Stellar Dynamics

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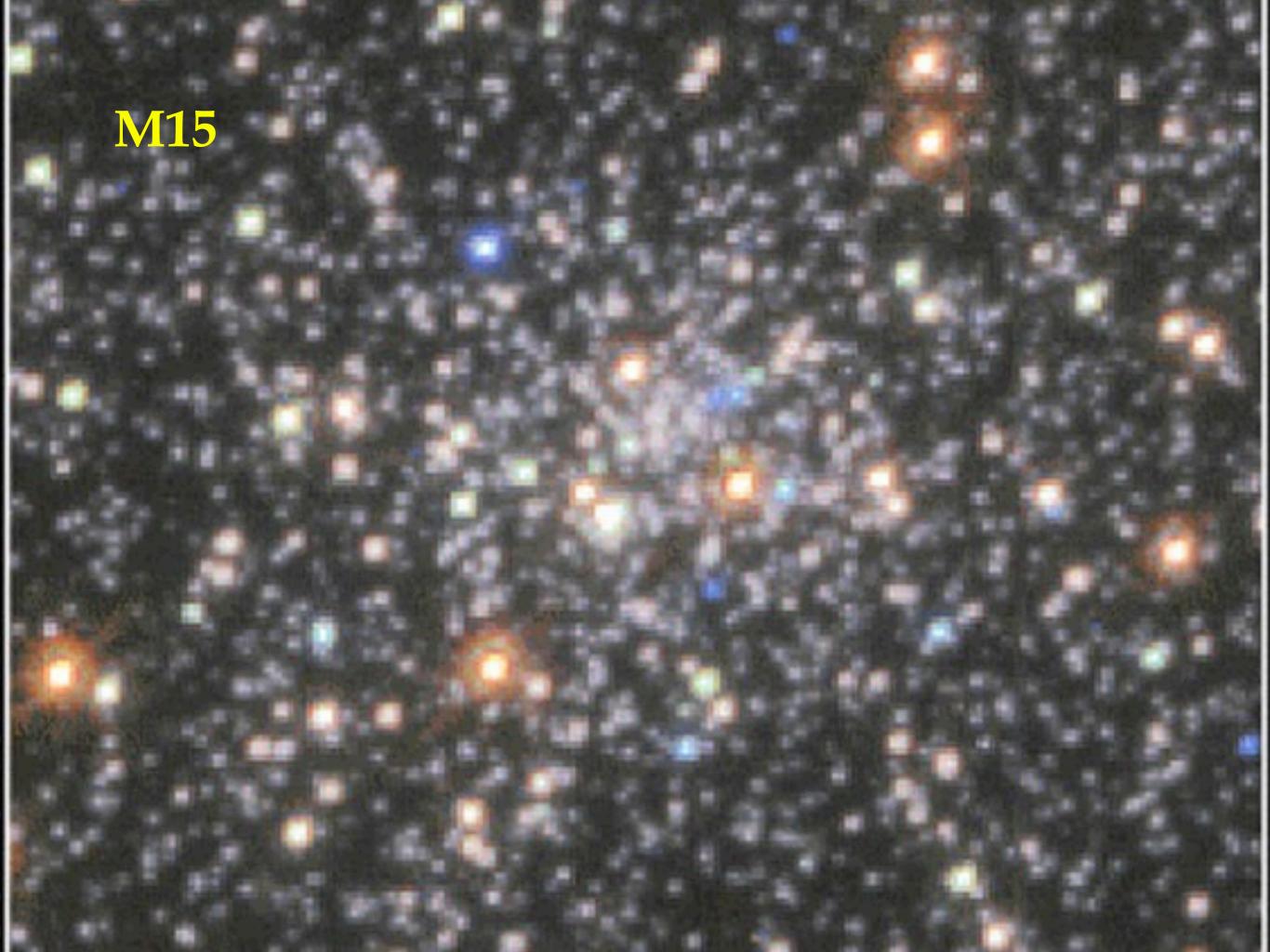
Observations

- Emblematic case: globular cluster
- DIY on the web (really!)









The 1-Body Problem

B

Not as trivial as it seems

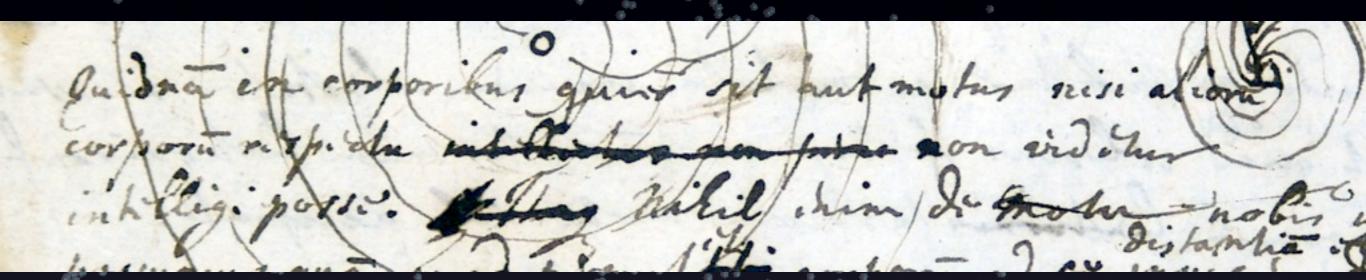
The relativity of position and velocity

Christiaan Huygens

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- Motus inter corpora relativus tantum est
- The mutual motion of objects is entirely relative

Position and velocity are not observable



 Quidnam in corporibus quies sit aut motus nisi aliorum corporum respectu non videtur intellegi posse.

Relativity of position and velocity

- $x \rightarrow x + a$ constant translation a
- $\bullet dx \rightarrow dx$
- \bullet v = dx/dt
- $v \rightarrow v + w$ constant translation w
- $\bullet dv \rightarrow dv$
- g = dv/dt acceleration

Mechanics: the change of change

Second-order differential equation

The 2-Body Problem

Kepler and Newton

Binary Orbits

A.E. Roy, Orbital Motion Chapter 4

The N-Body Problem

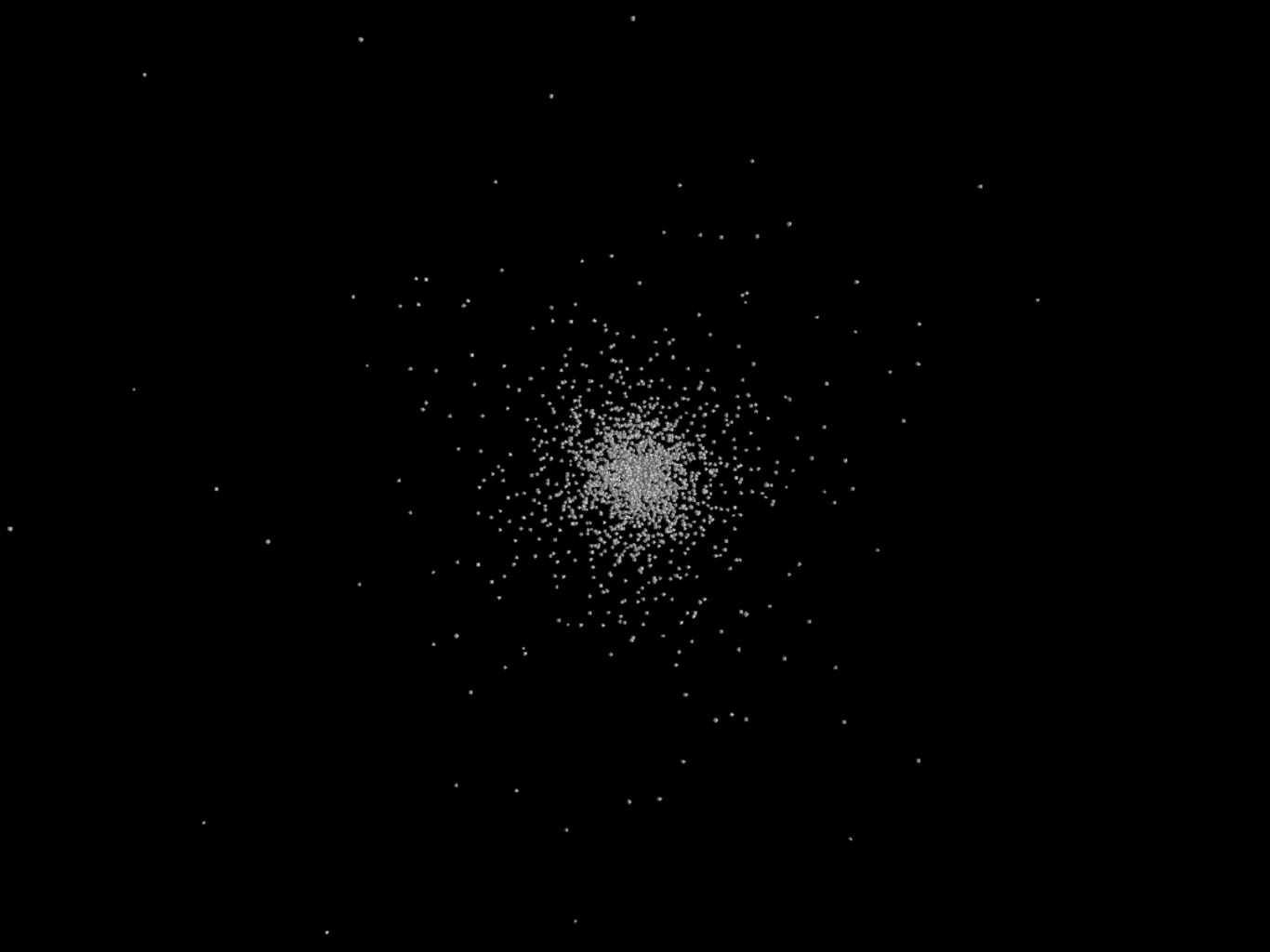
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Gravithermodynamics

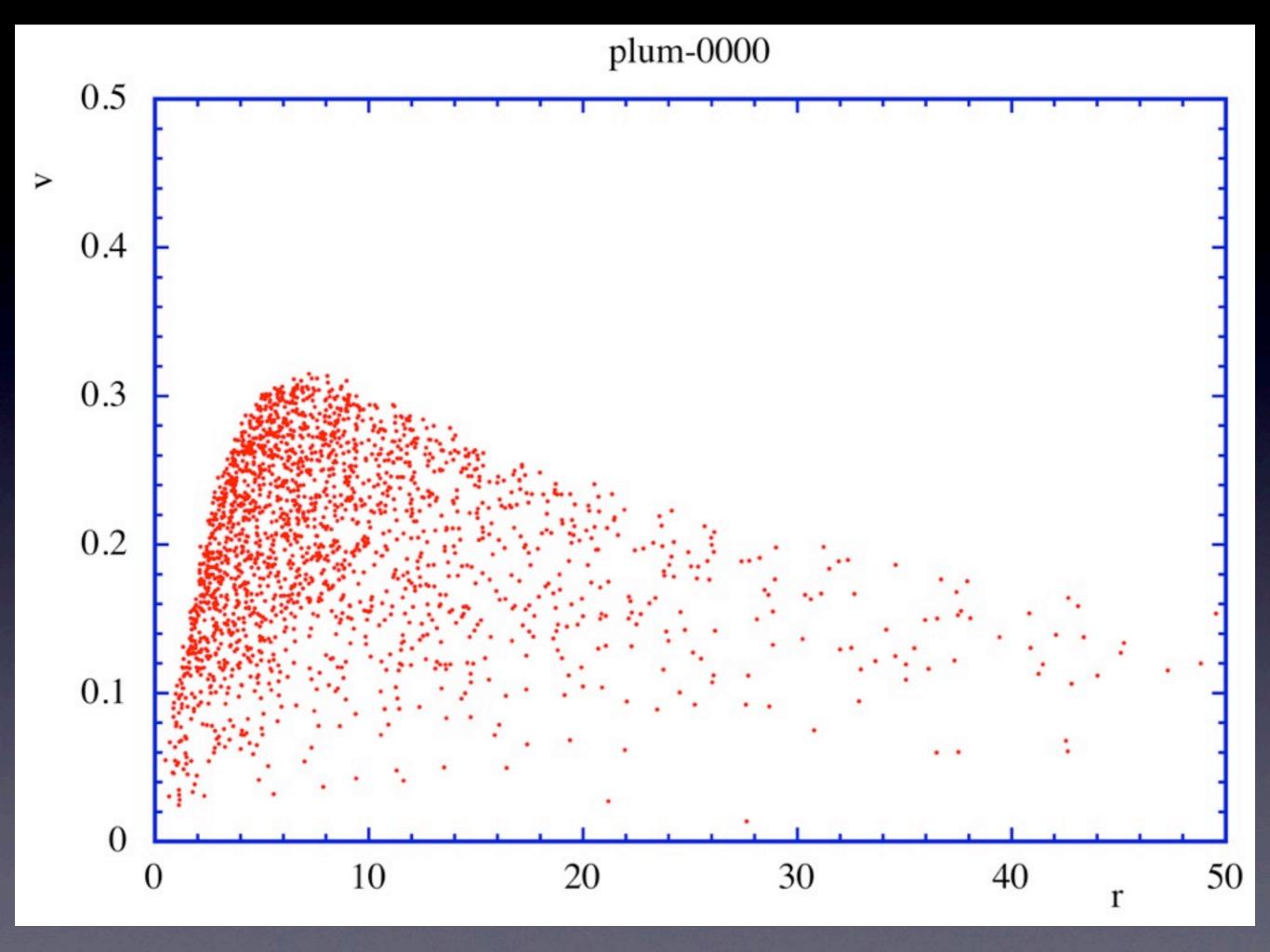
Plummer Sphere

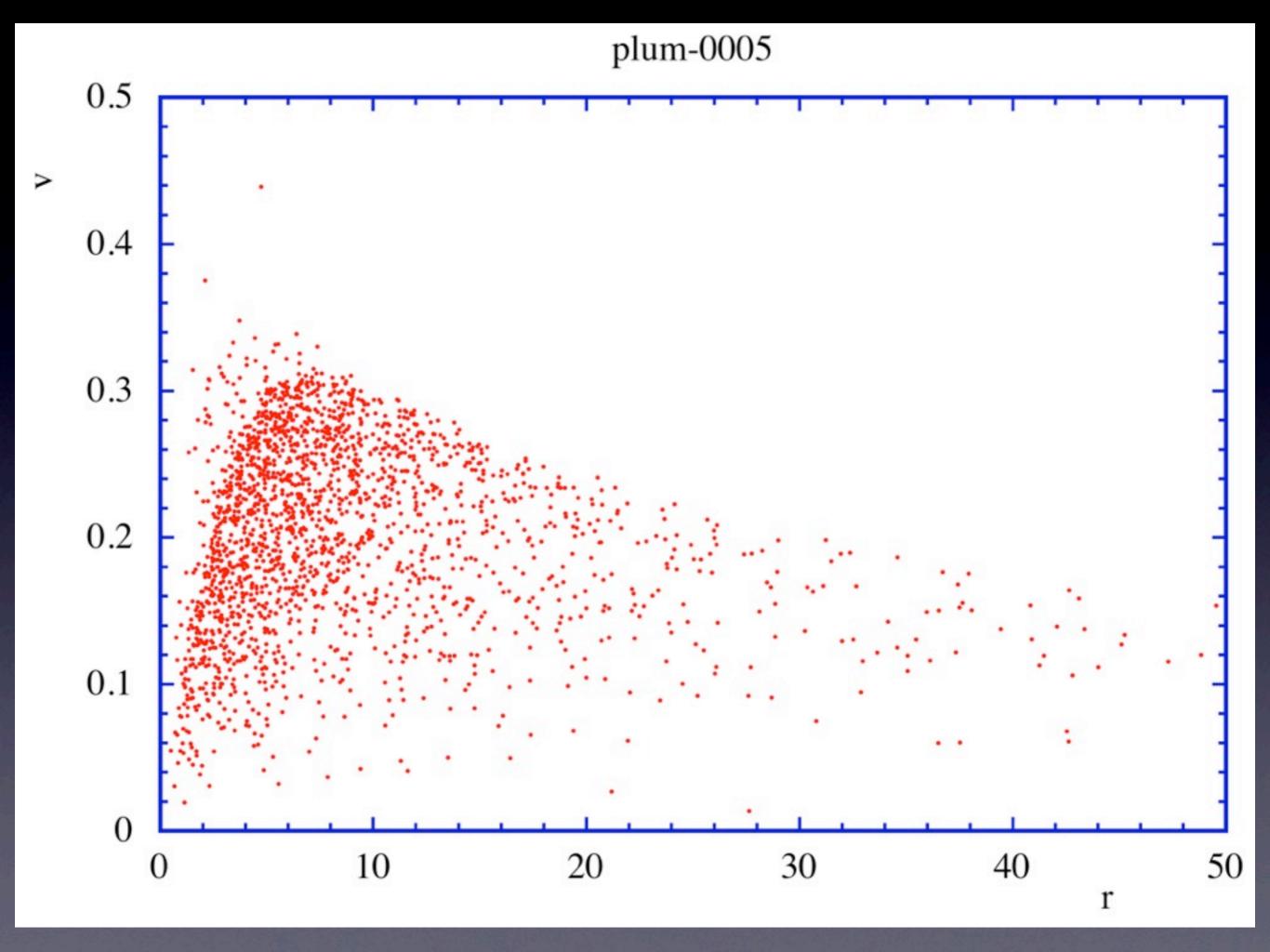
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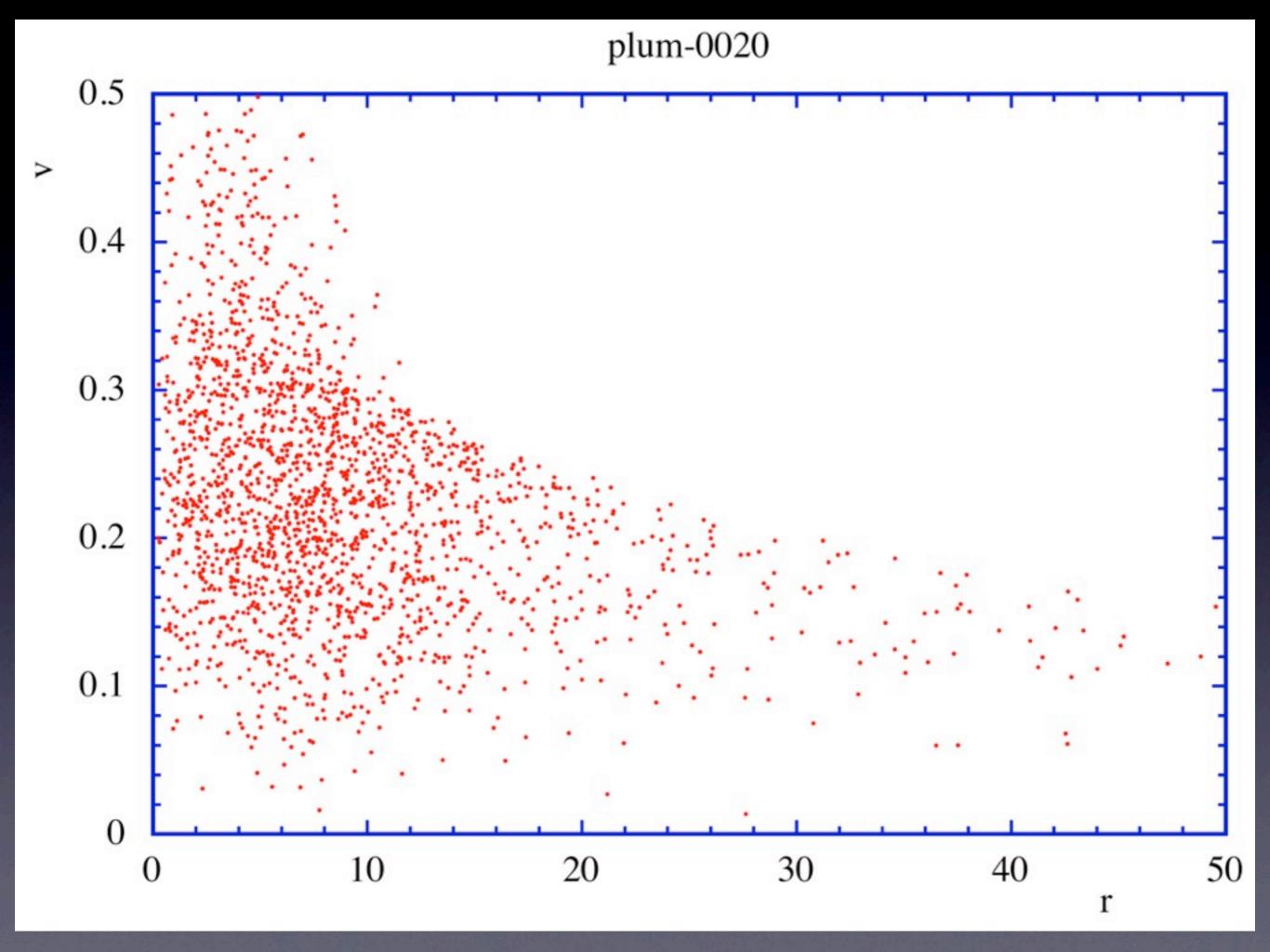
Polytropic Distribution

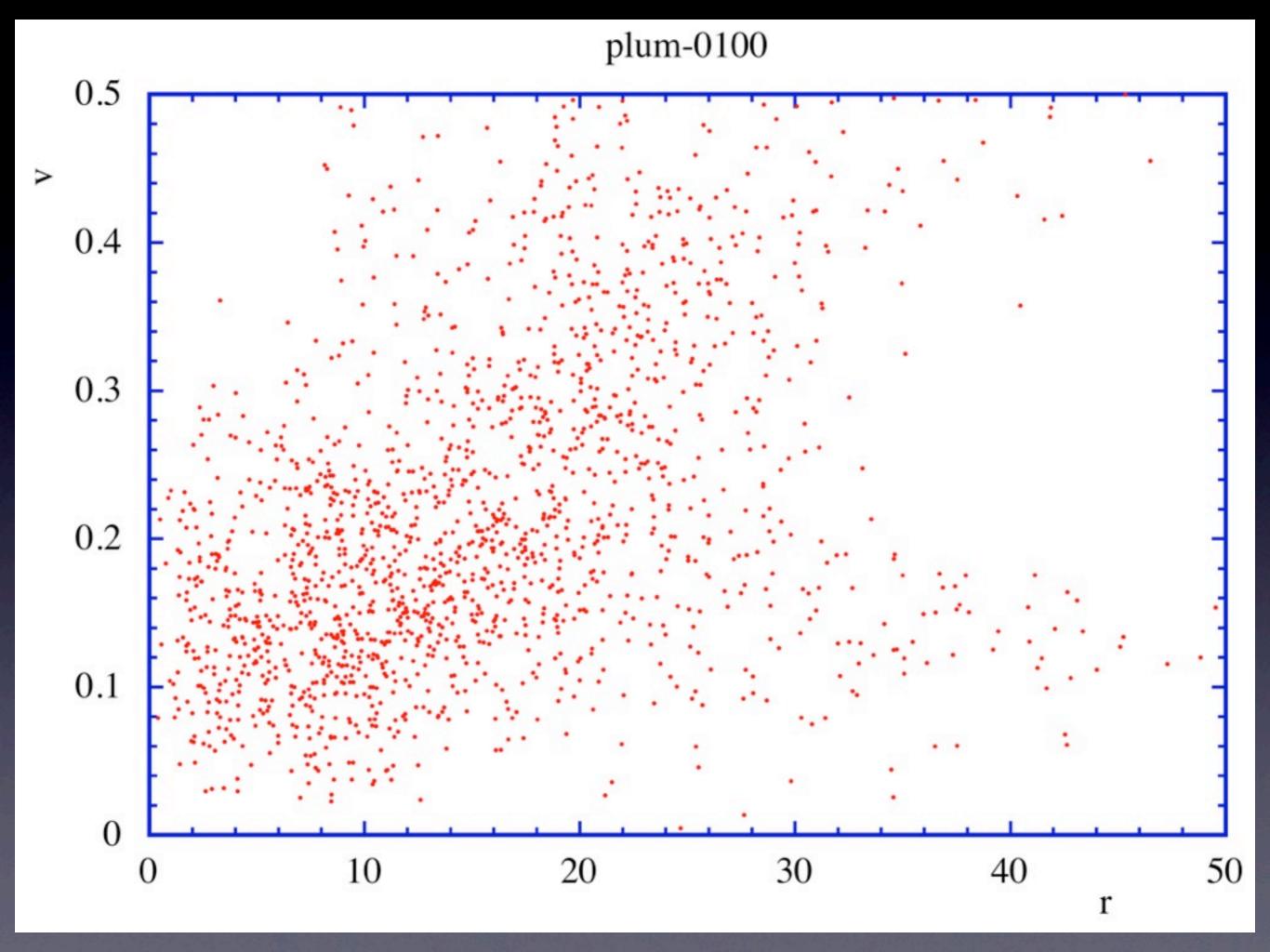


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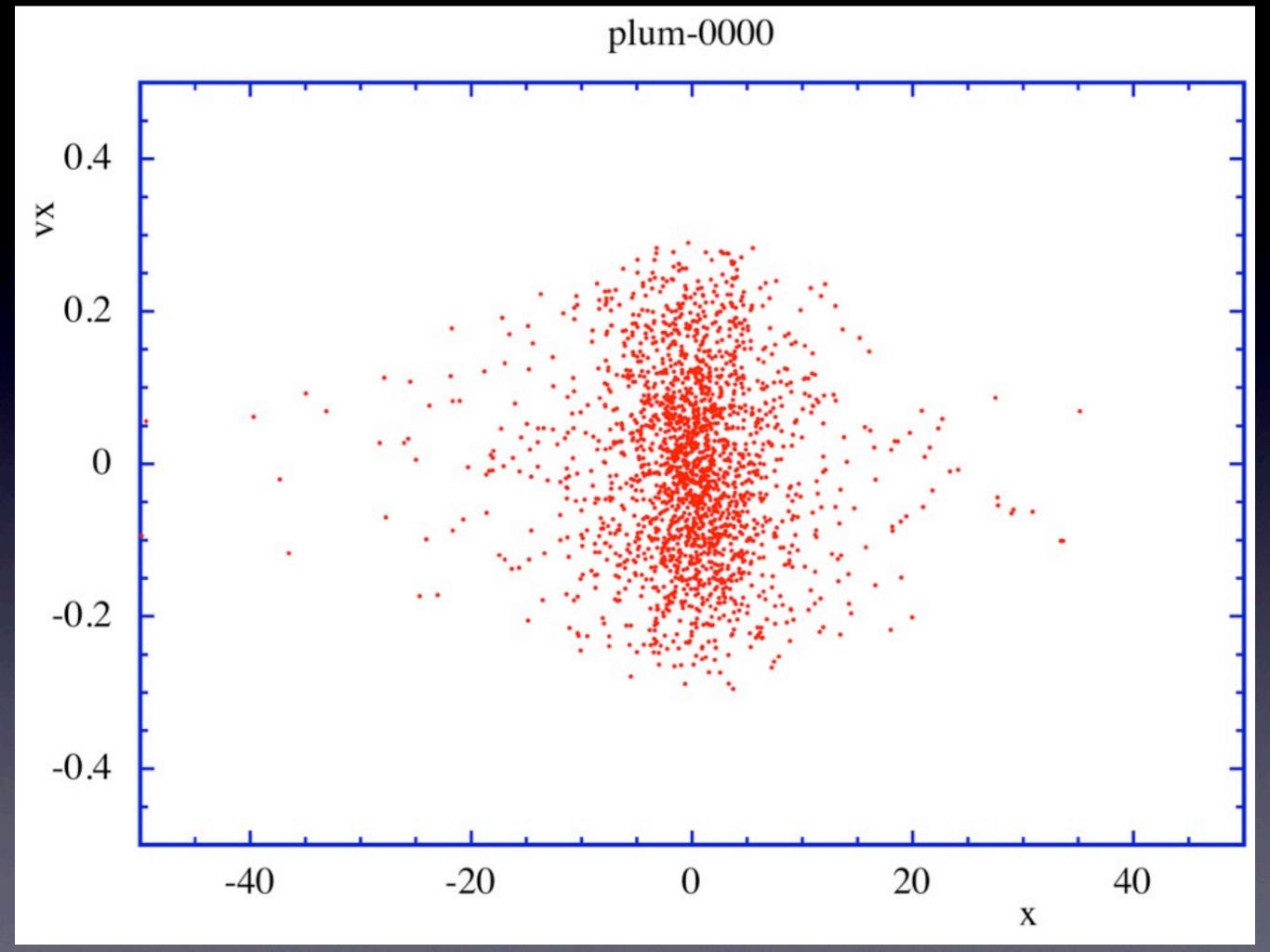




