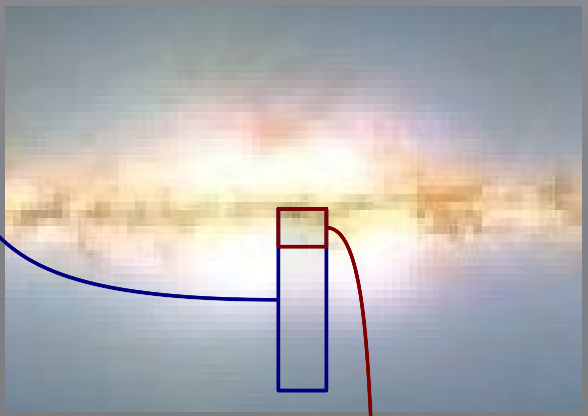
(Saito et al. *in prep.*)

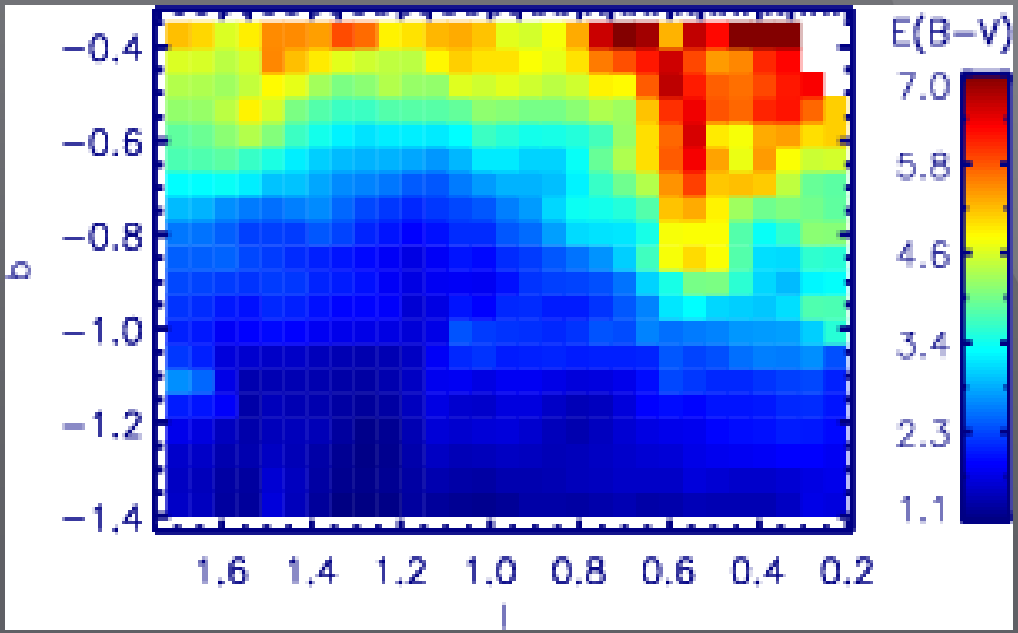


First results from VVV : reddening maps

Gonzalez et al. 2011a

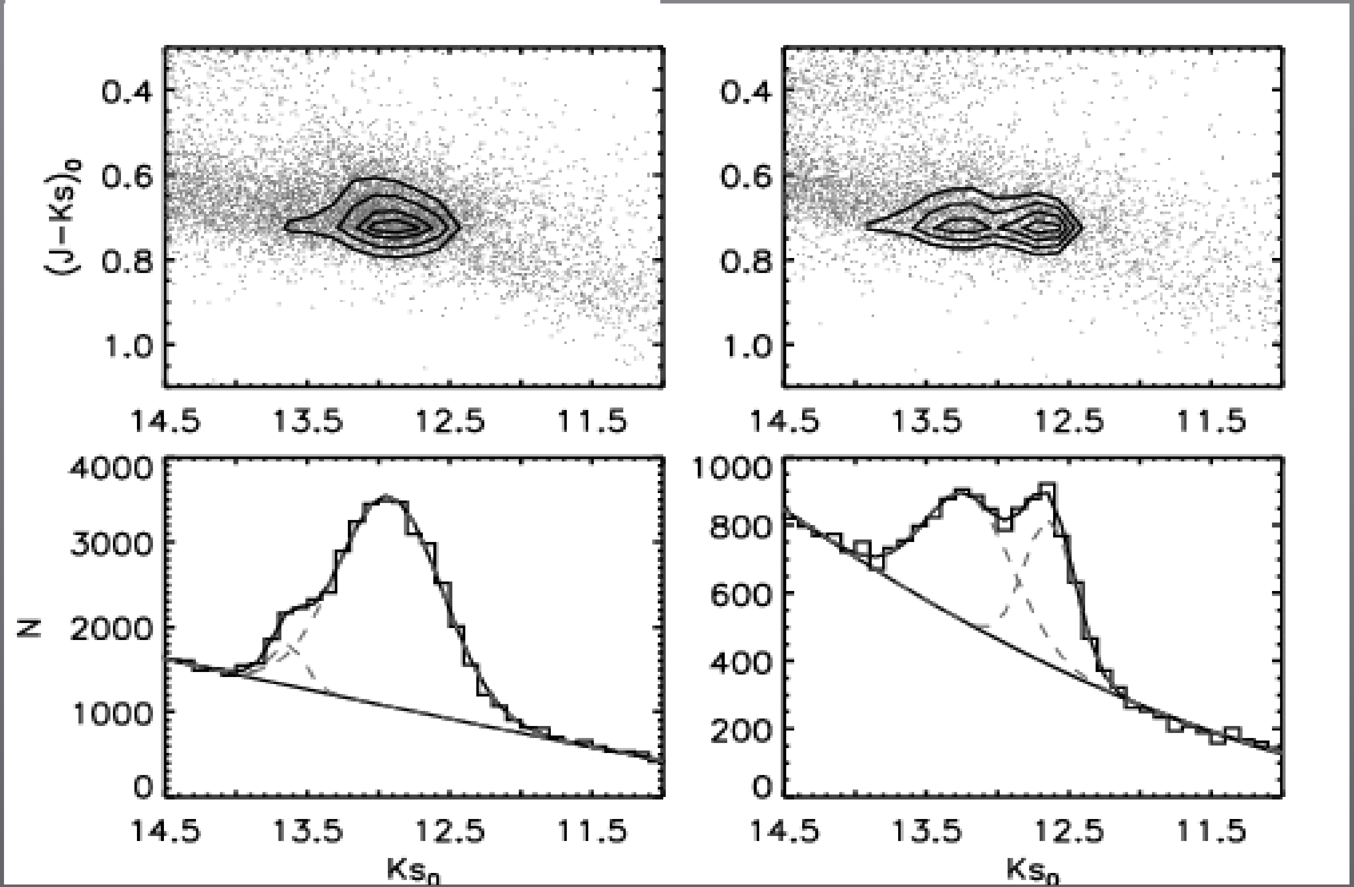




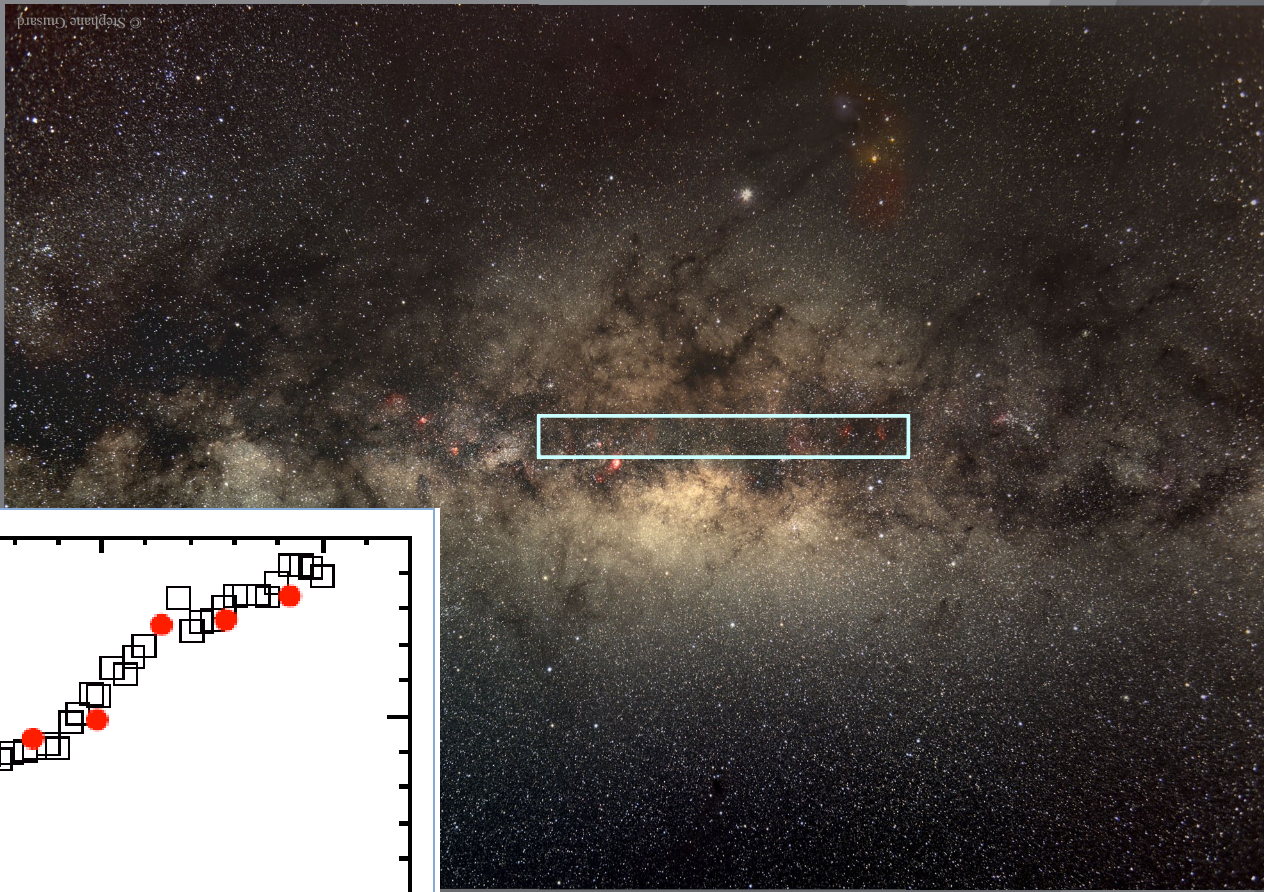


First results from VVV : confirmation of the double clump → X-shape

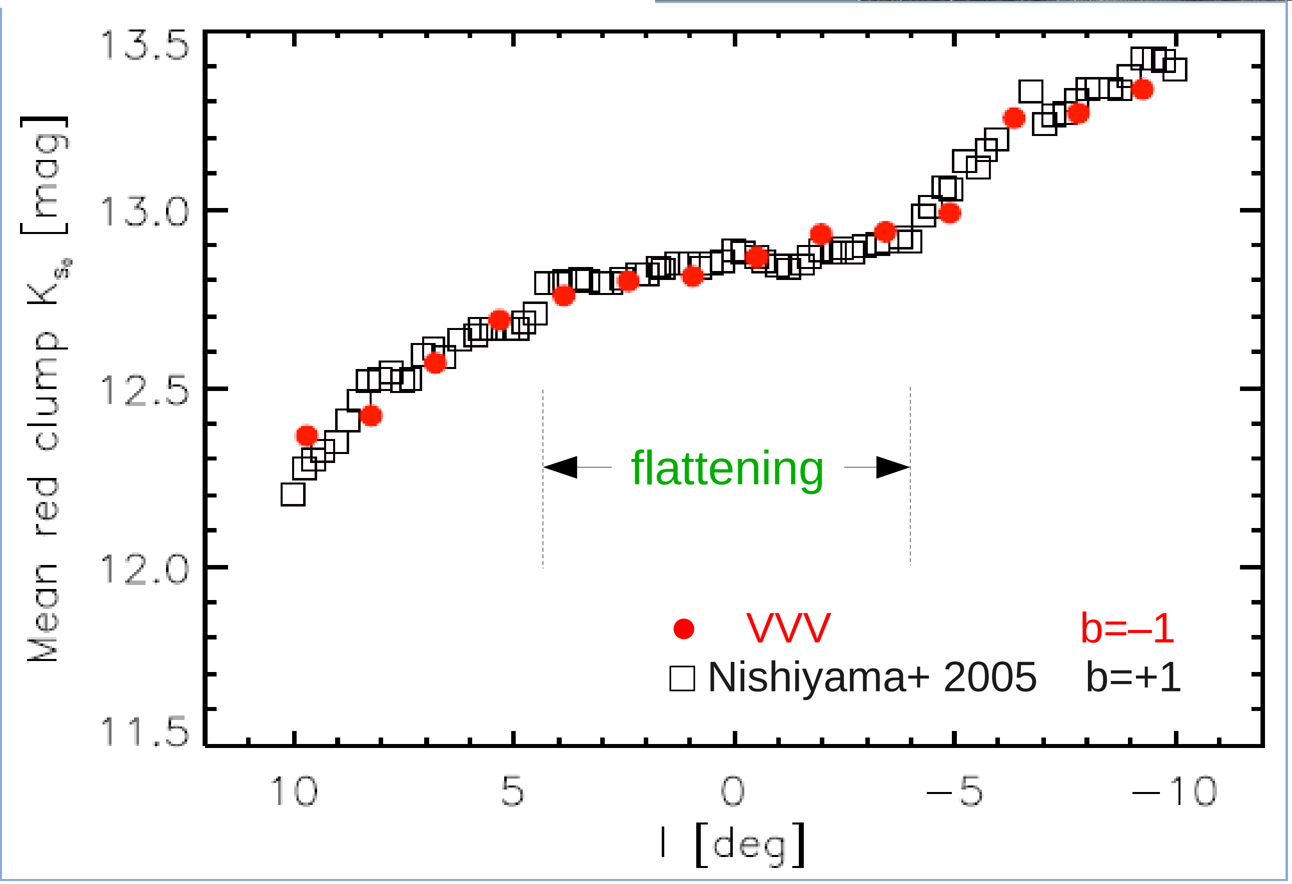
Gonzalez et al. 2011a



First results from VVV : confirmation of the *inner bar*



Gonzalez et al. 2011b



First results from VVV : new star cluster candidates

