Exploring the dynamics and subpopulations of the bulge using WFIRST

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HST Legacy

Bulges appear be either spheroidal (classical) or barlike (pseudobulge)

Canonical formation picture is that spheroids form via early mergers, while pseudobulges/ bars evolve from a buckling instability over longer timescales.

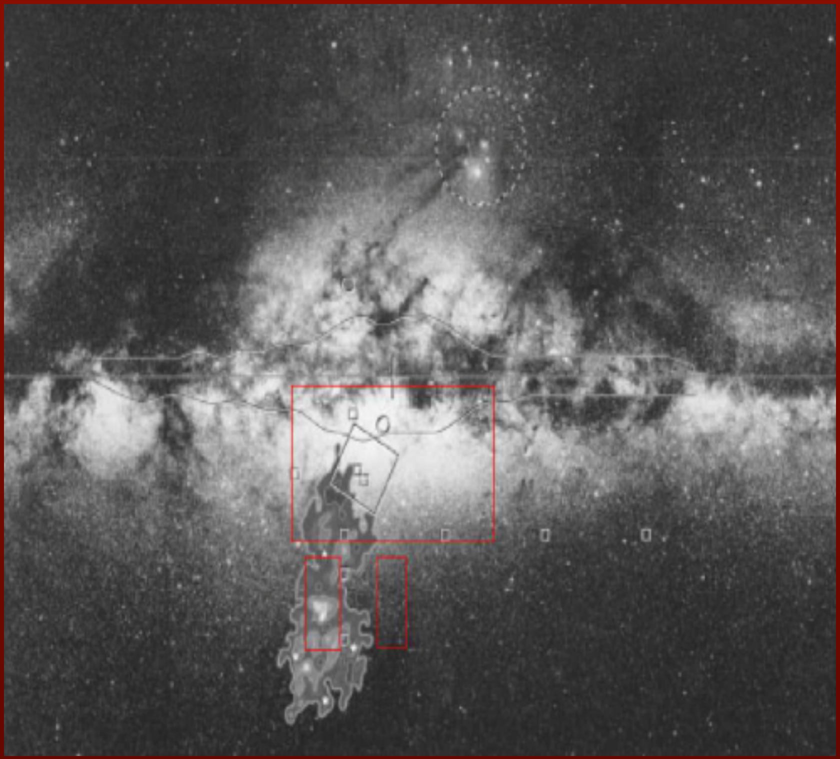
Milky Way has dynamics characteristic of pseudobulges, yet age/chemistry consistent with rapid formation.

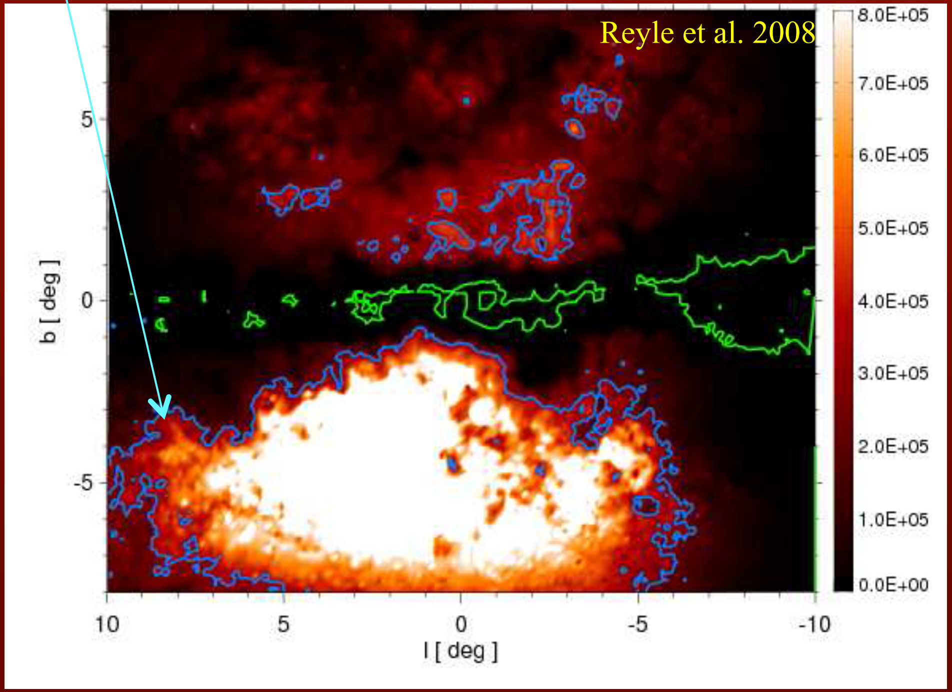
see "The Galactic Bulge" by R.M. Rich in Planets, Stars, and Stellar Systems, Vol 5 (ch. 6).

Unique chance to study edge-on bar system in deep detail

Wyse, Gilmore & Franx 1997

> 6e5 stars/sq deg boundary



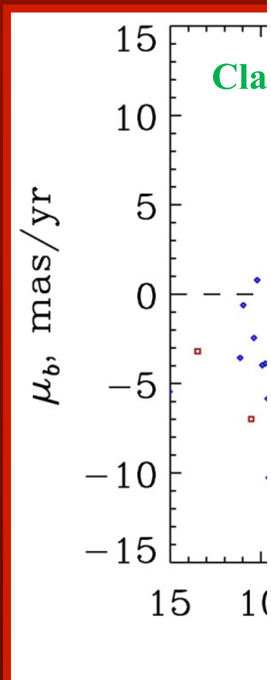


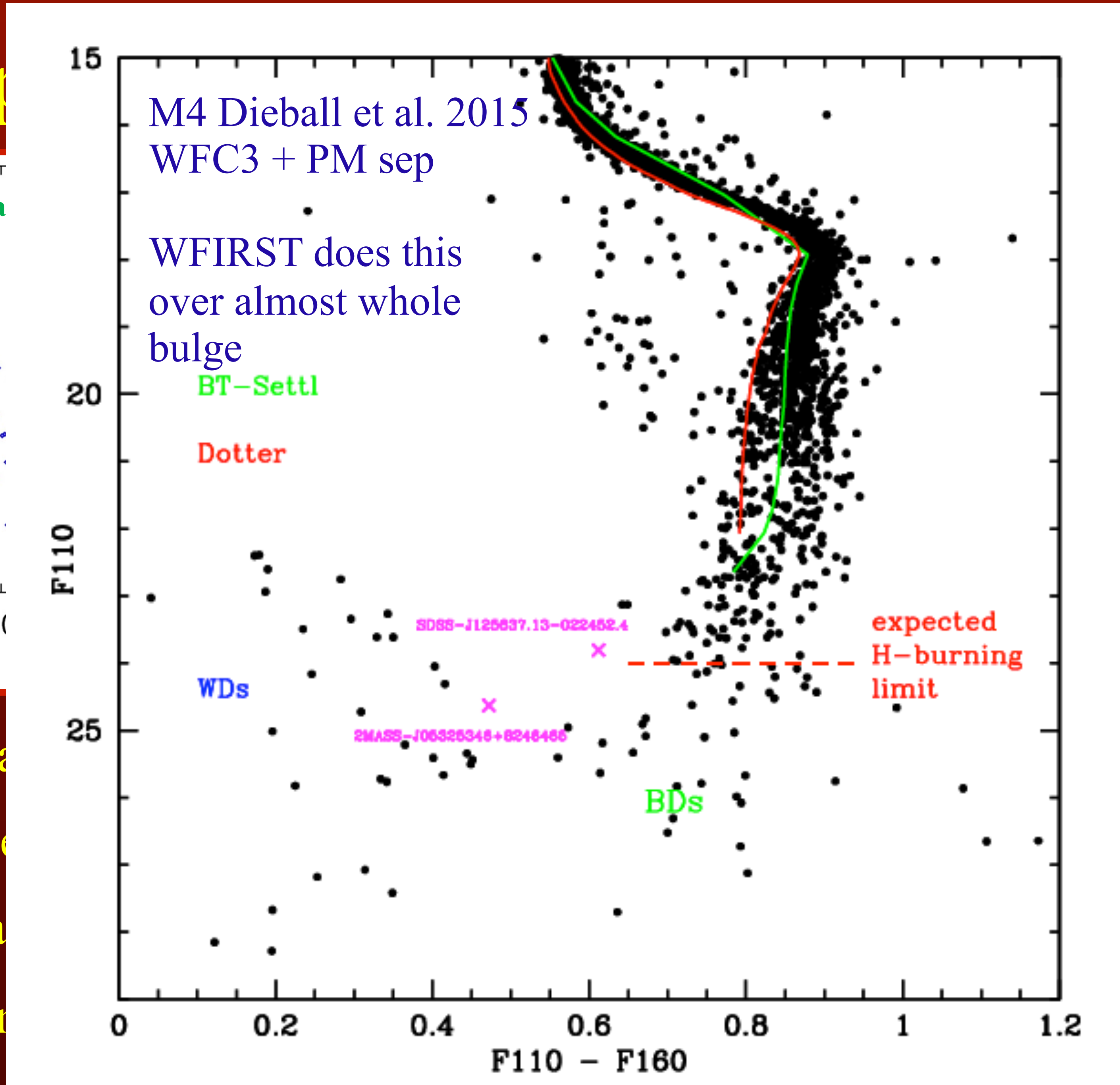
Optical mission like GAIA hurt by crowding, extinction

WFIRST potential for wide-field bulge astrometry survey

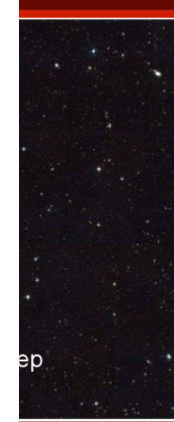
Push into |b|<2° where extinction extreme-new territory

Pop… T





- HST qua…
- Large fie…
- Long ba…
- IR minin…



Major Problems:

Deep HST Photometry favors ~ 10 Gyr age; spectroscopy of microlensed bulge dwarfs finds ~25% population < 8 Gyr

Milky Way has dynamics characteristic of pseudobulges, yet age/chemistry consistent with rapid formation.

Chemical composition [α/Fe] vs [Fe/H] consistent with rapid formation, yet not strikingly different from thick disk.

Bulge has and abundance gradient that in principle requires dissipative or wind-driven formation, yet N-body models succeed best at explaining its structure.

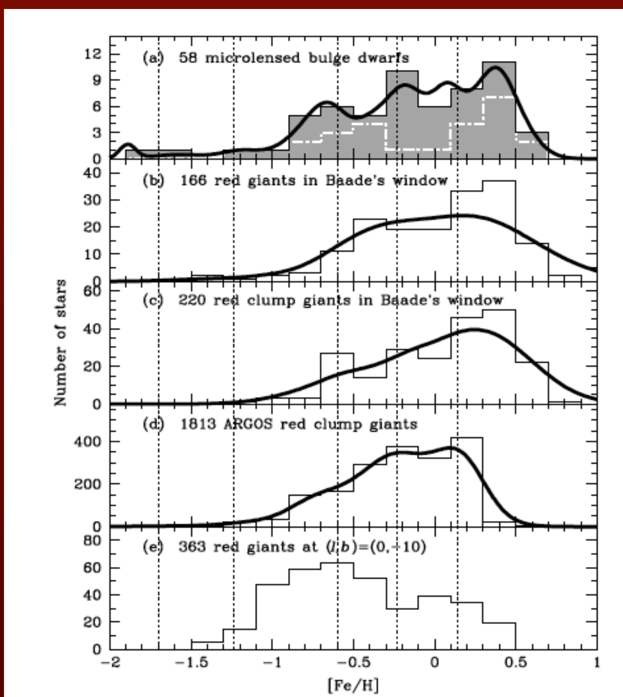
Can we find substructure and dissolved systems in addition to the Sgr dwarf?

