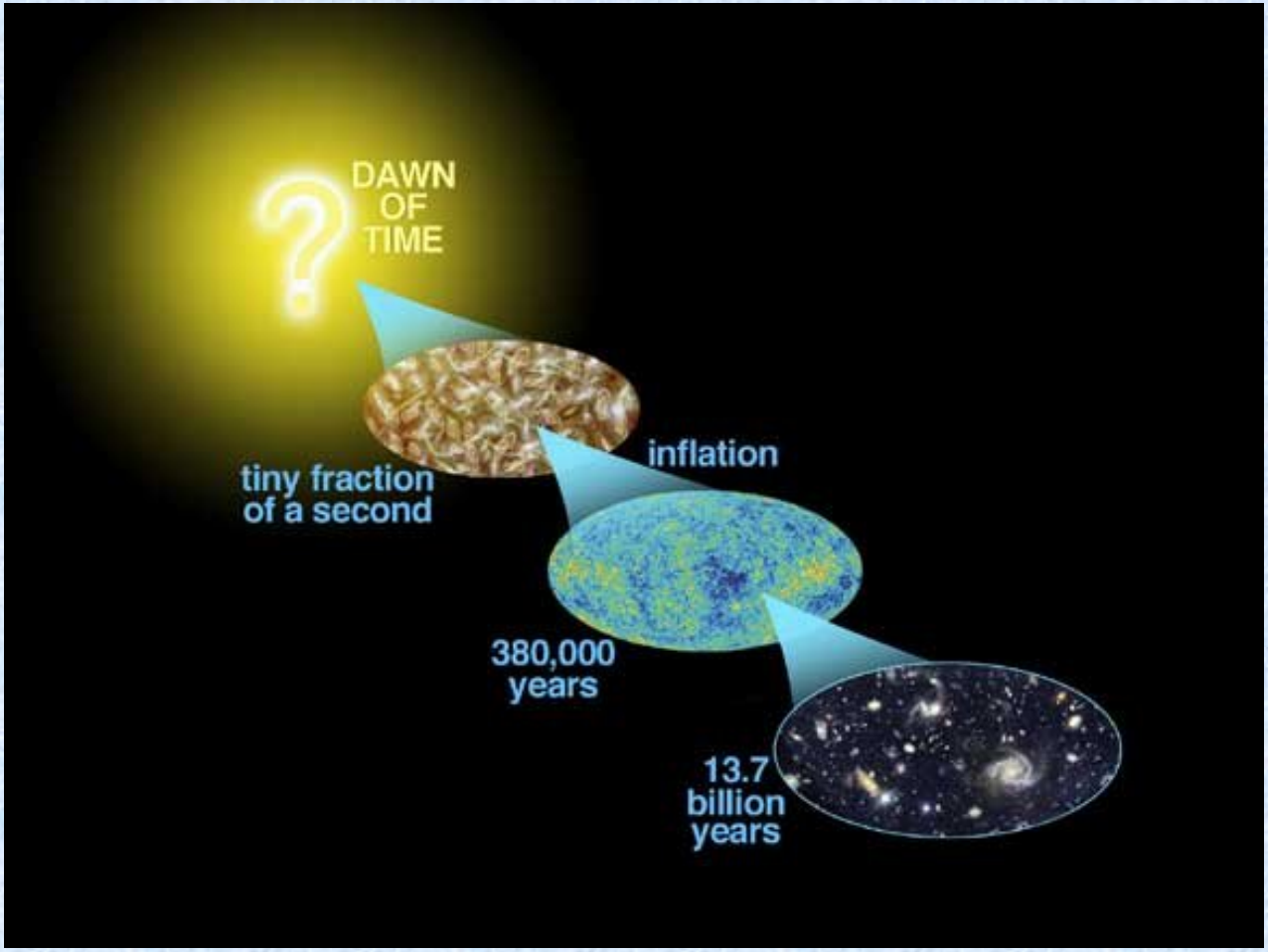
Origins



Lecture 15; May 29 2014

Previously on Origins

- Time of history/humans vs. time of "god"
  - What was there before time?
  - Does this make sense?
- The way we measure time influences the way we use time
  - The measure of time is a historical event and there is not only our way to measure time (linear vs circular)
- Independence of the laws of physics and speed of light on reference frame

Time: beginning, end.

- Time:
  - Definition
  - The twins paradox - measurements
  - The cosmological principle and cosmic time
- Observational foundations of the Big Bang Theory:
  - Olbers' Paradox
  - Hubble's Law

What is time?

- Time (interval) is what you measure with a clock.
- *The base unit of time in the International System of Units that is equal to the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the Caesium-133 atom (1967), at mean sea level (1980). This definition refers to a Caesium atom at rest at a temperature of 0 K (1997).*
- Note that in the IS a meter is defined as the distance covered by light in 1/299,792,458 seconds.

Why the funny numbers? History

- Previously the unit of time was (approximately) based on the rotation of the Earth on its axis (day) or around the sun (year).
  - Remember Augustine?
- But those change slightly with time..
- *As people needed more precise measurements of time they developed more precise definitions. E.g.:*
- The fraction 1/31,556,925.9747 of the tropical year for 1900 January 0 at 12 hours ephemeris time (1956).
- Today's strategy is to lock units to fundamental physical constants (remember Popper?)

Is it that simple?

- Not really…
- Time as measured by clocks depends on:
  - Reference frame (special relativity)
  - Gravitational field (general relativity)

How can we then speak about "cosmic time"?

- If the Copernican (or cosmological) principle holds…
- What is that???
- It is possible to define uniquely a cosmic time, valid throughout the universe!

Observational foundations of the Big Bang Theory

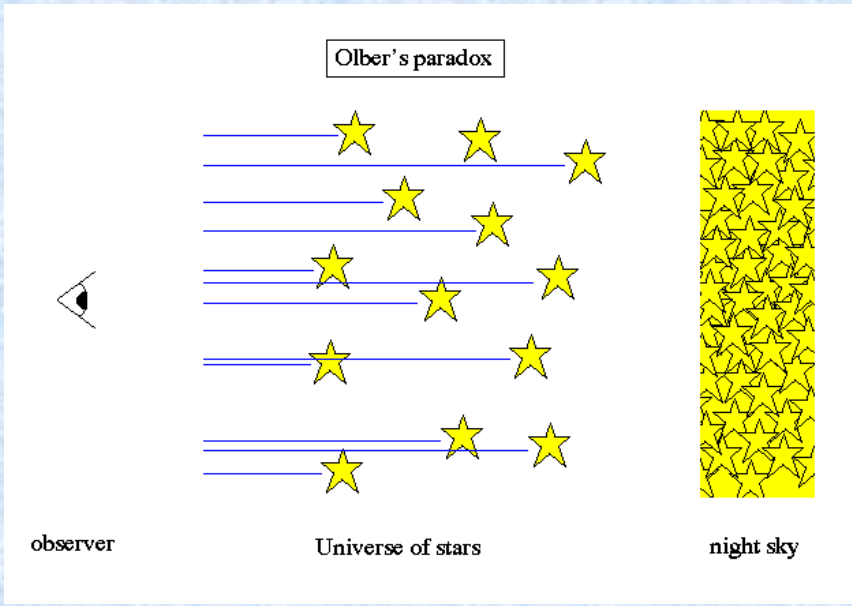
Olbers's paradox. A step back..

- Newton's model of the universe was:
- Eternal
- Infinite (otherwise it would collapse gravitationally)
- Flat Space
- Time independent of space

Isaac Newton 1643-1727

Olbers's paradox. What does the sky look like in Newton's model?

- For every line of sight sooner or later you find a star
- Surface brightness is independent of distance for a Euclidean flat space
- This would mean that the sky should have the same surface brightness of the Sun, your average Joe star.

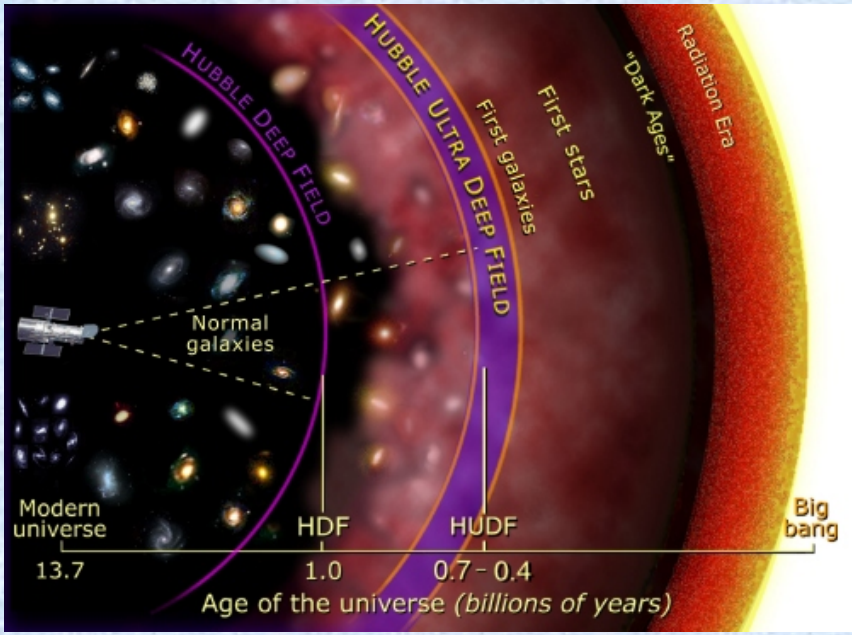


Olbers's paradox. Olbers's solution.

- Olbers postulated that the Universe was filled with an absorbing medium, like fog
- However, if light is absorbed it will also re-radiate, producing light albeit at different wavelengths, so this doesn't work!

Olbers's paradox. The Big-Bang's solution

- In the Big Bang model the Universe is finite in TIME (13.7 billion years)
- This means that we can only see as far away as light has had time to travel
- Furthermore stars were not always shining (the sun for example is 4.5 Gyrs old).



Olbers's paradox. Summary

- The night sky is dark
- This implies that the emission of starlight in the universe must be finite, in space, time or both.
- This is fundamental test for any cosmological model
- The Big-bang explains Olbers's paradox with the finiteness of the lifetime of the Universe and hence of its stars:
- The universe is NOT eternal in the past! The universe evolves!

Hubble's law: galaxies are moving away from us!