4 globulars

Minniti et al. 2011

Moni Bidin et al. 2011

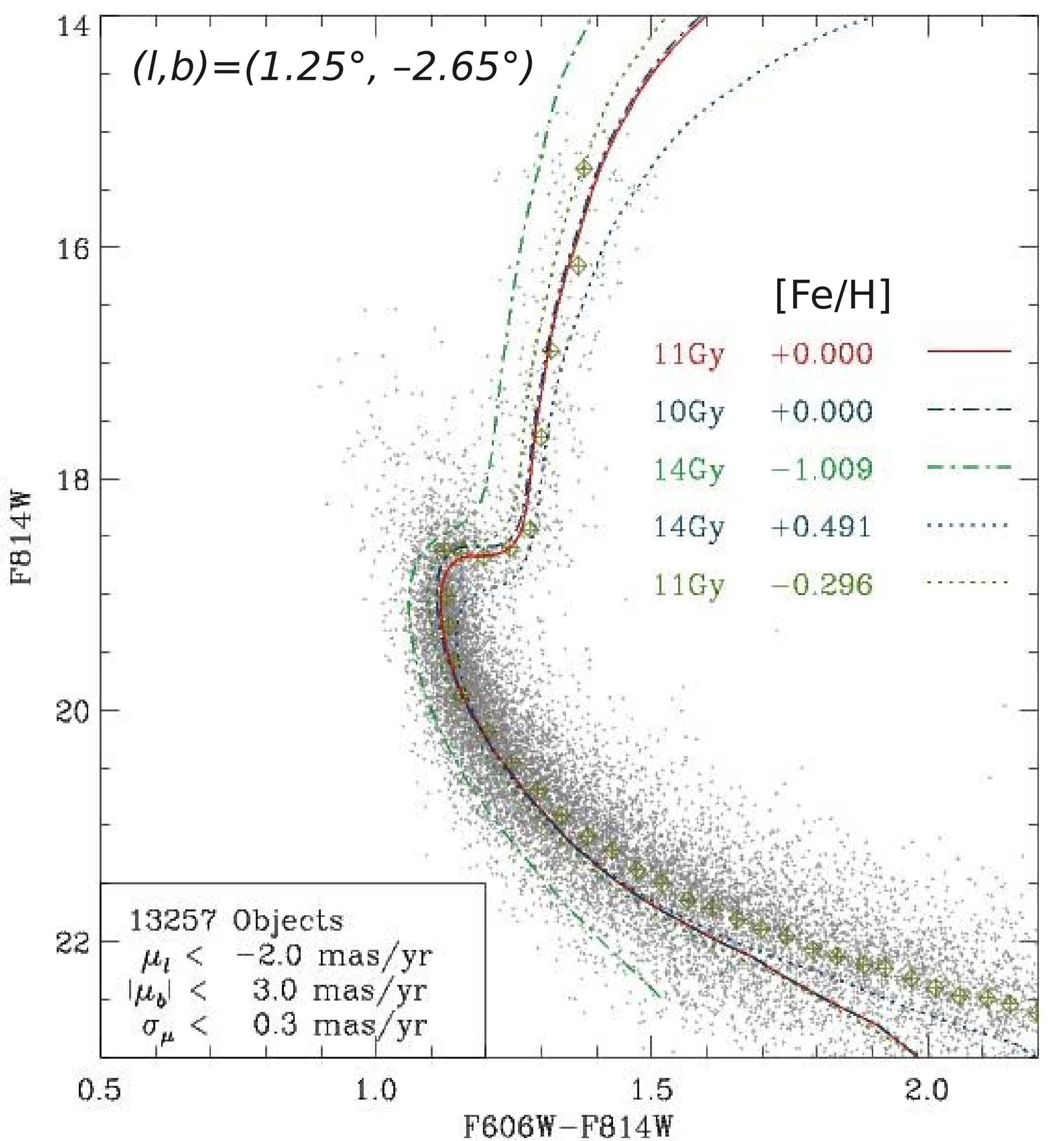
96 open

Borissova et al. 2011

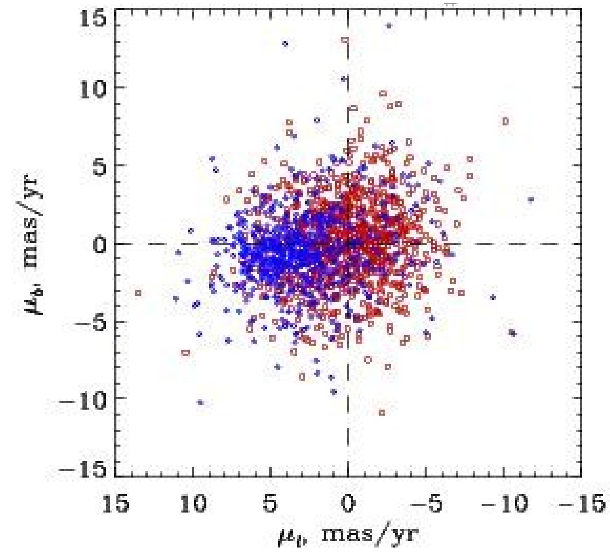
The bulge age

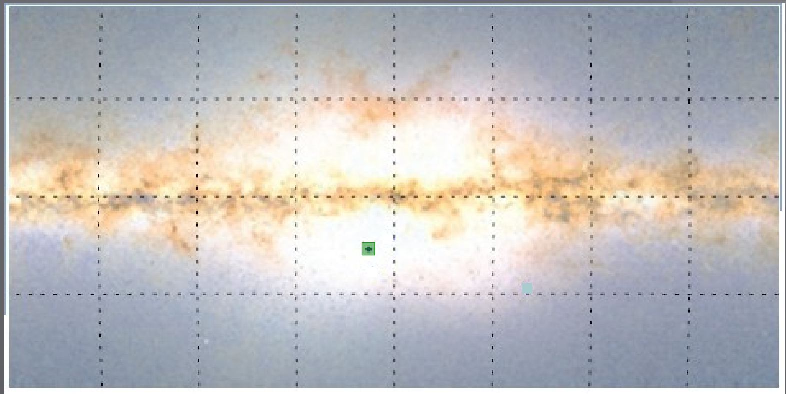
- pure old age (~10 Gyr)

Clarkson et al. 2008



Proper Motion Decontamination

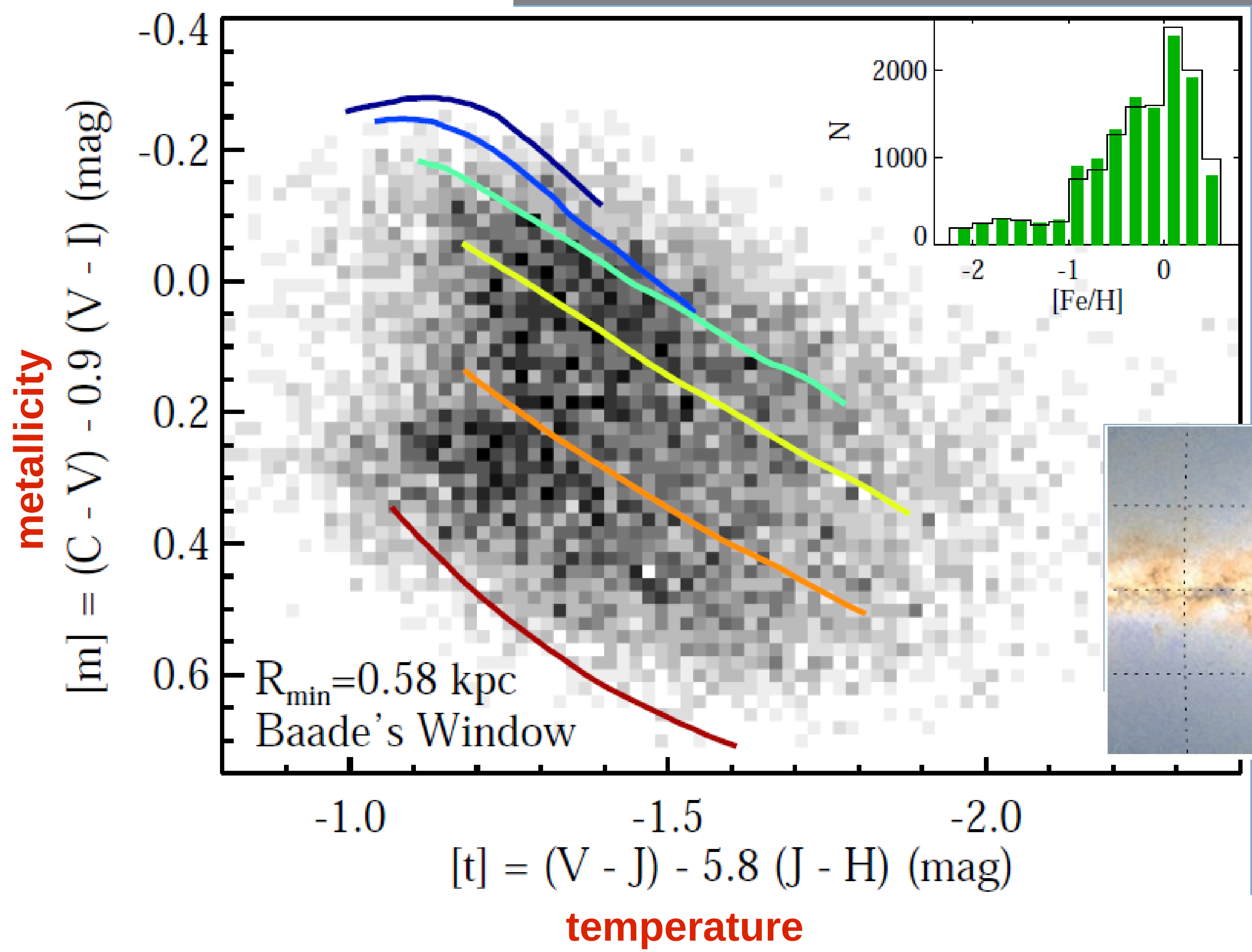


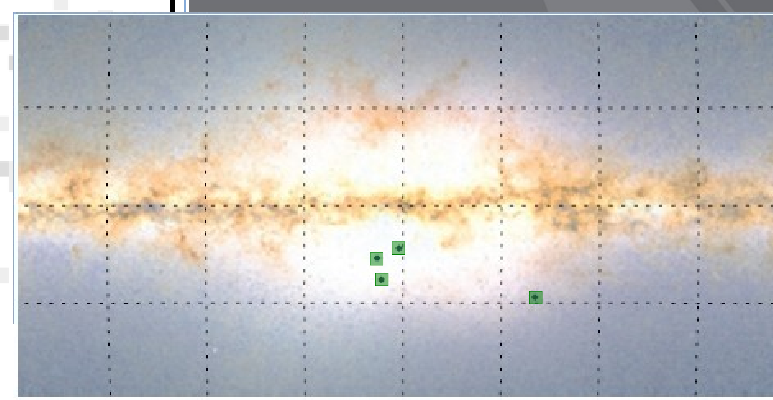


The bulge age

- age uniformly old (~10 Gyr) - no gradient
- confirmed radial metallicity gradient

