Using Results From Research on Undergraduate Learning in Cosmology to Build and Test an Interactive Student-Centered Curriculum

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Why Study Cosmology?

"We can use numbers to answer deep questions"

-CSU student RB

- The big picture: cosmology is the study of the universe as a whole, its contents, structure, and evolution.
- The cosmos is the backdrop against which we live and act.
- We are part of a web of cosmic processes much bigger than ourselves; appreciate where we come from in the broadest sense.

Why Study Student Ideas About Cosmology?

- Cognitive science tells us:
  - Students enter a course with different mental representations, and these representations can affect their learning.
  - Need to know where the students are in order to take them where we want them to be.
- Misconceptions research may seem passé but...
  - Little research on cosmological topics
  - Prather, Slater, & Offerdahl, 2002
  - Wallace et al. 2011, 2012

The Big Ideas In Cosmology Project

- Powerful new cosmological observations and advances in computation and visualization have led to a revolution in our understanding of the structure, composition, and evolution of the universe.
- Gains in cosmological research have been vast but their impact on education has been more limited.
- We are bringing these tools and advances to the teaching of cosmology through two major components:
  - Research on undergraduate learning in cosmology
  - Development and testing of a series of interactive web-based cosmology learning modules

Collaborators

Chicago State University:

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K' Maja Bell, Porschoy Brice, Angela Fernandez, Kathy Flagg, Harold Johnson, Tim Sanders, Henry Swain, Mike Tyler

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APS / FIU:

Geraldine Cochran

Sonoma State University:

Lynn Cominsky, Kevin McLin, Anne Metevier, Carolyn Peruta,

Kevin John, Aurore Simonet, and the NASA EPO group

Temple / UNLV:

Janelle Bailey, Roxanne Sanchez

Northwestern / Adler:

Laura Trouille

UIUC:

Mallory Conlon

Great River Learning

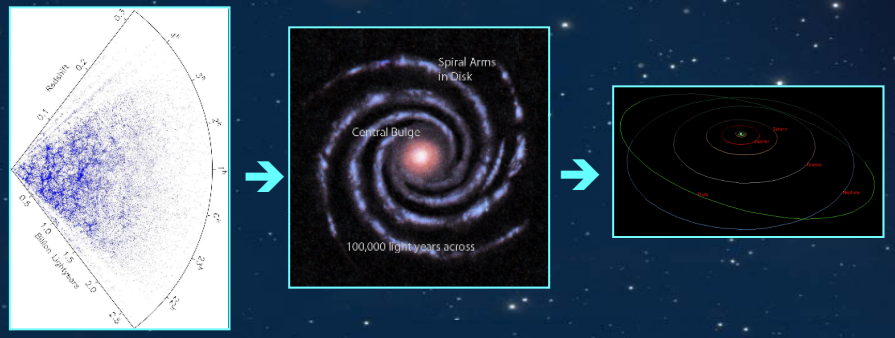
support from NASA, ISGC, and NSF

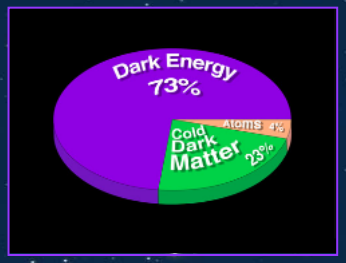
Key Things That Everyone Should Know About the Universe

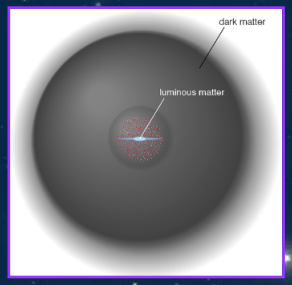
- Structure: the universe is vast in space and time.
- Composition: the universe is composed of not just regular matter, but also dark matter and dark energy.
- Change: the universe is dynamic and evolving.

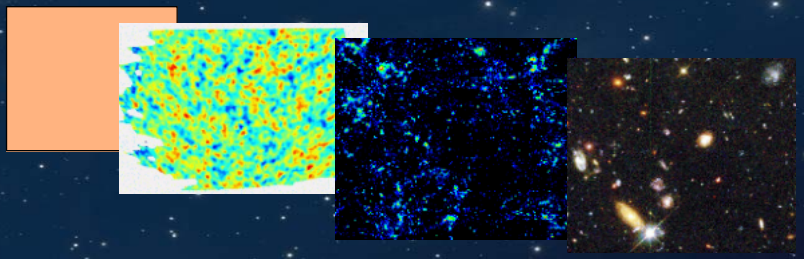
  This occurs in specific ways: according to the laws of physics.

Universe > Galaxy > Solar System









Curriculum Is Informed by Our Data

- Multi-institution open-ended written surveys (N = 1270)
  - Pre-instructional
  - Analyzed through iterative coding procedure
- Oral Interviews conducted at CSU (N = 15)
  - Taken throughout the instructional process
- CSU course-specific (N ~ 60)
  - Homework essays, open-ended lab pretests, short and long exam questions, lab comments, lab videotaping
- Targeted areas so far: structure, distances, composition, expansion/age/big bang, fate, geometry, interactive engagement and use of real data

Diverse Institutions

- PER/AER has had a major impact on how we view student learning and materials developed have been shown to be effective.
- BUT: many materials have been developed at R1 universities with traditional college students.
- We are including a diverse range of institutions and students from the start: R1 universities, state colleges, liberal arts colleges, community colleges, minority-serving institutions, high school teachers

Analysis

- Iterative thematic coding
- Correctness

Code	Meaning	Description
C	Correct	The response was complete and contained no wrong statements
I+	Incomplete (strong)	The response was missing some of the identified elements required for a correct answer
I-	Incomplete (weak)	The response was missing many of the identified elements required for a correct answer
P	Partial	The response contained both incorrect and correct elements
W	Wrong	No element of the response matched the identified elements of a correct answer
NR	No response	No response or "I don't know"
NS	Non-scientific	Non-scientific response
T	True but irrelevant	Included statements that were true but did not address the question in any meaningful way