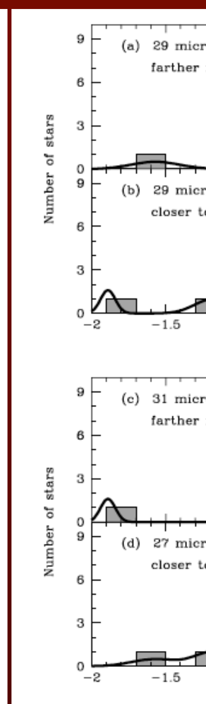
Nature of possible substructure at +200 km/sec (Nidever et al. 2012)

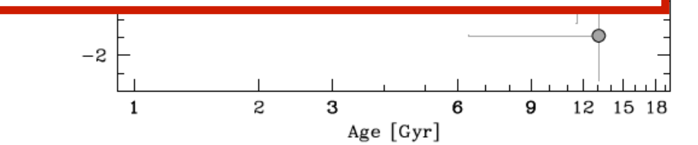
Bensby et al. 2012, 2013

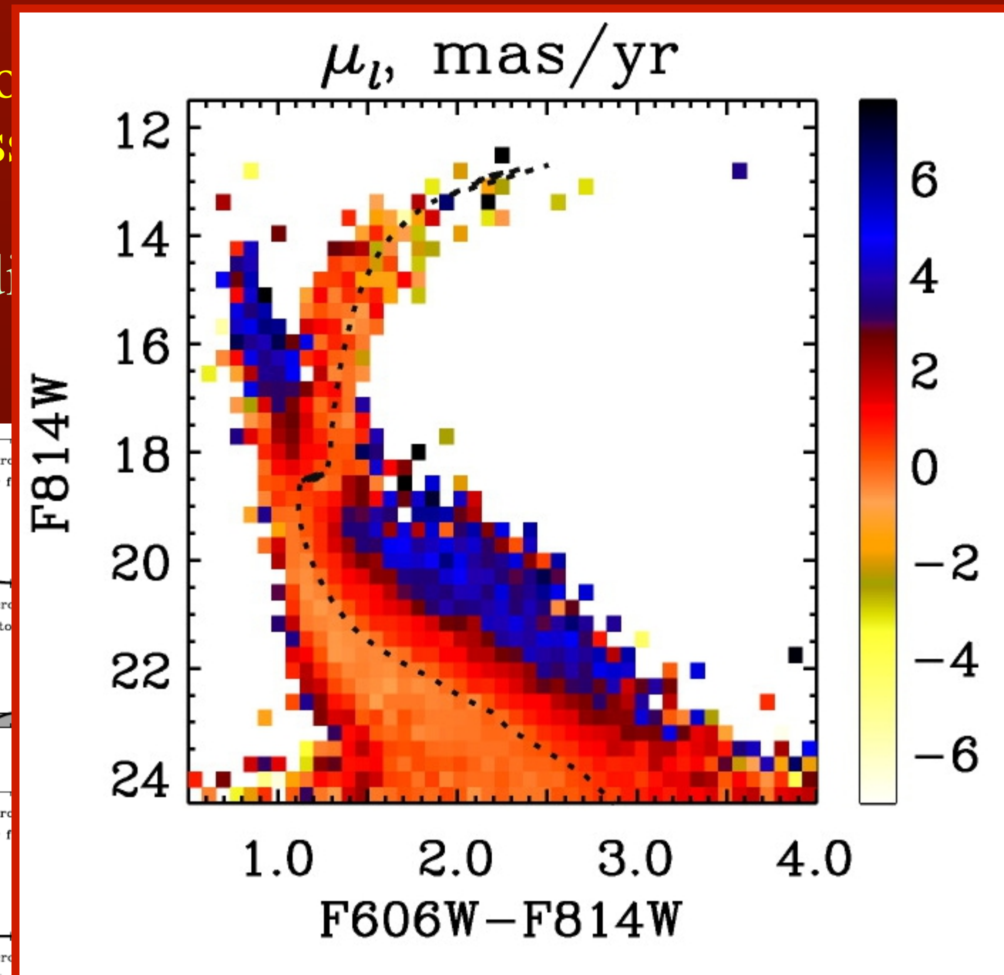
Microlensed bulge dwarfs: self-co
young, metal rich population, pos

A major goal of composition studi
complexity of the populations.