Brown et al. 2011





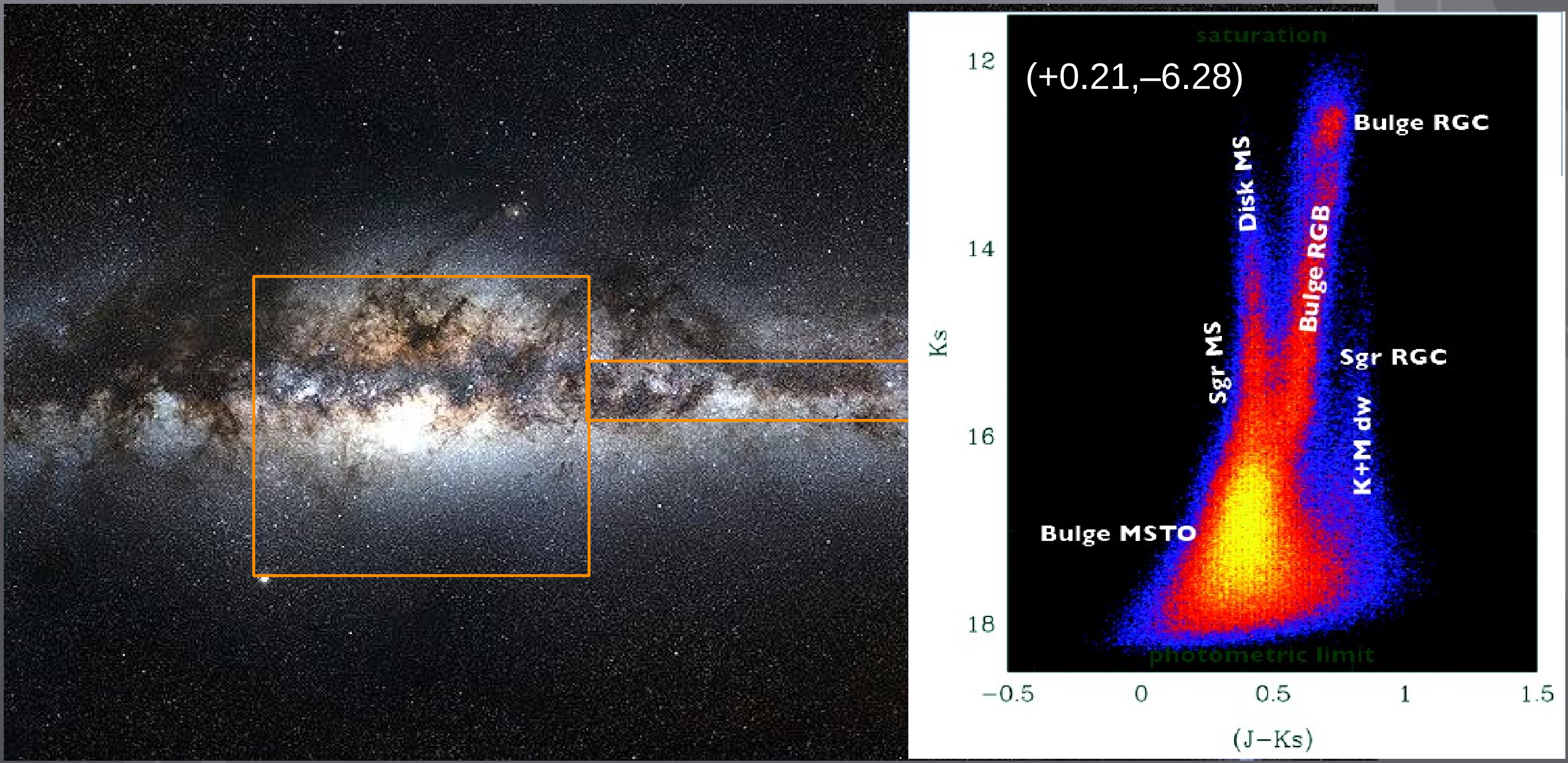
The bulge age

The VVV reaches the turnoff in most fields.

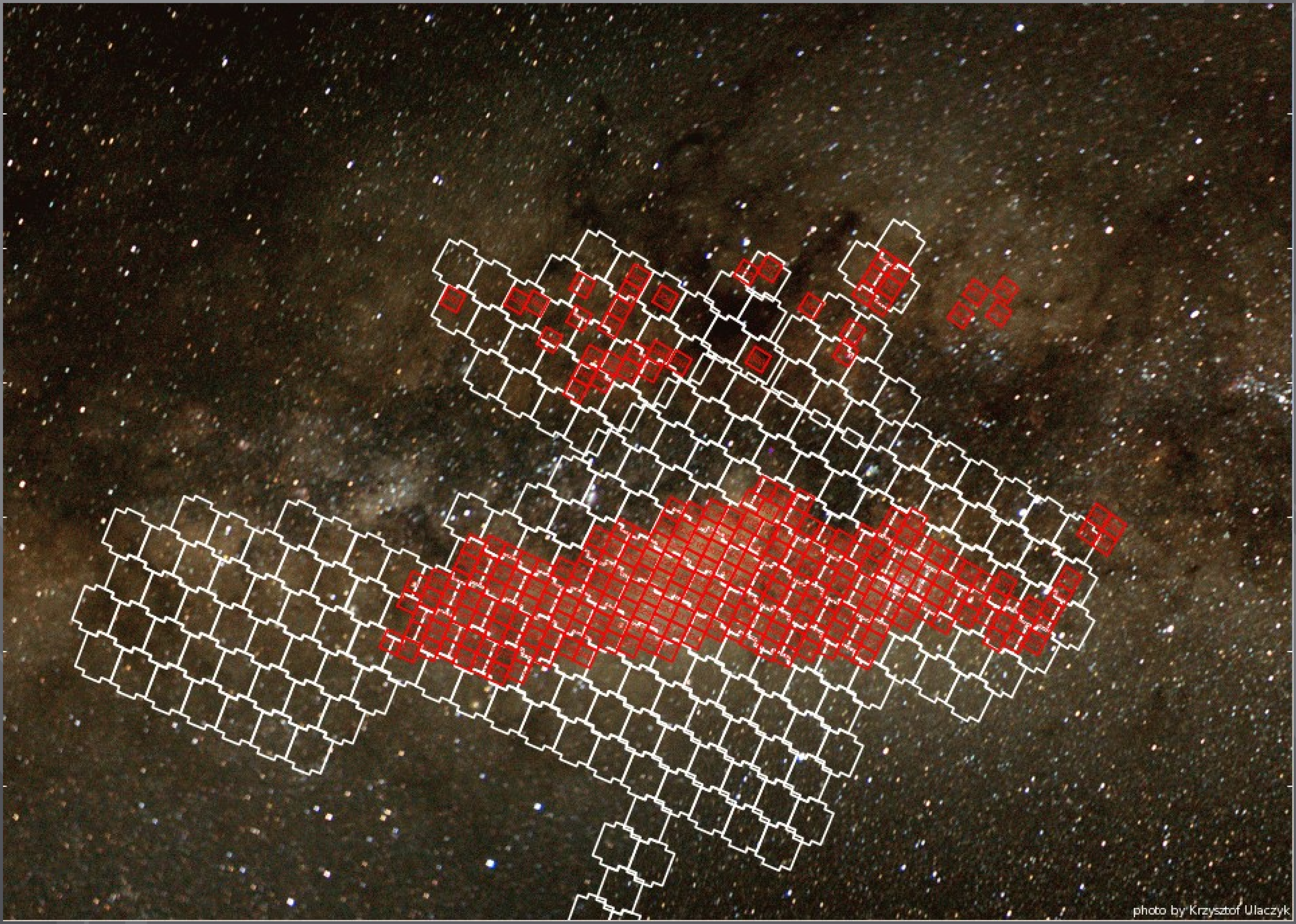
BUT: CMD analysis needs synthesis

disk decontamination needed (5 yr baseline)