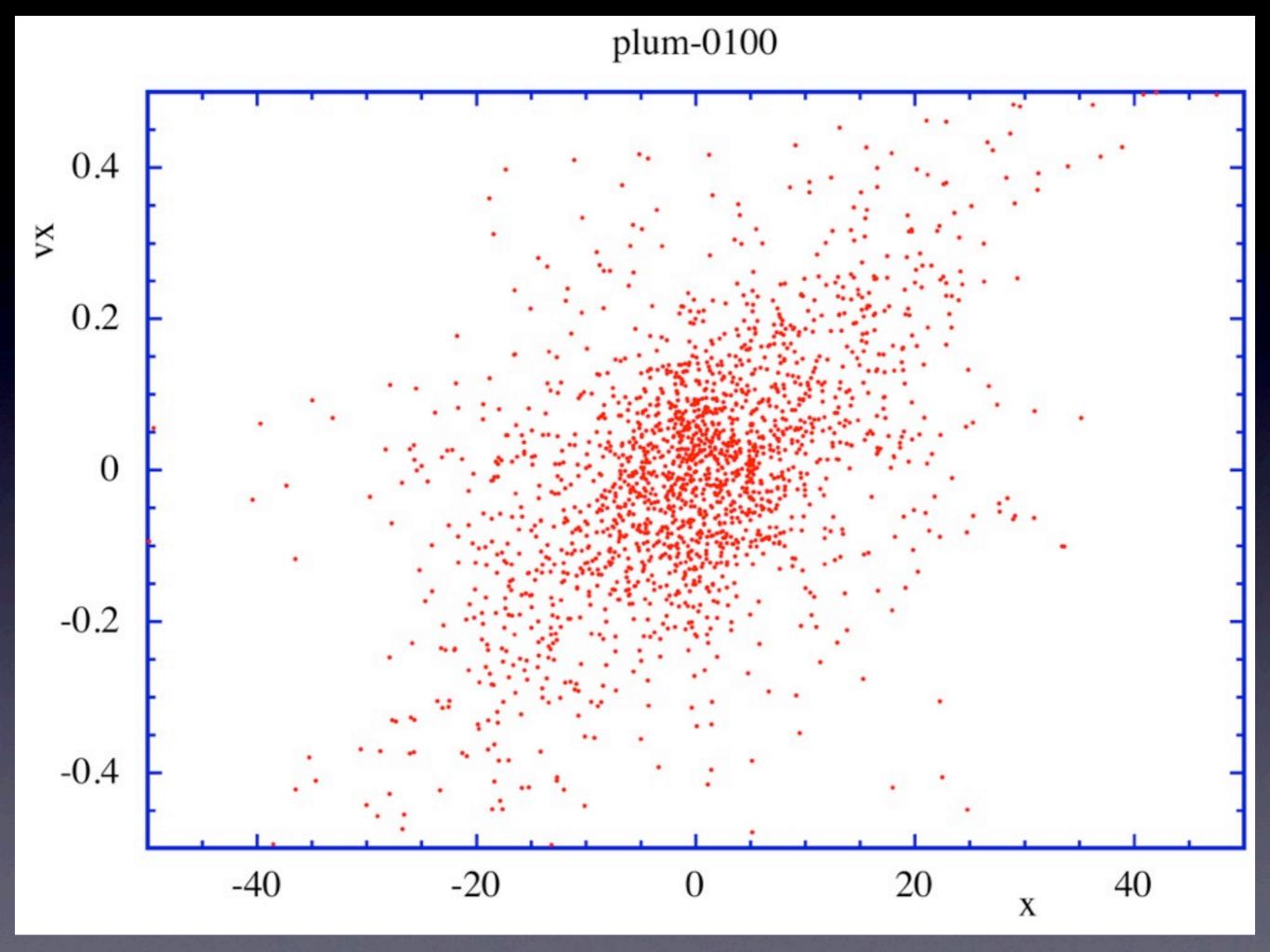


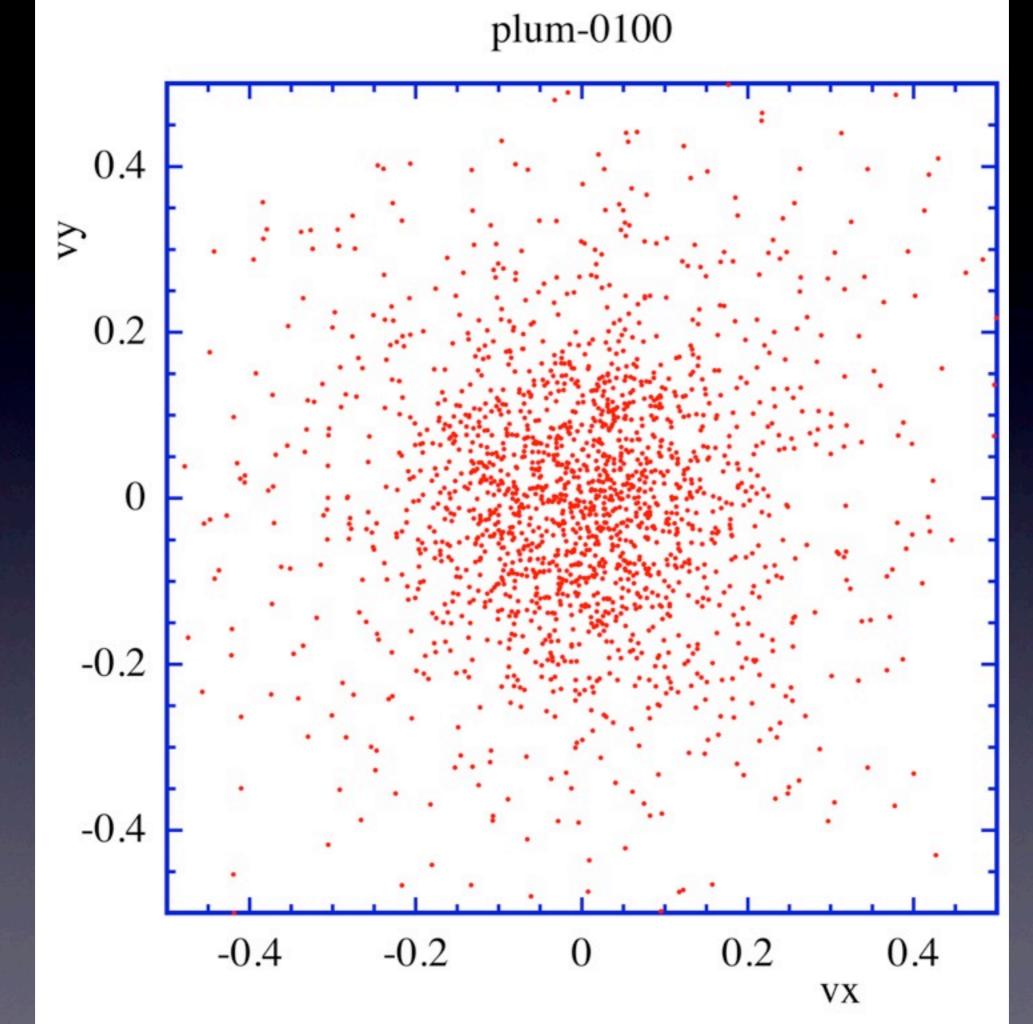


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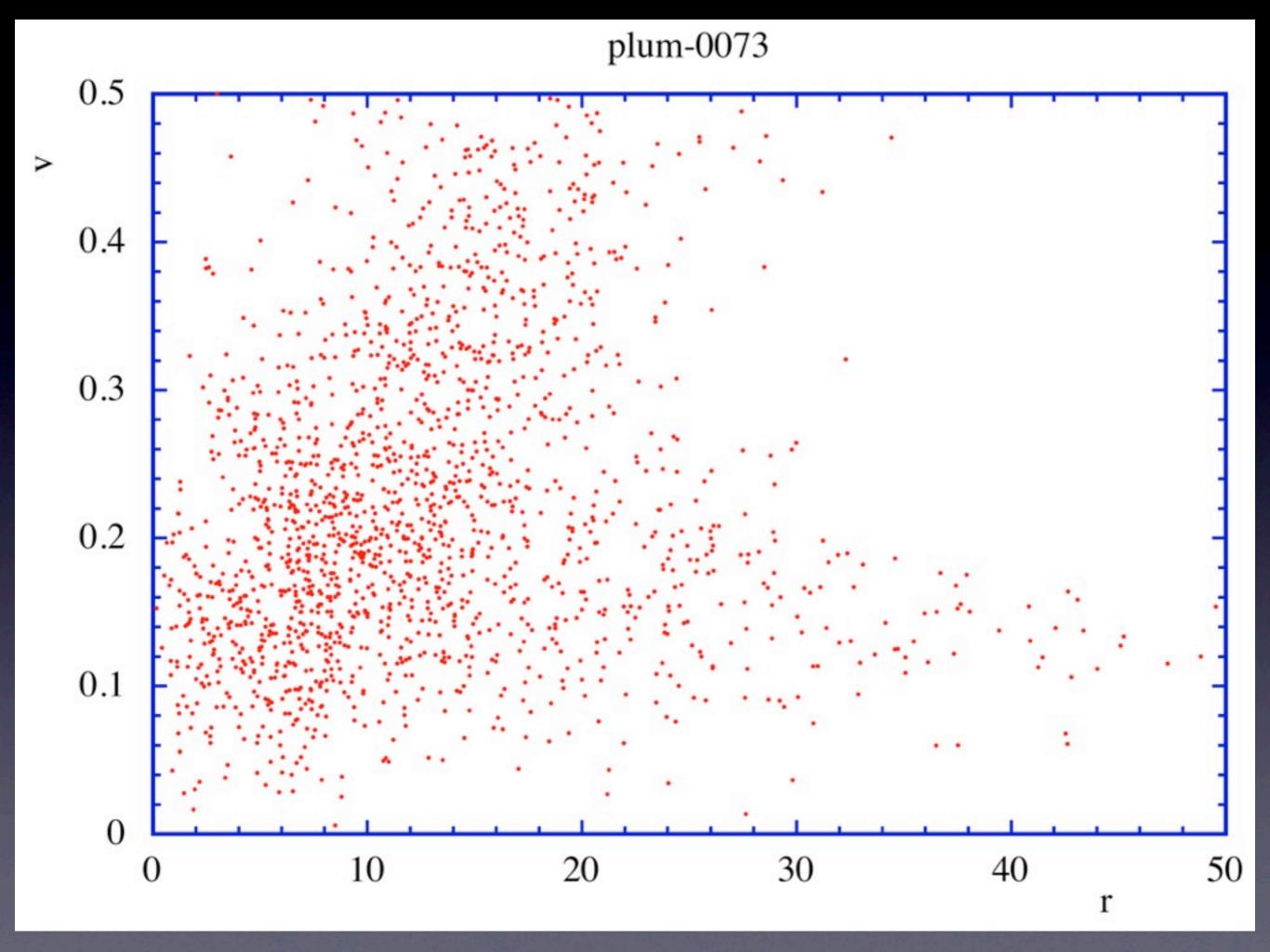
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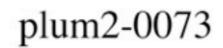
2000 stars at t = 0

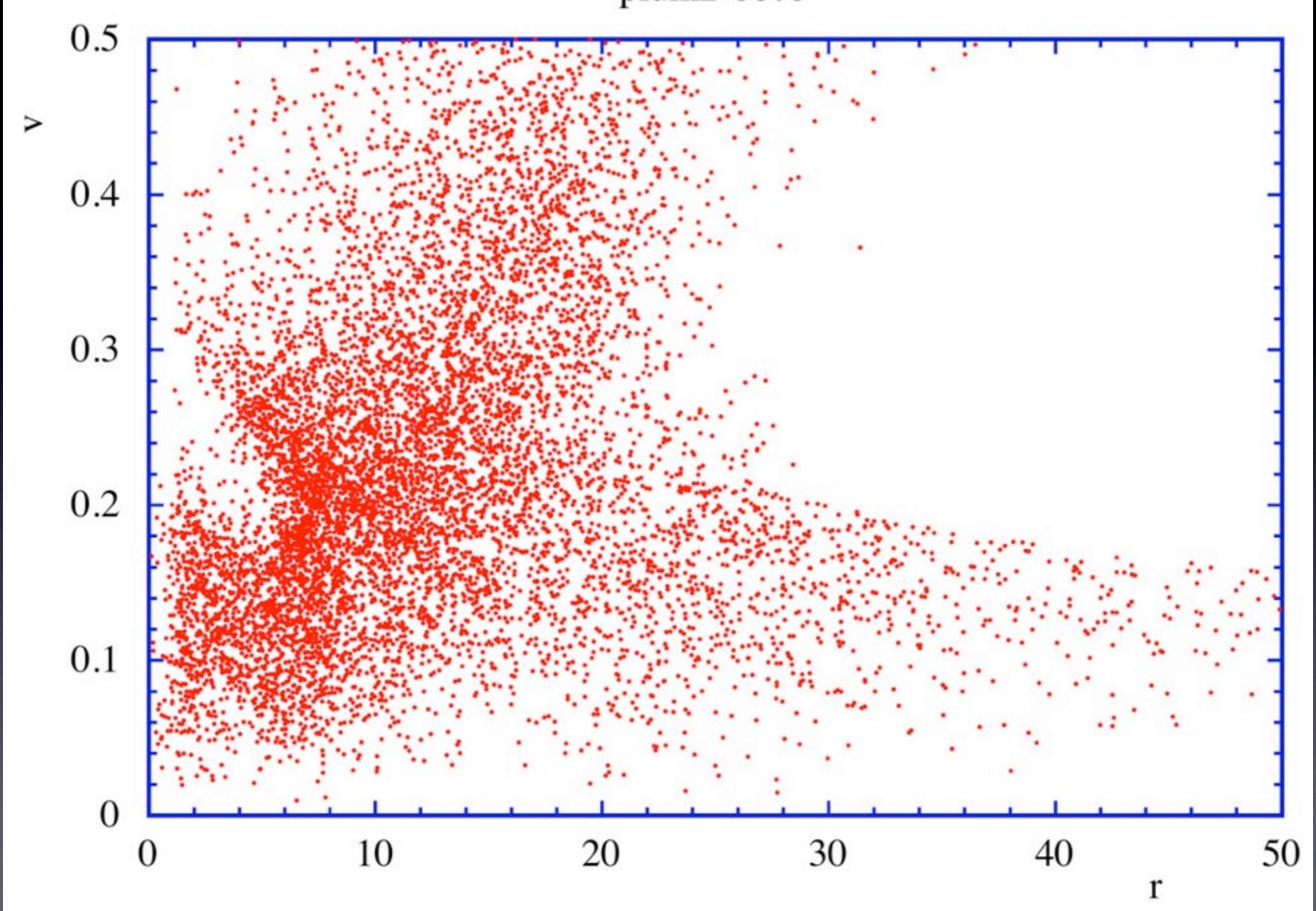
100000 stars at t = 0

2000 stars at t = 71.9

10000 stars at t = 71.9







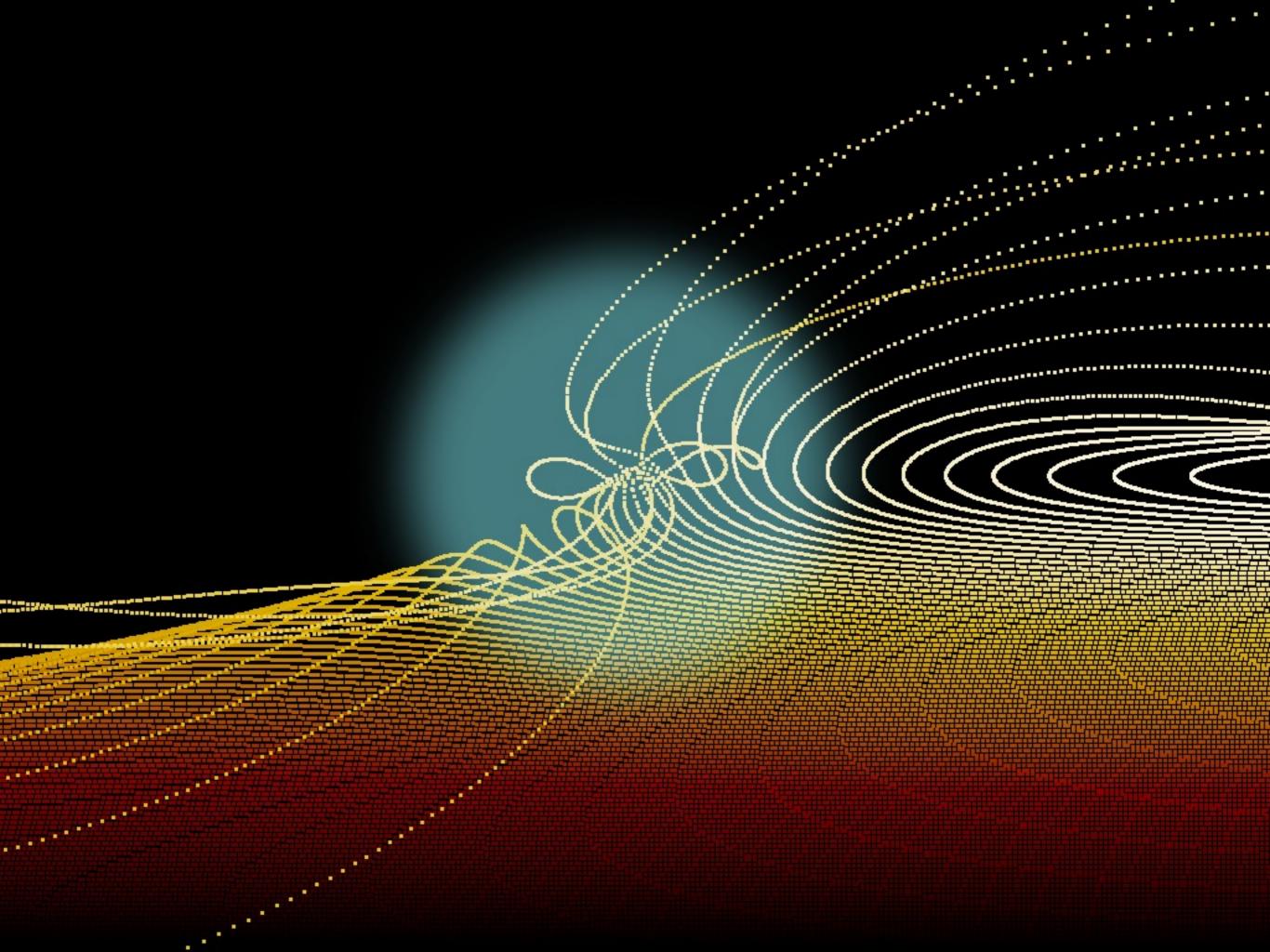
Epicycles

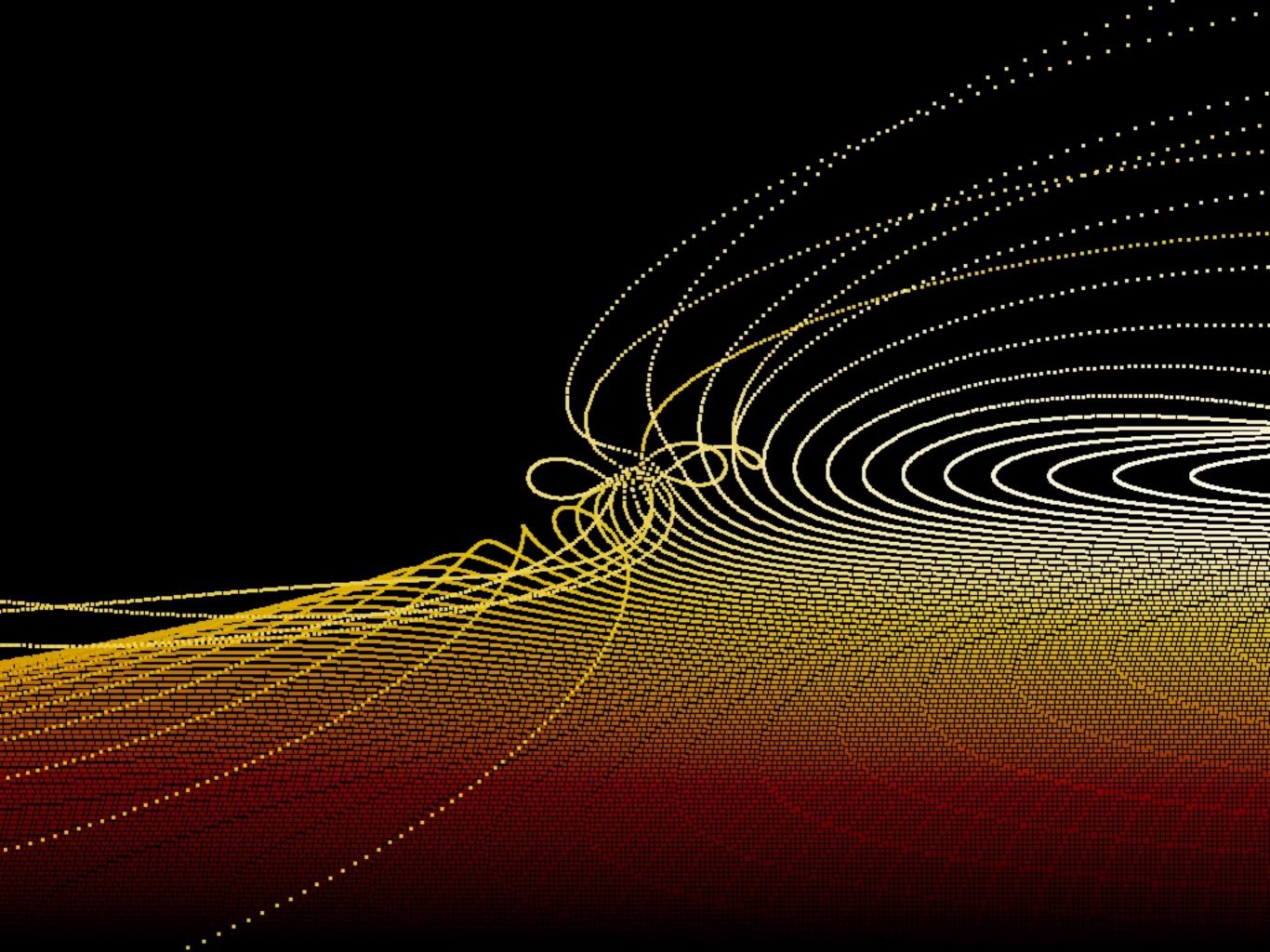
B

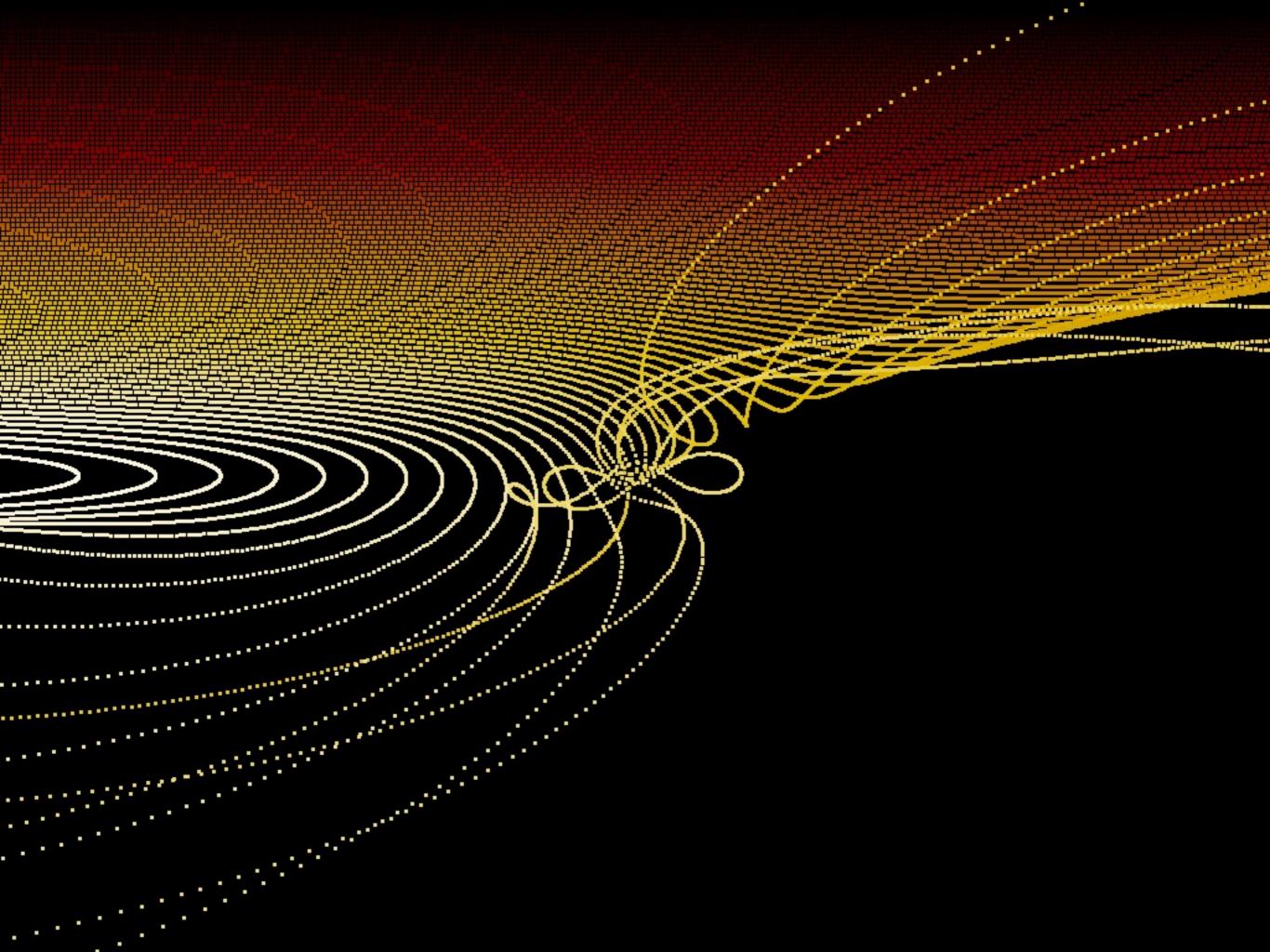
Approximation of dynamics in rotating coordinates

