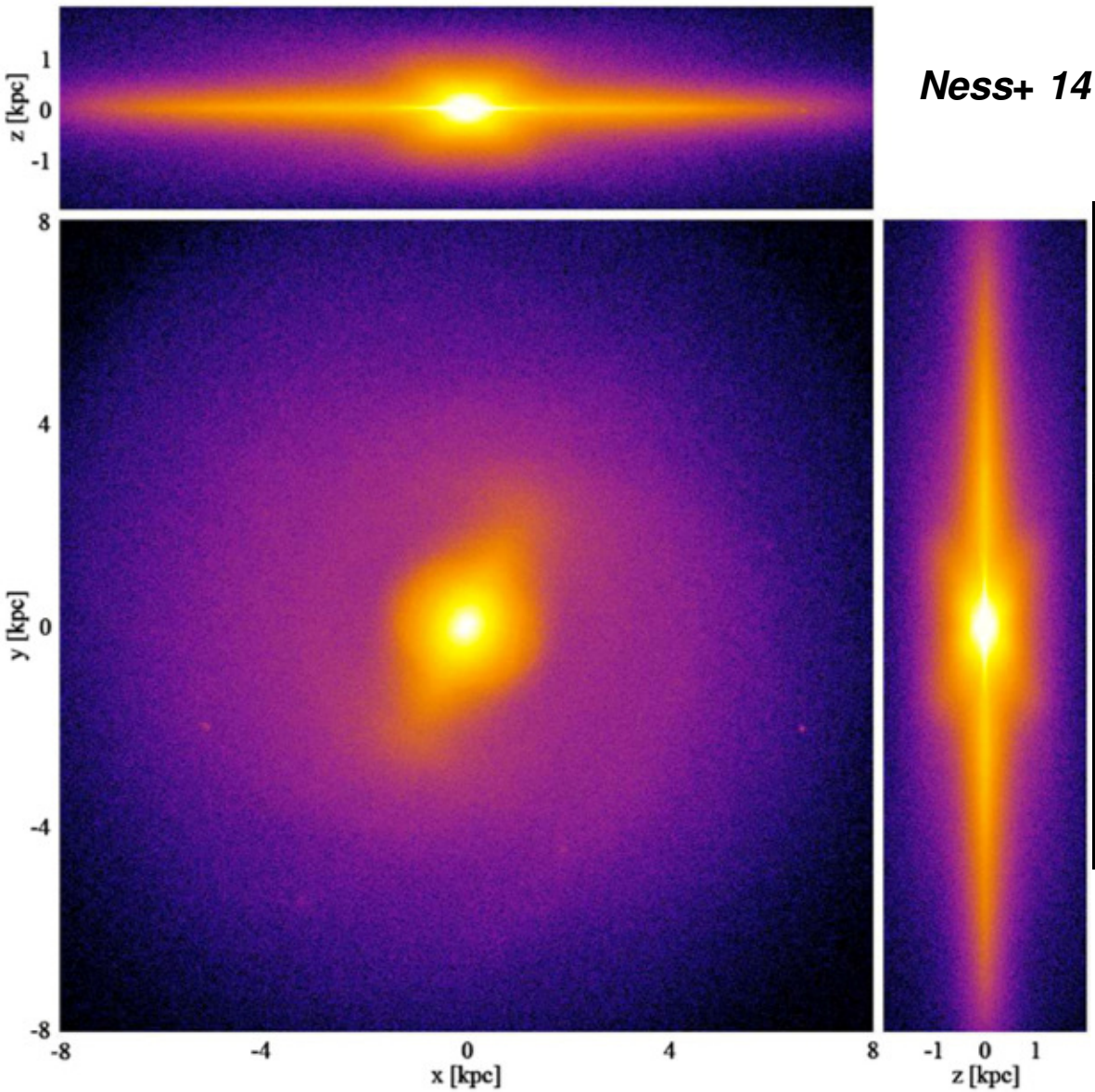
The Challenge of Orbits from Simulations

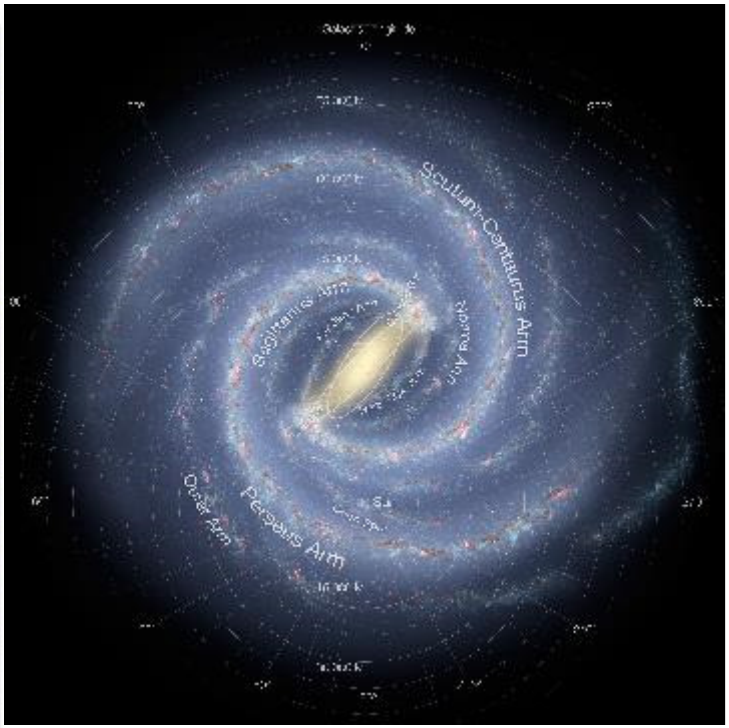
Victor P. Debattista

uclan
University of Central Lancashire

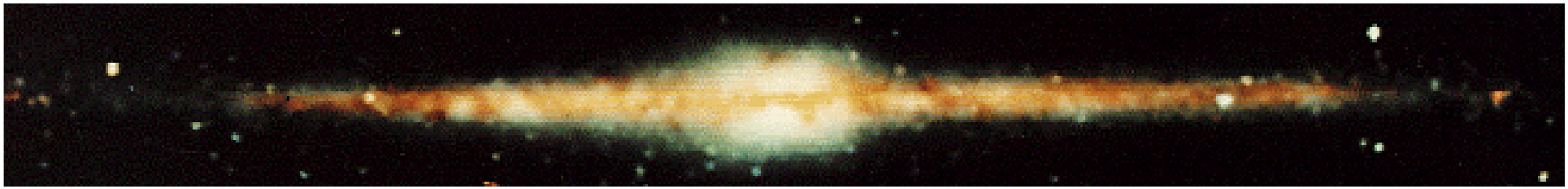
The Milky Way has 10^{11} stars. Each has its own mass, age, velocity, pattern of chemical elements

