Chapter 18: The Interstellar Medium

Gas and Dust among the Stars

Outline

Summary

In Chapter 15 you introduced the process by which a star is formed, namely through the condensation theory or nebular theory. This chapter studies the source of material, the interstellar medium, rather than the formation process itself. The characteristics and properties of the interstellar medium as well as the different types of nebulae and clouds that comprise it are discussed in this chapter. Methods of probing the interstellar medium are also addressed.

The story of interstellar matter is not completed in this chapter, but must await the completion of Chapter 21. At that time you may want to revisit this chapter briefly and look upon it with a new perspective. The exchange of matter between the interstellar environment and stars is cyclic, so the origin of stars is as good a place as any to start. And as you present the setting for the formation of stars, consider for a moment how this may also be the setting for the formation of life.

Major Concepts

- The interstellar medium
  - Gas and dust
  - Composition
  - Density
- Interstellar clouds
  - Emission nebulae
  - Reflection nebulae
  - Dark dust clouds
  - Molecular clouds
- Probing the interstellar medium
  - 21-cm radiation
  - Reddening
  - Radio observations

Teaching Suggestions and Demonstrations

The **interstellar medium** is often an overlooked component of the universe for beginning astronomy students. It is not nearly as obvious as planets, stars, and galaxies are. Moreover, it is often seen by the introductory student as a collection of wispy clouds of gas and dust, not as a substantial or significant contributor. At the beginning of this chapter, point out to students that not only is the interstellar medium fascinating in its own right, but it also is the birthplace of stars, giving it a rather important role in the universe as a whole.

Section 18.1

It should come as no surprise to students by this point in the course that most of the interstellar medium is hydrogen. Discuss the other components (formaldehyde probably *will* be surprising) and distinguish between **gas** and **dust**.

Small particulates and molecules in the Earth's atmosphere have much the same effect on light as does **interstellar dust** on distant star light. Because the particles selectively pass longer wavelength waves but reflect (scatter) shorter wavelength waves, the Sun appears reddish at sunrise and sunset. Seen through less atmosphere when higher in the sky, the effect lessens as the Sun rises towards noon.

Students often do not realize that the Earth's atmosphere affects all objects seen through it in the same way. This is fairly obvious for the Moon but is also important when viewing stars. Stars, the Moon, and the Sun all appear redder *and fainter* when viewed low in the atmosphere. Since the shorter wavelengths are scattered out of the line of sight (causing the sky to appear blue) we do not see all of the light from the object and it consequently appears fainter. The exact same process occurs for stars viewed through interstellar dust.

The effects of **reddening** and dimming, also called **extinction**, of starlight by dust cannot be overstated. On the average, dust dims starlight by about 1 magnitude every 1,000 pc. A star that would appear at magnitude 10 at this distance would appear as magnitude 11. This does not seem all that significant at first. But the same star at the distance of the center of the Galaxy should appear at magnitude 15 without dust. With dust, it would appear at magnitude 25; this is near the faint limit of our largest telescopes! Indeed, dust limits our view of the Galaxy to such an extent that we see little of it in visible light. It was not until the 1930s, when interstellar dust was proven to exist, that astronomers realized the Galaxy was not just a few thousand parsecs in radius but much larger; about 30,000 pc.

➲ **DEMO** To demonstrate reddening, put a few drops of milk in a jar of water and shine a light through it. To the side of the light beam, the milky water looks bluish, because the milk particles have preferentially scattered out the blue light. The effect of interstellar gas and dust on our ability to observe in visible wavelengths is dramatic. Have students imagine being in a dense forest. Even if they are not in the center, the view in every direction is about the same. Probing the forest in more than visible light would give students more information. For instance, they could yell or blow a whistle to see whether anyone responded. In a similar matter, radio and infrared wavelengths allow astronomers to "see" farther than visible light. (Be careful with this analogy. Sound waves are obviously not electromagnetic radiation; radio waves are.)

Densities in interstellar space are very low; however, the distances between stars are so vast that it turns out there really is a lot of gas and dust between stars. A density of only 10 hydrogen atoms per cm^3 is not unusual, although regions can be found with densities 100 times higher or lower than this. This density is better expressed as 1.7×10^{-20} kg/m^3. A volume of space one parsec in radius (a typical distance between stars) contains 1.3×10^{50} m^3. Since density is mass divided by volume, it is simple to calculate the total amount of mass in this typical volume of space due to interstellar gas. The result is 2×10^{30} kg, which is exactly one solar mass. The Galaxy, which is about 15,000 pc in radius and about 300 pc thick contains 2×10^{11} pc^3. Even at only 1 atom per cm^3 the total mass of interstellar gas is 20 billion solar masses. There is potential for star formation far into the Galaxy's future.

