Milky Way – Andromeda Collision
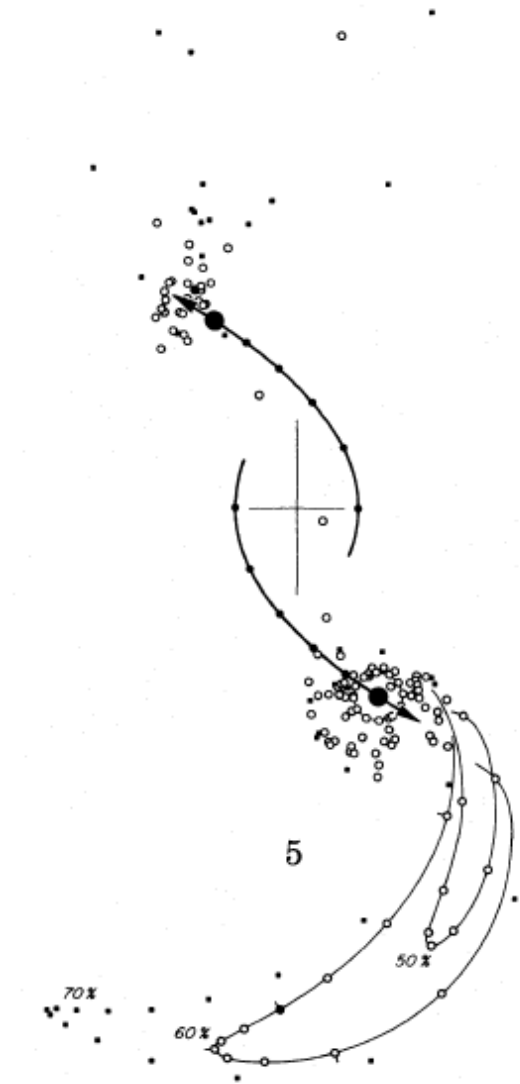
Andromeda

Milky Way

Toomre & Toomre model

- Galactic model
  - Concentric rings of increasing number of particles
  - 16 rings containing a total of 553 particles
  - massive core carries entire mass of galaxy
  - Ring particles interact with cores only, not with each other: 3 body problem
- Units
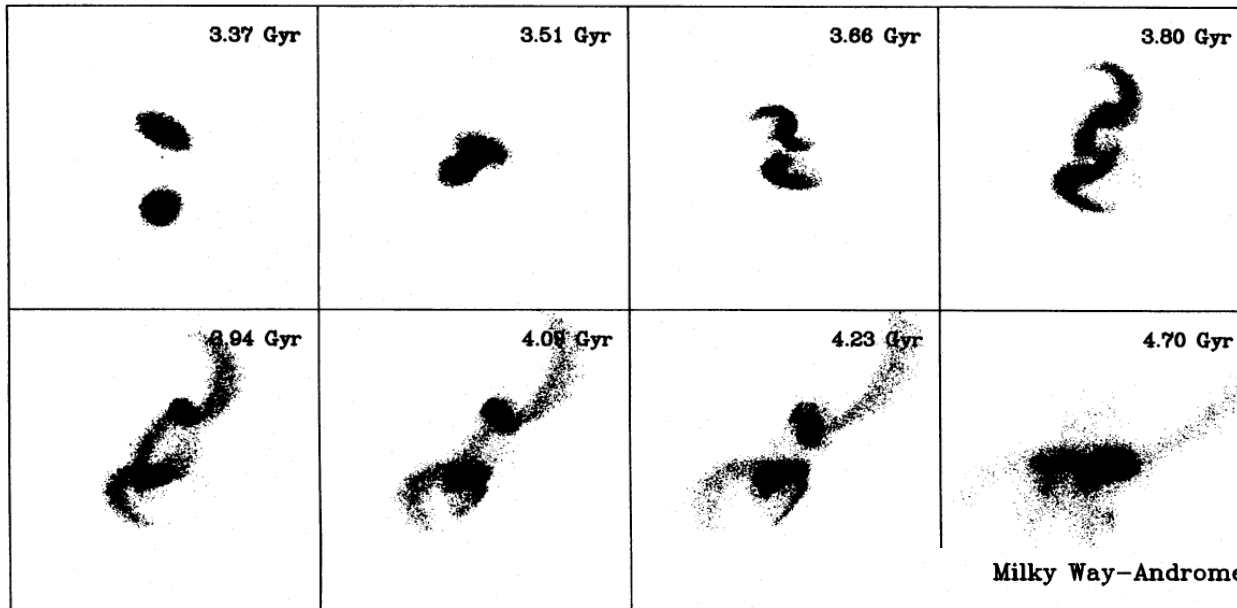 - Distances in kpc, mass in 10^{11} solar masses, G = 1, time in Myr