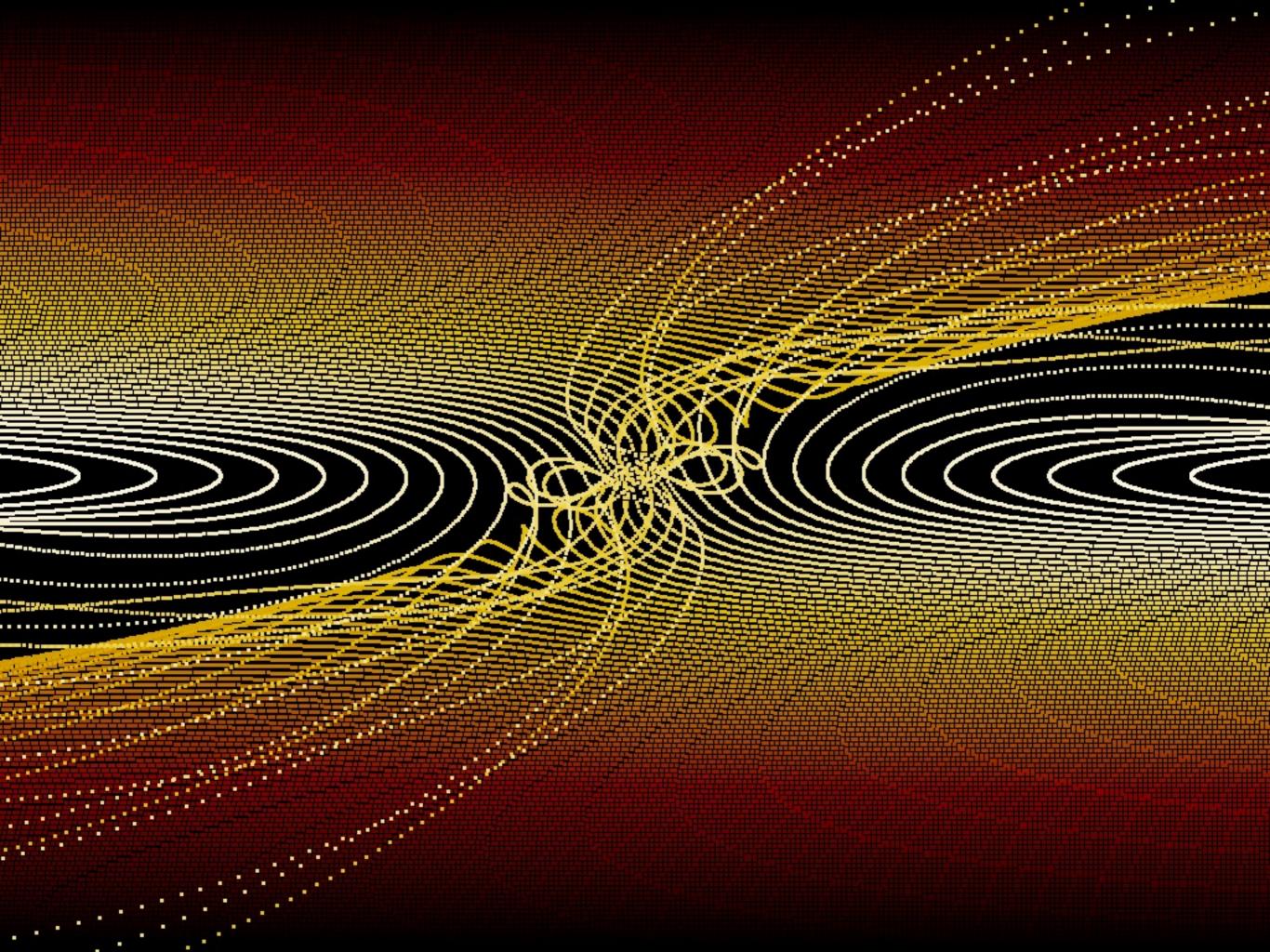
A chunk in a ring

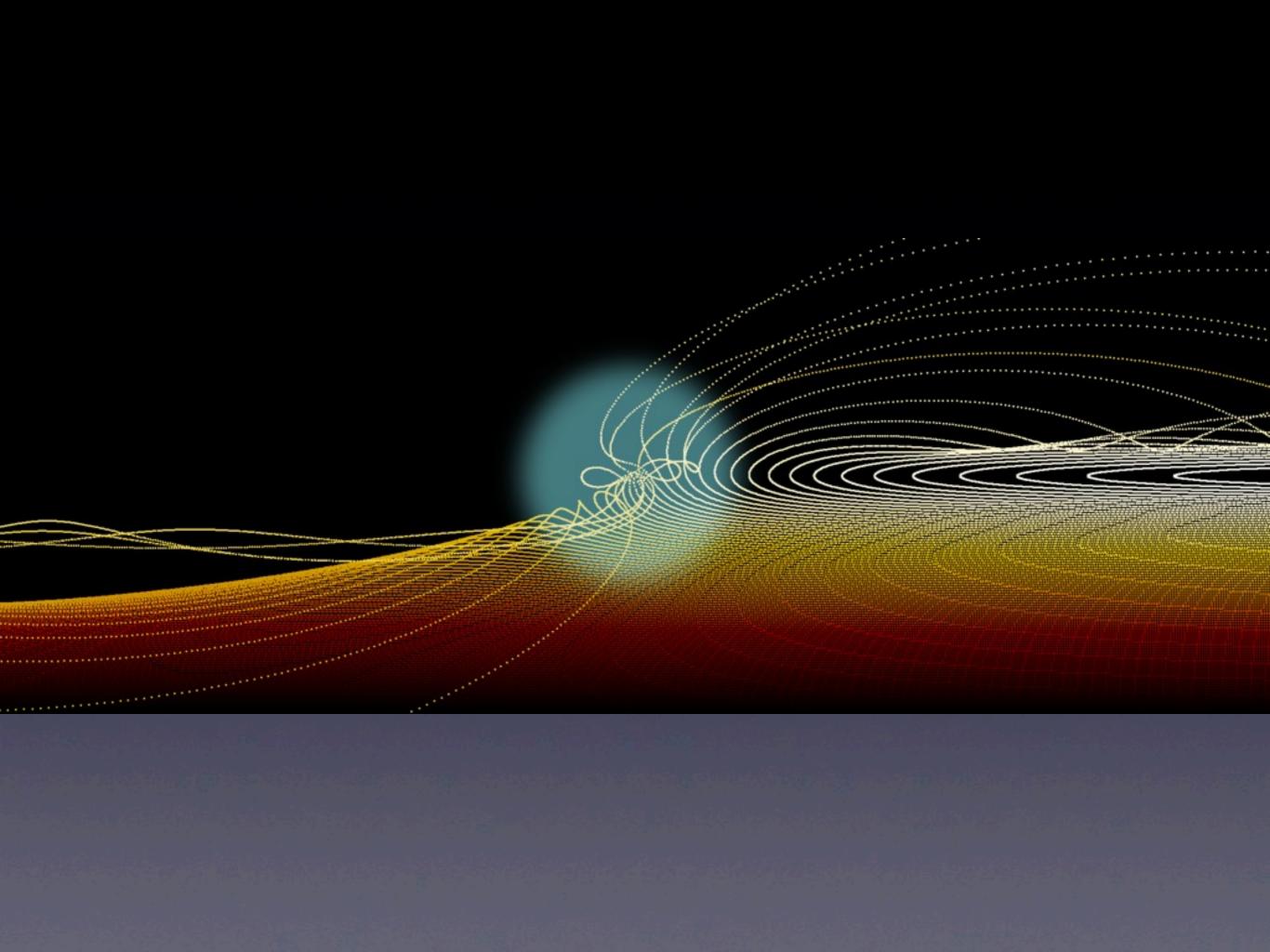
- Close-up example of N-body dynamics
- Corotating coordinates
- Epicycle approximation
- Corotating gravity acts as repulsion
- Saturn's rings
- Planet formation

