What's the Problem with Isotropy?

Suggested Grade Level(s): 10-12
Estimated class time: one 45-minute class period (assuming students have already read and discussed the 1993 Cosmic Times article, "Baby Universe's 1st Picture")

Summary

This lesson targets the significance of discoveries made with the COBE satellite in 1993. To fully support Big Bang Theory, small variations in the distribution of Cosmic Microwave Background radiation (CMB) needed to exist. These anisotropies were not able to be detected prior to 1993 because the necessary technology had not yet been developed and deployed.

Students will participate in an Engagement activity which demonstrates how very small variations in a pattern are unrecognizable without the use of technology. In the Exploration and Explanation sections of the lesson, students will understand why Big Bang theory requires variations in CMB (anisotropy); they also examine the significance of both anisotropic and isotropic observations. Finally, in the Extension and Evaluation sections, students complete activities that further reinforce and demonstrate their understanding of the material presented.

Objectives:

- Students will understand and correctly use the terms anisotropic and isotropic.
- Students will explain the significance of, and necessity for anisotropic CMB radiation to support the Big Bang Theory.
- Students will demonstrate the problem that isotropic CMB radiation created for the Big Bang Theory.

National Science Standards

- NS.9-12.1 SCIENCE AS INQUIRY
  As a result of activities in grades 9-12, all students should develop
  - Abilities necessary to do scientific inquiry
  - Understandings about scientific inquiry
- NS.9-12.4 EARTH AND SPACE SCIENCE
  As a result of their activities in grades 9-12, all students should develop an understanding of
  - Origin and evolution of the earth system
  - Origin and evolution of the universe
- NS.9-12.5 SCIENCE AND TECHNOLOGY
  As a result of activities in grades 9-12, all students should develop
  - Understandings about science and technology

- NS.9-12.7 HISTORY AND NATURE OF SCIENCE
  As a result of activities in grades 9-12, all students should develop understanding of
    - Science as a human endeavor
    - Nature of scientific knowledge
    - Historical perspectives

Knowledge Prerequisite

- Students should be familiar with the basic tenets of the Big Bang Theory:
    - An indescribably hot-dense "ball" of energy "exploded" and expanded.
    - As it expanded, all of the energy cooled and some of it became matter.
    - Over time, gravity collected the matter into the galaxies, stars, planets and other objects we observe today.
    - Evidence supporting the theory includes relic background radiation from the explosion (cosmic microwave background), and red shifts of galaxies outside of the Local Group.
- Students should have read and discussed the 1993 Cosmic Times article, "Baby Universe's 1st Picture"
- It may also be helpful if the students are familiar with the 1965 Cosmic Times article, "Murmur of a Bang"

Teacher Background/Notes

The success of this lesson is strongly influenced by the teacher's ability to engage all students in the dialogue. Encourage as much participation as possible while monitoring time. The lesson can be accomplished within a standard 45 minute period when students are held to strict time limits for each part of the lesson.

A clear understanding of the terms isotropic and anisotropic is needed to effectively deliver the lesson. A physical property that is isotropic is the same in all directions regardless of the direction of measurement. A physical property that is anisotropic *is not* the same in all directions. Reference to this is made in the Cosmic Times article "Baby Universe's 1st Picture."

It is important to first survey students and to check with the school nurse to learn about any students who might have a latex allergy. If this is a possibility, latex-free balloons must be used in the Exploration section.

Materials

- Small (approximately 3 cm square) sections of colored graphics cut from magazines. One per student. Each piece should be a solid color. Check carefully with a hand-lens to ensure the pictures are offset-lithographs that show a textured ink pattern when magnified. Lighter colors work better than saturated colors.
- Round, solid color latex balloons (see precaution above). Two for each two-student group. Pink works nicely.
- Black medium point, ball-point pens or black permanent markers. One per two students.
- (Optional) Golf balls or ping-pong balls. One per two students.

Procedure:

I. Engagement

- Hand out sections of colored graphics taken from magazines and ask students to examine the colors.
- ASK: Does the texture of the colors appear to be smooth and consistent, or is there any pattern or texture apparent? If the color of the sections is fairly consistent, students should assess the color as smooth and lacking any texture.
- Provide hand-lenses and, if necessary, demonstrate how to use these effectively. Provide supplemental light if needed.
- Have students carefully re-examine the color sections using a hand-lens to see if the color still appears smooth, or if a texture can be seen.
- Using hand-lenses, students should be able to see there is a texture to the color. The texture is fine enough that the colors seem to blend together to form a uniform appearance.
- Review with students that the differences in the pattern of the color are only visible with the use of technology; that improves our ability to observe something we can't normally "see."
- Explain that advances in technology allow us to "see" very subtle variations in radiation in space; these small variations were critically important in terms of providing further support for the Big Bang Theory.