Our Web-Based Learning Modules

1. Size and Scope
2. Light
3. Telescopes
4. Motion
5. Time
6. Measuring Distances
7. Classical Physics
8. Dark Matter
9. Special Relativity
10. General Relativity
11. Black Holes
12. Gravitational Lensing
13. Expansion of the Universe
14. Large Scale Structure Formation
15. Cosmic Microwave Background
16. Early Universe
17. Dark Energy and the Fate of the Universe

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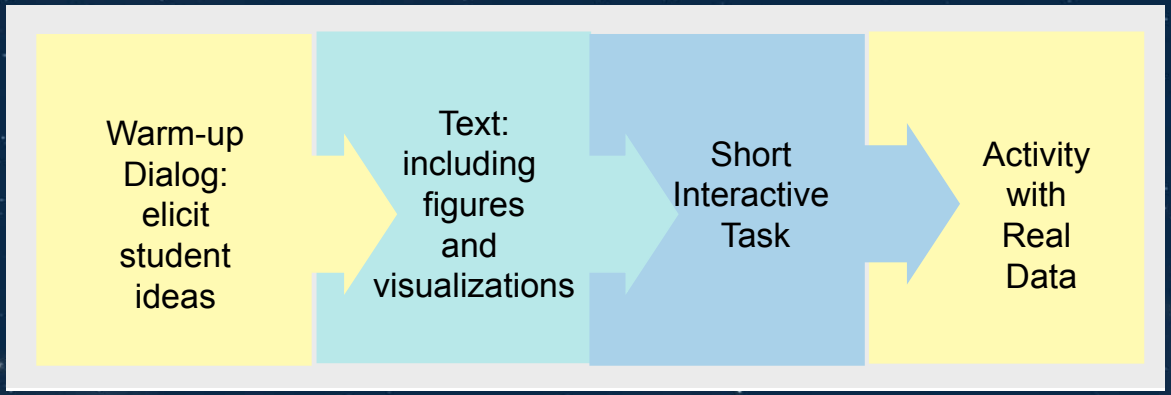
Pedagogical Approach

- Move beyond typical curricula, which are mostly text-based with occasional animations or simulations.
- Higher level of learner-centered interactions. Engaging connection to the material, go beyond what has traditionally been possible with textbooks and other passive media such as film.



Structure: Multi-Institution Survey Results

- Describe each of the following terms: galaxy, solar system, universe. Describe any relationships that may exist among any of these three things.

	Solar System	Galaxy	Universe	Hierarchical Relationship
Incomplete (Strong)	65%	65%	75%	61%
Incomplete (Weak)	22%	14%	14%	-
Wrong	10%	12%	4%	26%
No Response	4%	10%	7%	13%

- *Confusion of galaxy and solar system most common error*

Research on Structure: Interviews

- Early interviews confirm results from the written surveys that students do not have a concrete understanding of the structure of the universe.
- Students' understanding of structure does increase by the end of the semester.

"Like I kind of thought the galaxy was the universe, and the universe was something they just talked about like when kind of, you know constellation oh that's the universe. That's what I thought the universe was. I didn't know, I just thought it was referring to stars or something."

Research on Structure: CSU Class Results

- Students' understanding of the hierarchical nature of structure is weak pre-instruction; a substantial number of students view the Universe as chaotic, random, or swirly, like a "kaleidoscope" of colors and shapes.
- However, by the end of the semester, student understanding of the hierarchical nature of structure grows to become fairly robust.
- Open-end essay question on the Final Exam (N=48); Solar System
  - Students have difficulty moving beyond the solar system as the Sun and planets that they learned in elementary school
  - They also have difficulty with size scales.
- Open-ended essay question on the Final Exam (N=48); Galaxy
  - The biggest conceptual difficulties students seemed to face were the size and scale of the Galaxy and the role of the halo.
  - Students have difficulty visualizing dark matter halos, both in the context of galactic structure and in the context of understanding the composition of the Universe.

What Do You Think: Starter Q on Structure

Solar System and Galaxy

Three students are discussing which objects are in our Solar System.

Annie: "A solar system has different things in it like galaxies and planets and stars and stuff like that. Our solar system has the planets Mercury, Venus, Earth, and so on. The planets have moons, so I think moons, too."

Brenda: "I disagree. I think a galaxy has stars inside it. Each one of the stars has planets orbiting around it, and that's what a solar system is. So, a galaxy has solar systems in it, but a solar system doesn't have galaxies in it."

Charles: "I think that the terms 'solar system' and 'galaxy' mean the same thing."

Do you agree with any of these students, and if so, whom?

A. Annie
B. Brenda
C. Charles
D. Disagree with all of them

Explain your reasoning.

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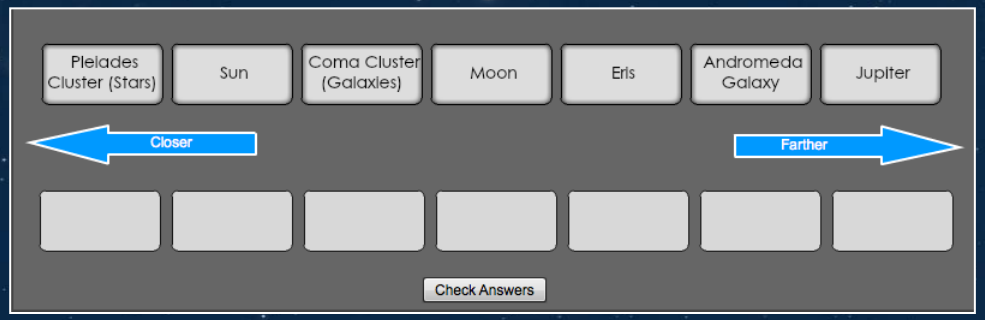
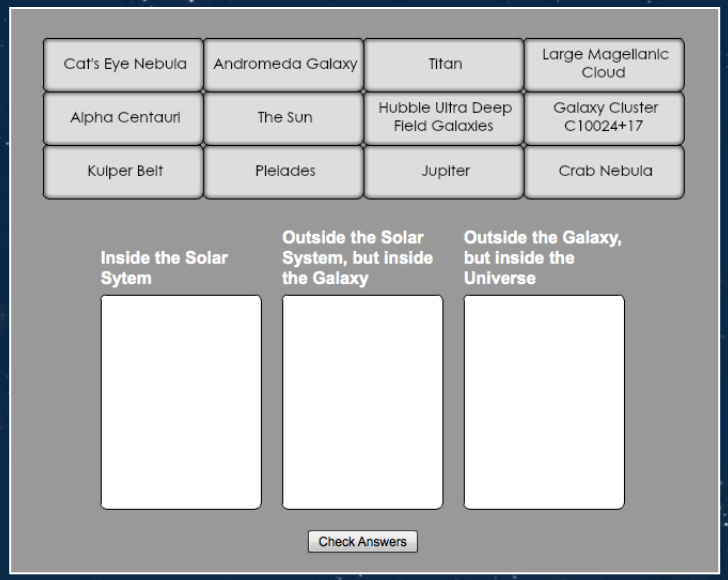
Sample Short Interactives

