ASTR 1040 RECITATION 3 CRAZY STARS

9/12/2023

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LOGISTICS

First homework due Thursday – last ~15 min of recitation will be reserved for questions.

Observing report due next week if you came last night, next observing session is 10/10

Prof. Nelson is gone this week

I will be gone 9/21 - 9/30

QUANTUM MECHANICAL UNCERTAINTY

$$\Delta x \Delta p \geq \frac{h}{4\pi}$$

x = position
p = momentum
h = Planck's constant

Practice problem:
In the Sun's core the temperatures are very high (~14 million degrees Kelvin) and with very large fluctuations (~1 million degrees K). The average kinetic energy of a particle with temperature T is:

$$E = \frac{3}{2}kT = \frac{1}{2}mv^2$$

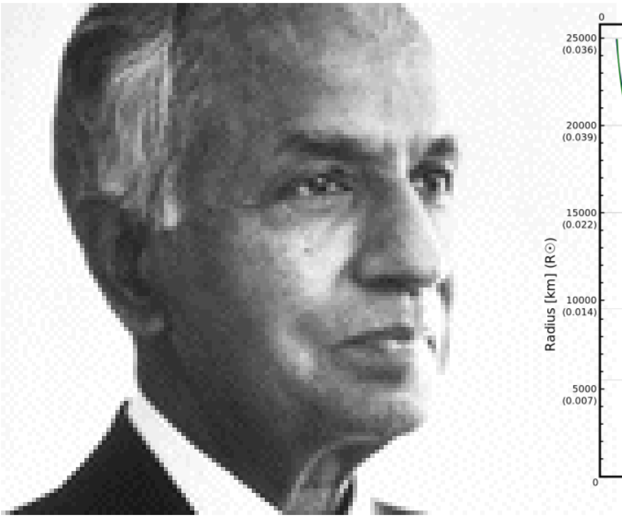
Calculate the quantum uncertainty in position for a proton with the kinetic energy associated with such temperature fluctuations, and compare your answer to the size of an atomic nucleus (i.e. He).