II. Exploration

- Provide each pair of students with two balloons and a pen or marker.
- Instruct students to flatten out one balloon, and draw approximately 50 dots in a small area on one side of that one balloon using a pen or marker. If golf or ping-pong balls are available, students can drape the balloon over the ball and then draw the dots. No particular pattern to the dots is needed, but they should be small (2 mm maximum diameter), dark, and closely spaced. (The other balloon will remain un-marked.)
- Have students inflate their two balloons and pinch the end to hold the air in.

- Instruct students to consider color as a measure of temperature. Pink areas are one temperature and gray (pen-marked) areas are another temperature.
- ASK: *Which balloon is similar to the first view of the piece of colored paper?* Ensure students understand the unmarked balloon is similar. The surface appears smooth and without texture or structure.
- ASK: *What would this imply about the temperature of the balloon?*
- Students should recognize this would mean all regions of the balloon have the same temperature.
- Introduce the term ***isotropic*** to describe this condition.
- Have students observe the other balloon where they drew the dots.
- ASK: *What would you infer about the temperature of the balloon in the area where you drew the dots?*
- When the balloon expands the dots fade, but there are still distinct differences in color, grading from pink to light gray to dark gray. Therefore students should recognize the temperature is not the same in all regions.
- Introduce the term ***anisotropic*** to describe this condition.
- Instruct students to carefully watch the dots while they allow the air to quickly escape from the balloon. They will observe the dots moving closer together.
- ASK: *If someone else had drawn the dots, and they moved so close together that you could not tell they were individual dots, would you describe the temperature in this area of the balloon as isotropic or anisotropic?*
- You would describe it as isotropic.
- ASK: *How would this be similar to your experience with the colored paper?*

III. Explanation

- ASK: *Which balloon could represent a view of the universe … the smooth part that's the same everywhere, or the part with the dots?*
- If necessary, help students understand the area of the balloons with the dots represents a view of the universe. We see galaxies dispersed throughout space …
- EXPLAIN: When Penzias and Wilson discovered relic Cosmic Microwave Background (CMB) radiation in 1965, their measurements found this radiation coming from all areas of space. In 1991, COBE (NASA's Cosmic Background Explorer satellite) also measured the temperature of the radiation and found it to be smooth and *isotropic*, just as Penzias and Wilson did.
- EXPLAIN: Although Penzias and Wilson's discovery of the CMB was generally highly supportive of the Big Bang theory, a smooth (isotropic) distribution of CMB presented a problem for the theory. This would be equal to a pink balloon with no dots and a universe with no galaxies.
- ASK*: If all the relic CMB radiation is the same temperature, what do you infer about the distribution of the energy at the moment of the Big Bang?*
- Guide students to understand that the explosion would have evenly and smoothly distributed energy in all directions.
- ASK: *If matter formed from the energy, what would this infer about the distribution of matter in the universe?*

- Guide students to understand that matter would also be smoothly and evenly distributed.
- ASK: *Do we observe a smooth and even distribution of matter?* Of course students should readily respond no … matter appears to be clustered in galaxies separated by large areas of space.
- At this point it is likely that some students will want to attribute the collection of matter into galaxies, etc. as a result of gravity acting on matter. Guide them to consider: Would gravity have accomplished this structure if all the energy (matter) was smoothly and evenly distributed at the moment of the Big Bang and then continued to expand in a perfectly smooth and even pattern? With guidance they can see that this would not occur. There would need to be irregularities in the distribution of the energy (matter) at the moment of the Big Bang which would ultimately allow gravity to act to bring masses together.
- ASK: *What is the problem with the observation that all the relic CMB radiation is smooth?*
- Guide students to understand that the CMB should not be smooth, based on our observation that the distribution of matter is lumpy.
- ASK: *What would you expect to find about the temperature of the relic CMB radiation?*
- Guide students to understand that it should not be smooth and even, but rather anisotropic, or "lumpy." Only a very small amount of "lumpiness" would have been needed in this early universe to create the distribution of matter we observe in the universe today. In 1993, COBE released its second result that showed this lumpiness.

IV. Extension

If desired, engage students in a further discussion of how discoveries feed into technology development (such as the need to find anisotropies in the CMB led to the development of a NASA mission to search for those anisotropies).

An interesting question to pose to students is "Did the scientists find what they were looking for because they were looking for it or because it's really there?"

IV. Evaluation

- Have students work in partners to develop posters or storyboards which demonstrate the following points:
    - Why the structure of the Universe observed today that implies anisotropic relic CMB radiation should be observed.
    - Why galaxies, stars, planets, etc. would not exist if the relic CMB radiation really was isotropic.