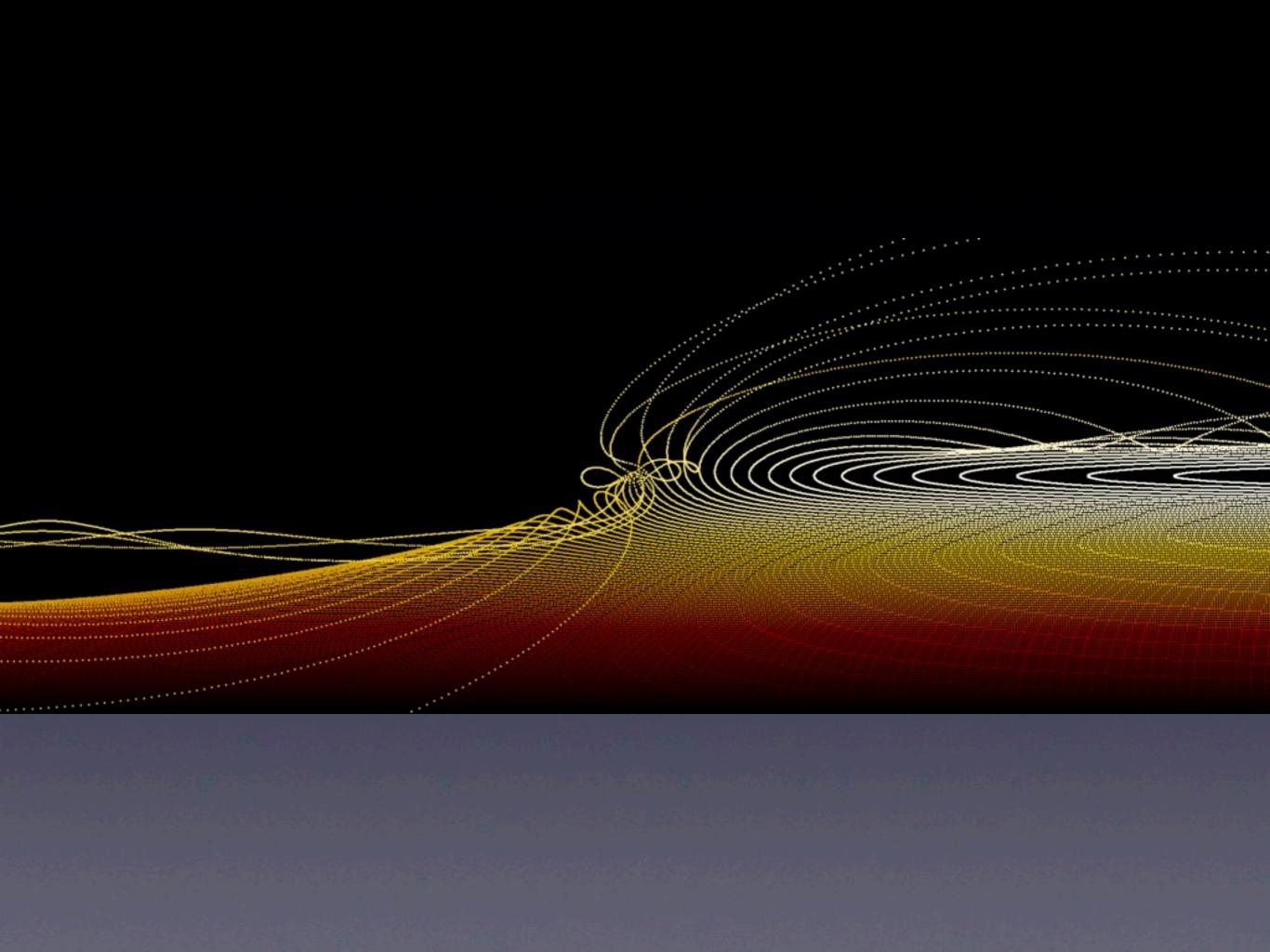


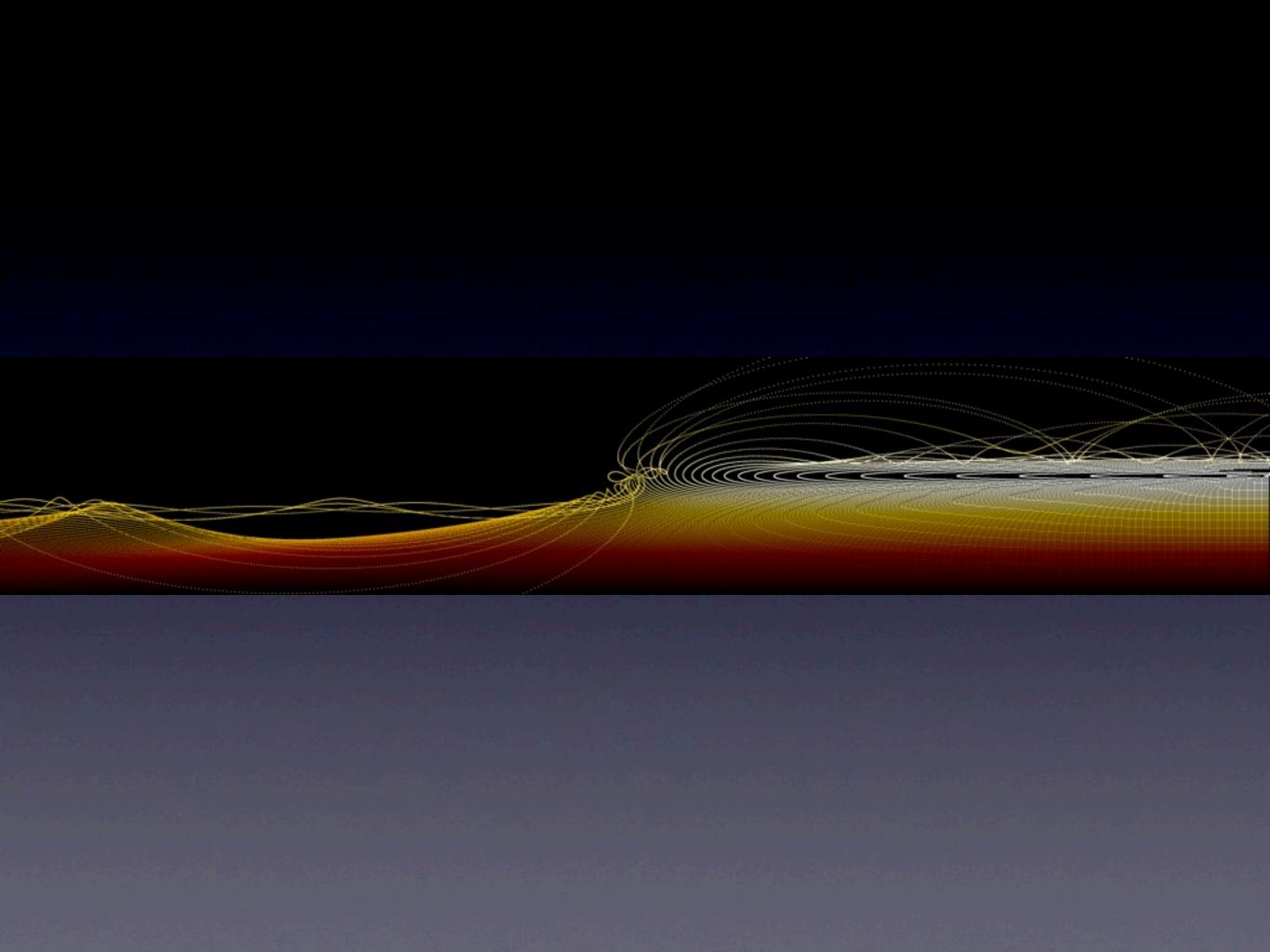


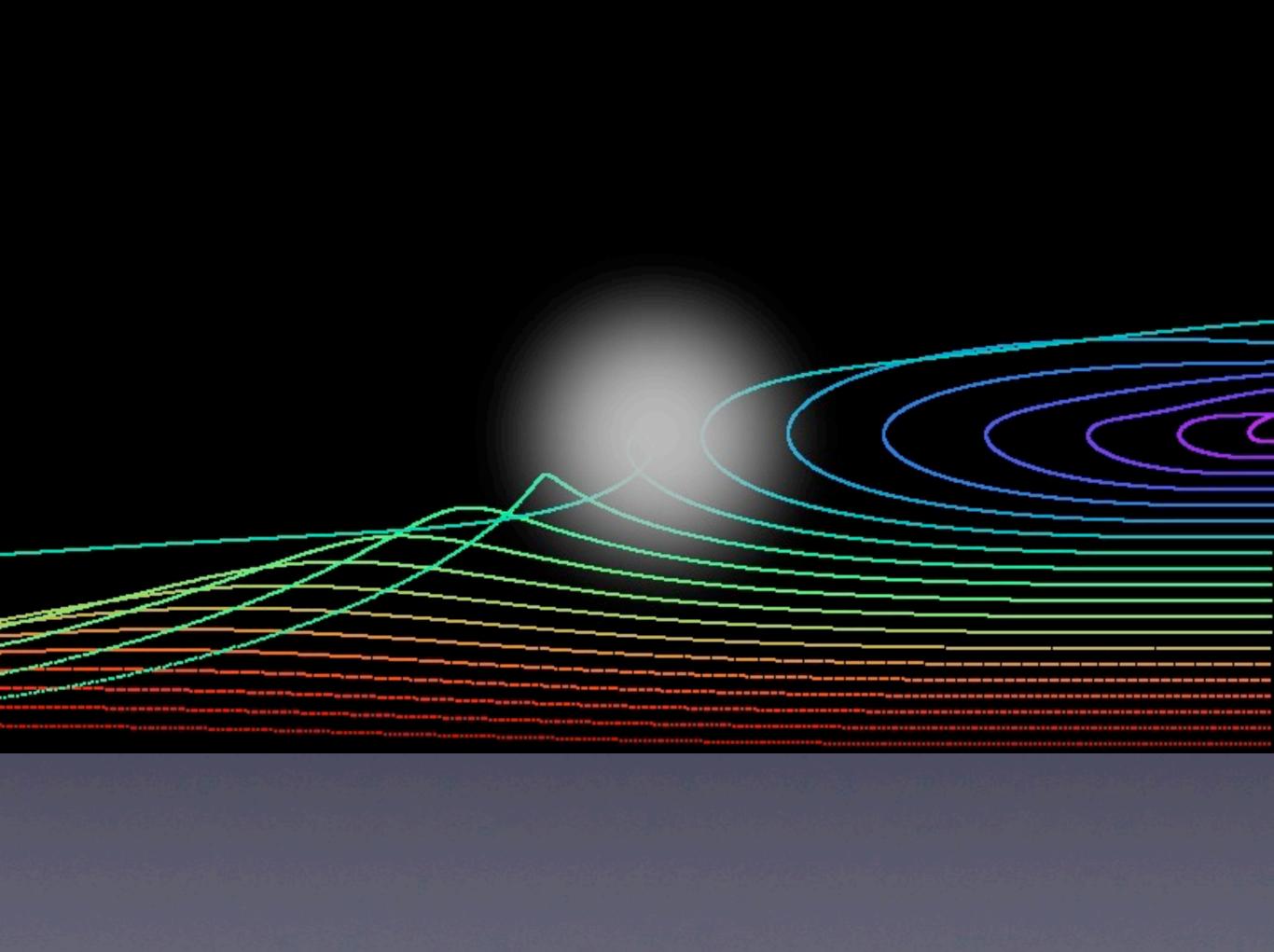


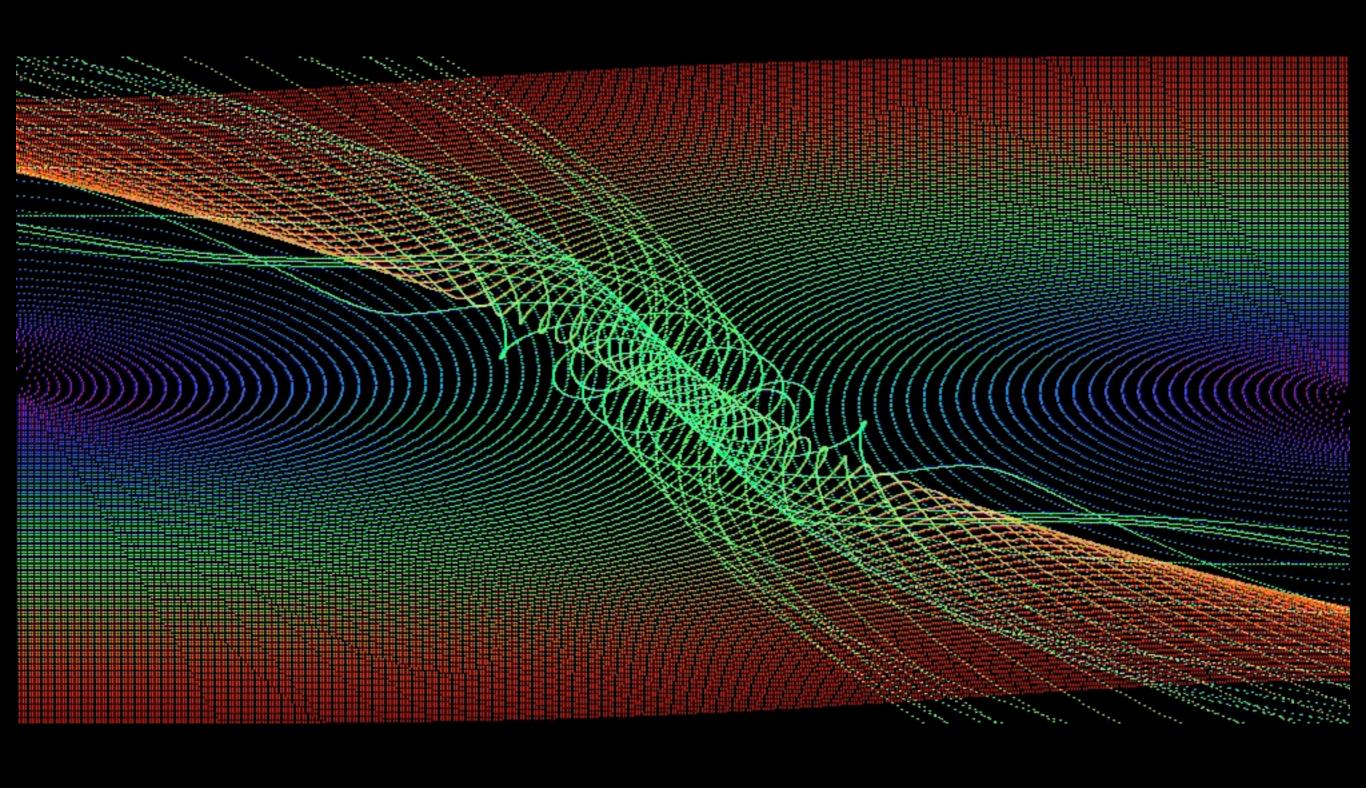


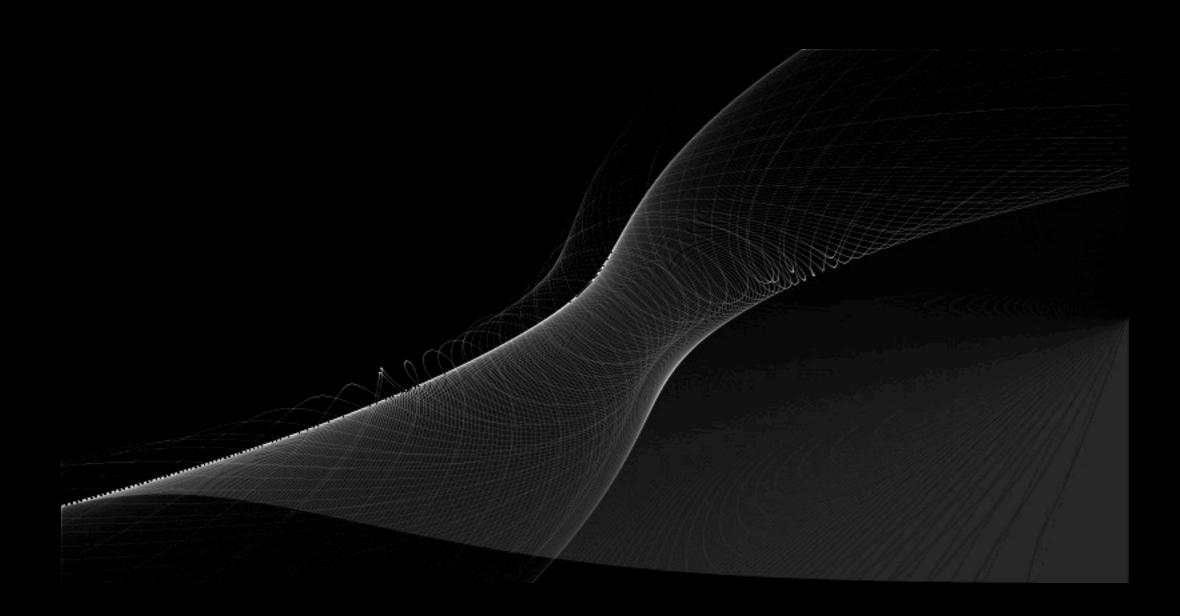




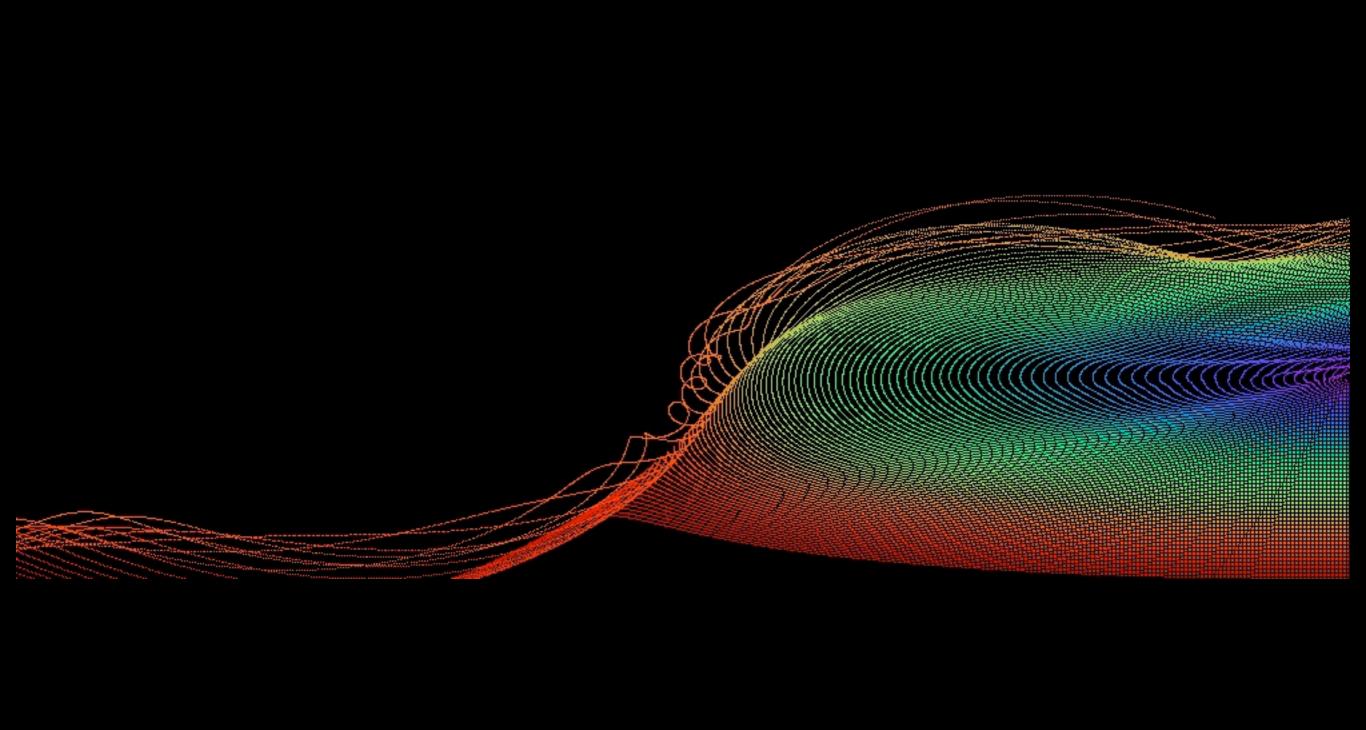


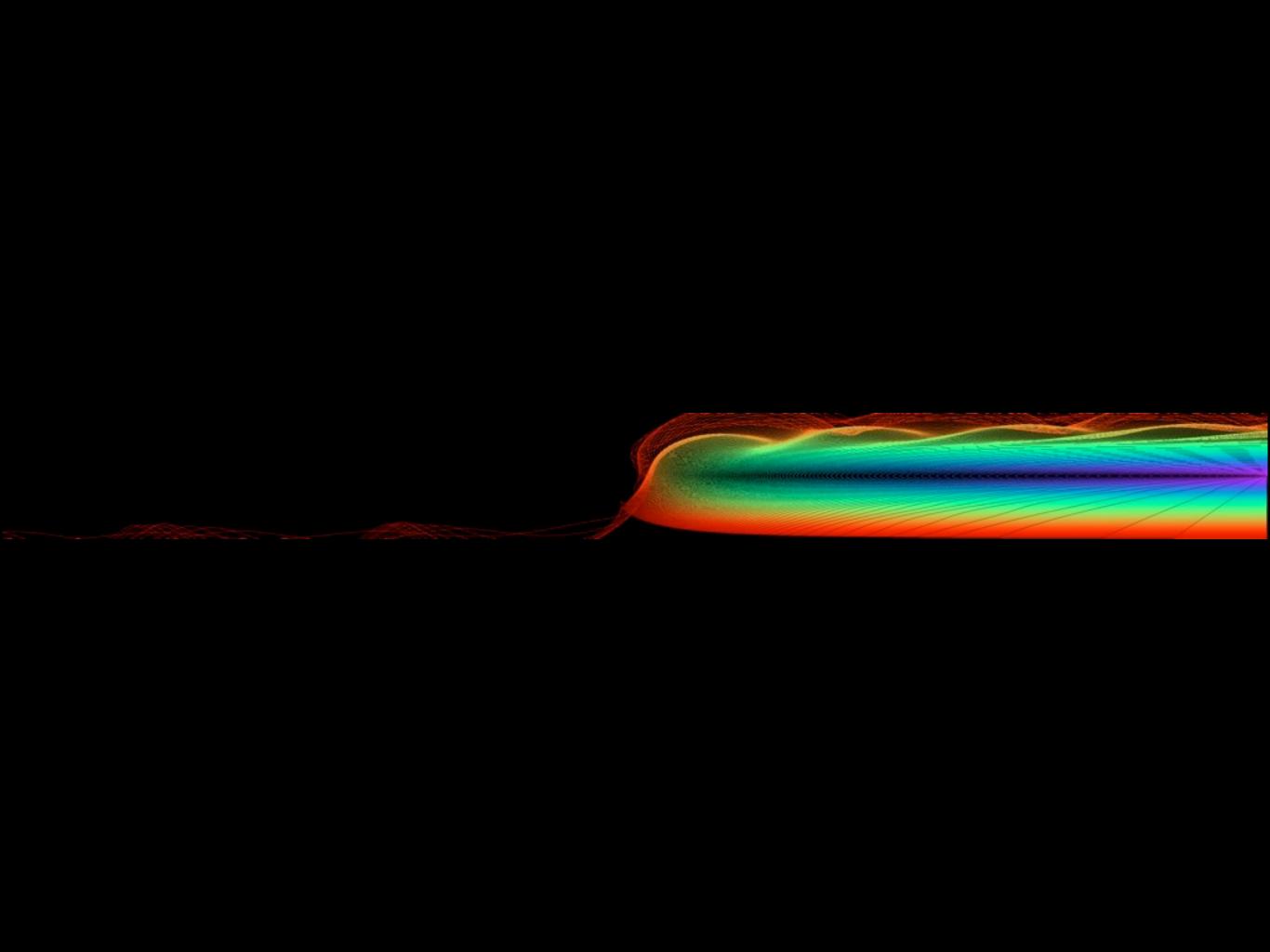


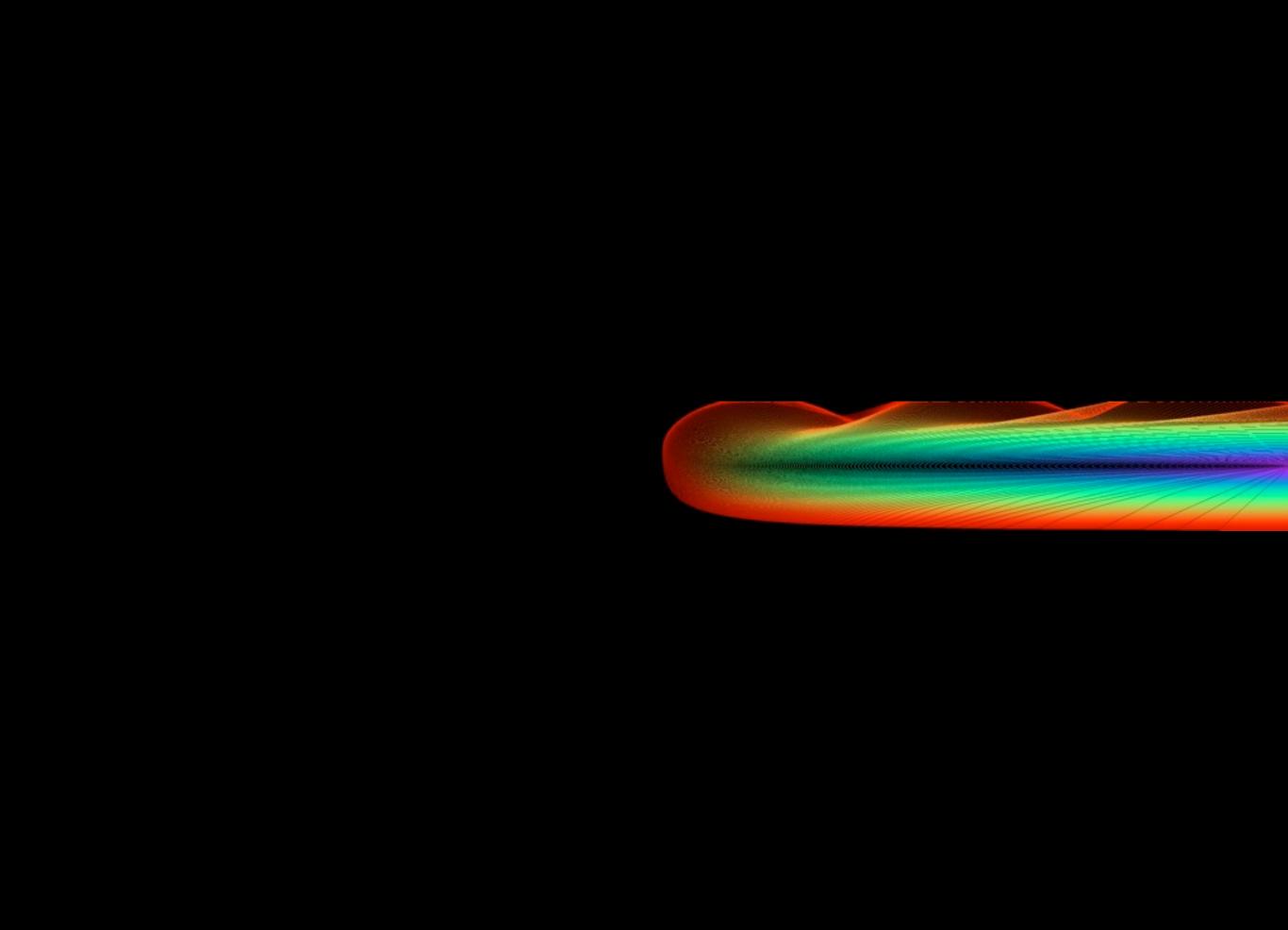


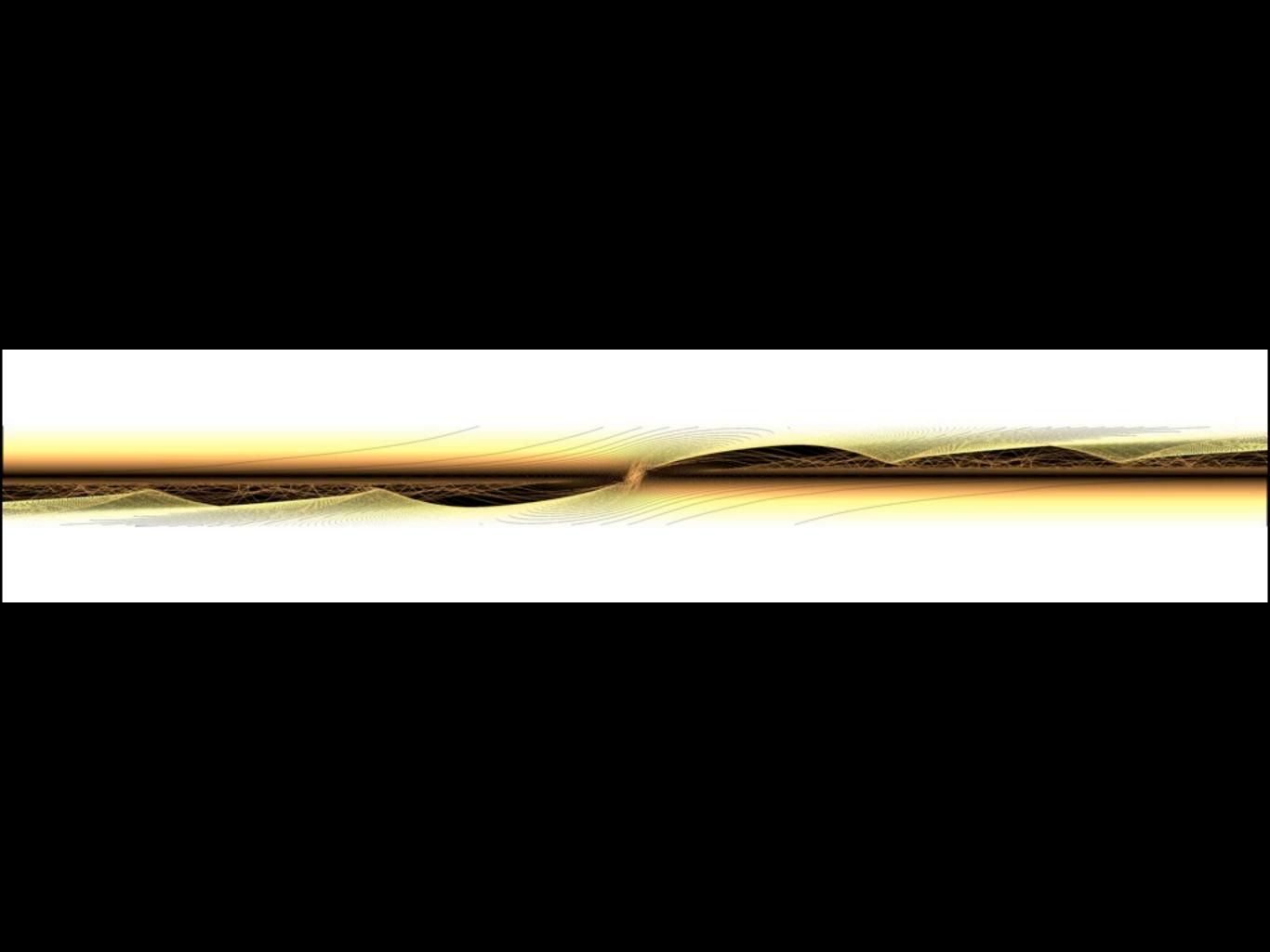


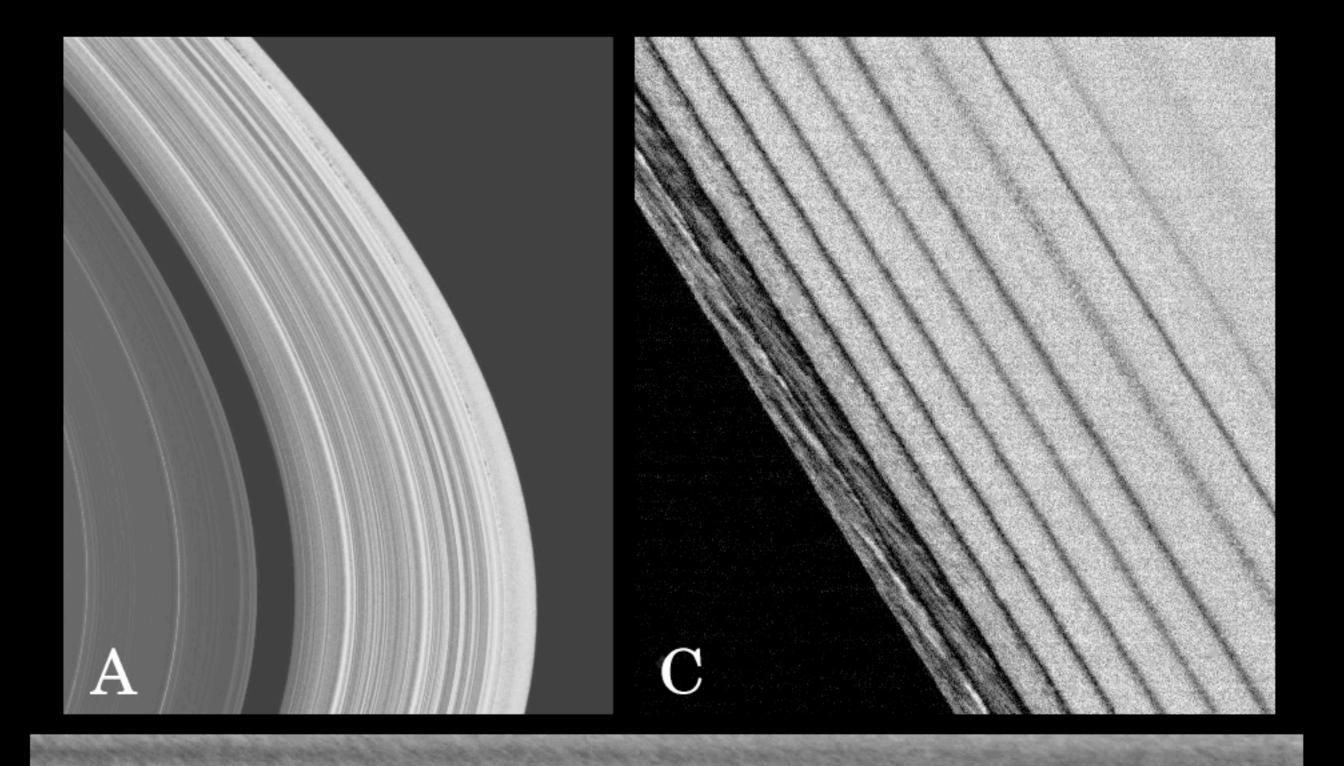
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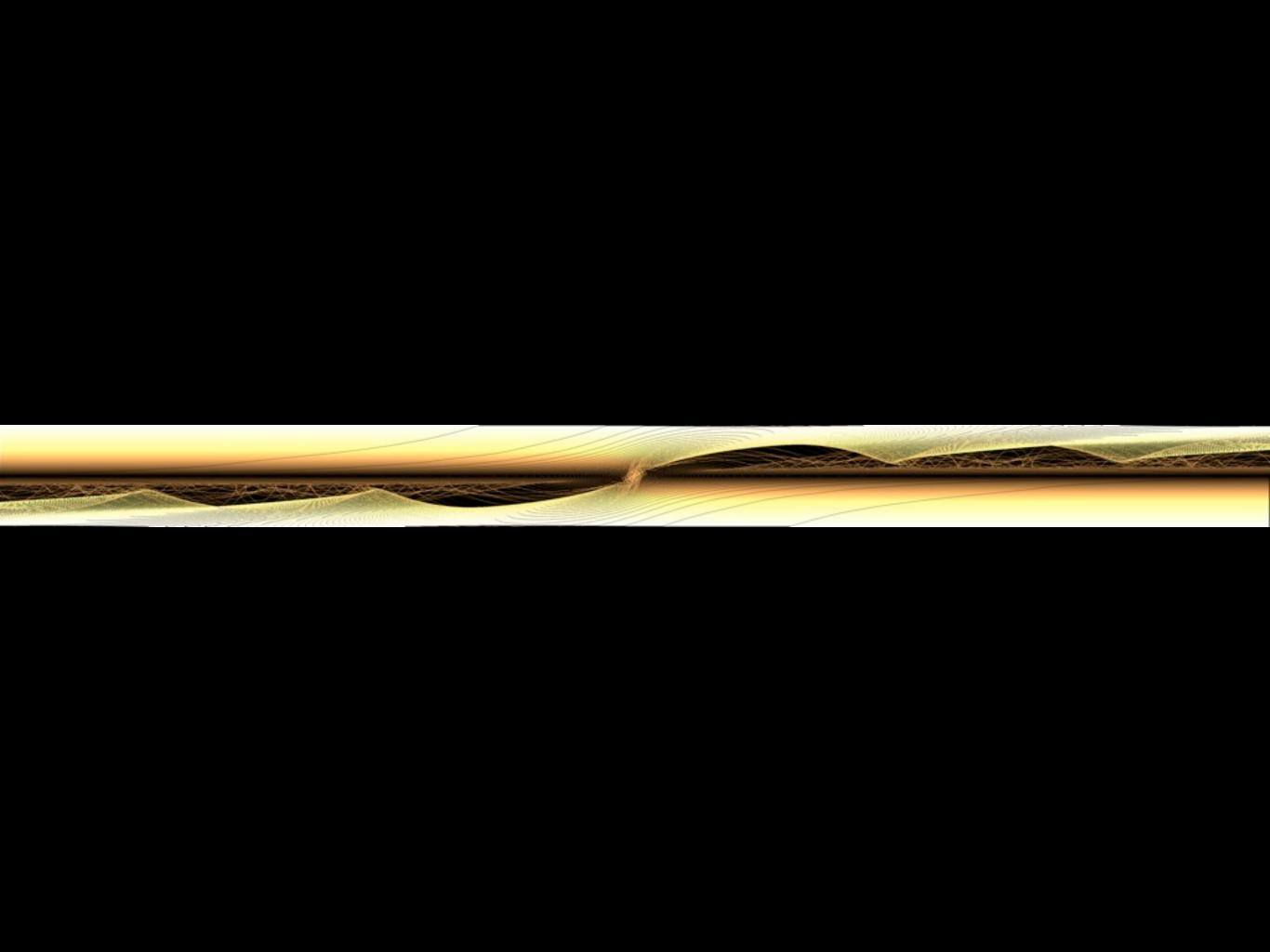




