Virtual Galaxies

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Speakers:

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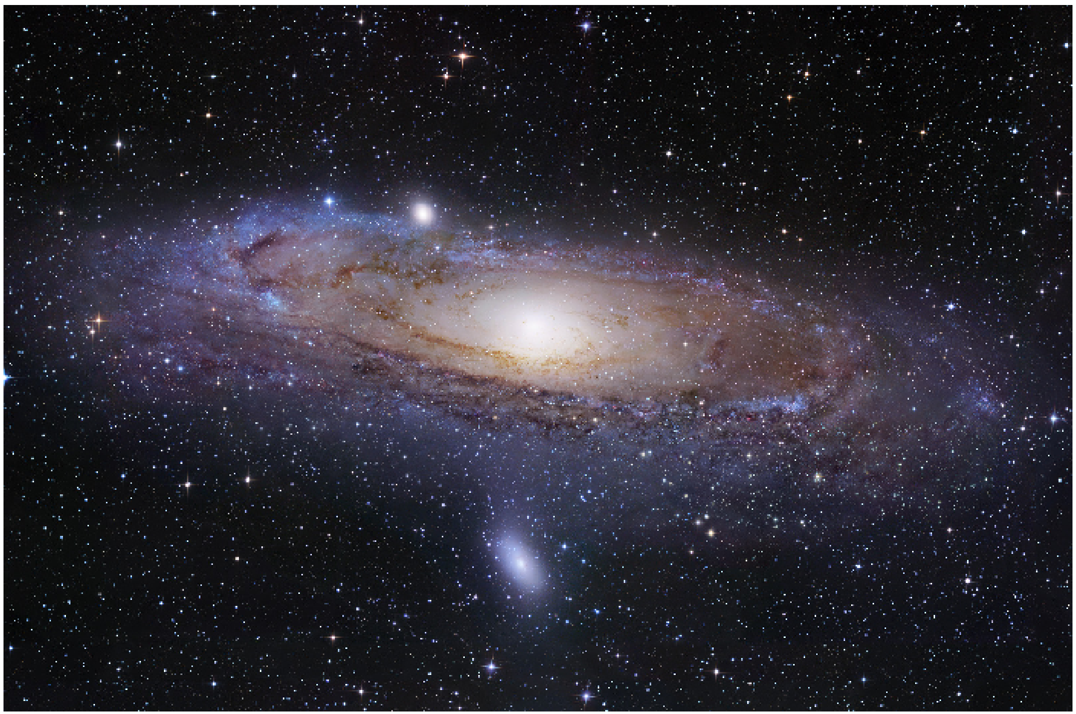
Introduction overview

- Why “Virtual Galaxy”?
- Brief history of our understanding of galaxies
- Computer modeling of galaxy formation

Why “Virtual Galaxy”?

- To make galaxies in a lab is just impossible.
  - (true for almost every astronomical object...)

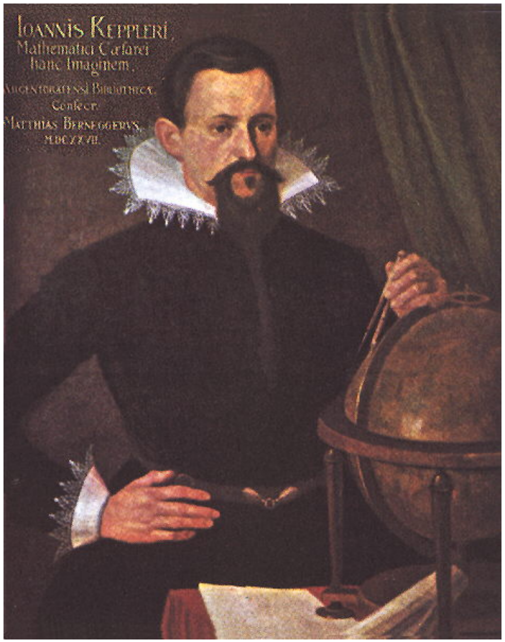


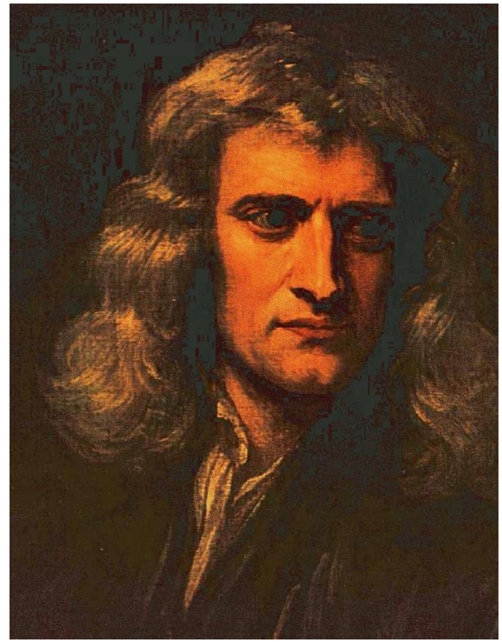
- Timescale depends on average density.
- Real experiment would require degenerated matter

So how we study astronomical objects?

Modern Astronomy

Kepler's laws explained by Newton's equation of motion and law of gravity.