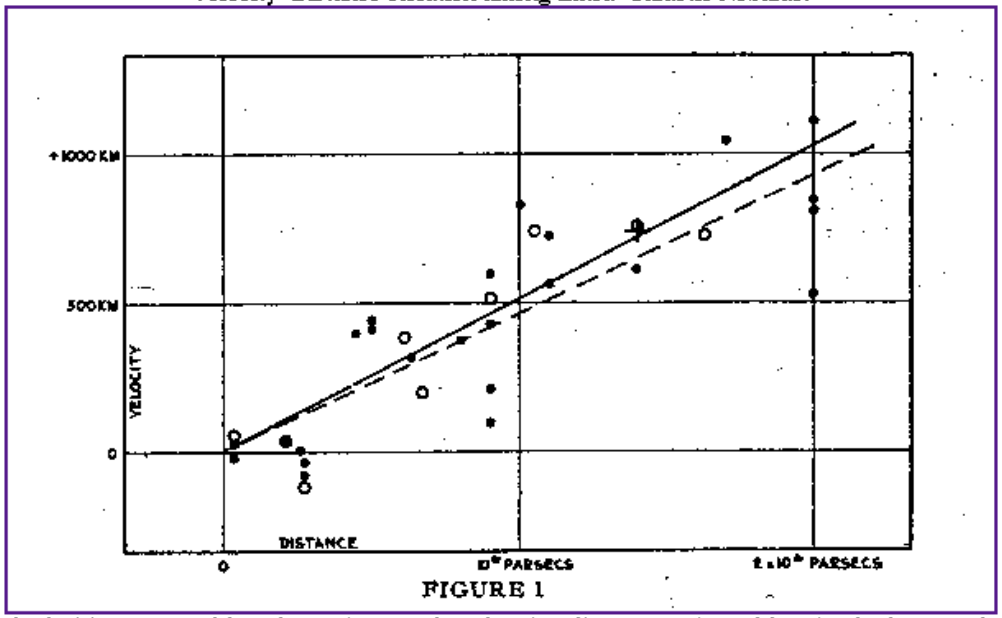
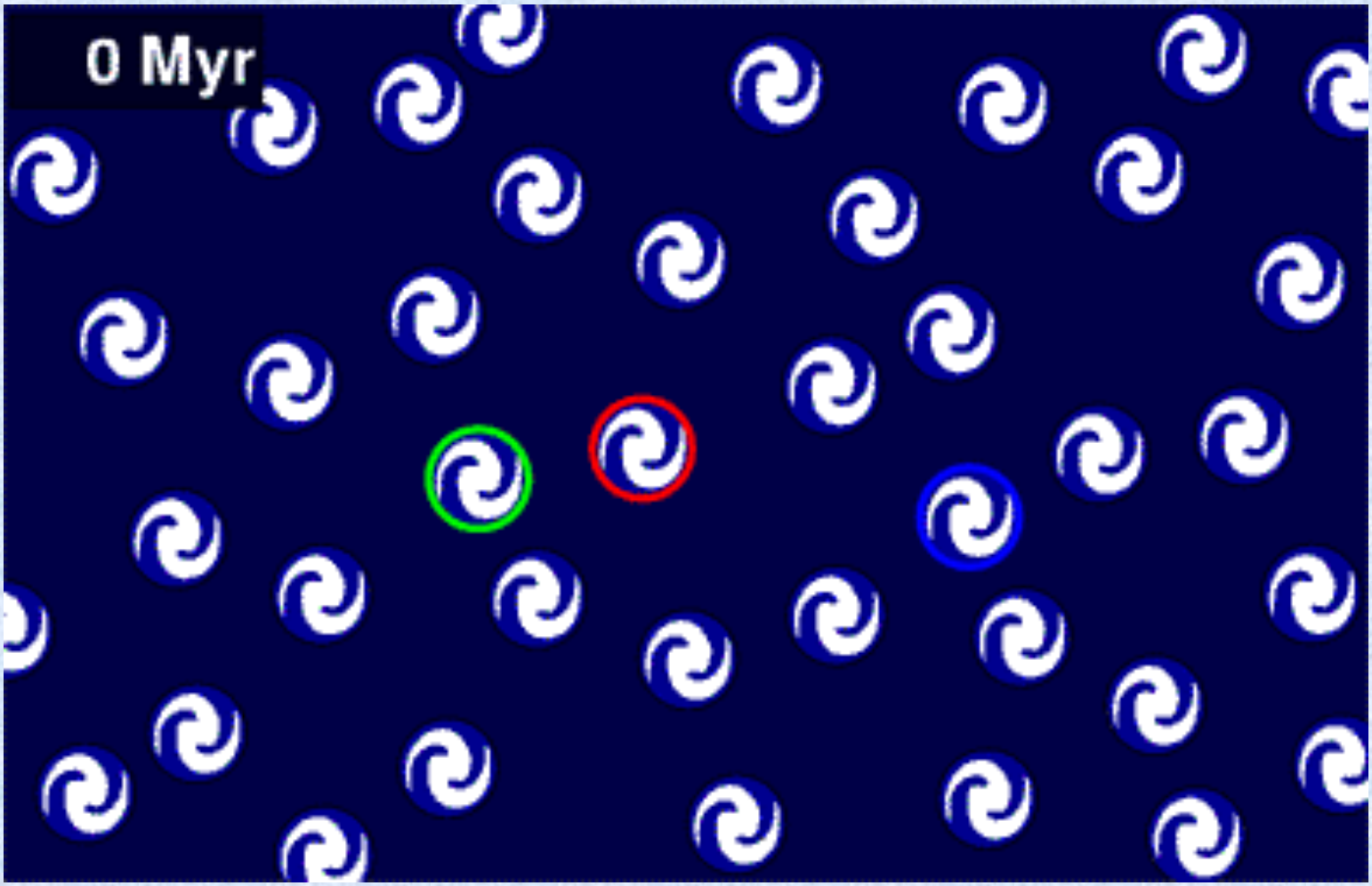


Figure 1: *Radial velocities, corrected for solar motion, are plotted against distances estimated from involved stars and mean luminosities of nebulae in a cluster. The black discs and full line represent the solution for solar motion using the nebulae individually; the circles and broken line represent the solution combining the nebulae into groups; the cross represents the mean velocity corresponding to the mean distance of 22 nebulae whose distances could not be estimated individually.*

- Hubble found that redshift (or velocity) is proportional to distance (Hubble's law): if you measure double speed, you also measure double distance!