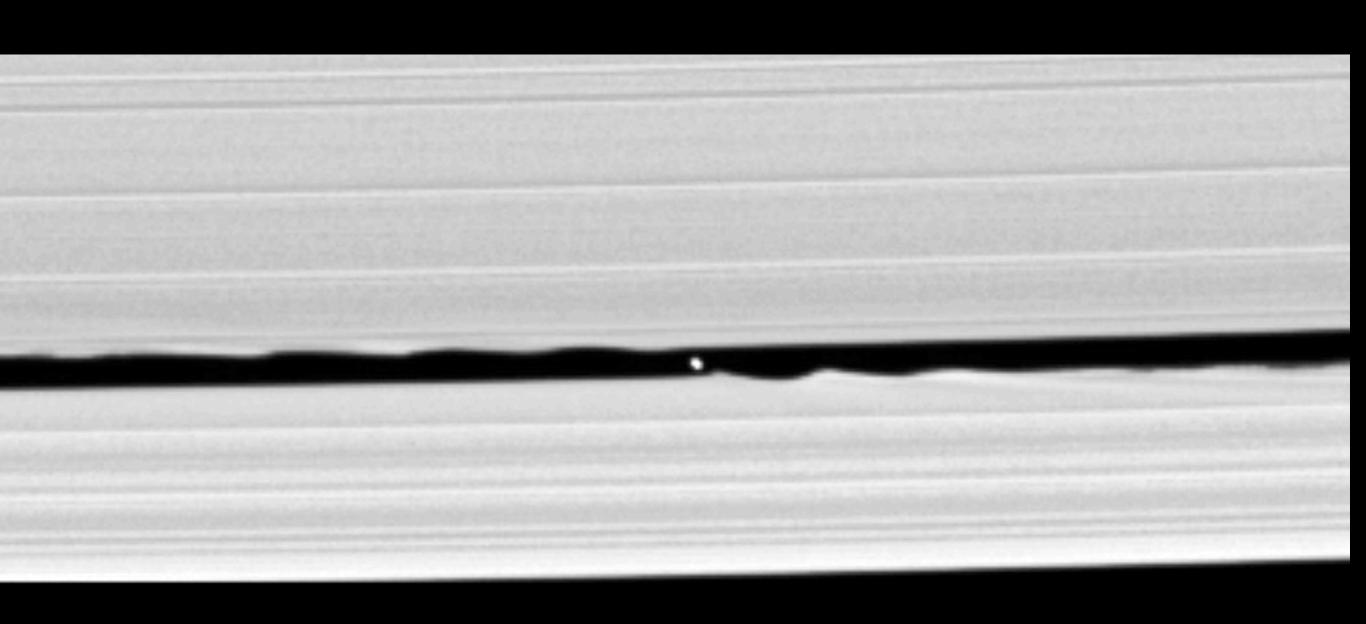


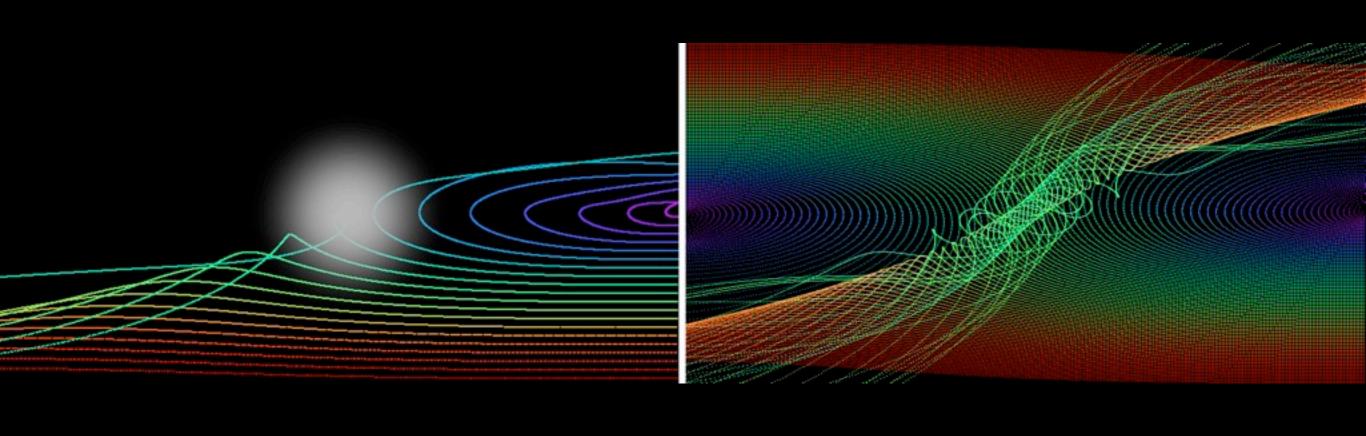




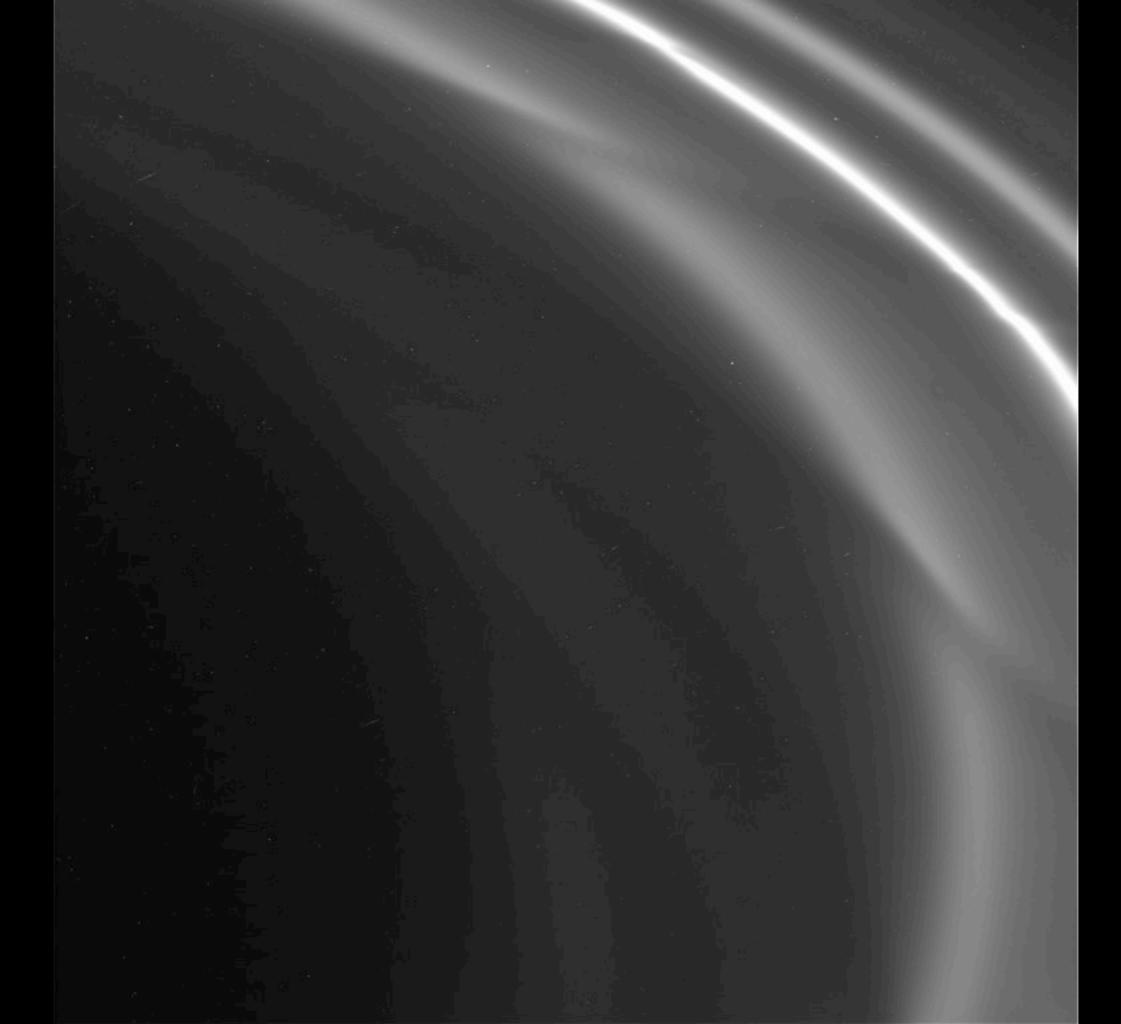


Daphnis

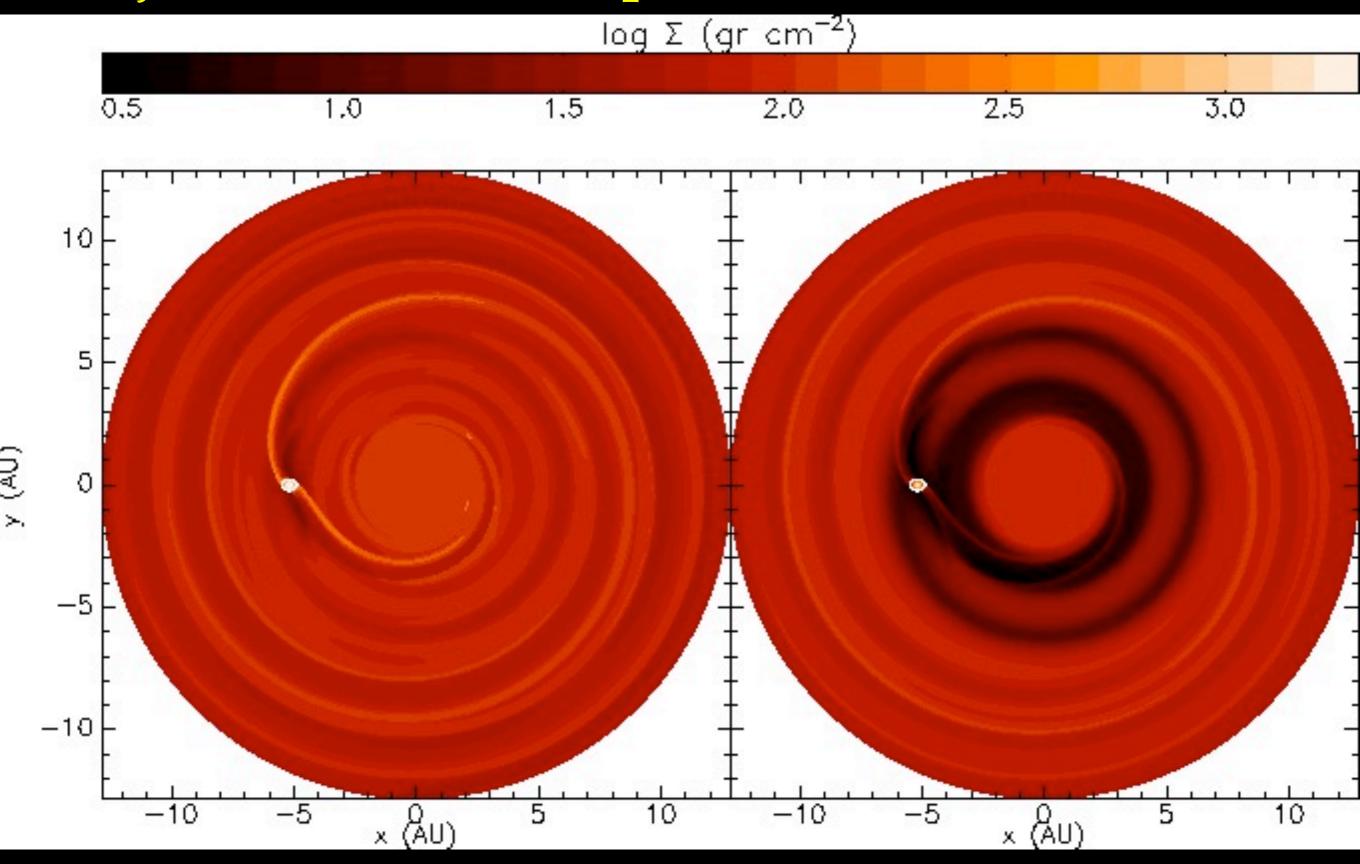


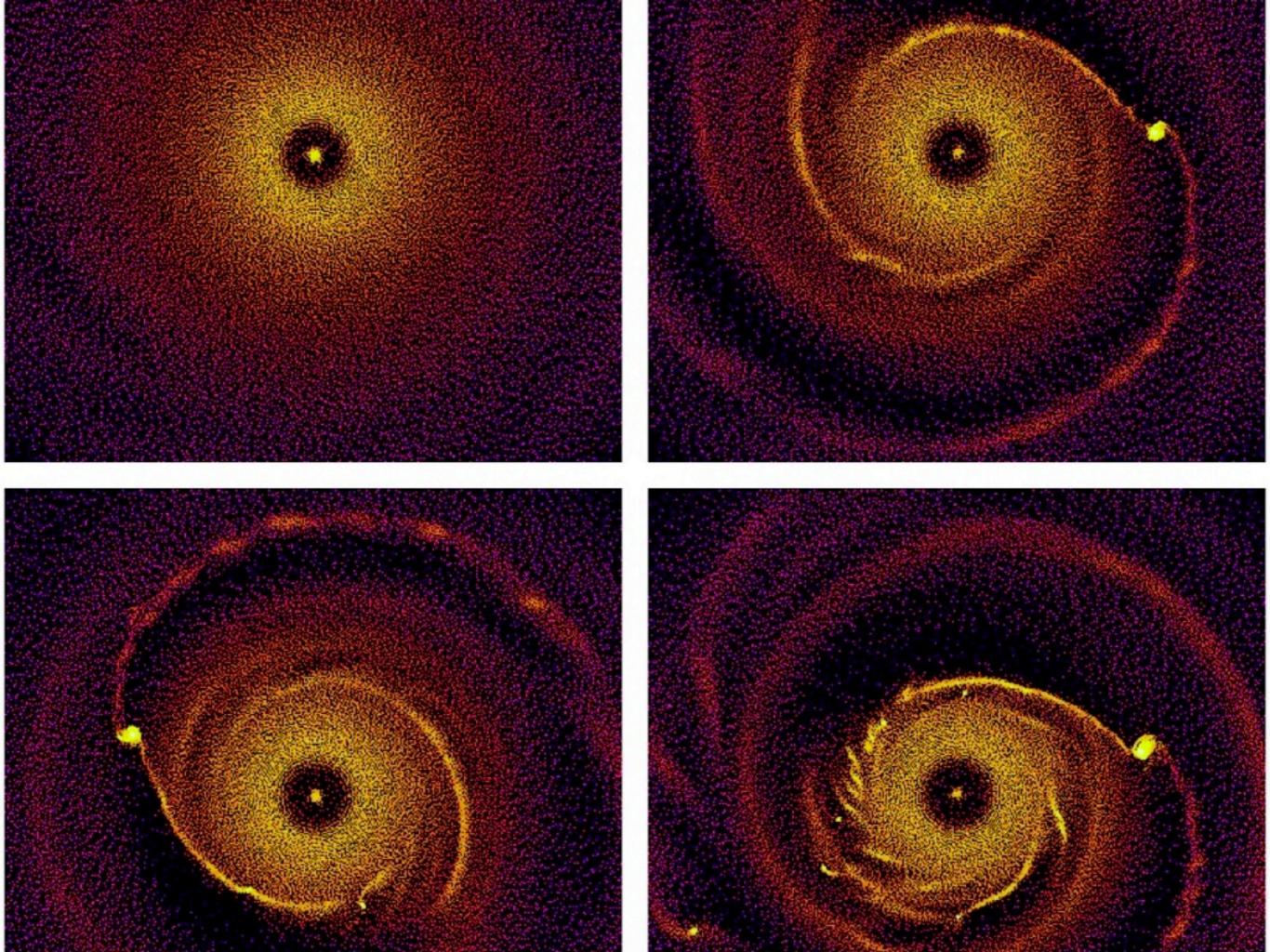






Sijme-Jan Paardekooper





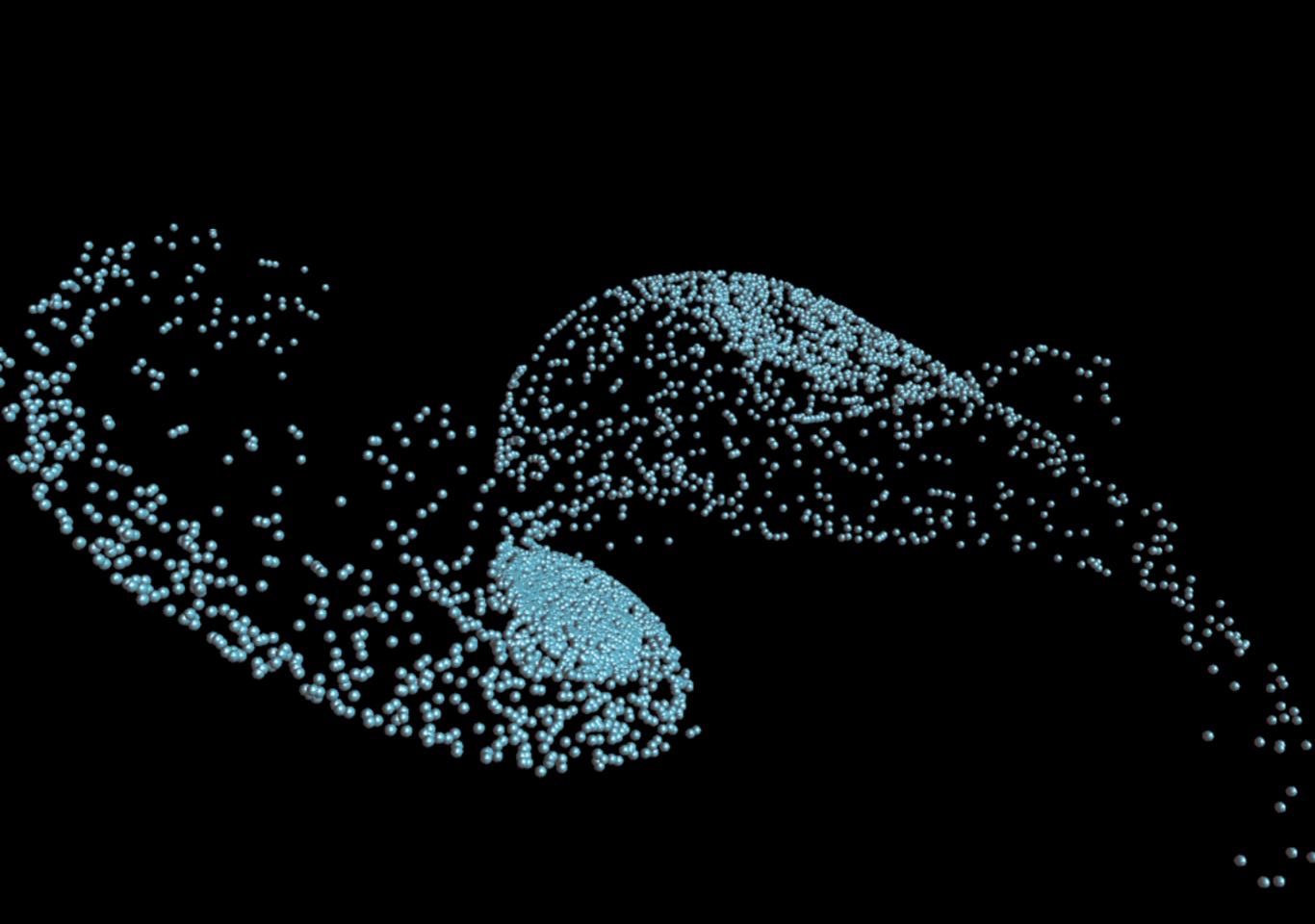
Toomre & Toomre

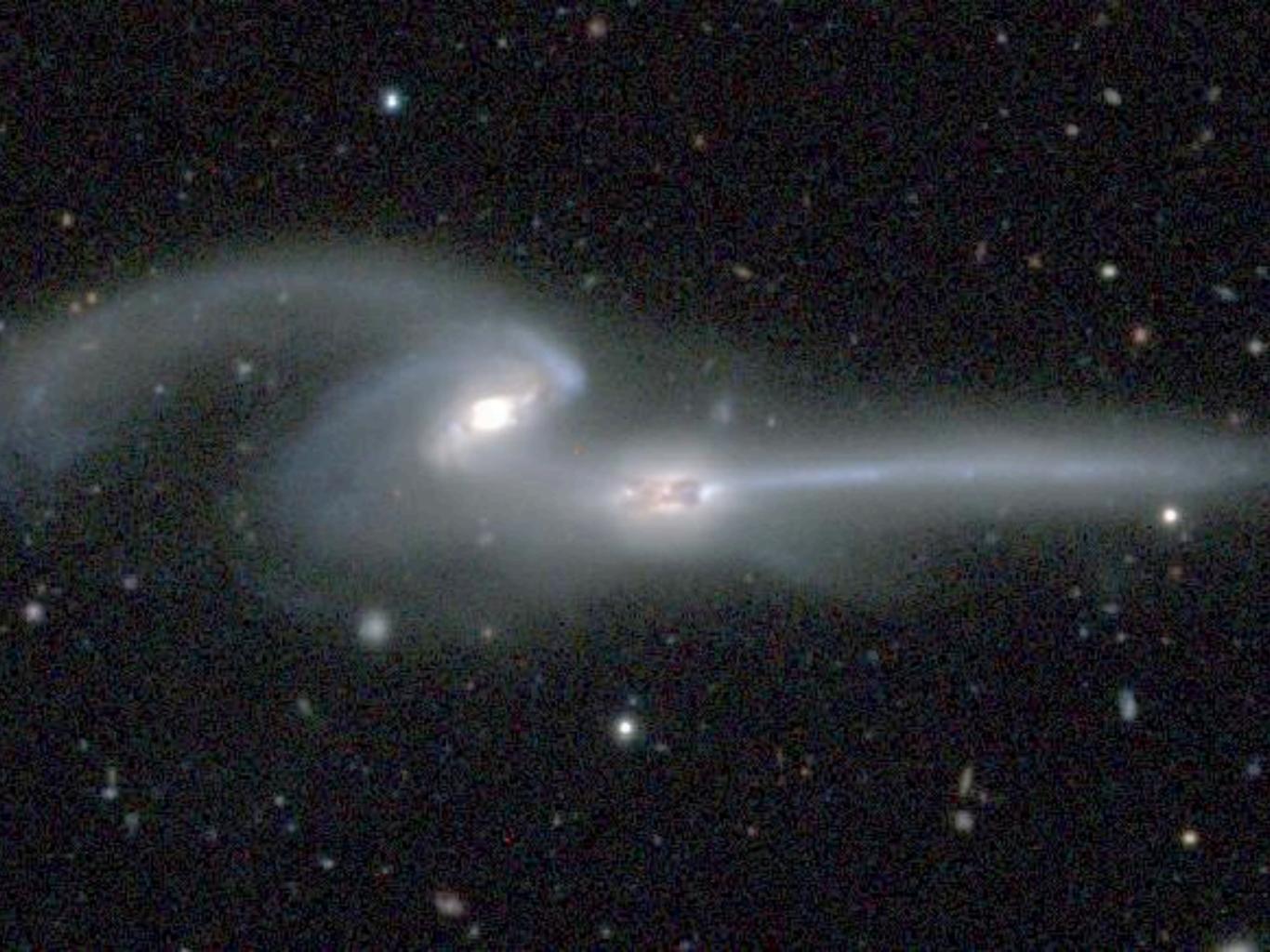
Approximation of halo-dominated galaxies

Toomre Movie

- Demo of colliding galaxies
- Specify intial t, x, v
- Specify acceleration g
- Compute change of v
- Compute change of x
- Add to previous position to find orbit

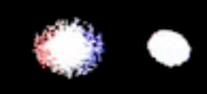






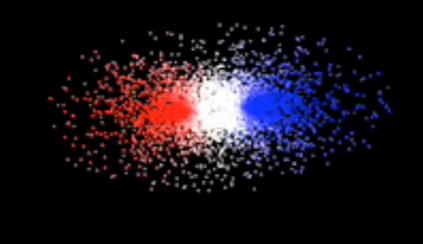












Phase Space

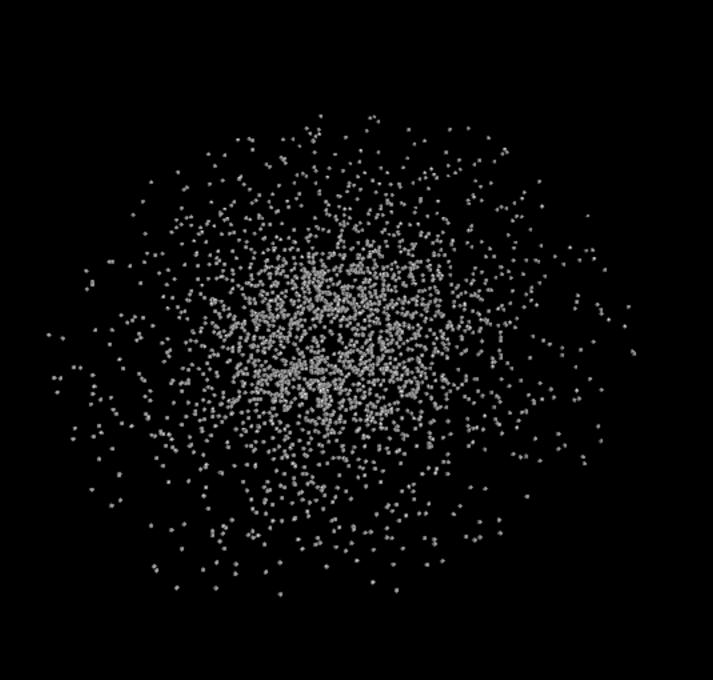
A view of six-dimensional dynamics

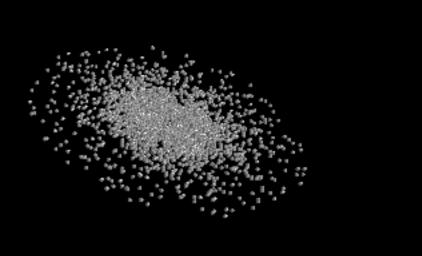
Phase Space

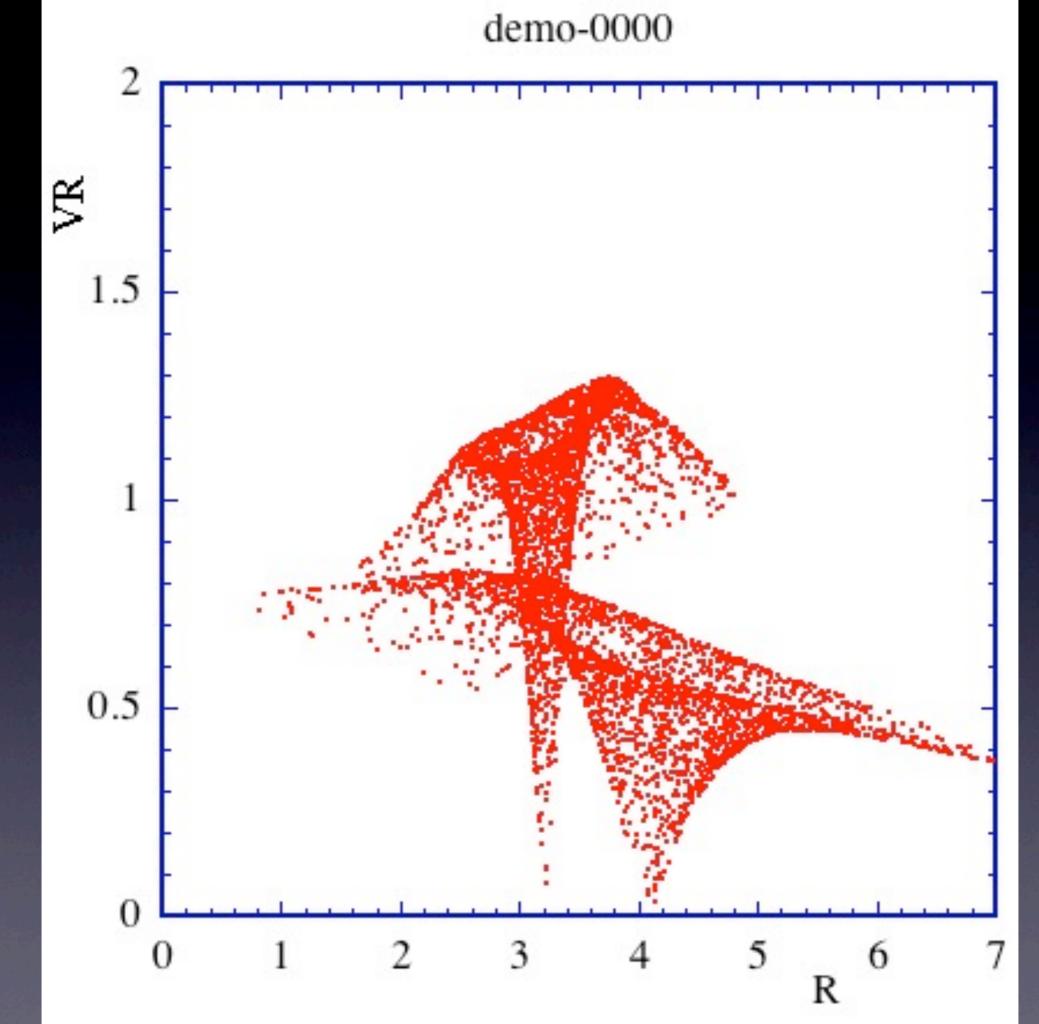
- t, x, v are not observable
- must be given as initial conditions
- evolution due to acceleration
- {x, v} phase space
- trajectories in phase space

Colliding Galaxies

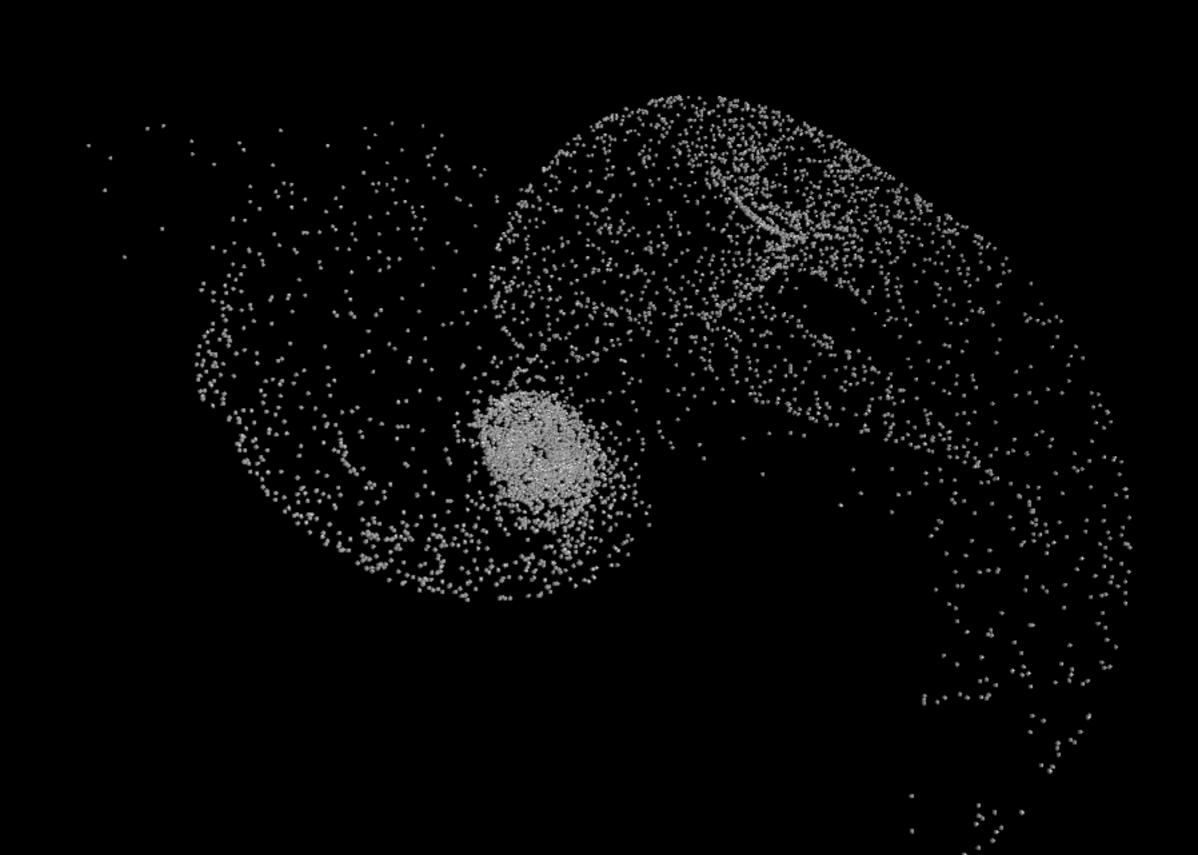
- From two individual rotation curves...
- ...to a complex merger product
- Long-lived subsystems stellar streams