- Size and distance ranking tasks

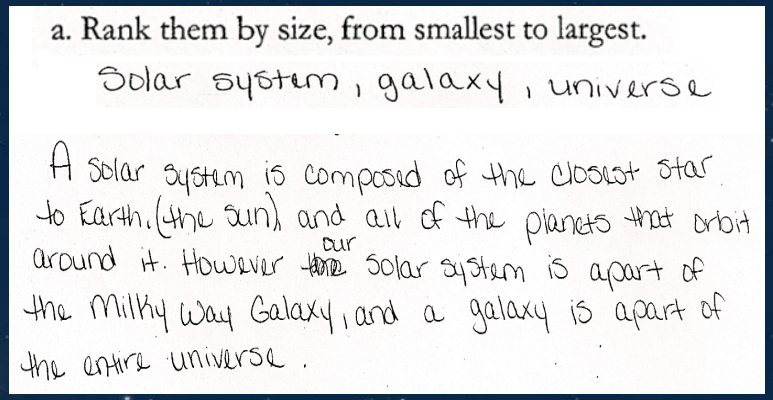


- Object sorting task



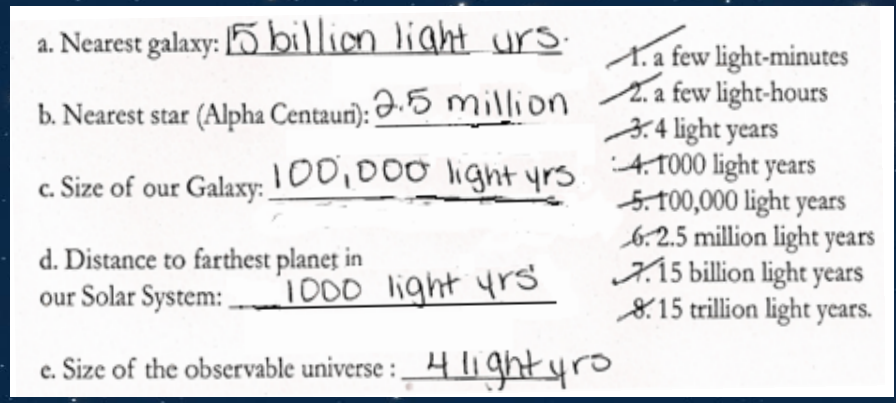
Exam 1 Q's: Structure and Distances

- Students find relative scales (ranking tasks) easier than tasks dealing with absolute scales and might not be consistent in their reasoning between the two


a. Rank them by size, from smallest to largest.

Solar system, galaxy, universe

A solar system is composed of the closest star to Earth, (the sun) and all of the planets that orbit around it. However ~~the~~ our solar system is apart of the Milky Way Galaxy, and a galaxy is apart of the entire universe.


a. Nearest galaxy: 15 billion light yrs

b. Nearest star (Alpha Centauri): 2.5 million

c. Size of our Galaxy: 100,000 light yrs

d. Distance to farthest planet in our Solar System: 1000 light yrs

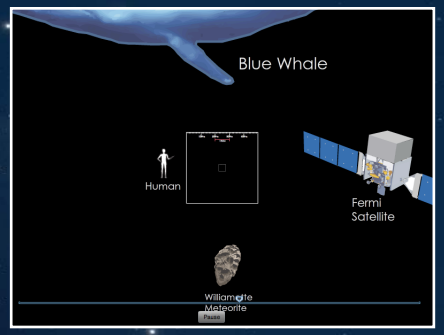
e. Size of the observable universe: 4 light yrs

~~1.~~ a few light-minutes
~~2.~~ a few light-hours
~~3.~~ 4 light years
~~4.~~ 1000 light years
~~5.~~ 100,000 light years
~~6.~~ 2.5 million light years
~~7.~~ 15 billion light years
~~8.~~ 15 trillion light years.

- Instructors should consider explicitly linking different types of scale activities so that students can practice being internally consistent in their reasoning with size, scale, and distance

"Wrapping It Up" Activities

- Longer "lab"-like part at end of chapter where students can explore, answering Q's in ebook
- Short "Mission Report"
  - Section with same basic assessment Q's for all mission reports (like, dislike, rate, summarize, etc.)
  - Section with Q's similar to longer "lab"
  - Easy for instructors to grade
- Sample activity uses "Scale-the-Universe" tool



Further Implications

- We suggest teaching the hierarchical nature of the Universe, namely, that the Solar System is part of the Galaxy, and that there are many galaxies in the observable Universe, as part of the upper elementary and middle school astronomy curriculum.
- Given students' difficulties with absolute scales, but greater ease with relative scales, this effort could focus on relative scales, or scale models, which are major themes in elementary and middle school math standards.

Preliminary Evaluation

- Three astro 101 classes at Sonoma State:
  - Traditional lecture, instructor 1
  - Traditional lecture, instructor 2
  - Flipped class using modules, instructor 2
  - N ~ 80 – 100 for each
- Assessments
  - Attitudes: CLASS
  - Content (MC): From ADT, LSCI; topics on hierarchical structure, speed of light, half speed of light, wavelength, light-year, what is a star, parallax, inverse square law (light, gravity), what if sun shrank, geometry
  - Content (Open-response): From our prior surveys; topics on hierarchical structure, composition, age, big bang

Evaluation: Structure

- Students using online modules made greater gains than those in traditional lecture sections.