The Big Bang explanation: The Universe is expanding



Frequently asked questions…

- What is the universe expanding into?
- Nothing, the universe is all there is, spacetime is expanding itself
- Where is the center of the expansion?
- Nowhere, there is no center, the universe is homogenous and isotropic
- Do we expand as well?
- No, because we are bound by electromagnetic forces
- Do galaxies expand?
- No because they are bound by gravity and they detach from the Hubble Flow

Summary

- Time intervals are defined by the way they are measured.
- We strive to define units in terms of fundamental constants (principle of invariance of the laws of physics)
- Homogeneity and isotropy of the Universe (copernican or cosmological principle) allows us to define a cosmic time
- The four observational pillars of the Big Bang Theory are:
  - The night sky is dark
  - Galaxies “move” away from us
  - There is a cosmic microwave background
  - He (and other elements) abundances are “universal”

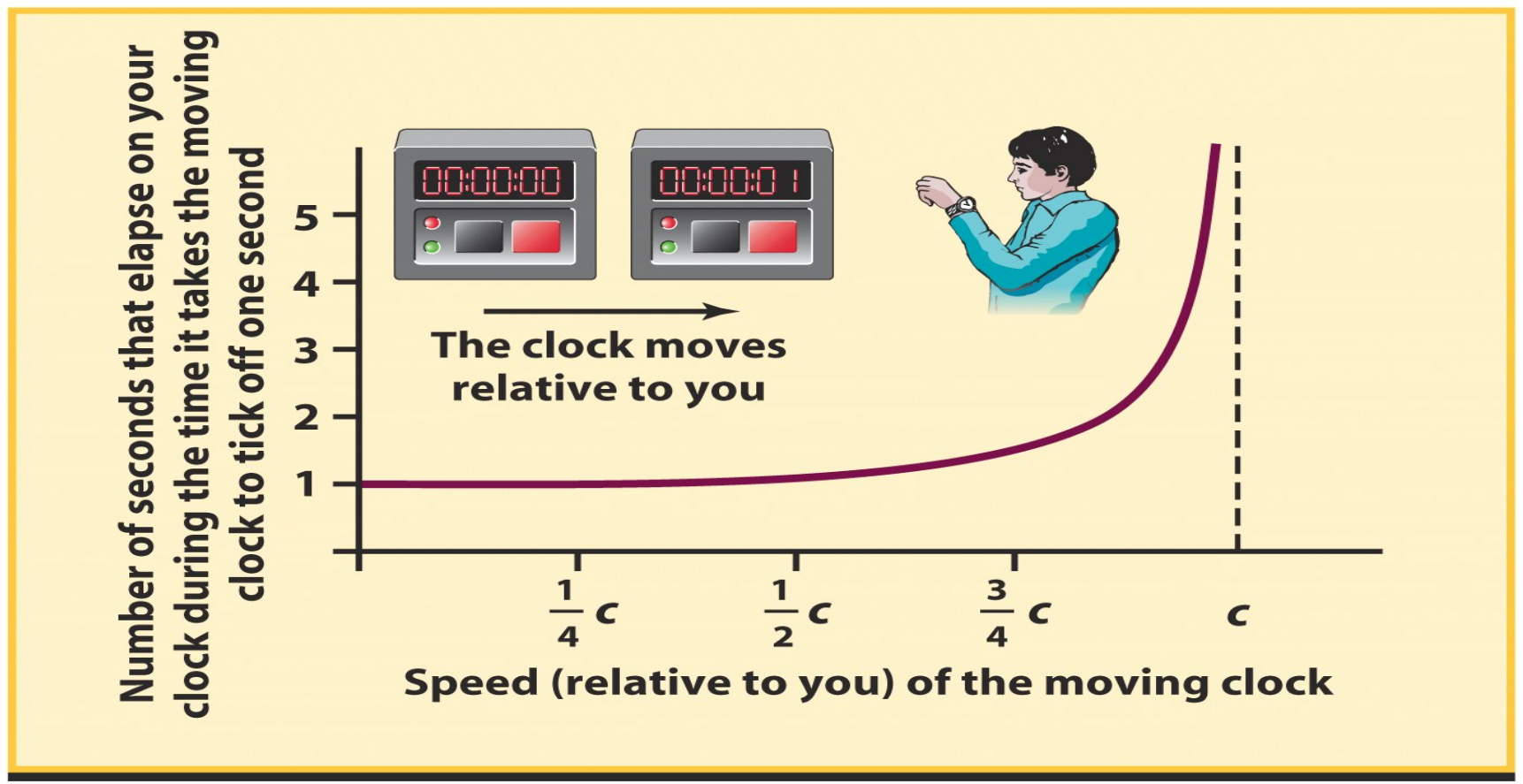
Where to get help

- Academic matters:
  - College of Letters and Science: 1117 Cheadle Hall (805-893-2038).
  - College of Engineering: 1006 Harold Frank Hall (805-893-2809).
  - College of Creative Studies: CCS Building 494, room 104 (805-893-5319).
- Any other matter: (805) 893-4411

The End

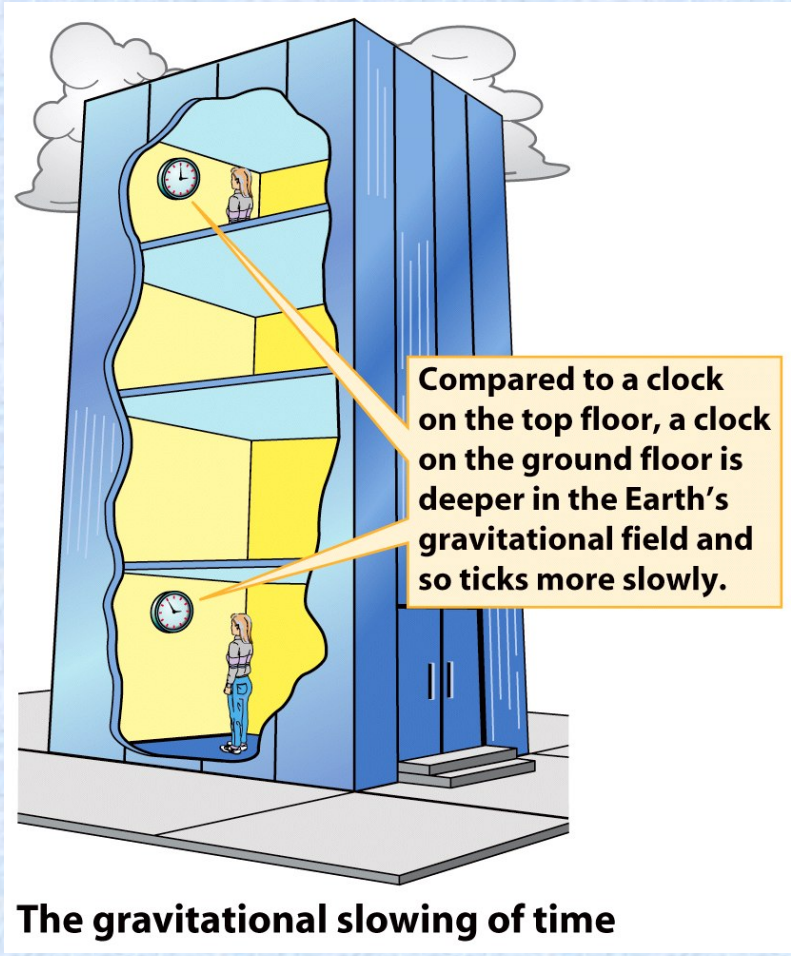
See you on Tuesday!

Relativity and Time. I



Time dilation

Relativity and Time. II



The gravitational slowing of time

Are you serious?
The twin paradox tested

- Hafele & Keating experiment (1971).
- Two atomic clocks on two airplanes (flying around the world E and W). A third one as a reference did not not move.
- Compound effects of gravity and speed.
- Expected vs measured (over ~40-50 hours):
  - -40+-23 ns vs. -59+-10 ns (E)
  - 275+-21 ns vs. 273+-7 ns (W)