Polarization, as discussed in this chapter, is another phenomenon that results when light passes through a medium such as interstellar matter. ➲ **DEMO** To demonstrate polarization, use a light source that produces a beam of light and several sheets of Polaroid. With light passing through one sheet, nothing much is observed. Place another sheet in front of the first and rotate it. It is very obvious that as the second sheet is rotated the amount of light passed varies from what was passed by the first sheet alone to virtually zero.

The first Polaroid passes light of only one electric field orientation. When the second sheet is aligned perpendicular to the first, no light can pass through. Students can usually understand the geometry of this simple explanation. It is not quite this simple. While the two sheets are perpendicular and no light is passing through, insert a third sheet between the first two and at about 45° to the other sheets. Some light now passes out of the third sheet! Although this effect is difficult for students to understand (because it involves the vector nature of the electric field) it shows them that there is additional complexity beyond the scope of this course.

Section 18.2 and 18.3

The term nebula comes from the same word in Latin which means "cloud." Early astronomers with small and poor quality telescopes saw many objects that appeared as clouds which now can be well-resolved. The word nebula is still used in describing those objects that are indeed "cloudy."

Some of the most beautiful space images you can show are of **emission nebulae**, so you may want to have plenty on hand while discussing this subject. Emission nebulae are also among the largest luminous objects in the sky. Several are easily visible to the naked eye under dark sky conditions. M 42, Orion Nebula, is 460 pc distant and 5 pc in diameter. It appears about 0.5° in diameter, the angular size of the Moon. M8, the Lagoon Nebula, is 1200 pc distant and 14 pc in diameter and appears about the same size. The density of gas in these nebulae is typically about 10 hydrogen atoms per cm^3. Using the fact that a sphere of 1 pc radius and this density contains one solar mass of gas, a nebula with a radius of 10 pc should contain 10^3 times as much mass or 1000 solar masses. This is in fact the approximate mass of M8. Images projected on a large screen can serve as an effective back-drop for your lecture. You can also show reflection nebulae, dust clouds, star-forming regions, and a picture of the Milky Way. Darken the room so that students get the full effect of the images. They may not be able to take notes, but that's good. Let the visual images and drama of the scenes sink in a bit.

➲ **DEMO** Because emission nebulae produce an emission spectrum, demonstrating emission spectra with gas discharge tubes is once again useful if not done previously. In particular, point out the red emission line of hydrogen. In the tubes, fast moving electrons excite the gas atoms through collisions. The electrons in the atoms then make transitions downward and produce the characteristic emission lines. It is helpful to relate this process back to the discussion in Chapter 3 about emission and absorption processes. In the nebulae, the gas atoms are excited by absorbing ultraviolet light from a hot luminous star nearby. In both cases the gas being excited must have a relatively low density, although admittedly the gas in the tube is at a much higher density than that found in the nebulae. In color photographs of many emission nebulae, the color red shows up very distinctly.

Many of the available photographs (slides, laser disc, or CD-ROM images) show not only the red emission of hydrogen, but dark dust clouds, blue reflection nebulae, young stars usually in a cluster, and the ever-present, multi-colored background stars. Describe what is happening in each image and try to give the third dimension perspective, a depth perception. There is a wealth of information going on in each one.

Is a dust cloud dark or is it bright? We normally think of dust clouds as dark, as seen in Figure 18.1 and 18.5 of the Milky Way or in Figure 18.14 of Rho Ophiuchi or 18.15 of the Horsehead nebula. So, what happens to the blue light that the dust particles scatter? Generally, it is still there but it may be hard to see. At other times it is easy to see. Examine Figure 18.8 of M20; the blue light around the star at the top is starlight reflecting off of the dust cloud that surrounds it. Another nice example is the Pleiades star cluster, Figure 19.18 (a). Again, the blue light is originating with the stars but is reflected or scattered off of the dust that remains in the cluster. Under these circumstances, dust clouds are sometimes referred to as **reflection nebulae**.

