Curriculum Units by Fellows of the Yale-New Haven Teachers Institute
1996 Volume VI: Selected Topics in Astronomy and Space Studies

Scaling Down the Universe

Curriculum Unit 96.06.06
by Victor Leger

It is the aim of this unit first to instruct students in the concept of 'scale', the idea of uniformly changing the dimensions of all germane material in context to each other. Without a firm understanding of this concept it is impossible for the student to fully comprehend the scope of the second objective of this unit.

The second objective is to clarify to the student the basic make-up of the Universe, beginning with the Earth and Moon, the Solar System, and Milky Way Galaxy. It is hoped that the student will come away from these lessons with a better awareness of our planet's relationship to the other planets and to the stars.

Being an elementary school art instructor, I believe that children grasp concepts quicker and easier through manipulatives; and that they will be motivated faster if they can help create those manipulatives. That is the basis for all the following lessons in this unit. The students will create scale models of the Solar System, the Galaxy, the Local Cluster of Galaxies, and then the Universe. For each new arrangement, we will need to re-scale down our models. This is where it is necessary to understand scale and the integral changing of all applicable sizes corresponding to each new microcosm.

This unit is intended for an upper elementary class but there is no reason that with simplification some of these concepts cannot be explained and taught to a younger group. Likewise, an older class could gain considerable inspiration and pursue innumerable directions at any point and continue on tangents. That is one of the awesome insights that the Universe invites to the spectator. Of all the sciences, Astronomy still offers the most potential for the amateur to contribute significant data and information. This is because of the overwhelming size and distances inherent in any discussion of the Universe, there is still so much 'stuff' out there to be explored from even just a backyard telescope.

With the aid of a planetarium and some telescopes, these ideas will become more lifelike and real. Ultimately it is hoped that the students will gain a better perspective of the immense size and structure of the Universe.

INITIATION:

Begin the unit by discussing with the class what they already know about the 'Universe'. This will give you an idea of how much is known by the students. Many of them will probably talk about some aspect of the Solar System, the planets and such without saying the word or concept 'Solar System'. Most elementary students may also associate stars with the idea of the Universe. However the basic structure of the planets revolving around the Sun, and then the Solar System being a minuscule element in a massive arrangement we call the Milky Way Galaxy, and the Milky Way just being one in billions of other galaxies spread throughout the vastness of nothingness known as the Universe, will probably be an ambiguous or totally new concept for many of them. By the end of this unit they will understand this order better.

In this discussion, a few key and inspirational statements or facts can be given about the Universe. These would depend on the direction that the class is taking the dialogue. For instance, if the students were concerned with the Earth and Moon, then the analogy of the Earth being reduced to the size of a quarter and the Moon being a nickel and placed approximately 90 centimeters away (for the sake of mathematical convenience, all measurements will be in the metric system) could be pertinent.

This is where the teacher should have previously done his homework and read any of the informative texts listed in the bibliography so that depending on the conversation, the teacher can give the appropriate information. There are many stimulating resources for any novice with an open mind to read up on and quickly gain a perspective on the simplest terms necessary for a discourse about Astronomy. Anyone can easily be drawn into a discussion of some of the overwhelming facts involved in Astronomy. I believe there is something intrinsically attracting to the human spirit in any discussion about the heavens. The teacher will have very little problem motivating the class to learn more about the planets and stars.

After this first class initiation into Astronomy, give a homework assignment for them to write down in essay form, all they know about the Solar System, stars, Milky Way Galaxy and the Universe. This will give the teacher the opportunity to get a better understanding of what they know and where to go from there. Give this assignment again when the unit is completed, as a way to assess the students and what needs to be done differently in the future from the teacher's perspective.

The next lesson needs to involve a talk about 'scale'. As an art teacher, I begin this topic with a drawing on the board of a person. Then I would draw two trees, one very small and one to scale with the person. Ask the class which of the two trees appears to be the 'right' size to the person. This can be repeated for any symbol from dogs, cars, building, etc. What we are trying to do is to make the connection that once one symbol is changed in size, then all other symbols relevant to the subject must be changed also in order to match.

Next the class can be given a set of blueprints (see material list) of a familiar building. Ideally, if the original plans for the school are available, they would be very helpful and befitting for this discussion about scale. With the blueprints, demonstrate once again how scale is used. Show the class the scale reduction used in the key legend. Point out how everything is drawn to match everything else in size. Explain how this is the simplest and most convenient way we have for the designer to illustrate to the builders how big to make all the components of the building, from windows, doors, wall heights, etc.