Section 1

Section 2

Section 3

Math Skills: Results

- Students are impaired by weak math skills, including graph reading and proportions.
- These come up in a variety of situations, such as the "half speed of light" problem, the inverse square law, and rotation curves of spiral galaxies, among others.
- With continual practice students improve on tasks that use these concepts. For example, understanding proportions from equations is a course theme, and we see that students' ability to answer questions about the inverse square law improves continuously throughout the semester.

Distance Measurement Techniques: Inverse Square Law

	N	**Correct**	Incomplete	Partial	Wrong	True but irrelevant	No Response
Pre-test	36	**28%**	14%	31%	22%	3%	3%
Midterm	56	**41%**	16%	21%	21%	0%	0%
Final	32	**59%**	16%	13%	13%	0%	0%

- Lab Pre-test: Star C and star D have the same luminosity (inherent brightness), but star C is 5 times farther away than star D. If the intensity of light is inversely proportional to distance squared, how does the apparent brightness of star D compare to that of star C. Be specific (give a number) and explain your reasoning.
- Sample Exam Q: Stars A and B are both G-type stars. Star A is 3 times closer than star B. The brightness of star A will be 9 times brighter compared to B. Use a number.

Use of Basic Mathematics

- Equations explained in words
- Equations explained conceptually (proportions)
- Consistent step-by-step process for numerical exercises:
  - Given, Find, Concept(s), Solution, Think About Answer
- Example:
  - "The mathematical expression relating the flux of an object to its distance is known as the inverse square law:

$$F = L/(4 \pi d^2)$$

This means if an object is twice as far away, it will look four times dimmer…"

Inverse Square Law

- Conceptual activities
  - Flux vs. Distance
- Activities with real data
  - Cepheids
  - Supernovae
  - Tully Fisher

5. When Star A is twice as far away as Star B, Star A appears
   - 2 times brighter
   - 2 times dimmer
   - 4 times brighter
   - 4 times dimmer

   SAVE & CHECK | VIEW ANSWER

6. When Star A is 3 times as far away as Star B, Star A appears
   - 3 times brighter
   - 3 times dimmer
   - 9 times brighter
   - 9 times dimmer

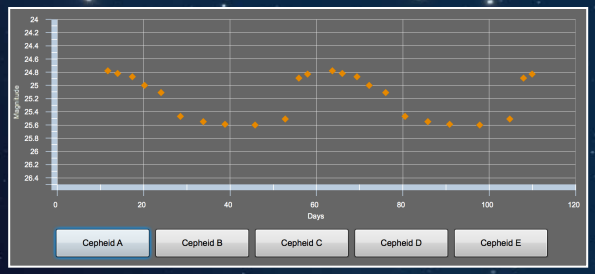
   SAVE & CHECK | VIEW ANSWER

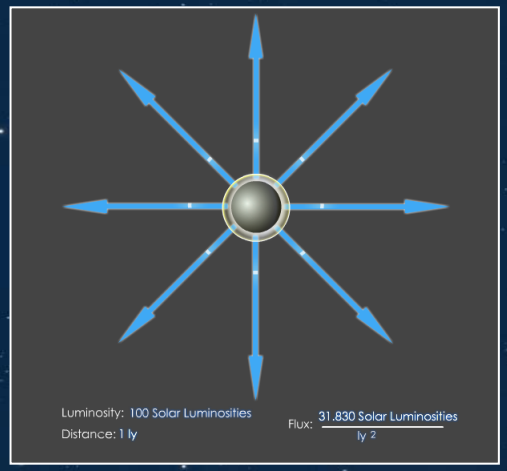
7. When Star A appears 100 times dimmer than Star B, Star A is
   - 10 times farther
   - 10 times closer
   - 100 times farther
   - 100 times closer

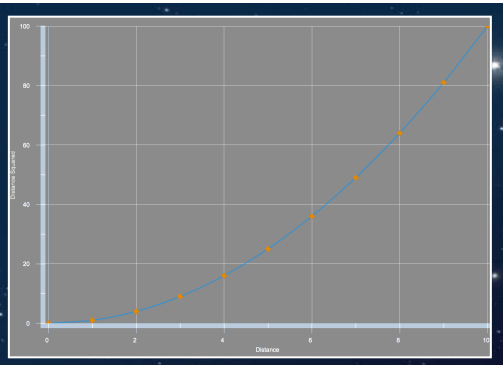
   SAVE & CHECK | VIEW ANSWER

8. When Star A appears 25 times brighter than Star B, Star A is
   - 5 times farther
   - 5 times closer
   - 25 times farther
   - 25 times closer

   SAVE & CHECK | VIEW ANSWER







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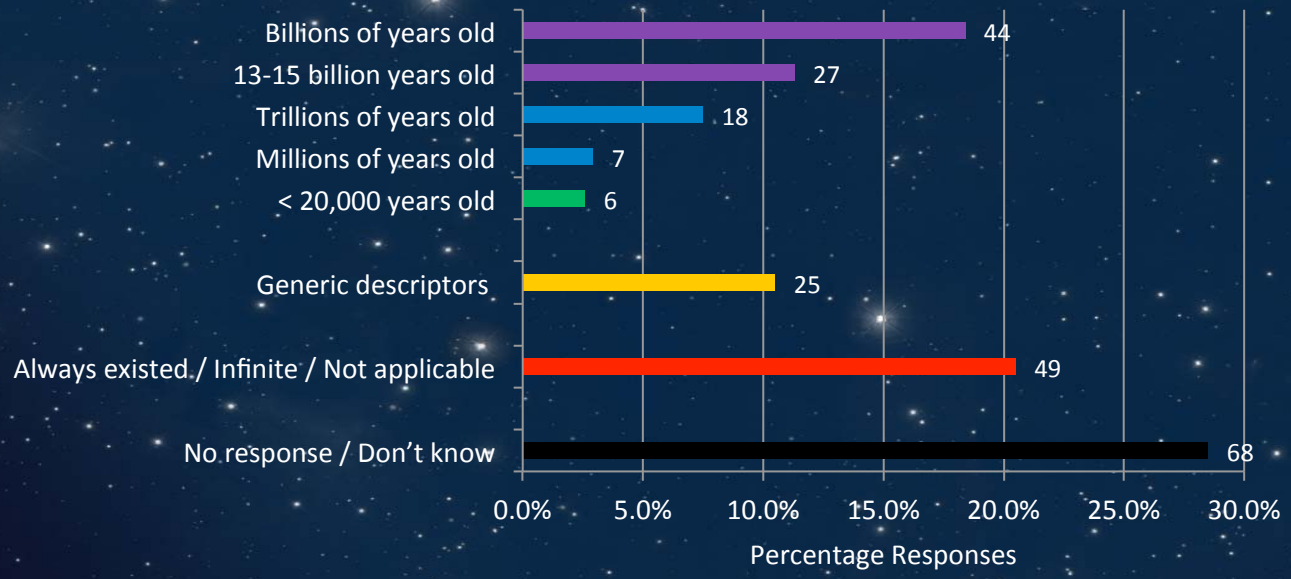
Age of the Universe: Survey Results