Dust clouds also emit light of their own, a fact often overlooked and possibly confusing to students. They emit light in the infrared because the dust is warm, about 100 K. Each dust particle is like a little black body which absorbs starlight, is warmed up, and re-radiates this energy back into space. Using Wien's law, the peak of radiation coming from dust is about 0.0029 cm or 29 μm.

So, are dust clouds dark or bright? They appear dark when blocking the light of background stars, they appear deep blue when a star near to them provides sufficient light to reflect, and they appear bright in the infrared, especially when warmed by starlight.

Section 18.4

An extremely important source of information about our Galaxy is **21-cm radiation**. Determine whether your students can come up with some of the advantages of using it. For one, it results from a spin-flip transition in atomic hydrogen, and because hydrogen is (by far) the most abundant element in the interstellar medium, we should be able to find plenty of it to study. Second, because the energy difference in the two states of the hydrogen is so low, the frequency of the emitted radiation is low and the wavelength is long. (Now would be a good time to do a brief review of emission spectra and the relationships among energy, frequency, and wavelength.) The long wavelength means it is in the radio frequency range, and, as was seen earlier, radio waves travel unimpeded through the interstellar medium.

Section 18.5

Regarding molecular clouds, point out the increased complexity as compared to previously discussed nebula constitution. Molecules have additional energy states such as rotational and vibrational, which each have their own emission characteristics that are usually of much lower energy. Review the fact that lower energy translates into longer wavelength radiation, which is often better able to penetrate the interstellar media. Use the term **"tracer"** in the context of a signal that announces the presence of something else which cannot be seen directly.

Student Writing Questions

1. Choose a color photograph of a region of interstellar matter that is rich in detail. It might be one from your text, one shown in class, or one that you have found in an article. Describe it! Use an artistic approach, rather than a scientific one. Remember, one picture is worth (at least) a thousand words!

2. Describe how our Milky Way galaxy appears at various wavelengths. Refer to Chapter 23 for more information about its structure. What does it look like if you can see just starlight, hydrogen gas emissions, infrared from dust, 21 cm radiation, molecular OH emissions, UV, X-rays, long-wavelength radio waves, and so on? How do these various views interrelate to one another?

3. What would it be like to live inside an emission nebula? Suppose the solar system moved into such a region. What would the sky look like at night? Consider both the gas, dust, and stars that you would see. Would this region be dangerous to life on Earth? How often might this actually occur?

4. What would it be like to live inside a dark dust cloud or molecular cloud? Consider the same questions as posed in the previous question.

5. Complex organic molecules form in molecular clouds, exactly where stars and solar systems would form. What does this suggest about the chemistry of life that might exist elsewhere in the Galaxy? Does this mean that all life would resemble the life we see on Earth?

Answers to End of Chapter Exercises

Review and Discussion

1. The interstellar medium is made up of gas and dust. Gas is much more abundant yet has a density of only about 1 atom per cubic centimeter. The density of dust is even lower, about 100 times less by mass. The composition is about 90% hydrogen, 9% helium, and 1 % heavier elements. Most of the heavier elements are found in the dust particles. Temperatures average around 100 K, although they can be much higher in emission nebulae and lower inside molecular clouds.

2. Interstellar gas is composed of 90% hydrogen, in atomic and molecular forms, 9% helium, and 1% heavier elements. Some of the heavy elements are underabundant compared to stars and our solar system. Presumably these elements have gone into making up interstellar dust. The dust is believed to be composed of silicates, graphite (a form of carbon), and iron.

3. Interstellar gas is mostly transparent to radiation, absorbing only a few specific wavelengths. Dust particles can absorb many wavelengths and selectively reflect only the shortest wavelengths. Therefore, more of the spectrum is affected by dust than by gas.

4. The density of interstellar matter is about 1 atom/cm^3; however, local values can far exceed this by 1000s and some places have a density 100 times lower. Dust is even rarer, 1000 particles/ km^3.

5. Interstellar matter is not spread uniformly through space. By just examining Figure 18.5 it is obvious that the clouds of interstellar dust vary greatly over the galaxy. Our view of the stars in some directions is severely limited, in other directions there is virtually no dust. Gas is also unevenly distributed. On average there may be only 1 atom per cubic centimeter but in large molecular clouds the density can be 100s and 1000s of times greater.