After the class has been acquainted with the plans, ask someone to calculate the actual sizes of furniture inside the rooms if it where to be drawn in the scale of the plans. This will start the students in the math computation necessary for this unit.

FIRST LESSON, SOLAR SYSTEM:

The first lesson will require some student handouts informing them what they will be expected to learn. The Solar System will comprise the first lesson. From the first hand out, the students will see in numerical form the sizes and distances of the Solar System. This will not mean too much until they start forming the Sun and planets from papier-mache.

Inform the class that they will be creating the Solar System so that they can get an idea of the sizes of the planets compared to each other. Remind the students what scale is and that it is necessary to reduce the sizes of everything so that they may fit in one room. Start with the convenient scale of one centimeter equaling 3,500 kilometers. Give the assignment of reducing all sizes and distances with this scale. Depending on the math comprehension of the students it may be necessary to give this as a cooperative group task with each group dealing with only one planet and it's distance from the Sun. Also, for ease, the numbers can be reduced to the nearest thousand. Just for suspense, save the s ize of the Sun for last. Check their answers against the Reference Chart at the end of this unit.

Once the class has estimated the appropriate sizes, they can start constructing the planetary models. They will need the following:

Materials

4, 18 inch balloons
1 lb. oil-based clay in red, yellow, green, blue, white
newspaper
175 square feet of cardboard
papier-mache mix
tempera paint in a variety of colors, extra yellow
colored markers
24 inches of 1/8 inch smooth steel rod
roll of duct tape
roll of wide masking tape

Tools

metric rulers for students
20 foot (7 meter) tape measure
assorted paint brushes
razor knife

STEP 1:

Since there are only nine planets and most classes have 20 or more students, it may be necessary to work in cooperative groupings. An alternative is to have everyone construct a planet, thus having two or three versions of each planet. This detail would depend on the teacher's preference. The important factor is that the creations come out to the correct size so that they are all in scale to each other.

The four gas giants (Jupiter, Saturn, Uranus, and Neptune) are created from the balloons with papier-mache, and then painted the appropriate colors. For anyone not familiar with the papier-mache process, there are two approaches worth considering. There is a product available from art supply houses called, "Art Paste" that is ideal for the novice as well as the professional. It is just a matter of adding water and waiting an hour for it to cure. Another viable product is standard wallpaper paste. After selecting a paste, tear the newspaper into 2 inch strips and cover the balloons with at least three solid layers of the paste-soaked newspaper strips. Let dry at least one day and then paint to match the planets.

The rings of Saturn can be created from a sheet of cardboard that is 78 centimeters wide (the size necessary for this scale to match the 274, 000 kilometer diameter). This will give the class the opportunity to work with geometry. If a large-size compass cannot be be obtained, then it is just a matter of using two pencils attached to opposite ends of a string 39 centimeters long. One pencil is the pivot and the other draws the diameter. Each smaller ring can be done by exchanging the outside pencil for a colored marker and shortening the string. Cut out the cardboard with a razor knife and continue the colored rings on the other side.

Attaching the cardboard ring to the papier-mache balloon is a little tricky. Take the 24 inch steel rod and pass it through the outside of the ring via one of the channels of the corrugated cardboard. Place the Saturn model inside the cardboard ring and continue passing the rod until the rod protrudes through the sides of Saturn and can slide into another channel on the opposite side of Saturn. Refer to **Illustration A** below for a clearer idea of how this is to be done.

STEP 2:

The five remaining planets (plus our moon) can be rolled from the oil-based clay or plasticene. Try to get colors to match the planets. The important concept is that they are rolled to the appropriate size. These five planets will be distinctively smaller then the four gas giants.

STEP 3:

By this point the class will become very awe-inspired by the discrepancy in sizes from the extremes of Jupiter and Pluto. The best has yet to come. Constructing the Sun. Because of the size difference, the most convenient solar fabrication is a flat 2-dimensional representation and constructing it in two halves to be taped together later. Start by laying out half of the cardboard ton the floor and taping the edges together with the duct tape. Because duct tape does not accept tempera paint very easily this will be the back side. Refer to **Illustration B.** Carefully turn the cardboard over and tape the front side with the wide masking tape. The radius can be drawn by finding the center on the long edge and using the tape measure as a pivot, one person holds the tape at 198.8 cm.(or at 92 3/8 inches). Another person can carefully hold a pencil at the end of the tape measure and walk it around the cardboard to end up with a semi-circle. Cut the cardboard with a razor and the class can now paint the cardboard with the yellow paint. Repeat this process with the rest of the cardboard to make up the second half of the Sun.

