Exploring the dynamics and subpopulations of the bulge using WFIRST

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Bulges appear to 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.

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
Population Separation with WFIRST

Clarkson et al. (2008)

- HST quality astrometry
- Large field-of-view
- Long baselines
- IR minimizes extinction

M4 Dieball et al. 2015
WFC3 + PM sep

WFIRST does this over almost whole bulge

\( \mu_b, \text{mas/yr} \)

\( F_{110} - F_{160} \)

- Dotter
- BT-Settl

- expected H-burning limit

- WDs
- BDs
- SDSS-J125537.13-022452.4
- 2MASS-J06525343+8246146

expected H-burning limit
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 $[\alpha/Fe]$ vs $[Fe/H]$ consistent with rapid formation, yet not strikingly different from thick disk.

Bulge has an 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-consistent log $g$, $T_{\text{eff}} >$ possible young, metal rich population, possible complexity

A major goal of composition studies is to place limits on the 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.*

See also Inoue et al. 2013, Elmegreen et al. Complex globular Ter 5 a proto-clump?
No evidence for low [$\alpha$/Fe] sub populations (C. Johnson et al. 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)

Vertical thickening of the bar into a bulge would leave no abundance gradient in the z-direction.
M104 (Hubble)

NGC 4710 (Hubble)

NGC 4565

“classical”

“boxy/ X-shaped”
“cylindrical” vs “classical” rotation

“The Nature of Boxy/Peanut-Shaped Bulges in Spiral Galaxies

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“boxy/peanut” = edge-on bar
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
Shen et al. 2010 N-body model used to fit BRAVA data.
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
Which orbits build this structure?

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

27.3° alignment X is 400pc off plane 10:6.3:2.6 axis ratio

WFIRST 2014
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 (4.5×2.8×2.4 kpc³ box) is $1.84 \pm 0.07 \times 10^{10} M_\odot$
VLA Survey of SiO masers.

WFIRST gets proper motions for the SiO masers.
Blanco DEcam Bulge Survey

LSST precursor survey

2014 progress on BDBS

Dark Energy Camera at CTIO Blanco 4m telescope. 3 sq. deg. field of view, 62 CCDs ugrizY SDSS colors imaging at 0.2”/pixel
Figure 1-(Left) Visible light image of the Milky way with the bulge and Sgr dwarf 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.
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.
6. Improved map of Sgr dwarf spheroidal
7. Basic community public resource

Reductions by C. Johnson and Will Clarkson