good handle on reddening

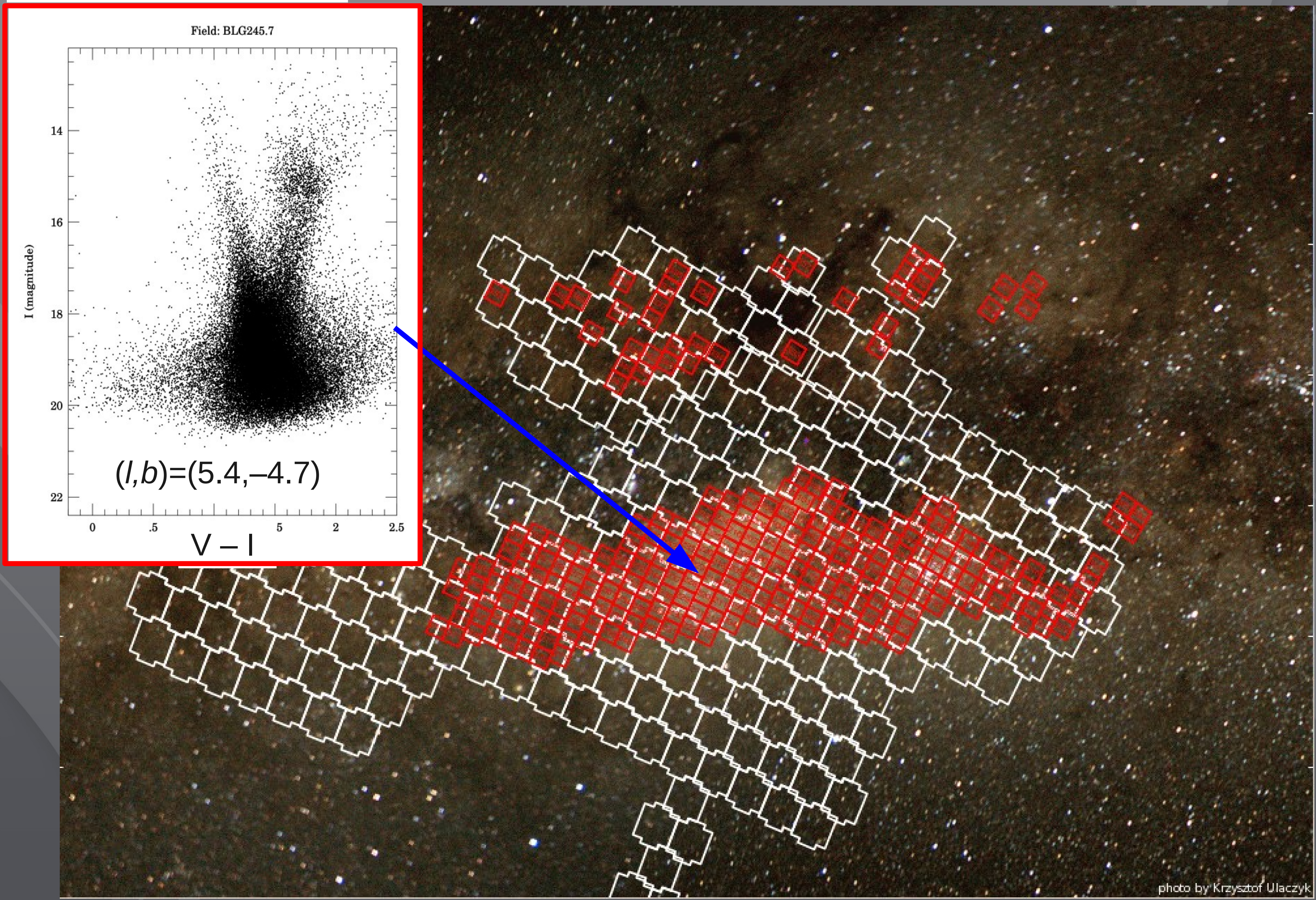


The bulge age → OGLE III + OGLE IV



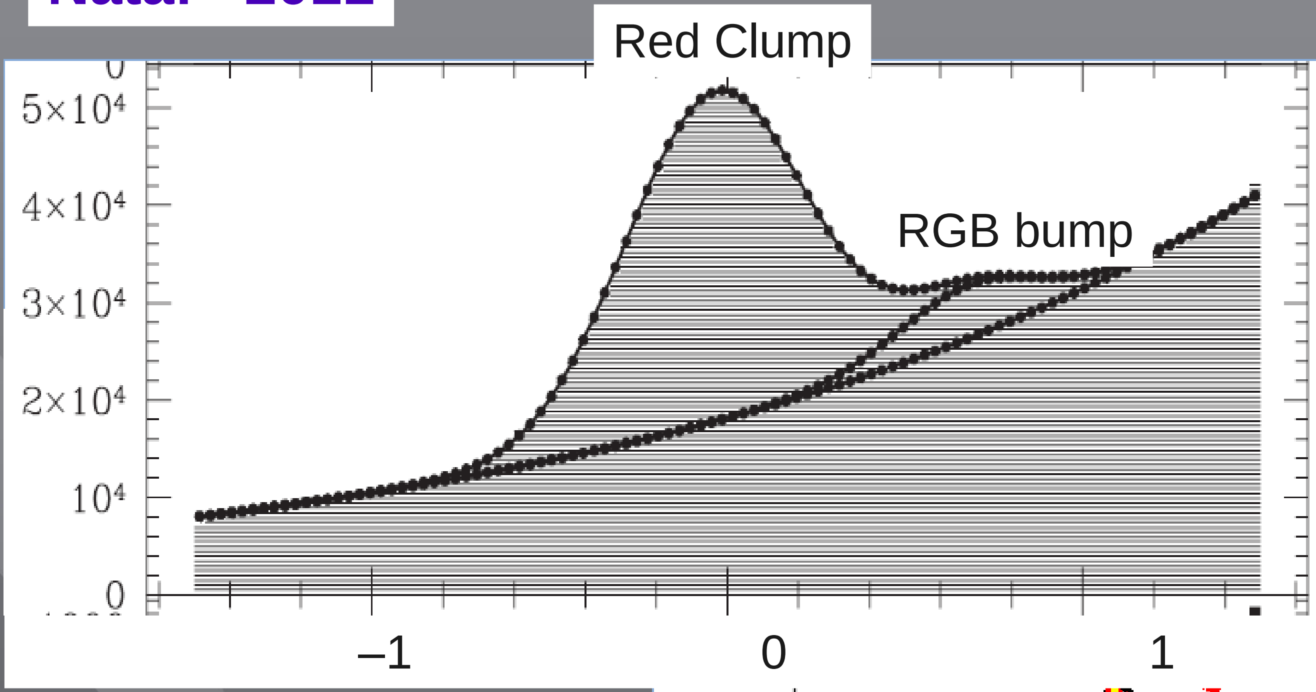
Szymanski+ 2011

OGLE III + OGLE IV



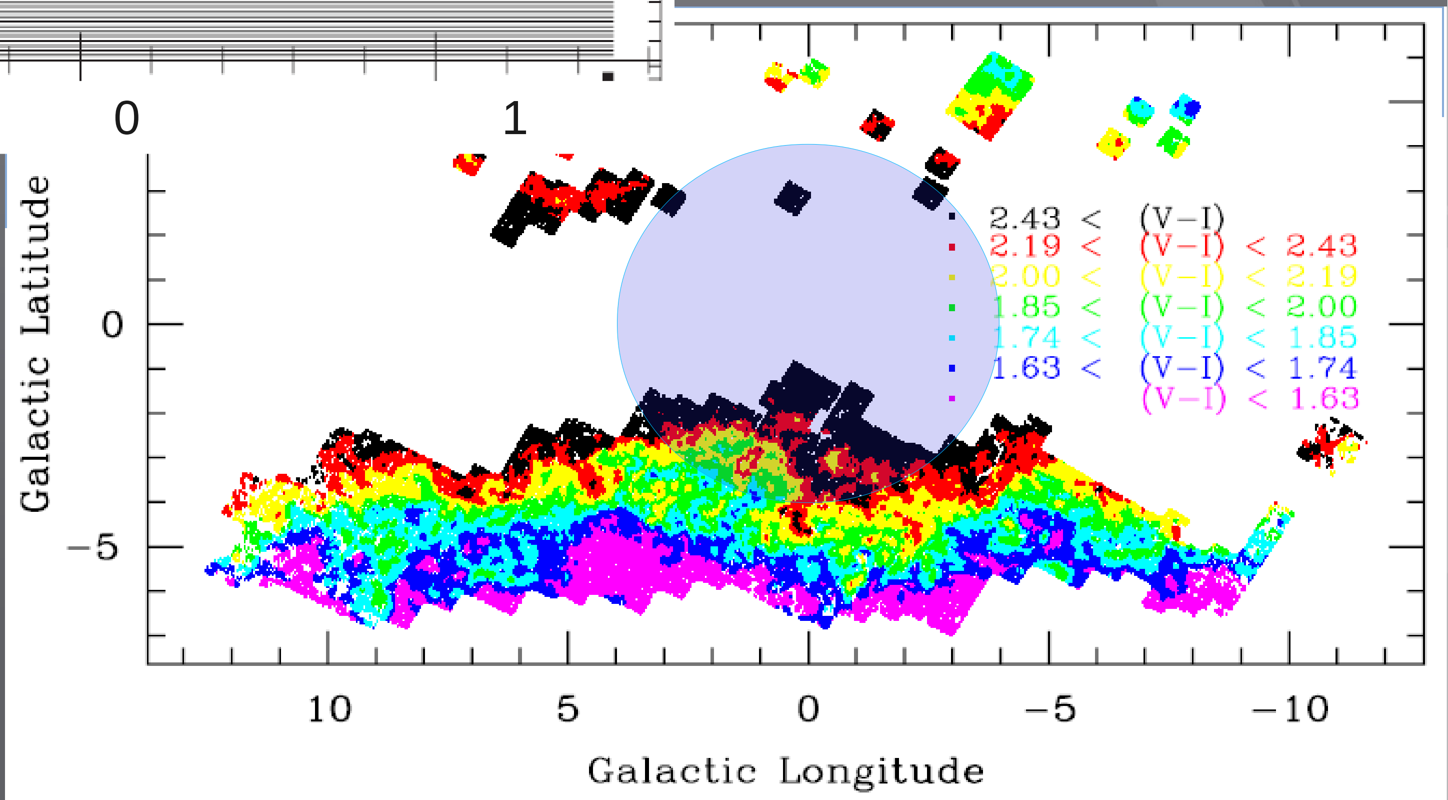
The bulge helium content from OGLE III

Nataf+ 2011

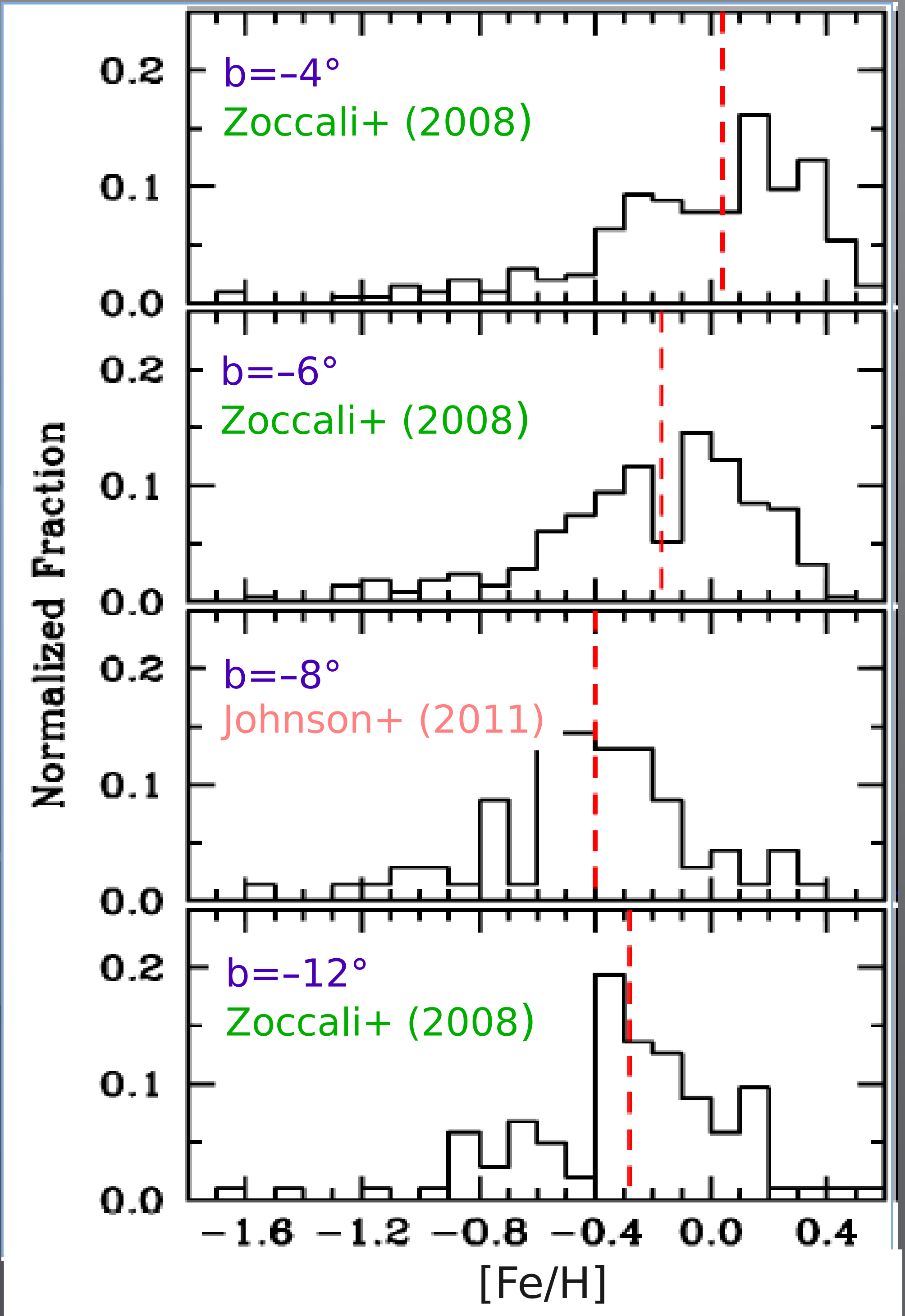


Observational evidence:
The bulge RGB bump is smaller than expected.

→ **ΔY/ΔZ ≥ 4**



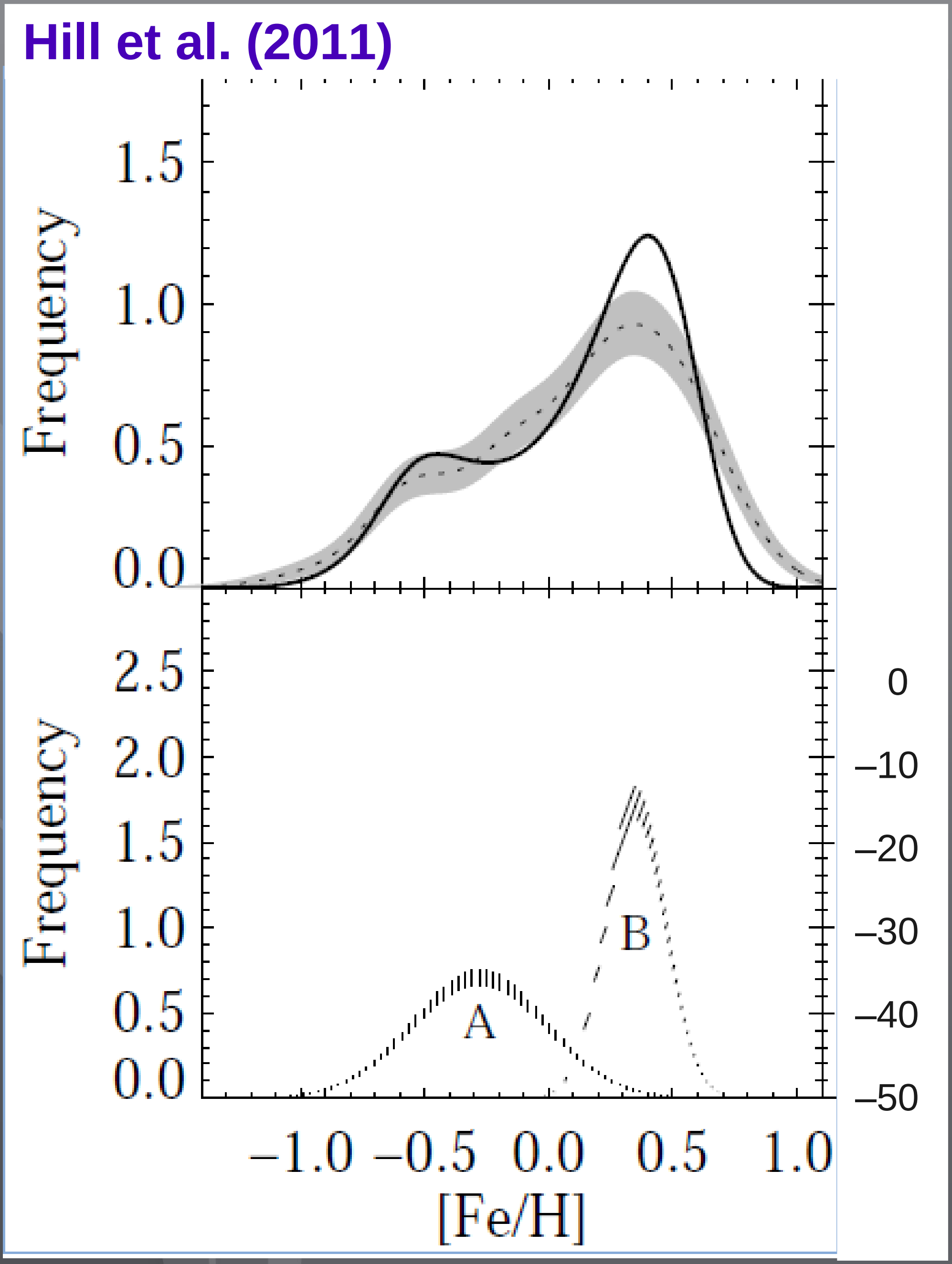
The bulge metallicity distribution



- broad metallicity distribution
- radial ***gradient*** along the minor axis

- **Bekki & Tsujimoto (2011)** proposes a 2-disk model for the bulge, to explain both vertical gradients and cylindrical rotation

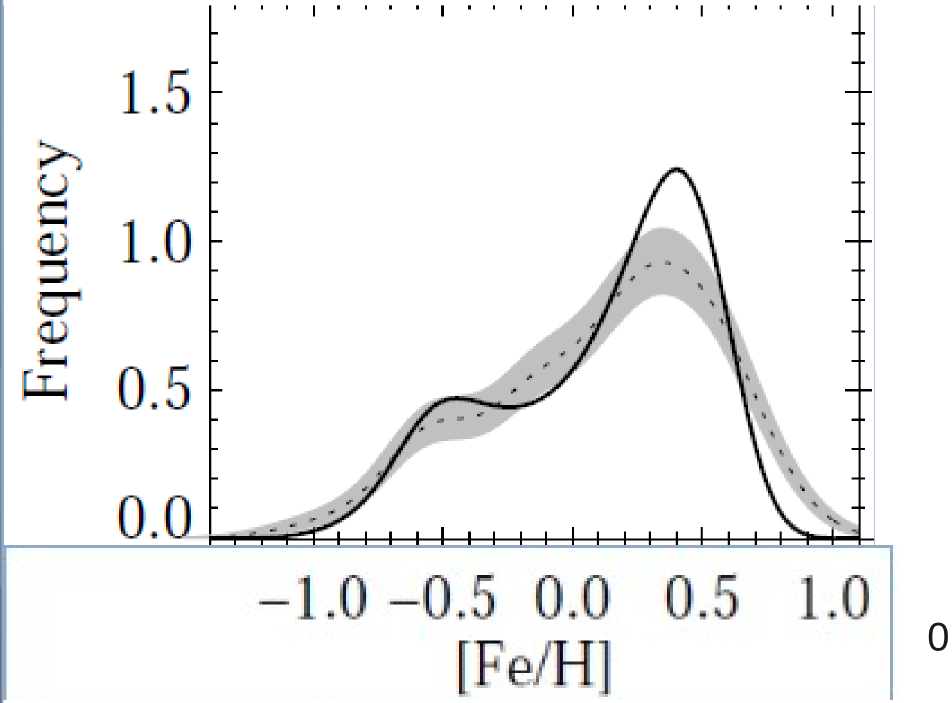
The bulge metallicity distribution



- Error deconvolution gives bimodal MDF (in Baade's Window)

The bulge metallicity distribution

Hill et al. (2011)



Babusiaux et al. (2010)