Hopefully, there is a place somewhere on the premises where these two halves can be taped together and displayed. Ultimately, the Solar System should be hung for all the school to see, because it is quite an awesome spectacle to behold. When one sees the incredible size difference in our Solar System between the Sun and the Earth, it can be a very sobering experience.

If it is possible, display the material in a high area. Then, have the class write a brief description of what they did. Also, a chart explaining the scale distances these planets would have to be from this miniature Sun in order to match these sizes. This has proven to be an exceptional way to motivate the rest of the school as a stepping stone for additional ideas about the Solar System and Astronomy.

As an extension to this first lesson it would be very revealing to the class to take a field trip with these planetary models and drop them off by the side of a straight and remote road at the scale distances. This experience would make it more concrete to the students the incredible reaches of our solar system.

Extensions to lesson:

- include more information about Earth and Moon relationship
- more about the individual characteristics of each planet
- more about meteors, comets and asteroids
- do some daytime solar and lunar telescope viewing *with filters*
- time a favorable planetary viewing with a local astronomical society
- calculate the speed of the field trip bus with the speed through the solar system

SECOND LESSON, MILKY WAY:

For the next lesson the class will need some facts about galaxies and if possible an actual night time viewing of our Milky Way Galaxy. This will make a big difference in the understanding of this next project and the scale of the Galaxy. The information at the least should include the fact that everything seen with the naked eye (with the exception of the Andromeda Galaxy and the Large and Small Magellanic Clouds) is in our Milky Way, and that all the *individual* stars we see are only in our 10% of the Galaxy. Also some data and pictorials about the basic layout of a spiral galaxy.

Depending on the class, the concept of light years could be given so that they can get an idea of the vast size of the Milky Way (100,000 light years in diameter). From the last lesson on the size of our solar system, they may get a feel for the distance of a light year if it is explained that it takes approximately eight minutes and twenty seconds for the light of the Sun to reach the Earth and almost 5 1/2 hours for the Sun's light to reach Pluto. This topic alone can take up many different directions. For our minimum purposes about sizes they should know the facts on **Handout B.**

Before the jump is made to the large size of the Milky Way Galaxy, the students should be taken from the Solar System scale in gradual steps, otherwise they will not get a clear picture of the basic framework of the Galaxy. Inform them that the closest star is a little over 3 light years away and that there are about 100 stars within approximately 100 light years. If we could reduce our Solar System to the size of a 1/2 dollar, the closest 3 stars would be the size of periods on this page and spread out over one city block. This should be done with the class, take a 1/2 dollar and three students holding periods cut from a newspaper and walk out the length of one city block.

The next scale model will be the Milky Way Galaxy. I would suggest using 1 foot to equal approximately 15,000 light years of the Galaxy as a convenient scale. Explain to the students that the real Galaxy is so large that even though there are billions of stars in it, there is still so much empty space. They will need:

Material

5, 1/4 inch thick 12 foot long cold rolled steel rods (can be acquired from a steel fabrication shop)
tie wire
8, 2 inch Styrofoam balls
small pulley
spool of 28 gauge wire (preferably black in color)
can of spray adhesive
large bag of iridescent flakes (an art supply store item, or can be cut on the school paper cutter from iridescent wrapping paper purchased at a card shop)
large size silver glitter and star shaped glitter
newspapers
nylon string to hang model while working on it

Tools

pair of wire cutters
pair of pliers

STEP 1:

Take 4 of the 5, 1/4 inch steel rods and bend them into the shape of an ’S’. Attach them at their center point with the tie wire so that when this step is completed, the basic structure of a spiral galaxy is layered out. Refer to **Illustration C** for clarity. Bend the remaining steel rod into a circle shape and attach to the spiral to lend the structure some stability. Push the 8 Styrofoam balls onto the ends of the steel rods for safety purposes. After these steps are completed, attach the small pulley to the ceiling and hang the model so that it can be accessible from any direction and pulled up to the ceiling when not being worked on.