6. Astronomers can study dust clouds by examining how it both dims and reddens starlight that passes through them. Spectra of the starlight can indicate the composition and temperature of the gas that is mixed in with the dust. Starlight also can reflect off of dust particles and this light tells astronomers about the size and possible composition of the particles. Lastly, dust particles emit infrared light, from their own warmth. The infrared spectrum gives added information about the composition of the dust.

7. An emission nebula is a region of hot glowing interstellar gas. Such a region surrounds a newly formed star or stars. It absorbs ultraviolet light emitted by the bright young stars, and

in return, emits a variety of emission lines characteristic of the gases of which it is composed.

. Hydrogen gas is in emission. One of its brightest emission lines is H-alpha, which has a red color. It is so strong that it often overwhelms all other emissions and colors that might be seen.

8. Photoevaporation occurs when newly formed stars' radiation slowly breaks up the dust particles left over from star formation.

9. The so-called "forbidden" spectral lines occur only in a very low density environment that is impossible to reproduce in a laboratory.

10. The local bubble is the region of space surrounding us to a radius of about 50 pc. This region appears to be of lower density than that surrounding it and is probably a result of one or more supernova explosions long ago. The low density allows for propagation of extreme UV radiation, which would not otherwise have been visible to us.

11. A dark interstellar cloud may be seen in silhouette against a bright background. But to actually see it, an astronomer can look for the blue light that it reflects, the infrared light it emits from having absorbed star light, and radio emissions from molecules that have formed inside it.

12. Dark dust clouds are typically parsecs across in size and about 100 K in temperature. Their densities are thousands or millions of times higher than other interstellar regions and they very effectively block starlight. They appear as dark silhouettes against the field of stars of the galaxy.

13. 21-cm radio radiation is emitted by cold hydrogen gas. This gas is found throughout the entire galaxy. This wavelength of radiation passes through dust clouds without being scattered; the entire galaxy is visible in 21-cm radiation. The temperature and density of the gas can be determined along with its motion. 21-cm radiation has been used to map out the entire galaxy.

14. 21-cm radiation is emitted by cold hydrogen gas anywhere in the Galaxy. But it also passes through all interstellar dust clouds, so the entire Galaxy can be observed. Because it is also an emission line, it can be used to measure the velocities of the clouds that emit it, allowing astronomers to study the dynamics (motions) of the Galaxy.

15. Molecular clouds occur in the densest and darkest interstellar clouds. Here, molecules of hydrogen and other complex substances form. The dense dust cloud protects the molecules from destruction by starlight and may also provide a surface on which the molecules can form.

16. Hydrogen cannot be used to study the structure of molecular clouds because hydrogen forms molecules that do not emit 21-cm radiation.

17. Astronomers use radio emissions from various simple molecules, such as CO and OH, to study molecular clouds.

18. Our Sun would not produce much of an emission nebula because it emits very little ultraviolet light. What little it emits would be quickly absorbed by the gas in its immediate vicinity; an emission nebula would not be seen because of the glare of sunlight.

19. The reasons for the reddening of stars by interstellar dust and the reddening of the setting (or rising) Sun are the same. Particles of dust selectively reflect short wavelength light and pass long wavelength light.

20. Polarization is an alignment of the electric fields of which light is made. This can happen when light passes through interstellar dust where the dust particles have all been aligned by a magnetic field. Studies of the polarization yield information on the interstellar magnetic fields and the size and shape of dust particles.

Conceptual Self-Test

1. F
2. F
3. T
4. T
5. F
6. T
7. F
8. F
9. F
10. T
11. A
12. D
13. C
14. A
15. D
16. C
17. B
18. D
19. A
20. A

Problems

1. Each cubic meter will contain 10^3 atoms/m^3 $\times$ 1.7×10^{-27} kg/atom = 1.7×10^{-24} kg/m^3. The Earth is a sphere, a radius of 6.4×10^6 m and a volume of $4/3\pi(6.4\times10^6)^3 = 1.1\times10^{21}$ m^3. Mass is equal to density times the volume, so 1.7×10^{-24} kg/m^3 $\times$ 1.1×10^{21} m^3 = 0.0019 kg or 1.9 g.

2. The distance to Alpha Centauri is 1.33 pc $\times$ 3.1×10^{16} m/pc = 4.1×10^{16} m. The volume of space is 4.1×10^{16} m^3. Multiplying this by the mass density from the previous question gives a total mass of 7.0×10^{-8} kg. This is equal to 0.070 mg.