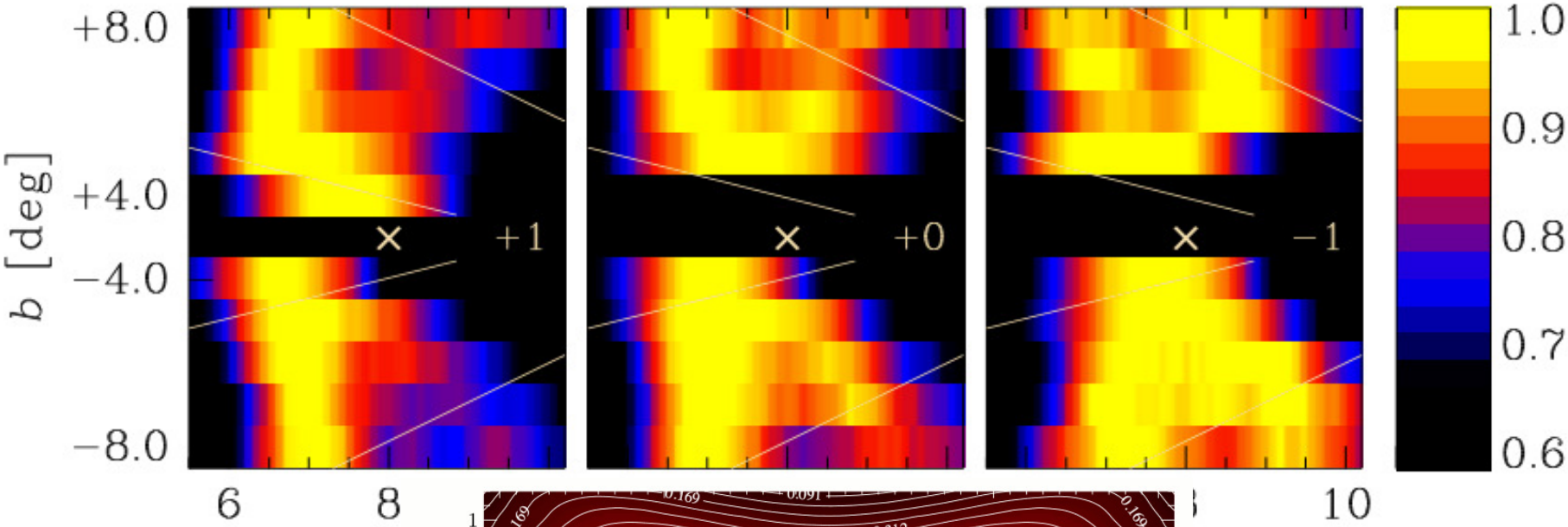


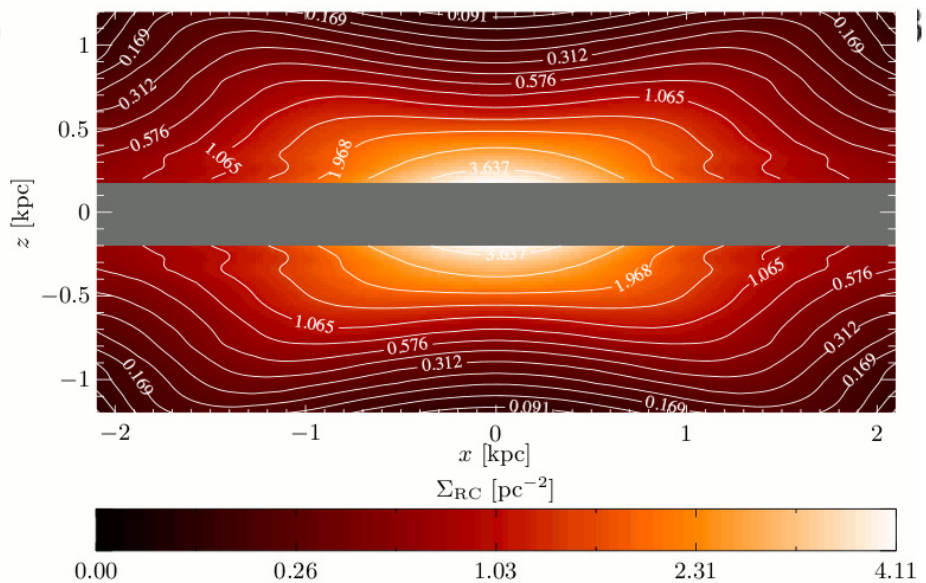
Ness+ 14



Typical of current largest simulations of a galaxy with a reasonable match to the structure of the Milky Way, and which includes full gas physics, star formation, and chemistry for ~10^7 particles



