Astrophysical Dark Matter Structures

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Gausdal 2012

Simulating the Formation of Dark Matter Structures in the Universe

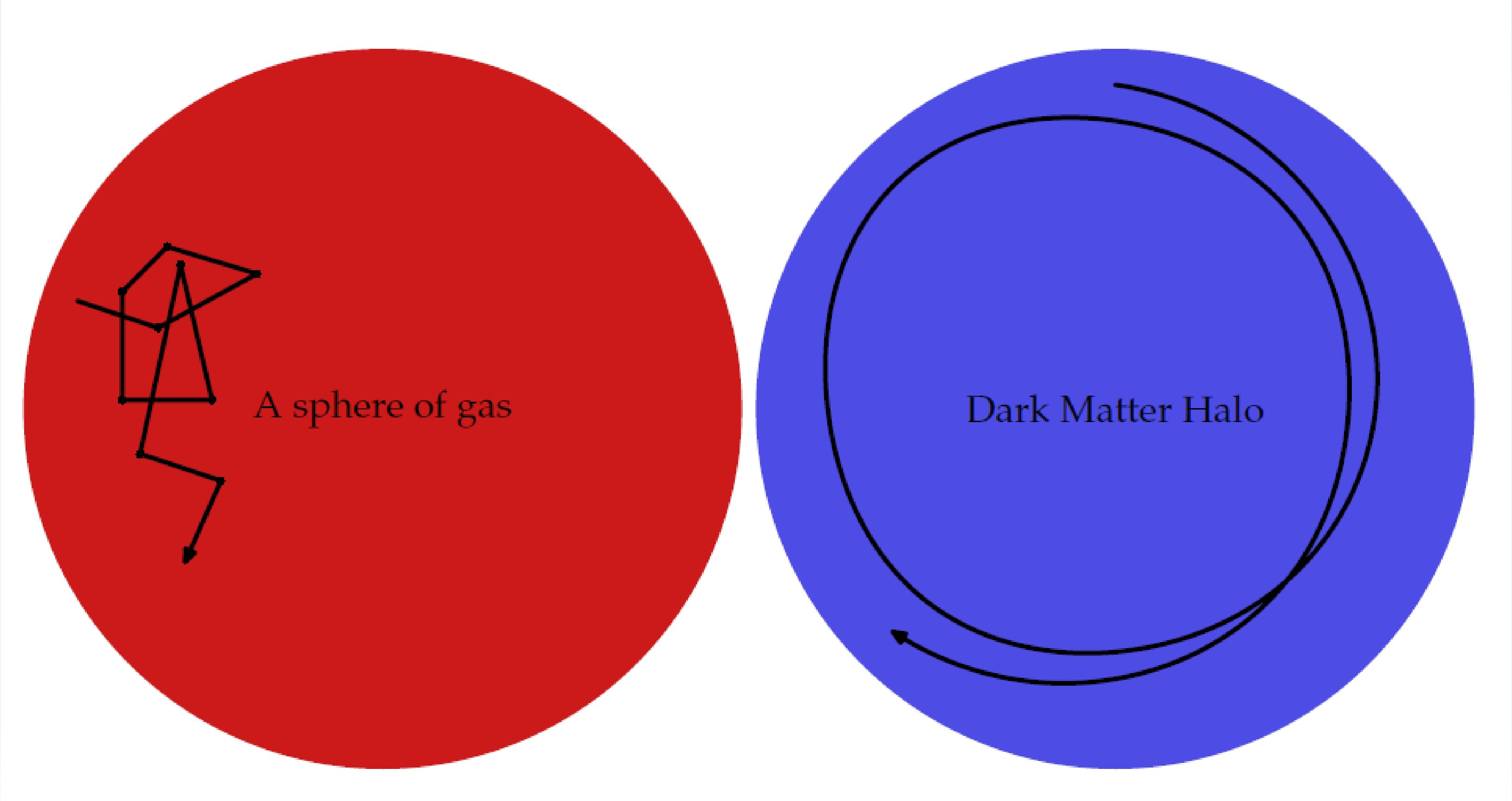
- The initial distribution of matter comes from inflation (Harrison-Zeldovich power spectrum).
- The growth of these perturbations is calculated with

1) Linear perturbation theory (until t~50 Myr).

2) Numerical simulations, where matter densities and velocities are represented by particles.