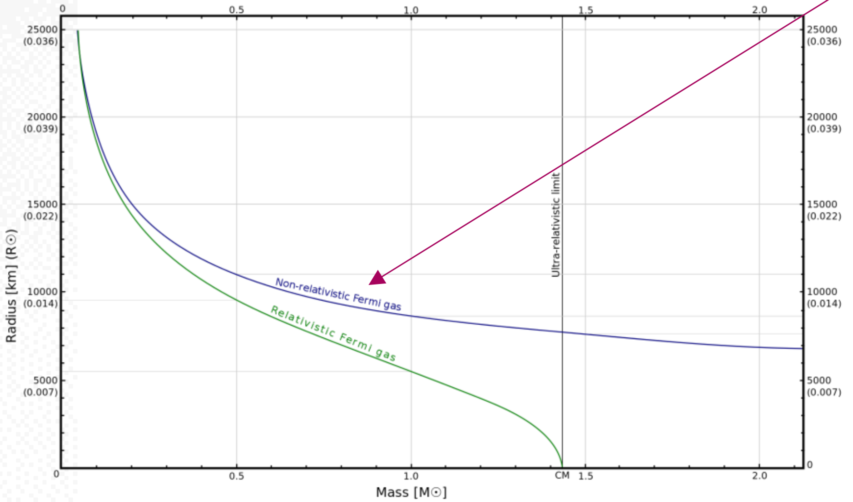
STELLAR POINTS

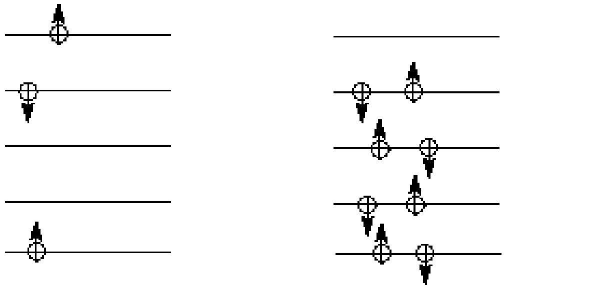
1. In space gravity is not the constant acceleration you're used to, but instead depends on (in simple Newtonian land) the inverse of your distance from the center of the object squared. You only feel the gravity of stuff interior to you, so in a star (or any meaningfully "large" object) there is a ***gradient*** in the strength of gravity – ie the strength of gravity is meaningfully different depending upon how far out you are!
2. For things to be in ***equilibrium*** there can be no net forces, which means there must be a corresponding equal and opposite ***gradient*** to counteract gravity in our star – what causes that?
3. Even crazier kinds of "stars" are neutron stars and white dwarfs – they no longer have fusion happening in their cores, so what is preventing their collapse?

SUBRAHMANYAN CHANDRASEKHAR

Chandrasekhar was studying degenerate "Fermi" gases – what particles do you think this situation applies to?







Regular gas: many unfilled energy levels. Particles free to move about and change energy levels.

Degenerate gas: all lower energy levels filled with two particles each (opposite spins). Particles **locked** in place.

Combined ~quantum physics~ with relativity to show that there was a maximum mass a star could have before collapsing further (potentially into a black hole!). First completed calculation on boat ride to Oxford, was then unfortunately publicly ridiculed by Eddington (likely racism involved…) who did not want to believe in things like black holes. We now know the Chandrasekhar limit (named in his honor) to be ~ 1.4 solar masses, and this has been very well documented observationally! One of NASA's flagship observatories, the Chandra x-ray telescope, is named in his honor.

Image credits: **L** – Wikipedia / Starchild NASA; **M** – Wikipedia / AllenMcC.; **R** – Nick Strobel

PRACTICE PROBLEM 1: YOUR WEIGHT ON A WHITE DWARF

Say you try to make first footfall on a white dwarf, but your co-pilot warns you the gravity could be pretty strong and you should do a quick calculation first to make sure you won't get crushed to death. The white dwarf is roughly the radius of the Earth (6 x 10^6 m) and the mass of the Sun (2 x 10^{30} kg). Use Newton's law of gravitation to calculate your weight in Newtons, then convert this to a more familiar unit by recalling that one Newton is roughly 0.225 Earth pounds.

Big mass

Little mass

Gravitational constant

$$G \approx 6.67 \times 10^{-11} \left[\frac{\mathrm{m}^3}{\mathrm{kg\,s}^2}\right]$$

$$F = \frac{GMm}{r^2}$$

Distance between M and m

Now set up a ratio – how much more do you weigh comparatively to yourself on Earth? Is it safe for you to land? To do the ratio you can use either Newton's second law ($F = ma$, with $a = 9.81\frac{m}{s^2}$) or use the mass of the Earth, which is about 6 x 10^{24} kg.

WHAT'S AFTER WHITE DWARVES?