- Does the Universe have an age?
  - Yes – 59%
  - No, always existed – 26%
  - NR/contradiction – 15%
- What is the age, if it has one?



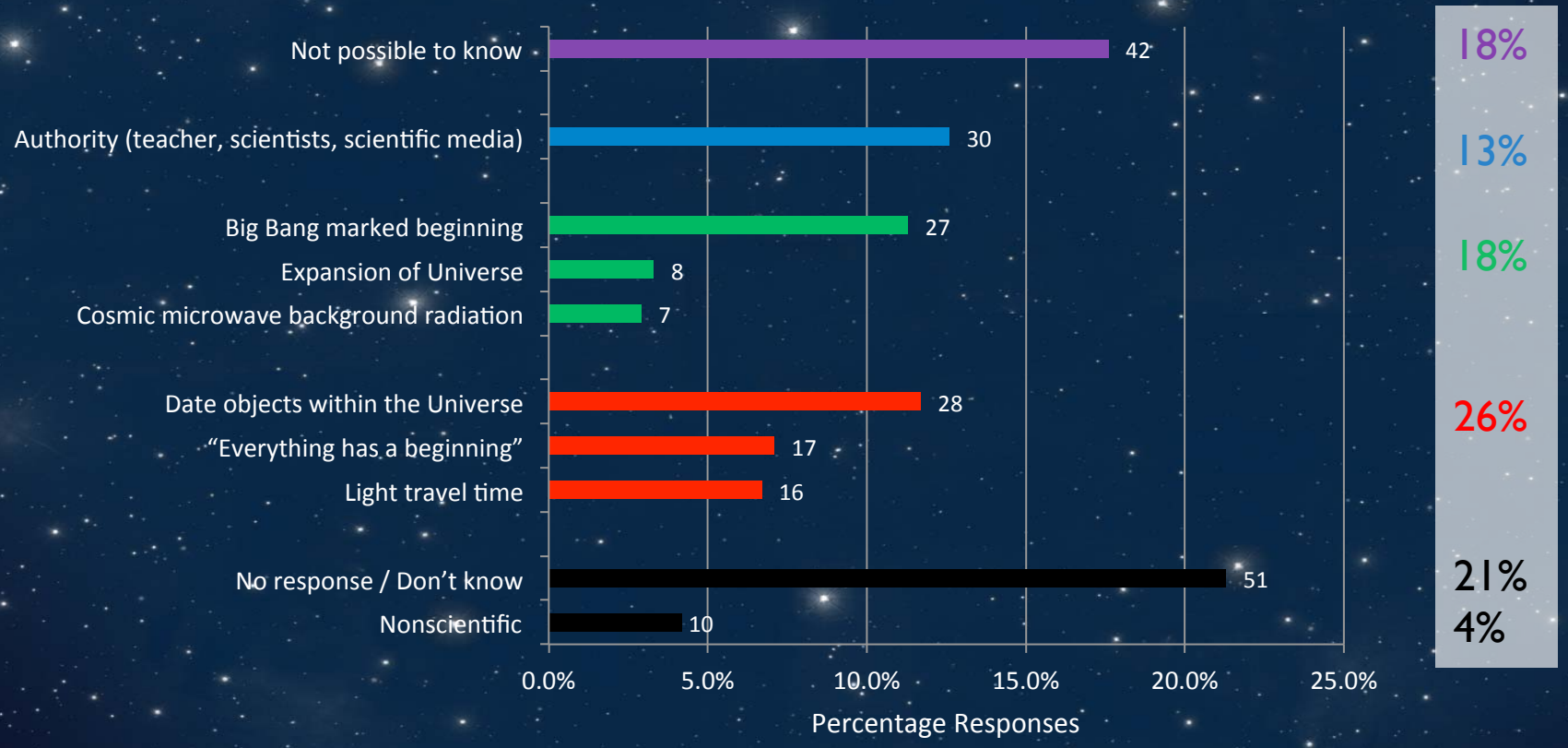
18% billions
11% 13-15 billion

3% < 20,000
11% "hella old"

29% NR

Age of the Universe: Survey Results

- How do we know the age of the Universe?



Age of the Universe: Example

3. Does the universe have an age? If so, what is its age? How do we know?

The universes age is infinity. It has been around longer than we have and dinosaurs. There isn't a way to tell except for scientific hypothesis. But those are not completely based on facts and real evidence.

