Tomographic Study of Bars from N-body Simulations

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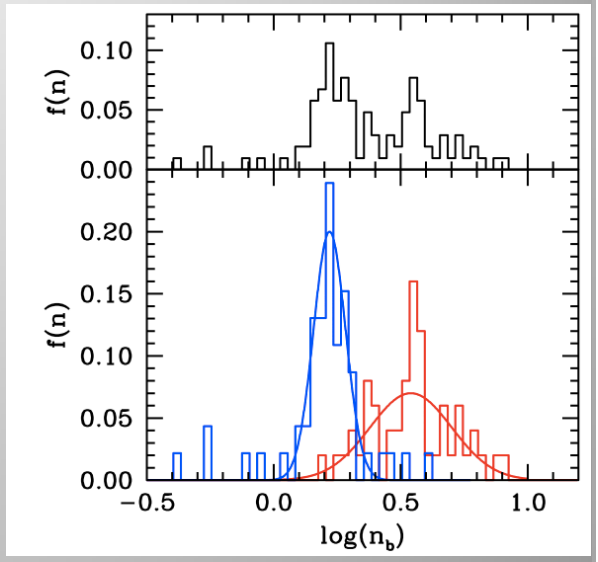
Bulges in Disk Galaxies

- Classical Bulge
  - Mini-ellipticals
  - Large Sérsic index (n > 2)
  - Merger or dissipational process
- Pseudo-Bulge
  - Disk-like
  - Small Sérsic index (n < 2)
  - Secular evolution



Fisher & Drory (2008)

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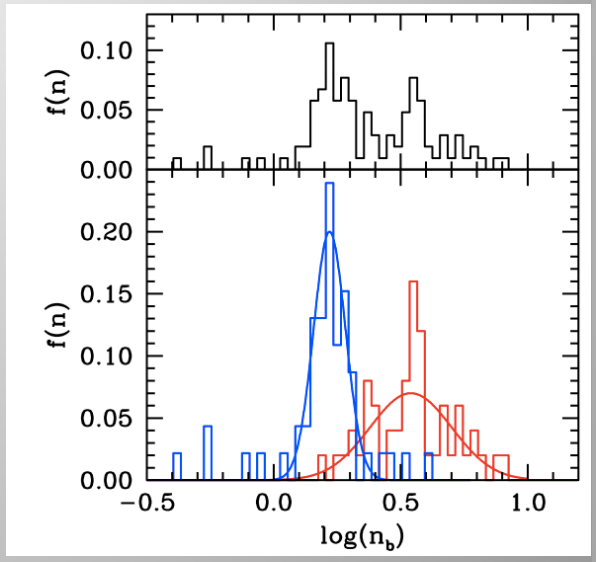
- Boxy/Peanut-Shaped (B/PS) Bulge
  - Found in edge-on disks



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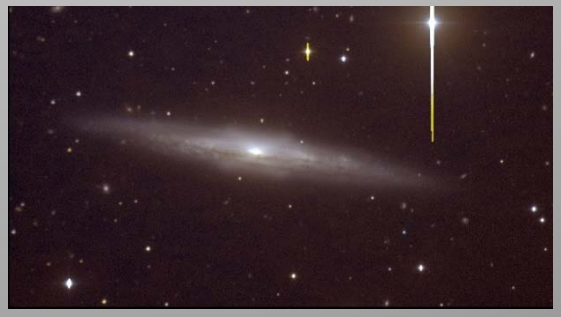

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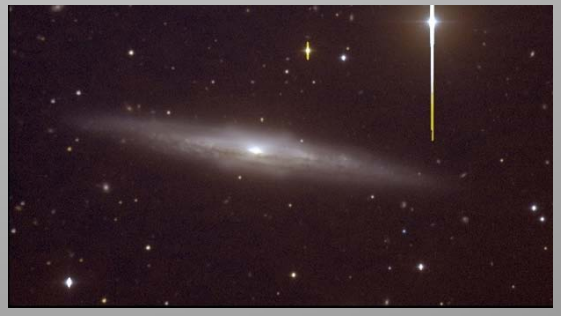

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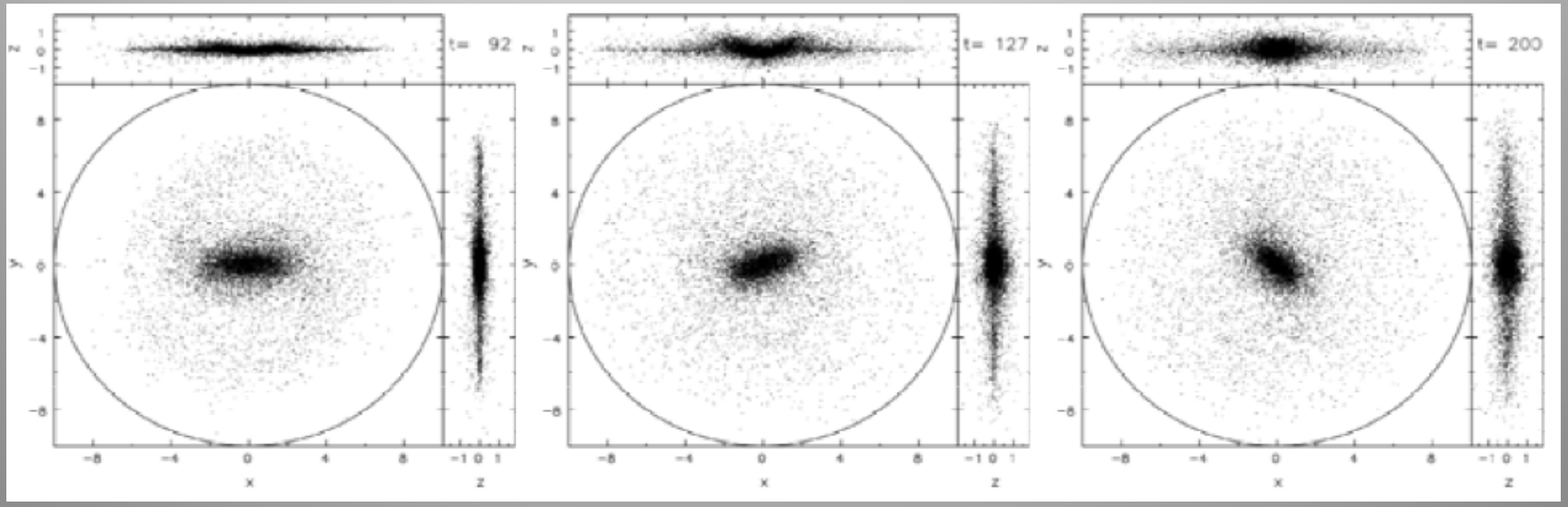
  - Connection with bars (Burbidge & Burbidge 1959; Jarvis 1986; Shaw 1987; Bureau & Freeman 1999; Lutticke et al. 2000; Burean & Athanassoula 2005)