Tidal bridges and tails

- Tails are produced by tidal interaction of incoming galaxy
  - Deform disk of galaxy, eject tails
- Bridges are parts of tail near the collision point which become bound to other galaxy
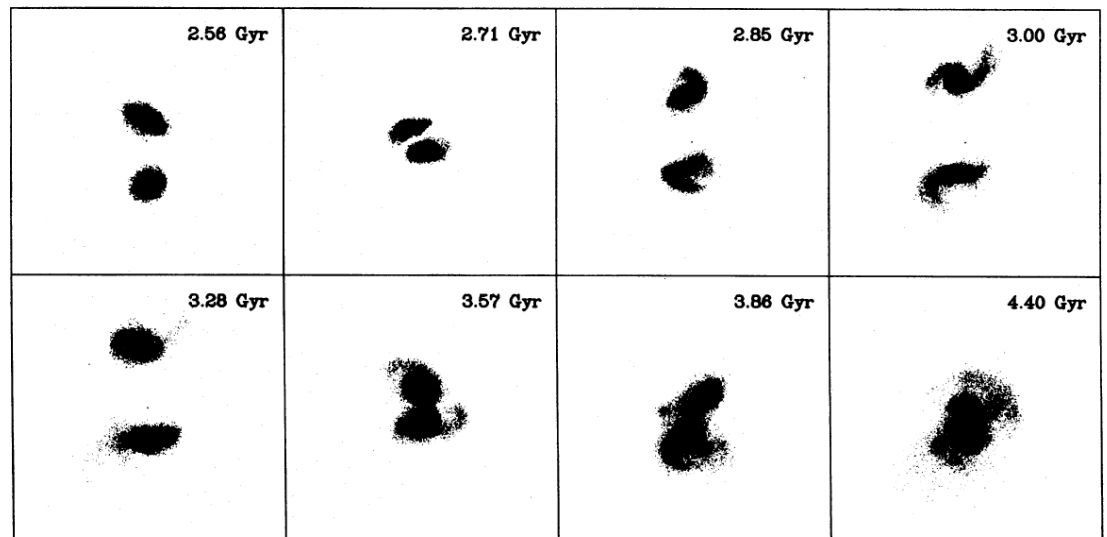 - Most of tail remains bound

5

70%

60%

50%

Goal: Dubinski or bust!

Milky Way–Andromeda Merger – $M_{MW}+M_A=1.6\times10^{12}\ M_\odot$
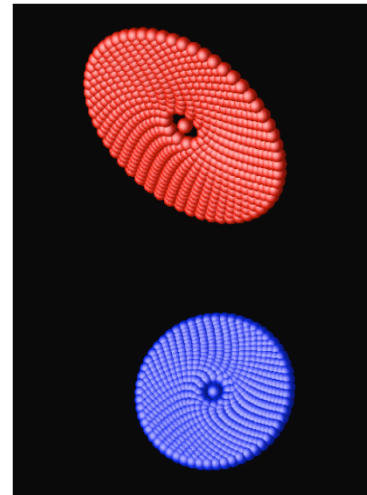

Milky Way–Andromeda Merger – $M_{MW}+M_A=5.2\times10^{12}\ M_\odot$

Orientation of the galaxies

- The orientation is specified in galactic coordinates
  - (longitude, latitude)
- Location of Andromeda: (121˚, -23˚)
- Andromeda Spin Axis: (240˚, -30˚)
- Milky Way Spin Axis: (0˚, -90˚)

Dubinski, Mihos, Hernquist, *The Astrophysical Journal, 462: 576-593*, 1996 May 10