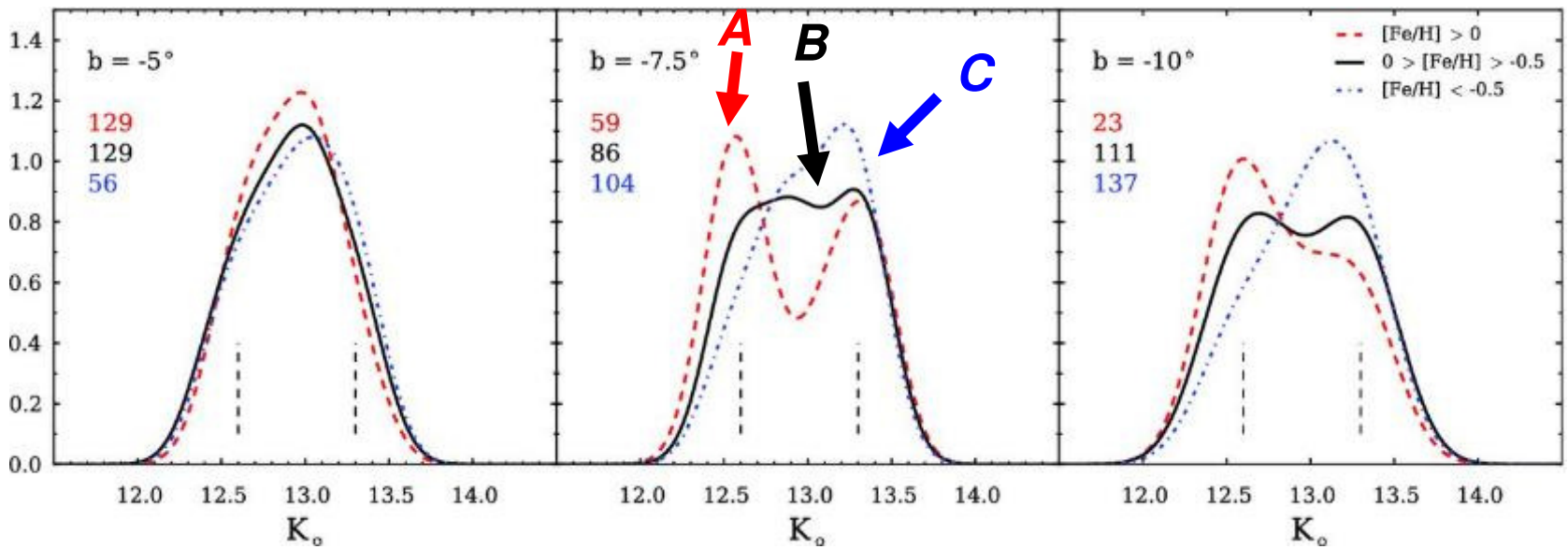




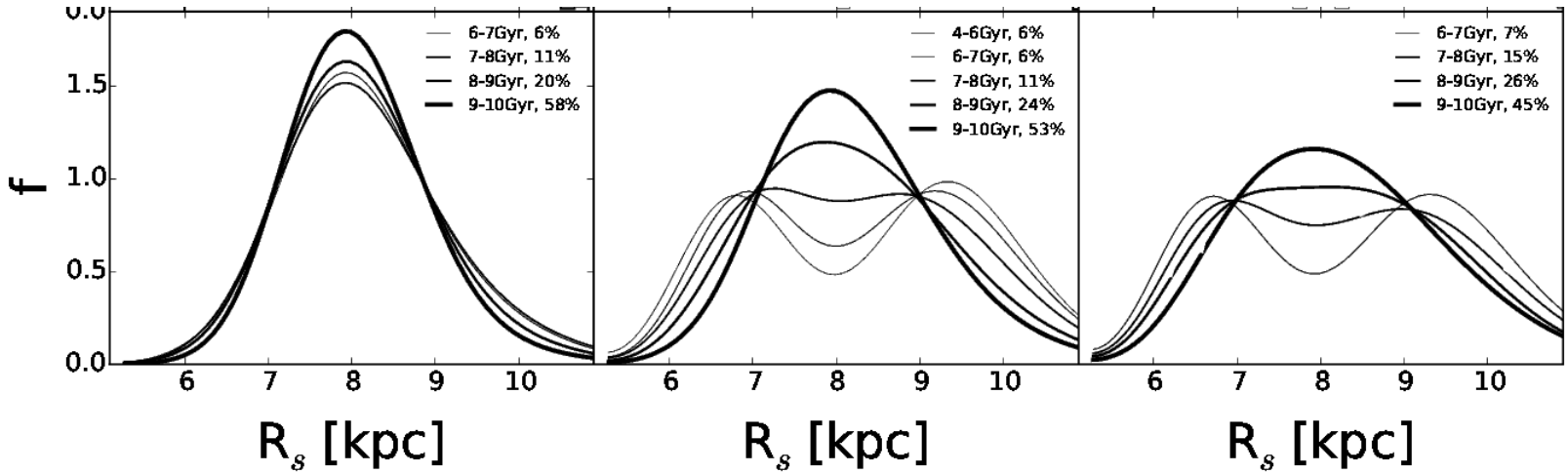
Saito+ 11

Wegg+ 13

Ness+ 13



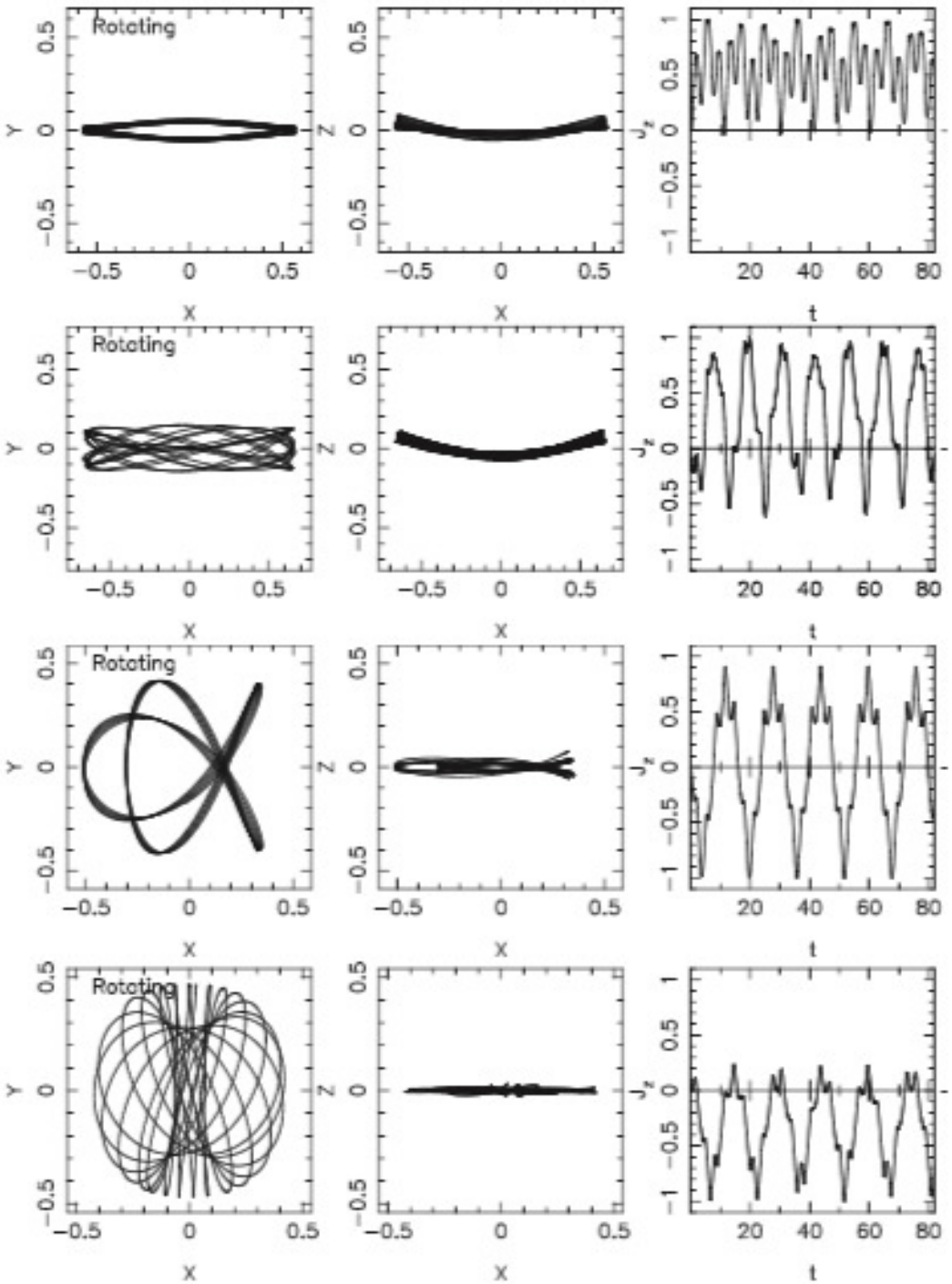
At low |b| no signature of the double peak. At higher latitudes components A & B have a double peak. But not component C.



Debattista+ 17

Orbits in barred galaxies are a very powerful way of understanding the structure and evolution of the galaxy.

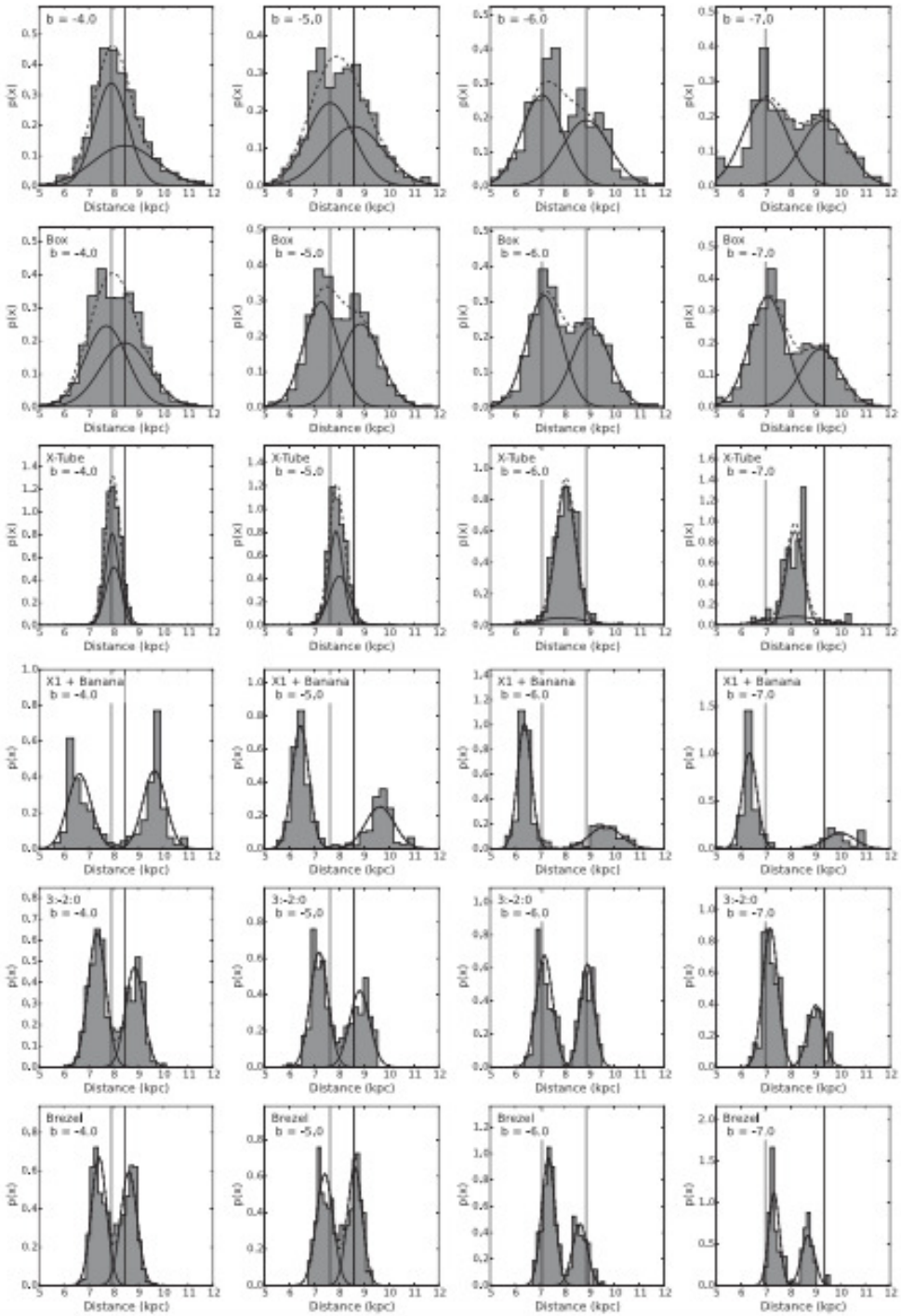
Orbits are classified into a series of families. These here are examples of "simple", bar-supporting orbits.