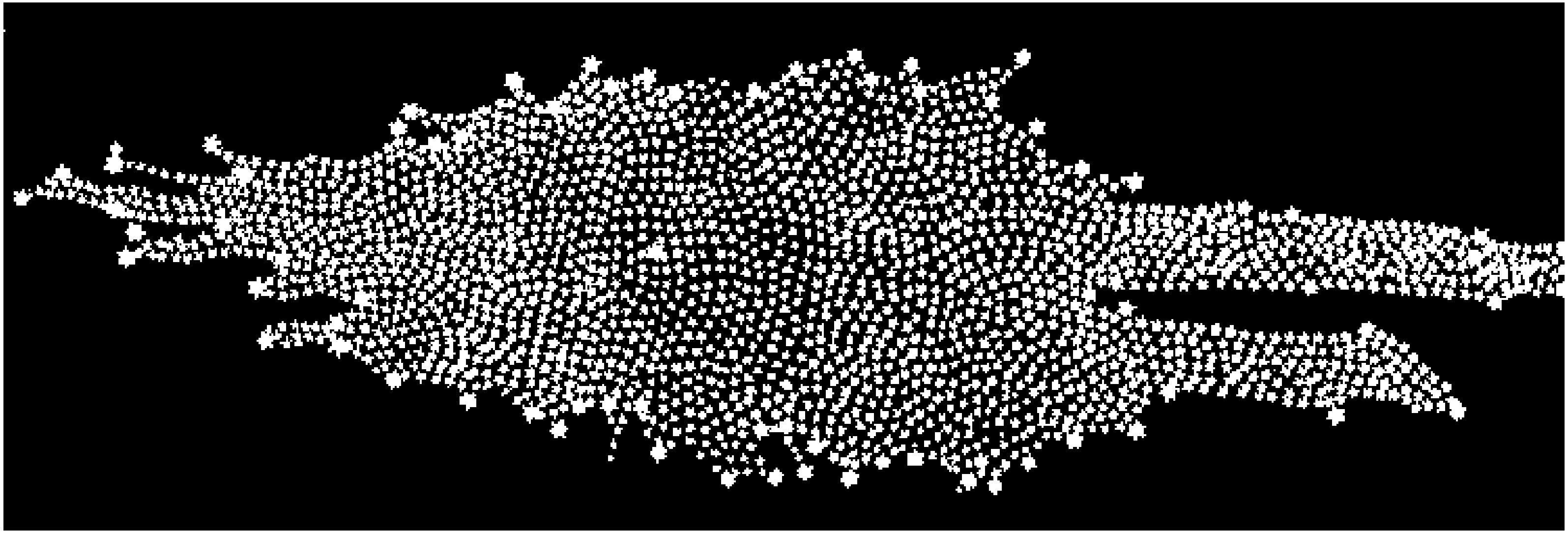


Behavior of heavenly bodies can be described by physics laws we learn from experiment.

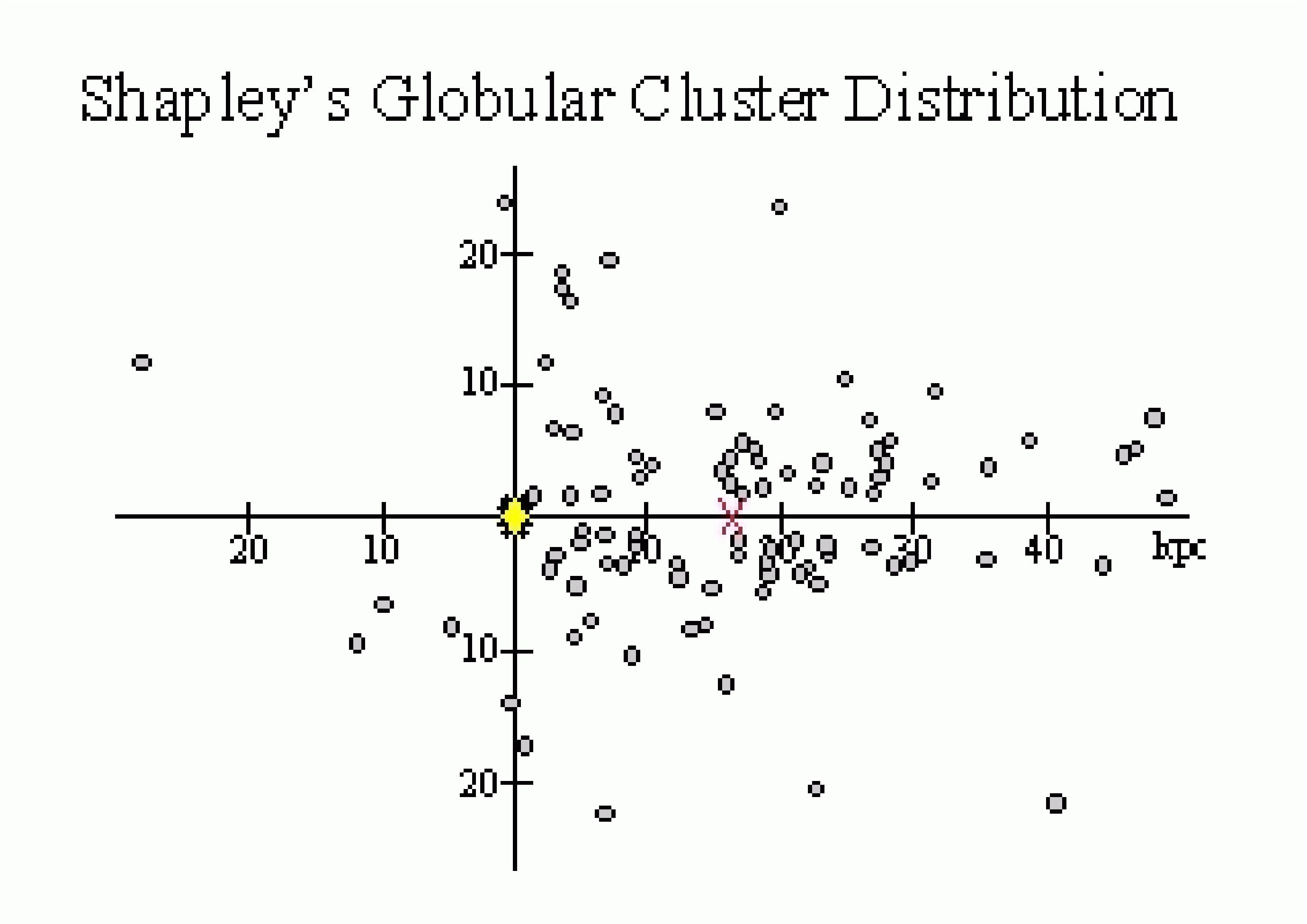
Certainly true for motion of planets. How about stars and galaxies?

