Understanding Units, Orders of Magnitude out to Cosmic Distances, and Scientific Vocabulary

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From the Subatomic to the Intergalactic

• activity: Sitting individually ponder these questions --
  – What is/are the smallest (in length and/or volume) thing(s) you can think of? Estimate their sizes using the metric system, and/or whatever units you feel most comfortable with as well
  – How much smaller than a person is the smallest thing you came up with? (Estimate the ratio)

• Get into groups of 6 to discuss for 5 minutes this now
  – Repeat the above exercise for LARGEST
  – How much larger than a person is what you’d thought of?

• A useful video, and drawing to recap, illustrating “orders of magnitude” on the web
  – http://htwins.net/scale2/?bordercolor=white
  – http://xkcd.com/482/ (uses a “logarithmic scale” plot)
Introductory Stuff

• Who I am: Dr. Matthew Szydagis, Assistant Professor of Physics. Office: PH 312 (where office hours will be held). I am an experimental astroparticle physicist looking for dark matter (you can Google “Szydagis LUX”)

• Read the syllabus, provided both on paper here today for you, as well as available digitally online as HTML

• Avail yourself of the invaluable resource of the course site (URL in syllabus), where everything will eventually end up getting posted
  – I DON’T use Blackboard. Grades will be e-mailed you weekly by the TA

• How class discussions will work: To keep everyone fully engaged, during most lectures we will break up into small groups to ponder some question(s) I’ve posed. Most often, this will have something to do with the reading of a previously assigned article. This activity will reinforce what you’ve read and heard. On Fridays, it’s online.

• The only homework will be to read and answer quiz questions online on your reading and on my lectures, every single Monday, Wednesday, & Friday, starting TODAY! Lowest 3 scores dropped

• NO textbook: save yourself some $$$

• My goal: keep math to a minimum, to enhance enjoyment for non-majors, and focus on cultivation of an appreciation of science
WELCOME TO PHYSICS 100: CONTEMPORARY ASTRONOMY (pretty pictures will be included)
The Basics of the Metric or SI System

• Three fundamental units: for distance, mass, and time (the meter, the kilogram, and the second). Traditionally also known as the “mks” system (default “metric system”) but others exist like cgs (centimeter-gram-second)

• Space, time, matter, energy: space and time are intimately coupled (general relativity), as are matter and energy ($E = mc^2$), and then so are space-time and matter-energy (GR). Once you have defined a standard and a unit as a basis for three (actually, two) of the four physical quantities, the fourth can be derived

• In fact, all other units can be derived from mks, sometimes in multiple different ways. Examples:
  – Temperature is just energy, which is just mass
  – Speed is just distance/time, velocity is speed with a direction attached, acceleration is speed per unit time (and the “jerk” is acceleration per unit of time)
  – Force is the product of mass and acceleration ($F = ma$)
  – Momentum is the product of mass and velocity, but is also just the same as force per unit of time (change in force over time)
  – Electricity, magnetism, light, everything!
Measuring Quantities: Basis for the MKS

- The meter is today defined as the distance travelled by light in a vacuum in \(1/(299,792,458)\) of a second. (Used to be based on a fraction of the size of the earth: imperfect because not perfectly adjusted for earth not being a perfect sphere)

- The second is 9,192,631,770 cycles of the transition radiation defined by the two hyperfine levels of the ground state of the \(^{133}\text{Cs}\) (cesium-133) atom. (Used to be based on a fraction of the day: imperfect because length of day changes long-term as earth orbits.)
  - Why such strange definitions for the second (and the meter)? Because makes the speed of light in vacuum exact

- The kilogram is equal to the mass of an international prototype (made of platinum and iridium) housed in Paris.
  - Common misconception: weight and mass are not the same. Weight measures the gravitational force on a mass. In free fall, same mass
  - Another one: “weightlessness” in space comes from “falling around” the earth, not from being very far away from the earth
The SI system is based on powers of 10. Prefixes denote how many times you multiply the fundamental unit (mks, or their derivatives) by 10, or divide by 10.

- Prefixes from Greek, Latin
- Decimal point moves for unit conversion
- No mess of seemingly random numbers as with the customary/British Imperial system
- For 2-D or 3-D: square and cube the distance units (-> area, volume)

Let’s take 1 m as an example. That’s 39.3701 in. 3.28084 ft. 1.09361 yd. (1/100)=0.01 of 1 m is 1 cm (centimeter) (= 0.393701 in.)
Special Units Used in Astronomy

- Masses with special symbols (1 kg = 2.20462 lbs.)
  - Solar mass $M_{\odot} = 1.98892 \times 10^{30}$ kg (mass of our sun)
  - Earth mass $M_{\oplus} = 5.9742 \times 10^{24}$ kg

- Time (nothing special: days and years, Gyr for billion, etc.)