The two peaks have different kinematics:

metal-rich : bar-like
metal-poor : classical spheroid

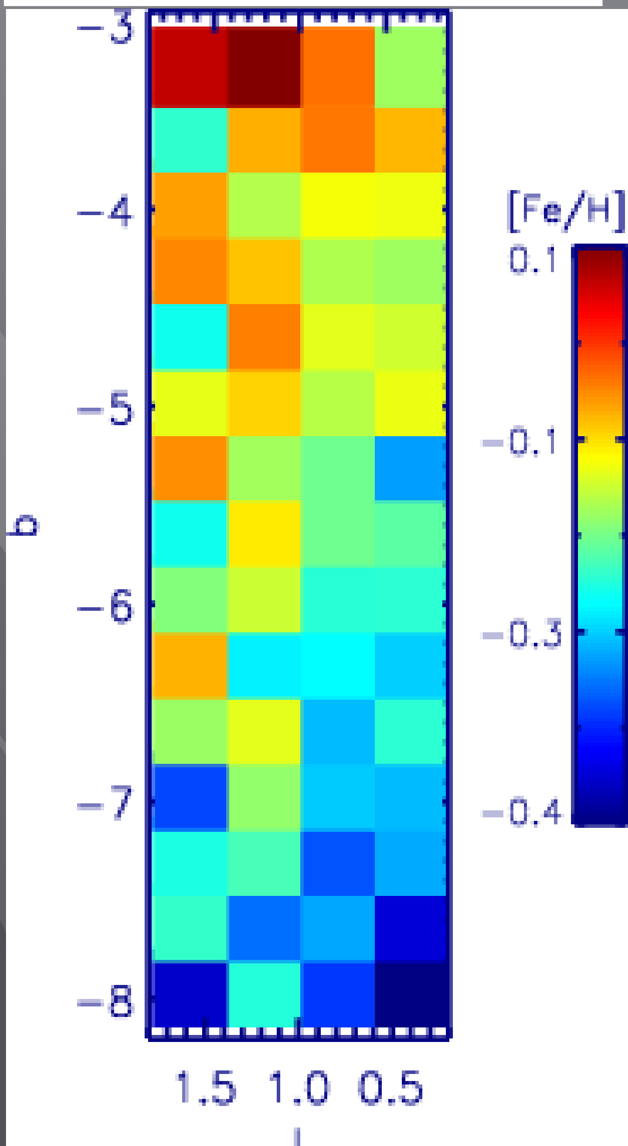
two component bulge?

► However, Howard et al. (2009), based on BRAVA data, found cylindric rotation: no need for a Galactic bulge

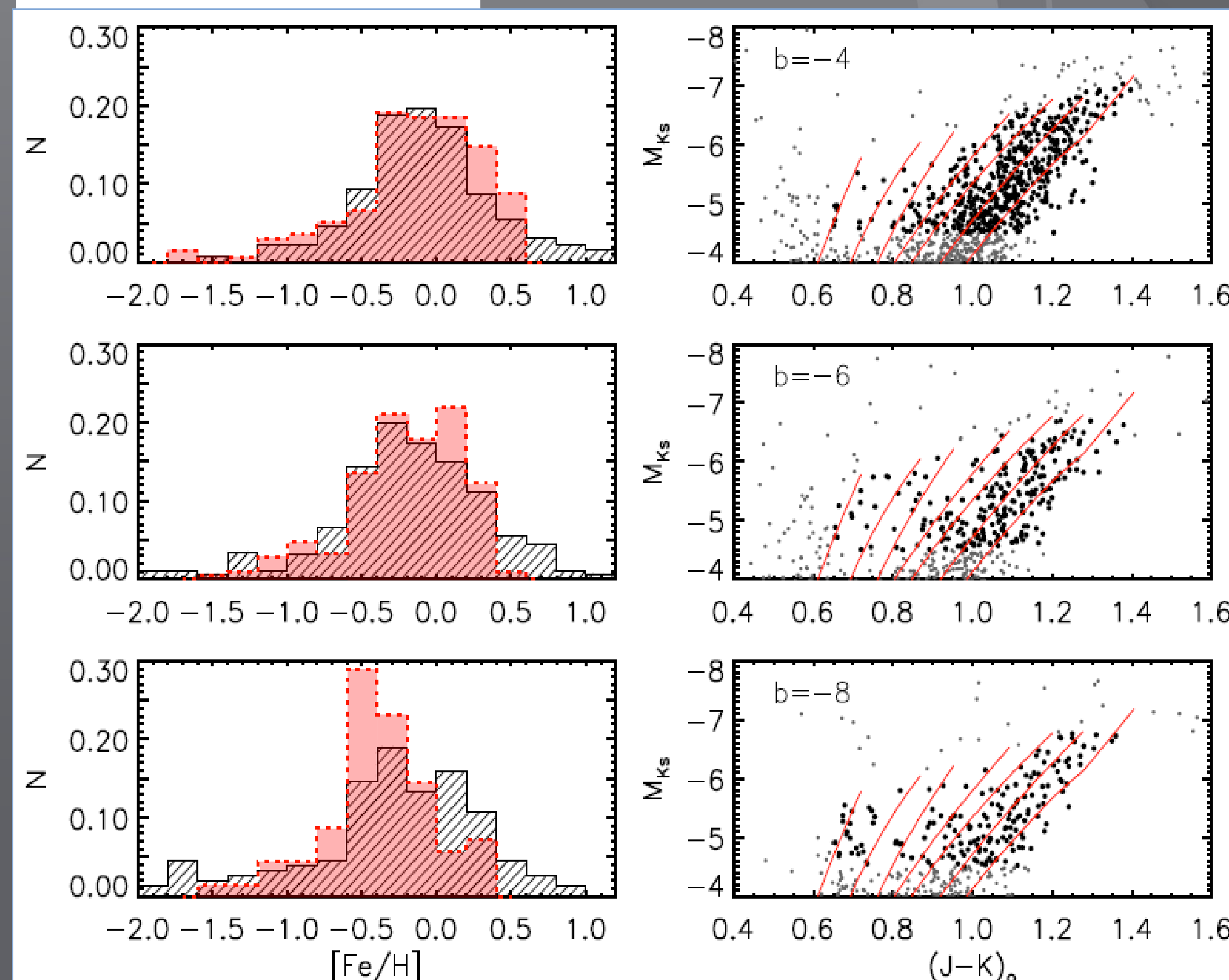
bulge metallicity → we need large scale maps

