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A Student-Constructed Three-Dimensional Model of Stars in Nearby Space

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Abstract

The construction of a three-dimensional model of star distribution within 17 light years of the Sun gives students a hands-on method to understand what might otherwise involve a dry discussion of stellar types and distribution in the Milky Way. The model construction is accompanied by a worksheet that guides students in exploring different information given by the model. Though no assessment of student understanding of stellar distribution or other related topics was done, anecdotal student feedback has been positive, both in the understanding of the material and in the method of delivery.

1. INTRODUCTION

Three-dimensional models help students visualize scenarios that may be misleading in a textbook or Web illustration. Astronomical models have the inherent problem of scale; the objects in an astronomical model (e.g., planets, stars, galaxies) are dwarfed by the scale in which they exist. Exaggerating the difference between the scale of the object and its distance scale is a good way to remind students of that difference. Consider the typical illustration of the Solar System, in which the planets are huge compared with the distances between them. Rarely do students believe that the planets are spaced that closely.

After the students have been introduced to stellar types and properties but before any discussions concerning galaxies, I use a student-constructed three-dimensional model that greatly exaggerates the size of the stars compared with the region of space they occupy. This model demonstrates the distribution of stars, both type and location, in nearby (< 17 ly) space and uses Styrofoam balls of different sizes to represent stars. The placement of these "stars" impaled on a metal skewer in a 2-meter or so square area of the classroom represents the volume of the Milky Way galaxy in which these stars exist.

With little or no instruction, students should realize the tremendous difference in scale represented by the stars and the scale represented by the distance between the stars. This allows the students to visualize how far apart the stars truly are and how the distribution of stars on this scale fails to show larger-scale structures such as galaxies.

The "17 ly or less" criterion was chosen to show the 50 nearest star systems, a number that allows for some statistical calculations about stellar distribution.

2. PREPARING THE MODEL PARTS

Styrofoam balls of differing sizes represent the stars. These balls are inexpensive and readily available. They can be lightly spraypainted to illustrate different qualities; one such painting scheme, to demonstrate spectral class, is shown in Table 1. Some brands of spraypaint dissolve the Styrofoam; I used a light coating of an acrylic-based spraypaint (Figure 1). Foam balls (such as Nerf balls) or construction paper circles can be used as alternatives to Styrofoam.

Table 1. Materials for building the "nearest 50 systems" model

Item	Use as
1.5-inch (38 mm) diameter Styrofoam ball	White dwarf stars (white)
2-inch (50 mm) diameter Styrofoam ball	M-class stars (painted red)
2.5-inch (63 mm) diameter Styrofoam ball	K-class stars (painted orange)
2.5-inch (63 mm) diameter Styrofoam ball	F-, G-class stars (painted yellow)
3-inch (76 mm) diameter Styrofoam ball	O- ,B- , A-class stars (painted blue)
Aluminum welding electrodes (1/8-inch diameter, 3-foot length)	Spindle for stars
Wooden 2-by-4 (foot) board, cut into 4-inch lengths	Bases for stars

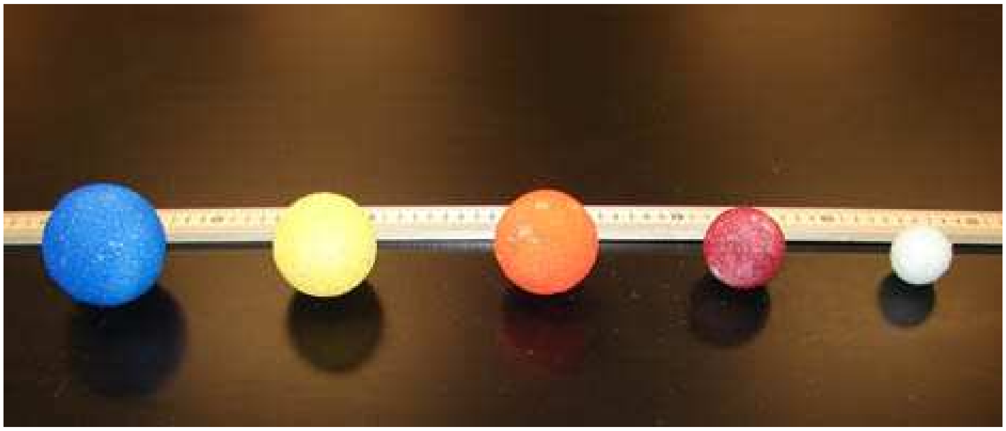

Figure 1. Spraypainted Styrofoam balls representing, from left to right, OBA-class, FG-class, K-class, M-class, and white dwarf stars. Note that some spraypaints dissolve Styrofoam.