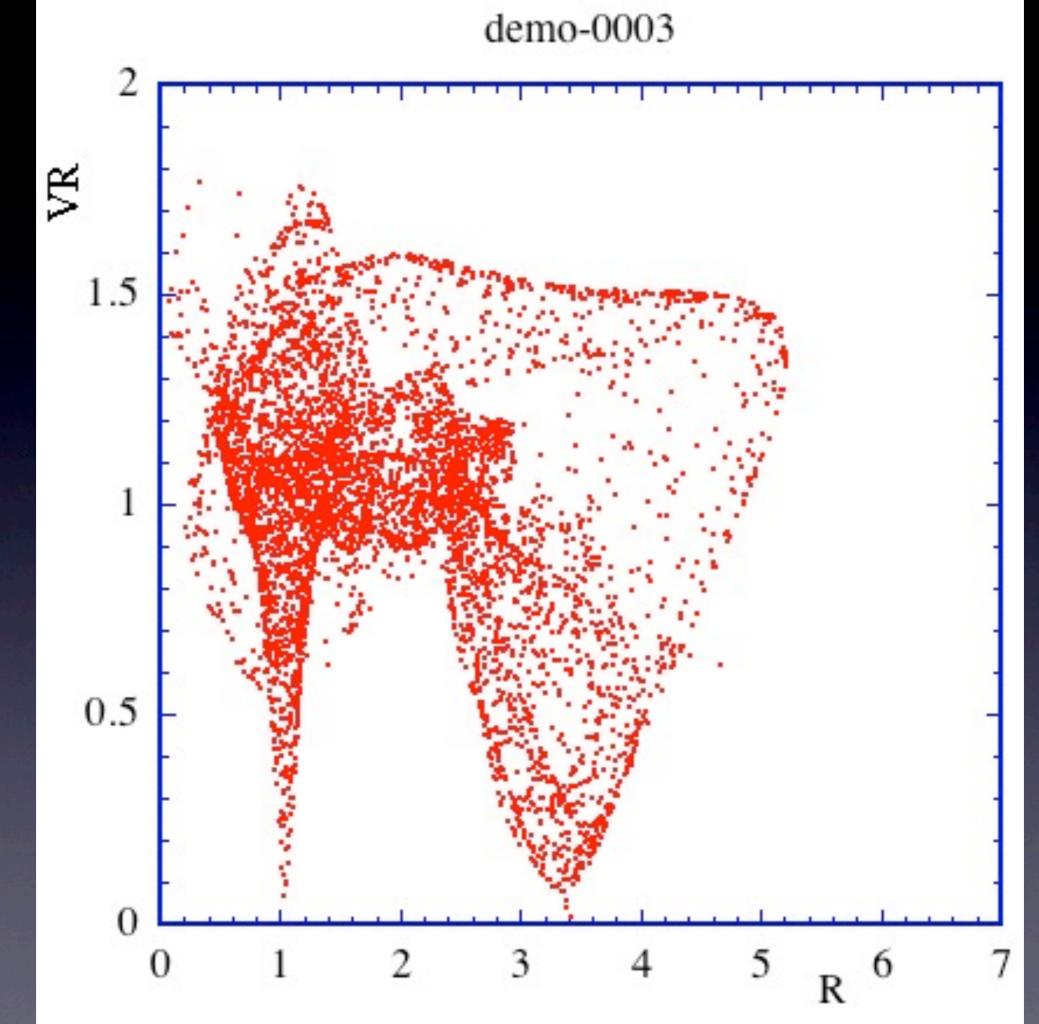


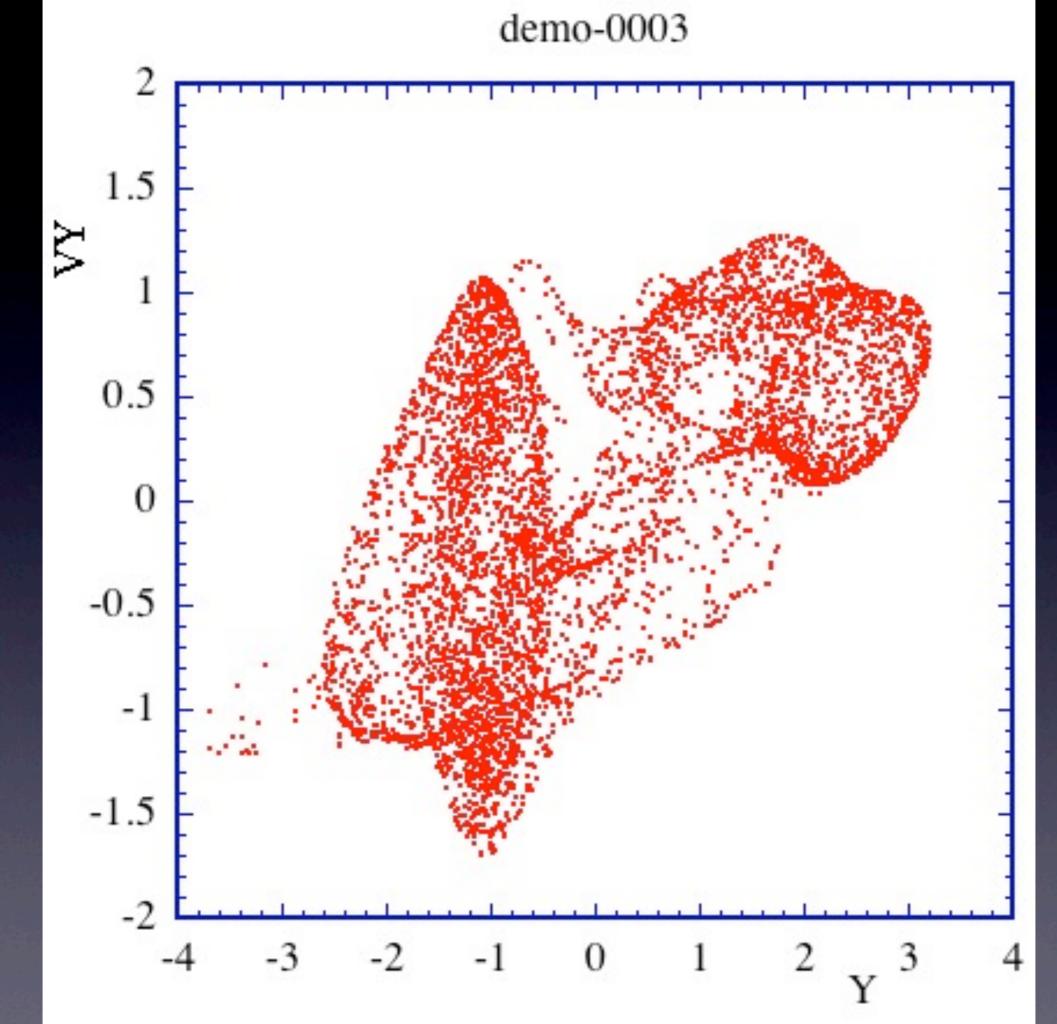


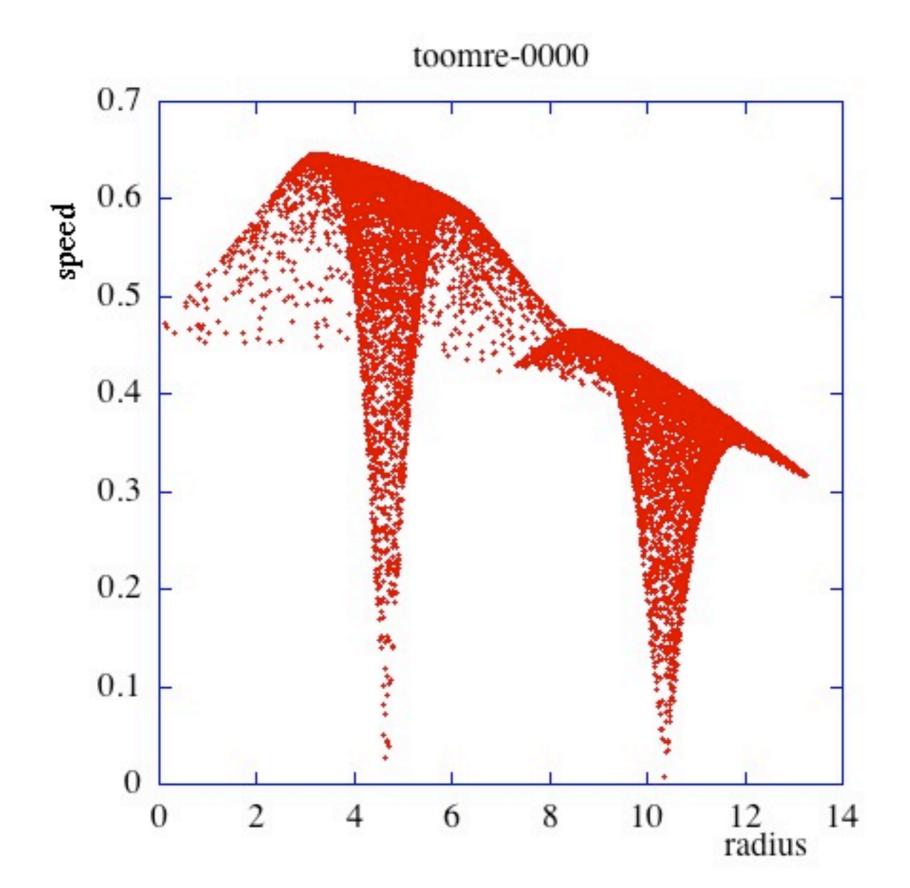


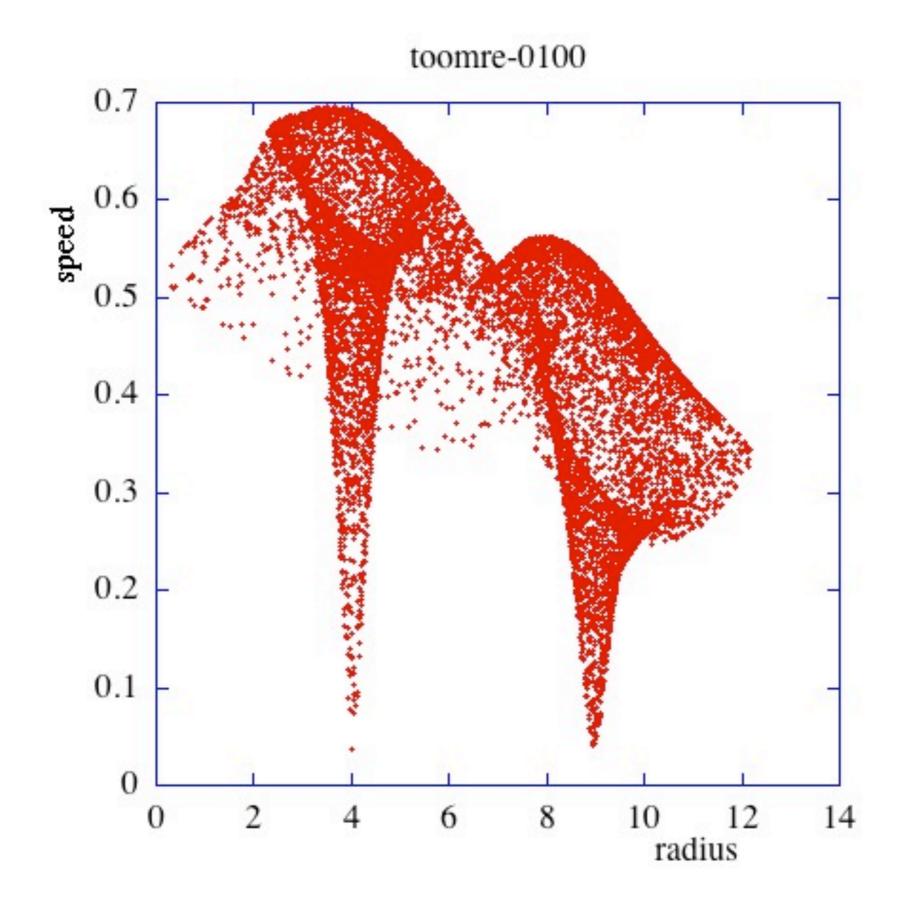
Star Cluster

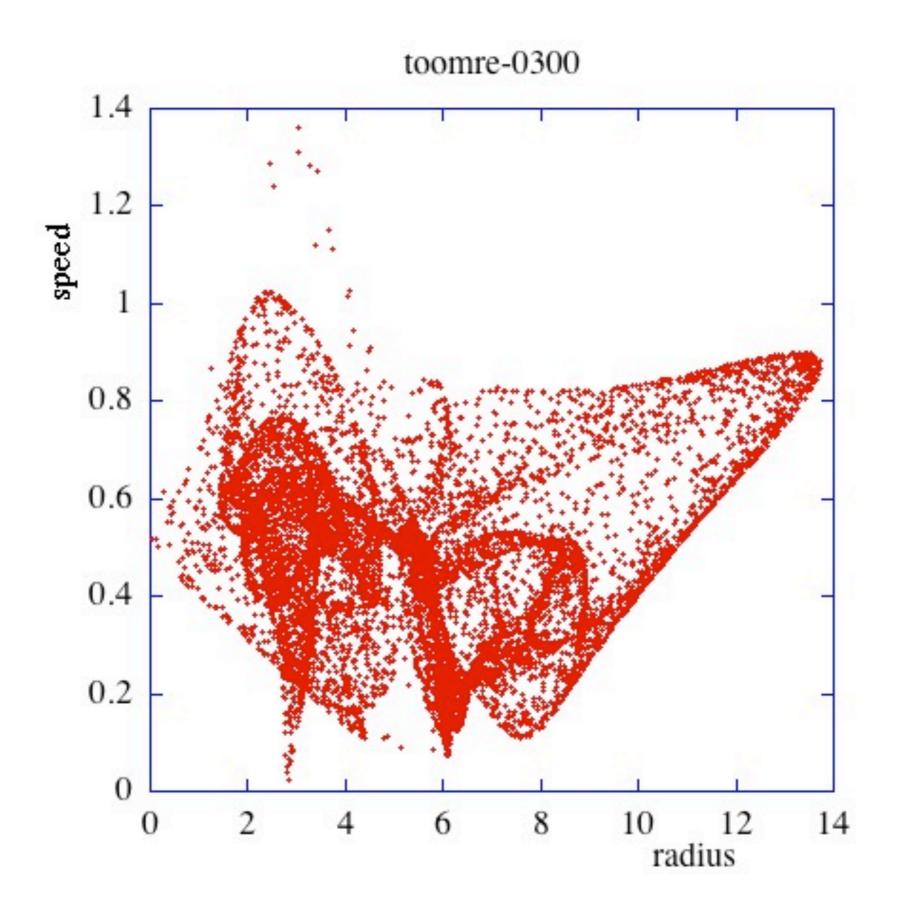


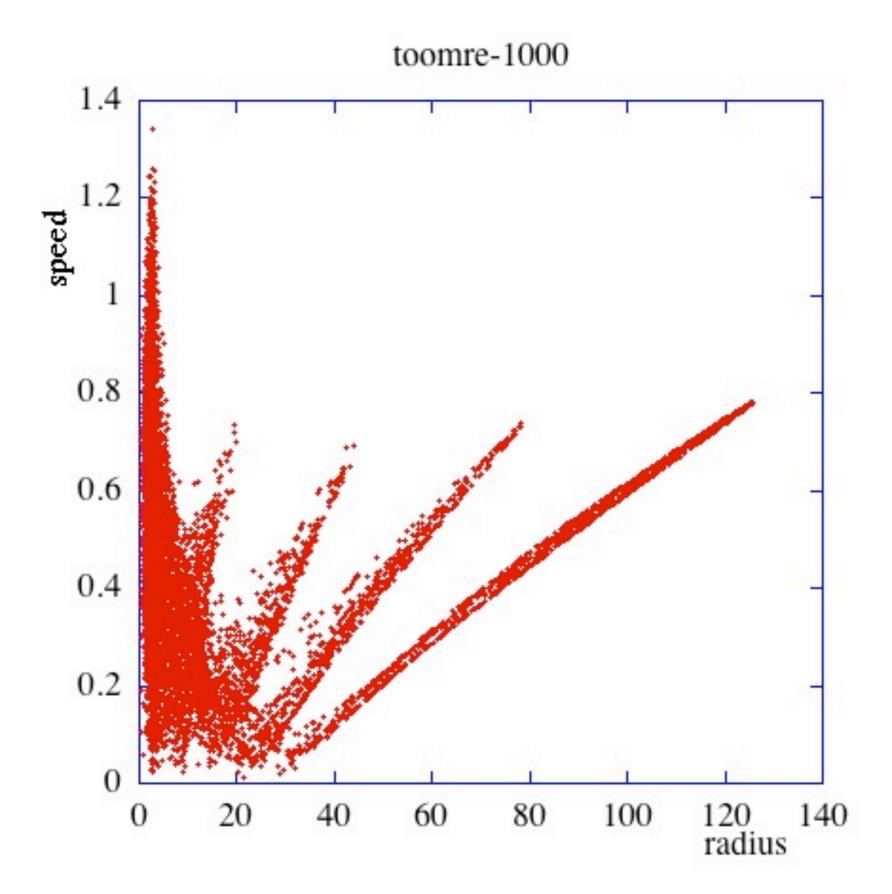






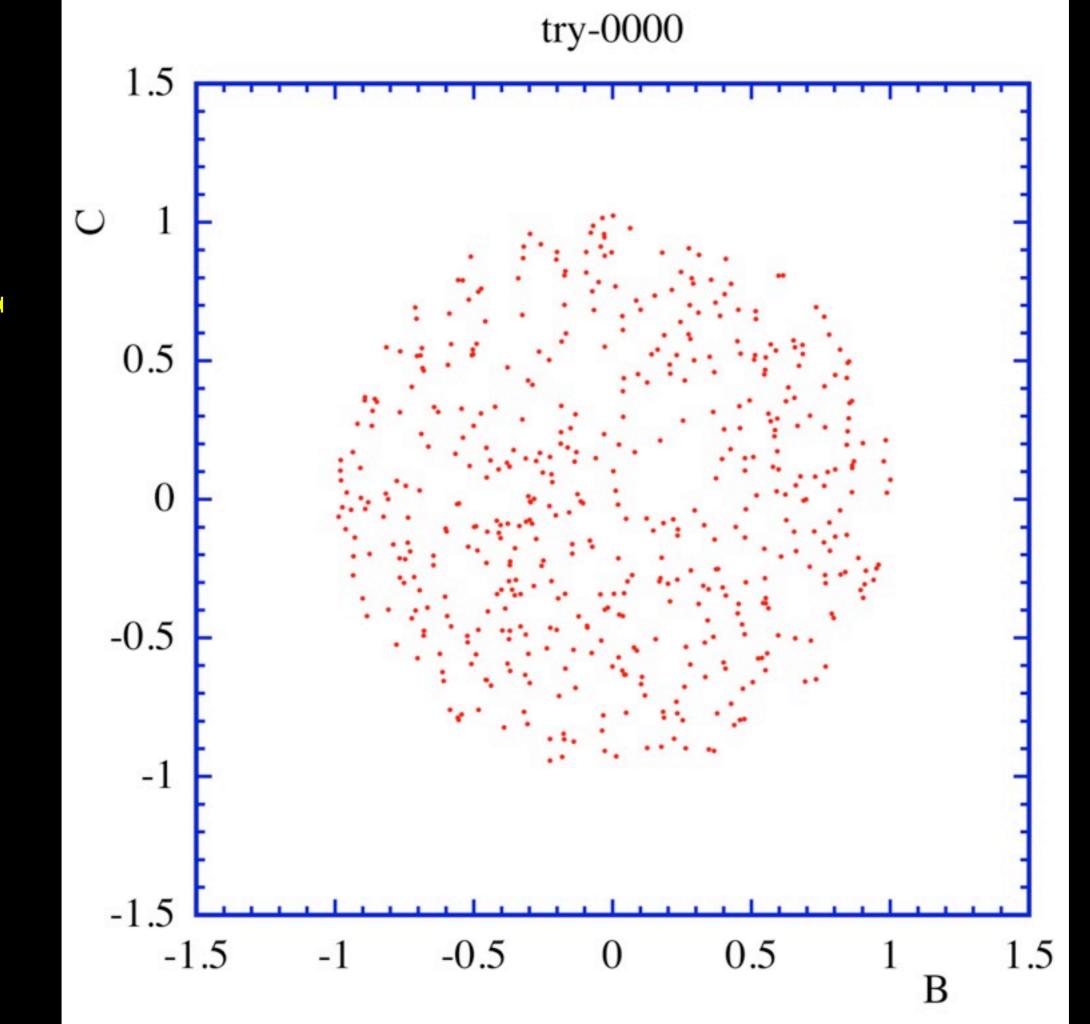


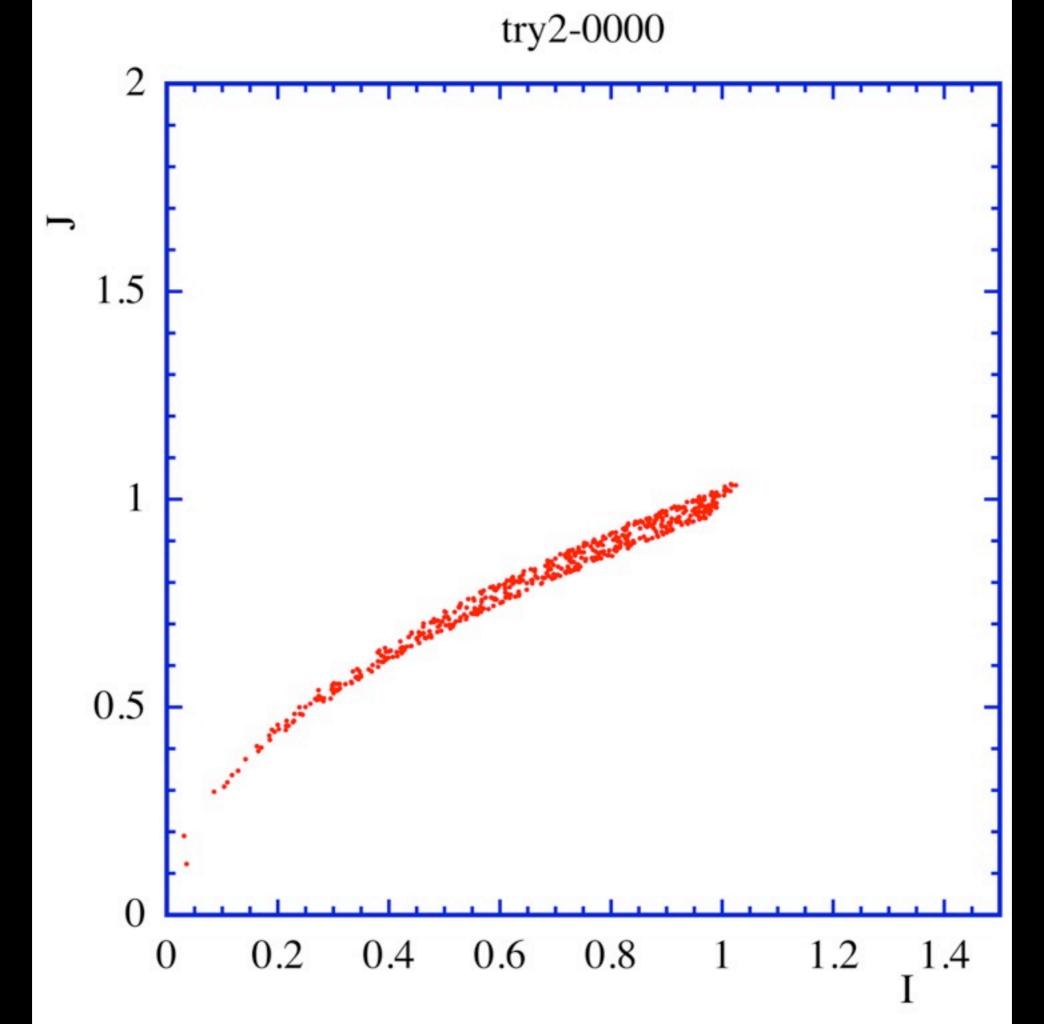


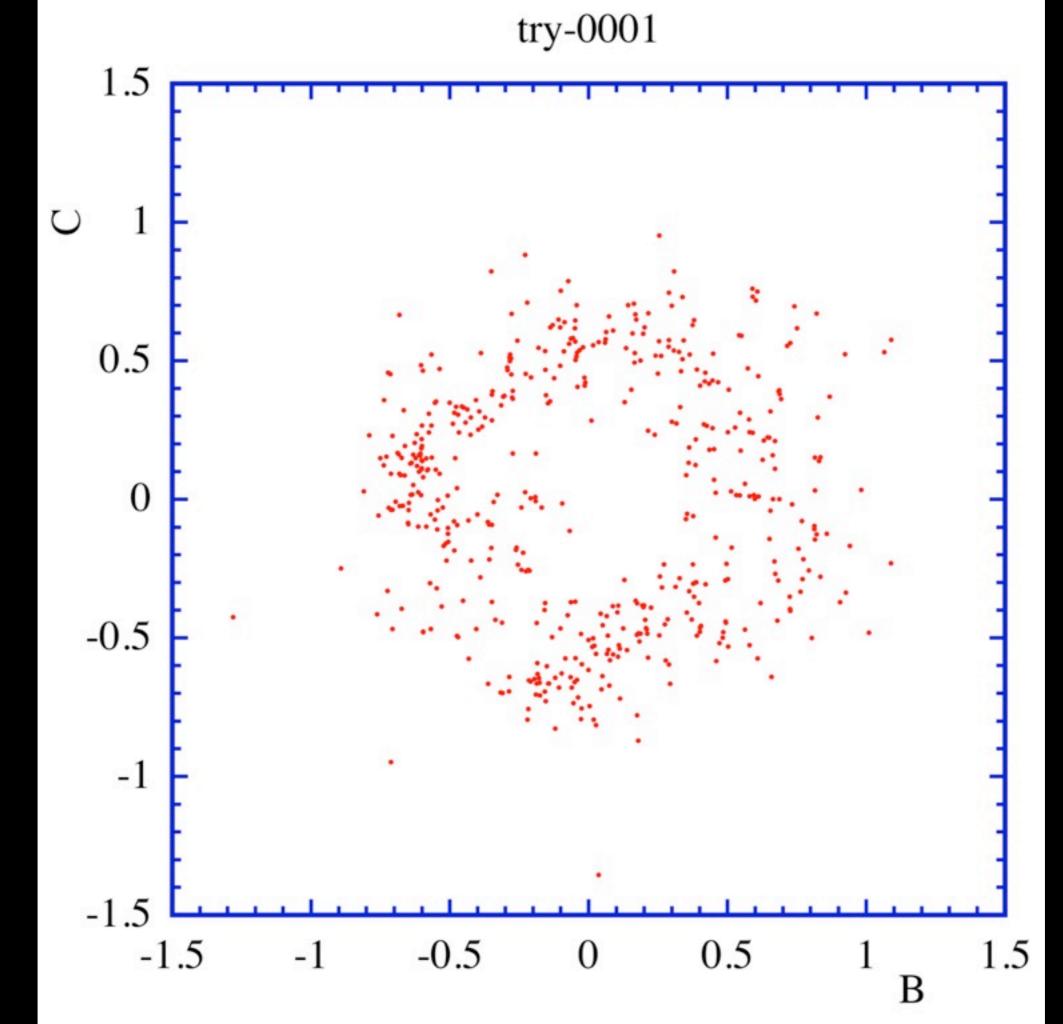


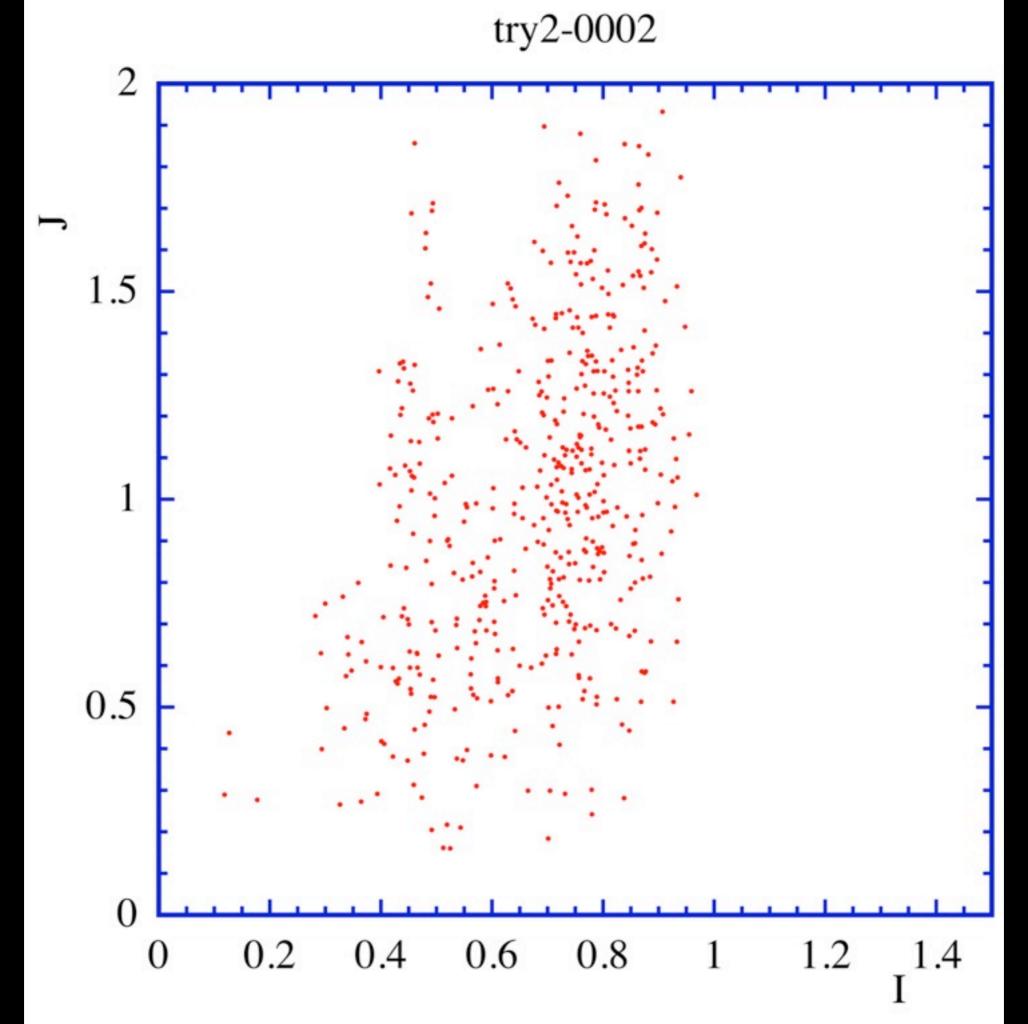
Two Disks

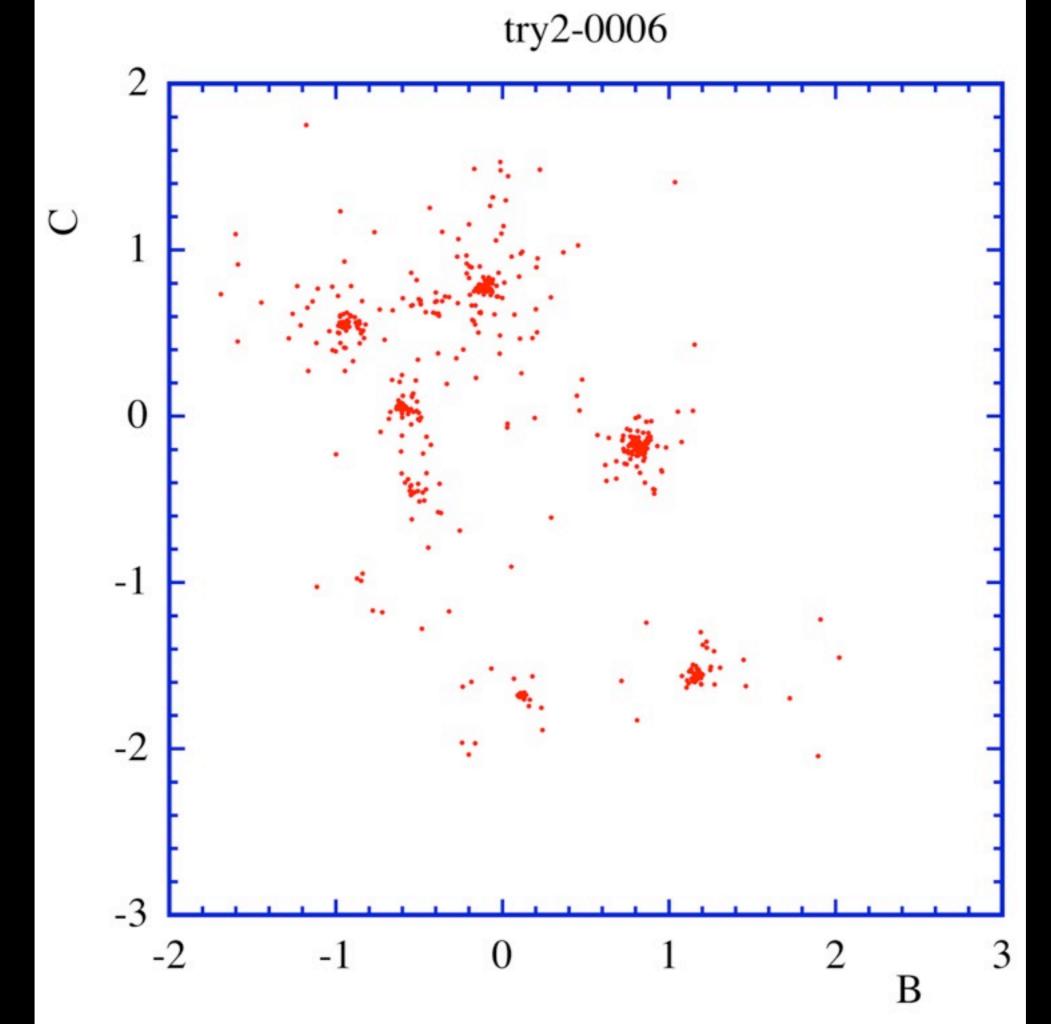
- Keplerian uniform disk
- Same but half of the stars counterrotationg