Valluri+ 16

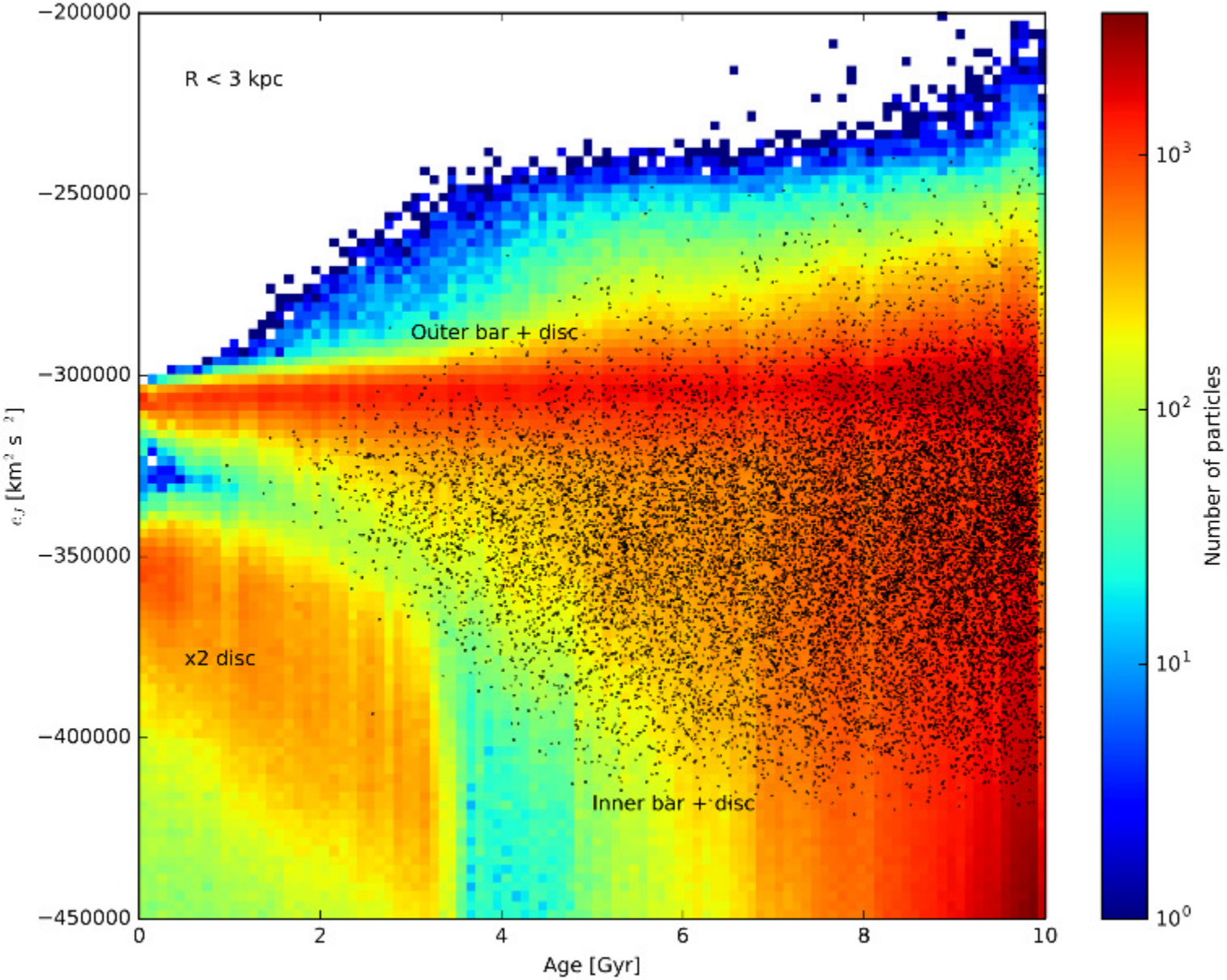
Example of orbits in a simple N-body simulation.

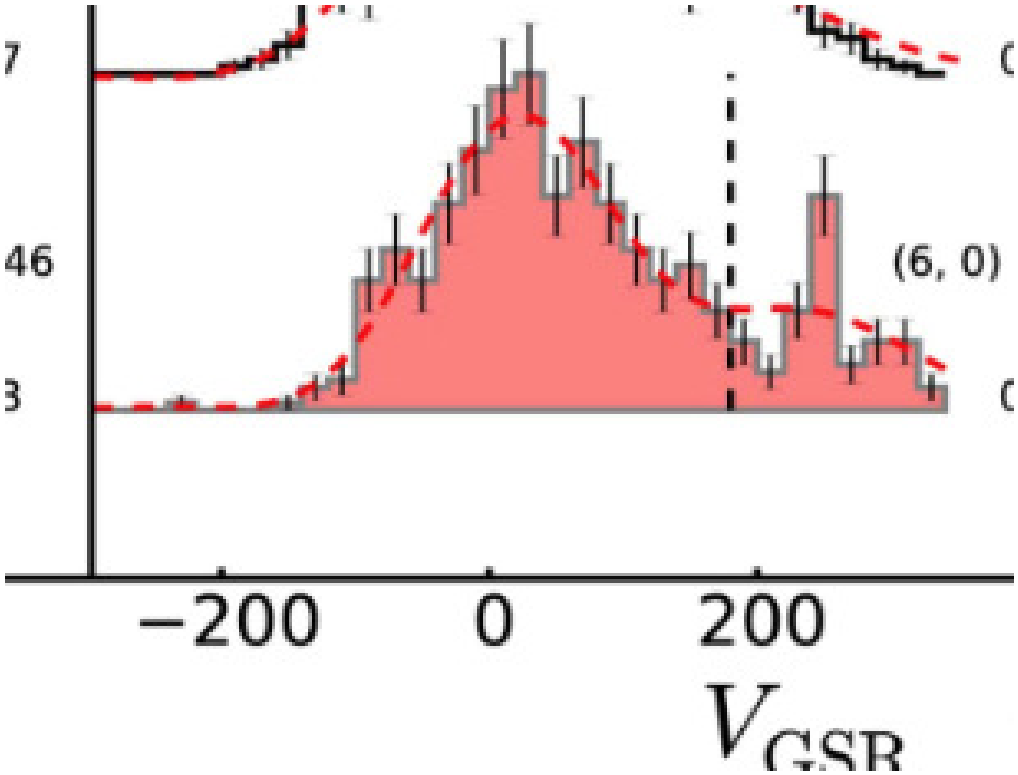
The split from the X-shape can be produced by different orbit families, but in different places