?

Buckling "Fire-hose" Instability of the Bar

- A dynamical instability of thin or elongated galaxies found in 3D N-body simulations (Combes & Sanders 1981)
- Cause the inner region of the bar to puff up in the vertical direction (Combes et al. 1990; Raha et al. 1991; Merritt & Sellwood 1994; Athanassoula & Misiriotis 2002; Patsis et al. 2002; O'Neill & Dubinski 2003; Martinez-Valpuesta & Shlosman 2004)



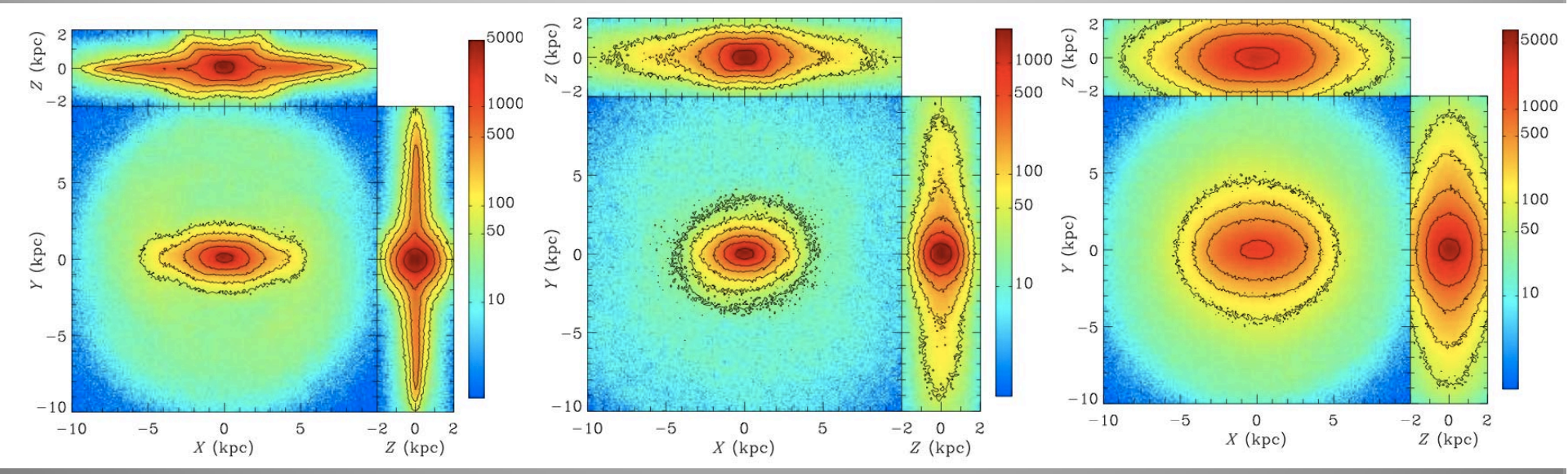
Bar formation → Buckling instability → Saturation → B/PS bulges

Questions Not Well Understood

- What is the density distribution and kinematic properties of the boxy/peanut-shaped bulge in the face-on view?
- Do the properties of the boxy/peanut-shaped bulge depend on the buckling strength of the bar?
- Does the bar have two components, i.e., the boxy/peanut –shaped bulge and extended thin component?
- What are the kinematic properties of particles inside the X shape related to the peanut structure?