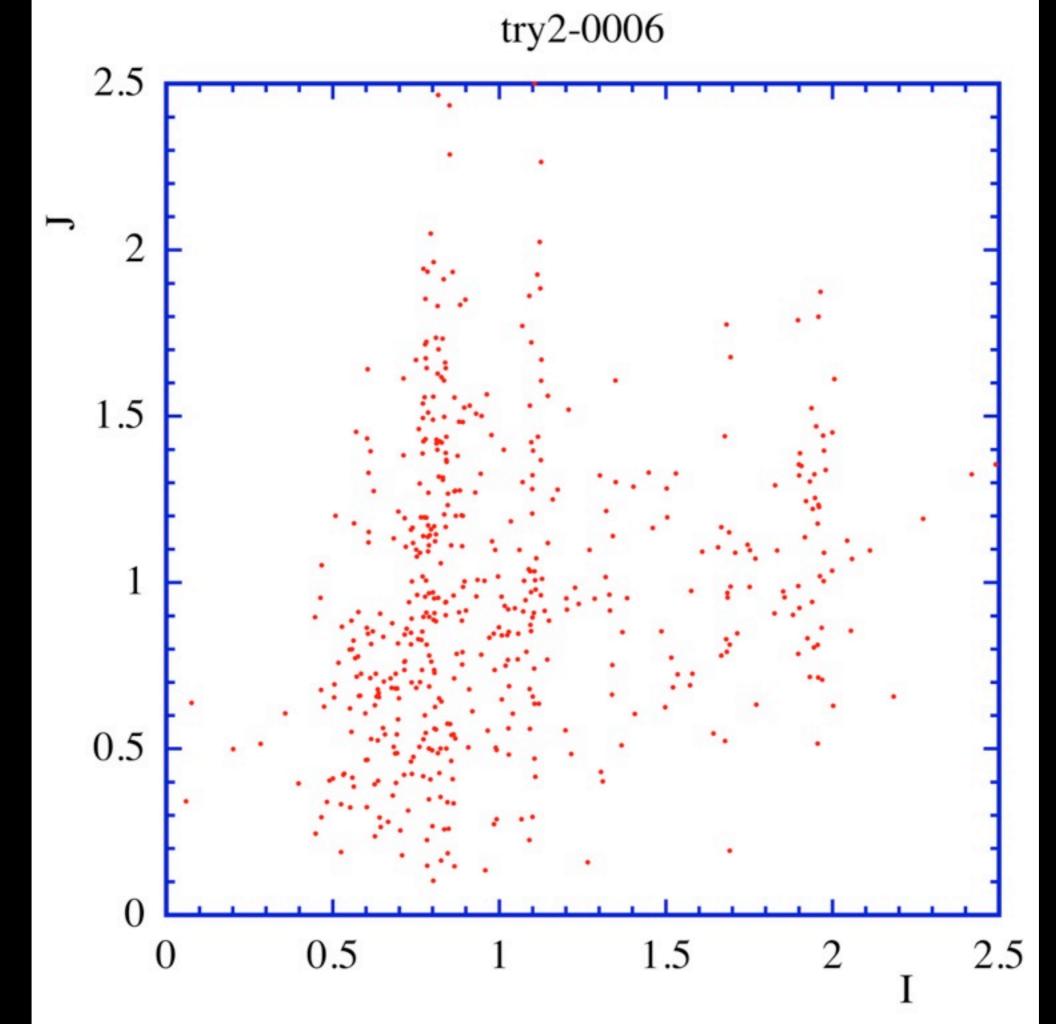


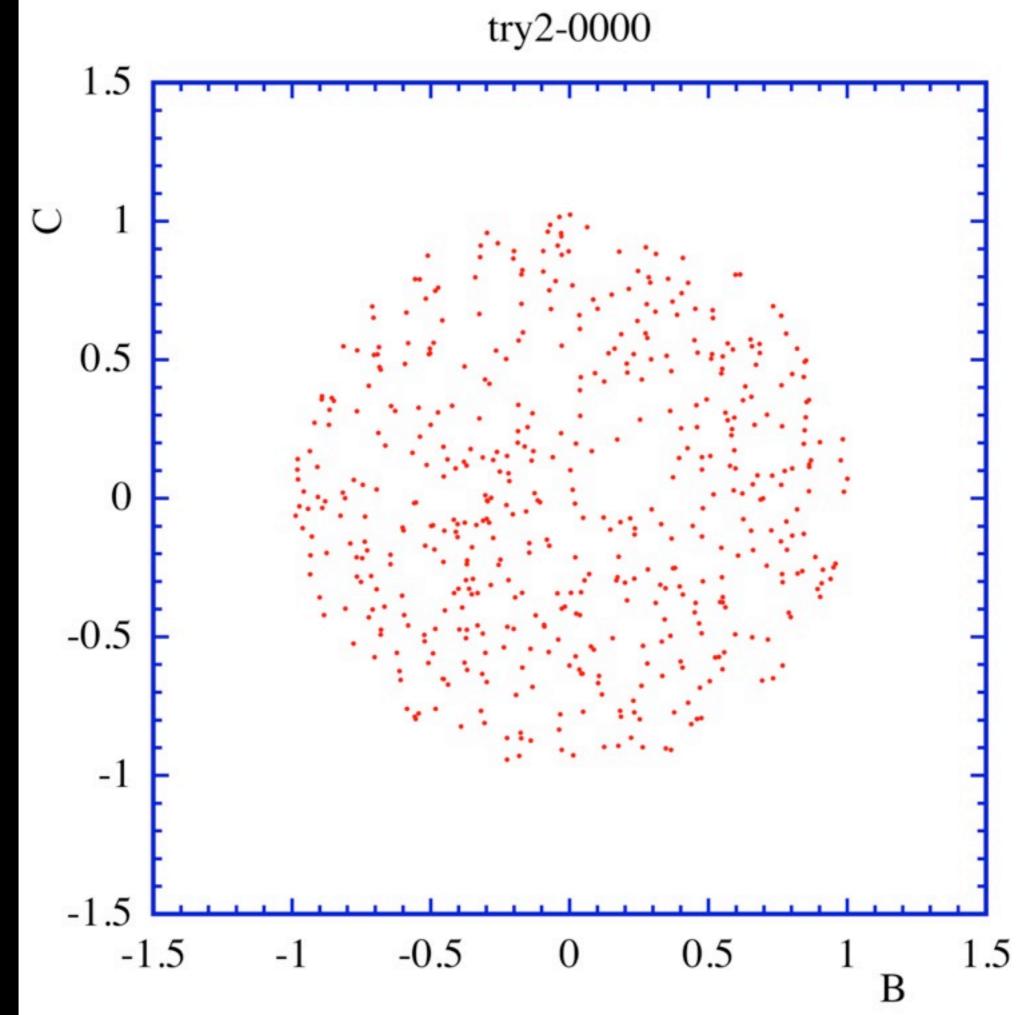


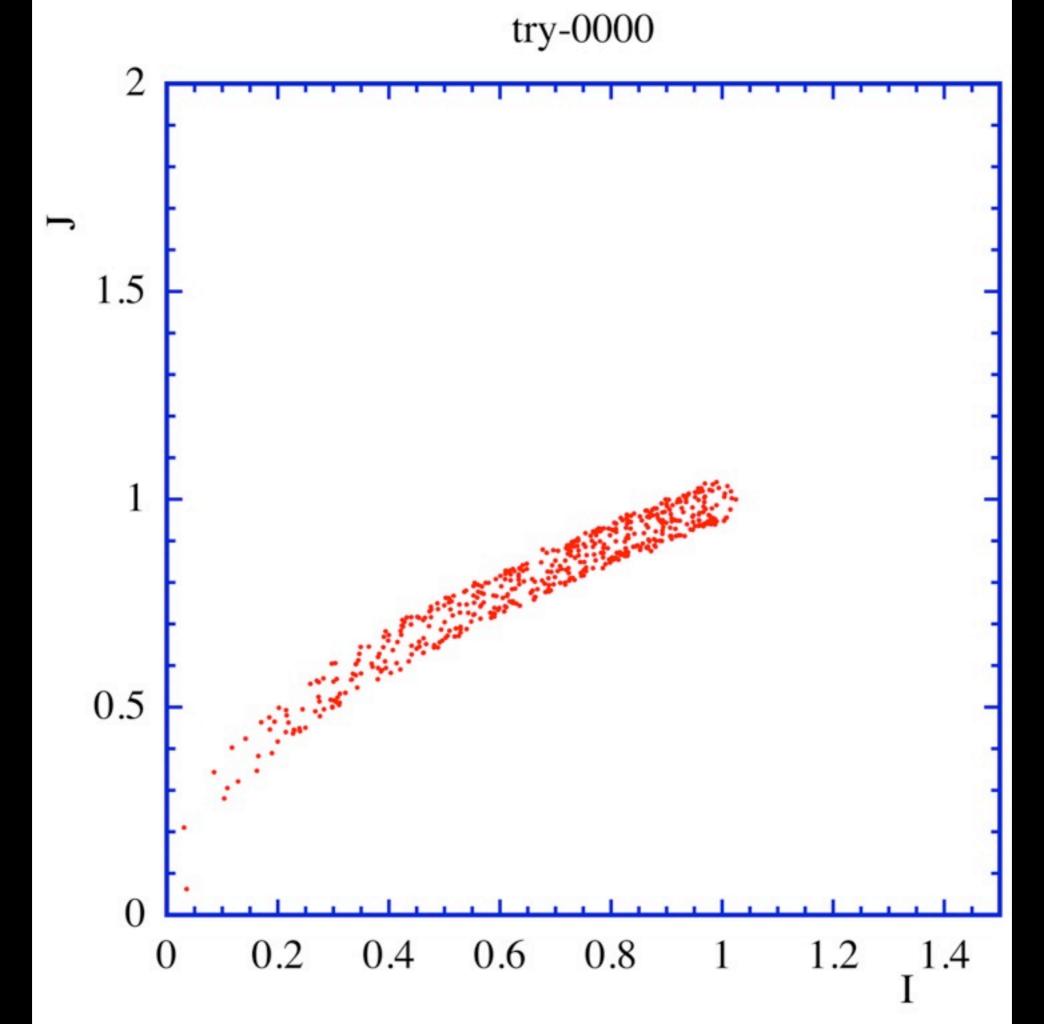


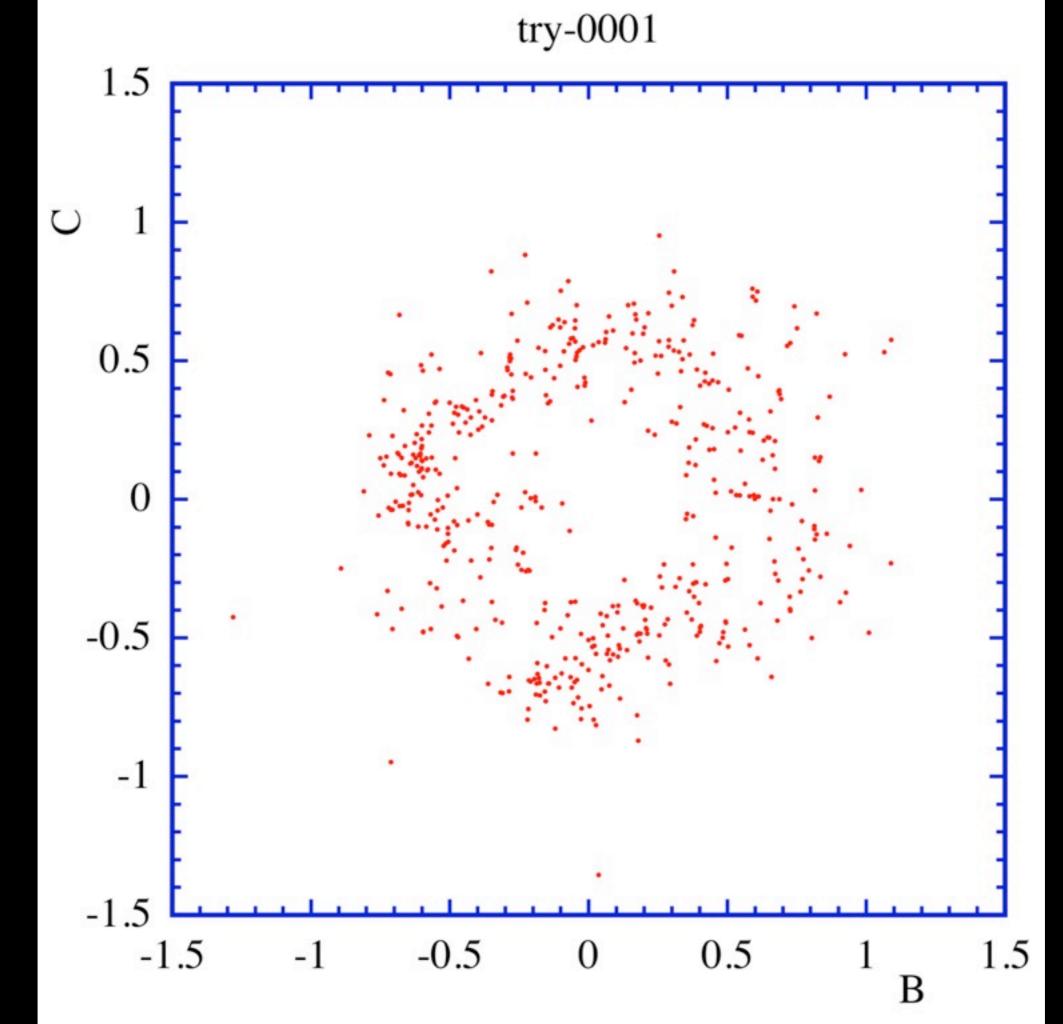


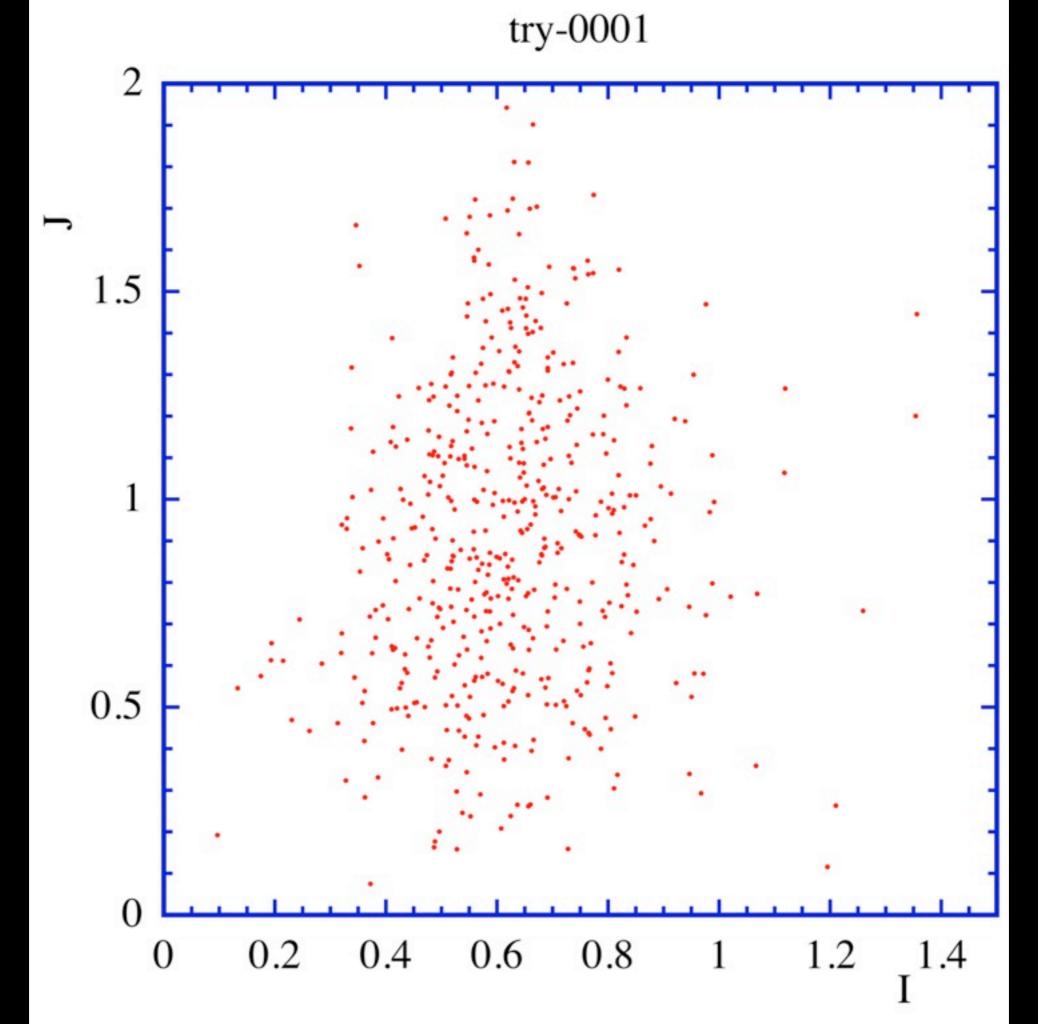


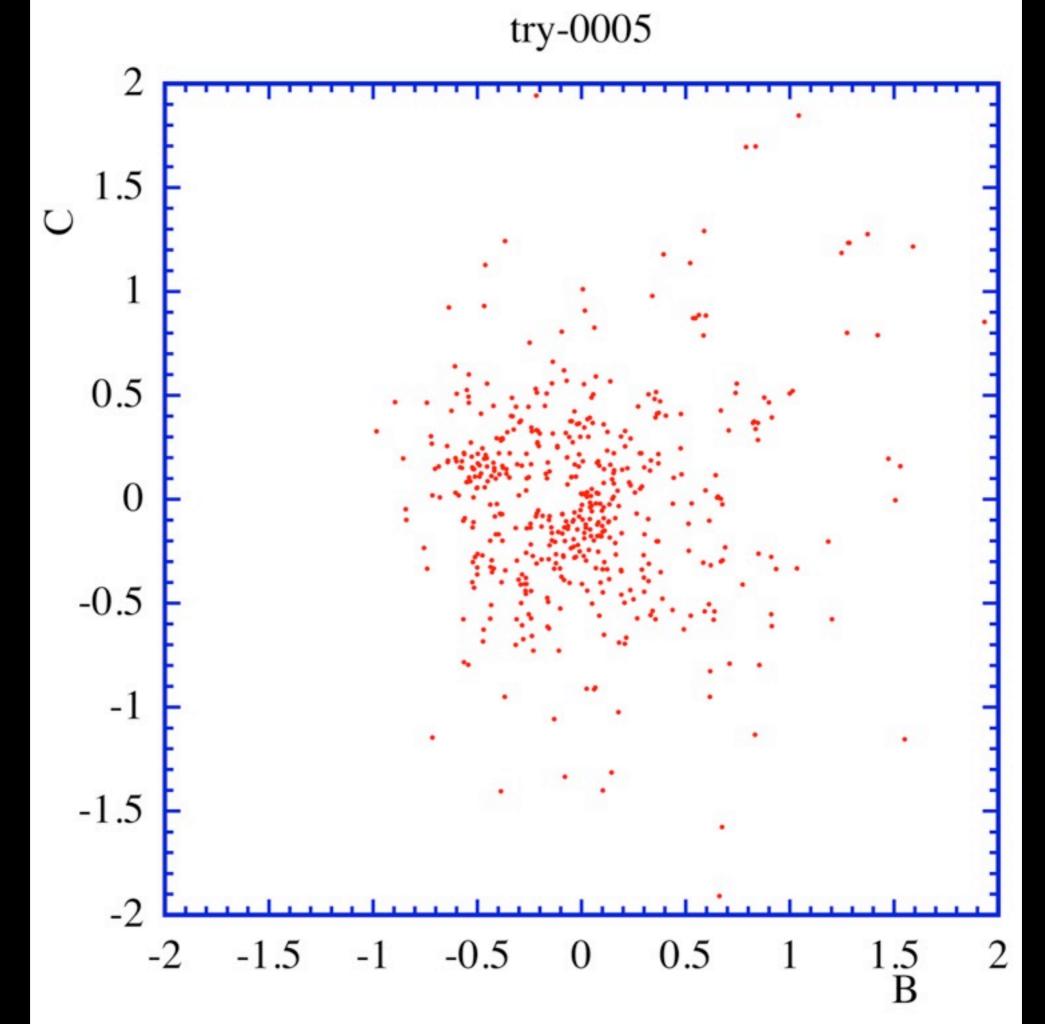


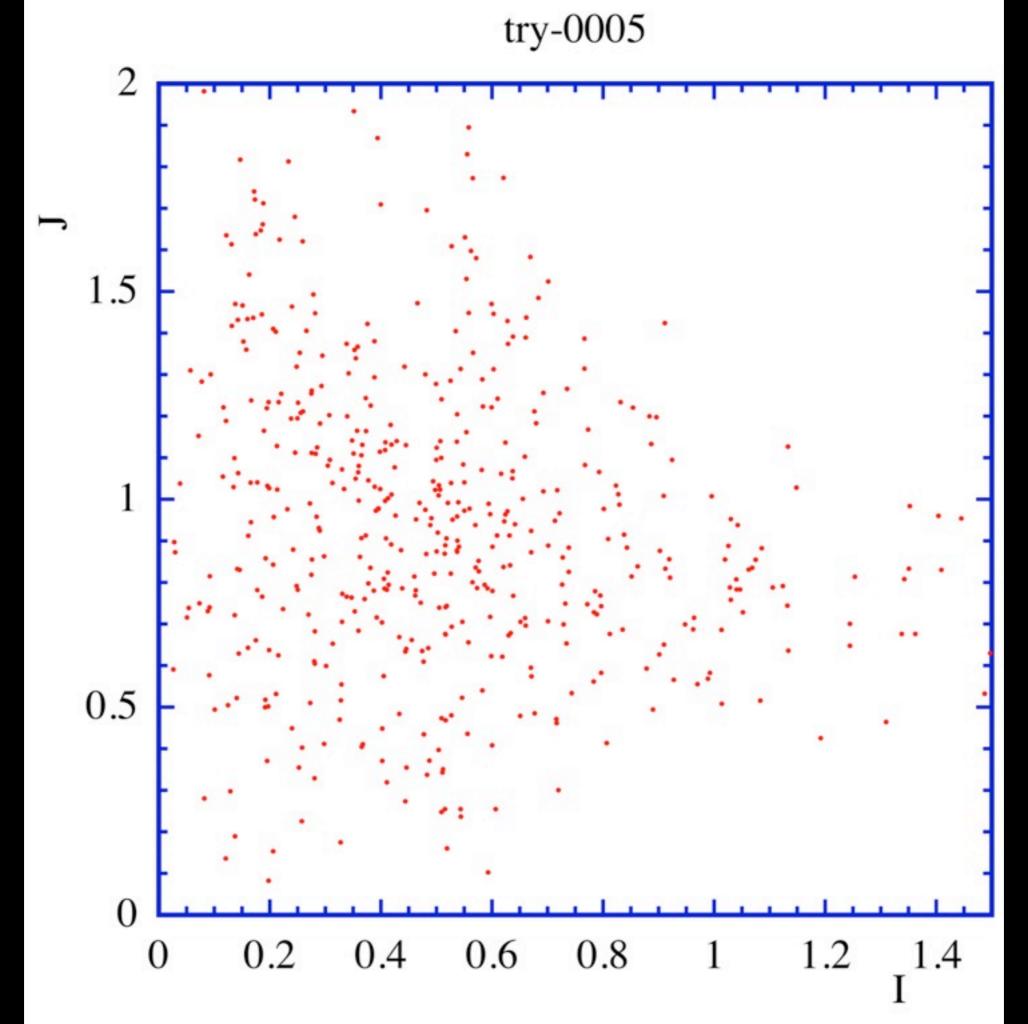












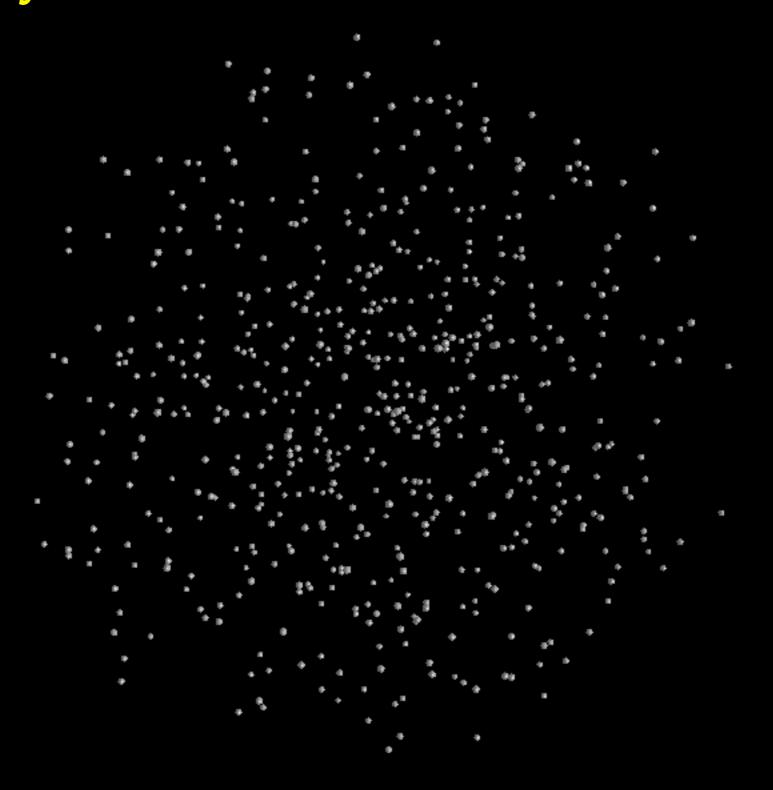
Plummer Model Evolution

2

5 core crossing times

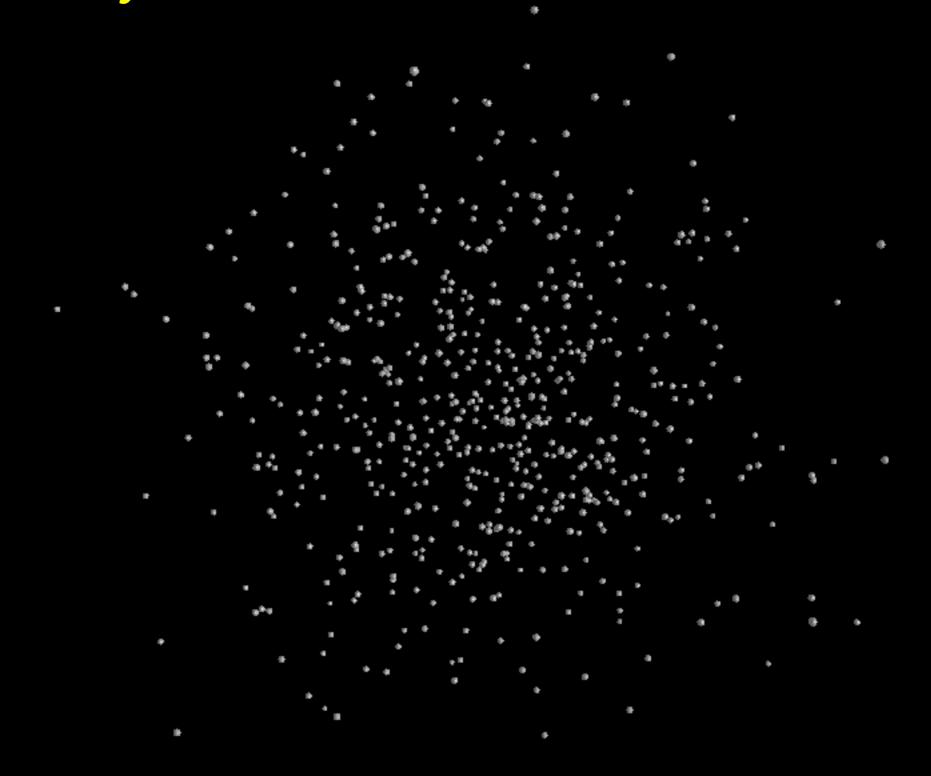
t=0 space

t=0 velocity



t=5 space

t=5 velocity

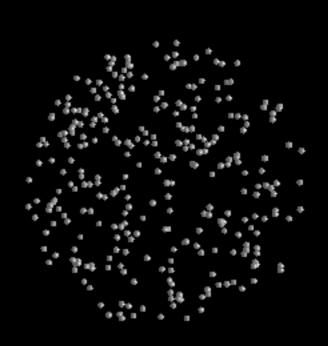


Colliding Spheres

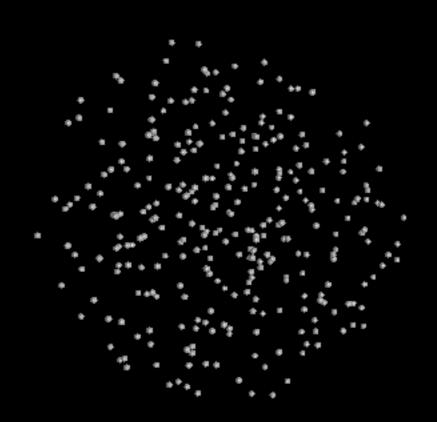
ips in the night

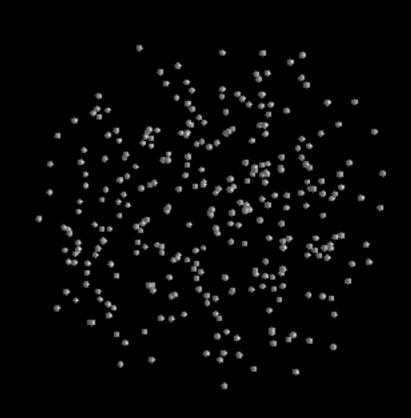
t=0 space





t=0 velocity

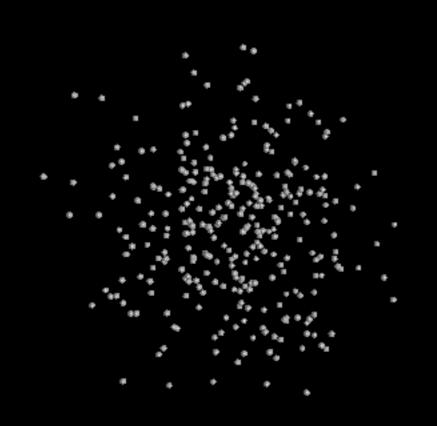


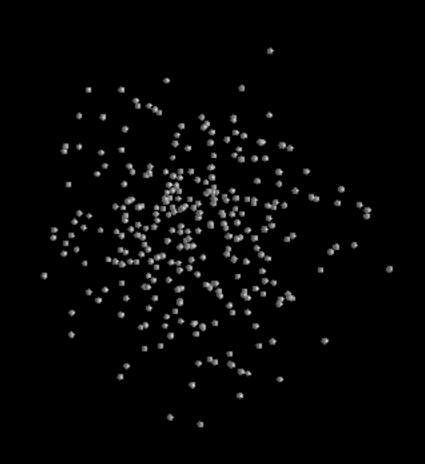


t=0.43 space

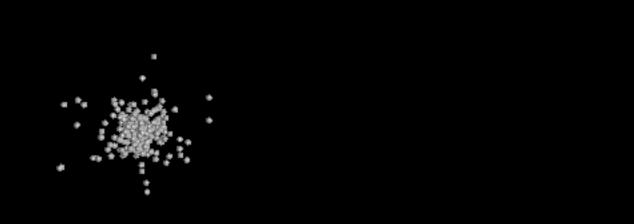


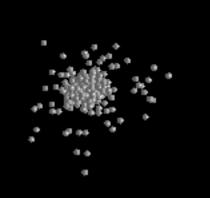
