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The Milky Way Model

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Abstract

In this article, I describe constructing a scale model of our galaxy—the Milky Way—and using this model to teach modern astronomy. The Milky Way model expands on concepts usually explored in the more common solar system model. The Milky Way model presents an opportunity to probe a broad array of physical processes and astrophysical systems, as well as multiple astronomical coordinate systems and far more expansive spatial scales. This exercise is kinetic, interactive, and designed to be done in large spaces (such as a gymnasium floor) with students at the middle school to high school levels.

1. THE MILKY WAY MODEL

Model solar system demonstrations and installations are a fixture of basic astronomy and astrophysics public education. A methodically simple but scientifically rich extension of this demonstration is to move beyond our immediate cosmic neighborhood and extend the model to the Milky Way galaxy. In a Milky Way model, students prepare a scale model of the galaxy using images of galactic objects combined with their sky coordinates and distances from Earth. Once completed, an instructor leads the students through a discussion that reflects on the properties of the model.

The educational value derived from modeling the Milky Way comes first from a number of fundamental astronomical concepts that must be understood to even create the model. In constructing the model, students must become familiar with the use of astronomical coordinate systems, the magnitude of galactic distances, and concepts of scale. Upon reflection, the variation in the nature, distribution or absence, and observed wavelength bands of the objects in the completed model serve to visually and interactively demonstrate otherwise abstract astronomical and astrophysical phenomena and the extent of our knowledge in this field.

2. A RUN-THROUGH AT YERKES

This demonstration was first used—motivating this article—for the winter session of a biannual astrophysics workshop (institute) for urban Chicago middle- and high school students. Both the summer and winter sessions are held at the Yerkes Observatory in Wisconsin as part of a joint University of Chicago and Kavli Institute for Cosmological Physics (KICP) outreach program (<http://kicp.uchicago.edu/education/explorers/index.html>). The entire demonstration and discussion was completed in little more than four hours. At the conclusion of the discussion, students prepared a presentation on what they had learned and provided a tour for a group of their parents, siblings, and peers.

In preparation for the Yerkes Winter Institute (YWI), approximately 50 objects were selected for use in the model (see the appendix). The objects were identified using online astronomy tools such as the SIMBAD astronomical database, the Astrophysics Data System (ADS) for literature searches, and hobbyist Web sites, as well as graduate student know-how. The source galactic longitude and latitude coordinates were recorded, as well as distance estimates. Once the objects were selected, images were located—mostly from the archives or publications just mentioned—in as many wavelength bands as possible. They were printed in color on letter-size paper and laminated.

The model for YWI was constructed on the floor of the renowned 40-inch refracting telescope dome. The circular floor space surrounding the telescope base is approximately 60 feet in diameter; given that the main extent of the Milky Way is nearly 60,000 light years (ly), the scale was chosen by the participating students to be about 1,000 ly per foot. Students designated the center of the room (base of the telescope) as the position of the galactic center and then identified the location of the Sun and Earth by their distances from the galactic center in an arbitrary direction from the center.

Students used protractors to measure the galactic longitude angle—from 0 degrees in the direction of the galactic center. They used string to measure the distance from the Earth to identify the positions of the objects, and placed them at those locations. Wooden stands were designed to display the images once their location was determined on the floor. The stands were simply three-foot wooden dowels fit into wooden blocks that had been predrilled with the appropriate-sized holes. Wooden clothespins were strapped and hot-glued to the tops of the dowels and used to clip the laminated images to the stands.

3. THE MILKY WAY VERSUS THE SOLAR SYSTEM

It is instructive to consider the virtues of this demonstration by comparing it to the more common solar system model. In a model solar system, planets are distributed, usually in a one-dimensional fashion, in order of their distance from the sun—if possible, with the distances between them or even their sizes scaled to fit the installation space. Aside from simply highlighting the existence of the planets and their distribution around the sun, the greatest impact of these models is to impress upon people the great distances between the planets—their sparsity in space—or their immense and varied relative sizes.

The Milky Way model achieves the same primary goals as solar system models but extends the scope of objects considered from a homogeneous collection of objects—planets—to nearly the entire range of currently studied astrophysical phenomena. Furthermore, whereas the majority of planets and orbits were identified by the 16th century and by now have been well studied, our discovery and understanding of extrasolar galactic phenomena is an almost purely modern endeavor, with breakthroughs made day to day.

Beyond the relevancy and appeal of studying an evolving and modern field, there are more practical advantages. For instance, the Milky Way model necessarily extends the one-dimensionality of the solar system model to three dimensions. Because the positions of the planets vary rapidly on a human timescale, placing them in some three-dimensional distribution is not very purposeful. On the other hand, the distribution of objects in the Milky Way is essentially fixed on human timescales, necessitating a multidimensional approach. The third dimension of the galaxy can, and probably should, be neglected given the relative thinness of the galactic disk with respect to its diameter—a discussion point worth making with students in and of itself.

The two-dimensionality then necessitates a review of coordinate systems. Whereas in a solar system model, one only uses the distances of each planet from the sun, the Milky Way model requires the use of both distance and direction. In the YWI demonstration, Earth-centric "galactic coordinates" were used to describe the directions of object positions; omitting the third dimension amounts to dropping the galactic latitudes. This provides an opportunity to interactively develop a better understanding of what angular positions on the sky actually represent. Moreover, because all our observations of the galaxy have been made within the confines of our Solar System, building the model from an Earth-centric perspective provides a very relevant analogy for the progress of astronomical study.

4. STAR FORMATION AND ASTROPHYSICS IN THE MILKY WAY MODEL

In the solar system model, the objects are all planets, and there is no choice regarding what to include. In the case of the Milky Way model, the objects to choose from are abundant, so it is important to choose objects that are representative of the galaxy in a meaningful way. Instead of treating the galaxy as a menagerie of physical curiosities, it is more scientifically meaningful to treat it as a site of stellar evolution assembled from essentially three components.

The first component, the stuff that will be stars, is mainly cold gas in the form of molecular clouds. The second component, the stars themselves, is represented by star-forming regions containing protostars or open and globular clusters. The third and most dramatic component, the stuff that was once stars, is populated by supernova remnants, planetary nebulae, neutron stars, and black holes. Presenting the galaxy in such a fashion allows for the opportunity to learn about the causal connection between the many seemingly unrelated curiosities in the sky and the ongoing active evolution of the galaxy.

Furthermore, each of the three components is observed in some signature electromagnetic spectral range, or band; Component 1 is mostly observed in the radio to far-infrared wavelengths, Component 2 from the infrared to ultraviolet, and Component 3 from visible to x-ray range. Including this spectral information is unavoidable, but it is a simple way to get students to think about the relation between wavelength and energy in electromagnetic radiation. The more energetic a component is, the shorter the wavelength band that it is observed in. This is also a convenient way to demonstrate the existence and necessity of multifrequency observation in astronomy.

Finally, let's consider some properties of the distribution of these objects. For one thing, when completed, the model galaxy will look a lot more like a half-circle than a disk. This is due to a number of factors, including the obscuration of distant objects by gas and dust in the galactic disk, and fundamental telescope resolution and sensitivity limits. The distribution of observations with respect to wavelength is also asymmetric, with longer wavelength observations dominating the farthest objects from Earth because

obscuration is generally stronger at shorter wavelengths. Contrary to this point, globular clusters are observable at very large distances in the direction of the galactic center, but they are also commonly found at very large galactic latitudes (violating the two dimensionality simplification).

5. STUDENT MISCONCEPTIONS AND DIFFICULTIES

Whereas the Solar System is a relatively well-understood astronomical system among the public, driven by press about recent successful planetary probes and the Pluto controversy, the Milky Way is not. Misconceptions regarding the size, extent, and composition of the Milky Way are rampant. Though no students participating in the exercise at YWI expressed the belief that the Milky Way is made of milk, they were at a loss regarding its composition aside from stars. Although some students were familiar with images of the Orion Nebula or the Ring Nebula, no one could identify their relationship to stars. Most students also considered the Sun, Earth, and Solar System as unique members of the galaxy.

Another prevailing misconception was that the Milky Way spans the entire Universe, or rather that there is no distinction between the two. Yet even among students who could correctly identify the Milky Way as a distinct entity residing in a greater universe, there was still a prevailing misconception regarding the relative size of the Solar System within the Milky Way. On the 60-foot scale of the model we constructed, students were shocked to learn that the entire Solar System could be contained within the width of a human hair. Most students expected the Solar System and galactic scales to be similar. Still, some could not identify that the Solar System resided within the Milky Way at all.

Though working with coordinates and scale can be difficult for some early high school students, the structure of the lab should make the implementation of these mathematical concepts adjustable on a per-group basis. The primary difficulty in successfully executing the activity lies in piecing together a clear and easy-to-follow narrative for the students during discussion. Because many of the objects and systems explored in this activity are new to many students, and their relationships can be nonlinear and complex, it is best to follow a simple story. This is why we group galactic structures into three oversimplified classes of objects even though one might object to the relationships implied by these groupings.

6. MODEL LIMITATIONS AND POSSIBLE IMPROVEMENTS

The source list is probably the major limitation and point for improvement in the model. The 50 objects selected for our activity were chosen to highlight the characteristics of the galaxy and the astrophysical concepts of interest. We intended to cover the three components, the major observational wavebands, and the known spiral arms. In this sense, they represent a biased sample of objects, contrived to suit our teaching points. They were also chosen because we could find them via searchable online astronomy source catalogs, published journal papers, and public image databases. Perhaps more care can be taken to choose a sample that better reflects our knowledge or ignorance of the galaxy. Or, a sample can be constructed that is randomly distributed. The source selection is complicated by the highly visual nature of the model. Radio frequency contour maps do not make for highly appealing images, and they are harder to find. Furthermore, the number of objects that can be included is somewhat limited by the size of the printed images and their spatial density, so some thought should be given to this seemingly nitpicky concern.

7. STUDENT RESPONSE

At the end of the YWI program, the students were asked to fill out a questionnaire intended to gauge their experience. In two particular sections, the students ranked the difficulty of the lab on a scale of 1–4 (1 = *too easy*, 4 = *too hard*) and how stimulating they found it, also on a scale of 1–4 (1 = *interesting*, 4 = *boring*). The average of approximately 30 students in Grades 6–12 indicated they found the lab to be challenging (2.4) but interesting (1.7). In comment sections, students reflected that it was "great to be able to show the arms" of the galaxy and that scale modeling helped them learn about "something large in a manageable way," a point relevant to their everyday lives. There were also complaints, particularly about "too much lecturing," as opposed to hands-on work.

8. CONCLUSION

Additional important technical points could be discussed here, such as spiral arm structure or distance uncertainties, but I leave it to the reader to consider the model in more depth. It should be clear that a galaxy model presents a unique opportunity to illustrate and explore many important and fundamental astronomical and astrophysical concepts and tools through a challenging but captivating exercise for high school-level students. Furthermore, there remains room for improvisation and modification of the model as presented here for any educator interested in this activity.

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APPENDIX

Click here for the appendix in PDF.

Appendix URL: <http://aer.noao.edu/auth/friedman.appendix.pdf>

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176 - 180