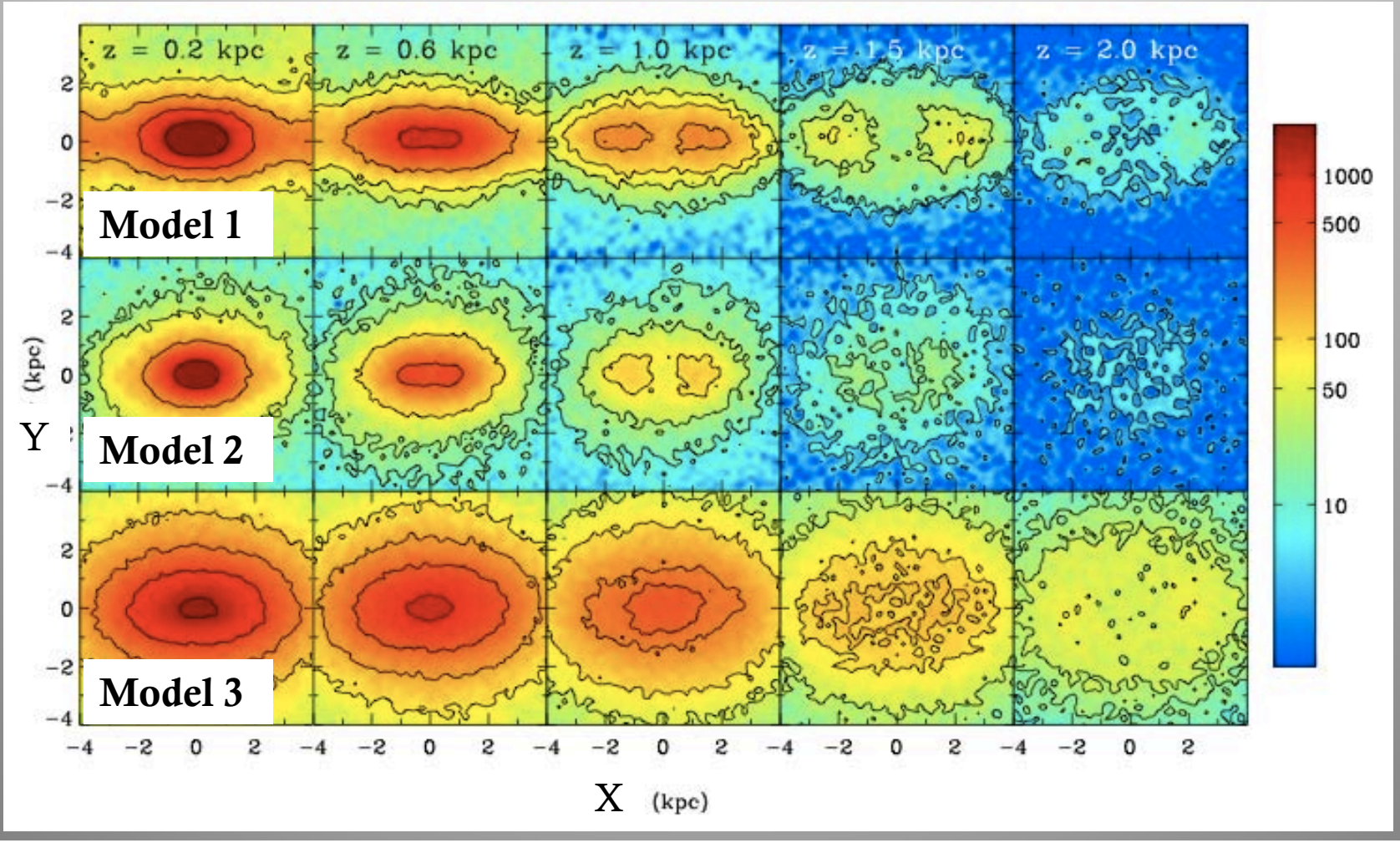
N-body Simulation

- Three models with different buckling strength
- Model 1: thin disk, live halo, strongly buckled
- Model 2: thin disk, rigid halo, buckled
- Model 3: thick disk, rigid halo, weakly buckled