We used our own integrator for running our simulation.
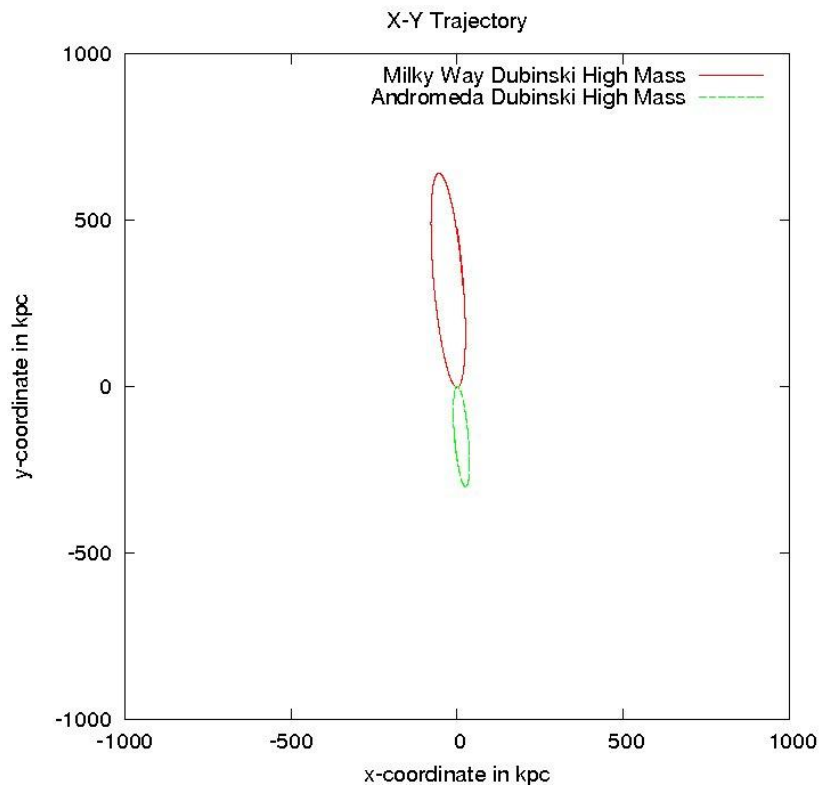
Dubinski Initial Conditions

High Mass Limit

- Radial velocity: 130 km/s
- Tangential velocity: 20 km/s
- Separation: 700 kpc
- Milky Way mass: 17 units
- Andromeda mass: 36 units
- Milky Way size: 4 kpc
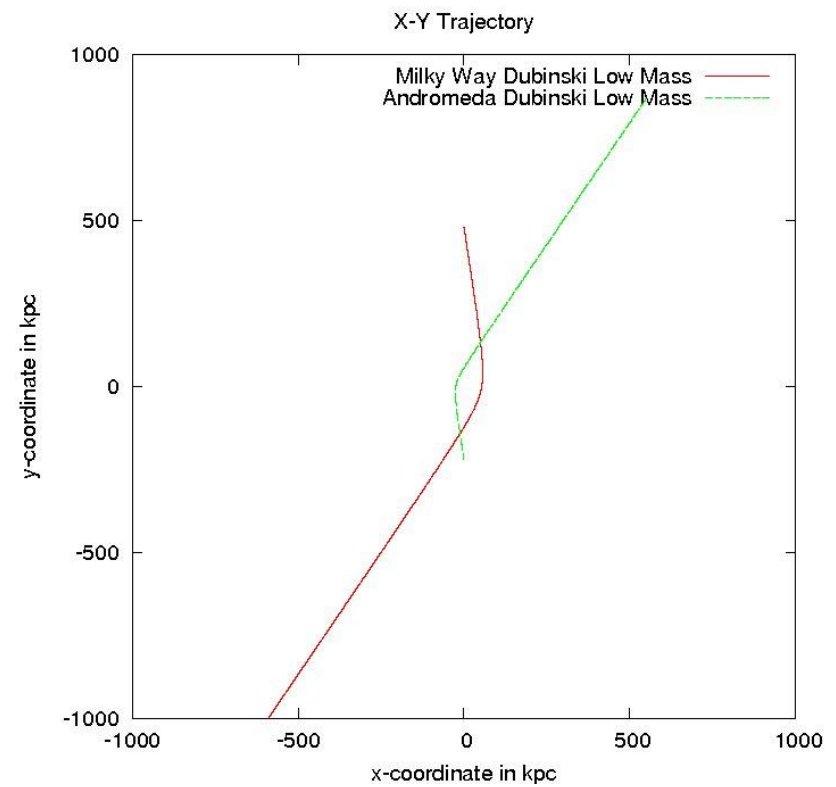- Andromeda size: 6 kpc

