

Simulating the Universe in a computer Claudia Lagos (ESO fellow)

The power of computer simulations



Supercomputing in our daily life...





From predicting the weather....

To manufacturing fuel-efficient cars...

Try to answer questions we could dream of a few decades ago





... to sequencing the human genome, to simulating the human brain....



Galaxy zoo (~13,000,000,000 years) A fundamental goal of astrophysics **Planck measurements:** CMB (~370,000 years)

A complexity problem:

- \rightarrow 8 orders in magnitude in temperature
- \rightarrow 10 orders of magnitude in volume density
- \rightarrow >10 orders of magnitude in scale



We need some perspective on the scales associated...

Distance between earth and sun: ~150,000,000 km = 1a.u. Distance between sun and nearby stars: ~500,000 a.u. Size of our galaxy (the Milky Way): 6,000,000,000 a.u. Size of our local group of galaxies: 200,000,000,000 a.u.

Large scale structure: 2,000,000,000,000,000 a.u.

Large scale structure relative to size of MW: 1,000,000 Large scale structure relative to local group: 30,000



The system is complex but in addition what we observe is only the tip of the iceberg... /

Problem is that the rest of the iceberg remains invisible

Early Evidence for Dark Matter



Further Evidence for Dark Matter



Galaxy Cluster Abell 2218, Credit:ESA/NASA









H, He, C, O, N, Si ... Ordinary matter; 5%

Dark Matter; 27%

Dark Energy; 68%

Do we know enough about dark matter and dark energy to simulate their evolution?

How do we know if our representation of the Universe is realistic?

If we only include gravity: The two-body problem



The N-body problem: solely gravity





CURIE SUPERCLUSTER: 11,520 2.6 GHz CPU cores

SuperMUC SUPERCLUSTER: 8,200 2.4 GHz CPU cores

z = 37.1

T = 0.08 Gyr

500 kpc







But how about galaxies? How do we make them?



But how about the galaxies? How do we make them?



EAGLE: Evolution and Assembly of GaLaxies and their Environments

The evolution of intergalactic gas. Colour encodes temperature

z = 14.0 t = 0.3 Gyr L = 25.0 cMpc

The Eagle Simulations EVOLUTION AND ASSEMBLY OF GALAXIES AND THEIR ENVIRONMENTS

The Hubble Sequence realised in cosmological simulations







SDSS galaxies

The complexity of galaxy formation simulations



Simulations are getting more and more sophisticated and we can put more detailed physics in them

Many processes that are involved in galaxy formation are not well understood yet and that is partially because we are resources-limited

A lot of the planning for how to do surveys with upcoming telescopes depend on how precisely we can simulate galaxy formation in a cosmological contents!

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I will miss ESO a lot!!