10/2

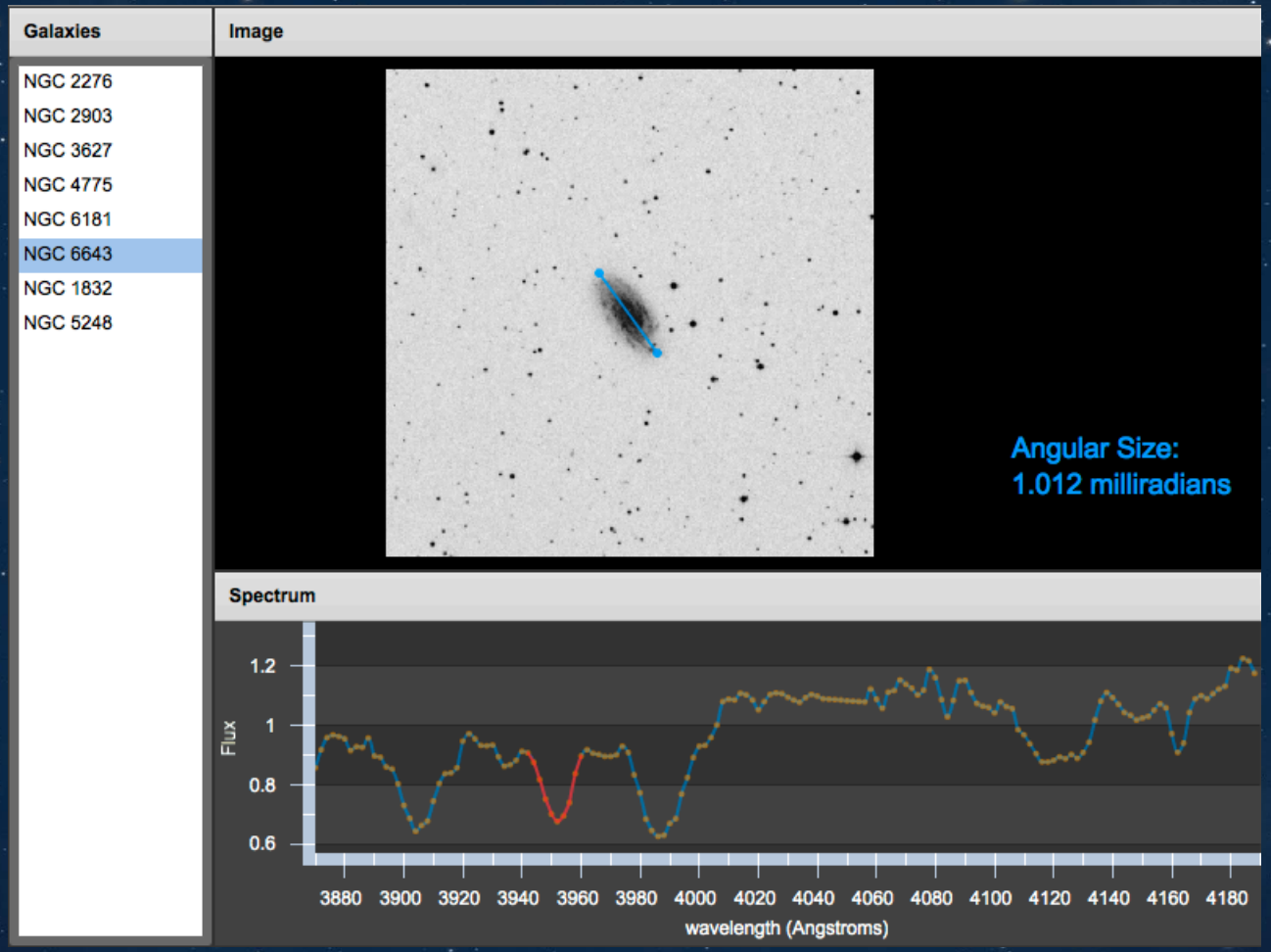
The Importance of Understanding Data

- Surveys show that students are initially skeptical that e.g. the age of the universe is measurable or that the Big Bang model is supported by evidence
- In interviews, students describe the value of real data and interactive engagement in understanding the material and in changing their beliefs

"Actually, when you told me, I was less inclined to believe it, to tell you the truth... I really didn't understand... At first I thought a lot of scientists kind of sometimes make up facts... I never understood it, so I thought a lot of stuff was made up. ... Now I do, now that I saw the calculations. And done it myself."

"We did it during the lab, which was awesome... we took pictures of galaxies and we actually measured them and we recorded them on the graph and we actually came up with real authentic data from real galaxies... it was really real authentic information, so I got a lot from that..."

Hubble Law and Age



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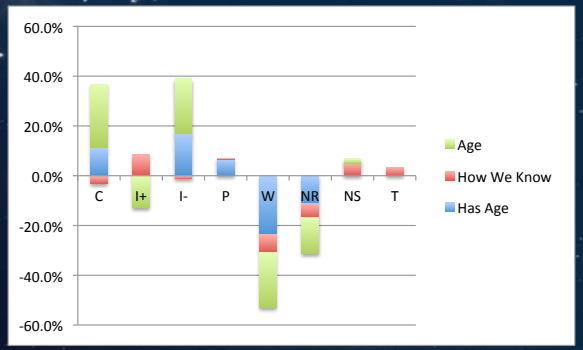
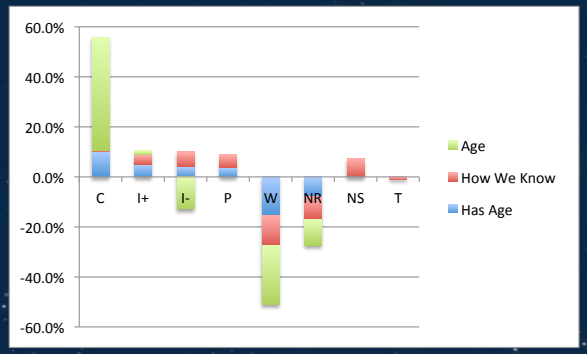
Preliminary Evaluation

- Prior to instruction, students had difficulty answering "why" or "how do we know" questions
- All three astro 101 classes at SSU learned concepts on the age of the universe through lecture only
- Gains are similar

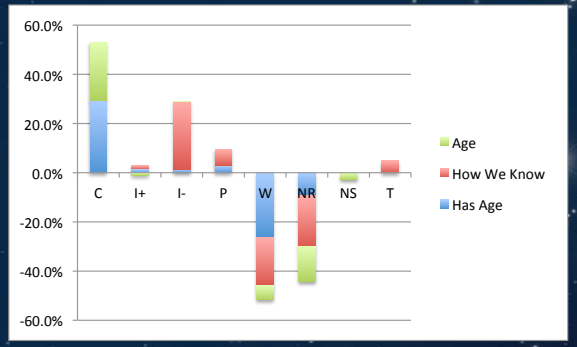
Section 1



Section 2



Section 3



What Do You Think: Big Bang

Expansion or Explosion?