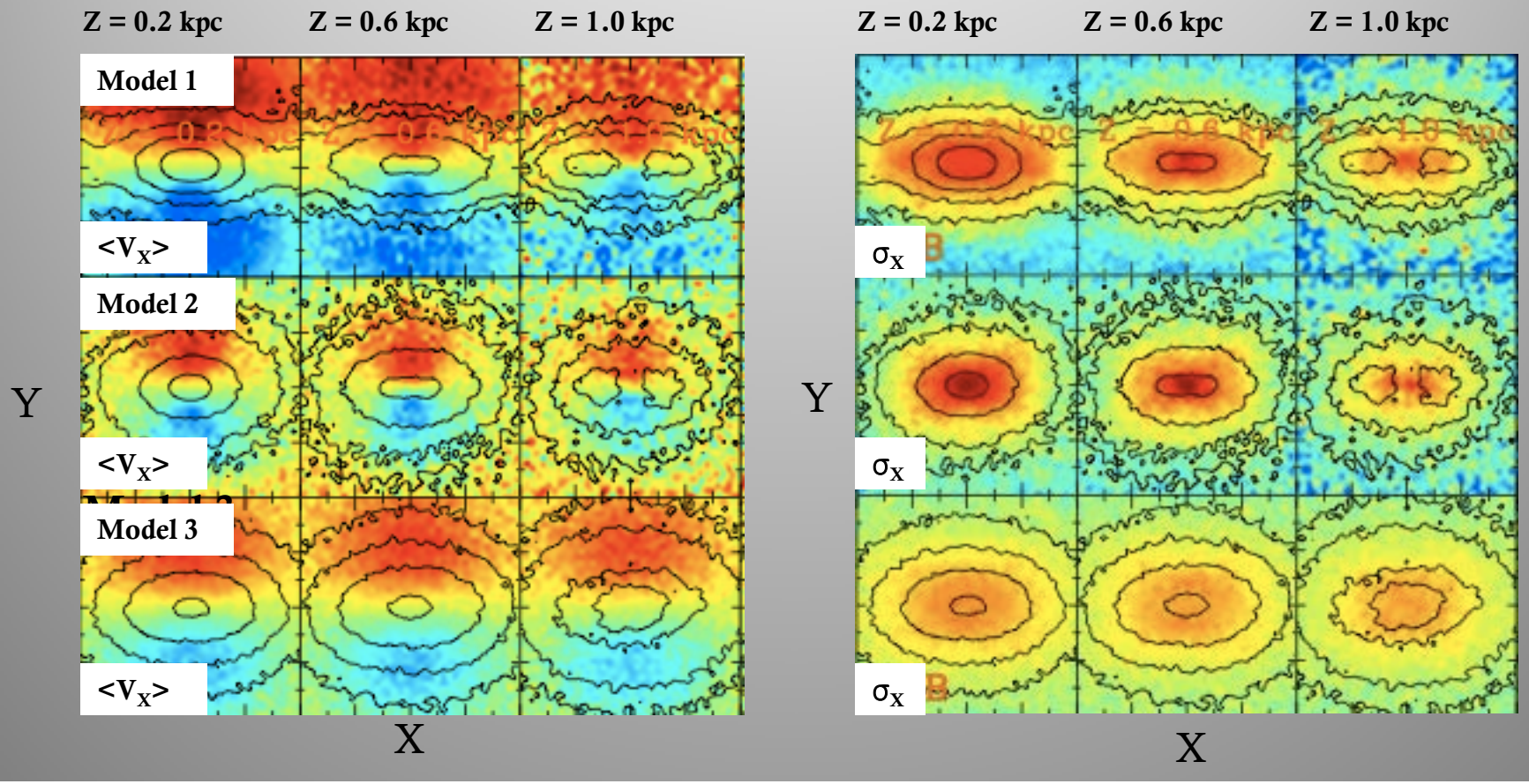
Slices perpendicular to the Z-axis

- Density maps at different heights



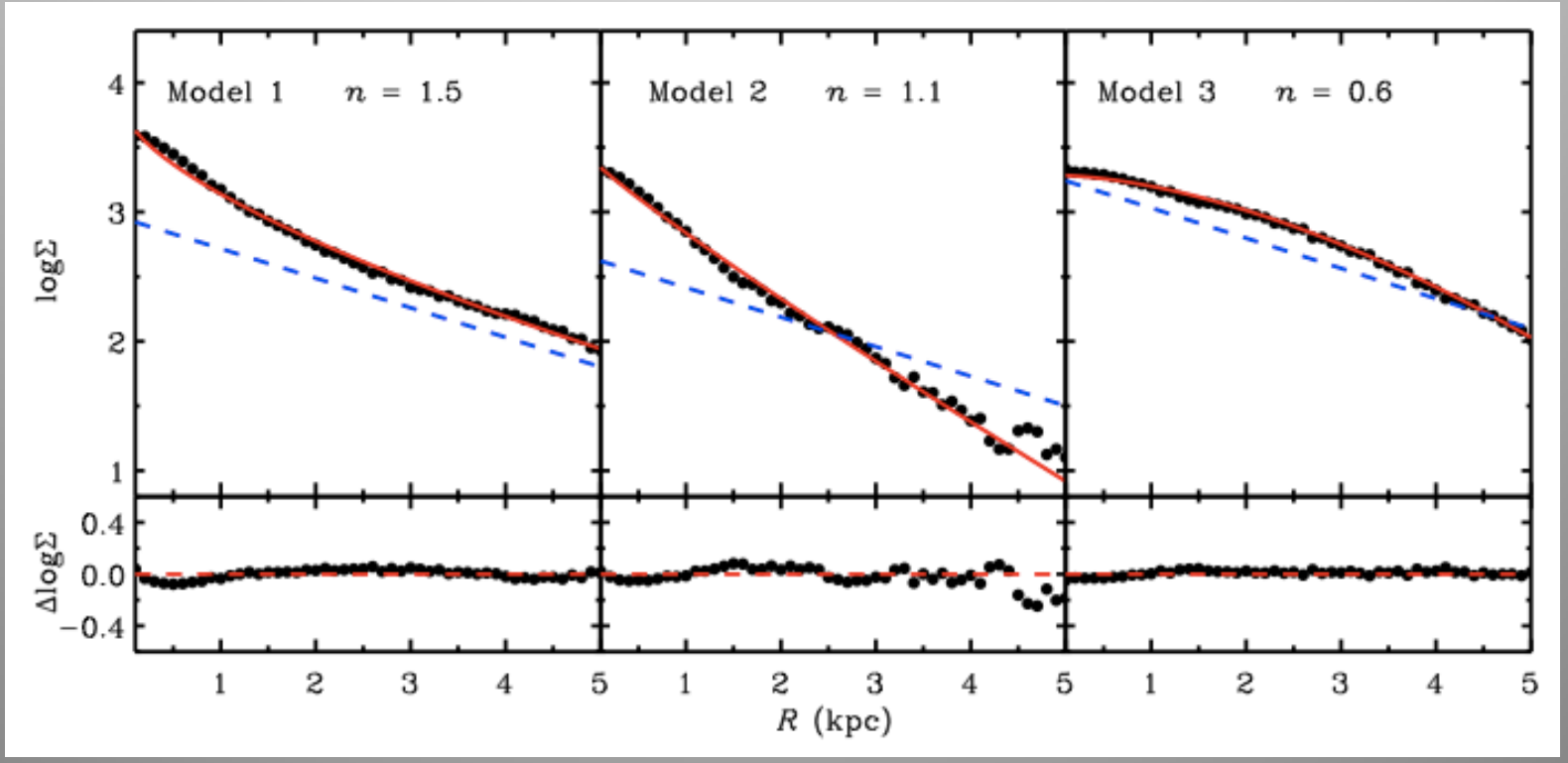
Slices perpendicular to the Z-axis

- Average velocity maps and velocity dispersion maps
- Different kinematic properties within different regions