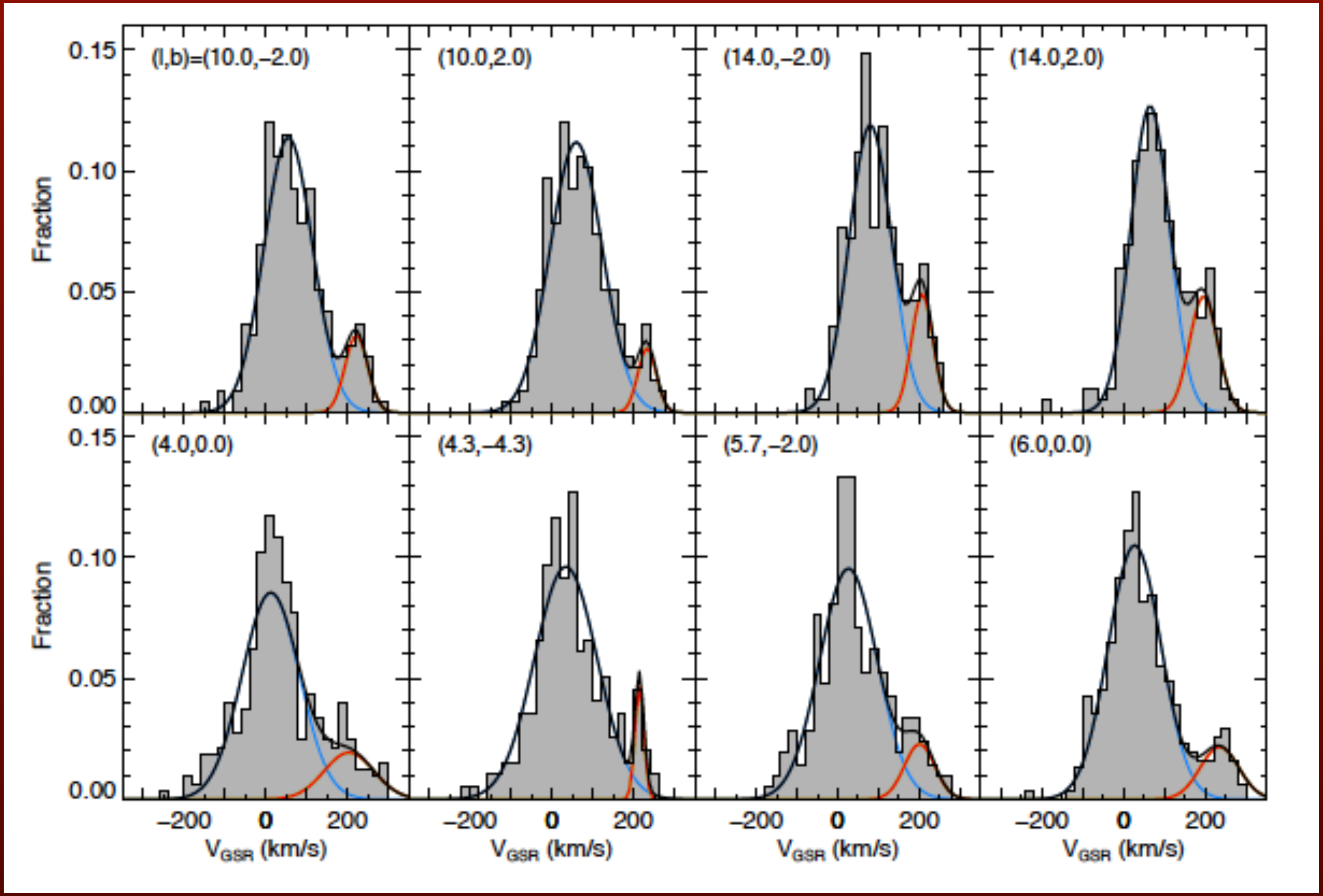




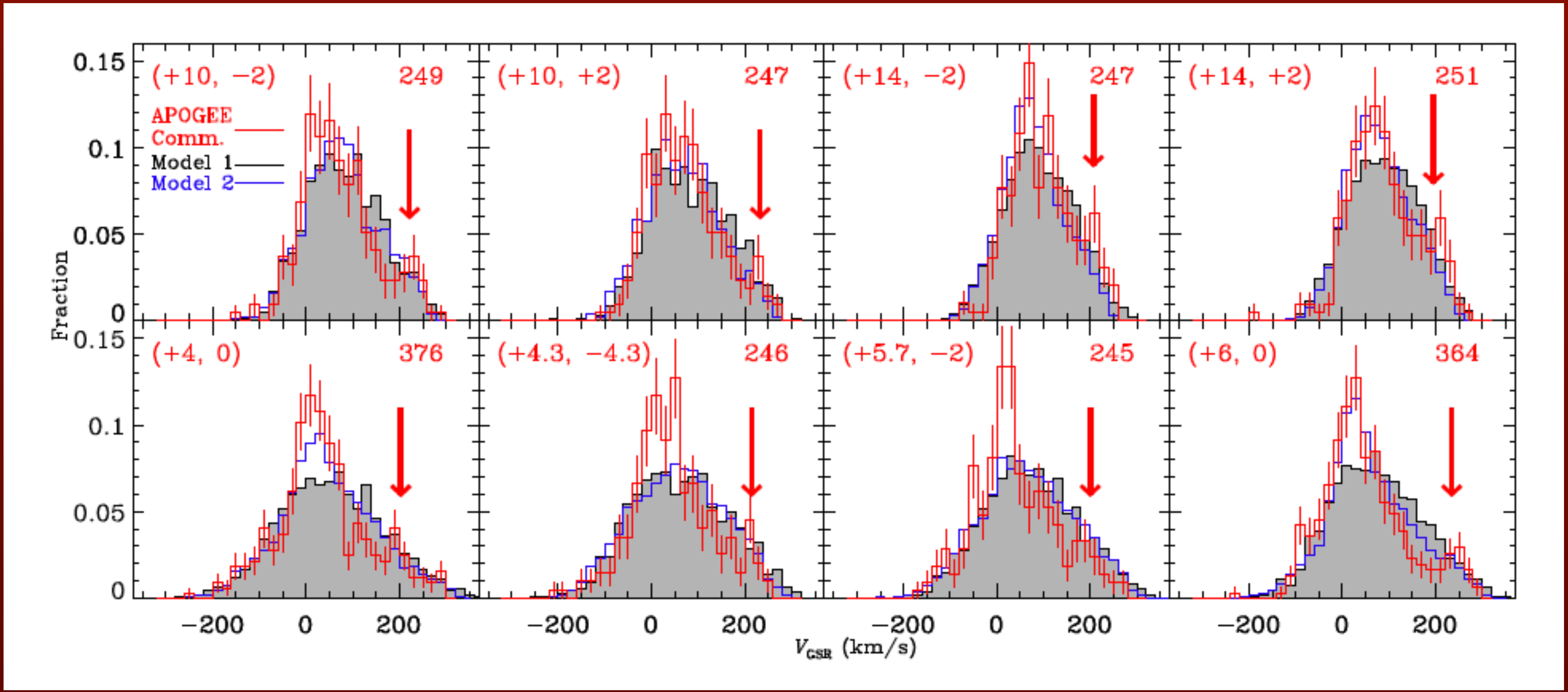




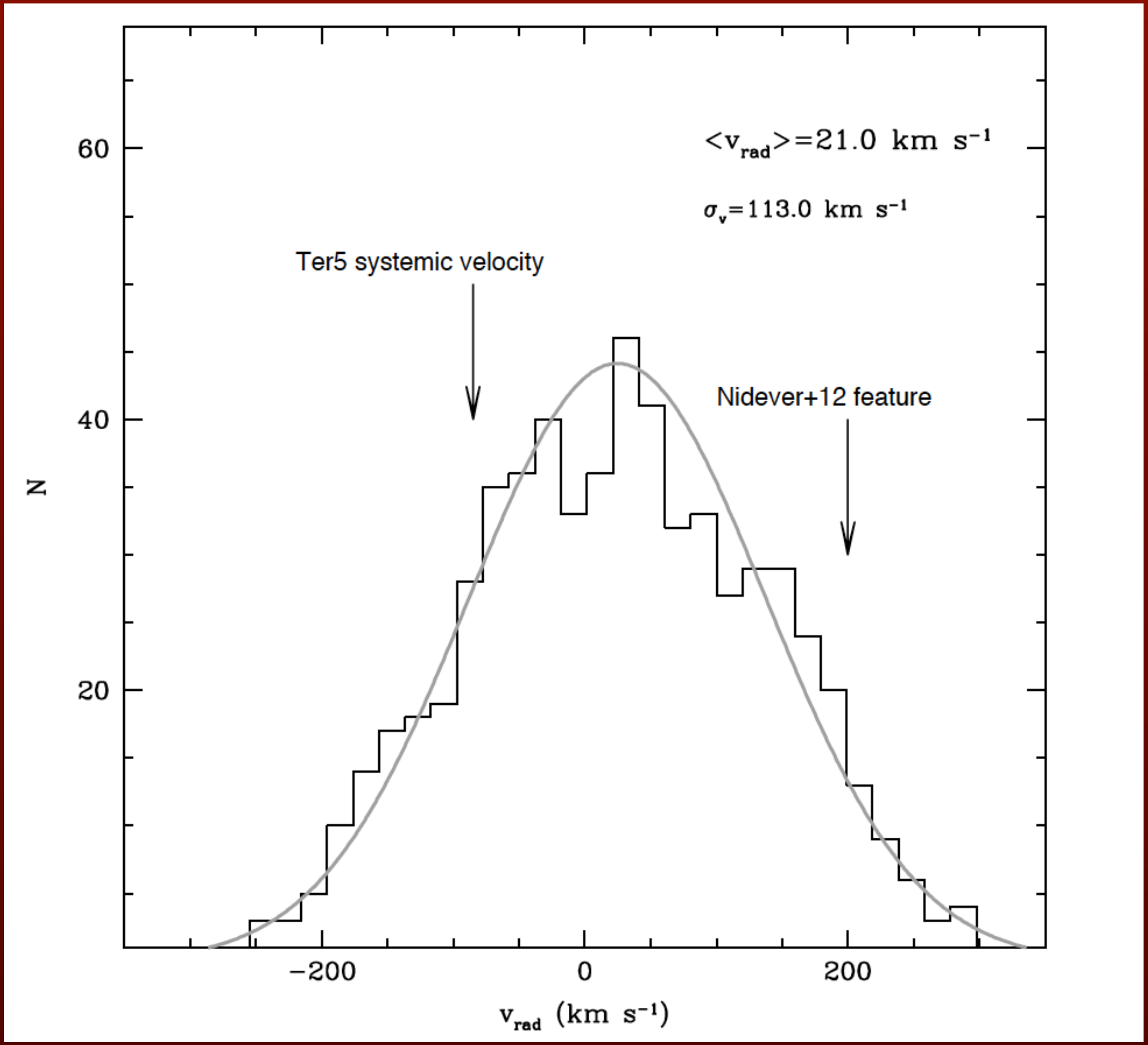
APOGEE +200 km/sec stream (Nidever et al. 2012)



Li, Shen, Rich, Kunder, Mao 2013
+200k/s not found in bar model.

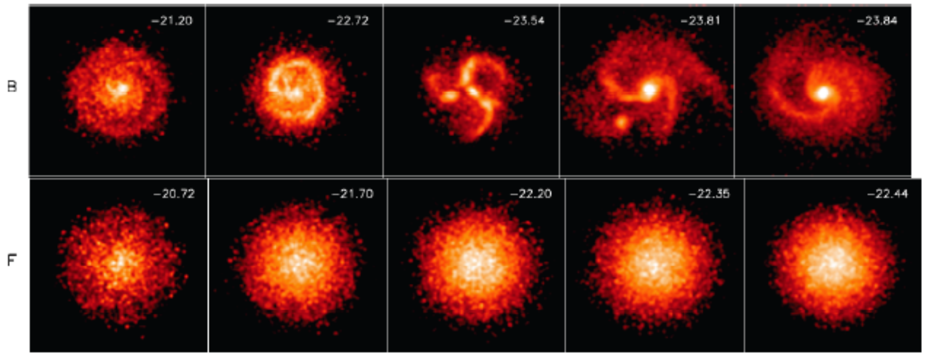


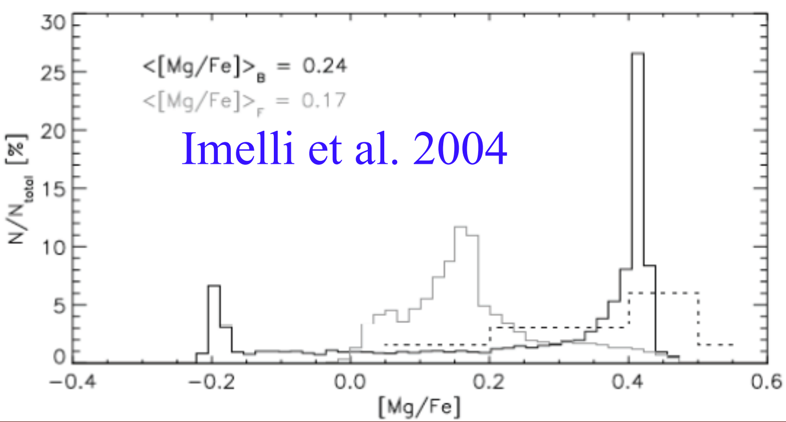
+200 km/s absent in Massari et al. 2014 1600 stars
Also Zoccali et al. 2013 (GIBS)



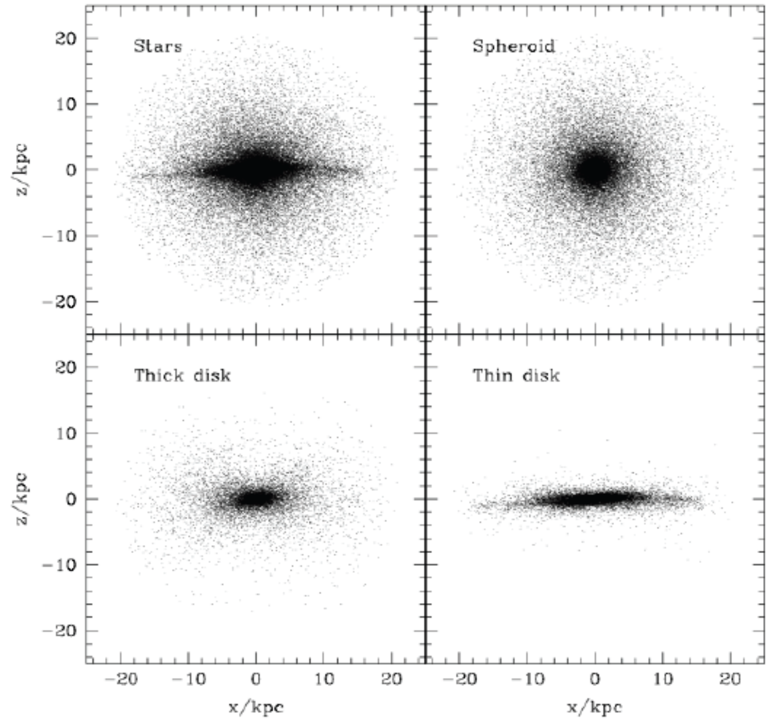
Imelli et al. 2004; Elmegreen et al. (2008) - major merger origin
Clumps dissipate rapidly into bulge or Classical early merger..

Multiple star forming clumps might produce kinematic subgroups with distinct chemical or dynamical fingerprints.





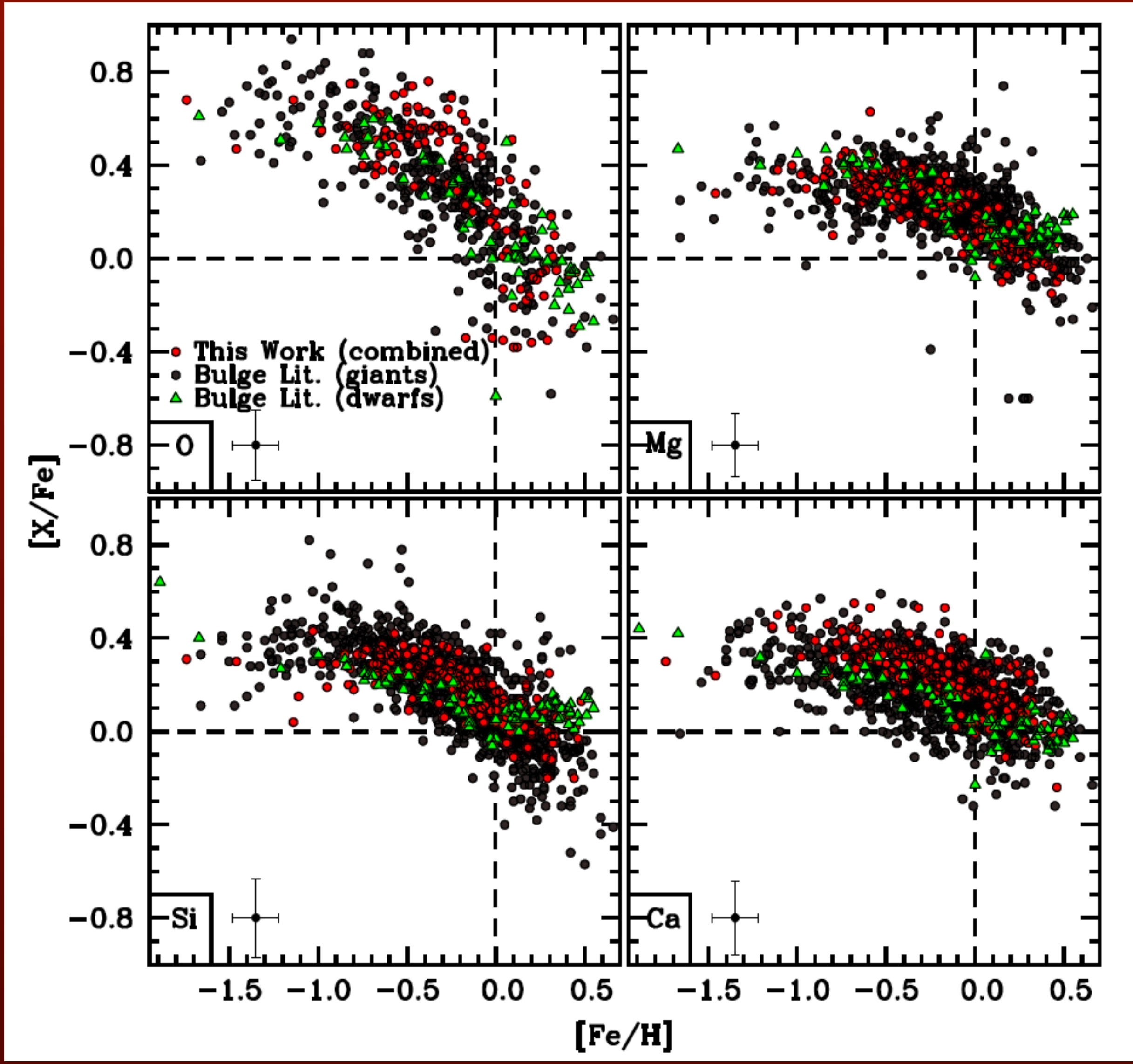
Abadi 2003



See also Inoue et al. 2013, Elmegreen et al.   Complex globular Ter 5 a proto-clump?

No evidence for low [α/Fe] sub populations (C. Johnson et al. 2014)

[α/Fe]



[Fe/H]

WFIRST 2014

N-body bar models attractive for representing the bulge

However, extended formation models favored; bar survival?

