

George will have a PowerPoint (I think) to clarify some of the material in this week's readings.

"Between the Galaxies"

How many galaxies are there? What is intergalactical space? What lies in that space?

What are the Large and Small Magellanic Clouds? Where are they?

What is our closest galactical neighbor? How far away is she?

What are dwarf galaxies? Where do they exist? How many are there? Besides size, how do dwarf galaxies differ from typical galaxies? How do dwarf galaxies "die"?

What is a galactical cluster?

Consider (p. 67): ". . . there may be as many vagabond, homeless stars as there are stars within the galaxies themselves."

How hot is the "space-filling, intra-cluster gas"?

What does this statement mean: ". . . if telescopes observed mass rather than light, then our cherished galaxies in clusters would appear as insignificant blips amid a giant spherical blob of gravitational forces" (p. 69)?

What are quasars? What do they do? (Is it difficult for anyone besides me to keep *quasar* and *quantum* clear?)

What is curved space? Where is it? As a result of what?

Distinguish between intergalactic and interstellar space.

What are cosmic rays? What do they do? What are virtual particles? And what is "the vacuum energy"?

"Dark Matter"

What is dark matter? Where is it? How is it like and unlike typical matter? How does dark matter interact with “our matter” and “our energy”? How do the laws of gravity apply (or not) to dark matter?

What is the Coma cluster? What did Zwicky discover about its galaxies? And about “escape velocity”? What is “escape velocity”?

What did Vera Rubin discover about spiral galaxies? What are “dark matter haloes”?

What do we understand when Tyson says, “Across the universe, the discrepancy averages to a factor of six: cosmic dark matter has about six times the total gravity of all the visible matter” (p. 82)?

In our solar system, “everything that is not the Sun adds up to less than one fifth of one percent of the Sun’s mass”—can we picture that?

Tyson remarks, “Dark matter exerts gravity according to the same rules that ordinary matter follows, but it does little else that might allow us to detect it” (p. 84). Then he adds, “If all mass has gravity, does all gravity have mass?” Does it? Do we fully comprehend the relationship between mass and gravity?

How does light travel through space?

What are neutrinos? Where do they come from? What do they do? How fast do they move? Where?

“Dark Energy”

How does dark energy differ from dark matter and from regular energy?

What are gravitational waves, and what do they do?

Do you remember listening to the collision of two black holes? How far did the gravity wave travel?

What is lambda? Why is it the “cosmological constant”? Why do we need it?

What does Tyson mean (p. 101) here: “. . . GR regards gravity as the response of a mass to the local curvature of space and time caused by some other mass or field of energy”? And Tyson quotes Wheeler: “Matter tells space how to curve; space tells matter how to move.” Do we understand that?

What was so significant about Hubble’s 1929 discovery about the speed of galaxies as they recede?

What did Perlmutter, Schmidt, and Riess discover about supernovas? Why do supernovas all have the same wattage? How do we measure the distances to various galaxies?

Why does Tyson call “dark energy” a repulsive force?

Tyson says, “The most accurate measurements to date reveal dark energy as the most prominent thing in town, currently responsible for 68 percent of all the mass energy in the universe; dark matter [constitutes] 27 percent, with regular matter [constituting] a mere 5 percent.” Can we imagine that?

What is “omega?” How well can we imagine a four-dimensional universe, including the saddle-shaped one? How does the value of omega determine the shape and speed of the universe?

Why does Tyson call cosmic dark energy “the great reconciler of differences”?

Is dark energy a quantum effect—something in the “vacuum of space” which, rather than being empty, “actually seethes with particles and their antimatter counterparts”?

Can we imagine (and agree) that “postapocalyptic scientists will know nothing of galaxies—the principal form of organization for matter in our cosmos—and will thus be denied access to key pages from the cosmic drama that is our universe? All the galaxies will have sped too far away from us even to feel?