Low Mass Limit

- Radial velocity: 130 km/s
- Tangential velocity: 20 km/s
- Separation: 700 kpc
- Milky Way mass: 0.5 units
- Andromeda mass: 1.1 units
- Milky Way size: 40 kpc
- Andromeda size: 60 kpc

Dubinski, Mihos, Hernquist, *The Astrophysical Journal, 462: 576-593*, 1996 May 10
Dubinski, *Sky & Telescope*, (2006)

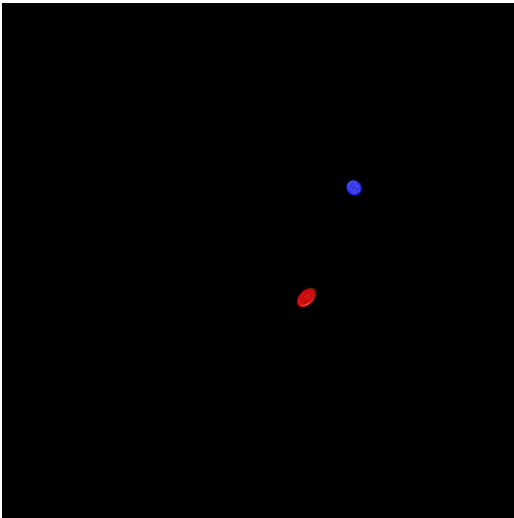# Trajectory of Cores

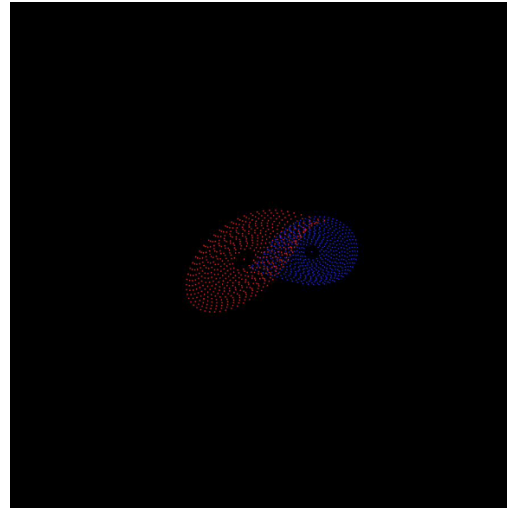**High Mass Limit**

Low Mass Limit

Dubinski Movies

High Mass Limit

Low Mass Limit

Most Recent Data

- Radial velocity: 125 km/s

- Tangential velocity: 100 km/s *

- Separation: 778 kpc ***

- Milky Way mass: 5.8 units **

- Andromeda mass: 7.1 units **

- Milky Way size: 200 kpc (our choice)

- Andromeda size: 300 kpc (our choice)