Bar dissolves due to central mass (Norman et al. 1996)

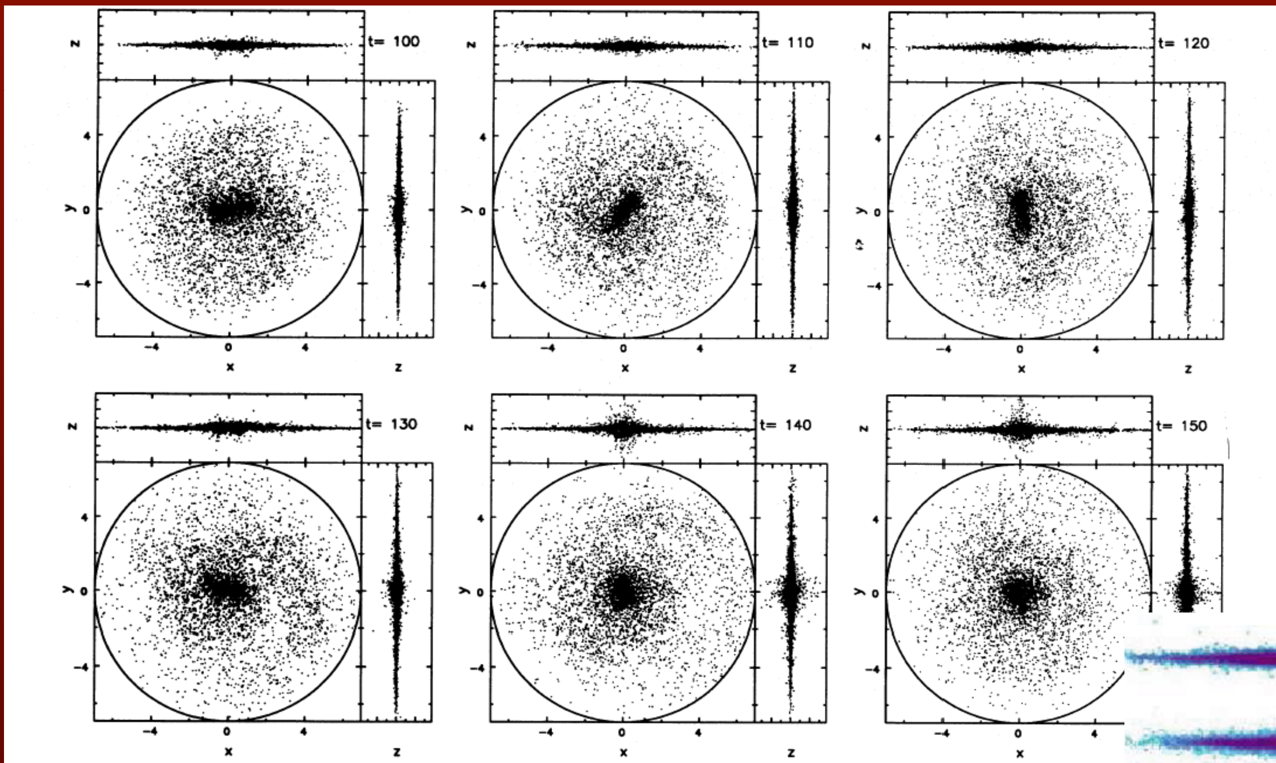
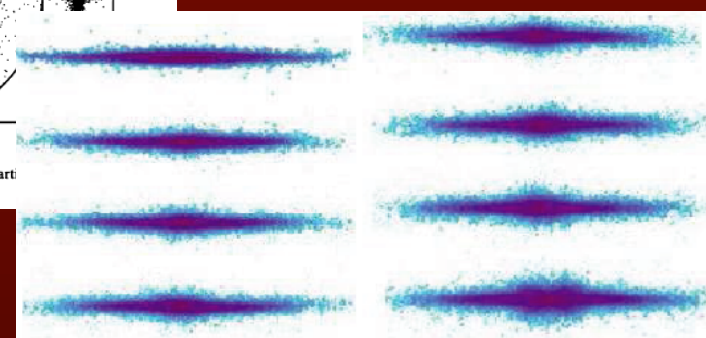


FIG. 6.—The evolution of a three-dimensional model in which a 5% central mass is grown from time 100 to time 140. The whole calculation volume is shown, but only one part
bar dissolves abruptly between times 130 and 140, forming a spheroidal bulgelike feature at the center.

Combes 09- bar resurrection via gas inflow



Vertical thickening of the bar into a bulge would leave no abundance gradient in the z-direction.

"classical"

"boxy/ X-shaped"

THE ASTROPHYSICAL JOURNAL, **256**:460–480, 1982 May 15

ROTATION OF THE BULGE COMPONENTS OF DISK GALAXIES

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Received 1981 June 3; accepted 1981 November 30

"cylindrical" vs "classical" rotation

THE NATURE OF BOXY/PEANUT-SHAPED BULGES IN SPIRAL GALAXIES

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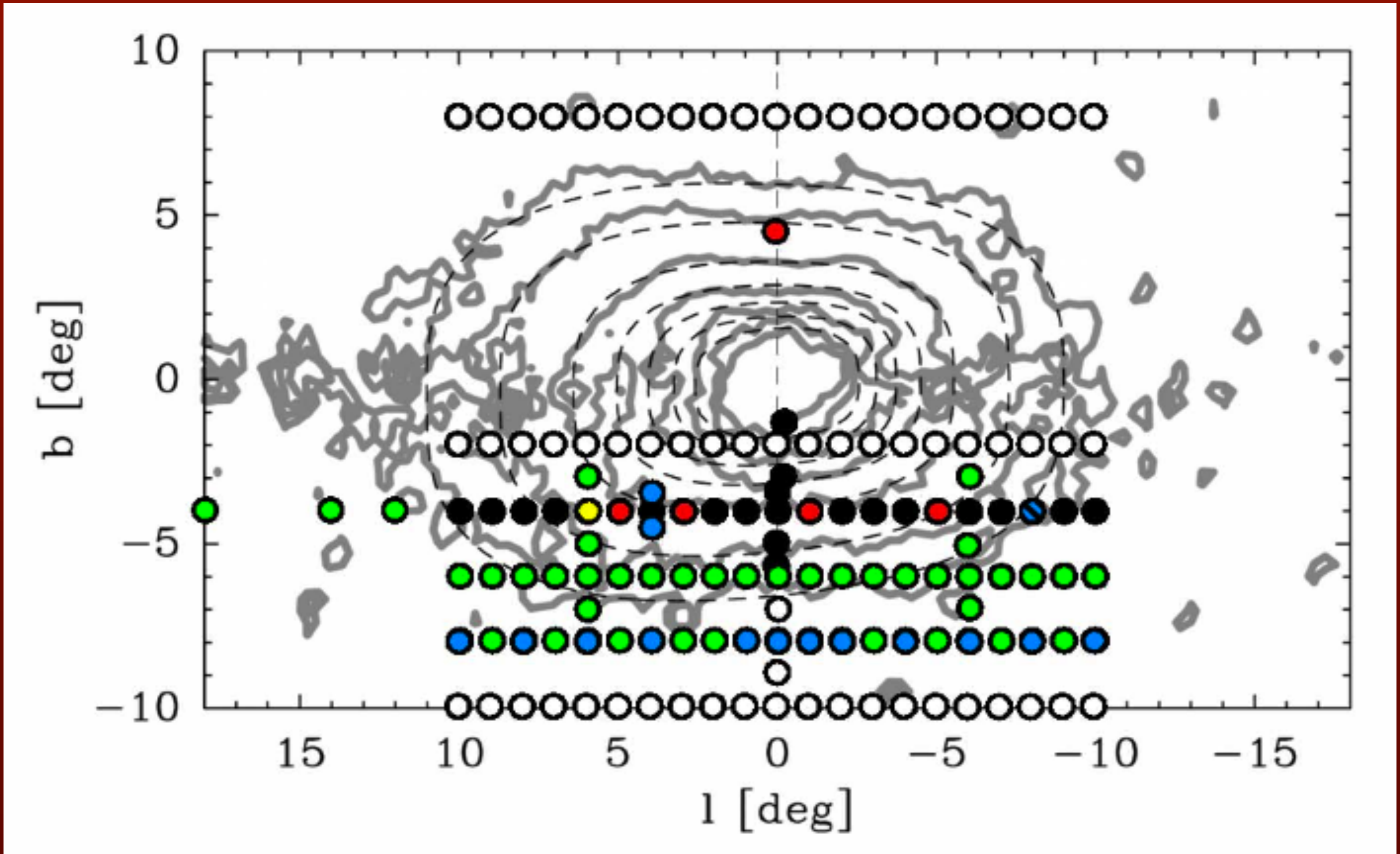
Received 1999 January 12; accepted 1999 March 30

"boxy/peanut" =edge-on bar

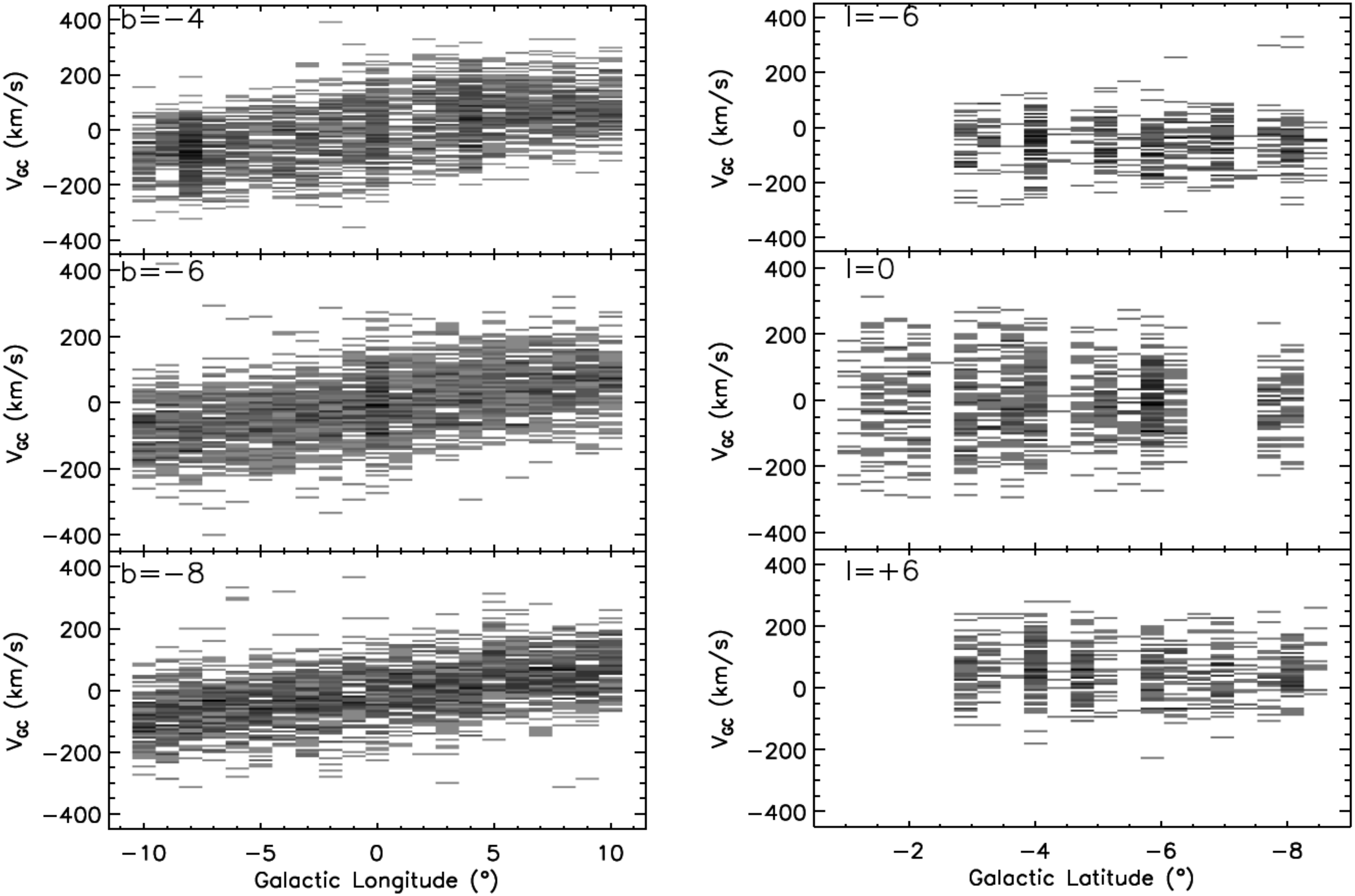
BRAVA Survey Fields 2005: blue 2006: red 2007: green



Rich et al. 2007, Howard et al. 2009, Kunder et al. 2012 (Public data release)

NSF AST-0709479

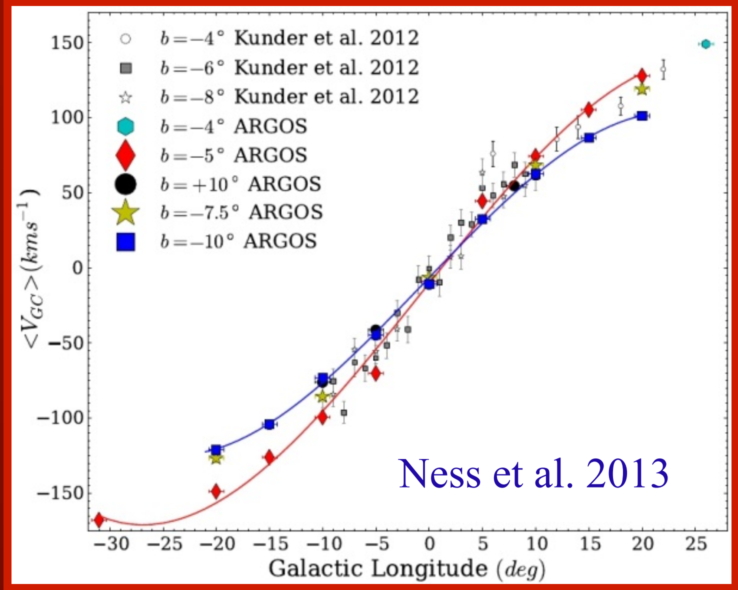
Cylindrical Rotation confirmed by ARGOS Ness, Freeman et al. 2012, 2013