STEP1: photometric metallicity maps

Gonzalez et al. 2011a



Spect *vs* phot MDF

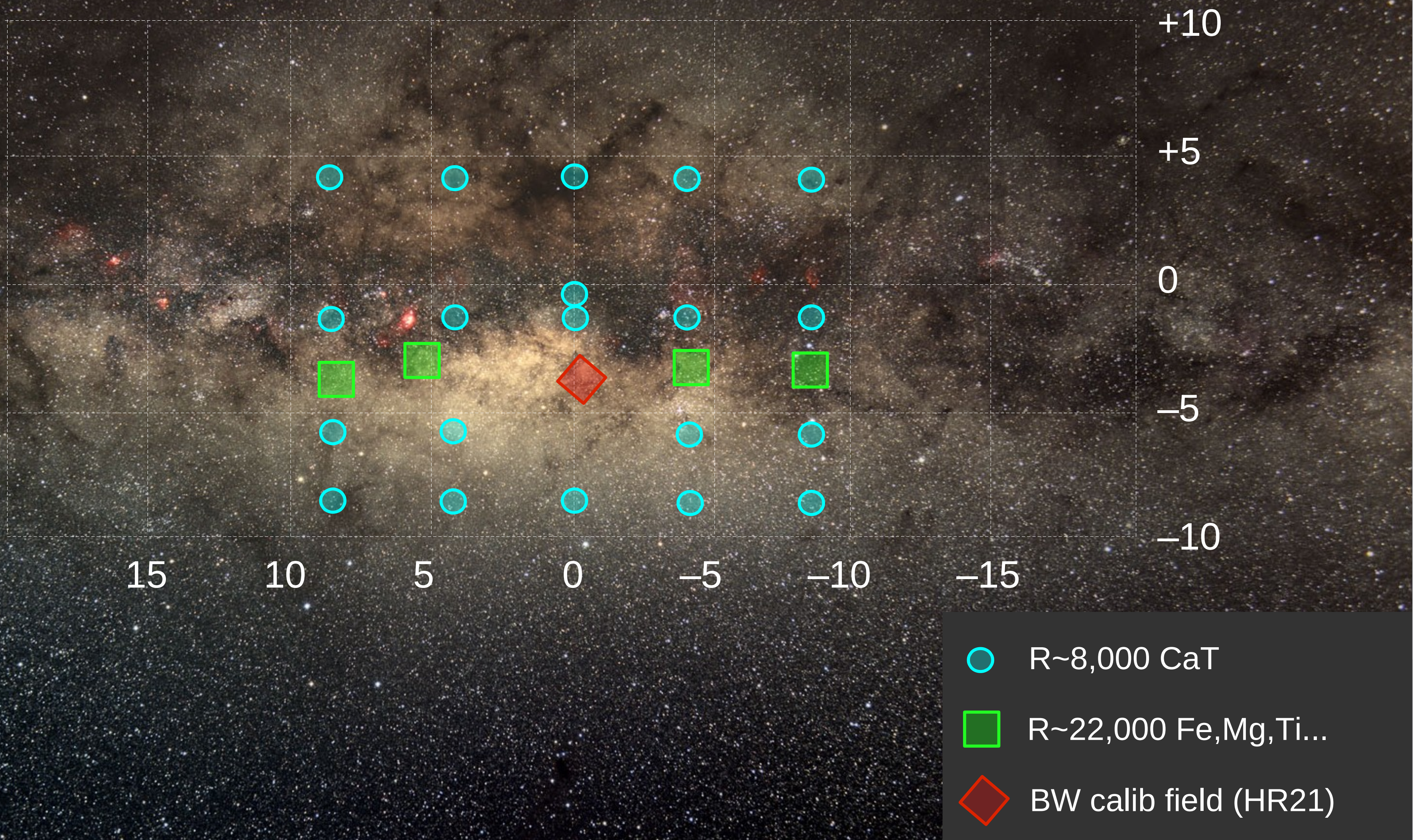


bulge metallicity → we need large scale maps

STEP2: ESO Large Programme 187.B-0909 PI: Zoccali

140 hr with FLAMES

> 4000 stars on CaT
~ 440 stars at R~22,000

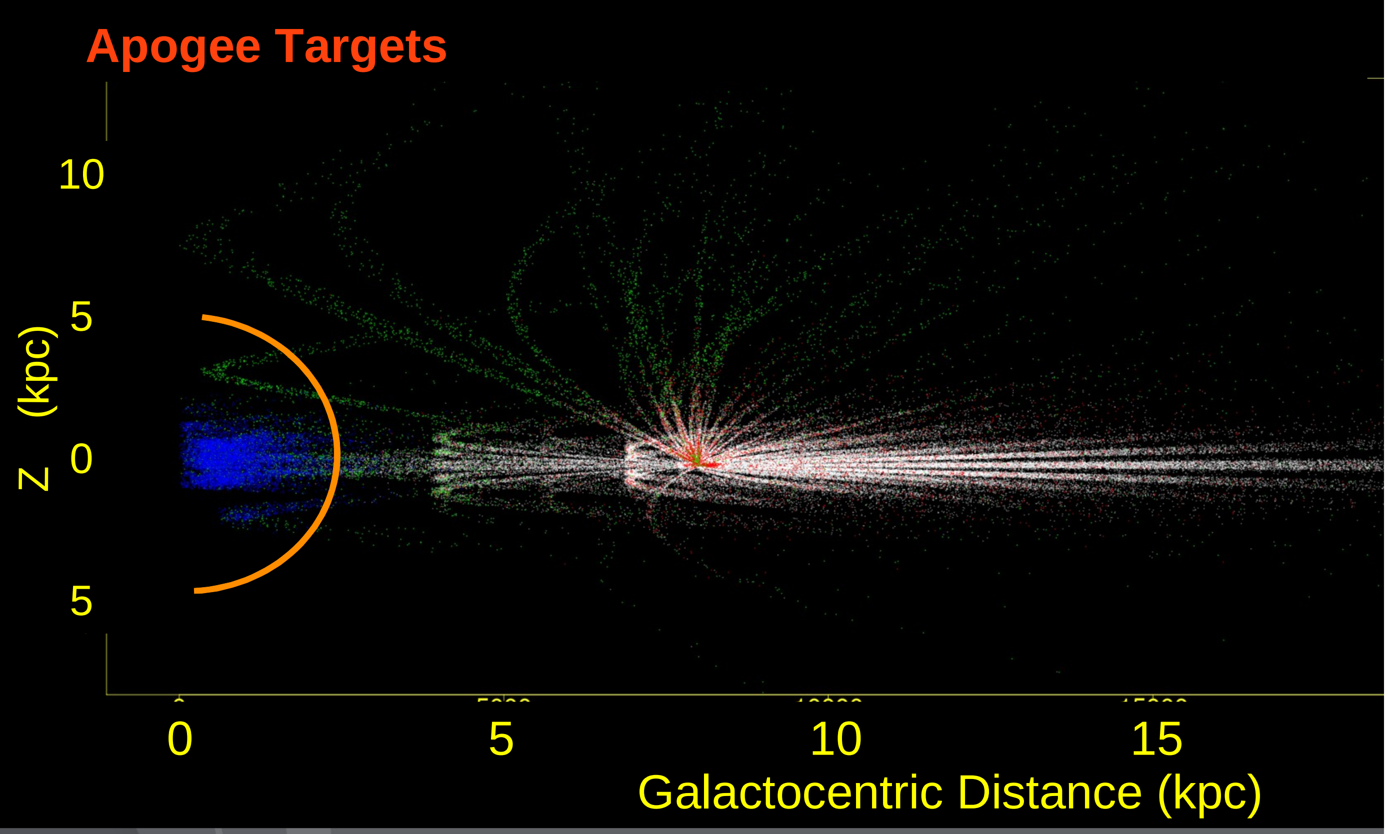


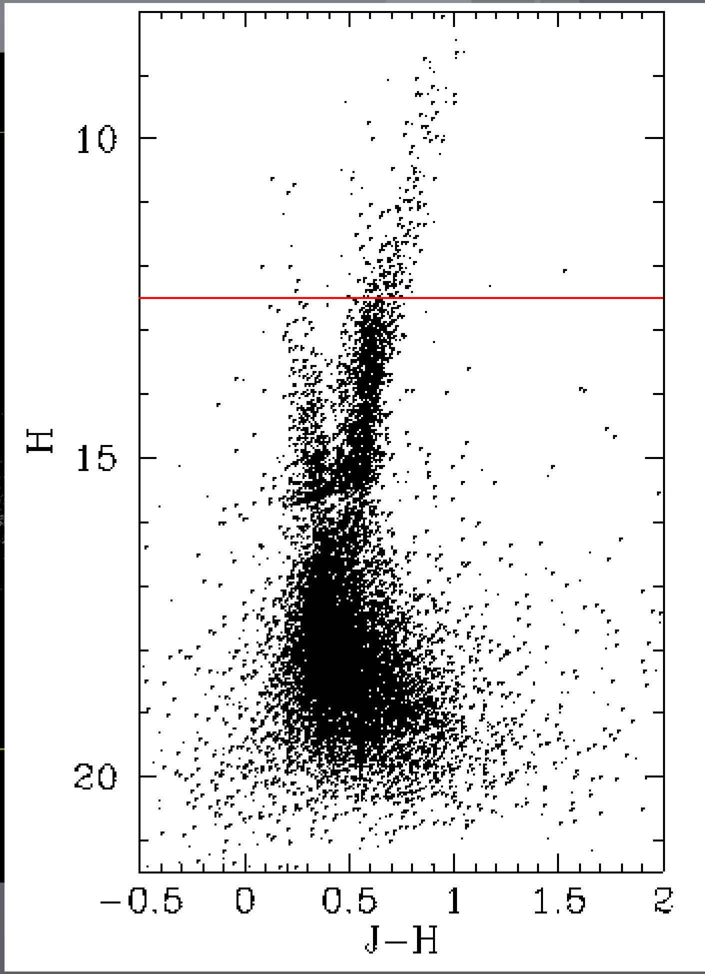
bulge metallicity → we need large scale maps

STEP3: APOGEE

PI: S. Majewski

A high resolution (R~24,000)
near-IR survey of
100,000 Galactic stars (H<12.5)





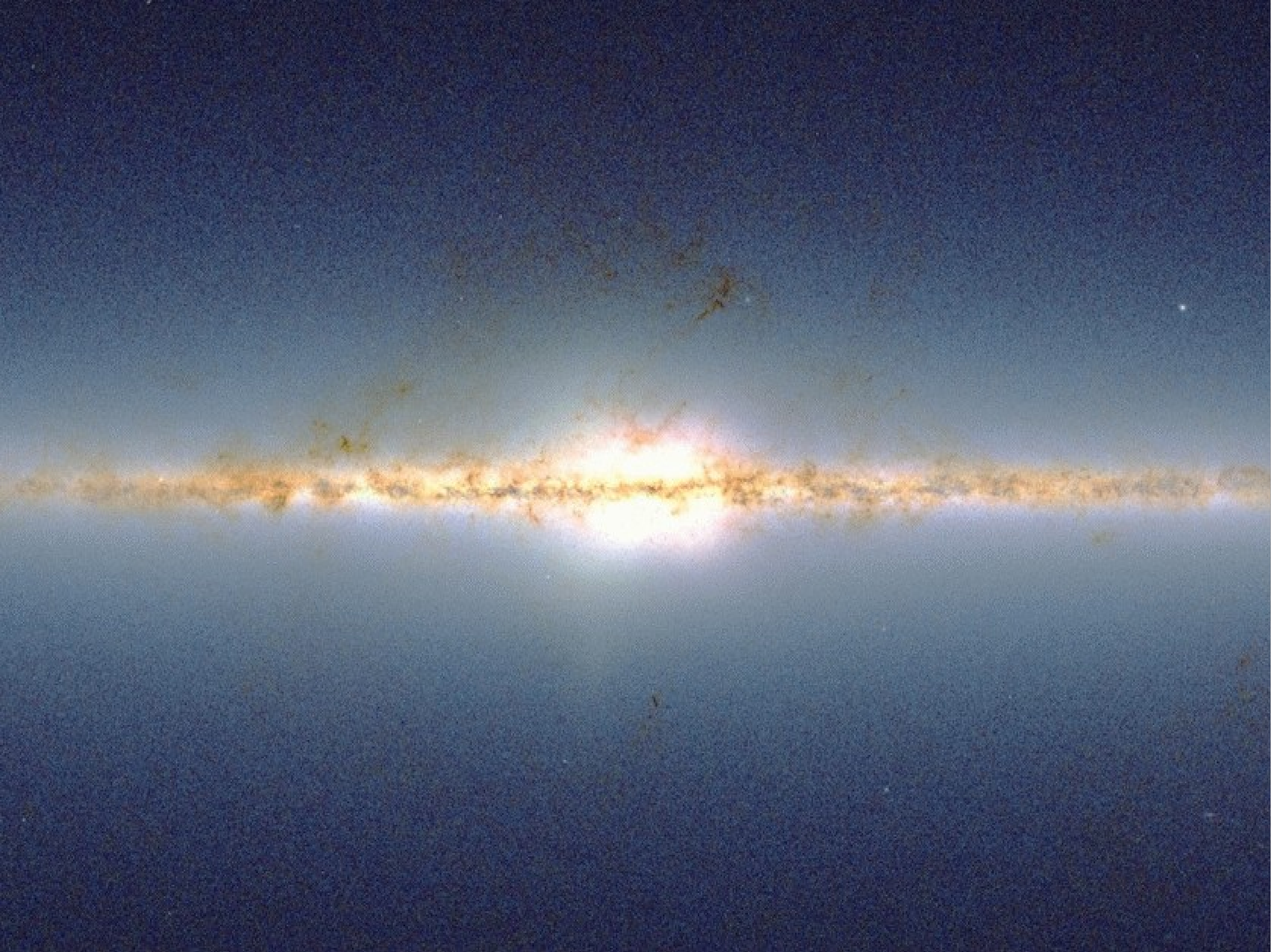
Conclusions

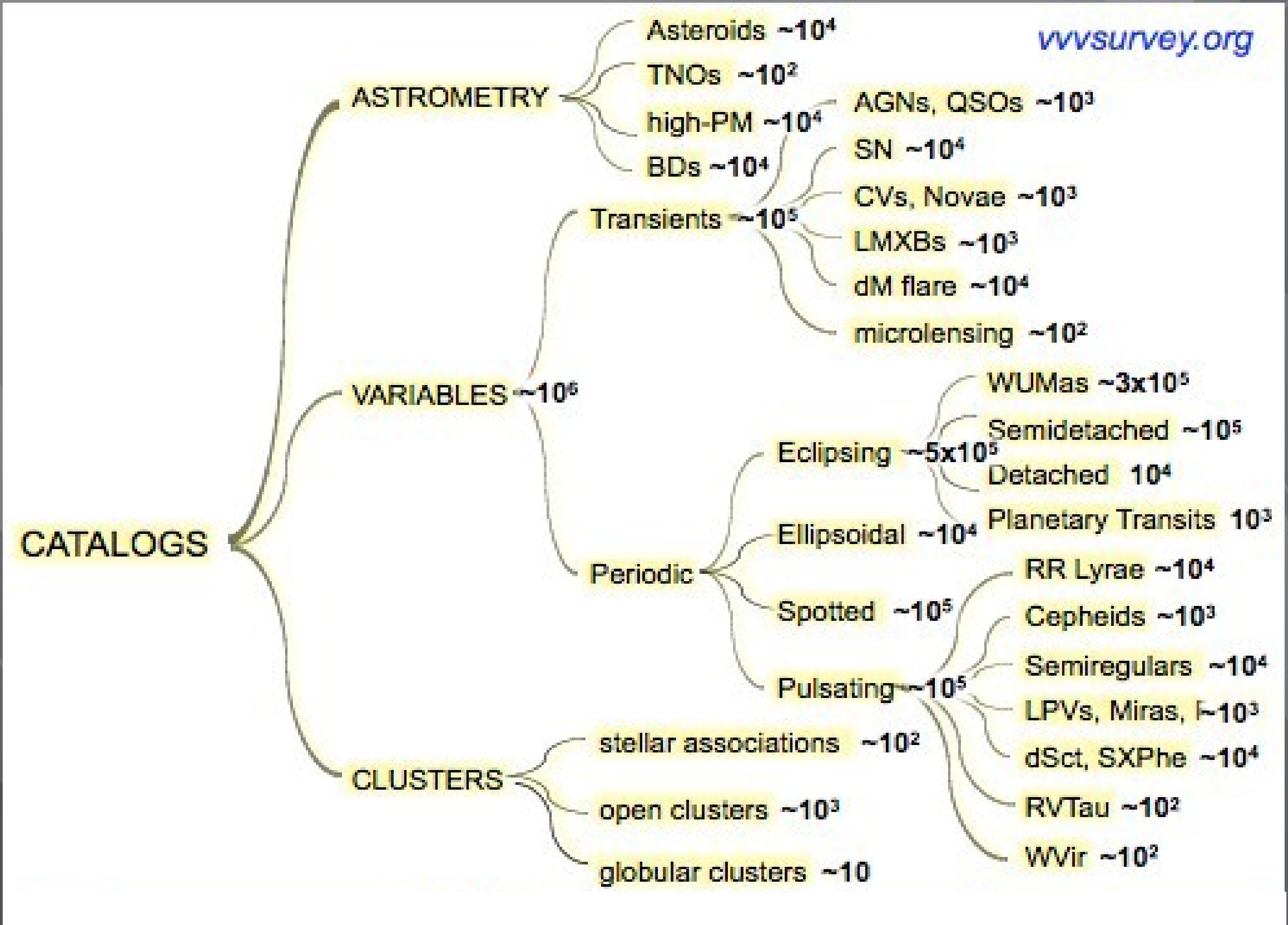
- The Galactic bulge is very complex.
  - it is certainly X-shaped (just a prominent peanut?)
  - it has a vertical metallicity gradient (2 component bulge, or just a double bar buckling episode?)
  - no age gradient (?)

- Large scale surveys are needed, with high resolution (spatial, *and* spectral), to characterize it.

- The ELTs will be crucial to study abundances in unevolved stars, and for a detailed chemical characterization of the most metal poor bulge stars (first stars in the Galaxy?)


PANORAMICUNIVERSE.COM

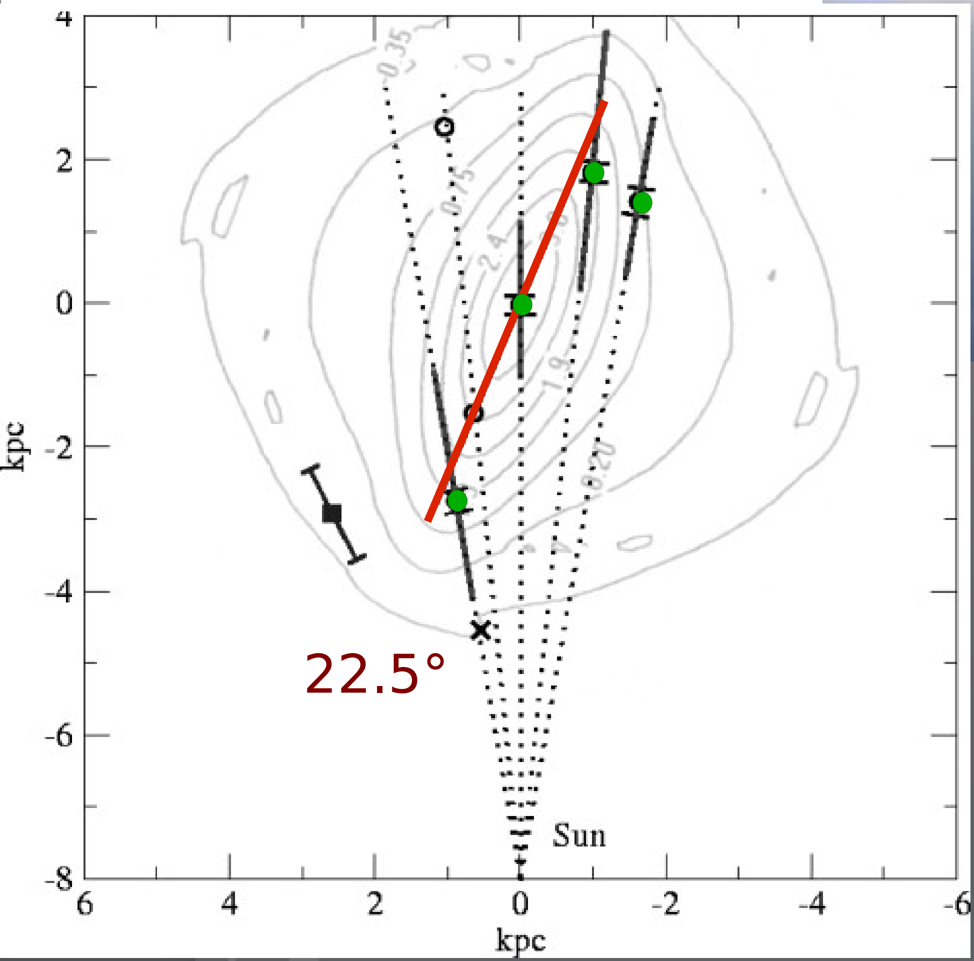



vvvsurvey.org
CATALOGS
ASTROMETRY
Asteroids ~10^4
TNOs ~10^2
high-PM ~10^4
BDs ~10^4
VARIABLES ~10^6
Transients ~10^5
AGNs, QSOs ~10^3
SN ~10^4
CVs, Novae ~10^3
LMXBs ~10^3
dM flare ~10^4
microlensing ~10^2
Periodic
Eclipsing ~5x10^5
WUMas ~3x10^5
Semidetached ~10^5
Detached 10^4
Planetary Transits 10^3
Ellipsoidal ~10^4
Spotted ~10^5
Pulsating ~10^5
RR Lyrae ~10^4
Cepheids ~10^3
Semiregulars ~10^4
LPVs, Miras, I ~10^3
dSct, SXPhe ~10^4
RVTau ~10^2
WVir ~10^2
CLUSTERS
stellar associations ~10^2
open clusters ~10^3
globular clusters ~10