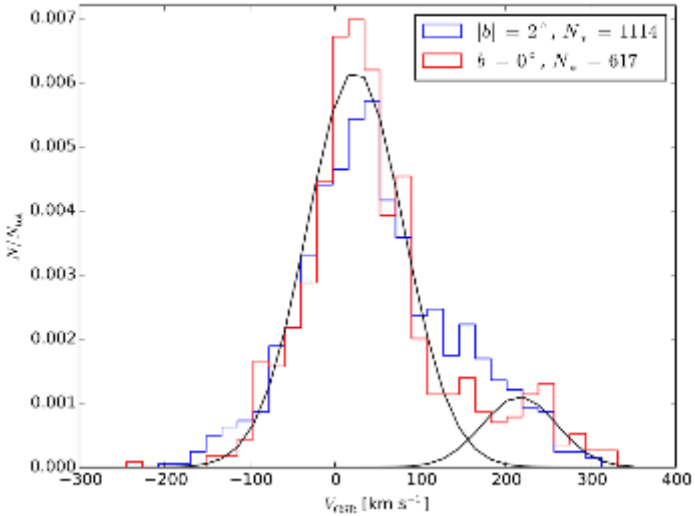
Abbott+ 17

Pilot projects



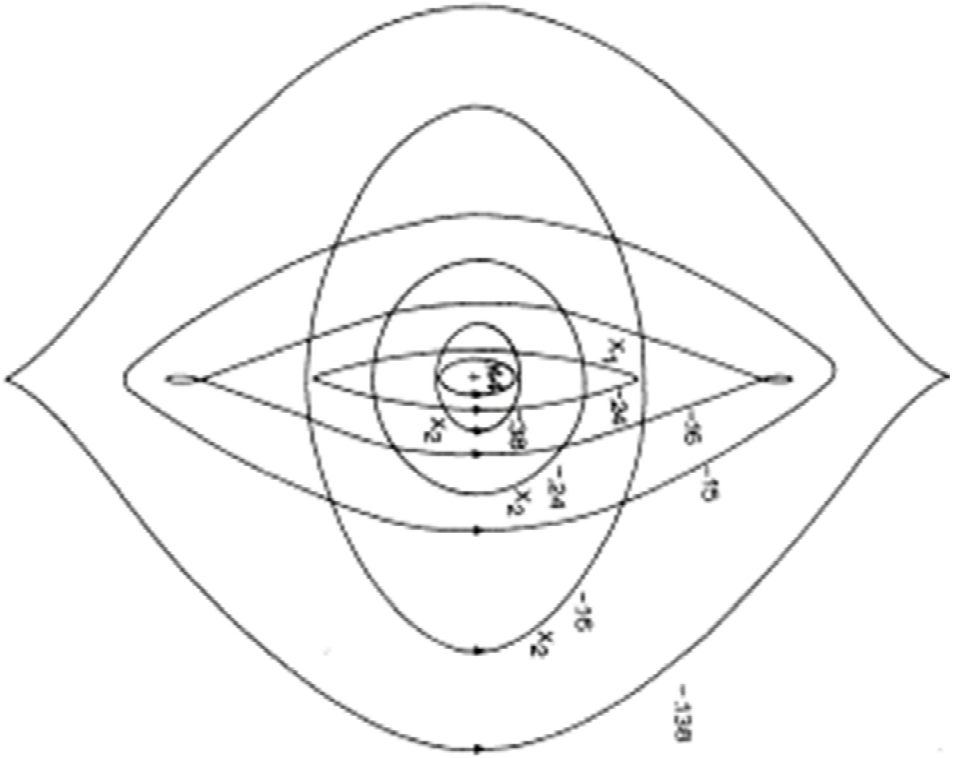


Zhou+ 17

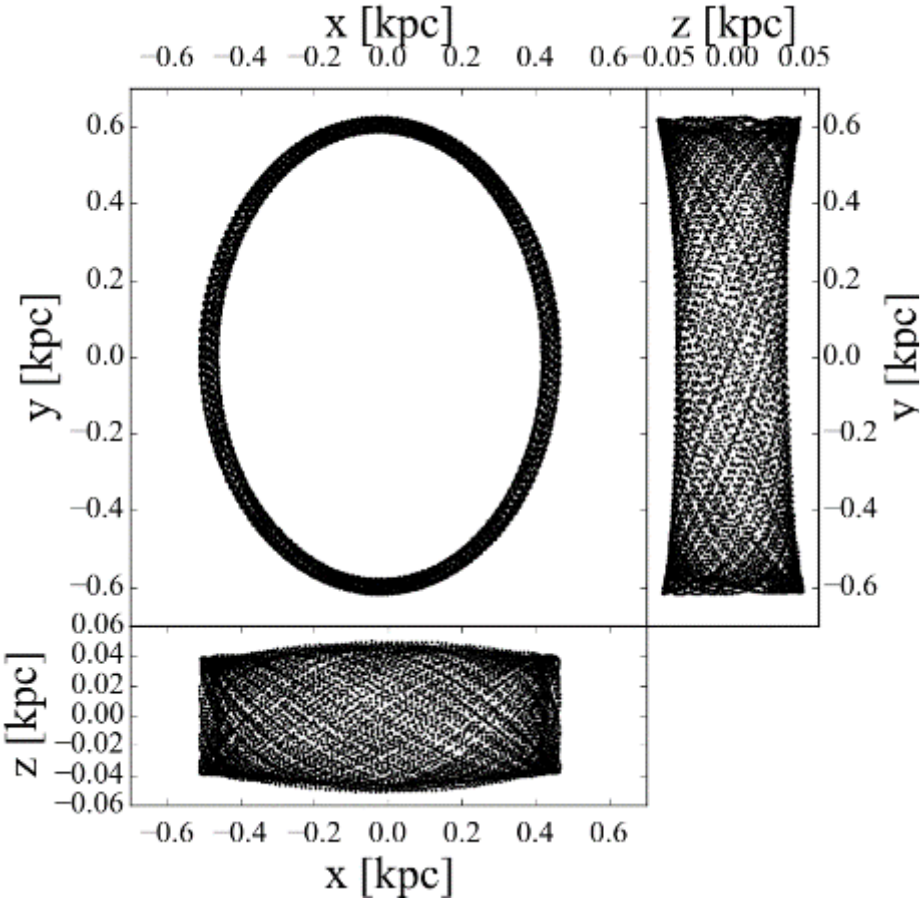


Debattista+ 15

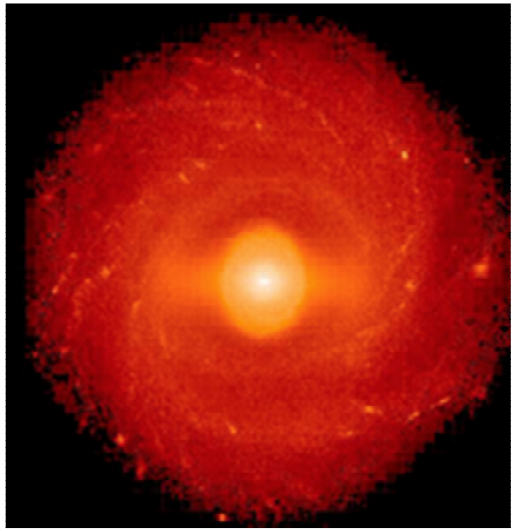
also Nidever+ 12



Contopoulos & Papayannopoulos 1980



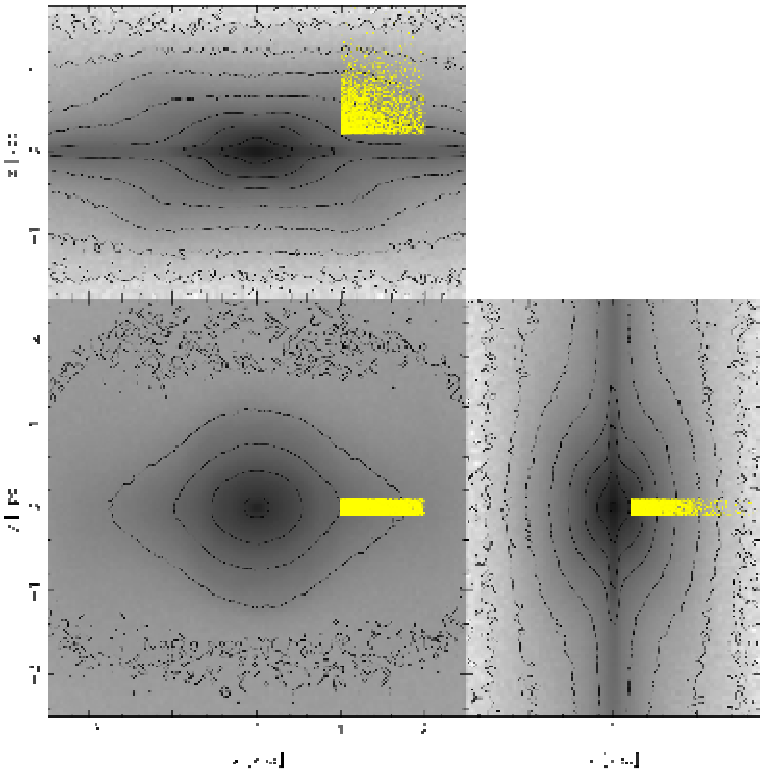
Earp+ in progress

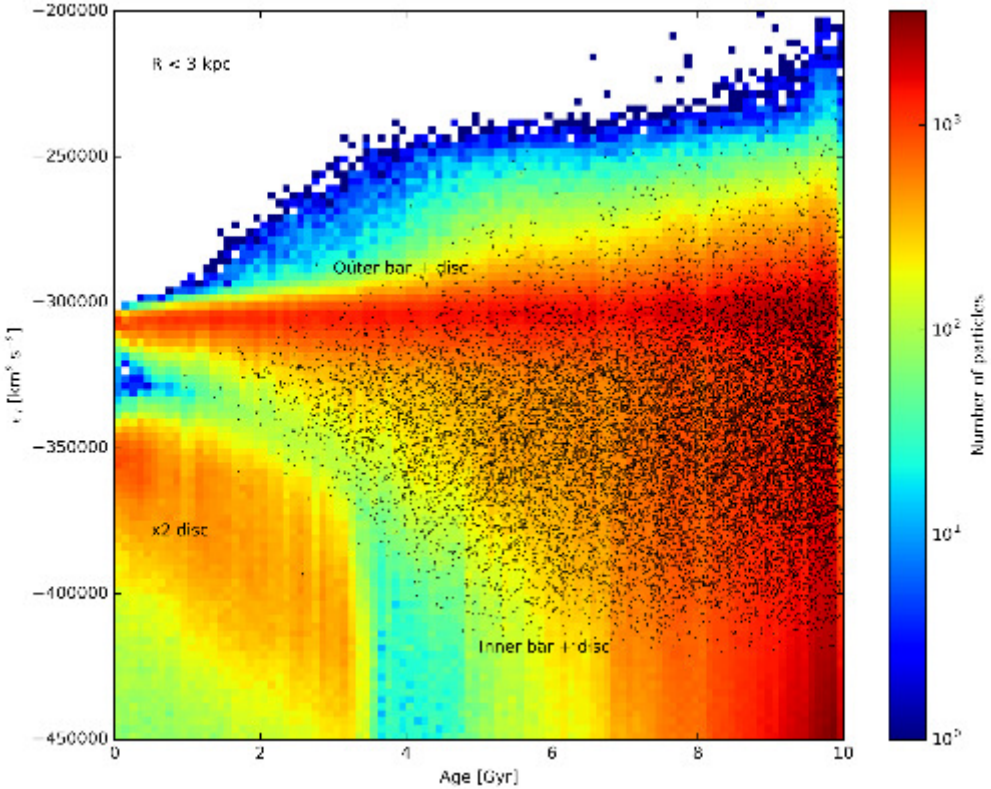