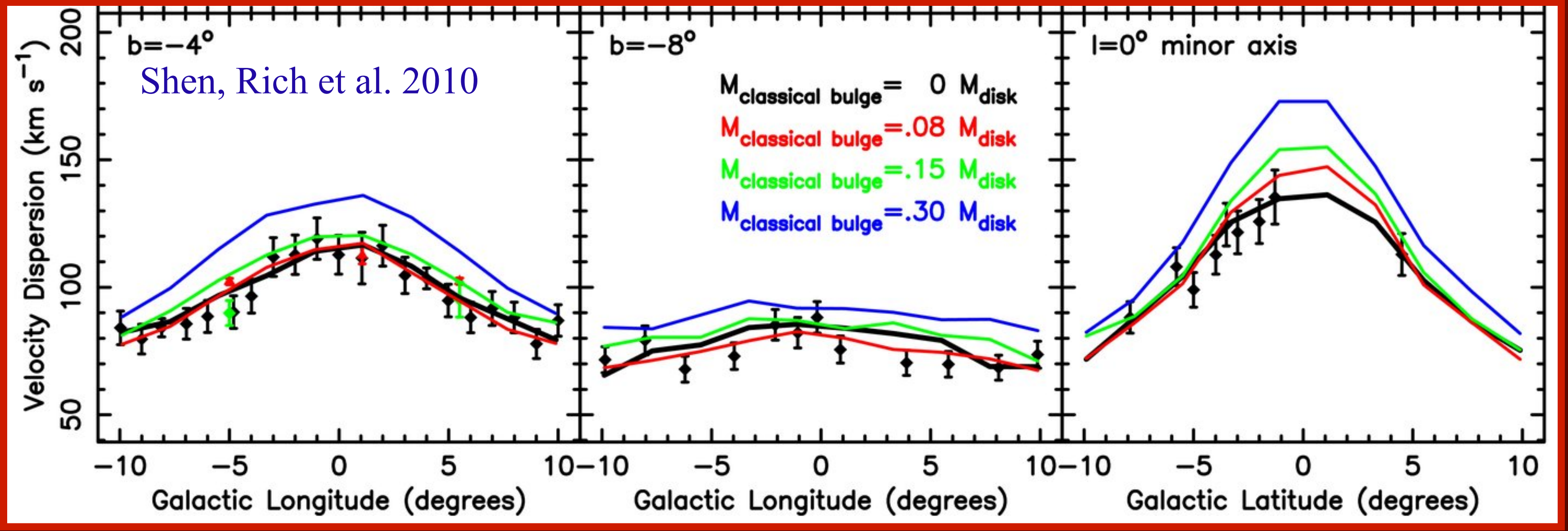


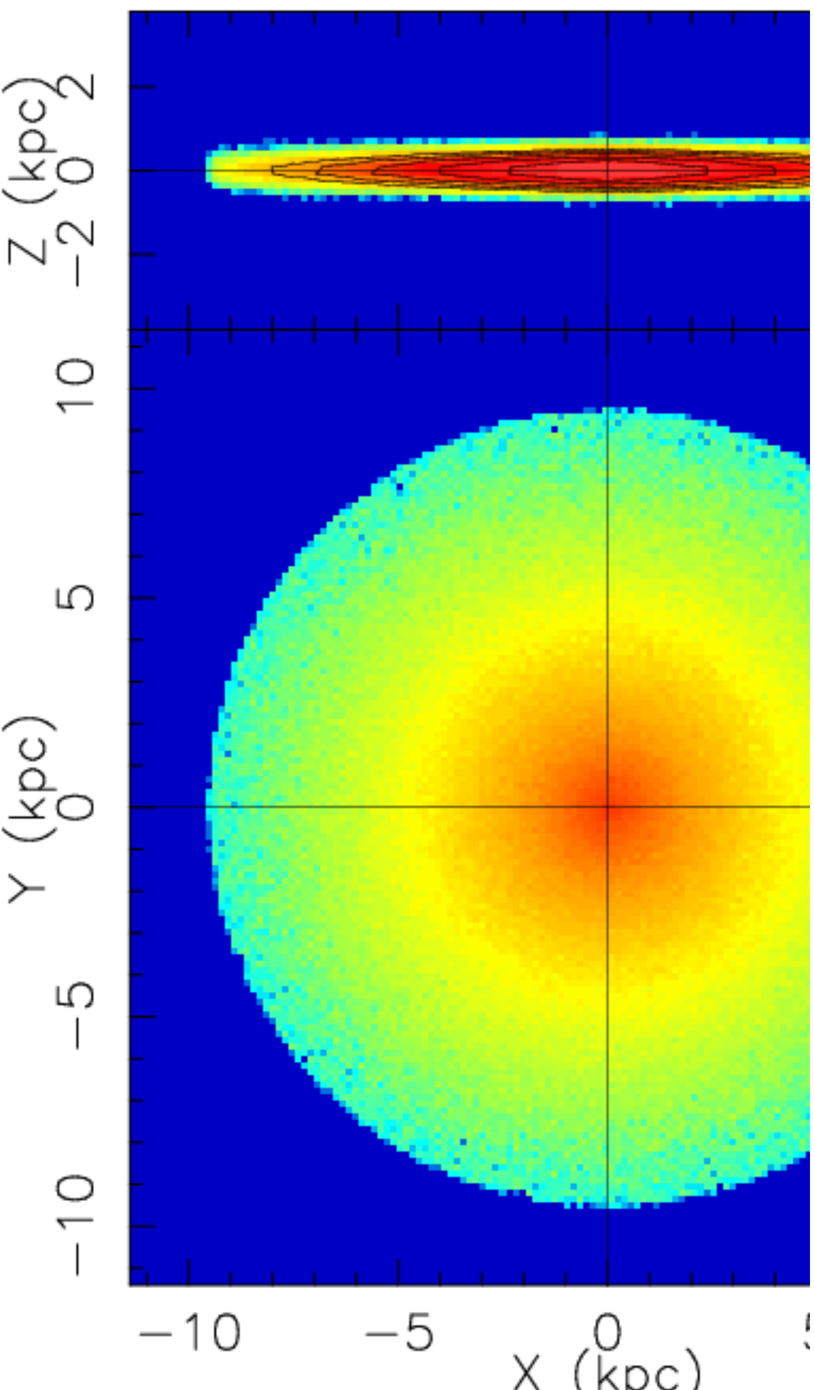
Cylindrical Rotation (BRAVA, ARGOS)

~5% metal poor subcomponent with slightly slower rotation (ARGOS)

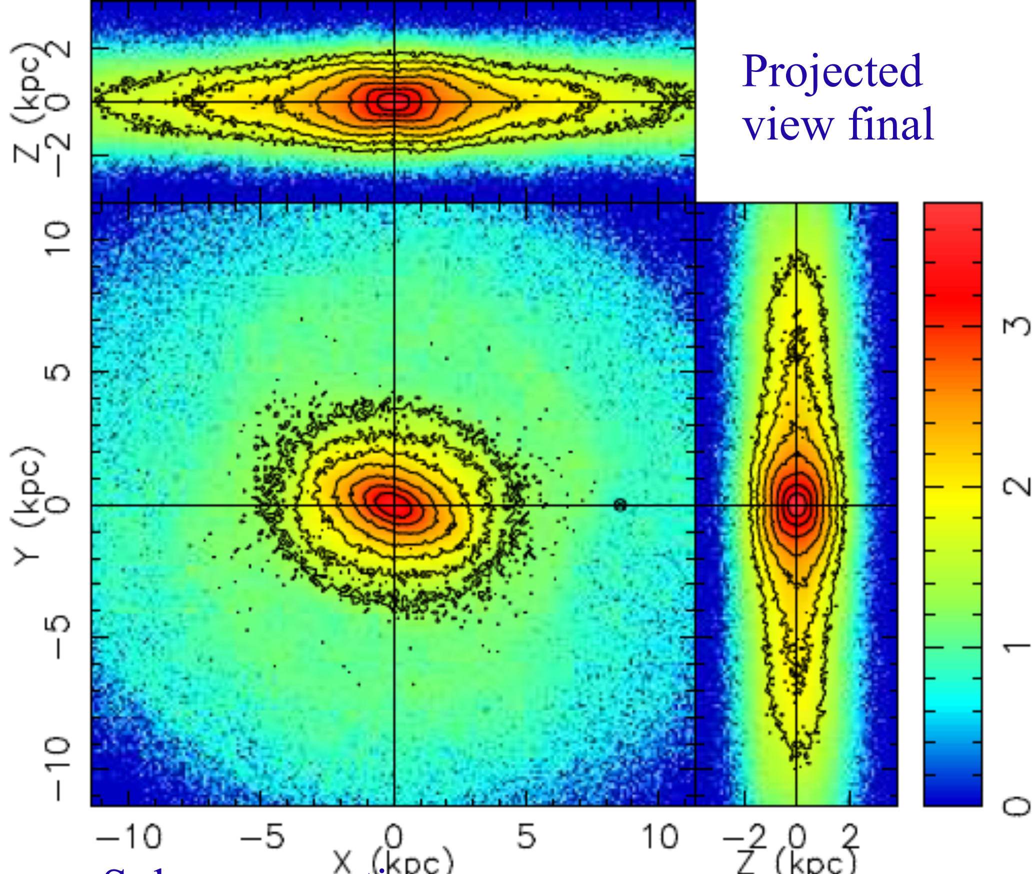
N-body model fits to BRAVA data rule out a significant (>10% disk mass) classical bulge component