3. The average density is 10^6 atoms/m^3. As in Problem 1, this density is = 1.7×10^{-21} kg/m^3. Volume is mass divided by density. In this case 1.2 kg / 1.7×10^{-21} kg/m^3 = 7.1×10^{20} m^3. This is a spherical volume about 87% the size of the Earth.

4. Assume the shape is a cylinder of length L and cross-sectional area πr^2, the product of which is the volume. From the scale of the diagram, the diameter is about 10^{-7} m and a length of about three times this. Using this to calculate the volume and multiplying by the density will give the mass.

$$3 \times 10^{-7} \times \pi \times (5\times10^{-8})^2 \times 3000 = 7.1\times10^{-18} \text{ kg}$$

5. Every 5 pc it gets fainter by a factor of 2. For example, in 10 pc it gets $2 \times 2 = 4$ times fainter. It gets reduced by 2 a total of $60/5 = 12$ times as it passes through the cloud. This is $2 \times 2 \times 2 \times$ ....., or more easily $2^{12} = 4096$. The light is seen 4096 times fainter than it was before it entered the cloud. On the magnitude scale, the light is reduced in intensity by 2.5Log(4096) = 9 magnitudes.

6. If the light has been diminished by a factor of 20, that is equivalent to 3.25 magnitudes. The extinction is then 3.25 mag / 1.5 kpc or 2.2 mag/kpc.

7. $M = -6$ and $m = 14$, $14 - (-6) = 5\text{Log(d)} - 5$, $d = 10^5$ pc.

   Solving for m, from the known distance of 5,000 pc, gives $m - (-6) = 5\text{Log}(5000) - 5$, $m = 7.5$ It has been dimmed by 6.5 magnitudes over 5 kpc or 1.3 mag/kpc.

8. $10 - M = 5\text{Log}(500) - 5 + 2 \times 0.5$, $M = 0.5$. $4.85 - 0.5 = 2.5\text{Log}(L/L_{sun})$, $L/L_{sun} = 55$

9. $M = -5$ and $m = 10$. $10 - (-5) = 5\text{Log}(d) - 5 + (d/1000)\times2$. Reduce this equation to $4 = \text{Log}(d) + d/2500$. You can not solve directly for d, so try various values for d, solve the right hand side and if the result is greater than 4, choose a smaller d; if smaller than 4, choose a larger d. The answer is approximately 1850 pc.

10. Wien's law states $\lambda_{max} = 0.29/T$, where λ_{max} is measured in centimeters. 9.12×10^{-6} cm $= 0.29/T$, $T = 31{,}800$ K.

11. Imagine an atom at the edge of an interstellar cloud. The temperature of the gas determines the average velocity of the atom. For a hydrogen atom, this is simply $v = 0.157\sqrt{T}$ km/s (from *More Precisely 8.1*). From the same source the escape velocity is $v = 11.2\sqrt{(M/r)}$ km/s, where M and r are mass and radius in Earth units. Changing these units to solar masses and pc gives $v_{esc} = 0.092\sqrt{(M/r)}$ km/s. Don't forget to divide the diameter given by 2 to get the radius.

Object	Diameter (pc)	Mass (solar masses)	v_{esc} (km/s)	T (K)	vel. of hydrogen (km/s)
M8	14	2600	1.8	7500	13.6
M16	8	600	1.1	8000	14.0
M17	7	500	1.1	8700	14.6
M20	4	150	0.8	8200	14.2

The velocity of the hydrogen is much higher than the escape velocity, so these emission nebulae are not held together by their gravity but are generally expanding.

12. Taking the second equation and data from the table in the previous question gives $13.6 = 0.092\sqrt{(M/7)}$, $M = 150{,}000$ solar masses.

13. The change in wavelength will be $\Delta\lambda = (75/300{,}000) \times 21.1 = 0.0053$, giving a wavelength of $\lambda = 21.1053$ cm. Similarly, $\Delta\lambda = (50/300{,}000) \times 21.1 = 0.0035$, giving a wavelength of $\lambda = 21.0965$ cm.

    Similarly, for the frequency $\Delta f = (75/300{,}000) \times 1420 = 0.355$, giving a frequency of $f =$ 1419.65 MHz. Similarly, $\Delta f = (50/300{,}000) \times 1420 = 0.237$, giving a frequency of $f =$ 1420.24 MHz.