Natale+ 2015

x_2 orbits are robust.

Stars on these orbits form out of gas on these orbits, not trapped into these orbits

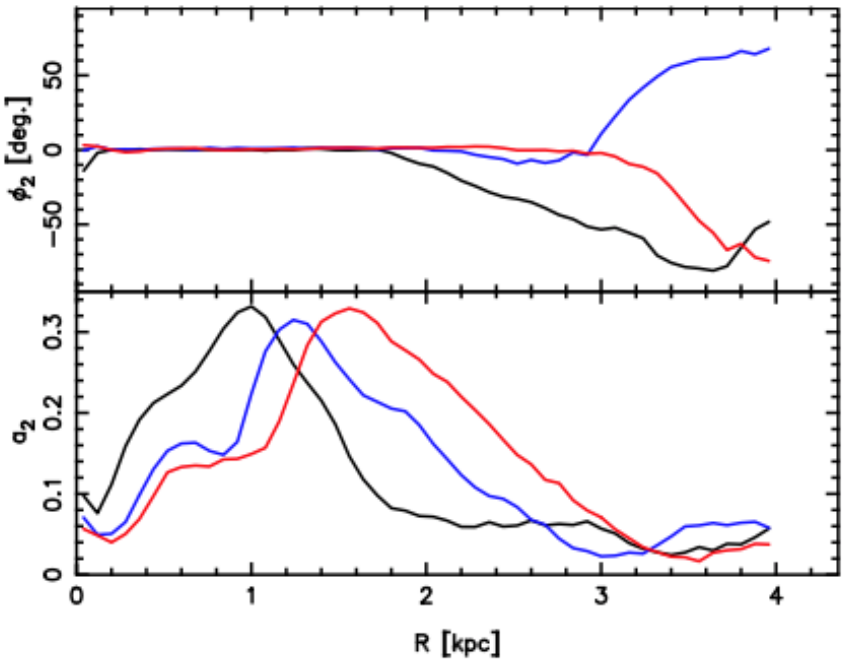


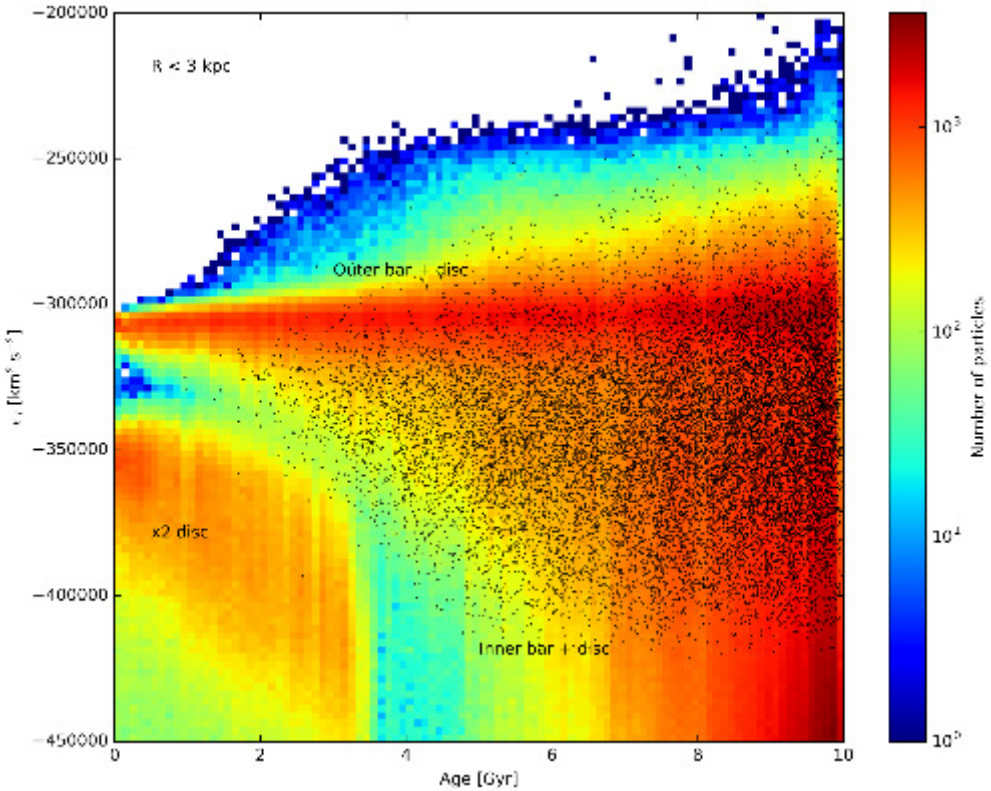


Did the X-shape form via 1 (or more) large scale instabilities, or via gentle trapping?

What orbits produce the X-shape in the bulge?

Stars on the X-shape are predominantly old, as observed in the Milky Way

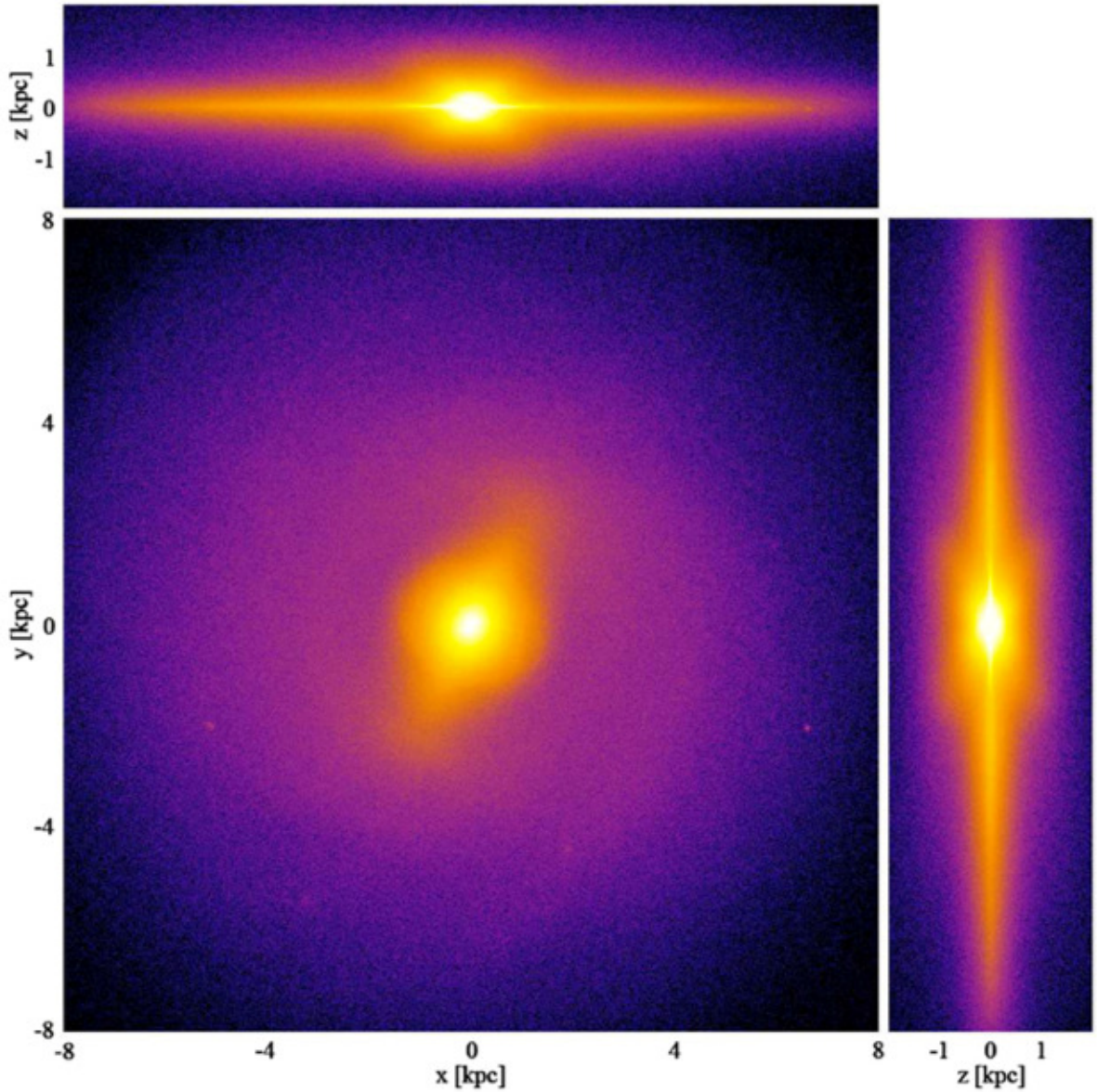




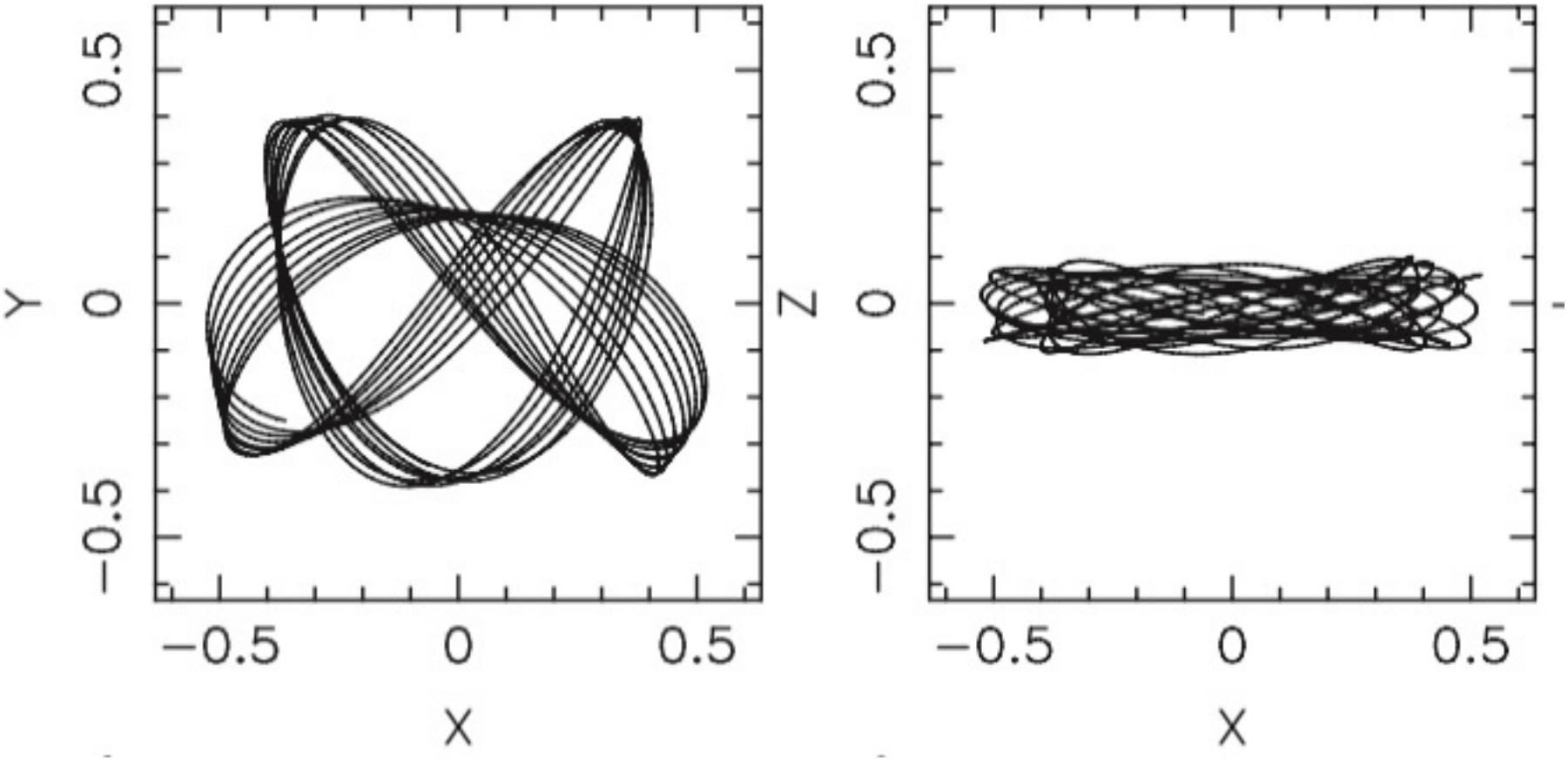
Bars grow by trapping stars at resonances.

Can we find the evidence of this growth in the MW? What is the signature of it?

Simulation is an HPC problem: 10^7 stars evolved over 10 Gyr with snapshots every 0.1 Gyr (this is like 10^9 particles)



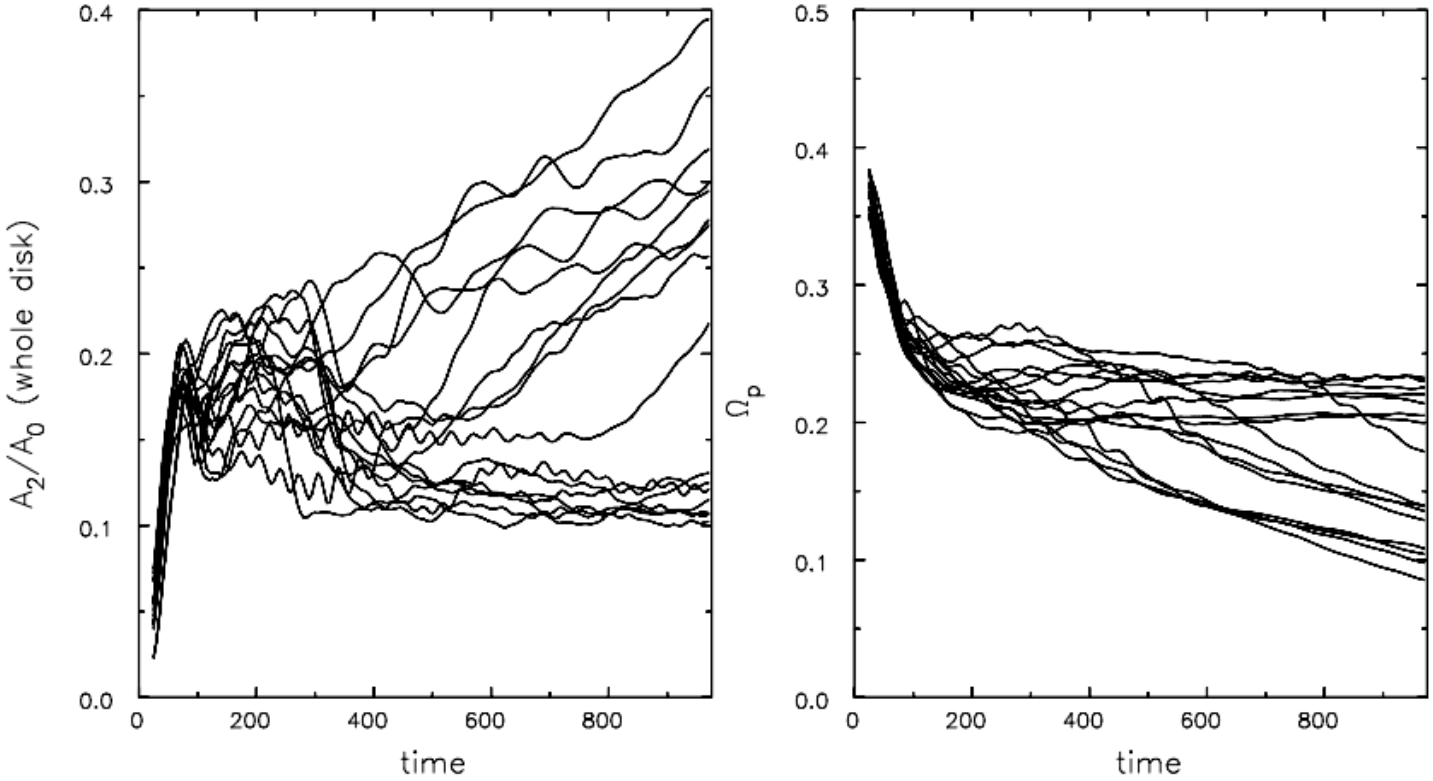
Orbits are an HTC problem: 10^7 stars with coordinates output every 10^4 years for 10^9 years (100,000 instances per particle when phase space coordinates saved.)
Like 10^{12} particles



10^{12} particles: More stars than the MW has!

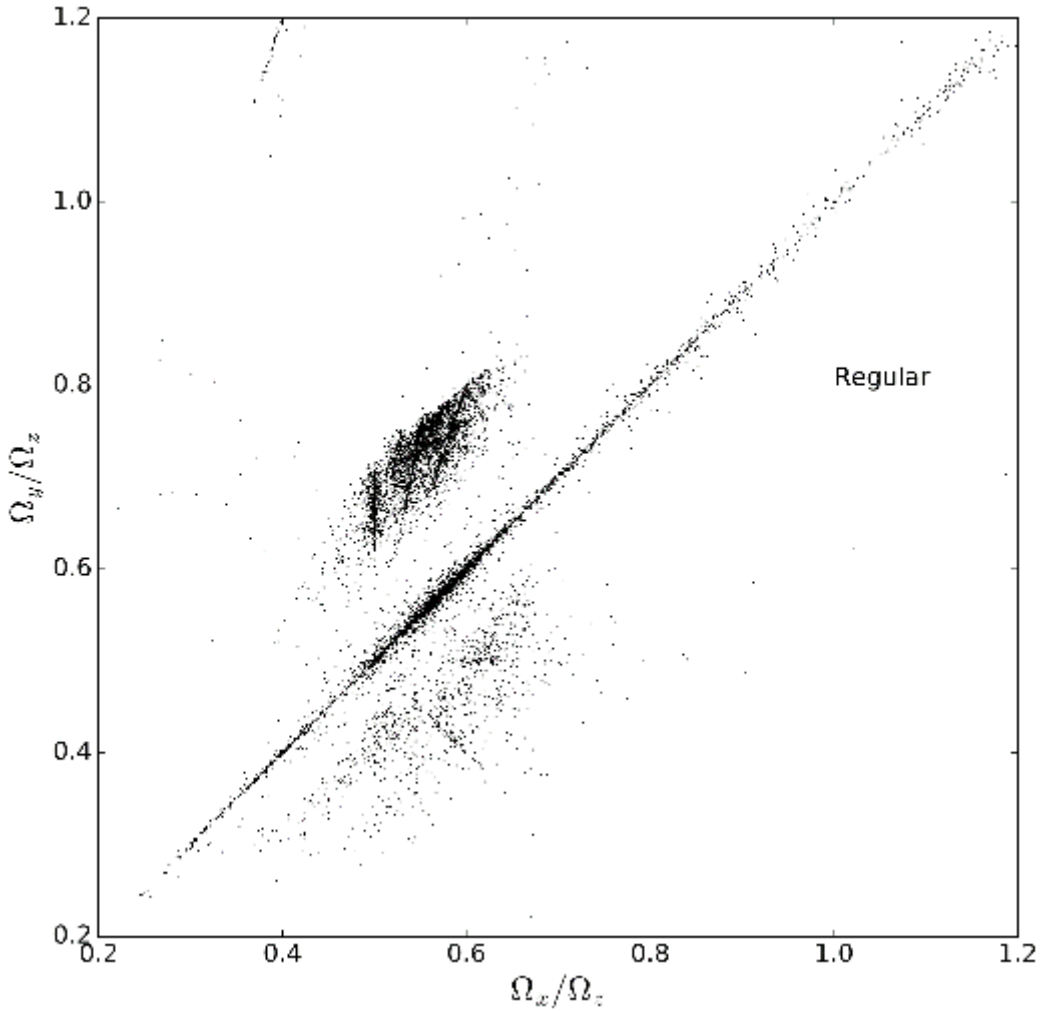
Worse: needs to be done for about 10 snapshots in each simulation 10^{13} particles

Even worse: one simulation only tells us about one pathway of evolution. Need say 10 simulations, Like 10^{14} particles



Sellwood & Debattista 2009

10^{14} particles but this is just data stream
Each orbit can be decomposed into about 10 numbers, e.g. frequencies, amplitudes, energies, etc
Reduces the problem to the equivalent of 10^9 particles with 10 numbers each



We will have 10^9 numbers in 10 dimensions. We want to use these to construct diagnostics of the evolution of the Milky Way

How do we find evolutionary sequences?

How do we identify outliers with possibly interesting physical insight?

How do we compare different simulations with each other?

We will have 10^9 numbers in 10 dimensions. We want to use these to construct diagnostics of the evolution of the Milky Way

How do we find evolutionary sequences?

How do we identify outliers with possibly interesting physical insight?

How do we compare different simulations with each other?

Ideas welcome! Thank you