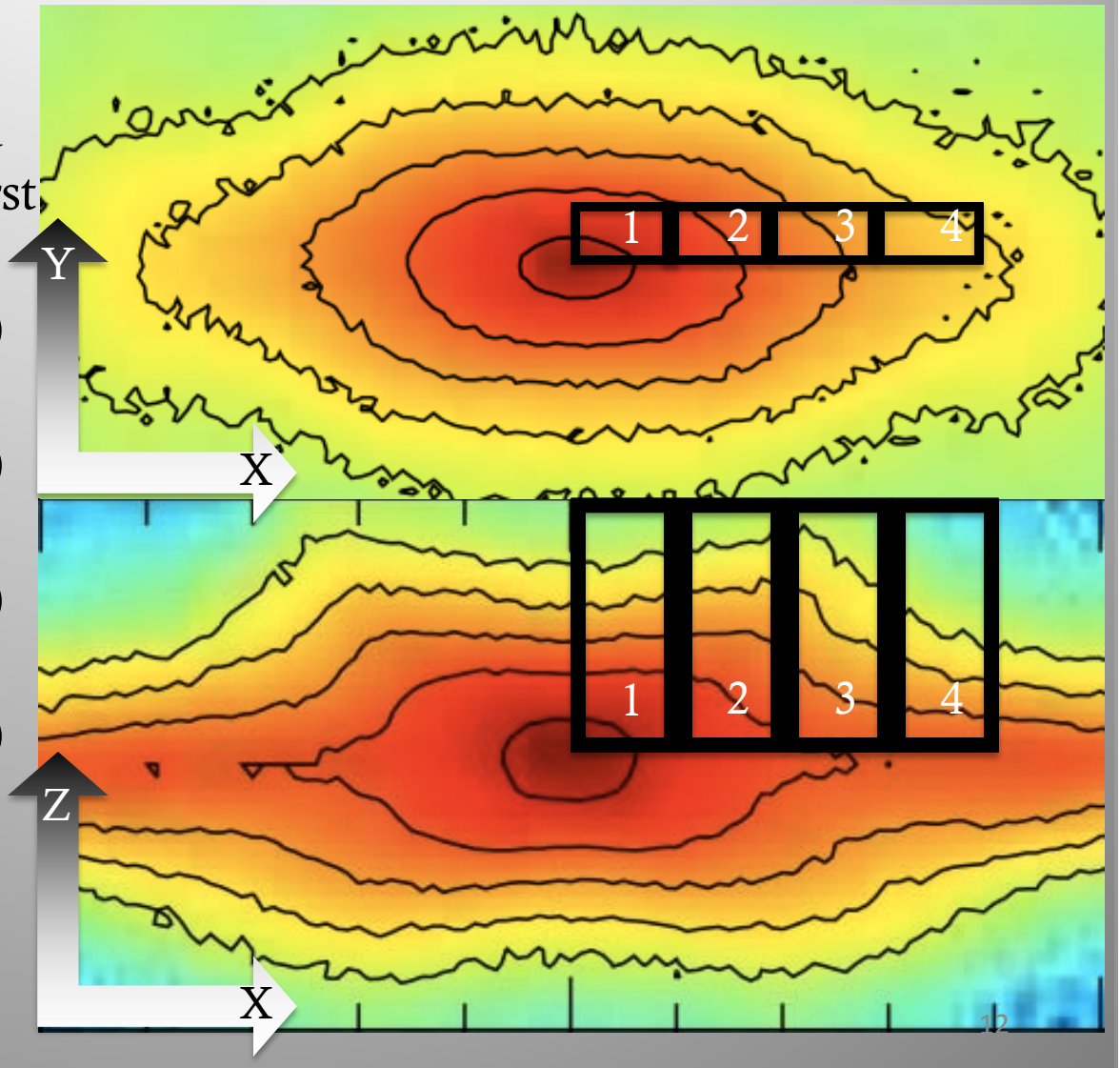
Density Profiles of the B/PS Bulge

- Face-on density profile along the major axis of the bar
  - Well described with a single Sérsic function, with larger index for strongly buckled bar (~1.5) than for the weakly buckled bar (~0.6)
  - No evidence for two components within the bar region



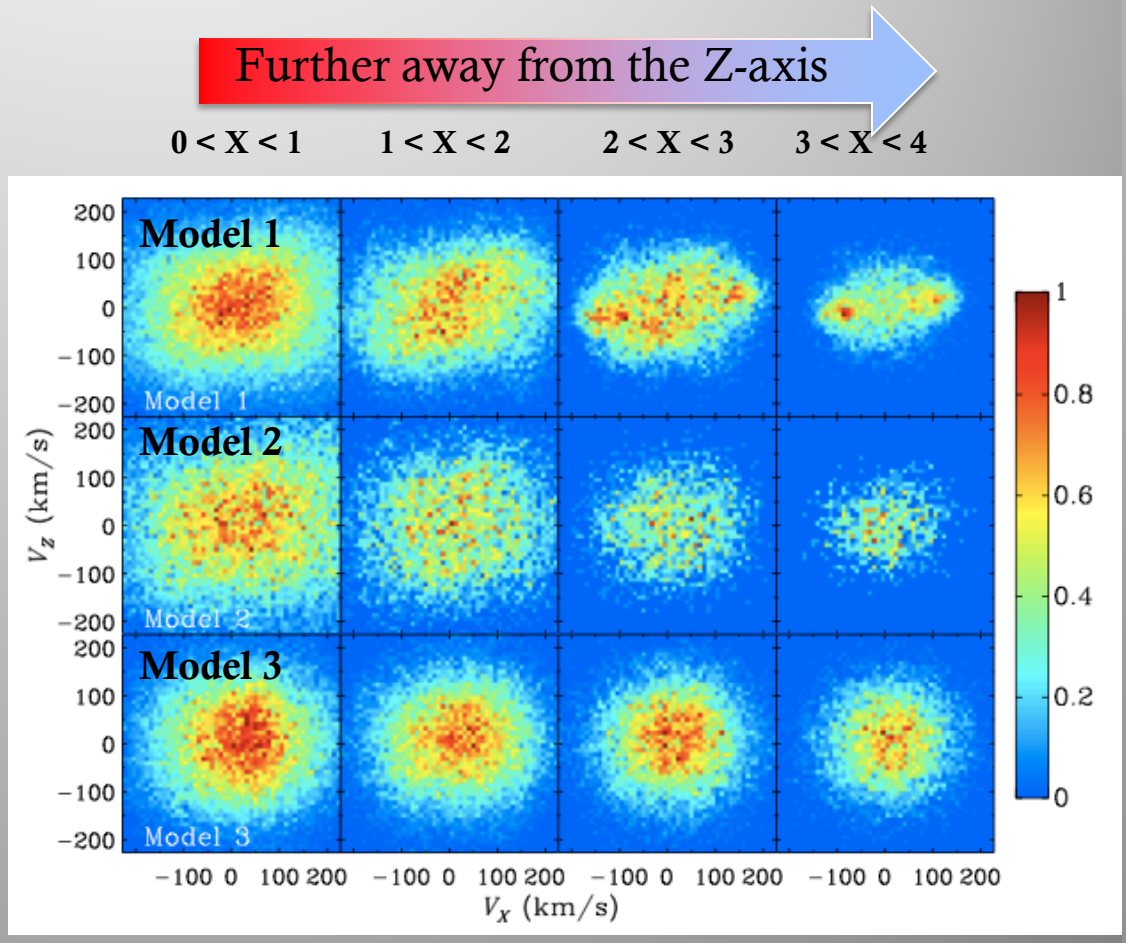
V_Z -- V_X Diagram

- 3D boxes with Z > 0 kpc and 0 kpc < Y < 0.5 kpc in the first octant space
- 0 kpc < X < 1 kpc (Region 1)
  - Close to center
- 1 kpc < X < 2 kpc (Region 2)
  - Inner edge of the peanut
- 2 kpc < X < 3 kpc (Region 3)
  - Outer edge of the peanut
- 3 kpc < X < 4 kpc (Region 4)
  - Thin bar region