Four students are discussing the expansion of the Universe after watching a TV show about the Big Bang.

Ishmael: "When I think of the 'Big Bang'… it's like, something went off, it exploded, and everything dispersed out."

Jasmine: "Yeah, the Universe was like a dense, hot ball and it got to the point where, I don't know, I guess the bonds or something really couldn't hold it any longer, so it just exploded. And through the explosion, things just started moving farther apart, like expanding, from the point where the explosion actually happened."

Khalil: "I'm not sure. I've always heard about the Big Bang theory and how it was this big explosion, and that's what they showed on TV. I don't really remember what the actual Big Bang theory is now, but I do know that I was told otherwise in my astronomy class. I need some kind of better visual to explain to me how things work in science."

Lizzie: "I think all of you are way off base. I think the 'expansion' just means our knowledge of the Universe is expanding."

Big Bang: Multi-Institution Survey Results

- What is the Big Bang?
  - Explosion – 50%
  - Small point/mass/ball – 18%
  - Collision between objects or particles– 9%
  - Distribution of matter– 10%
  - Beginning of expansion– 9%
  - Creation/formation of:
    - Universe - 33%
    - Solar System– 26%
    - Earth – 11%
    - Life – 8%
  - No response/don't know – 13%

Big Bang: Multi-Institution Survey Results

- What is the evidence for the Big Bang?
  - Expansion – 14%
  - Solar system or planets – 12%
  - Life – 6%
  - Fossils, dinosaur extinction – 5%
  - Authority – 8%
  - There is no evidence for it – 5%
  - "We're here" – 4%
  - No response/don't know – 38%

Big Bang: Interviews

- Students need good visuals to replace incorrect old ideas:

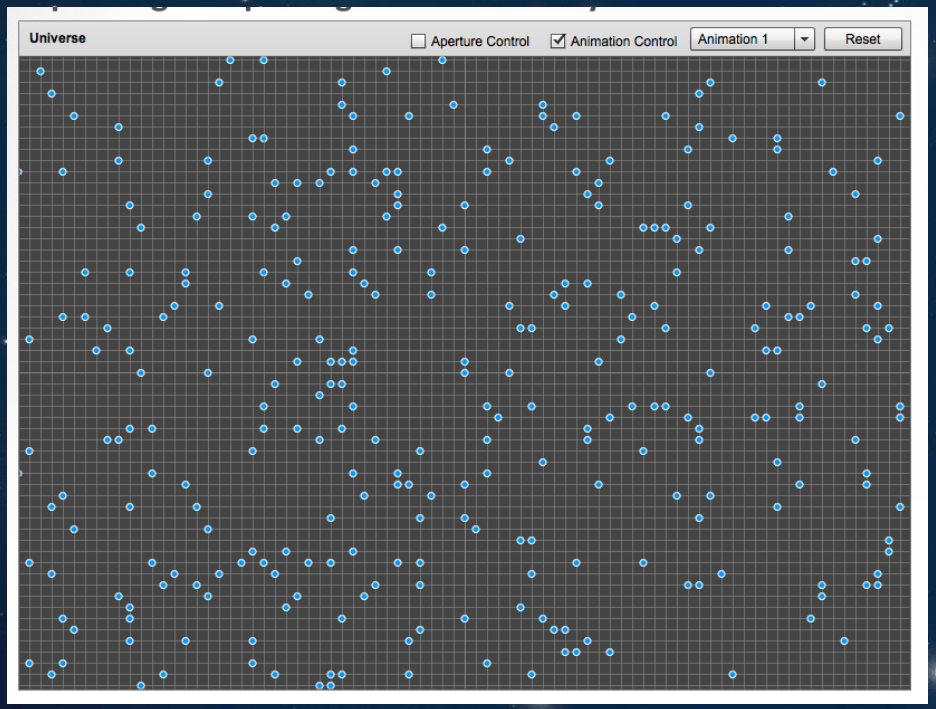
"I've always heard about the big bang theory and how it was this big explosion and that's how the planets and everything else came about... I don't really remember what the actual Big Bang Theory is now, but I do know that I was told otherwise in my new class... I need some kind of visual to explain to me how things work in science."

- Of the students who discuss the Big Bang in the post-instruction interviews, 71% explicitly state that while before taking the class they thought the Big Bang referred to an explosion, they now know that no explosion is involved.
- Two main visualizations that have helped them replace this misconception with a more scientifically accurate view:

"What [...] helped me learn it and get a better understanding of it was that whole movie going backwards in time

"I learned from the class the big bang was not that concept [an explosion] - it was more like uh-things beginning to stretch out and the universe is vast and continue to-to expand. That the Big Bang is really not a big bang, it's really a big stretch [referring to the stretchy band used in class to demonstrate the expanding universe]"

Expansion vs. Explosion



The Big Bang Theory

Watch the two animations, which each show a region of space and the matter in it. In both animations, the grid lines represent space, and the dots represent matter. You can toggle back and forth between the animations with a pull-down menu. The animation begins when you click on any dot. Reset the animation using the "reset" button. Answer the following questions.

Play Activity | View My Answers

1. In animation #1, how did physical distances between objects that you observed change, if at all?
- a. The physical distance became bigger.
- b. The physical distance became smaller.
- c. The physical distance stayed the same size.