Collisionless Particles

- Dark matter particles are collisionless unlike normal gas particles:



Cosmological Simulation Movie

- The formation of structure from
  z=12 to z=0 (t=0.375 Gyr to today):

  Credit:
  Diemand et al.
  The Via Lactea Project

Results from simulations

- Halos are complicated.
- Universal density profile ("NFW-profile"):

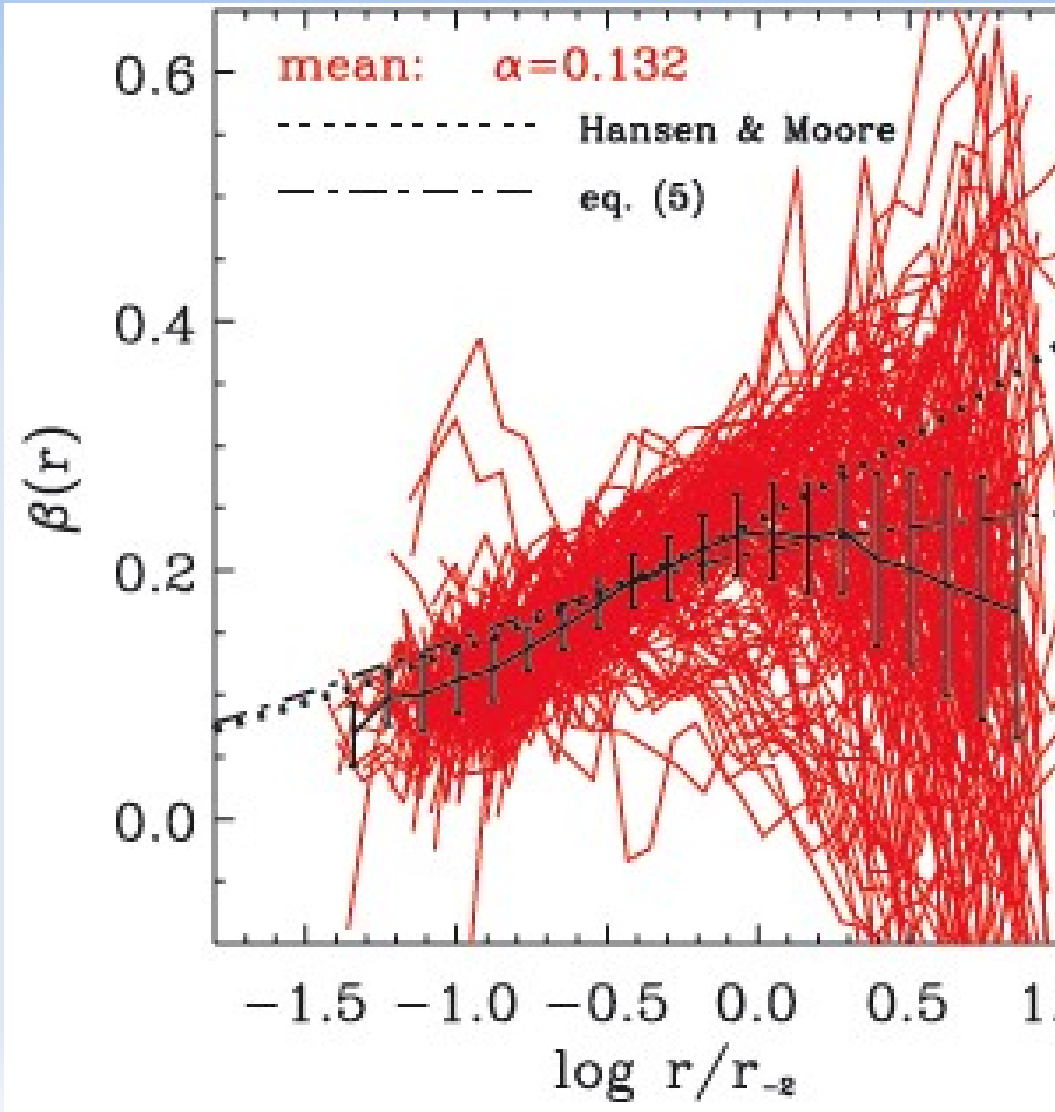
$$\rho(r) \propto \frac{1}{r} \frac{1}{(1+r)^2}$$

Anisotropic velocity distributions

- Velocity dispersion is larger in the radial direction than in a tangential direction.
- Definition:

$$\beta(r) \equiv 1 - \frac{\sigma^2_{tangential}(r)}{\sigma^2_{radial}(r)}$$

Ludlow et al. (2011) ->



My own work

- Controlled simulations....

  Collaborators:
  Steen Hansen, Diana Juncher, Johan Samsing

Simulations

- We generated many different initial DM structures.
- The particle-velocities were multiplied by different random numbers.
- The systems was then evolved in time (with a N-body simulation code...)
- … and then perturbed again.

Hansen, Juncher & Sparre (2010)

Simulations

- beta, the velocity anisotropy parameter.