- Distance units (there are many)
  - 1 AU (astronomical unit) = average sun-earth separation (why “average”? The earth’s orbit is not perfectly circular, but slightly elliptical). About 149.6 million kilometers, or 93 million miles
  - 1 ly (light-year) = $9.4607304725808 \times 10^{15}$ m (the distance that light travels in one year in space. Compare: earth to sun is 8.3 light-minutes and earth to moon is 1.3 light-seconds). Not a unit of time!
  - 1 parsec = 3.26 ly, comes from “stellar parallax” measurement: more on that in lectures on light and on tools
  - Radius of the earth $R_{\oplus} = 6,378.137$ km, and of sun $R_{\odot} = 695,990$ km

- Solar luminosity $L_{\odot} = 3.939 \times 10^{26}$ W (energy per unit time)
Magnitude in Astronomy

- Brightness of stars and other celestial bodies
- Not measurement of size; distance important

Five magnitudes is a 100 times change in intensity of light: this is not a linear scaling

Reference point for zero varies (stars Vega, Arcturus...) Perhaps counterintuitively, negative numbers mean really bright!
What is a Logarithmic Plot?

Power-law data on a linear scale

Logarithmic, or “Log” for short

- Please note that the data points are absolutely identical between both graphs. This is just a different way of visualizing the exact same points
- Common misconception: log scale does *not* imply taking a log of your data
Notation for Order of Magnitude

• O(1) means 0.5-5, O(10) means 5-50, etc.
• This is an extremely powerful technique for making estimations to within a factor of ~10-100
  – For example, in a long series of multiplications, overestimations of some parameters will cancel out with underestimation of others
  – “Fermi problems”: How many piano tuners are there in San Francisco?
• Something else astronomers and physicists use: ~ (tilde, but in center not top of line) to mean “approximate,” like ~2 × 10^{30} kg for the mass of the sun. (This is not as well defined as O symbol)
• Significant digits: 3 has one, 3.0 has two, 0.1 has one, 0.10 has two, 10 has one, 10.0 (or 10.) has two, and 1.23 × 10^4 has three. This is about precision
Levels of Approximation

• You will often hear scientists speak of the “first-order” answer, or that a certain effect is “second-order” and can thus be neglected in a calculation. What does this mean exactly? (The word “order” here is not related to “order of magnitude”)

• These terms are often used loosely, but are based on the fact that many different non-polynomial functions can be well approximated by polynomials, and the term order refers to an integer power. As one concrete example, consider the Taylor series expansion of the exponential function:

\[
e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots + \frac{x^n}{n!} + \ldots
\]

• This and similar techniques are very powerful ways of describing the world, and are used in a surprisingly broad array of fields within physics

• Sometimes we don’t even have the “correct answer” as a function we can write down, so all we can do is approximate up to various orders
What About Astronomy?

- All of these foundational concepts in this and in the next lecture were/are important before we could even start talking about this course’s namesake (and view pictures of the cosmos!)
- But now, what is astronomy? First off, it’s not astrology, which is not a science: the belief that the stars and planets, all trillions upon trillions of miles away, can affect our lives and be utilized in the prediction of our futures
- In this course, we will actually be covering more than just astronomy, in order to provide you with the broader context
  - **Astronomy**: deals with outer space and with celestial objects and their classifications, but also the entire universe
  - **Astrophysics**: as the name would imply, this is the physics of astronomy. Application of the laws of physics to space
  - **Cosmology**: the really big picture -- study of the origin, evolution, and ultimate fate of the universe as a whole (overlap with astronomy)
- Later in semester we will even get to discuss exotic subfields and interdisciplinary endeavors, of the big together with the small, such as “high-energy particle astrophysics” (~related to my work)
Some More Vocabulary

- Intra- (prefix): inside of something
- Inter- means between
- Extra- means outside of

http://science.nationalgeographic.com/science/space/universe/galaxies-article/
“The time will come when diligent research over long periods will bring to light things which now lie hidden. A single lifetime, even though entirely devoted to the sky, would not be enough for the investigation of so vast a subject... And so this knowledge will be unfolded only through long successive ages. There will come a time when our descendants will be amazed that we did not know things that are so plain to them... Many discoveries are reserved for ages still to come, when memory of us will have been effaced.”

— Seneca, Natural Questions

for HOMEWORK, you must take QUIZ by 11:59 PM Tue. 1/24

Go to the course website: http://www.albany.edu/physics/phy100.shtml
Readings are embedded in the quizzes. Names are NOT collected (UA e-mail)

WEEK #1 (this week): You get three chances to take the quizzes before the deadline (only the highest score is kept towards your grade)
WEEK #2 (next week): You get two chances to take the quizzes

In 2 weeks and rest of semester: only 1 chance. Additional submissions ignored. Note circles are single choice and boxes are multiple multiple choice

There is no WRITTEN homework (there never is) but the quiz deadlines are *ENFORCED* 100 level does not mean no work and instant A. Easier, but SOME work, especially for A!