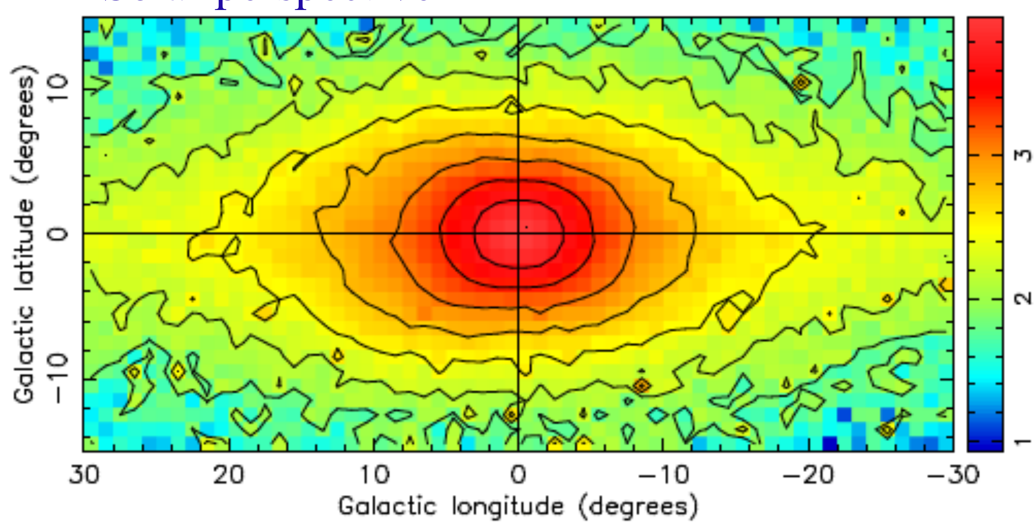




Projected view final

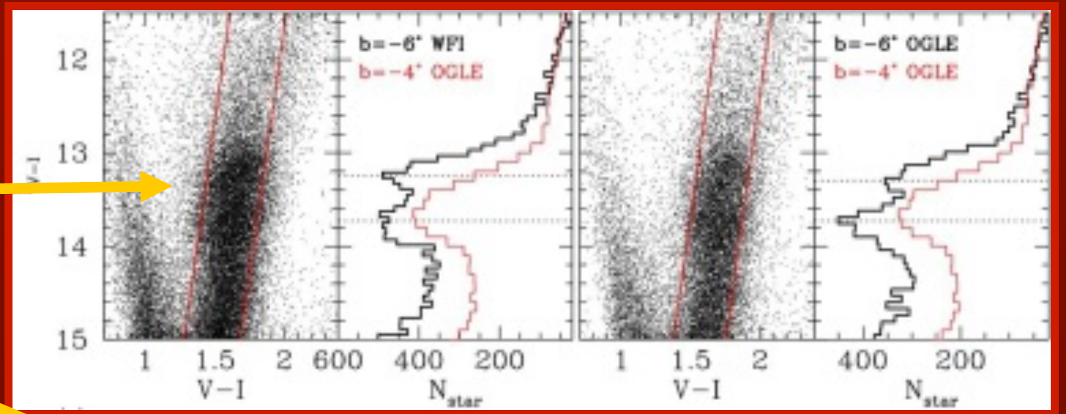


Solar perspective

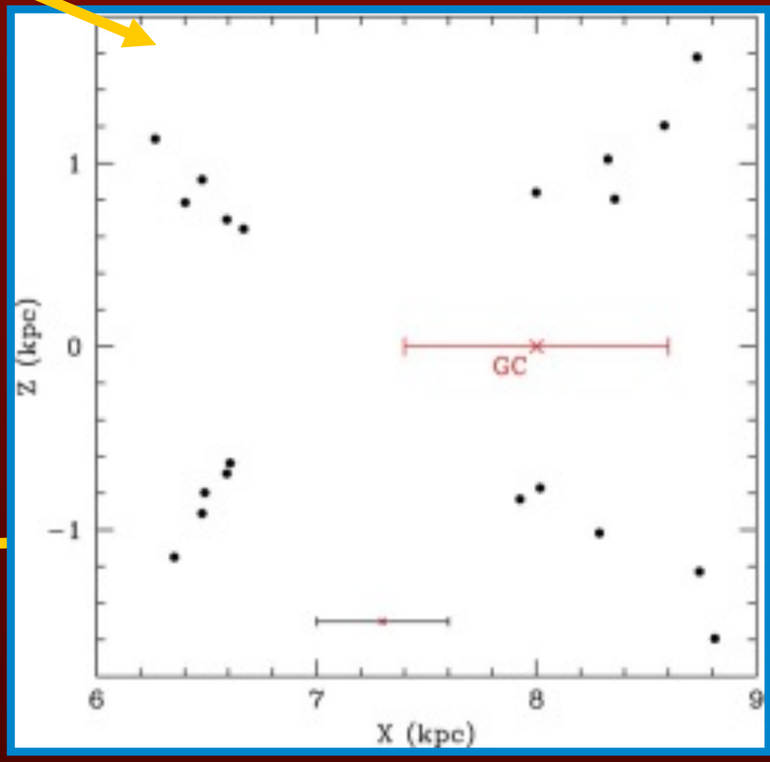


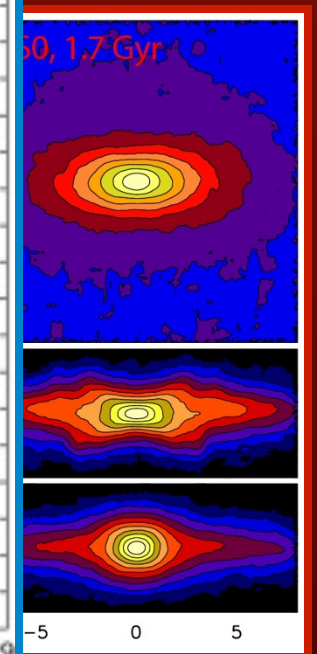
Double red clump> X-shaped bulge

- Optical and IR star counts reveal double red clump
- Tracing over multiple sight lines reveals X-shaped structure
- Orbital resonance from interaction with bar leads to X and boxy shape bulge
- X-shape or boxy shape depends on viewing angle



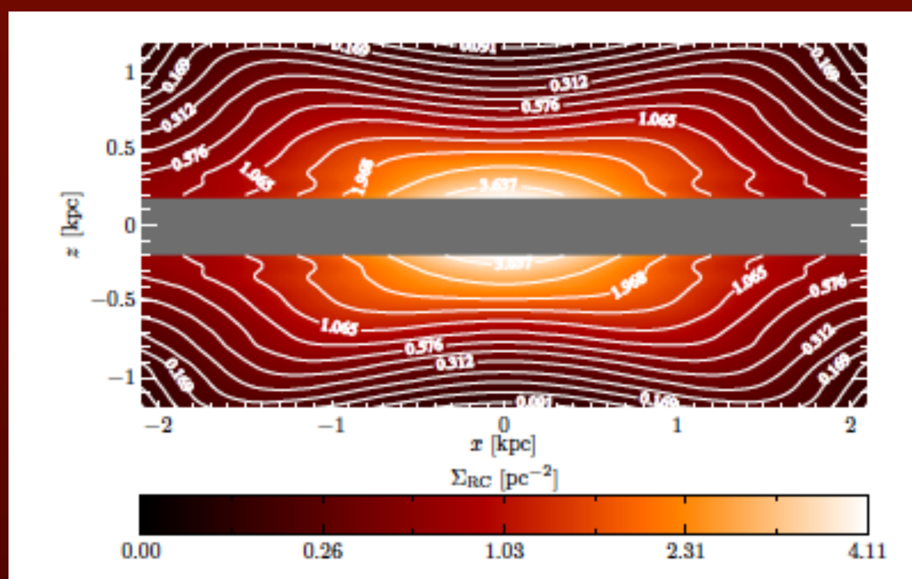
& Zoccali (2010)





uillen et al. (2014)

USE MODELS
TO PLAN
"FIELDS OF
INTEREST"
EARLY FOR
OPTIMAL
WFIRST/BULGE
STRATEGY



27.3^{o} alignment
X is 400pc off plane
10:6.3:2.6 axis ratio

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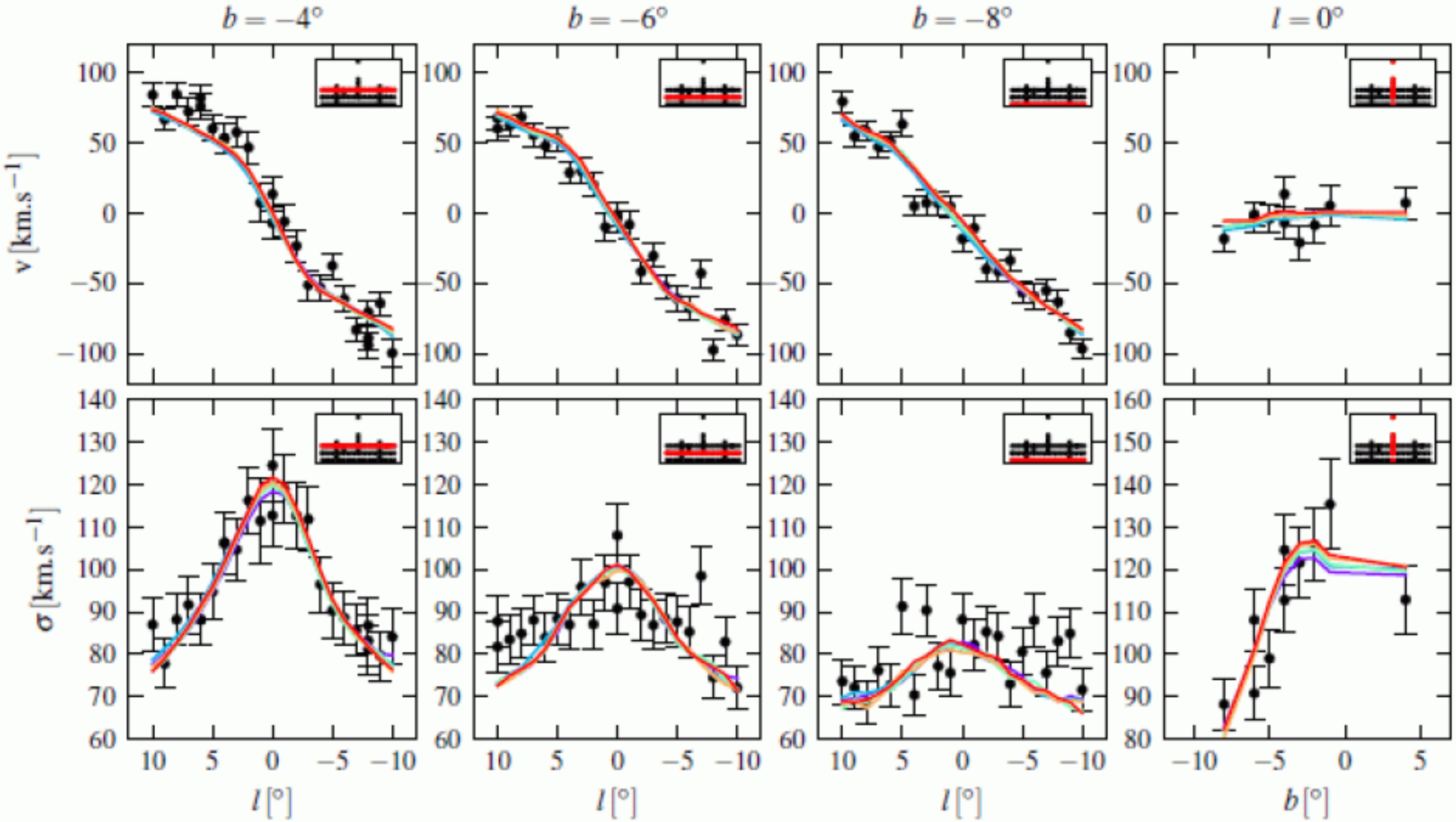
M2M Model Kinematics for VVV Bulge Density



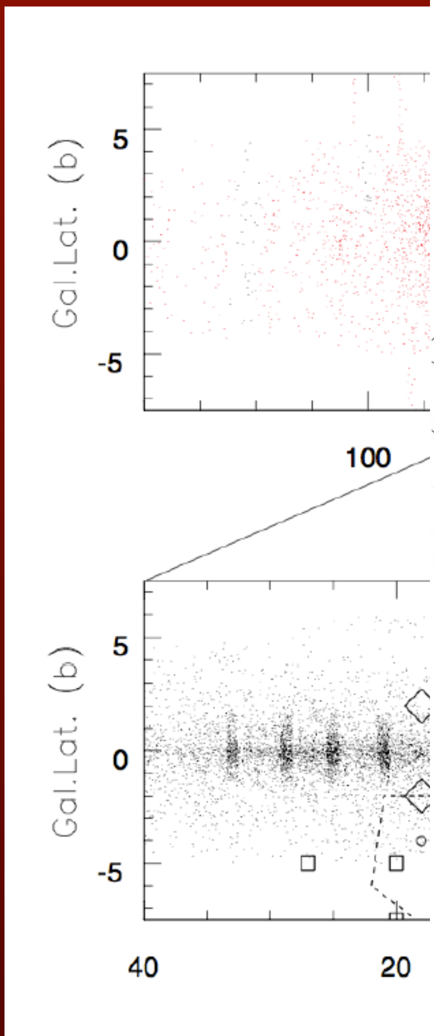
Portail, Wegg, Gerhard, Martinez-Valpuesta '14 submitted