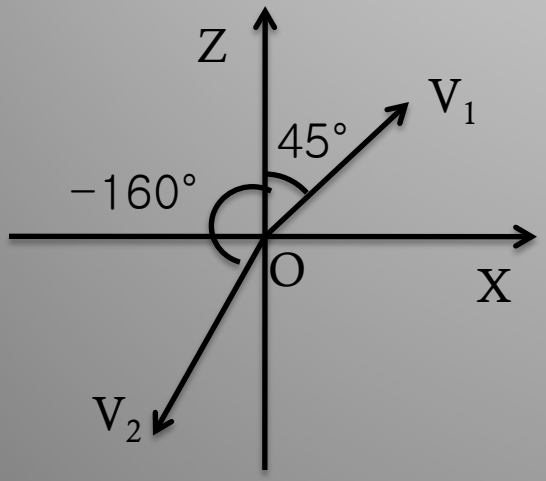
V_Z -- V_X Diagram

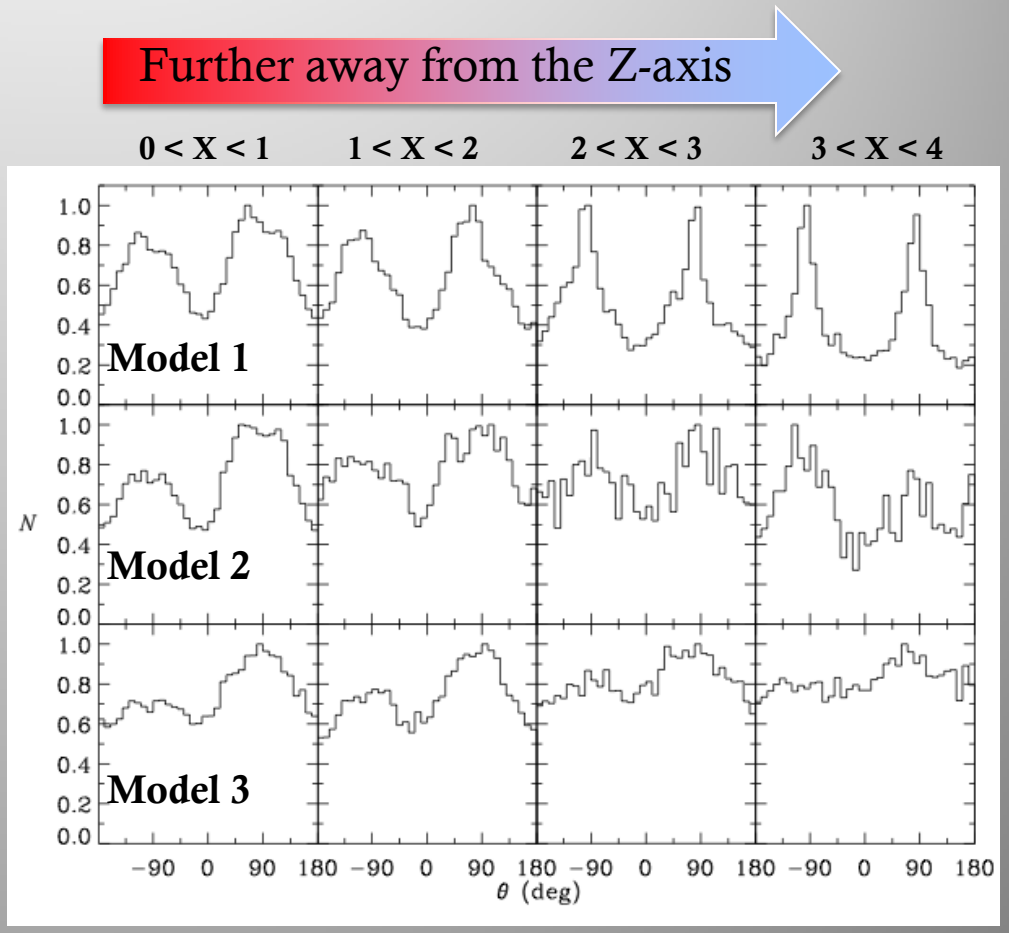
- Region 1
  - Large vertical motion, weak positive slope
- Region 2
  - Large vertical motion, positive slope
- Region 3
  - Small vertical motion, weak positive slope
- Region 4
  - Very small vertical motion, flat slope



