New Insights Into the Inner Milky Way

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Galactic Protuberances

“Considerable confusion has been brought by... a mixture of the seemingly appropriate buzzwords...”

Athanassoula (2005)

“Classical”
- smooth isophotes
- low/zero SRF, dust
- dominated by random motions
- ~elliptical galaxies, kinematically
- formed by hierarchical mergers or violent relaxation of disk

“Pseudobulge”
- asymmetric morphologies: bars, rings, spirals, &c.
- active/recent SF
- coherent rotation
- formed by secular, dissipative processes
Galactic Protuberances

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“Classical”
- smooth isophotes
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“Bar/Boxy/Peanut”
- clear elongated/boxy/peanut isophotes
- some SF, but pattern is younger than stars
- can have rings, spiral arms at the ends
- formed by disk buckling

“Disky/Pseudobulge”
- rounder, disk-like isophotes
- recent/active SF
- can co-exist with bar and spirals
- formed by gas migrating inwards(?)
1990s: Milky Way has a bar!

- Noncircular HI motions
- IR integrated starlight
- Asymmetric Mira variables
- Microlensing rate
- Asymmetric gamma ray emission
- Asymmetric RC stars
Highly Complex

- On *average*, bulge is old & metal-rich
- But it’s significantly richer than just that!

*Ness et al. (2013)*
Shape

Metal rich RC

$N_{\text{ataf et al. (2010), McWilliam et al. (2010)}}$

$\propto$ distance

Seen from the Sun

(Metal-rich) red clump giants

Seen from above the disk

Wegg et al. (2013)
Shape

Metal rich RC

\( \text{Number} \)

\[ L_0 \text{ [mag]} \propto \text{distance} \]

Nataf et al. (2010), McWilliam et al. (2010)

Metal poor RRL

\[ b < -5.5^\circ \]

\(-4^\circ < l < 4^\circ \)

Pietrukowicz et al. (2014)

(Metal-rich) red clump giants

(Metal-poor) RRL stars

Wegg et al. (2013)

Pietrukowicz et al. (2014)
Dynamics

Mean Velocity

Dispersion

Skewness

Distance from Center

Only galaxy in which we can make this separation

Metal Rich

Metal Poor

WISE Flux

Chung & Bureau (2004)

NGC 1381

GZ et al. (2016)
Metallicity & $\alpha$-enhancement

Ness et al. (2013)

Boxy bar?
Thick disk?
Halo?

Relative Number

[Fe/H]

$b=−5°$

$b=−7.5°$

$b=−10°$
Metallicity & $\alpha$-enhancement

Bensby et al. (2017)

Schultheis et al. (2017)

Red giants

GZ et al. in prep
Metal-Rich Stars
Barred distribution
Bar-like kinematics
X-shape
Low $\alpha$ abundance

Metal-Poor Stars
Triaxial (barred?)
distribution
Hotter kinematics
High $\alpha$ abundance
How did the bulge form?

- Hierarchical mergers ("classical" bulge)
- Clump migration
- Secular disk evolution

Simulated galaxy/halo and merger remnants
How did the bulge form?

- Hierarchical mergers ("classical" bulge)
- Clump migration
- Secular disk evolution ("bar")

z\sim2 galaxies with multiple large, off-center, star-forming clumps
How did the bulge form?

- Hierarchical mergers ("classical" bulge)
- Clump migration
- Secular disk evolution ("bar")

Simulated evolution of an isolated disk

Athanassoula et al. (2013)
Next Questions

• What is the connection with the thick disk?
• Where did the metal poorest stars come from?
• What is the connection with the halo?
• What is the stellar age distribution?

Nataf (2015)
The Future: SDSS-V

• 2020-2025
• All-sky O/IR spectra
• 5-6 million stars
  • 3D kinematics,
  • 20+ abundances
• Also 3000 deg² of ISM mapping
• Also BHs and galaxy clusters

Prototype of robotic fiber positioner, atop a fiber plugplate

Kollmeier, GZ et al. (2017)