*Abraham Loeb, Mark J. Reid, Andreas Brunthaler, and Heino Falcke *The Astrophysical Journal, 633*:894–898, November 10 2005
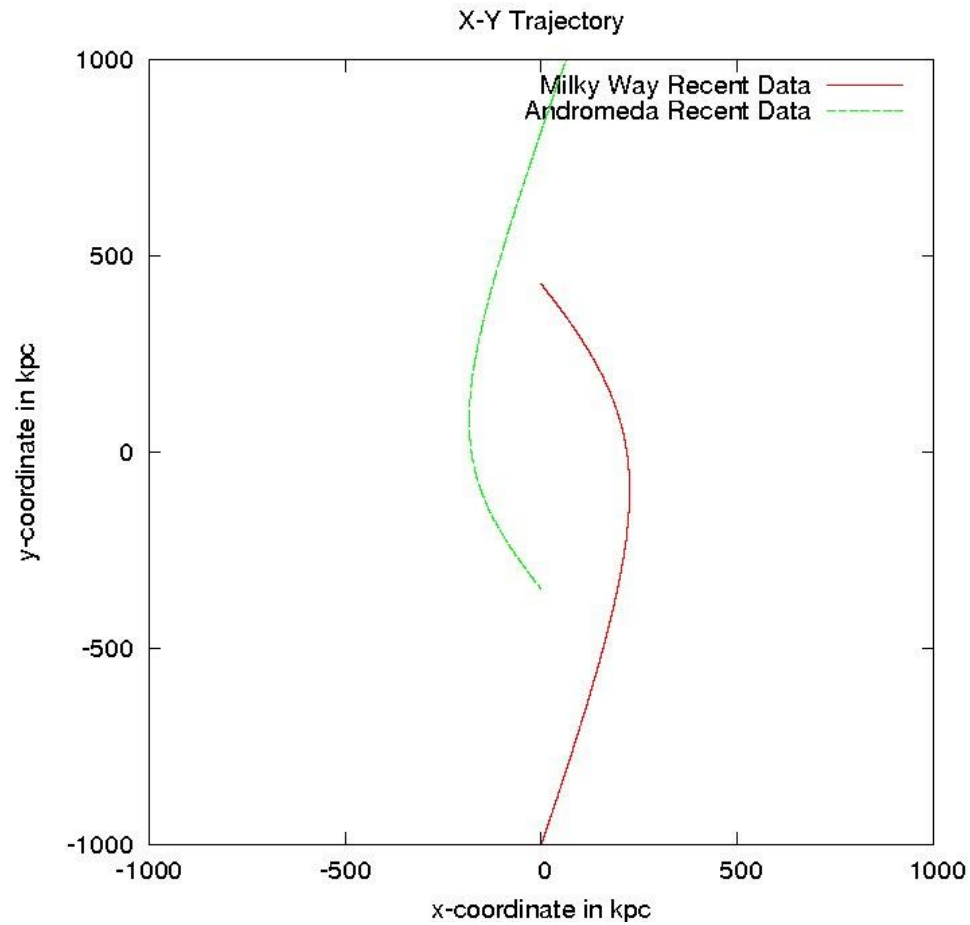
**Karachentsev, I. D.; Kashibadze, O. G. (2006). "
Masses of the local group and of the M81 group estimated from distortions in the local velocity field". *Astrophysics* **49** (1): 3–18.

*** D. Karachentsev, V. E. Karachentseva, W. K. Hutchmeier, D. I. Makarov (2004). "A Catalog of Neighboring Galaxies". *Astronomical Journal* **127**: 2031–2068.
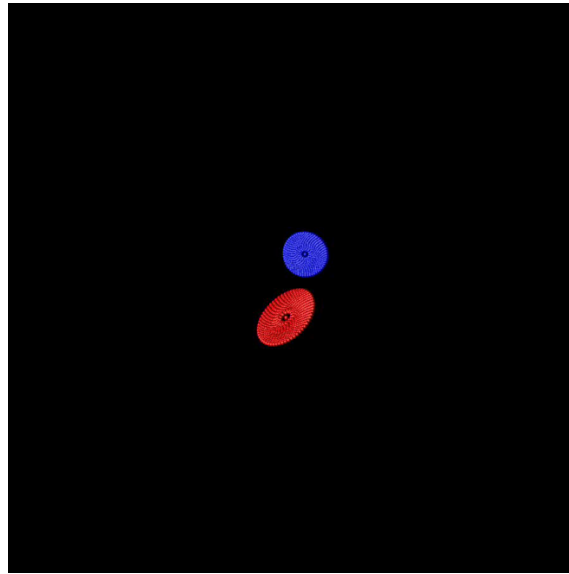
*** Ribas, C. Jordi, F. Vilardell, E.L. Fitzpatrick, R.W. Hilditch, F. Edward (2005). "First Determination of the Distance and Fundamental Properties of an Eclipsing Binary in the Andromeda Galaxy". *Astrophysical Journal* **635**: L37–L40.

*** McConnachie, A. W.; Irwin, M. J.; Ferguson, A. M. N.; Ibata, R. A.; Lewis, G. F.; Tanvir, N. (2005). "Distances and metallicities for 17 Local Group galaxies". *Monthly Notices of the Royal Astronomical Society* **356** (4): 979–997.