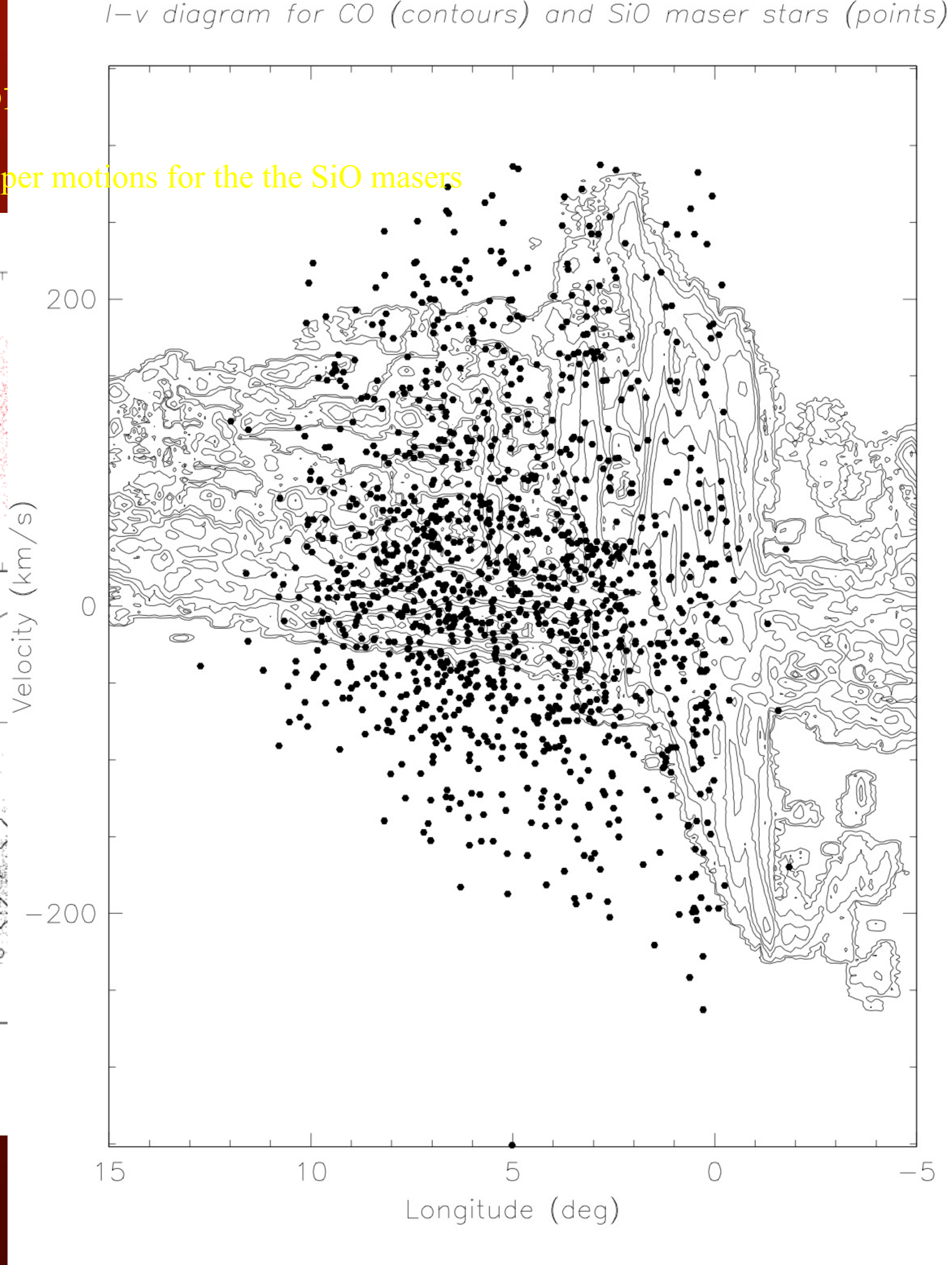
Dynamical model of Galactic bulge with M2M, VVV density of Wegg & Gerhard 2013, and BRAVA kinematics of Kunder+'12

Mass of bulge inside 3D bulge region ($4.5\times2.8\times2.4$ kpc^3 box) is $1.84 \pm 0.07 \times10^{10} M_\odot$

VLA Survey o) velocities

WFIRST gets proper motions for the the SiO masers





AaDE collaboration

ers:

nan, NRAO

NRAO

JNM

LA

ngevelde, JIVE

eiden

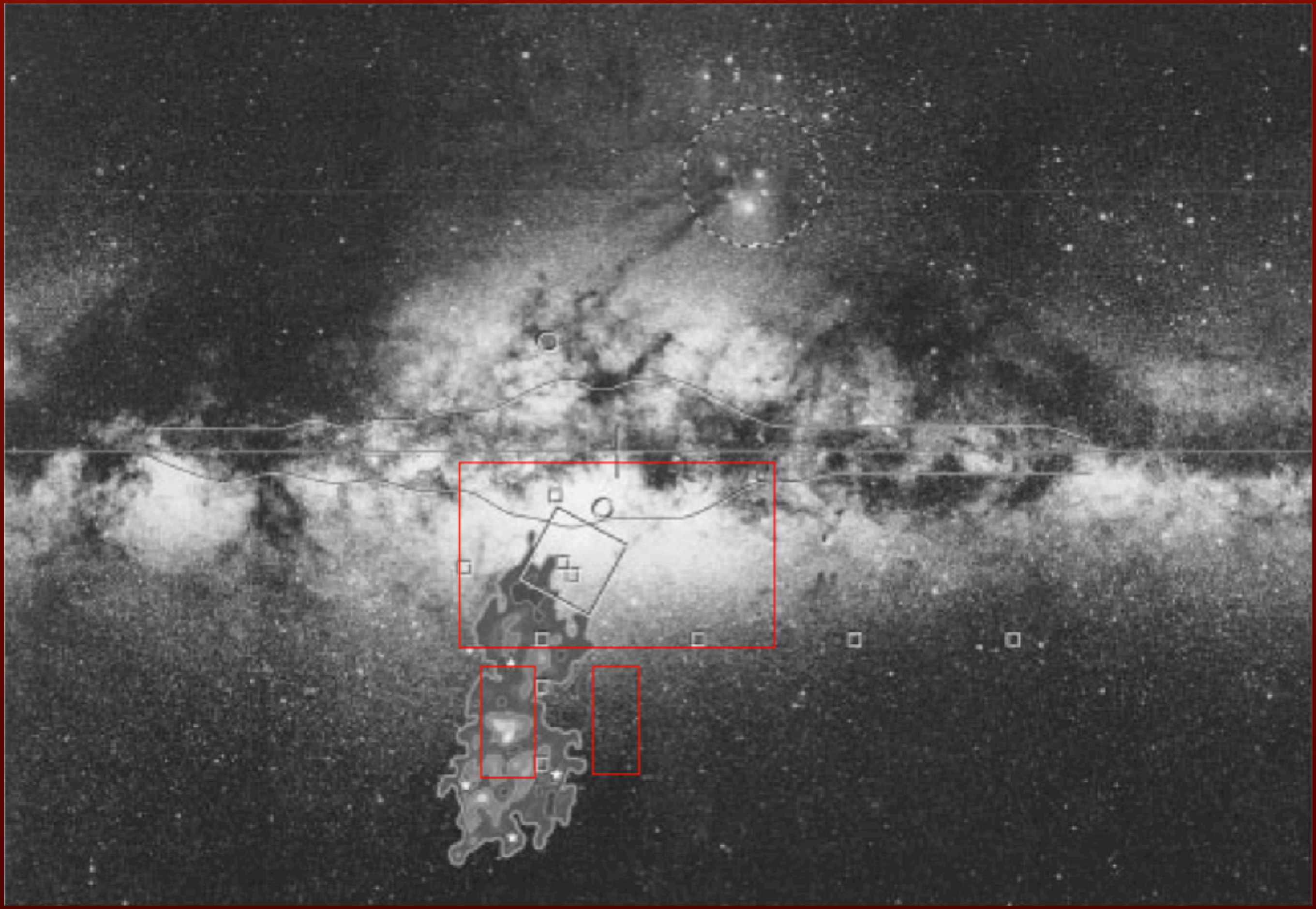
Boulder

n, UNM

nys.unm.edu/~ylva/baade/

Blanco DEcam Bulge Survey

R. M. Rich, A. Kunder, C. Johnson, A. Koch, S. Michael, M. Young, W. Clarkson, M. Irwin,R.Ibata, M. Soto, Z. Ivezic, R. de Propris, A. Robin, C. Pilachowski

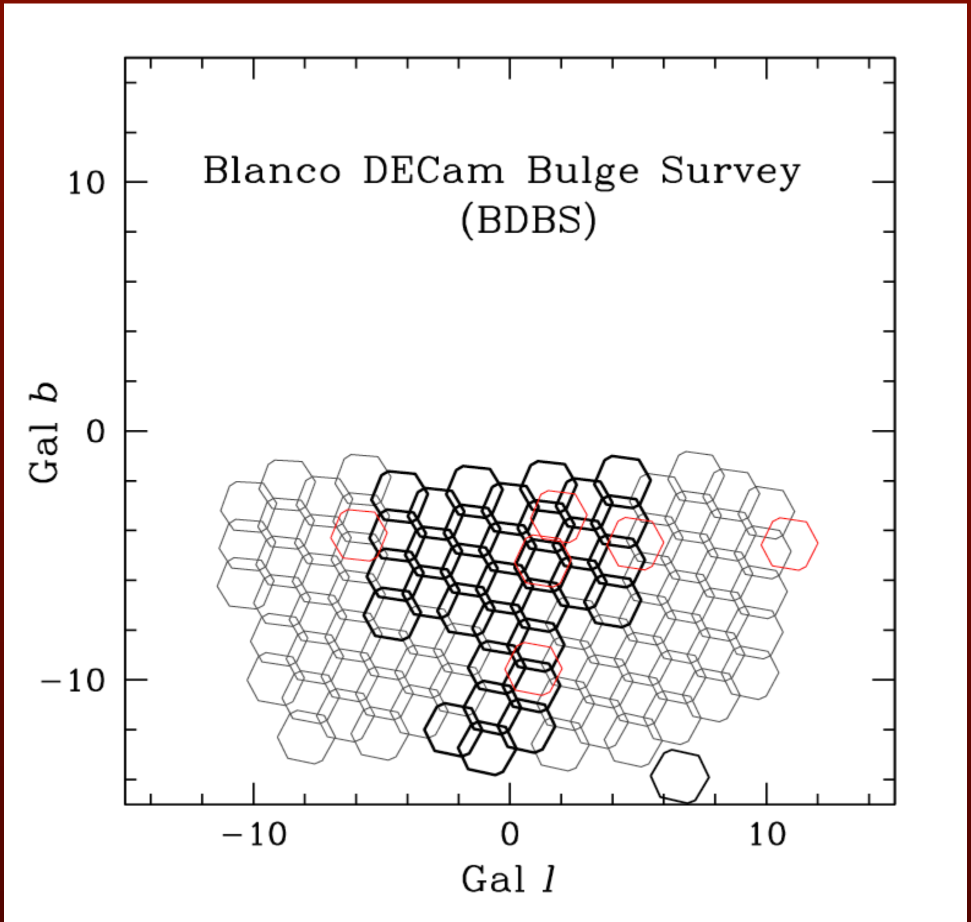


NSF AST 1413755

2014 progress on BDBS

LSST precursor survey

Dark Energy Camera at CTIO Blanco 4m telescope.   3 sq. deg. field of view, 62 CCDs ugrizY SDSS colors imaging at 0.2”/pixel