History of our understanding of galaxies

18 C: W. Herschel
assumed all stars are of the same luminosity.

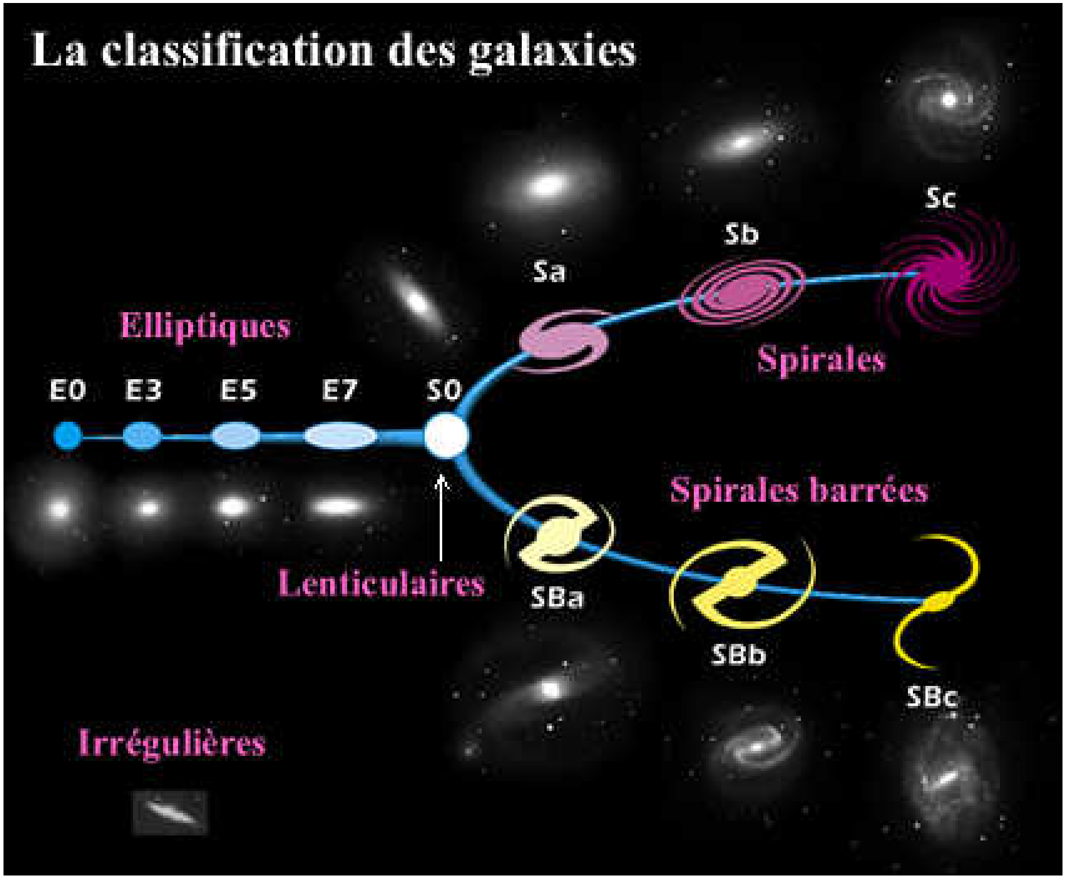


Early 20C: H. Shapley



Our solar system is not at the center of the Galaxy.

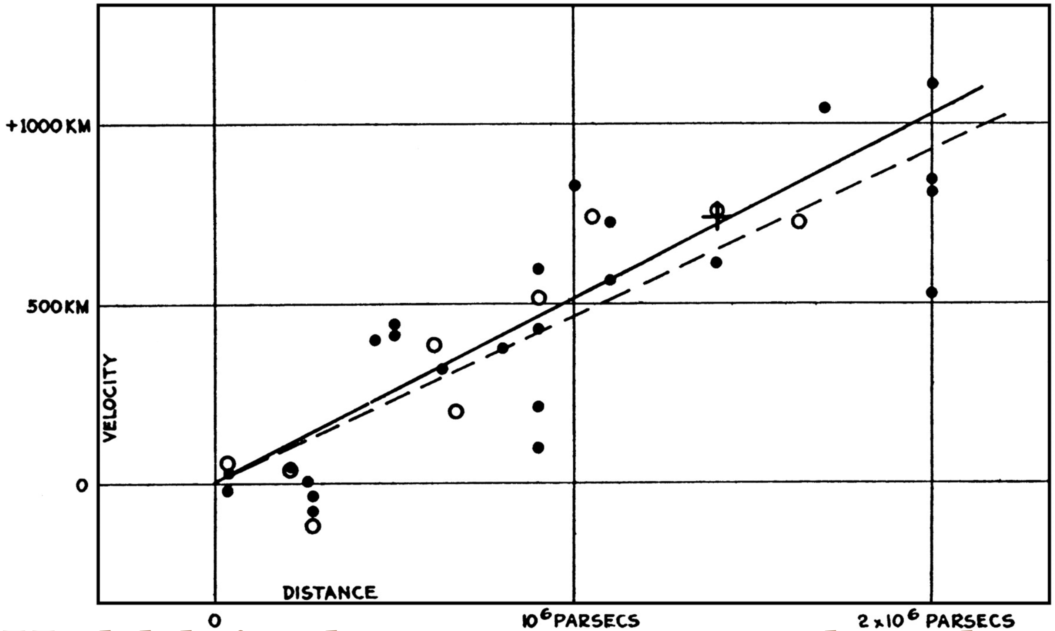
Early 20C: E. Hubble (1)



Many nebulae are galaxies similar to our own.

Galaxies can be classified to "Hubble Sequence".

Early 20C: E. Hubble (2)



Distant galaxies are receding from us faster than nearby ones.

”Cosmic Expansion”

Our universe started with ”Big Bang”.

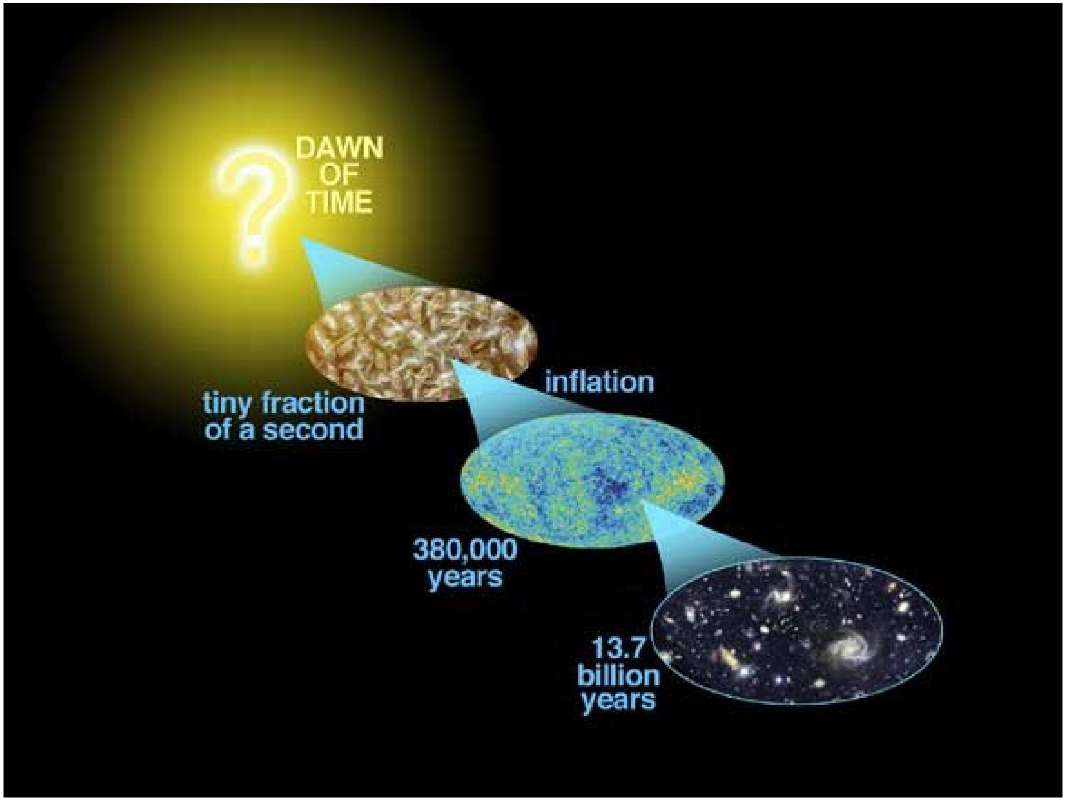
Hubble’s data was wrong by almost a factor of 10, resulting in a very short age estimate...

Basic question

Can we “understand” galaxies from basic laws of physics?

- **Essentially the same question as that Newton asked for the motion of planets.**
- **Somewhat more difficult to answer...**
  - **Initial/boundary condition**
  - **Equations to be solved**

Initial/boundary condition



Big bang

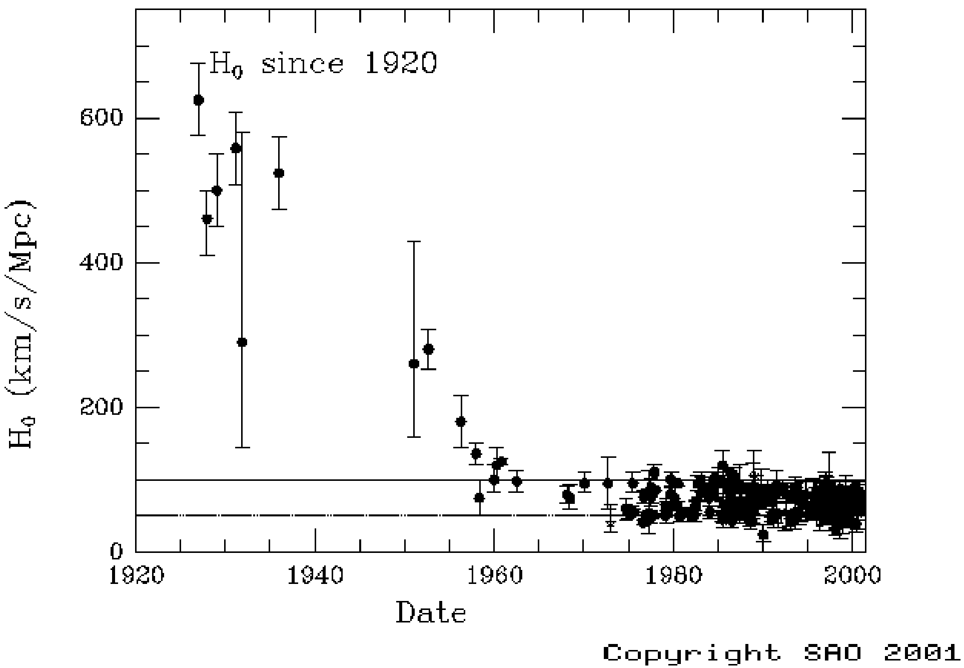
Small density fluctuations
$\rightarrow$ gravitational instability
$\rightarrow$ galaxies

Determining initial/boundary conditions

- **How the universe as a whole behaves?**
- **What's the origin of the fluctuations from which structures evolve?**

- **Until very recently, there was no consistent model which has no serious flaw.**
- **Partly because over-interpretation of observational data...**

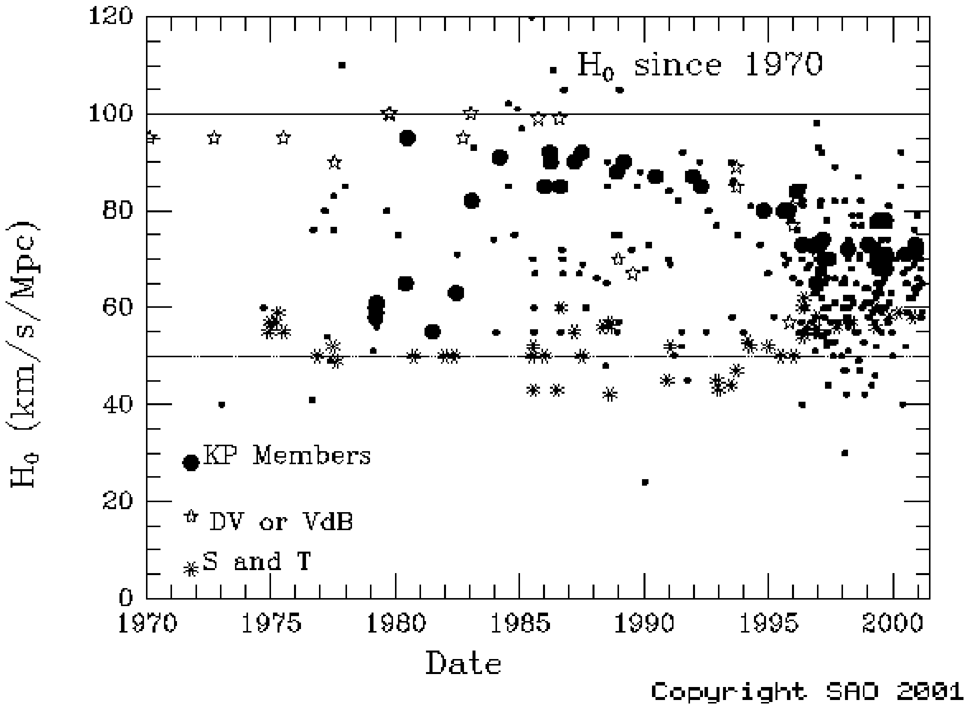
Variation of Hubble's "constant"



Causes of large errors:

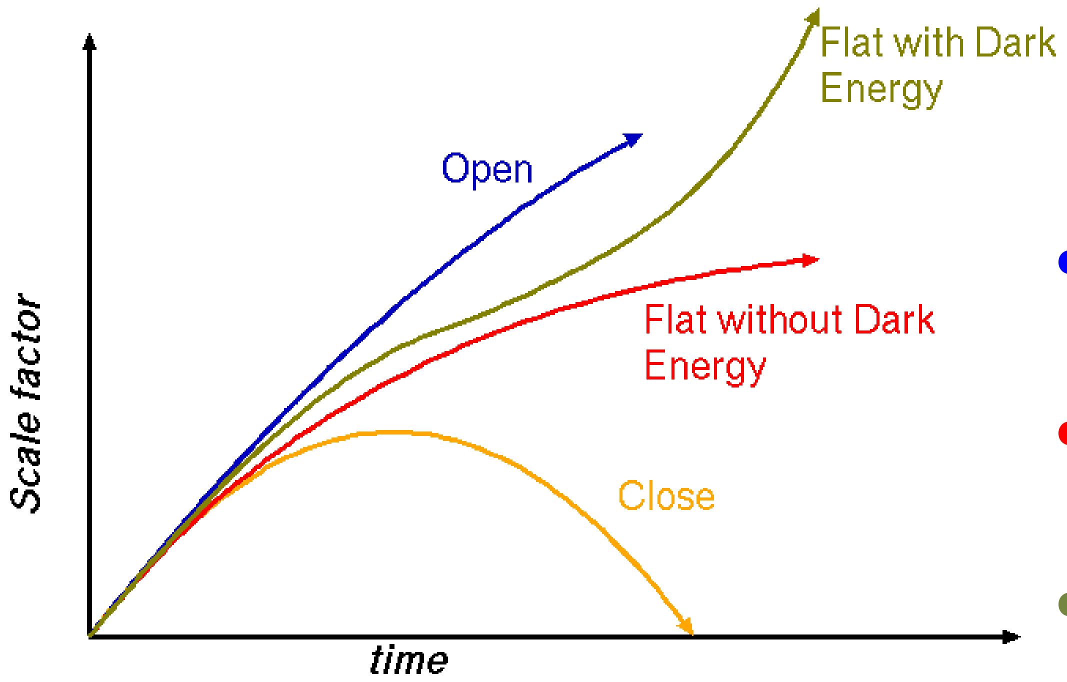
- **wrong interpretation of the luminosity of variable stars**
- **Effect of large-scale inhomogeneity of the distribution of galaxies**
- **...**

Variation of Hubble's "constant"



- Rather surprizingly, data from different measurements "converged".
- Hubble Space Telescope played a very important role.

The way the universe behaves



- **Open: Universe = Baryons**
- **F w/o DE: = B+Dark Matter**
- **F w DE: = B+DM+DE**

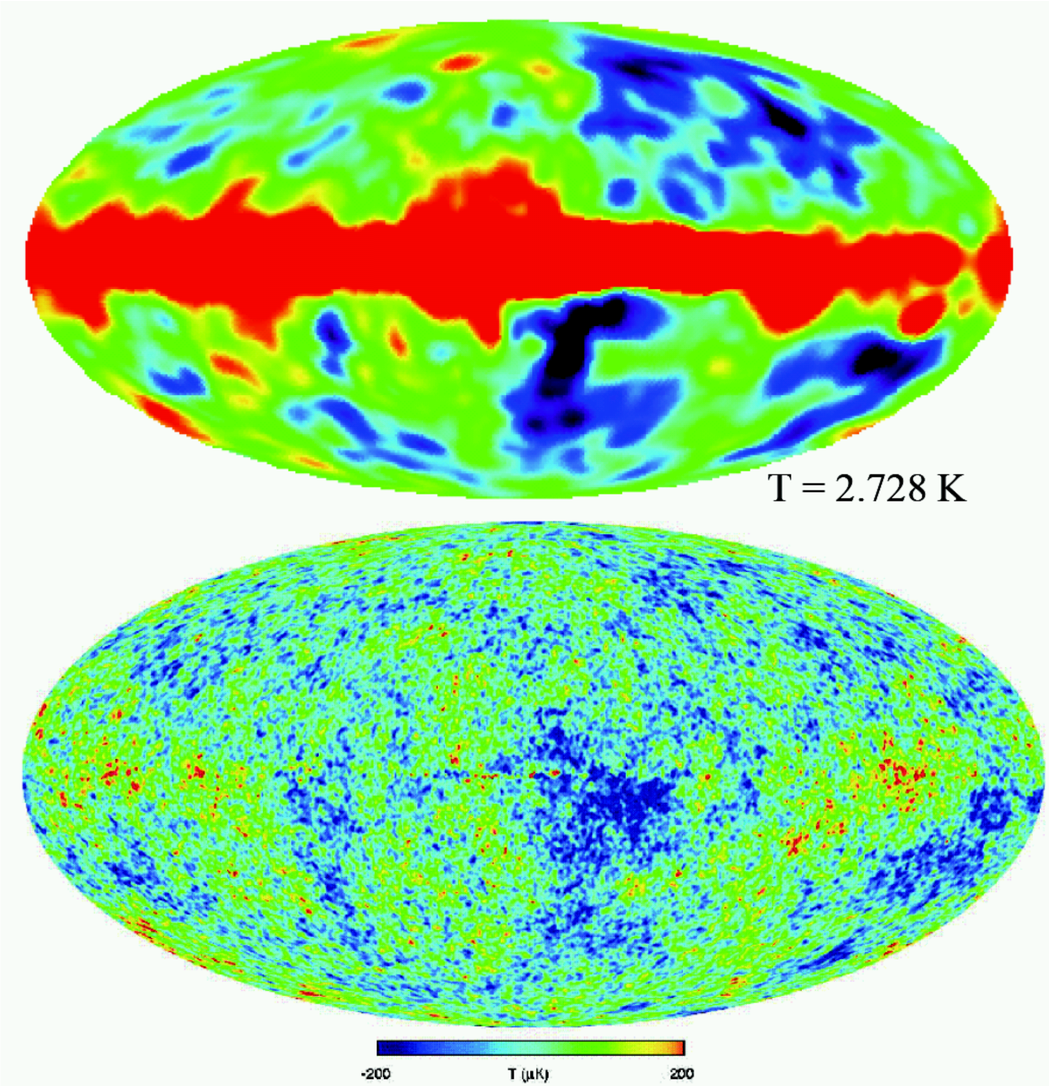
Measurements of distant Supernovae and other data rejected everything other than F w DE.

Origin of density fluctuation

- Thermal fluctuation
  - Hot dark matter (Neutrino)
  - Cold dark matter (Unknown elementary particles)
- Domain defects (Cosmic strings)
- others...

High-accuracy measurements provided us sufficient data to resolve the issue...
SDSS, WMAP, etc etc ...

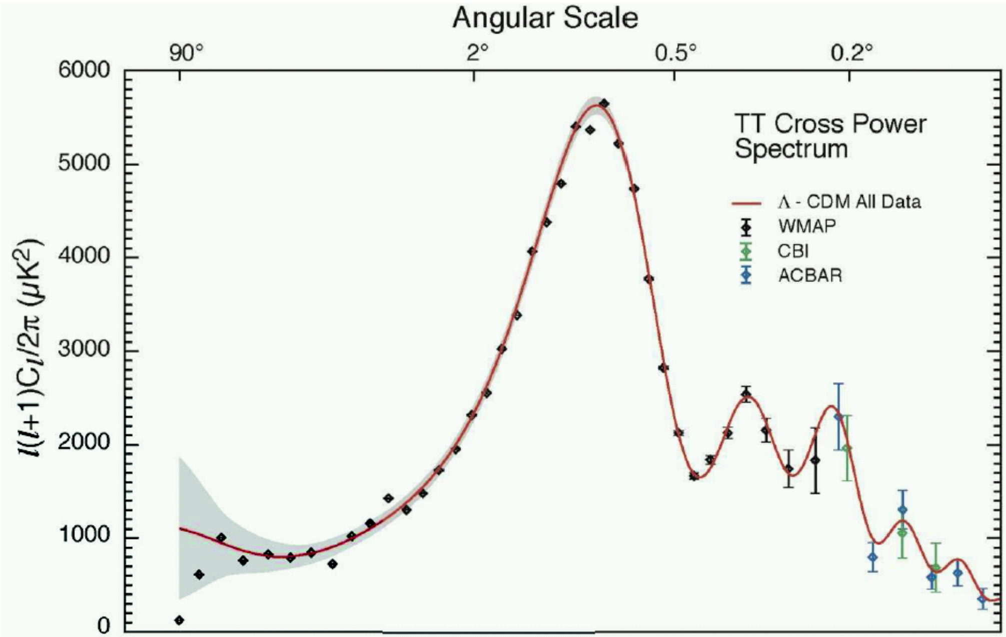
WMAP observation



COBE (1993): For the first time, fluctuation of cosmic microwave background actually measured!

WMAP (2003-): Much higher resolution and accuracy

WMAP power spectrum



Theoretical prediction (Flat, CDM+DE, Thermal fluctuation) agrees with observational data very well

(almost too well...)

"Concordance" Cosmology

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- **Flat universe with dark matter and dark energy**
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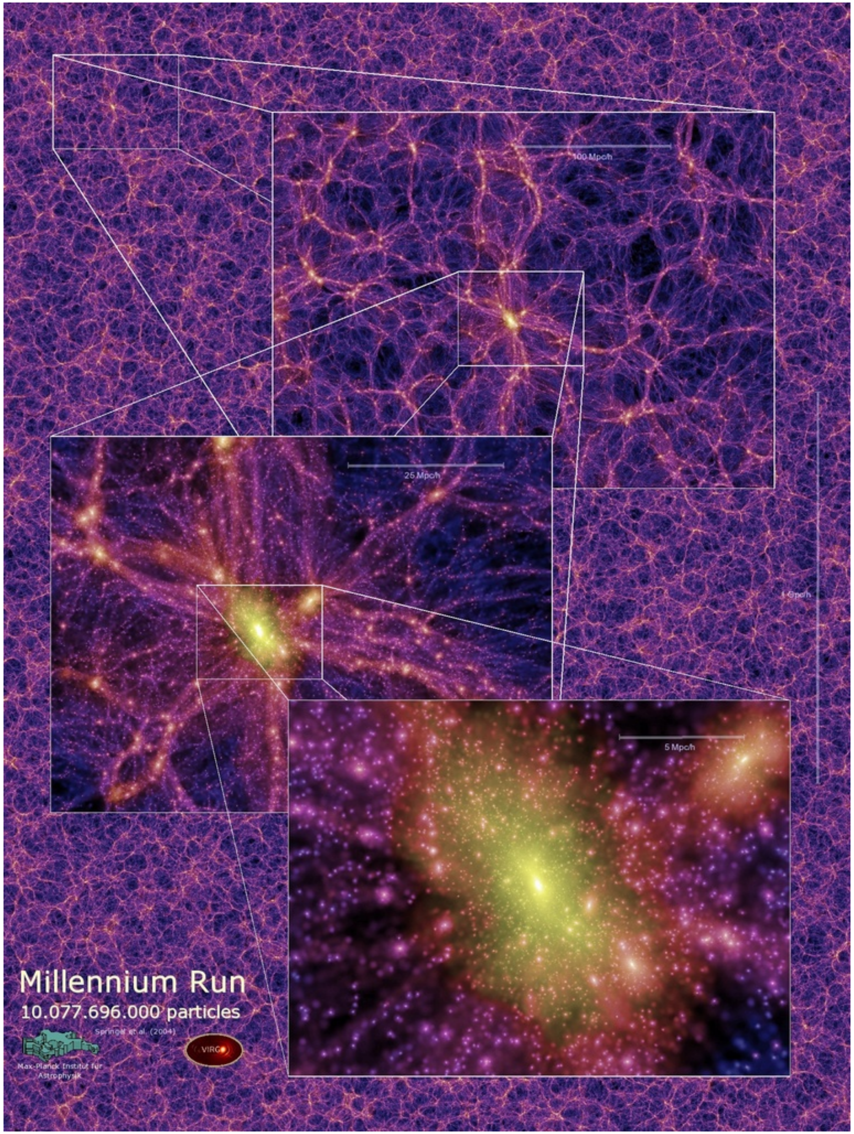
Solving equations

- Structure formation through gravitational instability
  - "Dark Matter", gravity and equation of motion
- Baryon (normal matter)
  - Hydrodynamics
  - Radiative transfer
  - chemical reaction
  - star formation and stellar evolution
    - nuclear reaction
    - ...

Dark Matter



Many-body problem

Gravitational interaction

“N-body simulation”

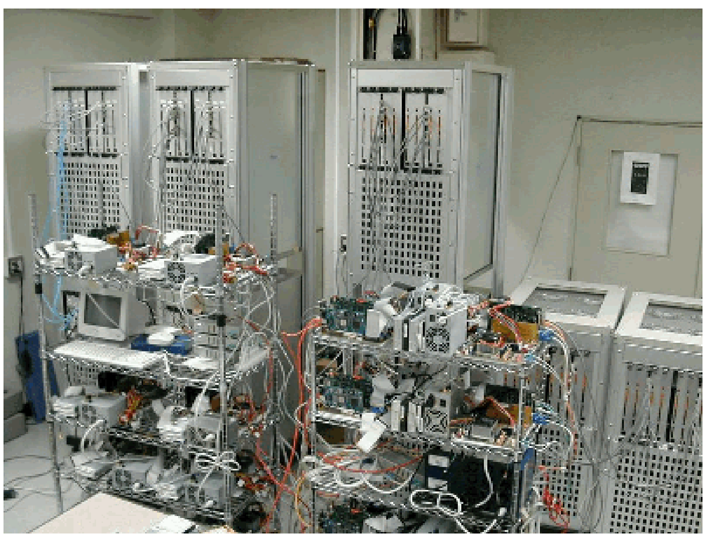
Up to 10^{10} particles

“Easy” part of the problem

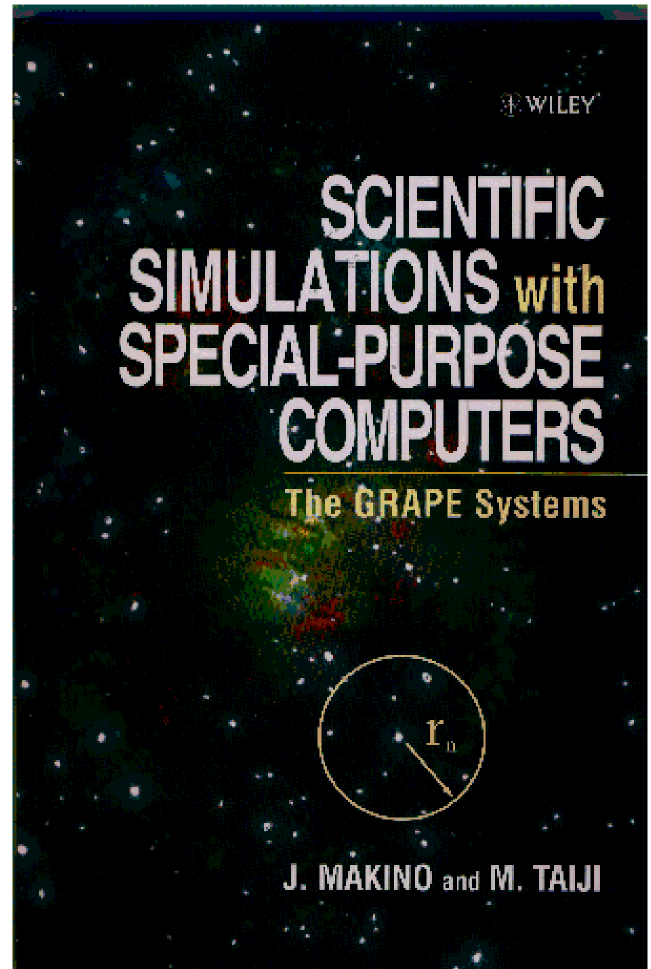
By the way, what I study?

I have been studying these easy problems. (called "stellar dynamics")

And even have built a series of computers to solve easy (but computationally expensive) problems.



GRAPE-6, 64 Tflops (2002)



Baryon Physics and more

Two approaches

- **Detailed simulation of single galaxy**
  - **Solve hydrodynamics**
  - **Solve radiative transfer (well...)**
  - **Model star formation**
  - **....**
- **"Semi-analytic" modeling of statistical sample of galaxies**
  - **Model the Baryon physics within each "Dark halo" as "sub-grid physics"**
  - **make statistical comparison with observations**

What we learned?

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Will be presented by two speakers.

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Will be presented by two speakers.

Stay tuned!

Speakers

- **Masao Mori**
  - **One of the most detailed simulations of single galaxy**
- **Julien Devriendt**
  - **Semi-analytic models**
  - **Full simulations**