Distributions of Particle Moving Direction

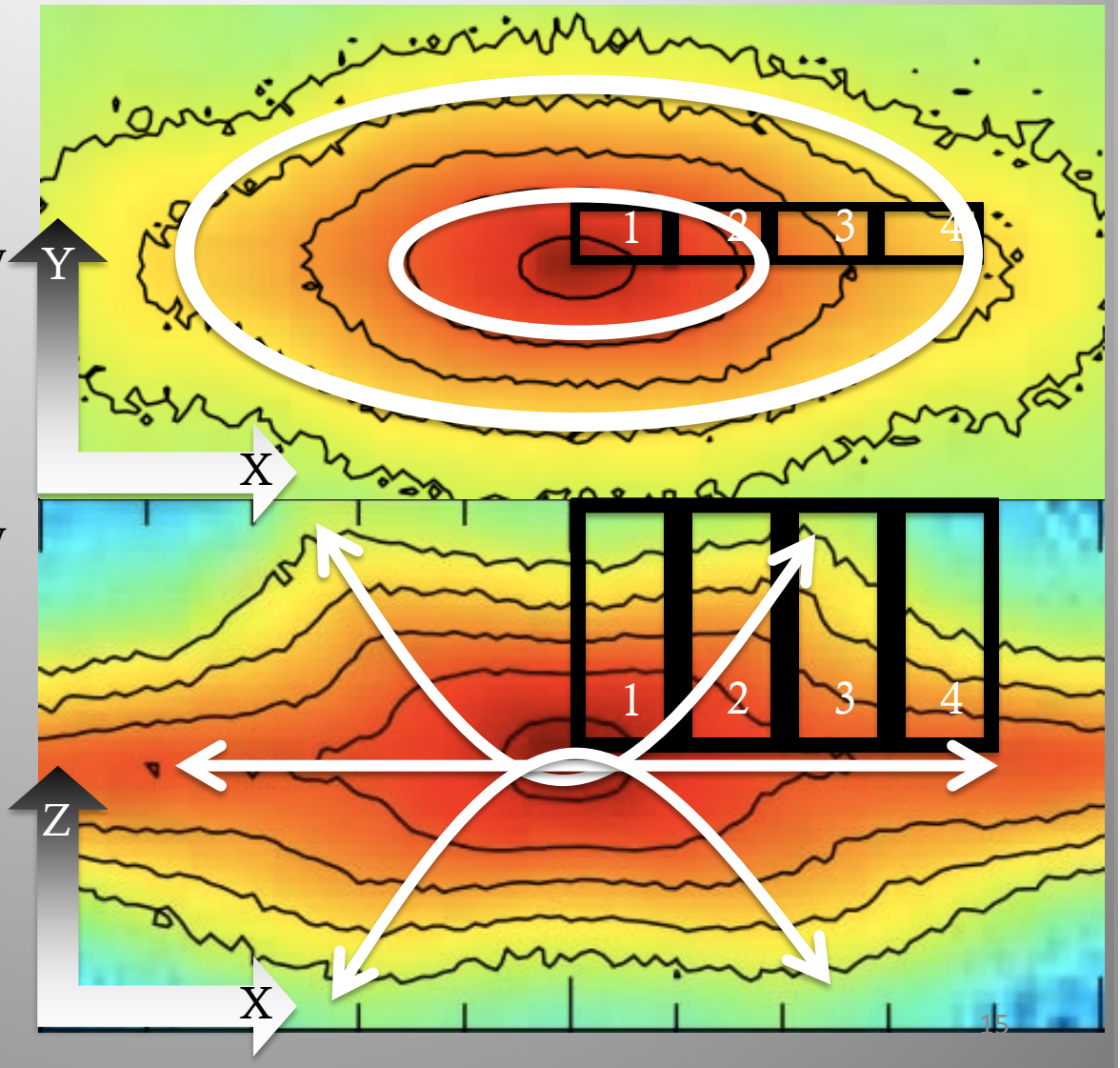
- Different regions with different peak positions, indicating the prevalence of particles on different orbits
  - Inner regions: peak less than 90° or -90°
  - Outer regions: peak at ±90° with small dispersion or weak amplitude