Constraining the Galactic Bar

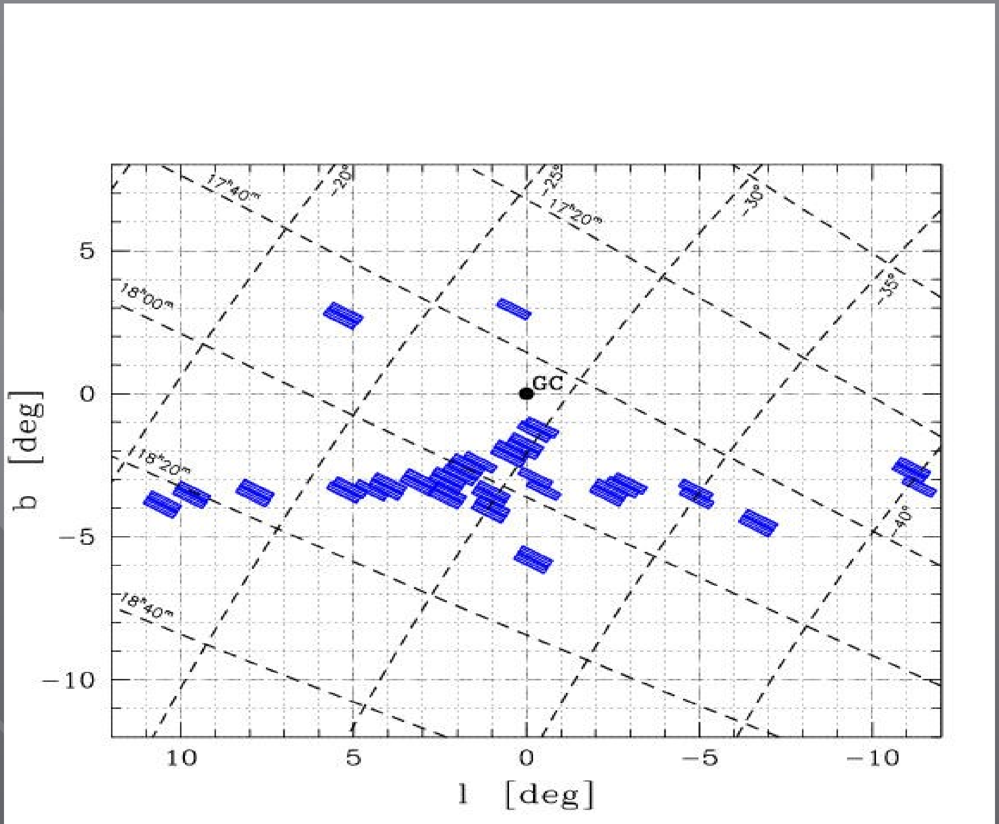
stars at positive longitudes are brighter (closer) than those at negative longitudes.

Babusiaux & Gilmore (2005)

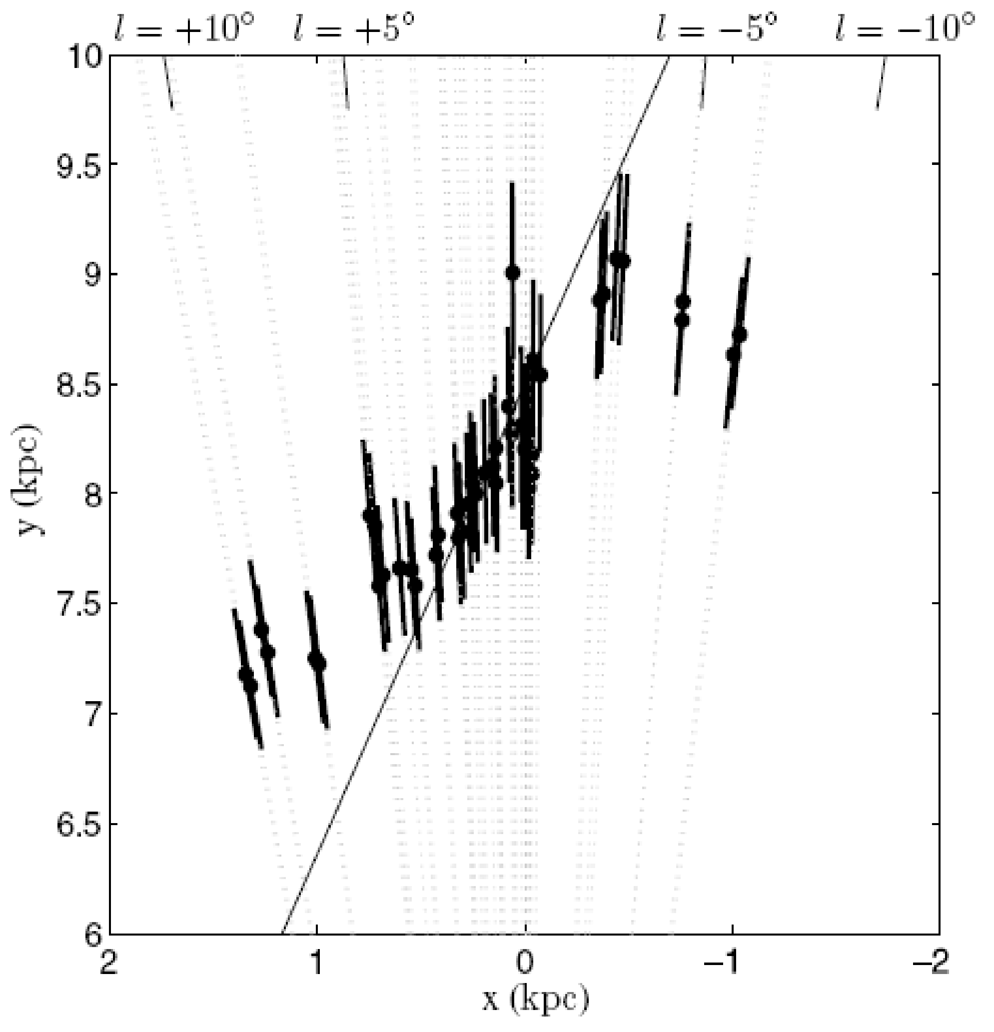


Constraining the Galactic Bar

from OGLE II



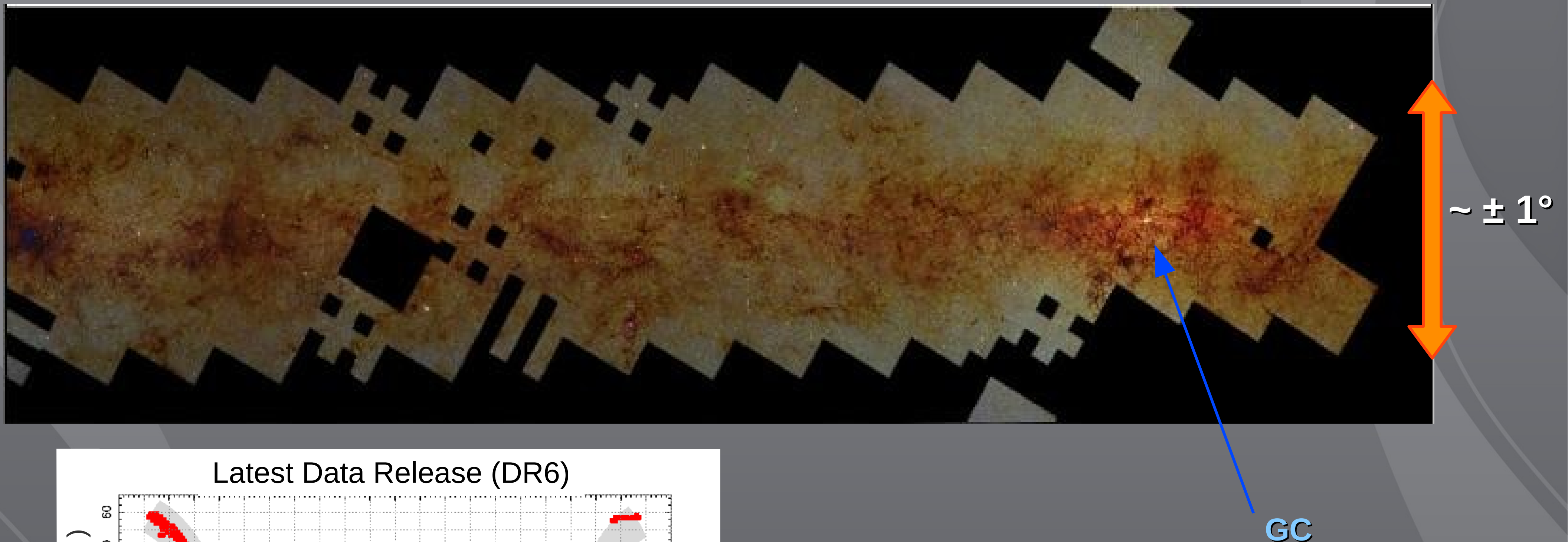
Rattenbury et al. (2007)