Save & Check | View Answer

6. Which animation shows an explosion?
- a. Animation #1
- b. Animation #2
- c. Both
- d. Neither

Save & Check | View Answer

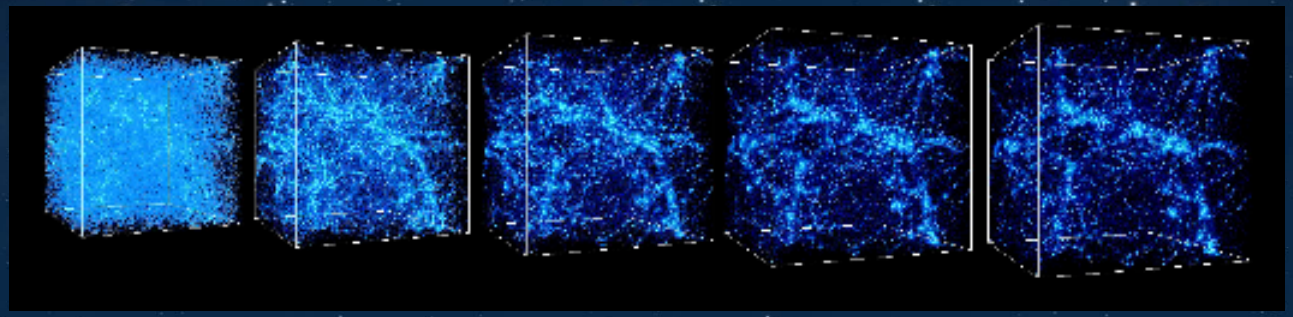
7. Which animation shows an expansion?
- a. Animation #1
- b. Animation #2
- c. Both
- d. Neither

Save & Check | View Answer

8. Which animation most accurately models how our Universe behaves?
- a. Animation #1
- b. Animation #2

Save & Check | View Answer

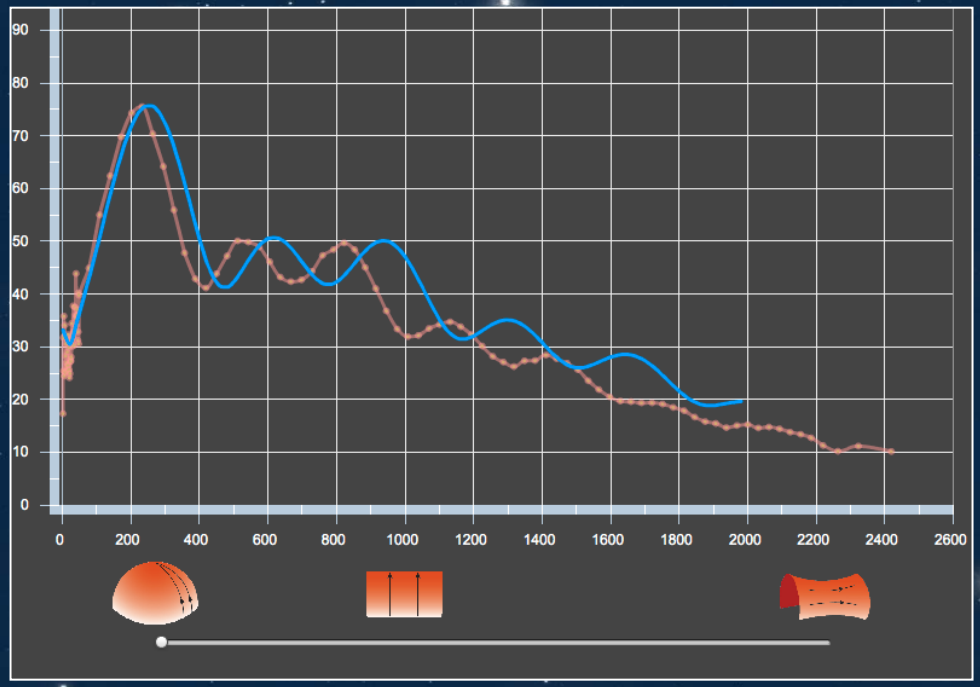
Visualizations: Evolving Universe



- Computer models:
  - Large Scale Structure Formation
  - Galaxy Cluster formation
  - MW Formation
- Compare with data:
  - Hubble Deep Field Fly Through
  - Sloan Digital Sky Survey

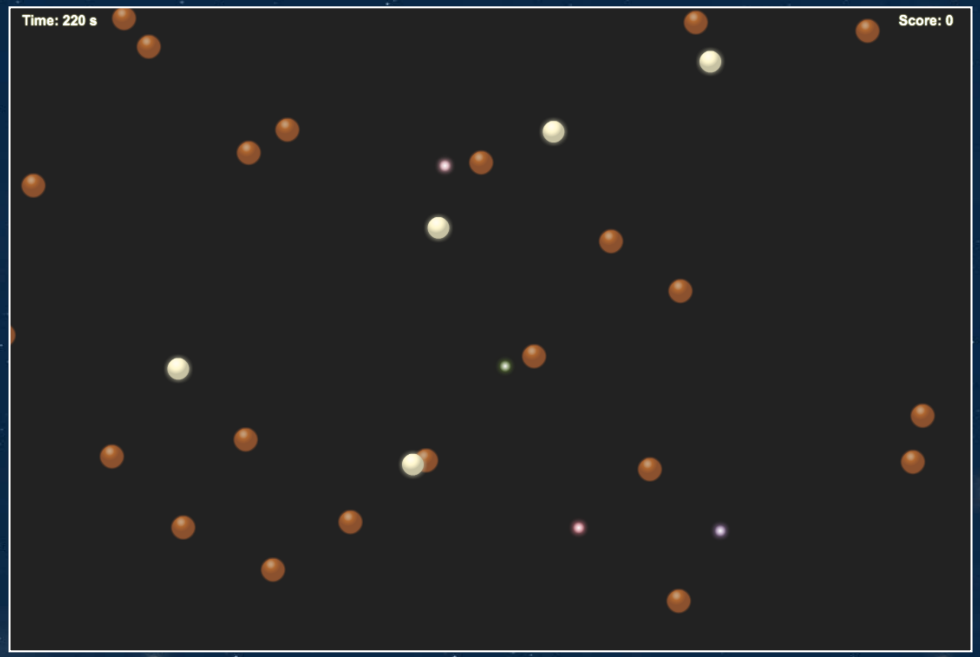
Comparing Models and Data: CMB

- Students can adjust parameters to fit data



Early Universe

- BBN Game, Particle Game



Summary

- Big Ideas about the Universe
  - How do we know this? We have data!
- Student learning in cosmology
  - Creation of interactive, web-based learning modules
  - Based on research on what students know and how they learn it
  - How do we know this? We have data!
- The importance of using "real data" and active learning in astronomy and physics curricula for undergraduates

Check out Lynn Cominsky's talk Thursday night!

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