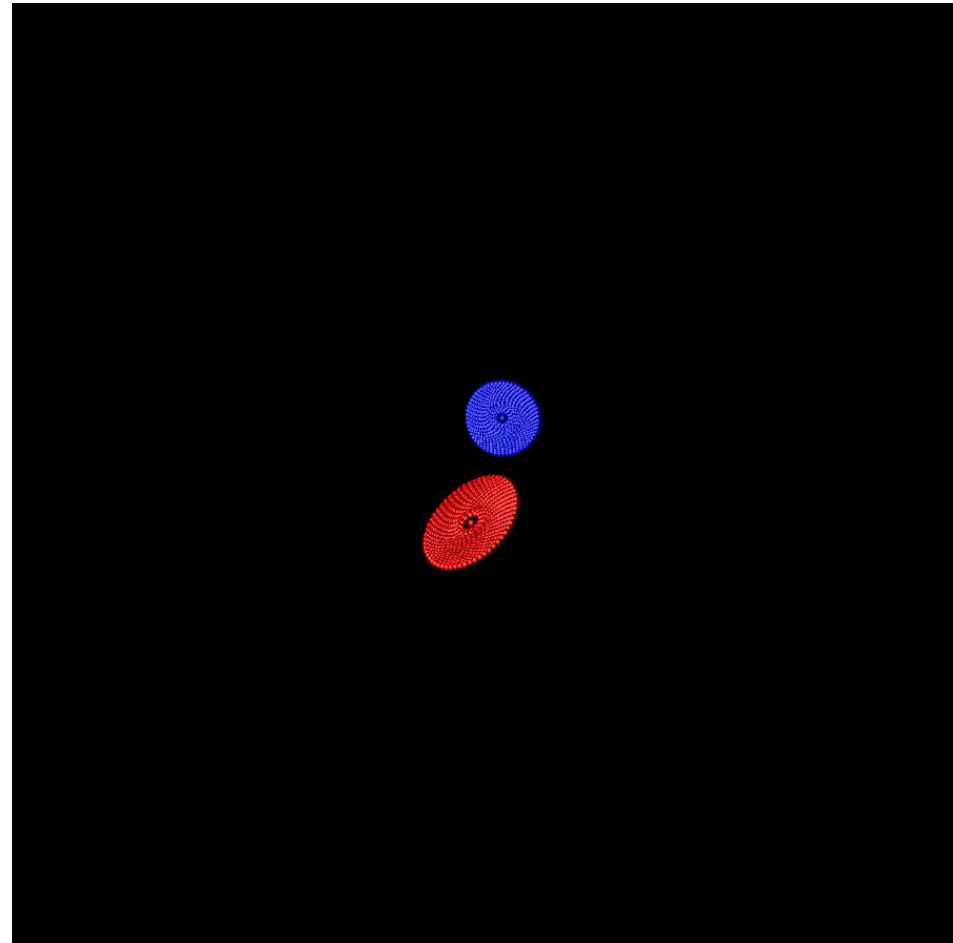# Trajectory of Cores

Movie on recent data

Results

- Tidal tails remain in galactic plane.

- Tidal tails are more tightly bound by heavier mass.

- Bridging is less frequent when inclination between galaxy and collision planes is high.

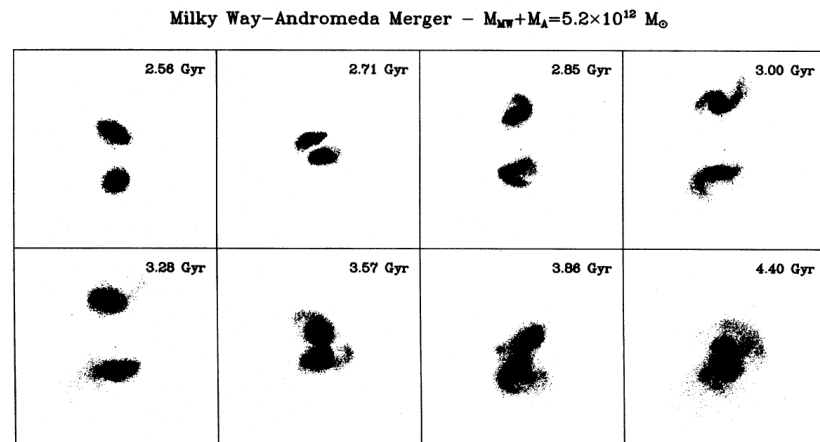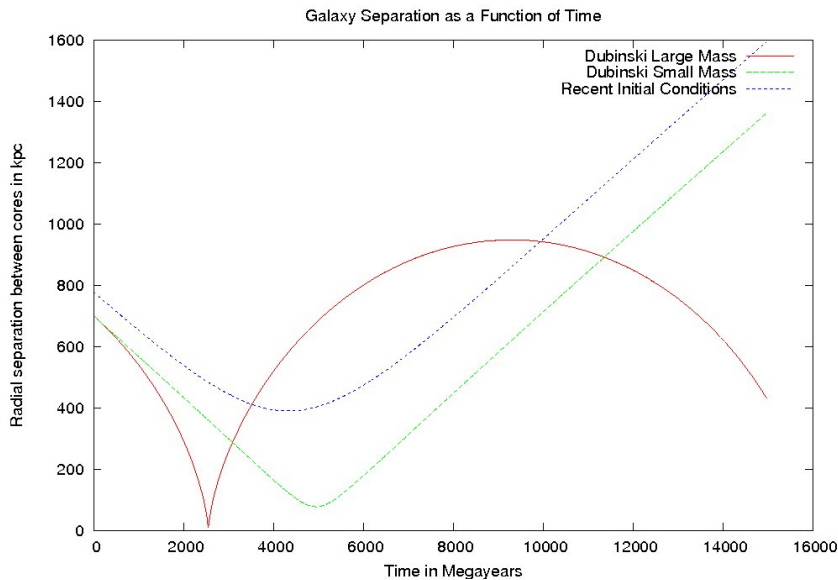- The Toomre model is too simple and very different from Dubinski's.