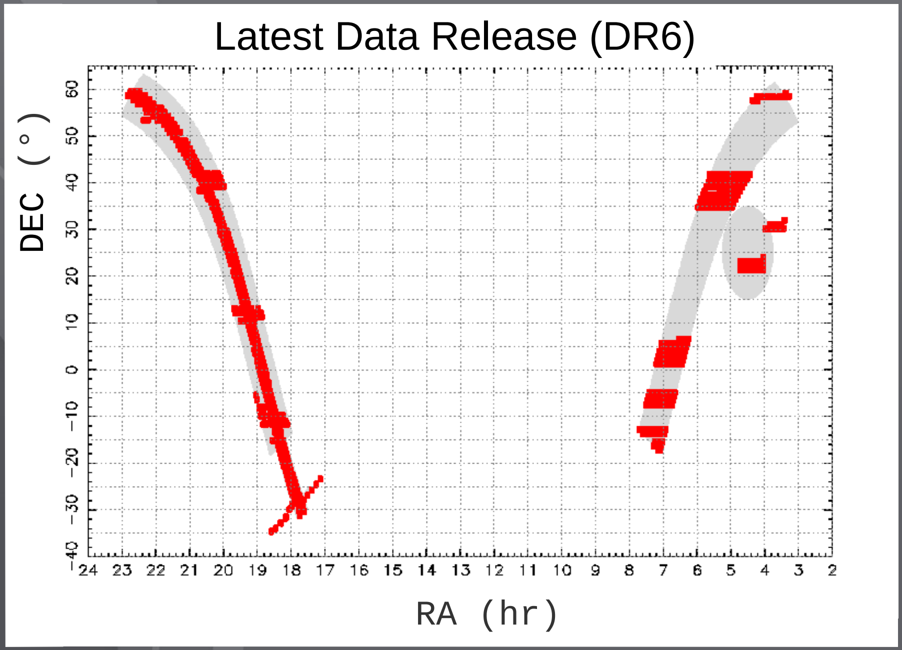


viewing angle: ~ 25°

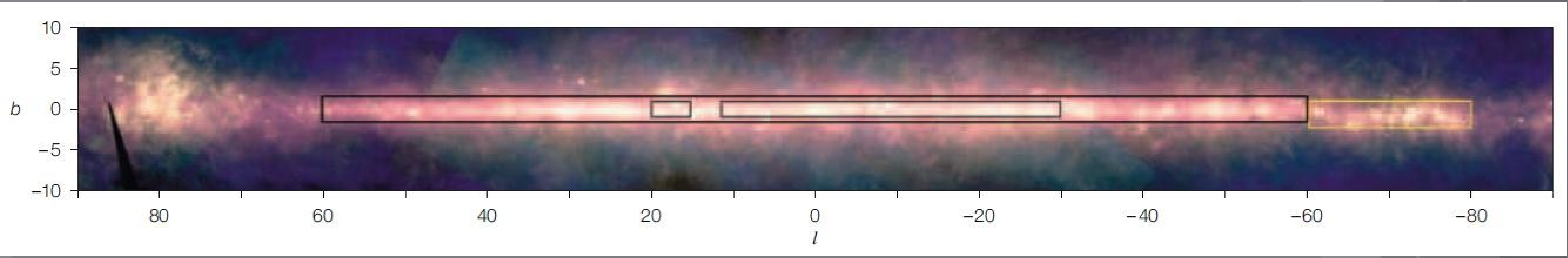
axis ratio: 1 : 0.35 : 0.26

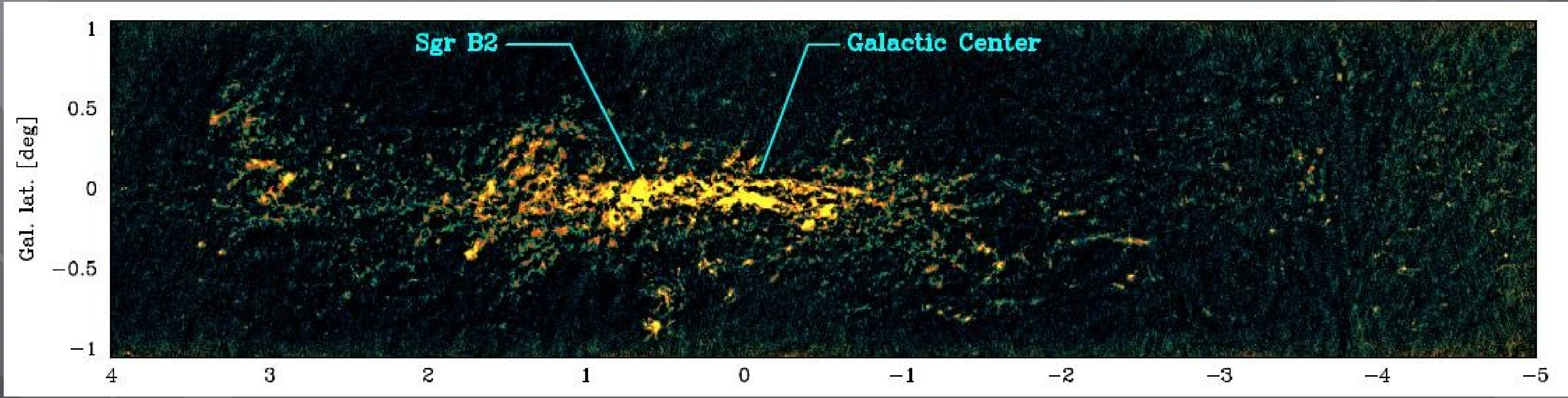
UKIDSS – Galactic Plane Survey



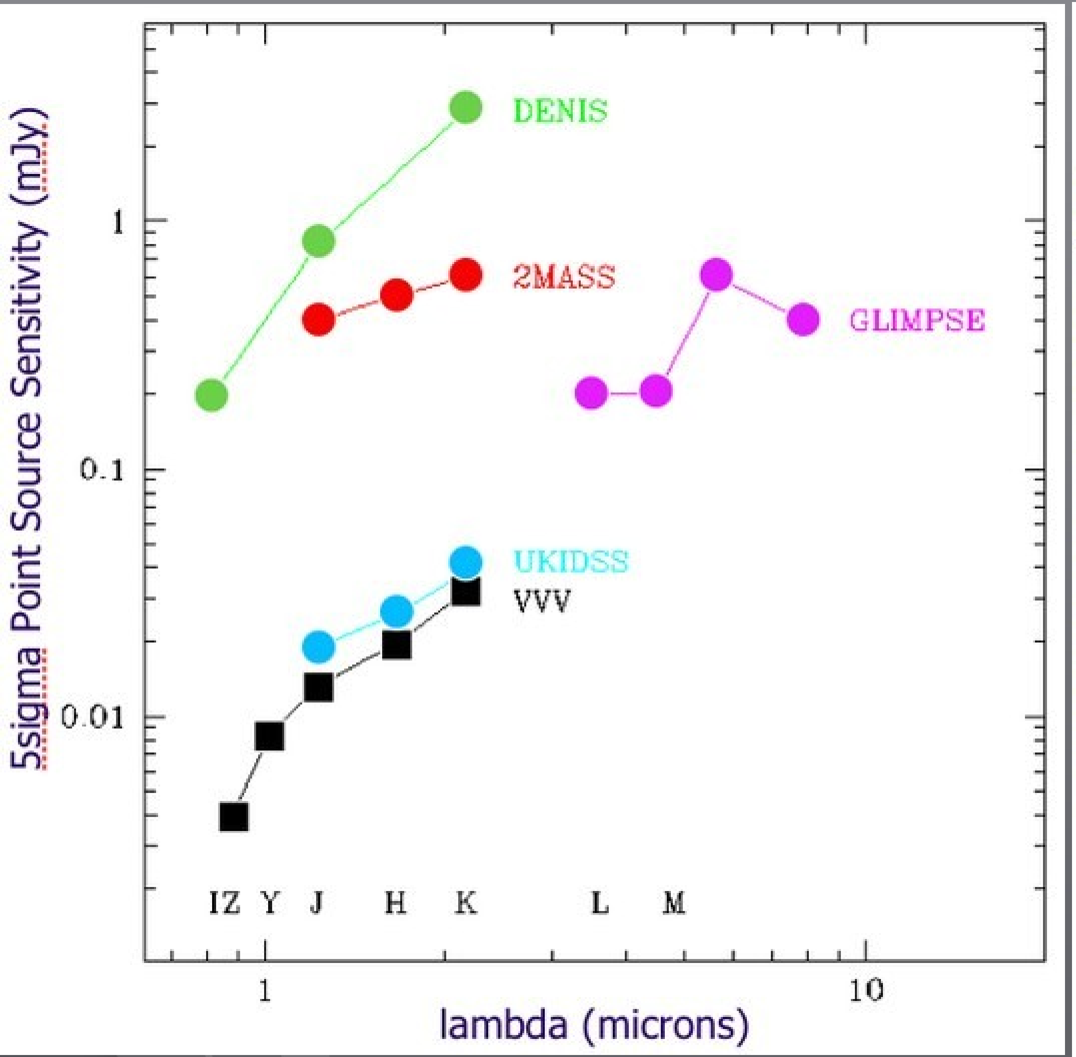


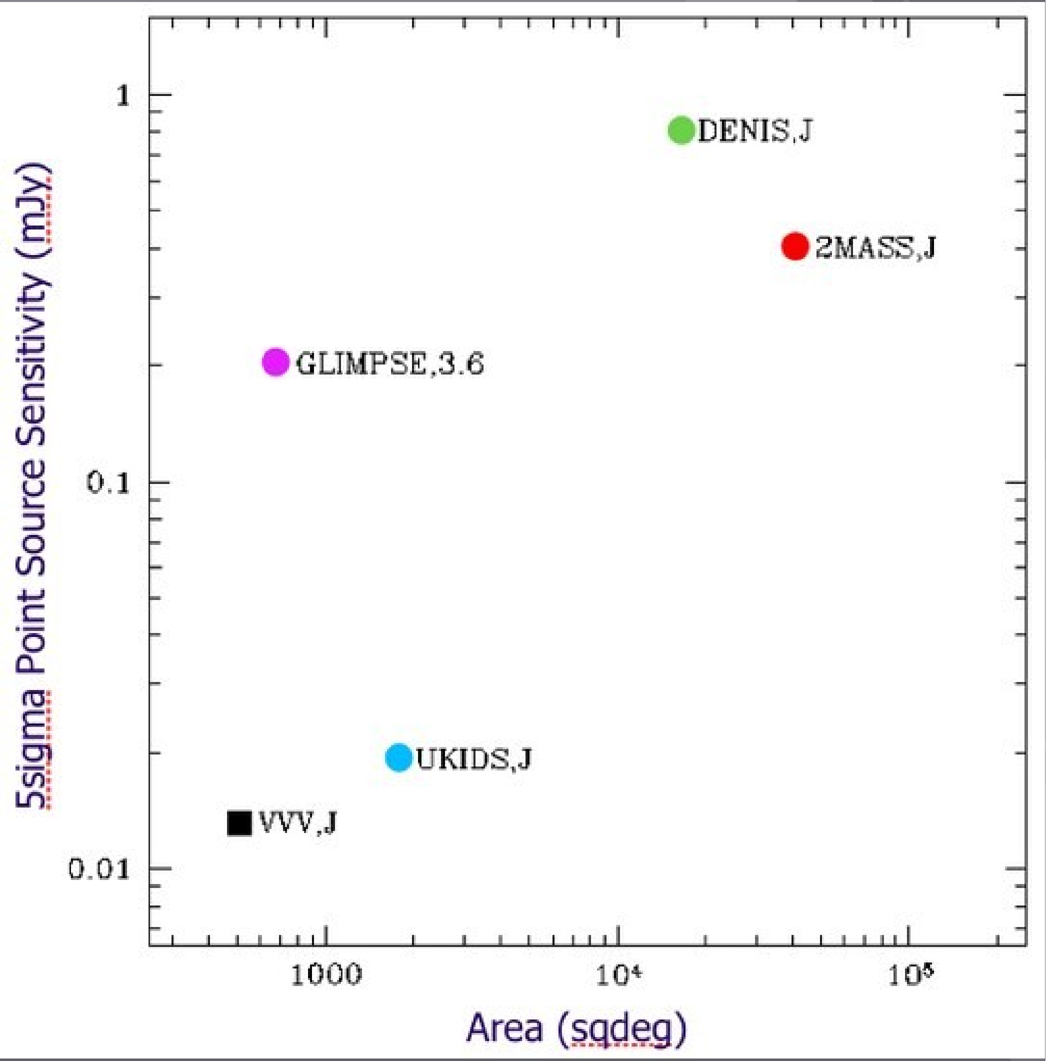
ATLASGAL – The APEX Large Area Survey of the Galaxy at 870 µm



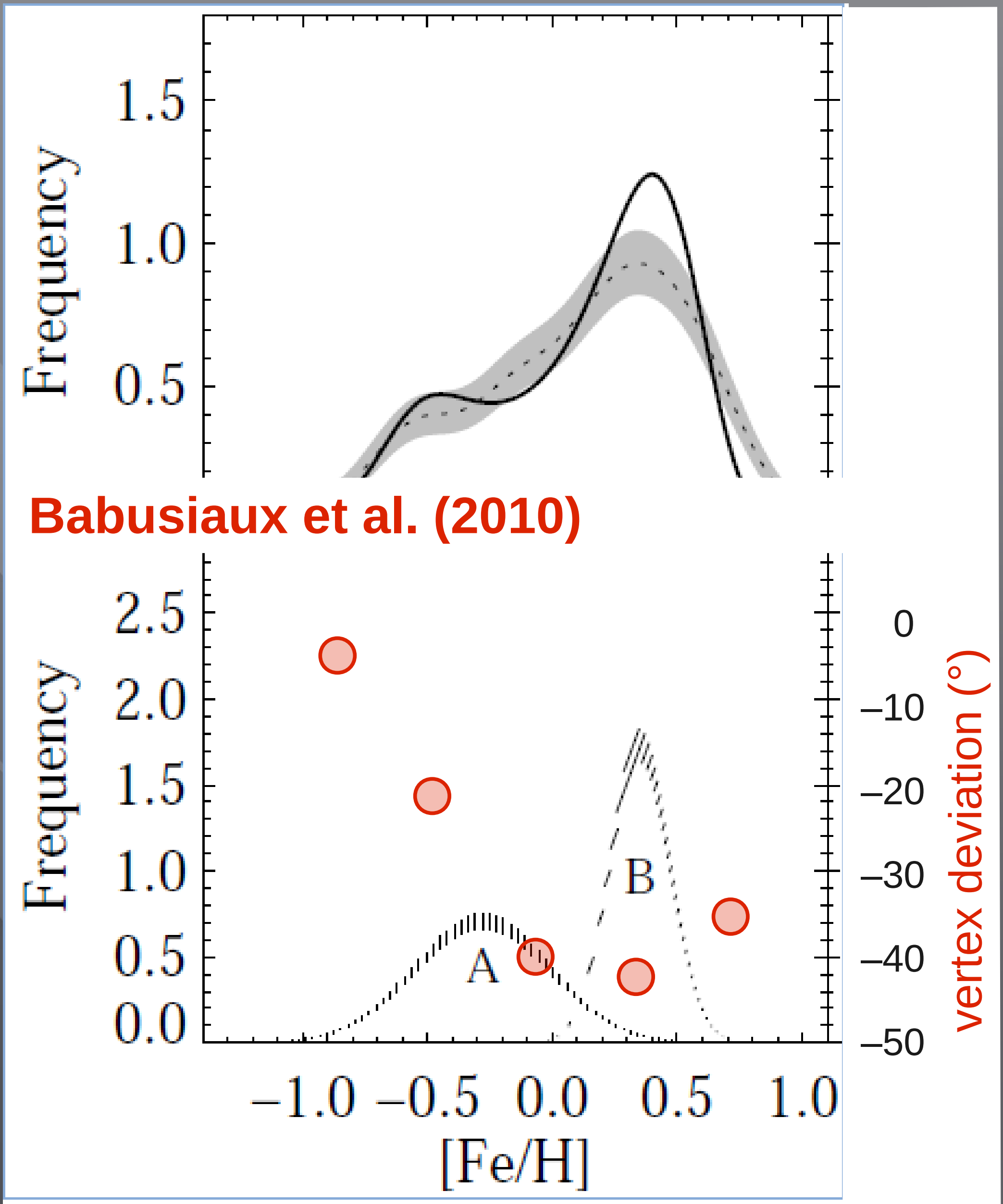


Recent bulge near-IR surveys





The bulge metallicity distribution



- the two peaks show different kinematics

  possible evidence of classical spheroid + bar

- However, **Howard et al. (2009)** found cylindric rotation: no need for a Galactic bulge