The stars are placed on metal wire spindles; 1/8-inch diameter yardlong aluminum welding electrodes worked well, both for remaining unbent even with heavy use and for not leaving too large a hole in the spindled Styrofoam ball. Copper and mild steel electrodes work as well, though they are more expensive. Additionally, a few electrodes in the 4-foot length are desirable, but that length is harder to obtain commercially.

The base to which the spindle is attached is made of 4-inch lengths of a standard 2-by-4 (foot), which gives the base a square appearance. An inch-deep hole is drilled roughly centered on the face of the wood; the metal spindle is then inserted into the hole.

The total cost of the materials listed in Table 1 is approximately $70.

Each base is labeled with the name of the star (or stars, in the case of multiple star systems), its right ascension (RA) and declination (dec) coordinates, and other information. I added the star's spectral class and its distance from the Sun (Figure 2). This information is readily available from any standard college introductory astronomy textbook (e.g., Hester et al. 2007), but because of recent discoveries of large numbers of nearby dwarf stars (Scholz & Meusinger 2002; Thorstensen & Kirkpatrick 2003; Lowrance et al. 2003; Phan-Bao et al. 2006), I used three databases with updates from 2005 or later: http://www.solstation.com/ (2007); http://www.nbso.org/ (update date not given); and http://www.chara.gsu.edu/RECONS/TOP100.posted.htm (2007). The databases overlap a great deal, and the differences probably depend on how their information is updated. I used a consensus criterion: If two of the three databases contained a star, it was included in my list. The appendix is my list of star labels.

There are a few familiar names in this group of stars, such as Alpha Centauri and Sirius. These stars may help students connect stellar properties learned in a previous section of the course with the representations of these stars in the model.

Figure 2. Bases for the star systems. The black label shows that this system is one of the 25 star systems closest to the Sun; the red label shows that this system is one of the next 25 star systems closest to the Sun.

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3. MODEL CONSTRUCTION

Students can work in teams, each with a set number of star systems to fashion, or else individually, with each student making as many star systems as he or she can. In both cases, the star system model is made by selecting a base, placing a metal spindle in the base, and selecting an appropriate size and/or color Styrofoam ball from the supply to represent the star on the label. In the case of multiple star systems, the appropriate number of balls should be selected and attached to each other with toothpicks (Figure 3).

Figure 3. A representation of the Sirius A&B system.

Meanwhile, an area of the classroom floor roughly a couple of meters square is cleared. The center is marked by placing the Sun model there, with the Sun ball placed about halfway up the spindle.

Next, the floor is marked with the RA coordinates—0 hours, 6 hours, 12 hours, and 18 hours—at right angles to each other (Figure 4). A scale for the distances in the model is chosen: I found that 5 centimeters per light year was reasonable given the limitations of room space.