t=0.43 velocity



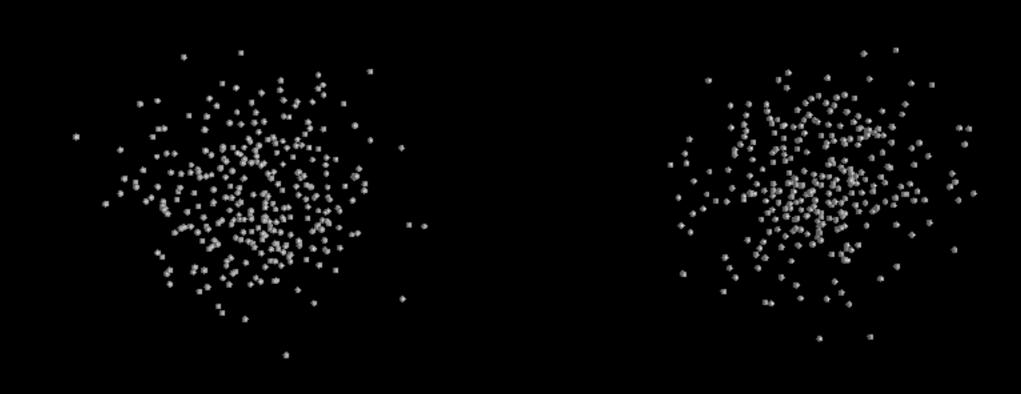


t=6.11 space





t=6.11 velocity

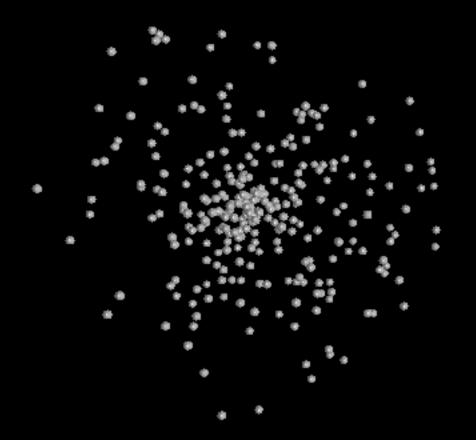


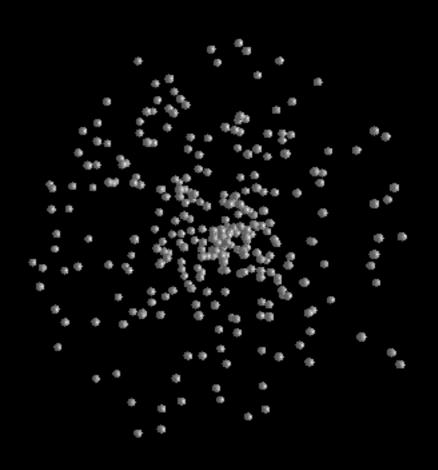
Colliding Spheres

3

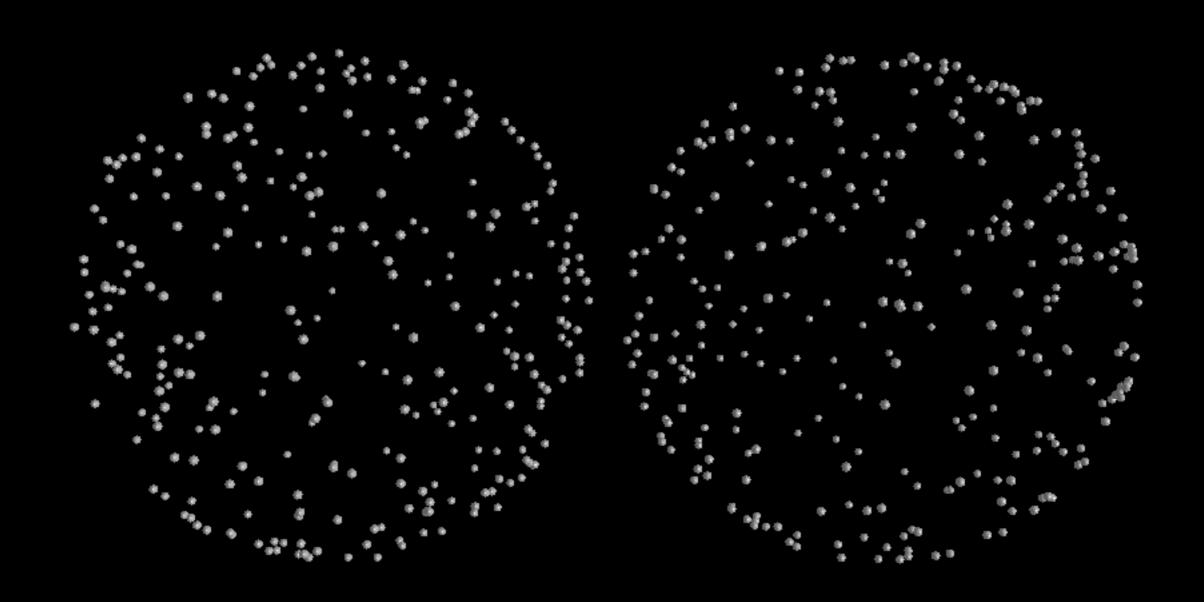
Energy and phase space

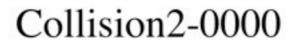
t=0 space

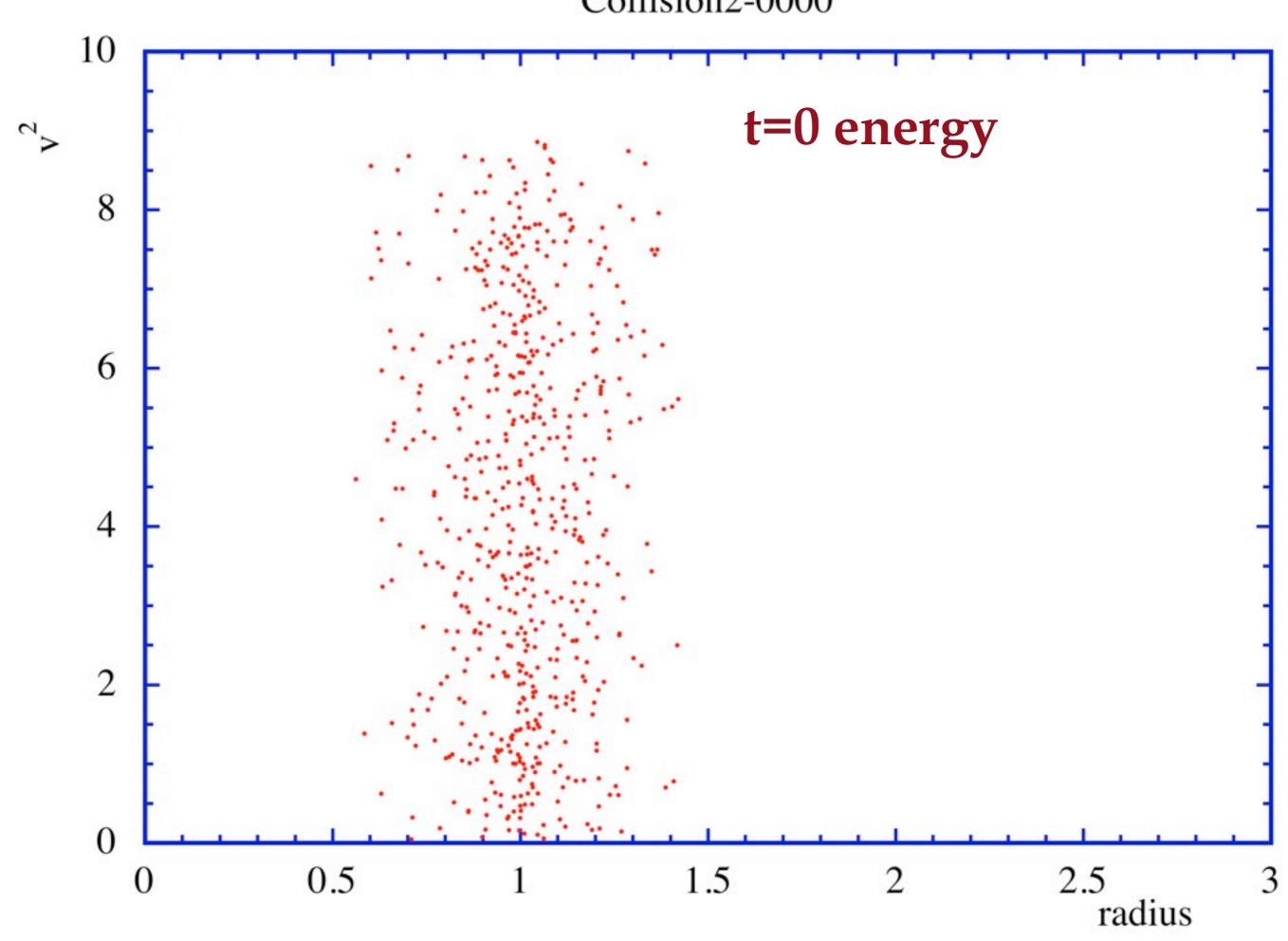


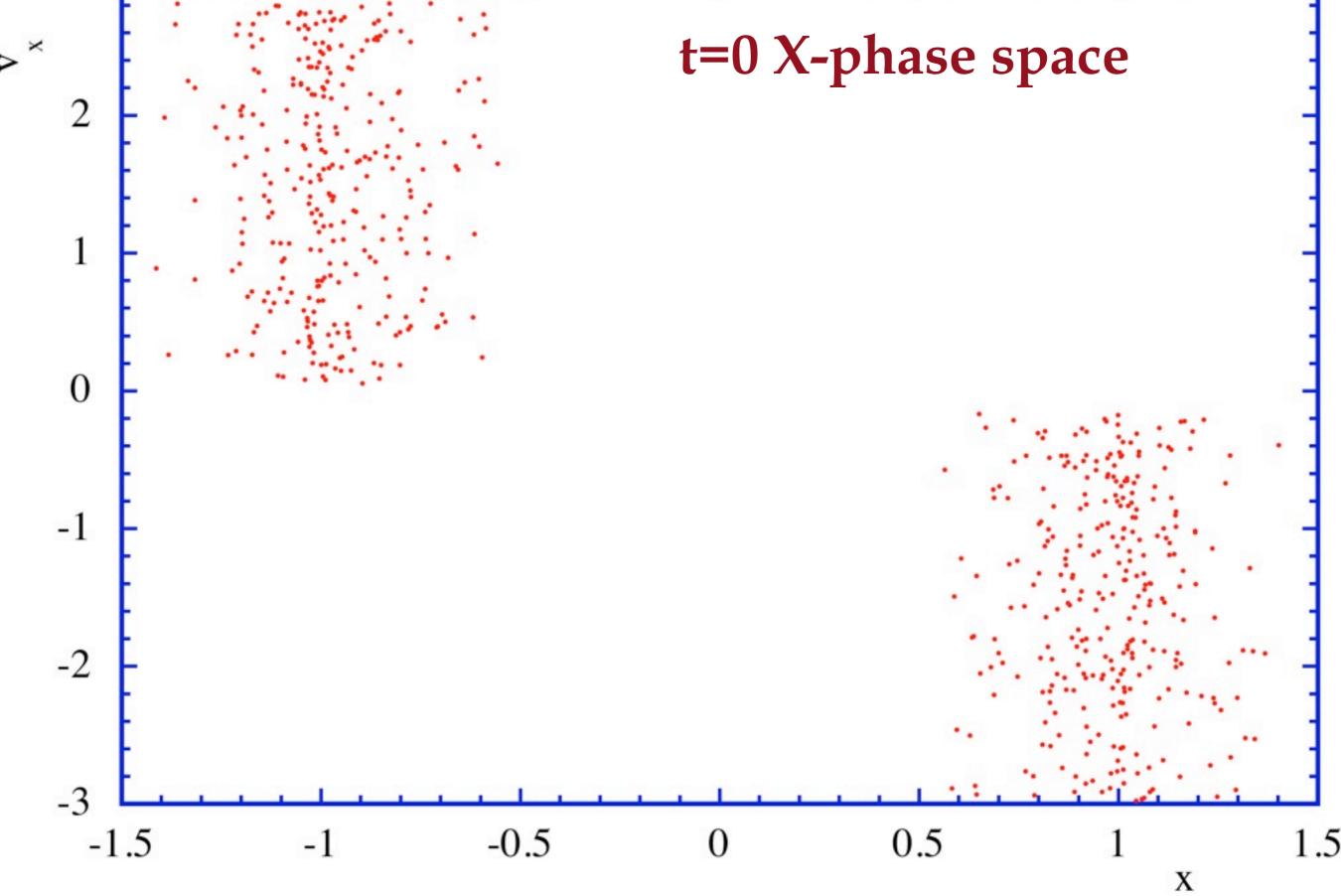


t=0 velocity

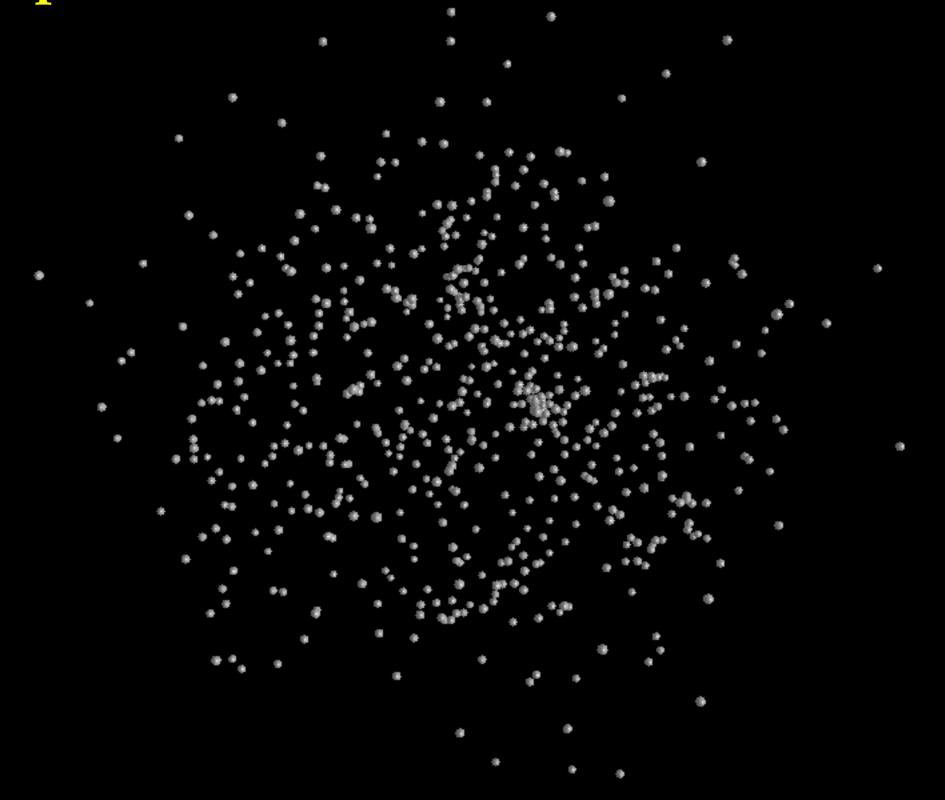




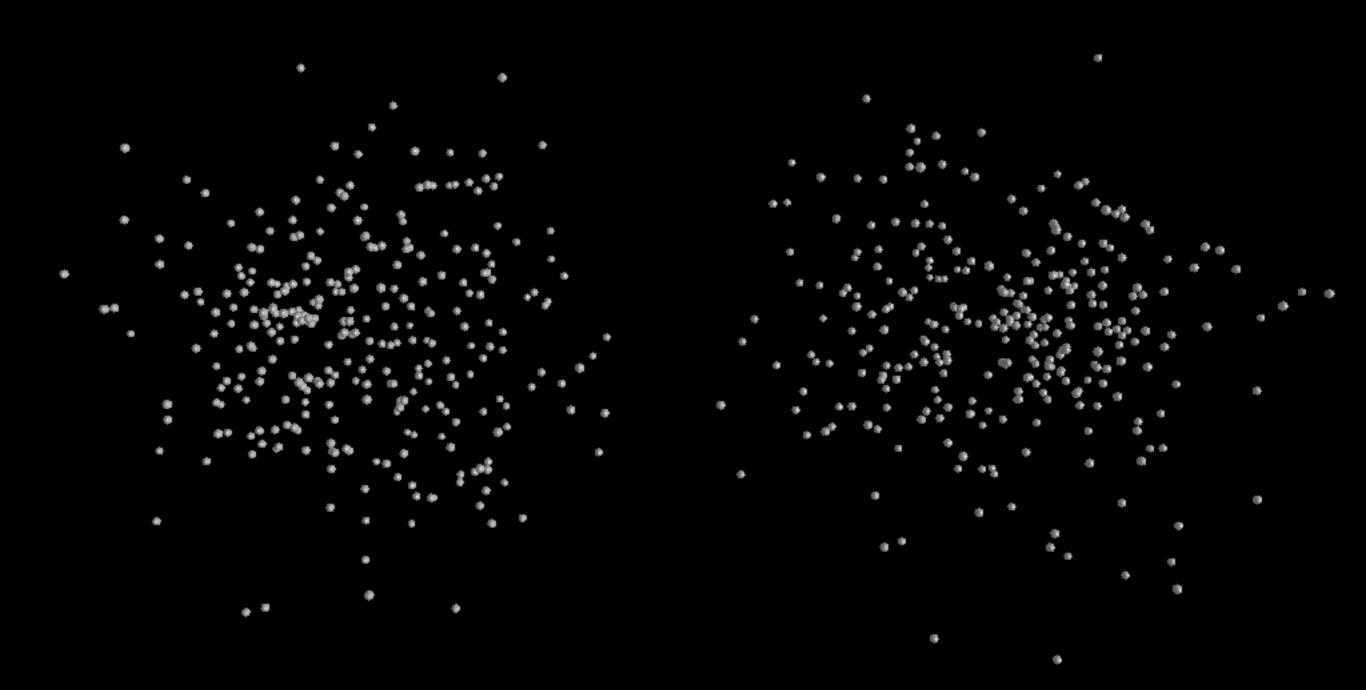


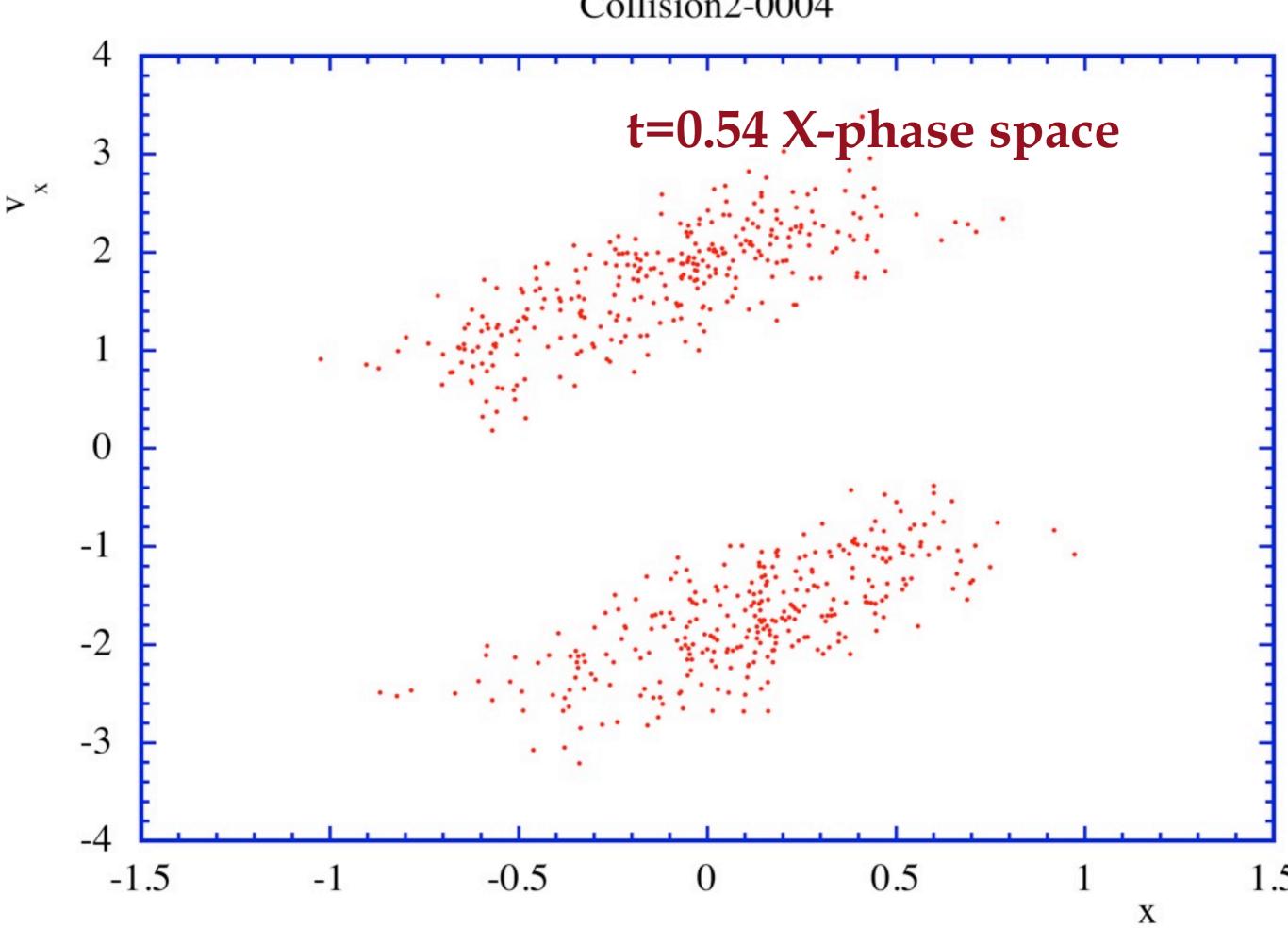


t=0.54 space



t=0.54 velocity



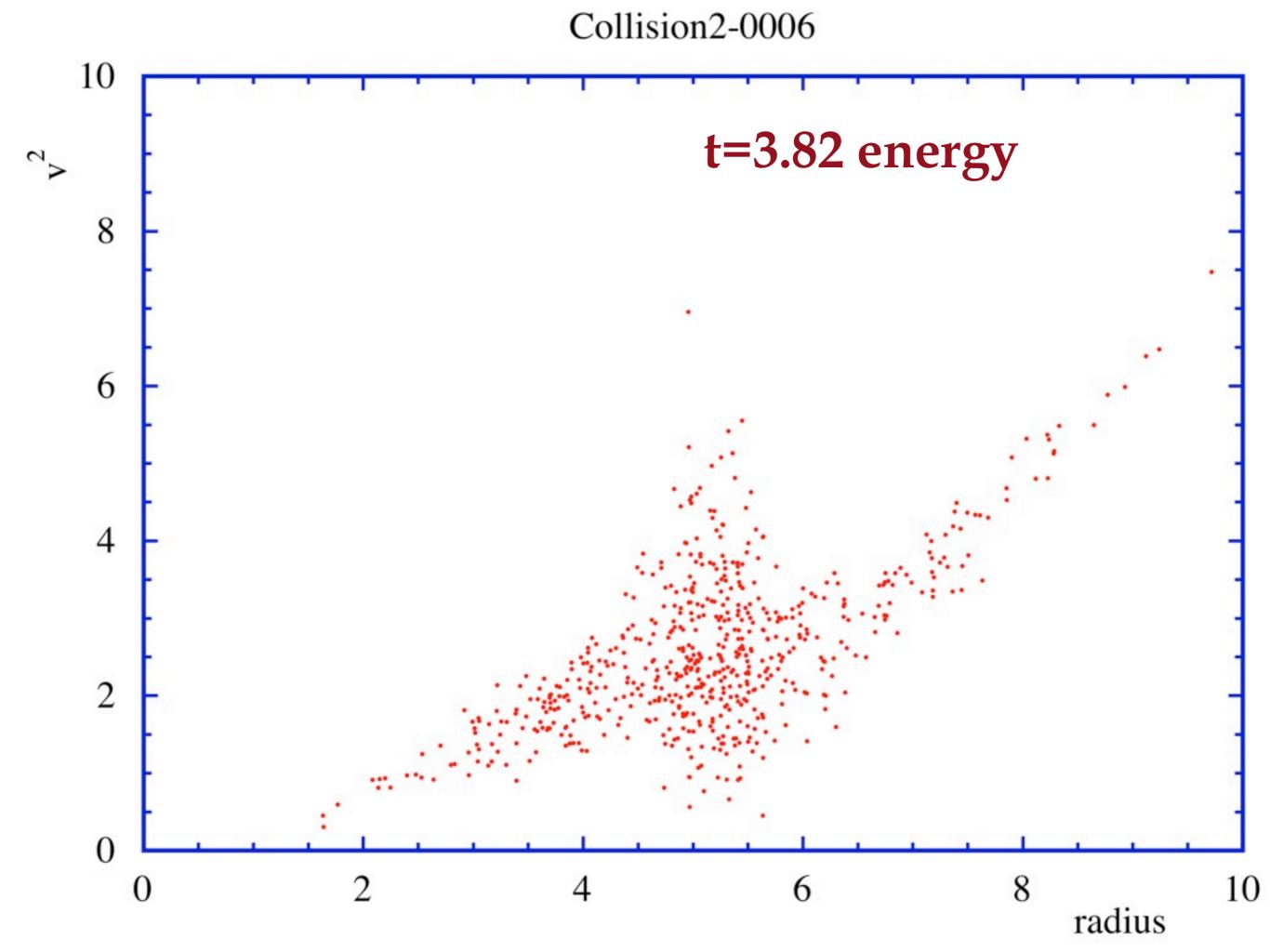


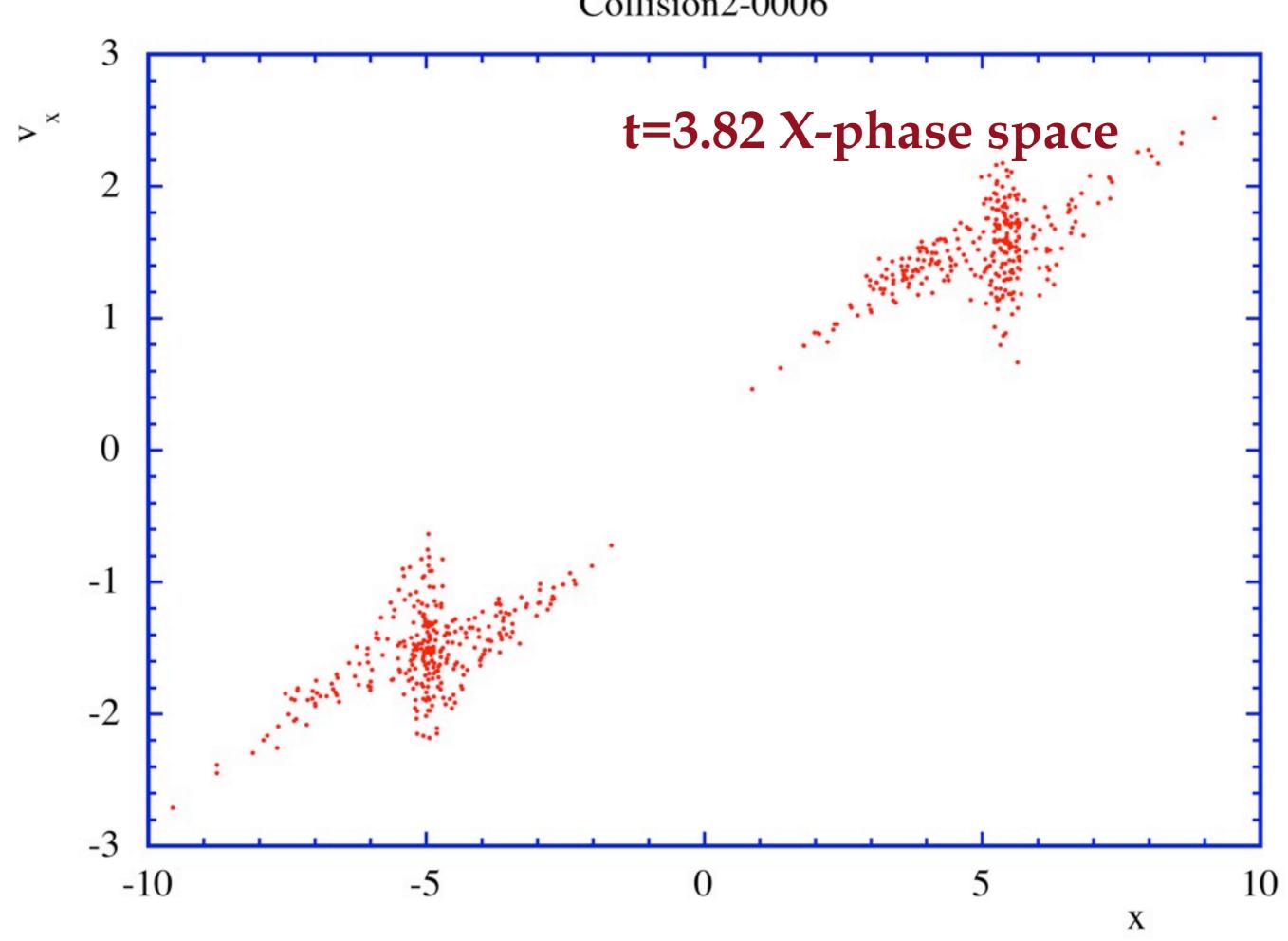
t=3.82 space



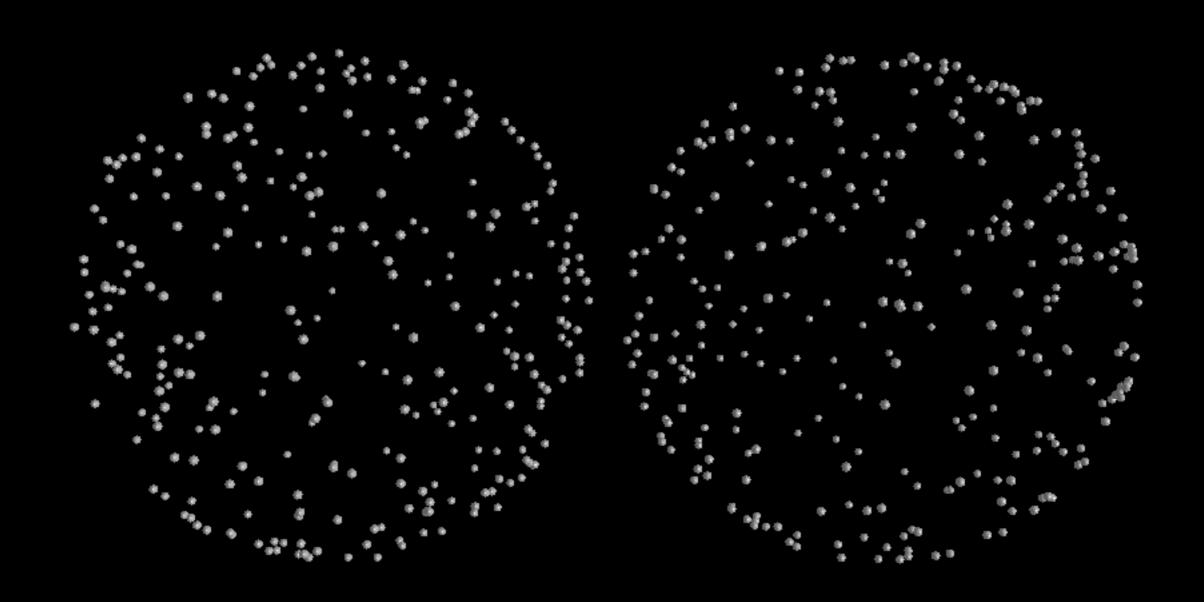
t=3.82 velocity



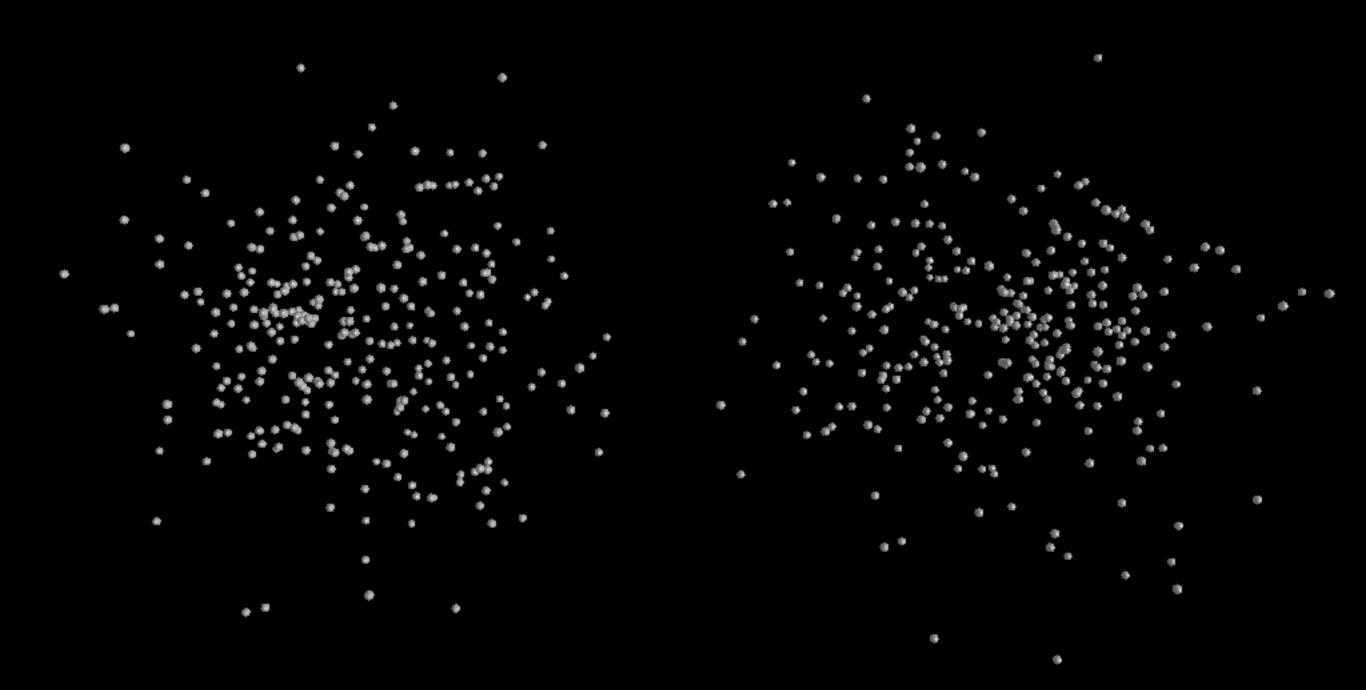




t=0 velocity



t=0.54 velocity



t=3.82 velocity