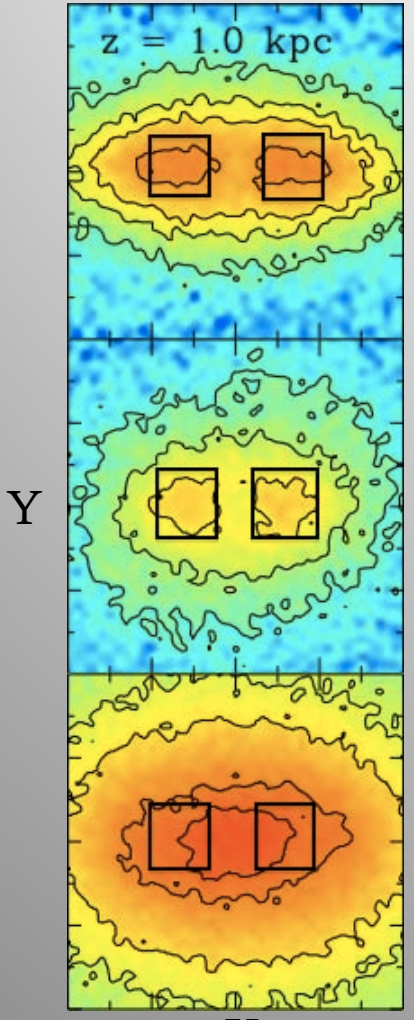


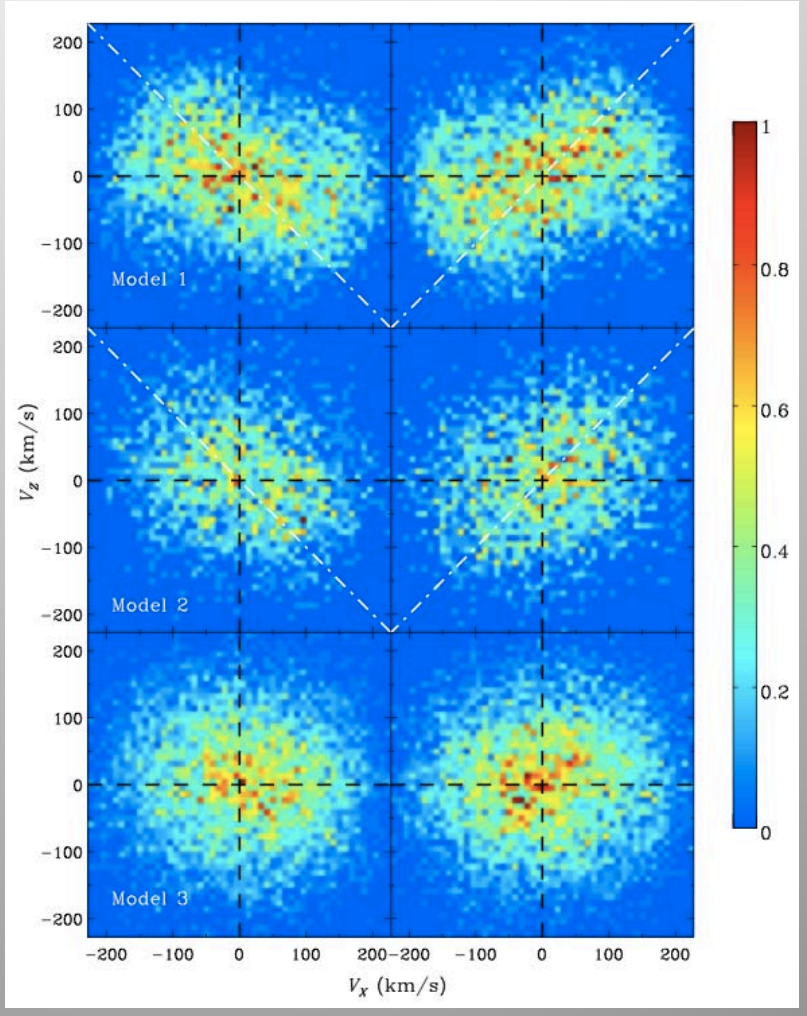
Implications for the Orbits

- Inner regions
  - Bifurcated x1 orbits
  - Ellipse-like in face-on view
  - Banana shaped in edge-on
- Outer regions
  - Regular x1 orbits
  - Ellipse-like in face-on view
  - Little vertical perturbation
- The relative importance of the two orbits produces the observed shape.



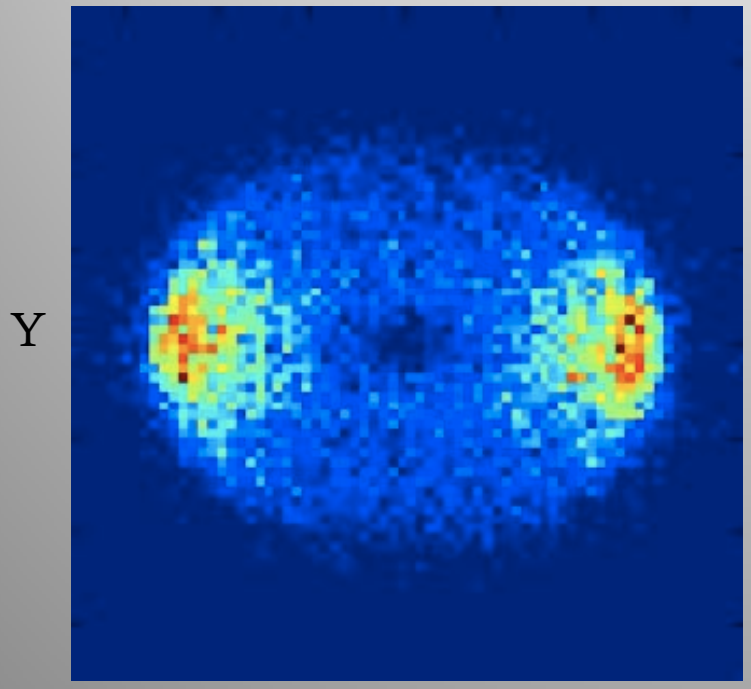
V_Z -- V_X Diagram of the *X* shape

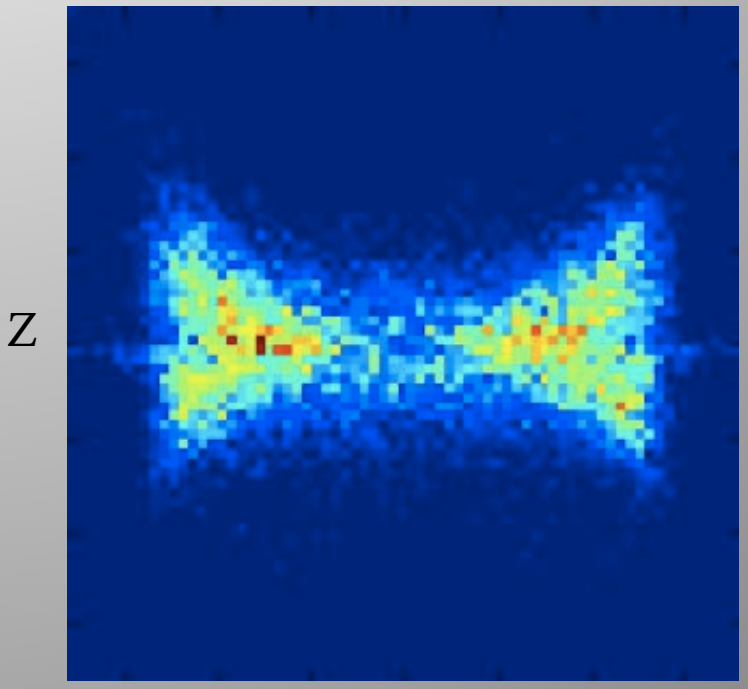




Particles with Banana Orbit

- More evidence from the spatial distribution of particles with banana orbits in our simulation (Model 2)





Qin et al. in prep.

Summary

- The buckling process thickens the bar to form an inner B/PS bulge, which has distinct kinematic properties compared to the outer thin component of the bar.
  - The inner component: dynamically hot, small average velocity
  - The outer component: dynamically cold, large average velocity
- Surface density profile along the bar major axis can be well described with a single Sérsic function, with stronger buckled bar a larger Sérsic index.
  - No evidence for two components in the density profile
- Relative contributions of the inner bifurcated and outer unperturbed x1 orbits produce the observed peanut shape, which also depends on the strength of the buckling.
- The particle motions within the X-shaped regions agree well with the banana-like orbits, which produces strong positive slope in V_Z--V_X diagram.