STEP 2:

Use the 28 gauge wire to fill out the mass of the Galaxy. Using the cutting pliers, have a student cut sections of wire approximately their arms’ length left to right. Starting with the center of the model, students can tie one end of the wire to it. With a little finesse, they are to ‘ *loosely* ’ , (this is a key word here), wind the wire around the steel rods so that it will ‘billow out’ and assume the volume of the galaxy after many windings. Refer to **Illustration C** again for clarity. Because of the natural tendency of the wire to return into a circular shape, the windings should extend away from the steel rod structure in various diameters. Work the wire so that the larger diameters are towards the center of the galactic model. This step alone will take some time in order for your model to attain it’s approximate Milky Way shape and mass.

STEP 3:

This step will require lots of ventilation because we will need the spray adhesive. If it is possible, take the model outside. Spray the center area of the model with the adhesive. Then place a sheet of newspaper under the model and carefully sprinkle all the iridescent flakes and various glitters onto the glue, catching any excess with the newspaper to be used again. Repeat this step as often as necessary until the entire model has been permeated with the flakes and glitter and approximates the look of the Galaxy. It may be necessary to turn the model over to get a consistent look.

The Milky Way Galaxy should be done and ready for installation. Just like the previous lesson about the Solar System, the school needs to view this structure. For some grounding, hang a small sign about 2/3 of the way out from the center denoting ‘our Solar System’. A written description of what the class created and some pictorials of the Galaxy should be exhibited also.

Extensions to lesson:

- depending on the comprehension level of the class or their desire to further the lesson, create other scale models of our local area of the galaxy, the Orion arm
- give info about all the various kinds of stars, i.e, red giants, white dwarfs, supernovas, etc.
- more about our immediate ‘neighborhood’ of stars
- an observatory and a planetarium field trip

THIRD LESSON, THE LOCAL GALAXIES:

The class can be given **Handout C** about our Local Group of galaxies and the different shapes and types that they come in. Focus attention on the Andromeda Galaxy because of it’s significance as the companion galaxy to our Milky Way. The next scale model will also involve 10 minor galaxies and take the class to the distance of the Andromeda Galaxy at 2.2 million light years. We will need the following:

Materials

- cotton batting
- 10 feet of malleable wire
- spool of white thread
- spool of fishing line
- masking tape

Tools

- cutting pliers
- scissors

STEP 1:

The scale for this model will be approximately 1 foot to 200,000 light years. Of course, all these models can have a different scale than what is suggested here. At this size we should be able to fit the two major galaxies (the Milky Way and the Andromeda) into an average classroom at 11 feet away from each other. This model will entail hanging the various galaxies in a room so from this point on it will be referred to as an installation.

The students should be able to make up the various galaxies form the cotton batting. Refer to **Handout C** for appropriate shapes and sizes. The Milky Way and Andromeda can be made up using the malleable wire bent into a pinwheel shape diameter of 1 foot as a substructure, much like the last model but on a much smaller scale. Then wrap the cotton around and tie with white thread to assimilate spiral galaxies.

STEP 2:

The galaxies, like the previous models should be installed in a space that gets a lot of school traffic so curiosity can be piqued. Then it is a matter of triangulation to approximate the placement of the 12 galaxies in the exhibition space. Refer to **Illustration D.** At this scale it will be necessary to use an area 20 feet across. Use the fishing line to hang the various galaxies and whatever is necessary to attach the fishing line to the ceiling.

Extensions to lesson:

- arrange for a deep space viewing with a local astronomical society or observatory
- go to a planetarium

FOURTH LESSON, THE UNIVERSE:

This lesson project will have the class making 1 inch representations of groups of galaxies, at least 25 of them. The scale will be 3 centimeters equals 2.2 million light years (I suggest this scale because it relates to the size of the last installation). Assuming the universe to be presently 15 billion light years across, the outside limit of this scaled down universe will be approximately 200 meters. This will obviously not be able to hang indoors; and considering the billions of galaxies in the universe, we will have to make do with representing many small versions of local groups of galaxies and imagine the rest to a distance of 200 meters.

