Homework 22

Due Tuesday, May 14th in class

Two things to turn in:

1. List and explain three things you learned about time from this course that you think you will retain into the future.
2. What should everyone know about time?

Readings we have done so far and topics in each book that connect to the lectures and homework:

J & F-R *From Sundials to Atomic Clocks*: Chapters 12 -16.

- Why dividing the world into time zones is useful.
- Different "real world systems" that require precise time coordination.
- Sending out time signals to coordinate time or to determine position.
- Re-reading Chapter 16 would be a nice review of our Physics of Time discoveries.

Rovelli *The Order of Time*: Chapters 9-12.
Carroll *From Eternity to Here*: Chapter 8.

- Increase in entropy ($\Delta S > 0$) corresponds to the direction of time.
- Time for macroscopic systems "emerges" from the time-less microscopic world.
- **Thermodynamic Arrow of Time:** Our choices of macro-descriptions (*blurring*, or *coarse graining*) determine the entropy, which in turn is where our notion of time comes from.
- Examples in class (playing cards) or in physics (gas spreading out in a box).
- Entropy (and thus time) are not *arbitrary*, but it is *relative* to our perspective.
- It is not *Energy sources* that we need, it is *sources of low Entropy. E.g.* the sun is a source of low entropy photons, which interactions on earth use to make things happen, generating high entropy heat in the process.
- But why was the entropy of the universe low at earlier times?
  - Maybe that's just the way it is in this universe (*Past Hypothesis*).
  - (Rovelli) We organize the world by our particular interactions with things, which gives $\Delta S > 0$.
- We have evidence of what we call "the passage of time" from the traces and memories that we sense, our basis for "cause and effect" explanations. Cause $\rightarrow$ effect is assymetric in time.
- **Quantum Time:** Until Hal & Carlo solve this, we won't ask you exam questions on it.
- The indeterminacy that all quantum systems have might be a kind of blurring.

Burdick *Why Time Flies*: Chapter on "The Present"

- We construct our sense of time from a variety of sensory input.
- There is no simple "ticking clock" in our brains ordering things in time.
- Insights about our sense of time from the psycho-physics of time perception experiments.

Lessons from labs:

- Electronic circuits and radioactive decay as types of clocks.
- Interchangability of time and frequency information for clocks.
- How to calculate averages and standard deviations, and what they mean.
- Why this is not a useful way to quantify variation in clocks.
- The ideas behind the Allan variance.
- Variation in these "clocks" and what we can say about them.
- Insights about our sense of time from the psycho-physics of time perception experiments.

Physics we studied, and relating them to clocks:

- Hafele & Keating experiment testing relativistic time dilation.
- Motion and gravity and their effect on time.
- The process of resonance, and why Q matters for clocks..

Thought questions, some of which may appear on the exam in some form:

1. (J & F-R, p. 179) Explain and comment on the quote, "'Better clocks mean more communication capacity."
2. In the radioactivity lab, you got a rate constant for Barium from your linear fit, $\lambda \approx 0.004\ s^{-1}$. What does that number mean?
3. The logarithm data that you plotted in that lab was close to the fit line, but did not fall exacty along the line. What do you think that was?
4. In the Pendulum Stability lab, your groups all got slightly different answers for how much time 100 boings of mass-spring system took. What contributed to that uncertainty?
5. (Repeat from HW #20) Why does Rovelli bring the observer's perspective into the discussion of entropy?
6. Choose one of the neuroscience experiments described in the Burdick reading, and
   (a) Describe the procedure of the experiment.
   (b) Describe the results of the experiment.
   (c) Comment on what this result tells us about human perception of time.