Tidal Examples in
Recent Data Collision

- Red = Andromeda
- Blue = Milky Way

- Heavier Andromeda holds tail closer

- During Rotation view plane of tail

- Bridging less common for Andromeda

Poor Agreement Between Dubinski's Large Mass Pictures and Our Film

Galaxy Separation as a Function of Time

- Dubinski Large Mass
- Dubinski Small Mass
- Recent Initial Conditions

Radial separation between cores in kpc / Time in Megayears

- Only similarity is time of collision:
  - Dubinski, Large M's – 2.71 Gyr
  - Our Collision – 2.55 Gyr

- Big Difference – No Merger!

Milky Way–Andromeda Merger – $M_{MW}+M_A=5.2\times10^{12}$ $M_\odot$

2.56 Gyr, 2.71 Gyr, 2.85 Gyr, 3.00 Gyr, 3.28 Gyr, 3.57 Gyr, 3.86 Gyr, 4.40 Gyr

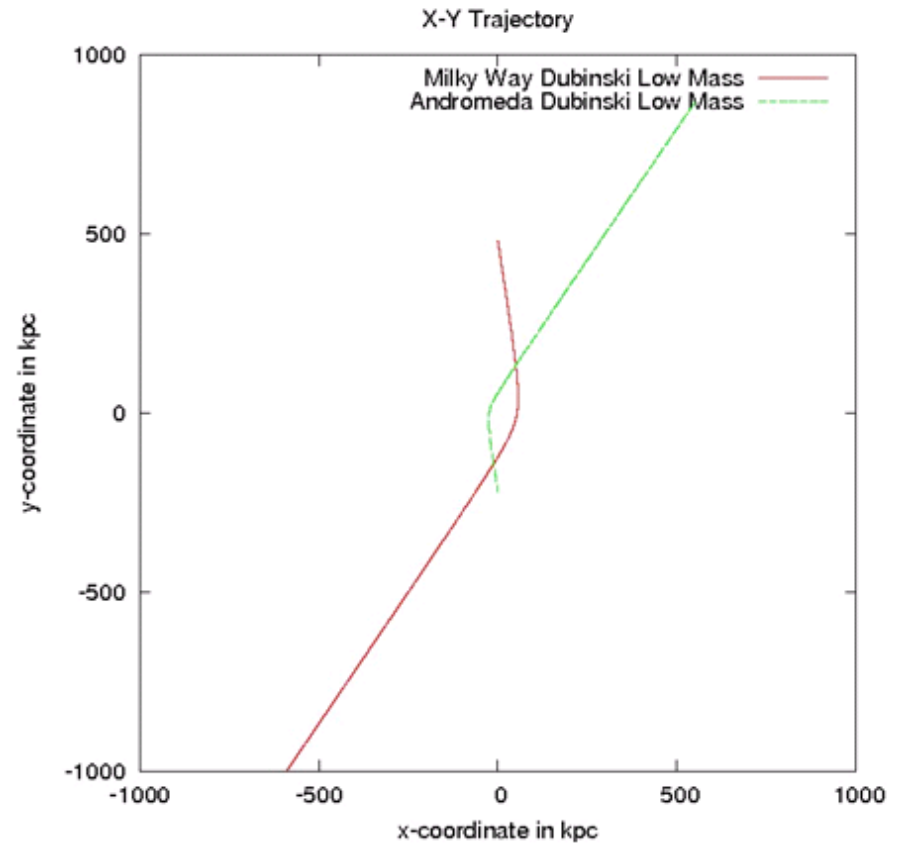# Even Less Agreement Between Dubinski's Small Mass Simulations and Our Own
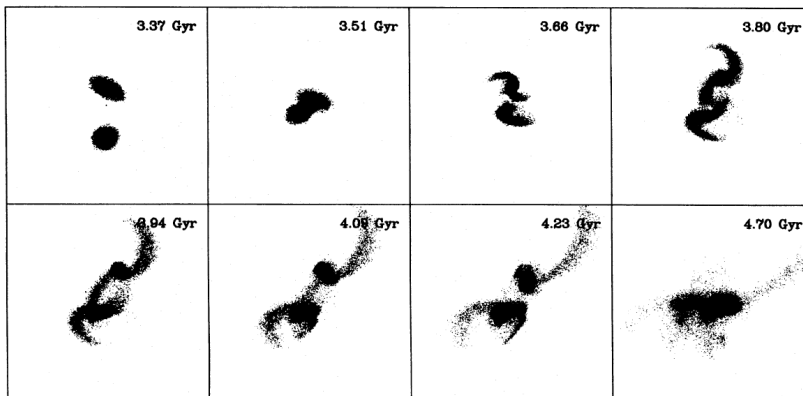
- Collision Time
  - Dubinski – 3.51 Gyr
  - Simulation – 5.0 Gyr
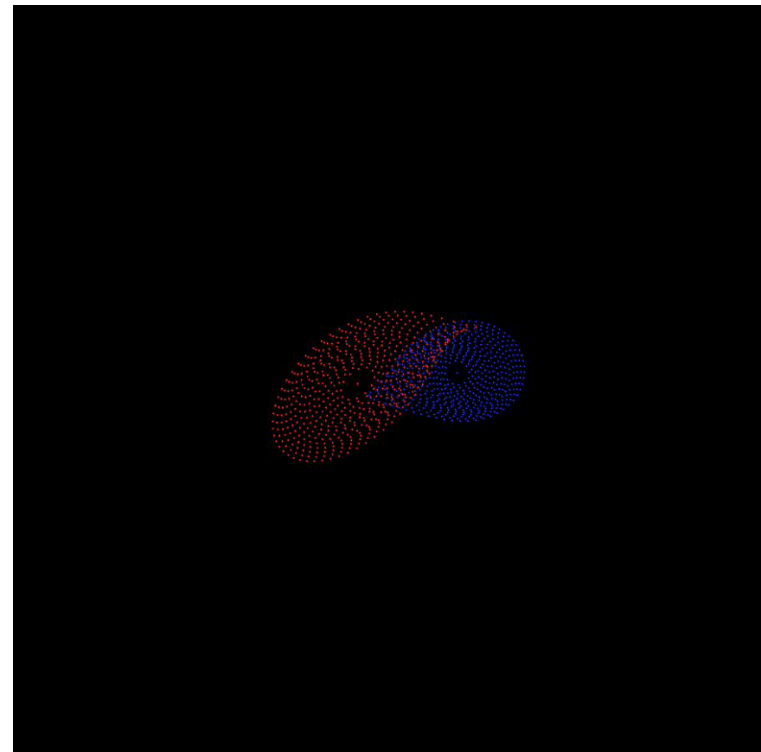
- Not even bound!

- Again no merger!

Milky Way–Andromeda Merger – $M_{MW}+M_A=1.6\times10^{12}\ M_\odot$

X-Y Trajectory

No Milkodema* In Our Simulations

Model Differences

- Toomre&Toomre model on Dubinski data.

- Dubinski masses are massive.

- All our mass is in center.

- Our trajectories are from two body interactions.

- Test masses move in three body interactions.

- No Halos.

*Cain, Fraser (2007). "When Our Galaxy Smashes Into Andromeda, What Happens to the Sun?". *Universe Today*. Retrieved on 2009-03-08.

Final Project Goals

- Use more complicated model for galaxies

- Include bulge, massive disc and halo

- Have up to 10^{11} particles?

- Make Milkomeda!