STEP ONE:

The class can be given **Handout D** , about the size of the universe. The list below will tell you what you need:

Materials

- roll of thin but stiff wire
- 25, 1/2 inch craft Styrofoam balls
- white 'Tacky' craft glue

Tools

- wire cutters
- needle nose pliers
- 100 foot tape measure(30 meters)

Each student will make a miniature model of a local cluster. To start, hand out 3 pieces wire cut at roughly 4 centimeters. The students are to twist these tightly around each other so that the 6 ends protrude away from their centers. Refer to **Illustration E** for clarity. At this point the students can be given a Styrofoam ball and told to chip off six of the smallest pieces possible. With the aid of the white tacky glue, they can press these minute Styrofoam chips onto the ends of the wire. These chips represent the various galaxies in a local cluster so at this scale they should not be any larger than 1/2 centimeter. Ideally the smaller the students can handle these chips the more accurately these models will be. Let these dry.

STEP TWO:

The next phase can be accomplished by the teacher or one of the more coordinated students. Using the needle nose pliers, more wire and whatever else is necessary, start attaching all the various clusters together so that you have a large supercluster of galaxies approximately 15-20 centimeters across. Save two of the local clusters aside for later. When it is done, have the class estimate the scale size of the supercluster if one local cluster equals the distance to our own Andromeda Galaxy of 2.2 million light years.

STEP THREE:

This final step of the unit will take the class to the edge of the Universe. To do this you will need an open area 400 meters long, a city park or a long open road should do.

Take the supercluster out to the selected area and start measuring off 200 meters in one direction from the supercluster. Leave one of the two extra local clusters set aside earlier at this 200 meter spot. Repeat these steps in the opposite direction from the individual local cluster so that the supercluster is in the center of the two individual local clusters. Refer to the drawing below for clarity. The class can now get a good idea of the size of the universe if they can imagine our Milky Way Galaxy as one of the tiny Styrofoam chips in the center of the supercluster and the two individual local clusters as the outside edge of the known universe. Congratulations on reaching the edge of the Universe!

(figure available in print form)

HANDOUT A

SOLAR SYSTEM REFERENCE CHART

FOR DIAMETERS AND DISTANCE

Scale: 3,500 kilometers = 1 centimeter

	SCALE DIAMETERS	ACTUAL DIAMETERS	
SUN	-397.7 centimeters.	1,391,400 kilometers	
MERCURY	- 1.4 “	4,878	“
VENUS	- 3.5 “	12,104	“
EARTH	- 3.6 “	12,756	“
Moon	- 1.0 “	3,476	“
MARS	- 1.9 “	6,787	“
JUPITER	- 40.8 “	142,800	“
SATURN	- 34.5 “	120,660	“
URANUS	- 14.5 “	50,800	“
NEPTUNE	- 13.9 “	48,600	“
PLUTO	- .7 “	2,300	“

1 Astronomical Unit = 428 Meters

(an astronomical unit is the distance of the Earth to the Sun, approximately 150,000,000 kilometers)

	SCALE DISTANCE	ACTUAL DISTANCE	
SUN	- 0	0	
MERCURY	- 166 meters	.387 astronomical unit	
VENUS	- 309 “	.723	“
EARTH	- 428 “	1.00	“

MARS	- 650 . “	1.52	“
JUPITER	- 2.22 kilometers	5.20	“
SATURN	- 4.08 “	9.54	“
URANUS	- 8.21 “	19.18	“
NEPTUNE	-12.87 “	30.07	“
PLUTO	- 16.88 “	39.44	“

HANDOUT B

FACTS ABOUT THE MILKY WAY GALAXY

Our sun is actually a star. It is a very average size star compared to some stars that are hundreds of times larger and tens of times hotter. It is one of approximately 10,000,000,000 stars in an arrangement we call the Milky Way Galaxy. If you have ever been out at night in a place that has absolutely no lights shining, then you might have seen the Galaxy as a hazy swath going right across the sky. This ‘milky’ swath is actually billions and billions o f individual stars very, very far away all blending their light together. Many of these stars may also have small planets revolving around them like the Earth. Unfortunately the distance from any two stars is so incredibly far that even if we could travel on a beam of light (the fastest speed that anything can move), it would still take years and years.

The Milky Way Galaxy is a very large group of stars. To get an idea of even the size of our ‘neighborhood’ of the Galaxy, we would need to shrink our Sun and the closest 3 stars to the size of a tennis ball, and then drop them in an area the size of North America! Obviously at this scale the rest of the Galaxy would still be incredibly large. If we could reduce the *whole Glaxy* to the size of North America, then our entire Solar System out to the orbit of Pluto would fit on a dinner plate and the Sun would be smaller than a period on this page.