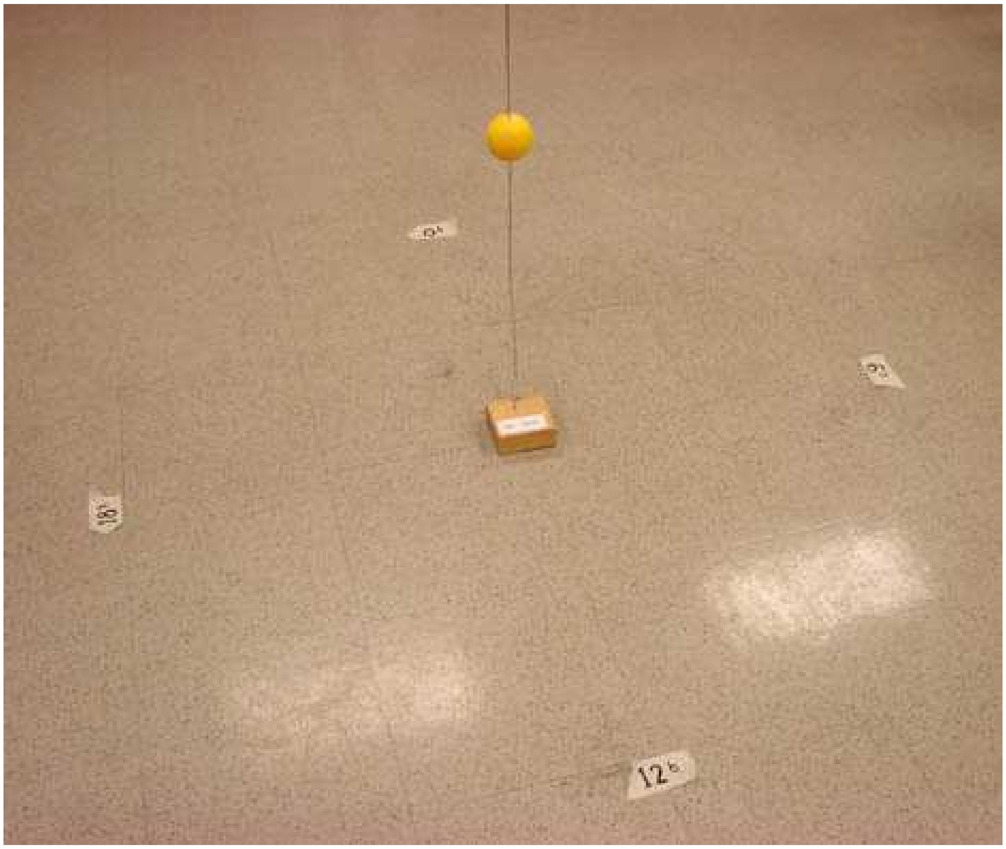

Figure 4. The Sun at the center of the model. The RA coordinate system is laid out around it.

The students use a meter stick to place their star systems in the appropriate position on the model. Most students find the RA position for their star system quickly, which involves a simple interpolation between two marked RA cardinal directions. However, the dec and the star's distance from the Sun will require two simultaneous actions: sliding the star system up or down on the spindle to approximately the correct dec (I demonstrate +45°, 0° and -45°, but a protractor can be used), and measuring the distance using the 5 cm/ly scale. Often, students discover that even with the correct dec, the distance is off, so as they move the model closer to or further from the Sun along the RA line to correct the distance, their dec drifts off (Figure 5). Many students get the idea that they can mentally draw a line between their star and the Sun and slide the star on the spindle as they move the base of the model, thus preserving the dec even as the distance changes.

