Comparison of Lengths Relevant to Our Universe

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This project has been used in an introductory physical geology course that has no prerequisites. This activity is used near the beginning of the course as we are discussing the ranges of such things as length, time, velocity, temperature, and pressure that affect the physical reality we study in geology. The results can be referred to in subsequent discussions, so it is best to use this exercise early in the semester. Students need to have a basic understanding of exponents (leading to scientific notation), which is reiterated at the beginning of the exercise.

Description

I usually begin with a story about lying on a cot looking up at the stars on a dark night in the mountains, seeing countless stars and the hazy Milky Way stretching across the sky. I talk about how they seem to be part of a celestial dome rising very high above me, and I note that I do not have any way to know, as I am looking at the stars above me, how far they are away from me. I talk about how ancient people used and envisioned the stars. I mention the experiment with the Hubble Space Telescope in which the "darkest" and most empty part of space was imaged, and found to contain countless distant galaxies (search on *Hubble deep field*).

I mention that this often leads people to consider how insignificant they are in the scheme of things. My feeling is that you are only as significant (or insigificant) as your actions make you.

I then talk a bit about how we now know that "visible" matter is organized into atoms, which are very, very small. In a way, they are like the stars in that they seem to be incomprehensibly small, while stars seem to be incomprehensibly large and distant. I then pose the question, “How does the part of this world that we observe and experience on a daily basis fit into a physical reality that spans from the incomprehensibly small to the incomprehensibly large?”

I pass-out the blank worksheet "Comparison of Lengths Relevant to Our Universe" to every student, and have them organize into groups of 2-3. The task is to fill-in the exponents corresponding to 9 distances listed in a box on the page, and to locate those distances on the logarithmic scale. I give them a couple of minutes to start working with the page, and then interrupt to ask what they need help with. This usually involves determining one of the lengths involving light years on the board. I let them complete the tasks in their small groups, then I ask group representatives to call-out their results.

Working from a set of correct answers, we then discuss the scale. For example, we note that there is a greater difference (in orders of magnitude) between the size of a proton or electron versus the size of a hydrogen atom, and the height of a person and the peak elevation of Mt. Everest. It is usually noted that humans fall near the middle of the length spectrum of the universe, which was also noted by Primack and Abrams (2006). Some students place great importance on this. I tend to note that there is a practical limitation to the size of individual cells that will have predictable functions (they need to be larger than the length scale governed by quantum mechanics) and constraints on the upper size limit of organisms made of cells, which determines where we are on the scale.

Resources

Joel R. Primack and Nancy E. Abrams, 2006, The view from the center of the universe: New York, Riverhead Books, 386 p., ISBN 1-59448-914-9

Robert B. Laughlin, 2005, A different universe, reinventing physics from the bottom down: Cambridge, Massachusetts, Basic Books, 254 p., ISBN 0-465-03828-X