All stars are different from each other in some way. There are stars that are still being created and aren’t able to give off their own heat and light yet. Some stars are just tiny remnants and embers of what they used to be after going through a huge fiery destructive phase that, despite their enormous distance, rivaled our own Moon at night in it’s brightness. There are stars so large that if they were in our solar system they would take up all the space out to the orbit of Mars! Stars even come in a variety of colors and names like red giant and white dwarf. Some stars are combined in pairs and triplets that are revolving around each other.

Because of the incredible size of the Galaxy we have to measure it in something besides miles because the number of miles is so large that we can’t even fit it on this page. Scientists have come up with the measurement of a light year. If you can think of the light from the Sun moving to reach us each day on a very fast beam, then you can understand a light year. Light from the sun takes about 8 1/2 minutes to reach us and over 5 hours to get to Pluto.That same beam of light would take over three years to get to the closest star, Alpha Centauri at 20,000,000,000,000 miles away. The entire Galaxy is about 100,000 lights years across!

HANDOUT C

THE LOCAL CLUSTER OF GALAXIES

We have learned that our Sun and planets are part of a huge group of stars called the Milky Way Galaxy and that it is in a flat pinwheel shape. If we could travel out of our Galaxy, we would see that there are other galaxies nearby that have different shapes and sizes. We would notice that about 2,200,000 light years away, there is another galaxy that is just like our's in size and shape called the Andromeda Galaxy.

It is the only galaxy that can be seen from the northern hemisphere with the naked eye. Below is a list of galaxies and information about them.

NAME	SIZE	DISTANCE (in light years)	SHAPE
Milky Way	100,000	0	Spiral
Large Magellanic Cloud	62,700	165,000	Irregular
Small Magellanic Cloud	26,000	209,000	Irregular
Draco	6,000	297,000	Elliptical
Ursa Minor	4,600	297,000	Elliptical
Sculptor	3,300	330,000	Elliptical
Sextans	6,600	330,000	Elliptical
Fornax	1,600	495,000	Elliptical
Leo I	3,300	594,000	Elliptical
Leo II	6,600	594,000	Elliptical
NGC 6822	11,500	1,650,000	Irregular
Andromeda	105,600	2,200,000	Spiral

ILLUSTRATION A

THE RINGS OF SATURN

(figure available in print form)

ILLUSTRATION B

FABRICATION OF THE SUN

1. Tape together about 90 square feet of cardboard
2. Cut out a half circle with a radius of 198 centimeters
3. Paint it yellow
4. Repeat above three steps and attach the two halves together

(figure available in print form)

ILLUSTRATION C

ASSEMBLY OF THE MILKY WAY GALAXY

1. 4, 12 Foot long, 1/4 inch thick steel rods bent into 's' shapes and tied at their centers to make a spiral about 7 feet wide.
2. Another rod bent into a circle shape and tied on top to lend some stability.
3. Fine gauge wire *very loosely* wrapped around steel rods in a billowing fashion.
4. Spray assembly with adhesive and drop flakes of iridescent paper onto it.

(figure available in print form)

ILLUSTRATION D

PLACEMENT OF THE LOCAL CLUSTER OF GALAXIES

1. Create the 12 galaxies from Hand Out *C* using cotton and wire.
2. Hand all 12 galaxies with fishing line in a high space refering to this illustration as a guide for coordinating their placement to each other.

(figure available in print form)

With the Milky Way Galaxy as the center plane to work from, all those galaxies noted with a *dotted* line would hang lower and all the rest of the galaxies noted with a *solid* line would hang above the Milky Way. Scale their distance from the chart on Hand Out *C* . Then it is just a matter of triangulation to hang each galaxy in it's appropriate orientation to the Milky Way.

ILLUSTRATION E

CREATING THE MINI-MODEL OF A LOCAL CLUSTER OF FALAXIES

1. Cut 3 pieces of thin stiff wire 3 centimeters long and wrap their centers together tightly.
2. Chip off 6 tiny pieces of styrofoam and adhere onto the ends of the wires with white craft tacky glue.
3. Let dry.
4. Leaving two mini-models aside, attach all the others together into a supercluster of galaxies.

(figure available in print form)

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