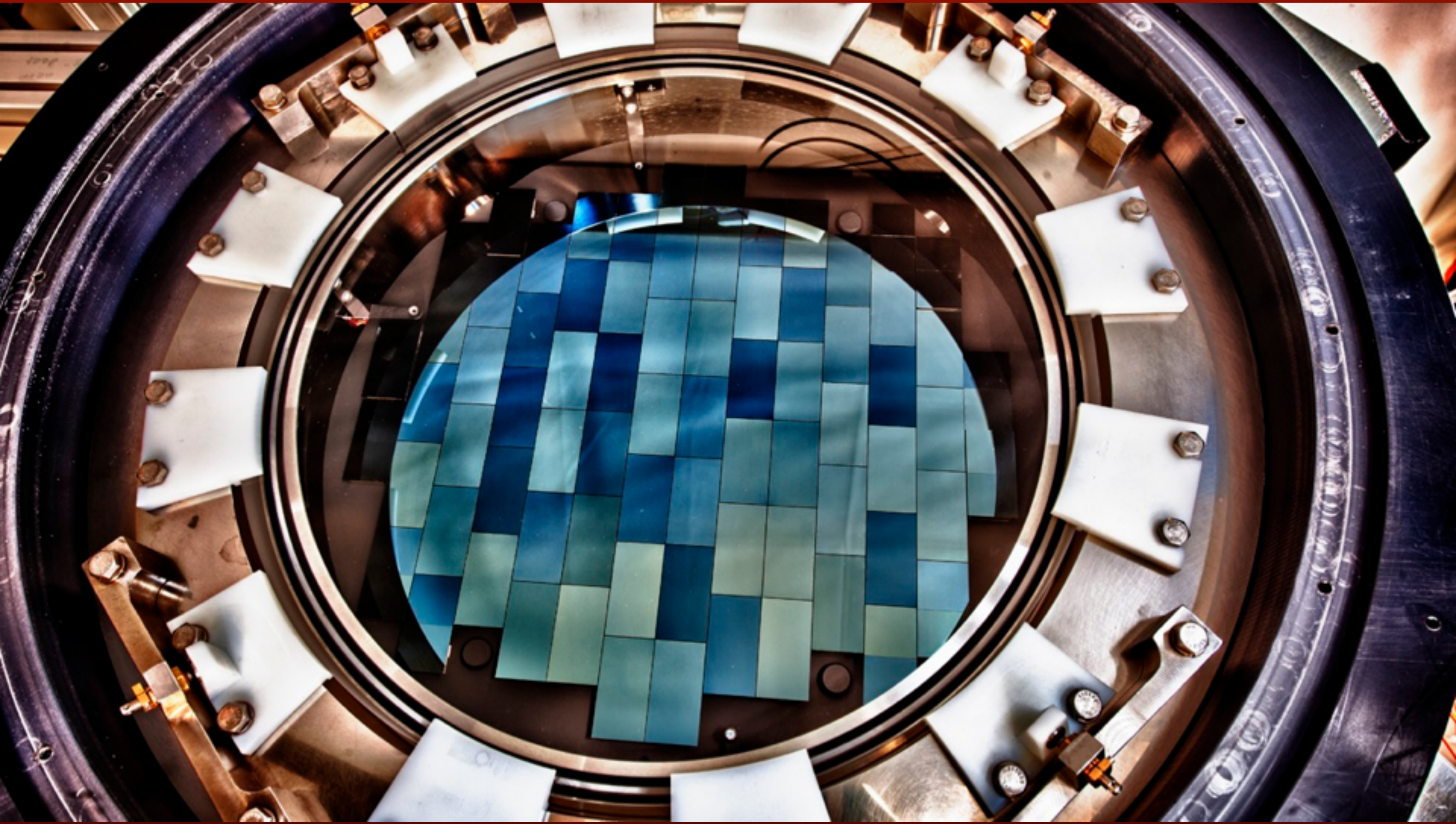
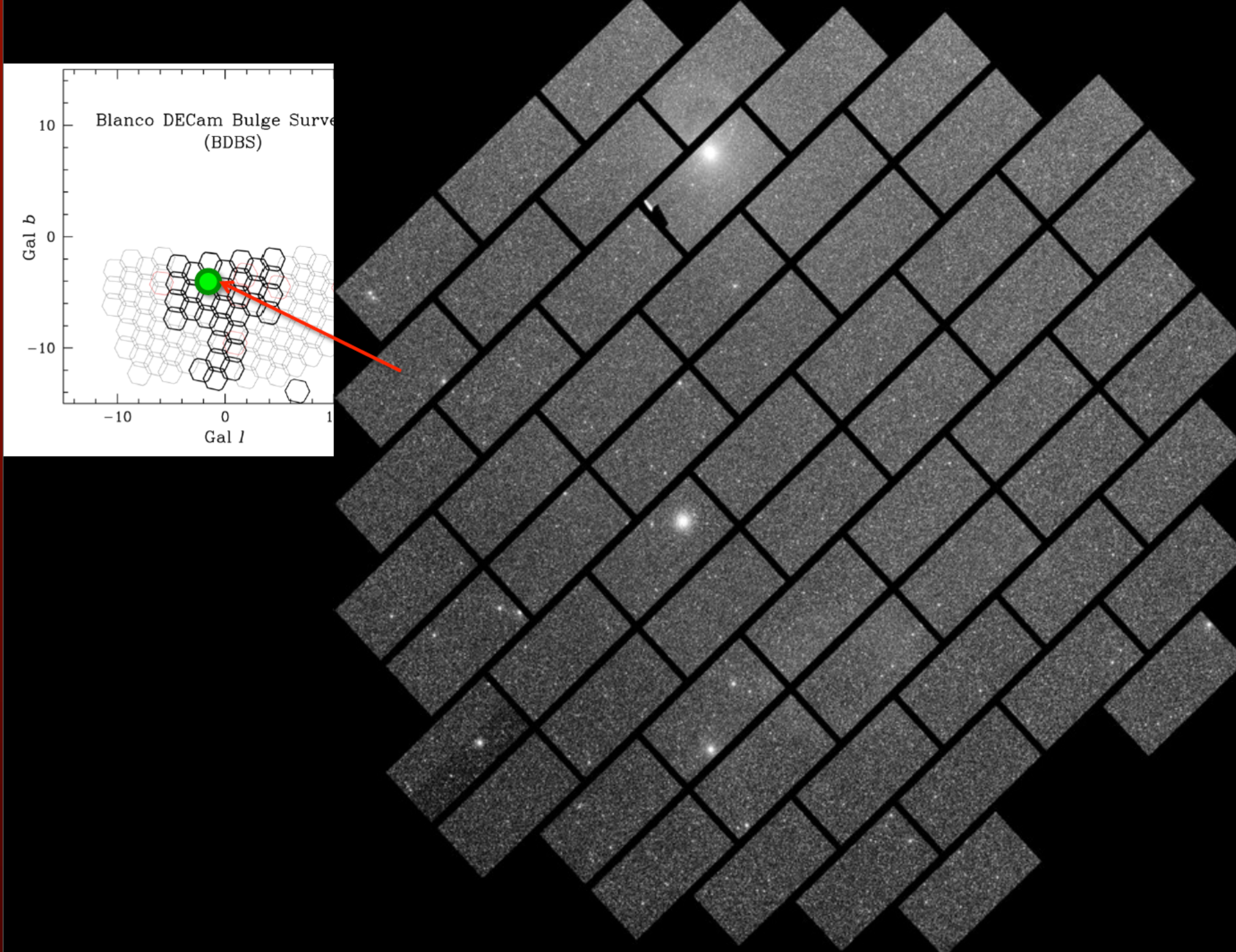


Image: W. Clarkson

Image: W. Clarkson


Blanco DECam Bulge Surve
(BDBS)
Gal b
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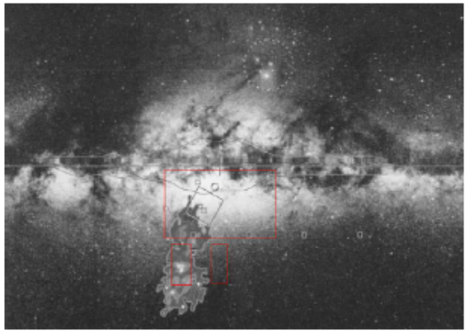
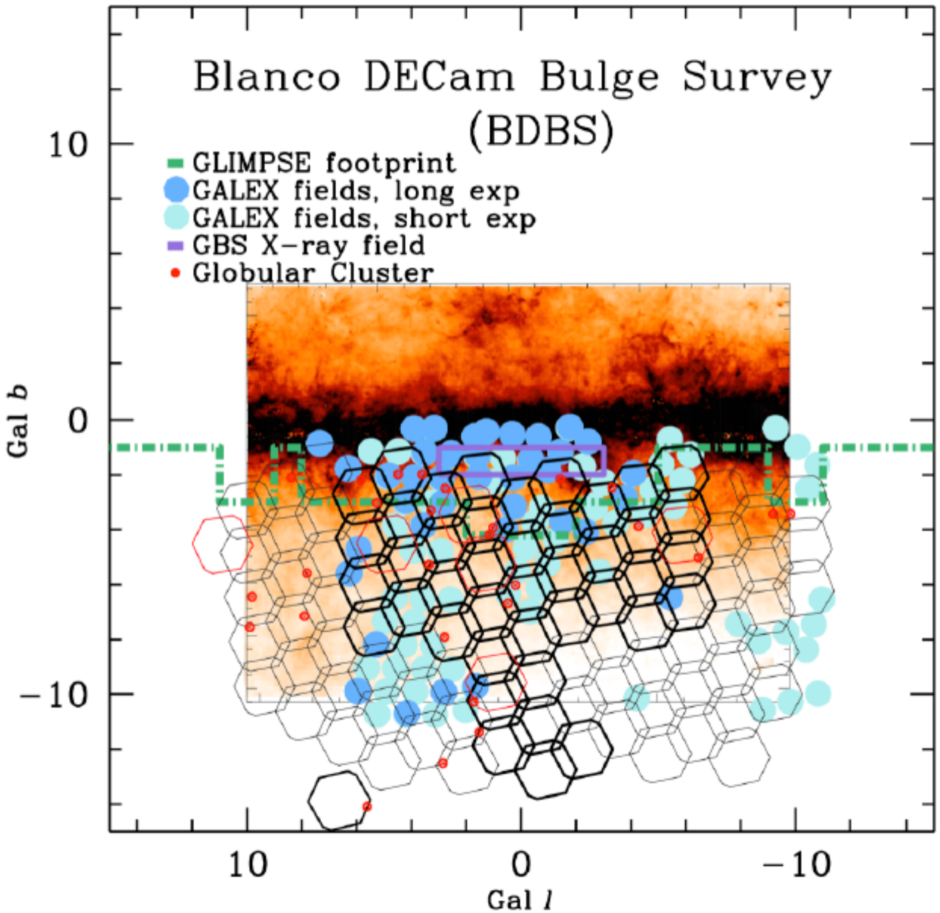
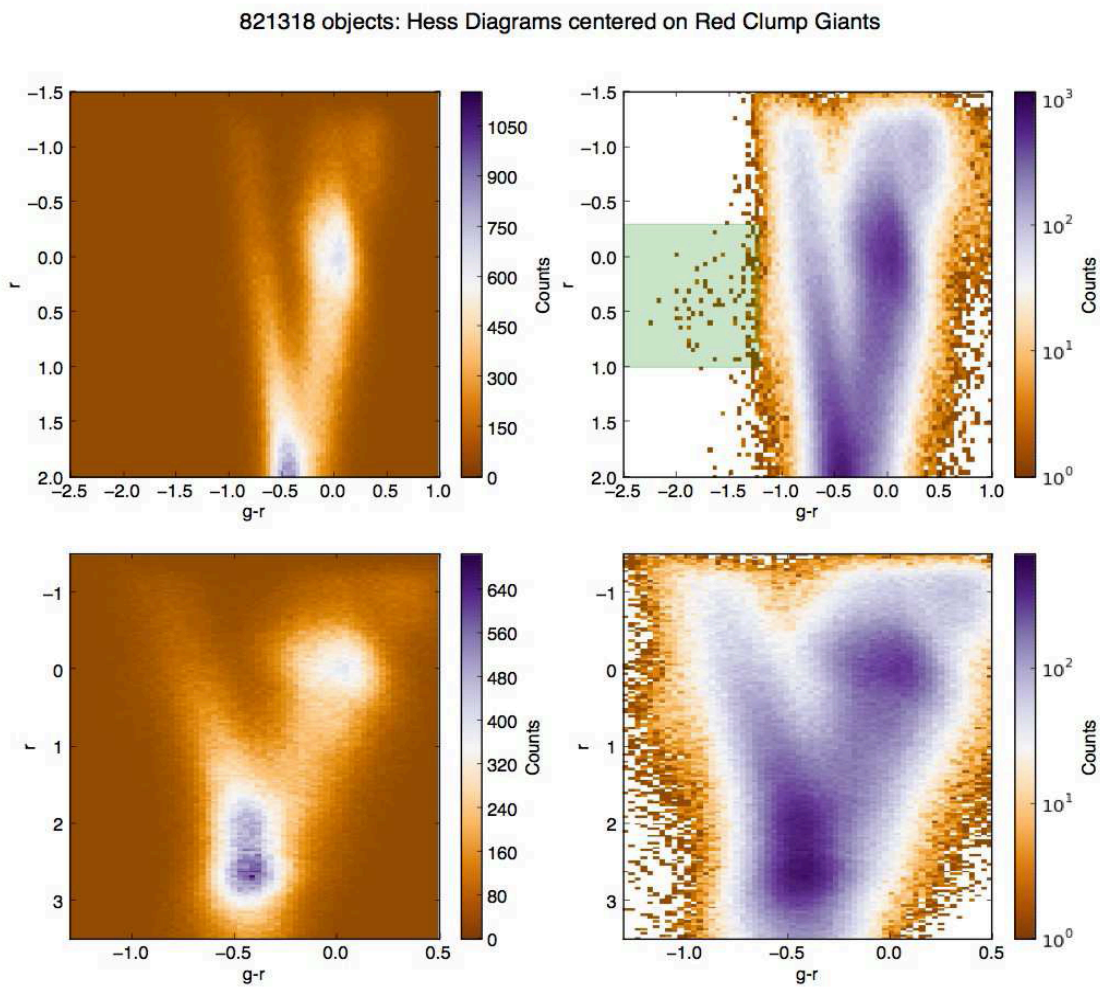


Figure 1-(Left) Visible light image of the Milky way with the bulge and Sgr dwar galaxy (illustrated as a blobby structure below the bulge) superimposed (Wyse, Gilmore, & Franx 1997). The red square regions cover the approximate location of the Blanco DECam bulge survey illustrated below.





Reductions by C. Johnson and Will Clarkson

BDBS Goals:

1. Map bulge in all 5 colors ugrizy, reaching deep enough in u to define the extreme HB.
2. Use 5 colors to map age, metallicity of bulge, separate foreground disk, define thick disk, halo
3. Search for ultra-metal poor stars
4. Multiwavelength match; Galex Spitzer, Chandra, etc.
5. High quality astrometry for population separation using Kuijken & Rich (2002) method
6. Improved map of Sgr dwarf spheroidal
7. Basic community public resource