http://en.wikipedia.org/wiki/Emergence

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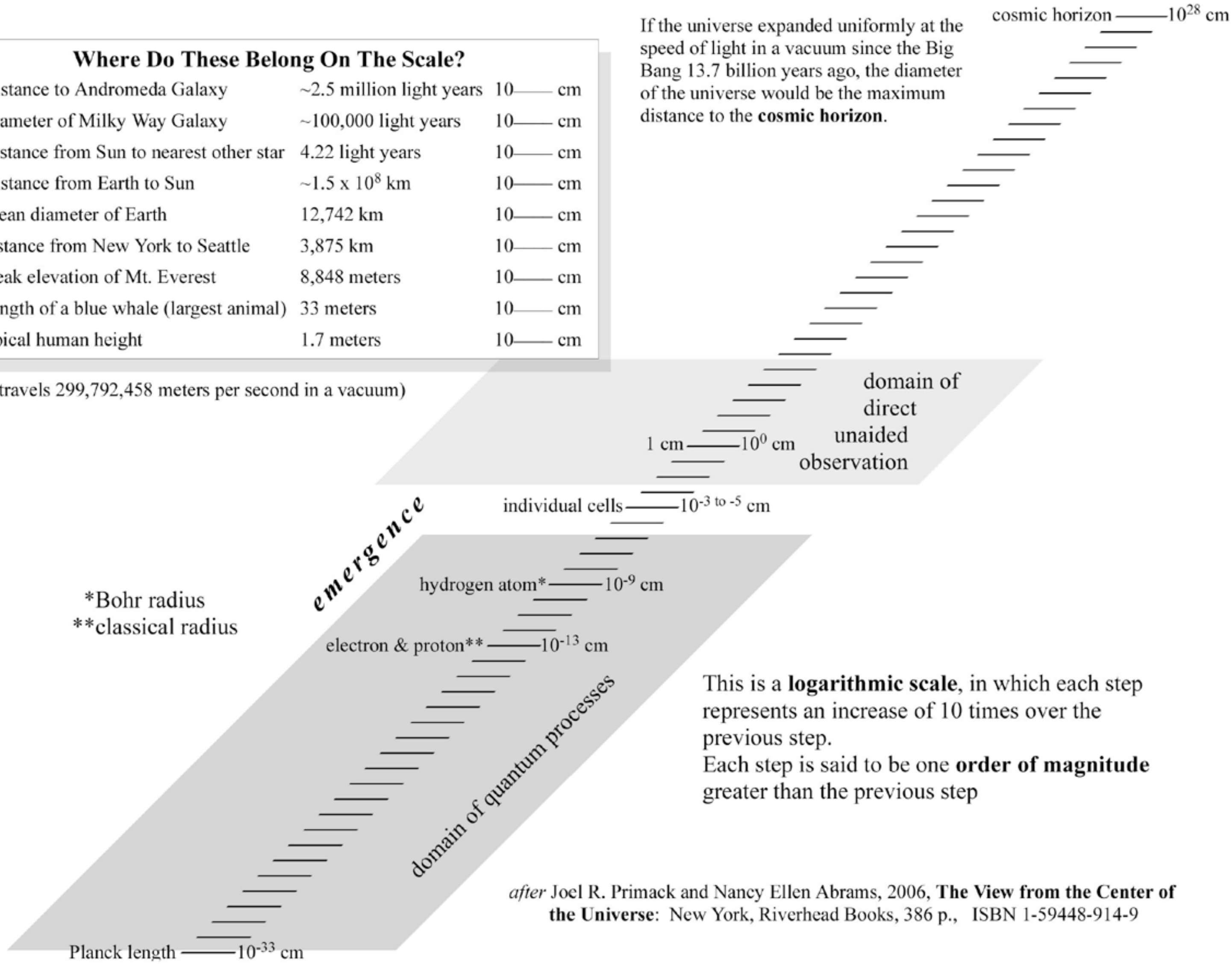
Where Do These Belong On The Scale?

A. distance to Andromeda Galaxy	~2.5 million light years	10—— cm
B. diameter of Milky Way Galaxy	~100,000 light years	10—— cm
C. distance from Sun to nearest other star	4.22 light years	10—— cm
D. distance from Earth to Sun	~1.5 x 10^8 km	10—— cm
E. mean diameter of Earth	12,742 km	10—— cm
F. distance from New York to Seattle	3,875 km	10—— cm
G. peak elevation of Mt. Everest	8,848 meters	10—— cm
H. length of a blue whale (largest animal)	33 meters	10—— cm
I. typical human height	1.7 meters	10—— cm

(light travels 299,792,458 meters per second in a vacuum)

If the universe expanded uniformly at the speed of light in a vacuum since the Big Bang 13.7 billion years ago, the diameter of the universe would be the maximum distance to the **cosmic horizon**.



*Bohr radius
**classical radius

This is a **logarithmic scale**, in which each step represents an increase of 10 times over the previous step.
Each step is said to be one **order of magnitude** greater than the previous step

after Joel R. Primack and Nancy Ellen Abrams, 2006, **The View from the Center of the Universe**: New York, Riverhead Books, 386 p., ISBN 1-59448-914-9

The **Planck length** is defined by three physical constants that are fundamental to the classical and quantum models of gravity and that combine in a dimensional analysis to yield a distance. The three constants are the Planck constant, the speed of light in a vacuum, and the gravitational constant. The Planck length is thought to be the smallest meaningful length in Nature, corresponding to the smallest distance over which quantum gravity operates.