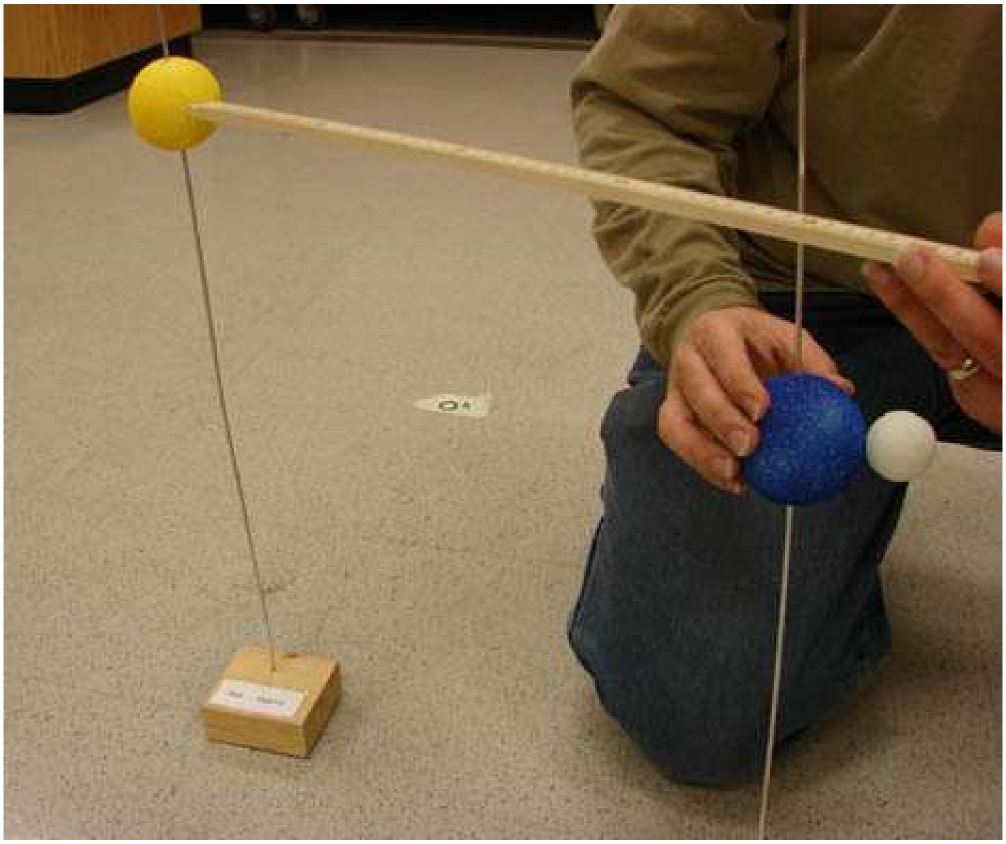

Figure 5. A student places the Sirius A&B system at the appropriate position in the model with respect to the Sun.

The model-building (with 50 star systems) takes about 30 minutes, and the teardown takes about 10 minutes. I have the luxury of leaving the model up in the classroom for a couple of days; other instructors have mentioned that the model sparks discussions in their physics and earth science classes (see Figure 6).

The advantages of having the students set up the model themselves (rather than the instructor setting it up beforehand) are two-fold. First, it is a simple way for students to discover for themselves how to plot points in a three-dimensional polar coordinate system. Once I tell the students the equatorial (celestial) system notation, they discuss it among themselves. Because of the confined quarters of the model, they rapidly converge on the correct way of arranging the stars. Second, it allows me to assess informally which students are having difficulties with the general idea of using a coordinate system, and it gives me some time to tutor these students individually as their peers continue building the model.

However, as noted, there may be space and time constraints that complicate having the students set up the model. Further, the building works best with fewer than 24 students. If there are time, space, or number constraints, the instructor can set up the model ahead of time, perhaps on a reduced scale that fits on a cart, and have the students complete the exercise as described next.

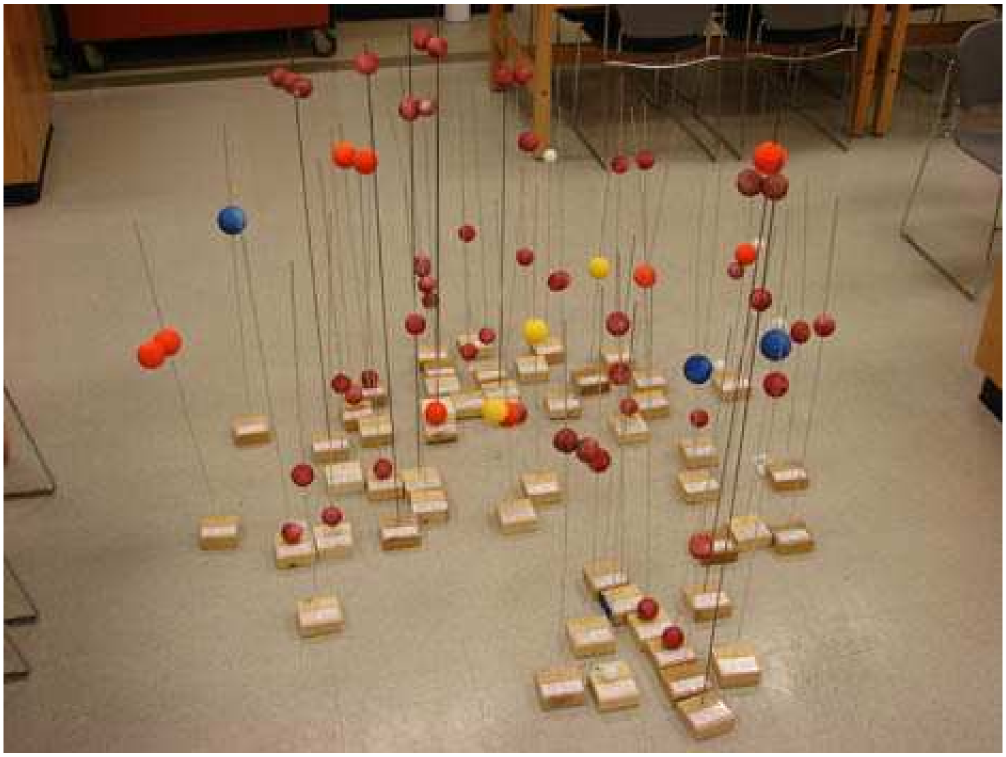

Figure 6. The completed model.