- Density slope, $\dfrac{d\log\rho(r)}{d\log r}$

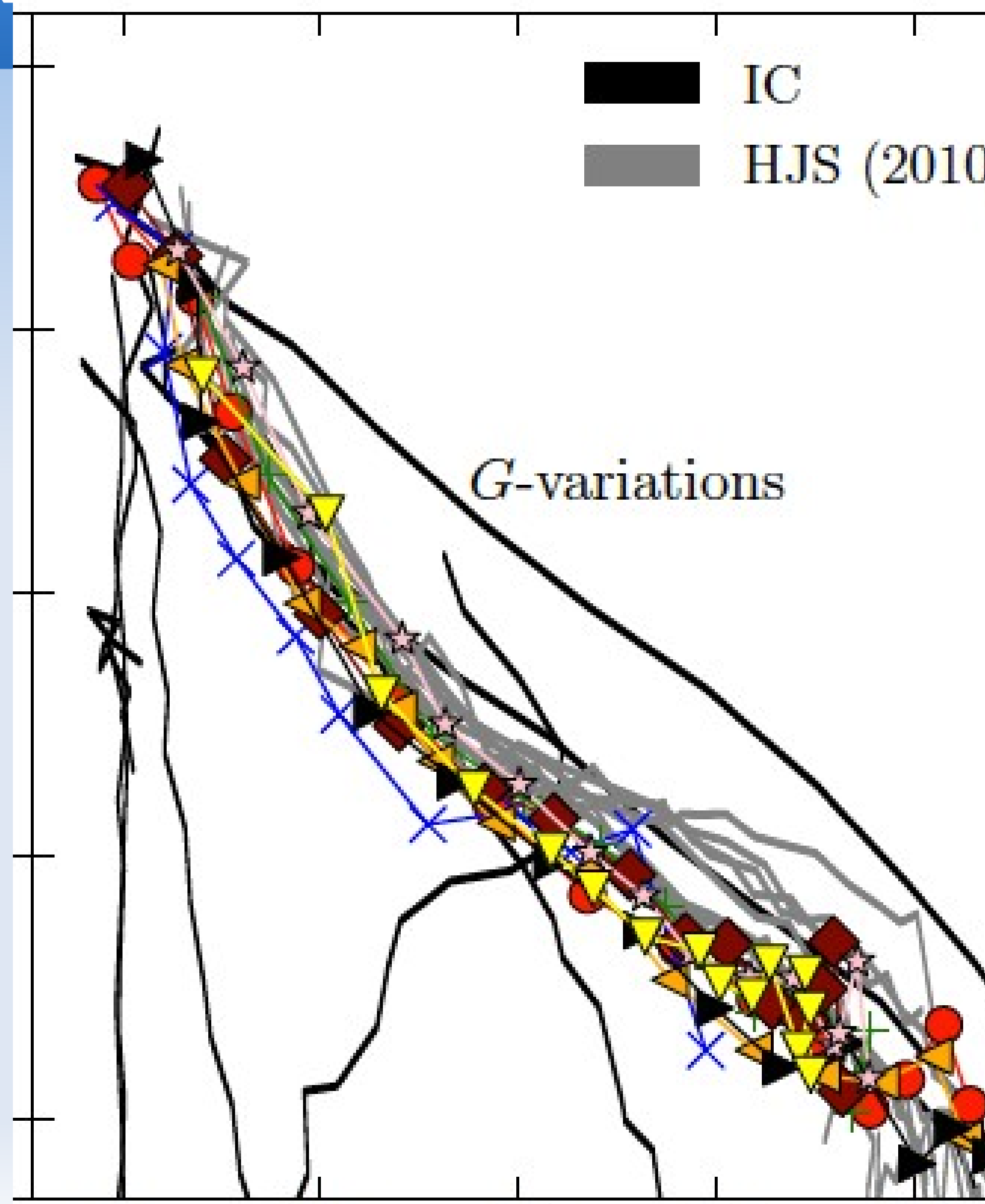
- Velocity dispersion slope $\dfrac{d\log\sigma_r^2(r)}{d\log r}$

Show animation...

Another Experiment

- The acceleration of the particles were changed instantaneously.
- The structures ended on ”the attractor”.

Sparre & Hansen (2012, submitted)



Conclusions

- A 1-dimensional attractor for dark matter systems has been identified in a set of simulations.
- The attractor determines the velocity distribution and the velocity anisotropy for dark matter systems.
- Halos in the universe are expected to be on this attractor.

See more in **Hansen, Juncher & Sparre (2010)**, and **Sparre & Hansen (2012, submitted)**.

What determines the end product of structures?

- The equilibrium state of (ideal) gas particles in a box can be calculated from the maximum entropy principle.
- This method does not work for dark matter structures.

  Example: Maximizing the entropy of a self-gravitating structures consisting of DM-particles leads to structures with infinite mass.