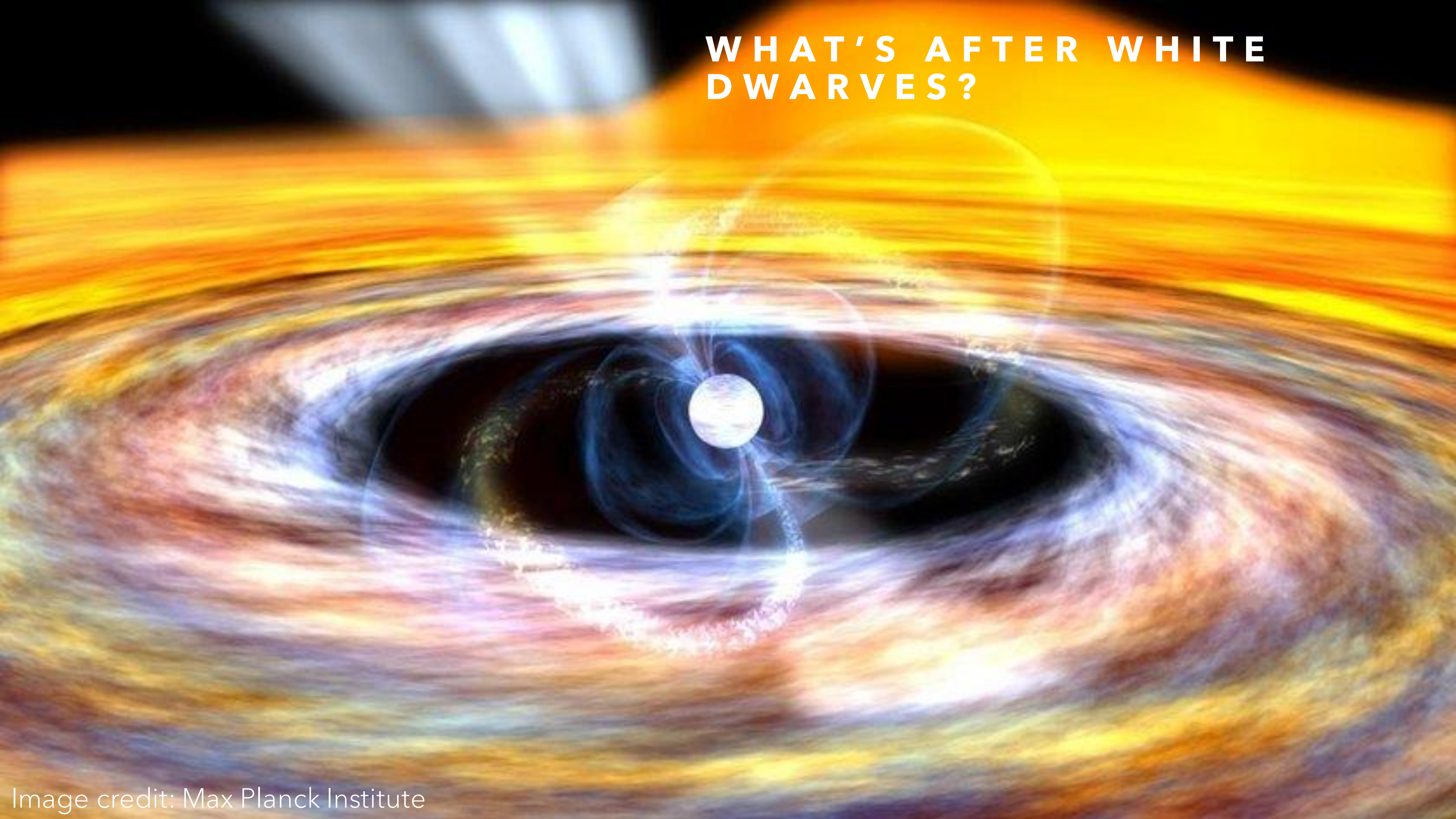


Image credit: Max Planck Institute

WHAT'S AFTER NEUTRON STARS?

$$G \approx 6.67 \times 10^{-11} \left[\frac{\mathrm{m}^3}{\mathrm{kg\,s}^2}\right]$$

$$c \approx 3 \times 10^8 \left[\frac{\mathrm{m}}{\mathrm{s}}\right]$$

Practice problem 2: Squeezing yourself into a black hole

While we often think of black holes as massive objects, there's no fundamental reason you couldn't become one if you were squished hard enough. Recall that the Schwarzschild radius is given by:

Gravitational constant

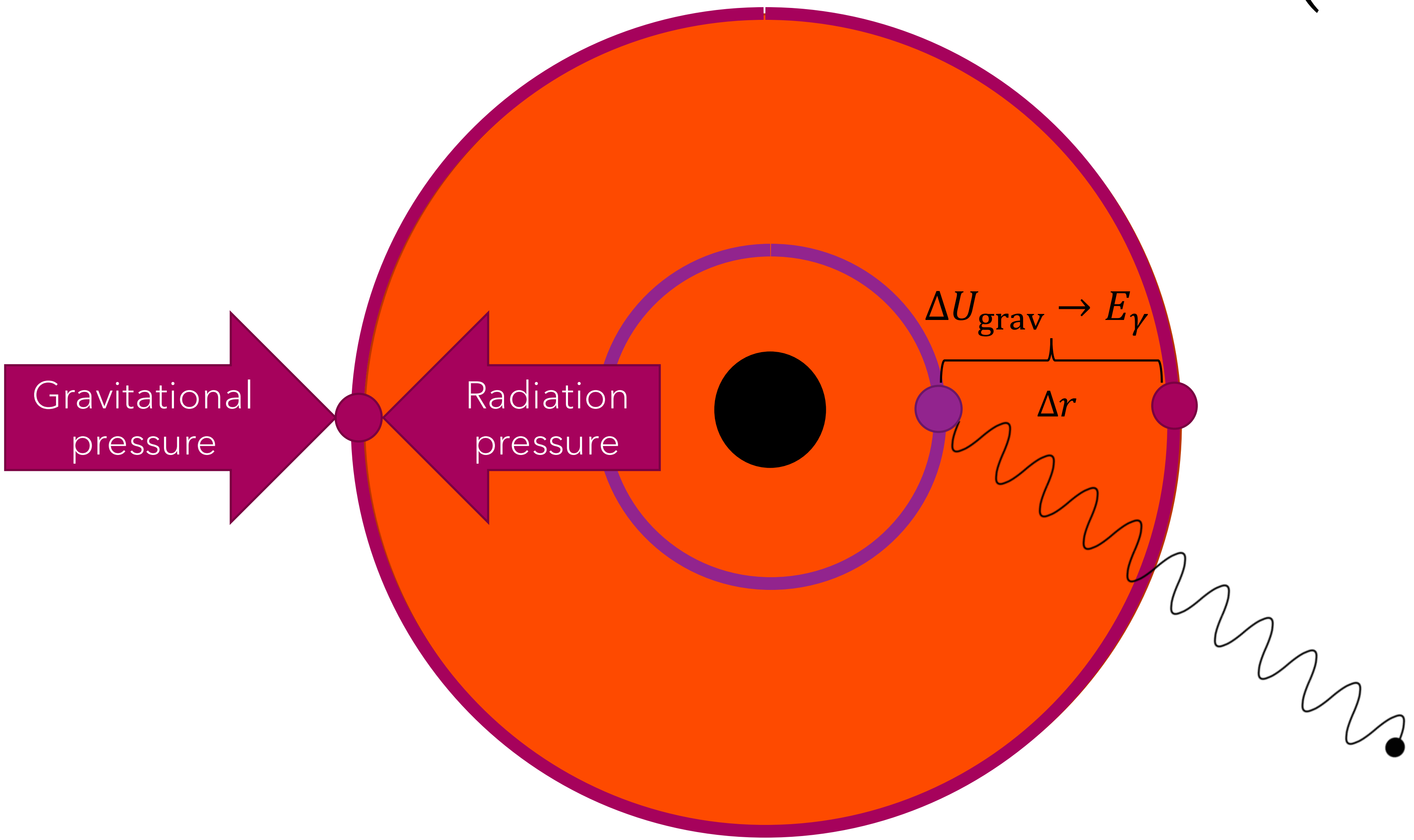
Mass of black hole

$$\boldsymbol{R_s = \frac{2GM}{c^2}}$$

Convert your approximate weight to kilograms, then use that to calculate how small you would have to get squished down to to form a black hole!

Image credit: NASA

$$L_{\mathbf{Edd}} = \frac{4\pi G M c}{\kappa} \approx 3.8 \times 10^4 L_\odot \left(\frac{M}{M_\odot}\right)$$



OPEN DISCUSSION / HOMEWORK

Some example questions for your consideration:

- What are you still confused about you'd like to talk through again?
- What esoteric / random thought experiments do you want to trip me up on?
- What homework questions do you have?
- What logistics questions / concerns do you have?
- What would you like to see in recitations?
- \+ whatever else you want to talk about!

Work with each other on your homework and ask for help!