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4. ORAL AND WRITTEN WORK TO ACCOMPANY THE MODEL

Prior to the exercise but after students have read some introductory material on stars and spectral types, I ask the students about their ideas regarding the size and shape of the Milky Way and the distribution of stars within it. A common misconception in my classes is that there is a uniformity to the distribution of stars—that is, roughly equal numbers of cool, small stars and hot, large stars.

Once the model is complete, I have the students step back and look at the model. Using oral prompts such as "Does this look like the photos of spiral galaxies you see in the textbook?" or "Does it seem that there are more stars in any particular part of the model?" I let the students infer for themselves how much larger a model of the entire galaxy would be (for the record, the Milky Way's disk would be 5 km wide, and the spiral arm thickness would be 50 m).

Using prompts like "It looks like those two stars are touching," I get the students to understand the exaggeration in scale between the model star size and the distance between the stars on the model. Using the "1 light year equals 5 centimeters" scale, the students perform a calculation about the size that Sirius, the largest star on the model, should be. It works out to be roughly 1 × 10 cm or 10 nm—about the size of a large molecule, such as an enzyme—so if the stars did not emit light, they would be invisible at this scale.

The mentioned calculations, which can also be done in worksheet form, reinforce the notion that there has been a distortion in scale between the scale of the stars themselves and the distances between the stars. A refinement of the model could be to use mini-LED lamps in place of the Styrofoam balls, but this has proved problematic to build.

At this point, I distribute a worksheet to the students regarding specific aspects of the model. The worksheet questions include a census of the stars by stellar class, in which their misconception of spectral class distribution is addressed. Even without a formal census, it is evident that there are a lot more M-class stars than O-, B-, A-class stars. This observation leads some students to ask why that distribution exists, and that question leads to a discussion of stellar lifetimes.

Another question is, "Does the stellar distribution by spectral type for this part of nearby space agree with a textbook’s statement of stellar-class distribution in the Milky Way?" In general, the distribution in the model overrepresents M-class stars and underrepresents the number of stars in every other spectral class. This leads to discussions about why some spectral classes might be over- or underrepresented in the model, such as the difficulty in detecting M-class stars over a larger distance than the model scale.

Because the nearest 25 star systems have black-lettered labels, and the next nearest 25 systems have red-lettered labels, the students can calculate the star number density in those regions of space (a sphere and a spherical shell, respectively) to determine whether the star number density varies greatly or whether a structure like the Local Bubble is visible (it isn’t).

Finally, the model can lead to a discussion about life in the universe. I pose questions such as these: How many Sun-like stars are there, as a percentage of all stars in the model? If life is unlikely to have evolved around a multiple-star system, how many stars does that criterion remove? How many years would it take to have a two-way radio conversation with civilizations inhabiting various star systems?

5. EVALUATION

I have not tested whether student understanding of stellar types and stellar distribution in the galaxy has improved as a result of building this model. Over the 10 years that I have had students make the model, a dozen comments from student course evaluations have mentioned the model even though the evaluation form did not ask about it. These comments, all positive, were from students who appreciated the information conveyed by the model (all variations on this comment: "Different and better way to look at stars in space") and from those who liked the group activity aspect of the project (variations on this comment: "It was cool that we could move around and talk to other people [as the model was being built]"). Two students mentioned that they understood three-dimensional coordinate systems better as a result of the exercise.

A more systematic approach to assessing the enhancement of student learning about stellar distributions (which I have not done yet) would be to have students draw what they think the model will look like before they build it. They might include details about what type of stars would be found at various positions within the model, as well as whether there would be equal or different numbers of stars of each spectral class. At the end of the exercise, the students would be given back their original drawings and asked to comment about whether their drawing of the model was consistent with what the actual model looked like, what the significant differences were between their model and the real model, and whether they were surprised by those differences.

6. SUMMARY

Having students build a three-dimensional model of nearby space gives them a tactile exercise in the distribution of stars, using a method that may be more accessible than reading a textbook or using an online resource. Though the exercise described may not work as well for large classes, student comments from smaller sections indicate that students enjoyed the communal aspect of the model-building.

Acknowledgments

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APPENDIX

Click here for the list of star labels in PDF.

URL: http://aer.noao.edu/auth/furutani.appendix.pdf