14. A cloud density of 10^{12} hydrogen atoms per cubic meter multiplied by the mass of a hydrogen atom will then give the mass density of the molecular cloud. Using the mass of a hydrogen atom gives 10^{12} atoms/m^3 $\times$ 1.7×10^{-27} kg/atom = 1.7×10^{-15} kg/m^3. The mass of the Sun is 2×10^{30} kg, volume is equal to the mass divided by the density. Vol. = 2×10^{30} kg / 1.7×10^{-15} kg/m^3 = 1.2×10^{45} m^3 .

    This volume is that of a sphere, $4/3\pi R^3$. Solving for the radius, gives 6.5×10^{14} m. Since 1 A.U. = 1.5×10^{11}m, this radius = 4,400 A.U.

15. A 1 pc radius cloud has a volume of $4/3\pi R^3 = 1.2\times10^{50}$ m^3. With a density of 10^6 hydrogen atoms/m^3, the total number of hydrogen atoms in this cloud is 1.2×10^{56} hydrogen atoms.

    As stated in the problem, 0.75 of all atoms are in the upper state and the probability of a transition is 3×10^{-15} transition/s. The total number of hydrogen atoms making a transition each second is $1.2\times10^{56} \times 0.75 \times 3\times10^{-15} = 2.8\times10^{41}$ transitions/s. The energy of the photon, of frequency 1420 MHz will be $E = hf = 6.63\times10^{-34} \times 1.42\times10^{9} = 9.4\times10^{-25}$ J. Multiplying this by the number of atoms per second making the transition gives 2.6×10^{17} W.

Resource Information

Student CD Media

Movies/Animations
Gaseous Pillars of Star Birth
M16 Eagle Nebula
Orion Nebula Mosaic

Interactive Student Tutorials
None

Physlet Illustrations
Spin Flip and 21-cm Radiation

Transparencies

T-167	Figure 18.2	Reddening	p. 469
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T-174	Figure 18.17	Hydrogen 21-cm Emission	p. 482
T-175	Figure 18.19	Molecular Emission	p. 483

Materials

Spectral tubes and diffraction grating glasses.

Beautiful posters of nebulae are available from the Astronomical Society of the Pacific.

Suggested Readings

"Name That Nebula." *Astronomy* (June 2002). p. 34. Shows many images of nebulae, which currently have no name other than their catalogue numbers. *Astronomy* magazine had a naming contest for them.

"Surveying galactic hydrogen clouds." *Sky & Telescope* (May 2000). p. 20. A brief news report about a radio survey of hydrogen in the galactic plane.

Croswell, Ken. "The Black Cloud." *Astronomy* (December 2003). p.51. Short article on a nearby very dark nebula. Fascinating photographs of a globule that will likely collapse some day to form stars.

Frank, Adam. "Starmaker." *Astronomy* (July 1996). p. 52. Describes accretion disks, jets, Herbig-Haro objects, and the role of angular momentum in star formation.

Greenberg, J. Mayo. "The secrets of stardust." *Scientific American* (Dec 2000). p. 70. Describes studies of the composition of star dust.

Kaisler, Denise. "Cosmic intrigue." *Astronomy* (Oct 2000). p. 42. Describes the characteristics of globular clusters, their formation, and their role in determining the age of the universe.

Kanipe, Jeff. "The giant star pillars of M16." *Astronomy* (Jan 1996). p. 46. Features images and a description of the star farming regions in the Eagle Nebula, M16.

Knapp, Gillian. "The stuff between the stars." *Sky & Telescope* (May 1995). p. 20. Gives an overview of the interstellar medium.

Lada, Charles. "The hidden treasure of M17." *Sky & Telescope* (Aug 2000). p. 58. A short article featuring images of the emission nebula M17 and its associated molecular cloud.

Swafford, A. "Seeing in the Infrared." *Astronomy* (August 2002). p. 39. Overview of a new interferometer telescope capable of viewing in the sub-millimeter band, which is good for imaging cool dust and molecular clouds.

VanDyk, S. "The Ultimate Infrared Sky Survey." *Mercury* (March/April 2003). p. 23. Nice overview of the 2MASS project, a systematic sky survey in the infrared. Several images of star forming regions within distant nebulae.

Notes and Ideas

*Class time spent on material: Estimated:*_______ *Actual:*______________

Demonstration and activity materials:

Notes for next time: