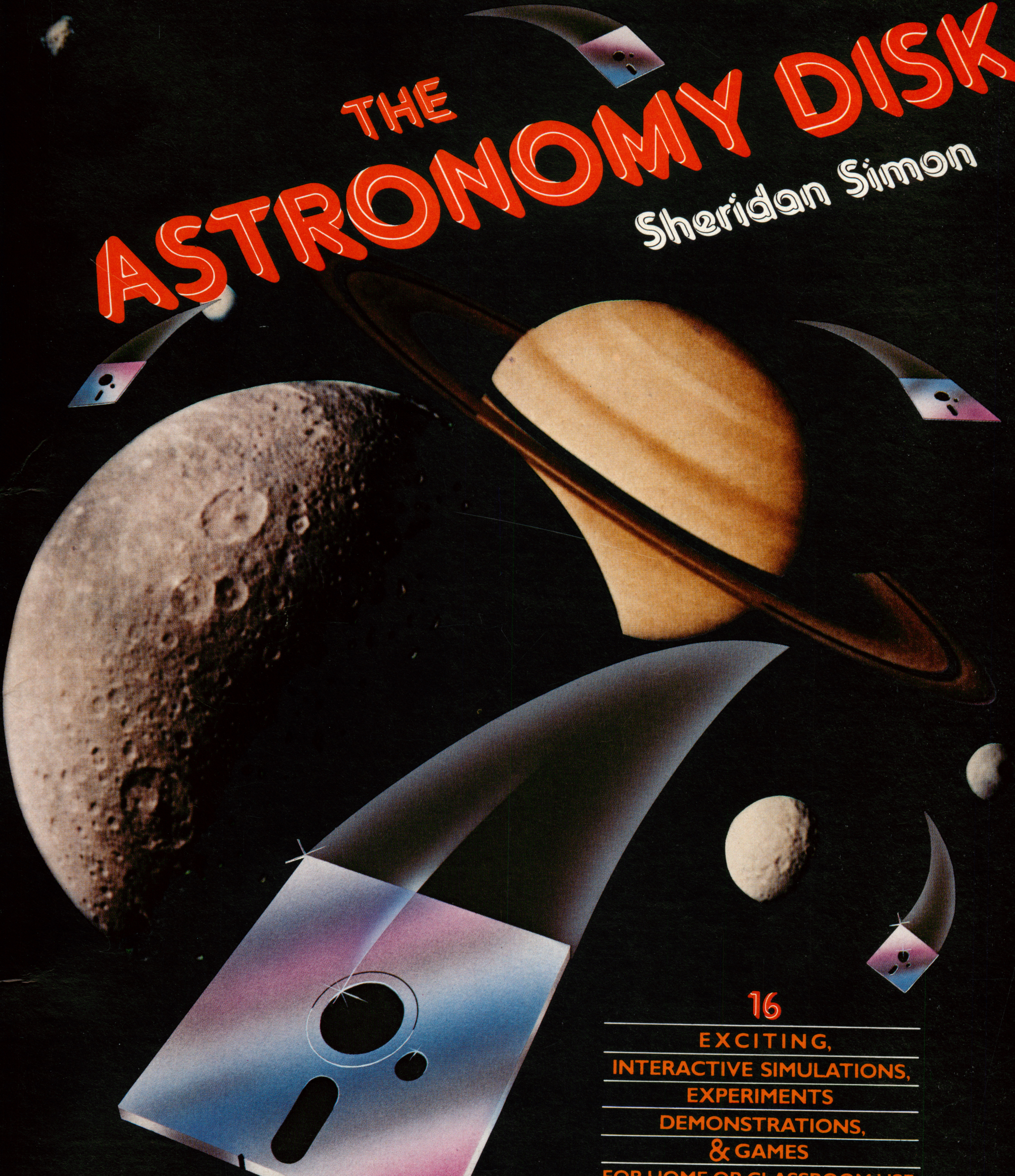
Introductory Astronomy Software for Nonscientists for the
APPLE II, II +, and IIe

THE ASTRONOMY DISK

Sheridan Simon



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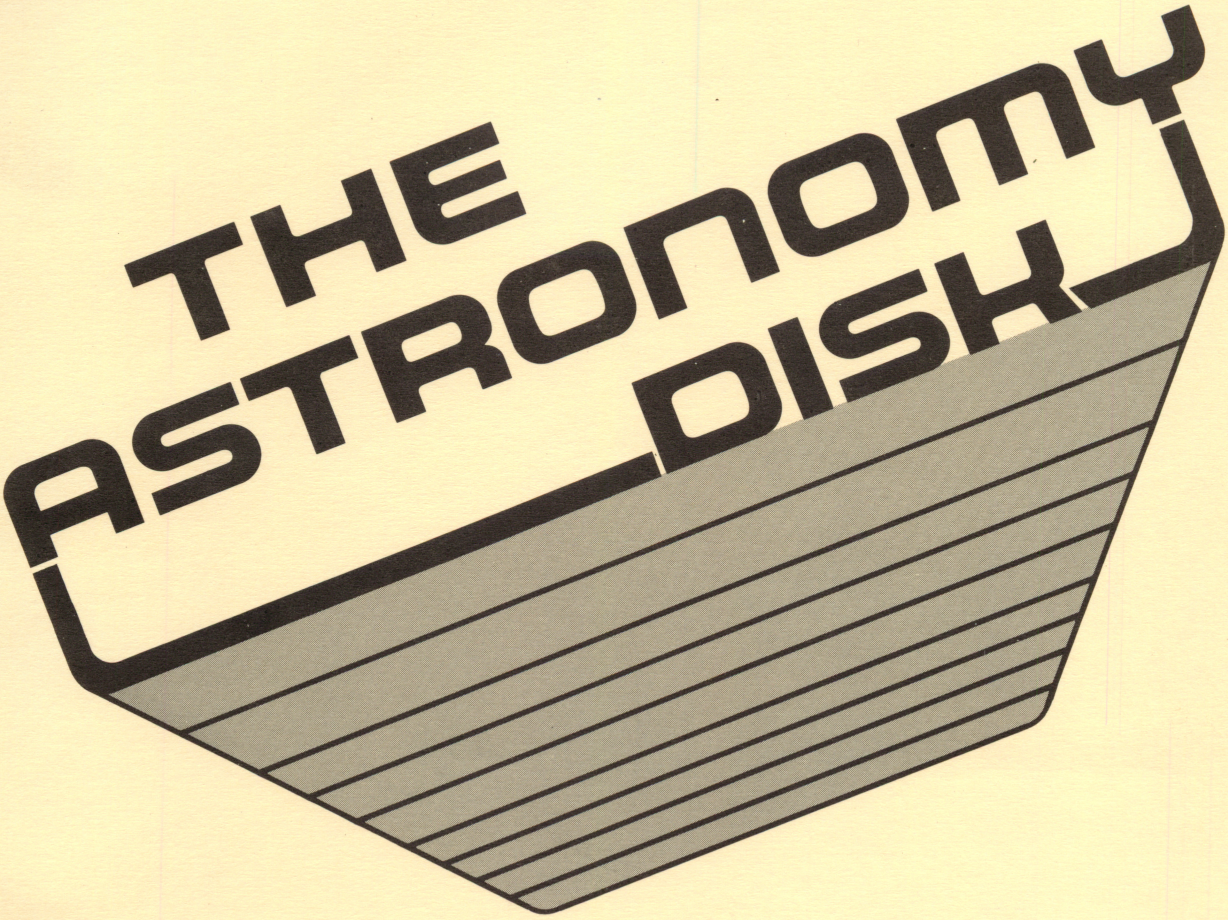

THE ASTRONOMY DISK

SHERIDAN SIMON

The Astronomy Disk

The
Astronomy
Disk

SHERIDAN SIMON
Guilford College

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To the astronomy students of Guilford College, 1974-1982

CONTENTS

Space Travel

The Solar System

The Stars

PREFACE

These programs are intended to help non-scientists learn about astronomy and space exploration. They require no knowledge of mathematics or computer programming. I have tried to include all the necessary instructions for their use in this manual.

These programs are meant to supplement traditional methods of learning astronomy such as books and lectures. Although these programs cannot replace the older types of presentations, they can make material more interesting and easier to understand by means of pictures and simulations that can be controlled by you, the user. No matter how long you stare at a book's photograph of Jupiter's moons, you won't see them moving around the planet, or see them as they would look from a point above Jupiter's North Pole. The program entitled JUPITER'S MOONS lets you do both -- and a lot more besides.

Computer programs are a more dynamic medium than books. You, the user, can interact with them, tell them what to do and what to show you. Every program on this diskette can be run over and over again in almost infinite variations. By running a program repeatedly, changing what it shows you a bit each time, you can rapidly learn material that is far harder to grasp using other methods.

It's also supposed to be fun, of course. Astronomy is fascinating to nearly any curious and intelligent person, and I see no reason why it needs to be presented in a dry and tedious way. On the other hand, you WILL need to spend time and thought on the programs. They are easy to use, but a deep understanding of what they portray and represent comes only with some effort on your part. Astronomy is awe-inspiring; no one should expect to understand in a few minutes a concept worked out after years of research. These programs will help you to learn astronomical concepts faster and more thoroughly, but they can't do your thinking for you.

My efforts in producing these programs were greatly aided by my interaction with several hundred students who have studied astronomy with me at Guilford College over the last nine years. Their advice, criticisms, and compliments have made me a better teacher and programmer. I have been inspired and encouraged by my wife, Dr. Rose Simon, whose considered belief is that nothing whatever worthwhile has been done since 1799, save for the invention of the microprocessor. I would also like to thank our close friends, Paula and Ken Jordan, whose talents, ambition, resourcefulness, and powerful vocabularies have served as strong examples to me throughout this work. Finally, I gratefully acknowlege the efforts of Dr. Bob Dukes of the College of Charleston and Dr. Larry Kirpatrick of Montana State University, who carried out their responsibilities as reviewers with vigor and enthusiasm.

INTRODUCTION

These programs are supposed to help people learn astronomy. In order to accomplish this, I've written them so they can be run by people with no knowledge of programming. However, you can't just walk up to the Apple and ask it for help in understanding double stars. This introduction will give you the instructions you need to get started. After that, each individual program has its own instructions in this manual.

Before I even get started, though, I want to give you an invitation. I want these programs, and the instructions, to be as useful as possible to you. For this reason, I want your comments and suggestions. Tell me what you like as well as what you don't like; I promise not to be insulted. The address is

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Formalities concluded, let's get on with the instructions. You should have available this instruction book, an Apple II computer with a TV monitor and a disk drive, and a disk. The disk is the square thing with the hole in the middle, a bit over five inches on a side.

You may never have run a computer by yourself before. If so, sit down in front of the Apple's keyboard, wipe the sweat off your hands, and calm the beating of your heart. Apart from the possibility of exploding with sufficient force to vaporize the solar system, which I assure you is very unlikely, the Apple is harmless, and even friendly. See? You've been sitting there thirty seconds already with no ill effects.

The computer programs you're going to run are recorded on a thing called a disk. A disk has much in common with a record. It spins around inside the disk drive, which acts like a high-speed turntable, and the different programs can be thought of as cuts on the disk. One difference between disks and records is that disks, like tapes, are magnetic. They can be erased and recorded over.

Your disk is sealed inside a black, square package, and you shouldn't open it. If you do, you'll ruin the disk and have to buy a new one. Disks are more delicate than records, and you have to treat them with respect. Handle them by their edges and don't leave them sitting near magnets, on stoves, or in places they'll be sat on.

Since all the programs are on the disk, let's look at it. It's probably inside a paper sleeve of some kind. Pull it out, black sealed package and all. One side has a label on it, and that's important because that side must be up when you put the disk into the disk drive. You can see the disk inside the sealed package; be careful not to touch it. With the label side up you'll notice an oval opening in the sealed black package. The oval extends nearly from the hole in the center of the disk to nearly the edge. The edge that the oval nearly touches must be the first one into the disk drive.

Now open the door of the disk drive. This works like the latch on a suitcase, and flips up if you pull it a bit from the bottom. If there are two disk drives, open the door of the one labelled "Drive 1" or something similar.

Opening the door provides a horizontal slot just big enough for a disk. With the label-side up, turn the disk so the edge the oval nearly touches is right in front of the slot in the disk drive. Ready? Slide the disk into the disk drive. When the disk is entirely inside the disk drive, you'll hear a slight click and the disk won't slide any further. Now close the door of the disk drive.

The next step is to turn on the TV monitor. Since the monitor is nothing but a TV connected to the computer, the switch ought to be in the usual place and work the usual way.

Next, turn on the Apple. The switch is usually located on the left in the back. I don't think this makes sense either, but then I'm not a computer manufacturer. When you flip the switch you'll hear the disk drive spinning the disk around for a few seconds, then the computer will start running the introductory show. I'll let you appreciate my artistic genius while this goes on. If you get bored with waiting for it to finish, press CTRL (the second key from the bottom on the left side of the keyboard) and, while holding it down, press the C key. This will automatically stop the introduction, if you want it to, or you can let it end by itself. Once the introductory show finishes, the disk drive spins again while more serious matters are loaded into the computer.

Once the disk drive stops spinning, you will be looking at something called the MENU. It is a table of contents, a list of the programs on the disk:

```
A   EARTH SATELLITE
B   MULTI-STAGE ROCKET
C   EXPEDITION TO MARS
D   ELLIPTICAL ORBIT
E   STARSHIP
F   JUPITER'S MOONS
G   SATELLITES
H   COMETS
I   SOLAR SYSTEM
J   TEMPERATURE AND COLOR
K   SPECTRAL TYPES
L   BUILD A WORLD
M   DOUBLE STARS
N   INSIDE STARS
O   EVOLUTION OF STARS
P   SPIRAL GALAXIES
```

Below the list of programs is

```
TO RUN ONE OF THESE, TYPE ITS LETTER, OR
TYPE Q TO QUIT:
```

This means exactly what it says. If you press A, the computer spins the disk for a moment, then starts running the program EARTH SATELLITE. The instructions for individual programs are in the rest of this booklet.

The things you type are "input." What the computer responds with is "output." Sometimes something you input has to be followed by pressing RETURN, a key on the right side of the keyboard. The instructions for individual programs tell you when this is necessary.

One thing that may be comforting is that you can't "hurt the computer" by typing something by mistake, no matter how dumb it is. Usually, the computer can figure out what kind of mistake you made and tell you how to correct it. For example, if you are asked to input your age and you type "-18", the computer might say

```
THIS HAS GOT TO BE POSITIVE.  TRY AGAIN.
```

and then ask you again to type your age. Occasionally, you may make a more creative error, like typing "&" for your age. The computer may respond with

```
THIS HAS GOT TO BE A  N U M B E R.  AGAIN?
```

and let you try again. If you do something sufficiently weird that the computer can't figure out what to do next, it automatically returns to the menu so you can start over. None of these things causes any damage, and most of them happen only by accident. No hassle if you make a mistake once in a while; computers are very patient and won't tell on you.

Please note that the zero key is located just to the right of the 9. The zero key looks just like an 0 with a diagonal slash running through it. Don't confuse it with the letter O.

When you type a number for the computer to use, DON'T USE COMMAS. 10000 is right; 10,000 is wrong. 1000000 is right; 1,000,000 is wrong.

You can quit any time you want except when the disk drive is spinning the disk. You can tell if this is happening if the red light below the door of the disk drive is lit (the label next to the light says "IN USE"). The drive nevers spins for long. Wait until it stops before you open the door, slide out your disk, reclose the door, and turn off the computer and monitor. You can even quit right in the middle of a program if you want to, and nothing bad happens. Just make sure the disk isn't spinning.

If the disk drive doesn't stop spinning within sixty seconds, something is messed up. Usually you've forgotten to put the disk in the disk drive before turning the computer on. If this happens, push the button labelled RESET. This stops the disk drive and lets you start all over from the beginning.

You can get a thorough understanding of each program's material in roughly an hour. You should actually save more time than this, since you'll need less rereading of the textbook and such to gain a good grasp of a particular topic. Different people will need different amounts of time, however, and some programs are more complicated than others, so the time estimate is only a rough one. Let me know if they take you a lot less or a lot more and why.

Since there are a total of sixteen programs, you'll be running roughly one a week during a one-semester course. Some topics I've written programs for won't be covered in your course, though, and a course will contain some topics for which there are no programs. If you'd like to see programs for other topics, let me know which ones.

Read through the instructions for each program before running it, to familiarize yourself with what is going to happen. This only takes a few minutes and it makes it a lot easier to use the programs.

The programs are supposed to be run several times each, changing the inputs. There are suggestions about this in the instructions for individual programs, but a key point is to have patience. Nobody learns astronomy in flashes of inspiration (Aha! I'll bet $E = mc^2$). You've got to look at a program's output and see how it changes when you change input quantities.

After a few tries, you'll gain some insight into the situation being described by the program. You should strive to understand the real physical situation that the program represents. These programs are supposed to make that step easier, but they still only *symbolize* what is happening in the real world.

I wrote the instructions (and the programs) so you could have some fun with them while using them. There is no reason why astronomy has to be dry or humorless. But don't let this *hide* the fact that astronomy is an incredible and even awe-inspiring subject. It certainly is to me. That's why I was interested in it in elementary school, and that's why I'm still interested in it. The enormous sizes and enormous time-scales involved in studying the universe are daunting to human beings -- but that hasn't stopped us from trying to learn more about it. American space probes have provided us with close-up photographs of all the planets from Mercury to Saturn, and four of these are headed out beyond the solar system, bound for the stars. We have become a people with a very long reach. I hope that the practical application of computers to the study of astronomy can help you share in the excitement of a new adventure for the whole human race.

A EARTH SATELLITE

This program displays the motion of a satellite as it orbits above the earth's equator. The satellite and the earth are seen in the monitor from a point far above the North Pole.

The path followed by a satellite as it moves around the earth is an ellipse, a shape similar to an oval. Some satellite orbits are nearly circular, others are very long and narrow.

You get to choose both the size and the shape of your satellite's orbit. The computer first asks you type the orbit's "semi-major axis." This is the term for half the longest diameter of the ellipse. It has to be a number between 6500 and 1000000 in this program. It can't be smaller than 6500 (kilometers) because it would run into the earth -- a waste of a good satellite, not to mention anyone unlucky enough to be underneath. There aren't many reasons to put a satellite as far out as 100000 kilometers, so I arbitrarily picked this as an upper limit.

Once you decide on a semi-major axis, type its value. If you haven't run this program before, type 10000. (DON'T PUT IN COMMAS. 10,000 is wrong; 10000 is right.) After you've typed the number, press the RETURN key.

The computer now asks you to type the orbit's eccentricity. This describes the orbit's shape. It ranges from 0 (a perfect circle) to almost (but not quite) 1, which is a very long, skinny ellipse. In this program eccentricity must be between 0 and .7. Once you've chosen an eccentricity, type it, then press RETURN. If this is your first time using this program, type 0, which gives you a circular orbit.

The computer now asks if you wish the orbit to be traced. You must press Y or N (no RETURN is needed here). Y results in the satellite leaving a "path" behind as it moves around the earth so you can see the shape of the entire orbit easily.

The computer now draws a white disk to represent the earth. If your semi-major axis is relatively small, the earth will nearly fill the screen; if your semi-major axis very big, earth may be only a small dot. Think of your TV as a window looking out on the earth and the moving satellite from a very large distance. If the orbit has a big semi-major axis, the "window" has to be a long way out for the whole orbit to be seen at once, and earth looks very small.

The computer puts two black dots on the earth. One, at the center of the disk, represents the North Pole. The "window" we are looking through is looking straight down onto the North Pole. The second black dot is at the position of Buffalo, N.Y., which happens to be my birthplace. It is put there so you can see how the earth rotates as time passes. The black dot at Buffalo will swing in a complete circle every 24 hours.

Your satellite is represented by a white dot. As the earth rotates, the satellite is seen moving along in its orbit, with the semi-major axis and eccentricity you chose.

Below the picture the computer prints the satellite's period (the length of time it takes to make one complete orbit) and a "clock" that shows how many days (D), hours (H), and minutes (M) have passed.

Once the satellite has made a few orbits the computer stops its motion and asks you if you want to continue watching the satellite or if you'd like to quit. To continue, press the C key. To quit, press the Q. If you press Q, you are offered a choice of running the program (press A) or returning to the menu (press M). No RETURN is needed. If you press A, you can try a new choice of semi-major axis or eccentricity.

To gain some understanding of satellite orbits, try this. Run the program with the semi-major axis equal to 10000, 20000, 30000, 40000, and 50000 kilometers and eccentricity 0 in each case. Do you understand what happens to the picture? Notice what happens to the period of this satellite. Now, run the program with eccentricities of 0, .1, .3, .5, and .7 and semi-major axis 50000 each time. Notice what happens to the shape of the orbit, and the period of the satellite. Notice also what happens to the speed of the satellite as it gets closer to the earth, then further away. Another thing to try is to see how far from earth a satellite must be in order to always be directly above Buffalo. Its period must be exactly twenty-fours for this to be true. Such satellites are called "geosynchronous" (synchronized with the earth) and are very useful for communications purposes, like TV relaying.

Earth's gravity controls the motion of satellites just as it controls the motion of thrown balls, but all of our experience and intuition deal with gravity's effects on objects near the surface of the earth. This program allows you to gain some insight into the influence of gravity over much longer ranges.

B MULTI-STAGE ROCKET

This simulation allows you to design a multi-stage rocket intended to launch a payload at a speed greater than escape speed from earth.

You get to choose the number of stages (1-4), the mass of each stage (1-1000 tons), and the burn rate of fuel for each stage (.1-10 tons per second). The computer first asks how many stages you want your rocket to have. You can choose this to be 1, 2, 3 or 4, but if you haven't run this program before it's best to start with 1. This probably won't work, but it will help you in understanding how rockets behave if you start with a simple situation. After typing the number of stages you desire, press RETURN.

You next get to choose the mass of each stage. Stages are numbered starting with the one that's on the bottom when the rocket is launched. This means that state #1 is the first one ignited. Since it has to push the other stages upward on top of it, it's usually the biggest and heaviest. If you haven't run this program before, you might try choosing the mass of your one-stage rocket to be 100 tons. After chosing the mass of each stage, press RETURN.

Finally, the computer asks you for the burn rate of the fuel in each stage. The burn rate has to be a number between .1 and 10. It indicates how many tons of fuel per second the rocket engines of each stage burn up. The bigger the burn rate, the harder the rocket is pushed upward and the faster its speed increases. However, if the burn rate is large the fuel is used up faster too. If you use up all your fuel before reaching escape speed, the rocket is blown up by the Range Safety Officer so it won't fall somewhere and hurt someone. If this is your first time running this program, try a burn rate of 2. After typing the burn rate for each stage, press RETURN.

Once you've typed all the necessary information, the computer is ready to start the simulation any time you press RETURN. It waits for you to do this so that you can write down the numbers you input, if you want to. Since you will probably make a lot of unsuccessful tries before you successfully achieve escape speed, it is a good idea to note what you've tried and what the results were.

Once you press RETURN to start the simulation, the computer shows you quite a bit of information. Across the bottom of the screen is a set of changing numbers. These are time since launch, height above the ground, speed of the rocket, which stage is firing, and how much fuel it has left. Above these are two graphs. On the left is a graph of the rocket's height as time goes on. 100 kilometers is indicated near the top of this graph so you can get an idea of its scale. On the right is the crucial one: the graph of the rocket's speed as time goes on. If the rocket reaches escape speed (11.2 kilometers per second, or about 25,000 miles per hour) your design is a success. This speed is indicated on the graph by ESC.

This simulation allows you a lot of freedom of choice, and that means that you have to proceed carefully or you'll not learn anything from it. Trying a lot of random numbers without thinking about them will eventually give you a design that works, but that is not the point. The point is to learn something about how rockets work. The best way to proceed is to start simple: one stage. Try running the program repeatedly with the choice of one stage, 100 tons mass, and different choices for the burn rate (say, 2, 4, 6, 8, and 10). Watch what happens in each case. Which one comes closest to reaching escape speed? At what heights do the rockets use up their fuel? Can you see any kind of pattern? Next, for a one-stage rocket try masses of 200, 400, 600, 800 and 1000, each time with a burn rate of 10. Which one gets closest to escape speed? Can you detect a pattern among your different tries? Once you think you thoroughly understand one-stage rockets, go on to two-stagers.

The idea here, as in much scientific work, is to be patient, to proceed in an organized fashion, and to keep alert for patterns. Since this is intended for non-mathematicians, you shouldn't try to find a "formula" or anything from the numbers the computer prints out. But it's easy to see that a rocket that gets to 10 kilometers per second before burning out is a more successful design than one that only gets to 9 kilometers per second.

NASA engineers have to take into account a lot of factors not included in this simulation, of course, but the basic idea is much the same. This program will give you a good idea of what sort of considerations and what sort of thinking go into design of launch vehicles.

C EXPEDITION TO MARS

This program will allow you to attempt to rendezvous with Mars after leaving a parking orbit around the earth.

The program immediately shows you a picture of the sun (a white dot in the middle of the screen), the earth, and Mars. The dot representing earth is the one closer to the sun. The basic problem here is that the Mars expedition will follow a path from earth to Mars that is part of an elliptical orbit around the sun. This means that unless earth and Mars are oriented correctly with respect to each other, the expedition may arrive at a point on Mars' orbit when Mars is somewhere else in its orbit. The idea is similar to what happens when a quarterback throws a pass. He has to throw it to the place where his receiver WILL BE when the pass arrives.

As usual, you should expect your first few attempts to be unsuccessful, until you gain some intuition for how the expedition's orbit behaves. Don't get discouraged. There have been human beings on this planet for forty thousand years, and the first spacecraft didn't land on Mars until 1976.

There are two important keys in this simulation. One is the "space bar." This might be a place for astronauts to grab a beer before a shuttle flight, but it isn't; it's the long, horizontal bar below the keys on your Apple. The second key is RETURN, on the right of the keyboard. When the picture of the sun, earth, and Mars appears, the planets' positions in their orbits are chosen randomly by the computer. It is very unlikely that they are exactly right for the launching of the expedition. You can "wait" ten days by pressing the space bar; the planets will move along in their orbits by the correct amounts. You can do this as many times as you like.

Of course, the first time you run this you won't have the vaguest idea of when to launch the expedition. This is OK; if you already knew, you wouldn't need to run this simulation. Press the RETURN key to launch your expedition, and watch what happens.

Once you've pressed RETURN, the computer takes over and automatically moves the planets and the expedition's space ship along in their orbits. Every ten days, the computer will plot the position of the earth, Mars, and the ship so you can see the orbital paths they are following.

The scenario for this simulation assumes that the expedition is counting on reaching Mars within 260 days after launch. Mars has ice on its surface (particularly near its poles, like earth) which the expedition can melt for drinking water and electrolyze to produce oxygen (for breathing) and hydrogen, which, with the oxygen, can make fuel for the return voyage. If the expedition fails to rendezvous with Mars within 260 days, you will be shouted at by your boss, snubbed by your colleagues, and lynched by an angry mob. In addition, you may be sued by the families of the unfortunate astronauts. Other than that, you can laugh the matter off and try again.

The point of this simulation is to allow you to gain familiarity with the motions of the planets and spacecraft as they move around the sun. After a few runs of this program these motions will begin to make sense. Try to keep in mind the scale here, however: the monitor can be thought of as a window looking down on the earth, Mars, and the sun from a distance of about two BILLION miles.

D ELLIPTICAL ORBIT

The objects in orbit around the sun include the nine known planets, several thousand asteriods, and an unknown (but very large) number of comets. All of these move in paths that trace out shapes called ellipses. An ellipse looks much like the shape commonly called an oval. Some of these ellipses are very long and narrow: comets move in such orbits. Other objects, such as most of the planets, move in orbits that are more nearly circular.

The size of an orbit is given by a number called the semi-major axis. Any ellipse has two different diameters: a long one and a short one. Half the longer diameter is called the semi-major axis of the ellipse. Half the shorter diameter is called the semi-minor axis. If these are nearly equal, the ellipse looks very much like a circle; earth's orbit is like this, only slightly non-circular. If the semi-minor axis is much smaller than the semi-major axis the orbit looks like a very skinny ellipse. The semi-major axis is measured in units called A.U. (for Astronomical Unit). One A.U. is equal to the average distance from the earth to the sun. A planet like Venus, which is closer to the sun than earth, has an orbit with a semi-major axis less than 1 A.U. -- about .7 A.U., for Venus. A planet like Mars, farther from the sun than earth, has an orbit with semi-major axis bigger than 1 A.U. -- about 1.5 A.U., for Mars.

The shape of an orbit is described by a number called the eccentricity. An orbit that is a perfect circle (there aren't any) has an eccentricity of 0. An orbit that is extremely long and narrow has an eccentricity of almost (but never quite) 1.

The computer will first ask you to type a value for the semi-major axis. The program will allow you to use any number between .1 and 100000 for this. .1 A.U. is quite close to the sun, inside the orbit of Mercury. 100000 A.U. (DON'T TYPE COMMAS. 100000 is right; 100,000 is wrong) is more than a thousand times as far from the sun as Pluto. Some comets may have orbits that have semi-major axes this large. After you type the semi-major axis, press RETURN. If you haven't run this program before, choose this to be 1. This will show you the orbit of the earth.

The computer next asks you to type the eccentricity. This can be anything between 0 and .99, but remember that 0 means circular and .99 means a very, long skinny ellipse. After you've typed this, press RETURN. For your first run, try 0.

The computer will output your values of the semi-major axis and eccentricity and also the period of the orbit, in years. The period of an orbit is just how long it takes an object to make one complete trip all the way around it. If you chose semi-major axis to be 1 and eccentricity to be 0 (much like earth's orbit), the period is (of course!) one *year.* The computer will also produce a picture of the sun and the elliptical orbit you've specified so you can see what it looks like.

Try running this program with semi-major axis taken to be 1, 2, 3, 4 and 5 and eccentricity chosen to be 0 each time. What happens to the period of the orbit? Is this what you expected? What does it say about the length of time it takes more distant planets to circle the sun? Now try running the program with semi-major axis equal to 1 and eccentricity equal to 0, .2, .4, .6, and .8. What happens to the period? Surprised? I sure was the first time I saw this. You might look up the semi-major axes and eccentricities of some objects in the solar system and use this program to see what their orbits look like.

E STARSHIP

It is 2247 A.D.

New America is the third planet of the sunlike star Athena. On June 23, 2247 its small human colony is attacked without warning by alien spacecraft. The attackers bomb the colony's industrial complex and spaceport.

By the thinnest of margins, you and a group of 99 other colonists manage to escape in the sole undamaged shuttle craft. You are able to rendezvous with the colony's only interstellar spacecraft, a Bussard Ramjet parked in synchronous orbit around Athena. With luck, you will be able to use the starship to reach the safety of another star system.

A Bussard Ramjet is a rocket that uses an electromagnetic scoop to sweep interstellar hydrogen into its fusion reactor (trivial to build, as any child knows) where it undergoes heating to very high temperatures and is expelled as exhaust. Because the fuel supply is effectively unlimited, the Ramjet can approach (but never quite reach) the limiting velocity of light.

The acceleration of the Ramjet determines how fast its speed changes. Acceleration is measured in gees. One gee is the acceleration experienced by an object dropped near the surface of the earth -- a coin, for example. Its speed increases by a little over twenty miles per hour for every second it falls (20 mph after one second, 40 mph after two seconds, and so on). An object which is slowing down, like a car being braked, has negative acceleration. An object slowing down by 20 mph every second has an acceleration of -1 gee.

You can control the acceleration of your starship, up to a point. It can be set at any value between -3 and +3 gees except 0. Unfortunately, because the starship is a rather clumsy object you only get to change the acceleration every six months -- once you choose an acceleration value, the ship will accelerate at that rate for the next six months, after which you can adjust it for the next six months of travel. You will want to start with a positive acceleration, to speed you up and get away from the aliens. Eventually, you will want to use a negative acceleration to slow down as you near your destination star. It makes no sense to find a safe new home and go zooming by it at .95 light (95% the speed of light). You should be a bit careful, though. If you use high acceleration, everyone on the ship will weigh more than they are used to. Normal weight is 1 gee (or -1 gee). If people weigh twice what they are used to (2 gee or -2 gee), they could easily be injured in falls or develop heart or circulatory trouble. Accelerations like 1.5 gee are easier to take than 2 gee; 2.4 gee (for example) would be worse than 2.

One challenge you have is picking out a suitable destination star, one likely to have habitable planets. I'll only give you some rough hints on this, and will (in my bloodthirsty way) let you sacrifice a multitude of ships and crews before you figure out how to get your starship to a safe haven.

Stars are classified according to spectral type and luminosity class. Spectral type tells you how hot a star is. From hottest to coolest, stars are classified as O, B, A, F, G, K, and M. ("Oh, Be A Foolish Guy; Kick Me"). There are subclasses as well, indicated by numbers after the letters (like O5 or K6, or A0) but you won't need to worry about these here. The sun is a spectral type G2 star, temperature about 5800 degrees. Type O stars are much hotter -- sometimes 50000 degrees -- whereas type M stars are a lot cooler, down to just over 2000 degrees.

A star also has a luminosity class, which tells you how big the star is. This is a Roman numeral. From biggest to smallest, stars are classified as I, II, III, IV, or V. All of these except V are a good deal bigger than the sun. Notice that a small, very hot star, like O5 V, might put out more total energy than a larger but cooler star, like an M8 III.

A good bet is to try to head for a star that is as much like the sun as possible. Luminosity classes other than class V include stars that are not stable in their heat and light production long enough for life to exist on nearby planets. Very hot stars "burn out" quickly and there is probably no time for life to evolve on their planets. Very cool stars may not warm their planets enough for life.

In order to make the simulation more realistic, the program includes measurements of time and distance from both the destination star and your ship. Since you will be moving close to the speed of light, relativity comes into play. Don't panic -- you don't need to understand relativity theory to run this. But moving at speeds near the speed of light means that the distance you measure from the ship to the destination star will be different from the distance measured from the destination star to the ship. Someone at the destination star (hopefully not an alien!) will also disagree with you as to how much time has passed since you left New America. I wanted you to be able to get some idea of these differences. They seem to make no sense -- but relativity has been checked by thousands of experiments, and it works. We just have no intuition for what happens when things move at speeds near the speed of light. Not surprising; no one's done it yet. The easiest way to understand the distance you still have to cover is to watch the distance as measured from the star. Don't forget that you have to slow down to rendezvous with your destination!

All distances are in light-years (one light-year is about six trillion miles). Times are in years. Speeds are in units of the speed of light: .25 light is a quarter the speed of light, for example. Accelerations are in gees, as mentioned above. If you can't slow down in time and zoom past your destination star, the distance will be shown as negative. To get back, you'll have to apply negative acceleration (like -1 gees) until your speed is negative (like -.5 light), which means backwards.

Just to make this a real challenge, you are operating under a kind of time limit. You've only got sufficient food for ten years on board ship (though if you have casualties, the food may last longer). If you run out of food ... you starve.

This is a complicated simulation. You have two basic problems: choosing a destination star likely to have habitable planets, and successfully navigating your ship to the destination by careful choice of accelerations. The simulation is meant to teach you several things. These include classification of stars by spectral type and luminosity class; how pushes forward (positive acceleration) and pushes backward (negative acceleration) can be used to move a spacecraft; how strange relativity can be. You will have to run this a number of times before you're successful, and the destination choices are randomly picked by the computer each time, so you won't run out of hassles quickly. You will have to pay close attention to what happens to speeds and distances, watching for patterns until you can successfully reach a new home.

If you get frustrated and want to quit in the middle of this one, press the CTRL key (second from the bottom on the left side of the keyboard) and, while holding it down, type C. You will automatically be returned to the menu.

F JUPITER'S MOONS

This program will allow you to watch the motions of Jupiter's four giant moons, Io, Europa, Ganymede, and Callisto, as they circle the solar system's largest planet.

The computer first asks you for the inclination angle you desire. Jupiter's larger moons move around the planet in nearly circular orbits lying above the planet's equator. If the orbits are seen from a point far above the North Pole of Jupiter, they appear to be circles. This orientation -- above Jupiter's North Pole -- is called inclination of 0 degrees. An inclination of 90 degrees places you at a point above Jupiter's equator. From here, the moon's orbits are seen "on edge" and the moons appear to move back and forth in straight lines. This is the orientation from which we observe the moons here on earth, and until a few years ago no human being had ever seen the moons from an inclination very different from 90 degrees. You can choose any inclination between 0 (over the North Pole) and 180 degrees (over Jupiter's South Pole). After choosing the inclination you desire, press RETURN. If you haven't run the program before, start with 0.

The computer then asks you for the distance from which you desire to view the scene. Once again, you should think of your TV monitor as a kind of "window" through which you can see the planet and moons. You can choose this distance to be anything between 1 and 5 million kilometers. Type a number between 1 and 5 (fractions like 2.5 are allowed), then press RETURN. If you haven't run the program before, try 5.

The computer displays the angle and distance you input, a "clock" (in days and hours) that shows passing time, and a moving sketch of the satellites as they circle the planet.

In order to get a feel for the situation, I suggest that you run the program with inclination angle 0 and distance 5, then 4, then 3, then 2, then 1 million kilometers. This means that you are viewing the moon system from closer and closer points. Do the results make sense to you? Now try inclinations of 0, 20, 40, 60 and 80 degrees with distance each time kept at 2.5 million kilometers. Can you understand what is happening as you increase the inclination? Finally, try inclination 90 degrees and distance 5 million kilometers. This gives you a result that looks similar to what is seen through a small telescope here on earth.

G SATELLITES

This program allows you to display any of the moon systems in the solar system, or, if you prefer, to design your own and see what they'd look like.

The computer first asks you if you wish to see a simulation of one of the real planets' satellites (press R) or if you wish to design one of your own (press D). No RETURN is needed. If you type R, you are offered six choices, one for each of the planets known to have moons (except Neptune). Press the number of your choice (no RETURN is needed). You can stop the simulation at any time by pressing RETURN.

If you press D to design your own system, the computer first asks you for the planet's radius. This is in kilometers, and must be a number between 100 (a VERY small planet) and 100000 (even bigger than Jupiter). Remember, DON'T TYPE COMMAS. 100000 is right; 100,000 is wrong. Type the planet's radius, then press RETURN. If you haven't run this program before, type 6500, the radius of the earth.

The computer next asks you for the number of satellites you wish to see displayed. This can be any number from 1 to 20. Type it, then press RETURN. If this is the first time you've run this program, try making this 1.

The computer runs through all the moons (as many as you typed in the last step), asking you to type the orbital radius of each one. Orbital radius is the distance of the moon from the planet. It has to be bigger than the radius of the planet and less than 20000000 (that's twenty million -- a 2 followed by seven 0s. NO COMMAS, remember.). After typing each one, press RETURN. If you haven't run this before, type 384000. This is the average distance of the moon from the earth.

The computer now produces a moving sketch of the moon system you described, drawn to scale and with the moons moving at speeds that are correctly proportional (though faster than real life, of course). You can stop the "movie" any time you wish by pressing RETURN. The computer will then ask you to press C (to continue the same moon system's motion), A (to run the whole program over again from the beginning), or M (to go back to the menu).

The point of this simulation is to allow you to see what whole systems of satellites at various distances from their planets look like in motion. You might try this with two satellites to learn some interesting things. Choose the planet to have a radius of 6500. Place one satellite at 10000 and the other at 40000 kilometers from the planet. How many times does the inner satellite circle the planet before the outer one completes one orbit? Now try 10000 and 90000, then 10000 and 160000. If you are clever with squaring and cubing numbers, you might see a pattern here. If you do, try other distances and see if the pattern works out.

Another thing to try is placing two or more moons at the same distance from the planet. This situation actually arises in Saturn's moon system, and the computer treats it correctly. The two moons orbit in such a way that they and the planet always form an equilateral triangle.

One warning: If you have satellites included with very different orbital radii (some very close to the planet, some very far away), the closer moons will all end up bunched very near the planet in the picture and it will be hard to see their motions as a result. This is one reason why only the inner moons of Jupiter and Saturn are shown in those planets' simulations.

H COMETS

This program allows you to see a scale model of the sun and the four inner planets as well as any of ten comets, including the famous Halley's Comet. Alternatively, you may enter orbital data for any other comet you desire, if you have this data available. The picture moves as time goes on, showing you the development of the comet's tail as it falls toward the sun and the shrinking of the tail as it falls away from the sun again. You can view the scene from a wide variety of angles to gain some impresssion of the three-dimensional motions involved.

Comets usually travel in long, narrow elliptical orbits, tilted at various angles to the orbits of the planets. They spend most of their time at large distances from the sun, well beyond the orbit of Mars, but their orbits always bring them back to the warm regions near the sun for brief periods. Since they are made mostly of frozen material, their surfaces thaw and then boil as they draw near the sun. This boiling vapor is pushed away from the sun both by sunlight itself and by fast-moving protons called the solar wind. The forces exerted by sunlight and the solar wind are both very small, but the only other important force acting on the vapor is the sun's gravity, which is even smaller. The vapor pushed off the warming surface of the comet's head forms the comet's tail. This can reach enormous lengths if a comet with a large mass of frozen material gets close to the sun, but once the comet falls outward again into the colder regions beyond the orbit of Mars the comet's head cools off, refreezes, and the tail disappears.

The program first asks you if you wish to input your own comet's data. Be warned that if you type Y (for Yes) you will be asked for such items as the angle from the ascending node of the comet's orbit to the orbit's perihelion. If you don't understand this, it is best to press N (for No) to get a simulation of one of the comets whose orbital data is already included in the program.

The program offers you a choice of ten comets, numbered 0-9. Press a number (no RETURN is needed). 9 is Halley's Comet, which might be a good one to start with. Comets are named for their discoverers (who might be any nationality at all), so some of the names might seem a bit odd. The computer next asks you to type a "tilt angle." This is the angle to the earth's orbit from which you'd like to see the display. A tilt angle of 0 places you in a position such that you are looking down on earth's orbit and it looks circular. A tilt angle of 90 degrees lets you see earth's orbit "on edge."

You can choose any angle between 0 and 180 degrees. After you type it, press RETURN. If you haven't run this program before, try 0.

Once you've typed this, the computer will take about ten seconds to do some calculations. It then prints the comet's name and its period, in years. The comet's period is the length of time it takes to complete one orbit. The computer will pause now for about twenty seconds to do some additional calculation. At the end of this time you'll see the sun and the four inner planets, Mercury, Venus, Earth, and Mars. The computer also displays a date. The planets are in their proper places for this date. The comet probably won't yet be in the picture. It's still far from the sun, falling slowly towards the inner solar system. Press the space bar (the long, horizontal bar below the keys on the keyboard) and the date -- and planets -- will leap ahead. After a few taps on the space bar, you'll see the comet come into the picture. Watch its motion as well as the date. As the comet falls closer to the sun, it moves faster and faster, covering more distance in a shorter time. You'll also see the tail develop as the frozen material of the head begins to boil in the fierce, unshielded sunlight. The tail always points directly away from the sun, pushed out by light pressure and the solar wind. Eventually, the comet will round the sun and start falling away from it, further and further outward. It will move slower and slower, taking much longer to cover distances, and as its temperature falls again towards freezing the tail of vaporized material will diminish and finally disappear completely.

Once the comet has left the picture, a few more taps of the space bar will make the computer give you the option of eitherof the following: same comet through its next passage through the inner planets, trying another comet, or going back to the menu. Press N to continue, A to run again, or M for the menu (no RETURN needed) as your fancy pleases.

I SOLAR SYSTEM

This program allows you to see the planets in their correct positions from a variety of distances and directions at any date between 1500 and 2500 A.D. You can also advance the planets in their orbits to get an impression of how they move with respect to each other as time goes on. This simulation is much more detailed than the others showing some of the planets. All of the eccentricities, inclinations, and other characteristics of the orbits are indicated as exactly as the screen resolution allows. This permits you to see that the planets' orbits are not perfect circles and that they are tilted at various angles and in various directions with respect to each other.

The computer first establishes the date on which you wish to start the simulation. The computer asks you to type a year between 1500 and 2500. Type your choice, then press RETURN. It next asks you for the month you desire. Type a number 1-12. As is customary, January is 1, February is 2, March is 3, April is 4, and so on to December, which is 12. Type the number of the month you desire, then press RETURN. Next, the computer asks you for the day of the month. Type this number, then press RETURN.

The computer now asks you to type either E or N. If you type E, it erases the images of the planets as time passes, showing only where the planet is at each particular date. This is more realistic than the other option, but I advise you to press N here if you haven't run this program before. If you type N, the computer leaves each image of the planet intact as it goes on to draw the one in the planet's new position. This means that as time goes on you'll see a string of dots indicating a planet's position at various times. This gives you a good idea of the shape and orientation of the planet's orbit. After you have typed either E or N, press RETURN.

The computer now asks you to type a tilt angle. This must be a number between 0 and 90 degrees, and refers to the angle to earth's orbit from which you wish to see the solar system. An angle of 0 is directly above earth's orbit, looking down on it. The earth appears to move in a circle. If you choose this to be 90 degrees, you look at earth's orbit "on edge" and the planet appears to move back and forth in a straight line. A value of about 70 for this gives a good general impression of the planet's motions and relative positions, but you should try several to see the system from various vantages. After you've typed this number, press RETURN.

Finally, the computer asks you for the distance from the sun you wish your viewpoint to be. Think of your TV monitor as a window looking out at the solar system; you are choosing the window's distance from the sun. This can be any value between 3 and 500 A.U. One A.U. is the average distance of earth from the sun, so you'll have to be several A.U. out before you can see many of the planets through your "window." If you get too far out, some of the inner planets may get lost in the glare of the sun.

Once you've typed the distance (and pressed RETURN), the computer pauses for about fifteen seconds to calculate the planetary positions. It then prints a list of the planets to be displayed. Some of these may not appear in the "window" for a while. They are far from the sun and you'll have to wait for them to drift across your view.

The computer next displays the view of the solar system you requested. You can advance time by pressing the space bar; this causes the planets to move in their orbits. You can press the space bar as many times as you wish to see the planets move forward. The program can be ended any time you wish by pressing RETURN. If you have chosen the No Erasure option the computer will stop recalculating a planet's position after it has made one complete orbit.

J TEMPERATURE AND COLOR

This program allows you to run an experiment to determine the color of a star. You can choose either the spectral type or the temperature of the star.

All stars emit light of almost all possible colors, including some like ultraviolet and infrared that are not visible to our eyes but can be detected by instruments. But at any given temperature a star emits more light of some colors than others. A very cool star, for example, with a surface temperature of 2500 Kelvin, emits small amounts of blue and green light, but the largest amounts are red and infrared, and to our eyes such a star looks red. The idea here is similar to mixing paints. A small amount of blue or yellow mixed with a lot of red looks more red than anything else.

This program simulates an experiment in which you point eight detectors at a star. The eight detectors (which are rather like meters on cameras) can "see" light coming from the star of eight different colors: ultraviolet, violet, blue, green, yellow, orange, red, and infrared. On the screen, these colors are indicated by abbreviations: UV, VIO, BLU, GRE, YEL, ORA, RED, and IR.

The computer first asks you if you wish to point your detectors at a star of a particular temperature (hit T) or spectral type (hit S). No RETURN is necessary for these. If you press T for temperature, the computer next asks you to type the star's temperature in degrees Kelvin. Type a number between 2000 and 50000 (DON'T TYPE COMMAS. 50000 is right; 50,000 is wrong), then press RETURN. If you press S for spectral type, the computer asks you to type the spectral type of the star. From hottest to coolest stars, spectral types run O, B, A, F, G, K, and M ("Oh Boy; Astronomy Final's Gonna Kill Me"). Subclasses are indicated by numbers following the letters. The sun is usually classified as G2, which at 5820 Kelvin is slightly hotter than G3 and slightly cooler than G1. The hottest G stars are G0, just cooler than F9. The coolest G stars are G9, just hotter than K0. The very hottest stars should be O0, but they aren't; the hottest classification ordinarily used is O5, followed by slightly cooler O6, etc. The coolest of all stars are spectral type M9. Type your desired spectral type, then press RETURN.

Whether you chose a temperature or a spectral type, the computer now starts running your experiment., The eight detectors are pointed at the star you want to see the color of, and you see them counting incoming light waves of the various colors. In a real experiment like this, the results are not exactly the same every time it is run. This is because of random things like haze, small electrical problems, and so forth. For this reason, I added a bit of randomness to the computer's results so you can see a more realistic version of what happens in a real experiment. This means that you may have to run the program several times with the same temperature or spectral type to gain an idea of what colors are most prominent in the star's light. You will notice too that usually one color doesn't dominate all the others; light from stars really is a mixture of colors. The first time you run the program you should choose to input the sun's spectral type, G2, to see what colors are present in sunlight. Chances are you won't be too surprised, but it's interesting to see nonetheless.

K SPECTRAL TYPES

This program allows you to study simulated star spectra and attempt to assign them to particular spectral types. It can be run at four levels of difficulty.

When sunlight or starlight is passed through a prism, it is separated into a spectrum of colors. It was discovered nearly two hundred years ago that if the sun's spectrum was examined closely it was not complete. Some very narrow color regions were absent, leaving dark lines in the middle of the spectrum. It was discovered later that this was true of starlight as well. For a time, these "dark lines" were a complete mystery. Today they are well understood, and we know them to be due to absorption of certain colors by particular kinds of atoms, ions, and molecules in the outer regions of the stars. The presence or absence of light of particular colors in a star's spectrum depends crucially on its temperature, so from looking at the pattern of dark lines in a star's spectrum we can find out its temperature. Before this was realized, back when the dark lines were a mystery, stars' spectra were classified according to particular patterns and widths of dark lines. This gave rise to the spectral types we assign to stars today. You can look at the discussion of spectral types in the TEMPERATURE AND COLOR program to review these if you wish.

The trick to correctly classifying spectra is to use a a set of standards. If a star's spectrum of dark lines looks very much like that of a star previously classified as G6 (for example), then we can say that the new star, too, is G6.

The first thing the computer asks for in this program is a level of difficulty. This can be 1-4. If you haven't run this before, type 1 (no RETURN necessary). Level 2 includes Doppler shifted spectra, level 3 red giant and white dwarf stars, and level 4 is so fiendish I'll let you discover its tricks for yourself.

The computer chooses a random spectral type and draws a sketch of it for you as an "unknown" you are to classify. No colors are shown with this, but the portion of the spectrum shown runs from violet (left end) through blue to about green (right end). You can see a variety of dark lines in the spectrum, some wide, some narrow. Bewildering, isn't it? Now you know what 19th century astronomers felt like. The computer now asks you for "top spectral type." The computer allows you to choose two standard, known spectra to compare with the unknown one. One is drawn above the unknown, one below. After you've tried a few, you'll notice similiarities between some of them and the pattern of lines in the unknown. With a little effort, you can then zero in on the correct spectral type. It's worth being systematic about this. First try comparing the unknown to (say) O5 and B0, then to B5 and A0, then A5 and F0, and so forth. Random guesses will take forever, and you won't see the patterns or learn to recognize any spectra. If you've never done this before (and most people haven't) be patient, and accept some initial frustration. After a few tries you'll begin making some sense out of the classification scheme. You should be aware that the spectra displayed here are actually only simple approximations to those seen for real stars, particularly with regard to line widths and sharpness.

Examination of a star's spectrum tells an astronomer an enormous number of facts about the star. These include its temperature, surface gravity, composition, speed towards or away from us, and magnetic field strength. The spectrum helps us to infer a star's size, mass, and age, as well. This program is intended to give you a brief insight into spectral analysis.

L BUILD A WORLD

This program allows you to design your own planet. You determine what kind of star it has, its distance from that star, the planet's mass and size, and something about its surface.

The computer first asks you for the spectral type of the planet's star. Spectral type tells what temperature a star is. From hottest to coolest, spectral types are O, B, A, F, G, K, and M ("Otto Brought Me A Fully Grown Kangaroo Monday").Subtypes are indicated by numbers. K0 is the hottest kind of K. K1 is a bit cooler, K2 a bit cooler than K1, and so on, K9 being the coolest kind of K type, only a little hotter than M0, the hottest of the M types. The very hottest stars ought to be O0, but they aren't. The hottest type used is O5. O6 are slightly cooler, and so on. Our sun is usually classed as type G2, with a surface temperature of about 5800 Kelvin. Once you've typed a spectral type, press RETURN. If you've never run this before, try G2 (like the sun).

The computer next asks for the star's luminosity class. Luminosity class tells how big a star is, and is indicated by a Roman numeral. From largest to smallest these classes are I, II, III, IV, and V. Ordinary stars are small, luminosity class V. Class IV and III are subgiants and giants; class II and class I are big supergiants and gigantic supergiants. Type the luminosity class you wish, then press RETURN. If this is your first time running this program, type V, like the sun.

The computer now moves on to the properties of your planet. It first asks for the planet's radius in earth units. This means that if you type .5, your planet will be half the size of the earth. Your choice must be between .1 and 20. After you type this, press RETURN. On your first try, use 1, like the earth.

Next it asks you for the planet's mass, once again in earth units. Type a number between .01 and 1000, then press RETURN. For your first try, use 1, like the earth.

Finally, the computer asks for the planet's albedo. Albedo is a number between 0 and 1 that indicates how much light the planet reflects. If it reflects a lot, like a *field* of snow, its albedo is nearly 1. If it reflects very little, like charcoal, its albedo is nearly 0. Earth's albedo is about .5. Type your choice for albedo, then press RETURN.

The computer now prints several pieces of information about both the planet and its star. Besides your own inputs, these include the length of the planet's year, its surface gravity, escape speed (earth's is about 25,000 miles per hour), density, and surface temperature. Also printed are the star's color, mass, radius, luminosity (that is, how much energy it emits per second), and how big it would look in your planet's sky. The last quantity is given in terms of how big our sun looks in our own sky.

This simulation can be used in many ways. You will note that for the "first try" choices I indicated above the planet's surface temperature is 70 degrees Farenheit, quite liveable. This is not surprising, since you typed in numbers for an earthlike planet and a sunlike star. But can you find a way to produce a habitable planet of say, a spectral type B5 star of luminosity class V? Or a spectral type M2 star of luminosity class III?

You can study what determines a planet's gravity. Keeping all the other numbers the same as in your first try, type 2 for the planet's mass. What happens to the gravity? Next, run again typing 2 for the radius but keeping all the other numbers the same as in the first try. What happens to gravity this time? Use different masses and radii until you see a pattern in their effect on gravity. Notice also the effects on escape speed and the planet's density.

Next, you can experiment with temperature. What happens if everything is the same as the first try but the distance is changed to 2? How about .5? Do the results make sense? Notice what happens to the length of the year and the size of the sun in the planet's sky. Now trying changing albedo to .9, leaving all the other numbers the same as in the first try. An albedo of .9 means the planet reflects more light than the earth does, and absorbs less. What happens to its temperature? Now try albedo of .1, which would be very dark and absorbent. See what happens?

This program is very flexible, and you can learn a lot from it. Be careful to change only one quantity at a time so you can see what happens when you change it.

M DOUBLE STARS

This program allows you to see an animation of a double star. The masses of the stars and the size and shape of the orbit are chosen by you, so you can design a wide variety of systems and examine their behavior.

Like those of planets, satellites, and comets, the orbits of double stars are ellipses. The size of the ellipse is specified by the quantity called the semi-major axis. Just as is the case for planets and comets, the semi-major axis of a double star orbit is usually measured in A.U. One A.U., or Astronomical Unit, is the average distance of the earth from the sun, about 93 million miles. The semi-major axes of double stars are often in the range of 5 to 20 A.U.

The shape of the double star's elliptical orbit is specified by a quantity called the eccentricity. Eccentricity ranges from 0 (for a perfect circle) to nearly, but not quite, 1. Eccentricities near 1, like .9 or .95, mean orbits shaped like very long, narrow ellipses. The two stars' orbits always have the same eccentricity.

As mentioned above, planets, comets, and satellites all move in elliptical orbits, too. In those cases, though, we have a comparatively huge mass in the middle with a much smaller one orbiting it -- like a planet around the sun, or a moon around a planet. In the case of double stars, the two objects may be nearly the same mass. As a result, one of them doesn't stand more or less still while the other moves around it -- both of them move significantly. This is quite hard to picture and can't be illustrated in books very well, so I thought this program might be useful to you.

The computer first asks you for the eccentricity of the orbit. This has to be a number between 0 and .95. Type your choice, then press RETURN. If this is your first attempt with this program, type 0. This gives a circular orbit, which is easiest to understand.

The computer pauses at this point for about ten seconds while it does some calculation, and then asks you to type the mass of the primary star. Since there are two stars, one is heavier, and that one is called the primary star. The lighter one is called the secondary star. Why didn't these get called the heavier and lighter stars instead of the primary and secondary? I have no idea. It's a tradition. Can't astronomers have traditions?

Star masses are measured in units called solar masses.

One solar mass is exactly equal to the mass of our sun, so a star with a mass of 2 solar masses is twice as heavy as our sun, one with a mass of .5 solar masses is half as heavy, and so forth. The two stars in your double star can have masses between .1 and 20 solar masses. After you type each one, press RETURN. If this is the first time you're trying this program, use 1 for both stars, which gives very simple results.

Finally, the computer asks you to type the semi-major axis of the orbit. This can be any number between 1 and 100. As mentioned above, it is measured in A.U. Once you've typed your choice, press RETURN. On your first try, use 10 for this. The computer now pauses for about twenty seconds to calculate positions of the two stars.

The computer next prints the semi-major axis (called S-M AXIS) and eccentricity (called ECC) you chose, the period of the orbit (how long it takes each star to complete one orbit), and the separations of the two stars at closest and furthest approaches. It also produces a "clock" showing the passage of time as the two stars move in their orbits. The animation runs smoothly enough to give you a good and fairly realistic picture of the two moving stars.

To learn about double stars, you should run this program a number of times. Keeping everything as it was in the first try except the semi-major axis, try making this bigger or smaller than 10. What happens to the period of the orbit? Is this what you expected? Next, try keeping everything as it was in the first try but change the eccentricity. Try .2, .4, .6, and .8. What happens to the period? What about the speed of the two stars when they are close together as opposed to far apart? Finally, try changing the mass of the primary star while keeping the other quantities as they were in the first try. Use values of 2, 4, 6, 8, and 10. Watch the motions of the stars and the period of the orbit. Do the results make sense to you?

Roughly half of all stars in the sky are members of double or multiple star systems. Below I've listed a few of the more famous ones you might like to see using this program. In each case, the semi-major axis is in A.U. and the masses in solar masses.

NAME	ECCEN.	S-M AXIS	MASS #1	MASS #2
Alpha Centauri	.52	23.2	1.08	.88
Sirius	.59	20.1	2.28	.98
Procyon	.31	15.9	1.76	.65
Kruger 60	.41	9.5	0.27	.16
70 Ophiuci	.50	22.9	0.90	.65

N INSIDE STARS

This program lets you have a look at the temperatures of the regions inside stars. Although we can only see the outsides of stars, theoretical astrophysics gives us a reasonably good idea of what their interior conditions must be like. This program makes use of one of the simplest methods of approximating the temperatures inside stars of a wide variety of masses.

The program asks you for only one quantity this time, the star's mass. This is in solar masses (1 solar mass equals the mass of our sun) and must be between .5 and 10. After typing this, press RETURN. On your first run of this program, try 1, so you can see an approximation to what the sun is like.

The program now pauses about ten seconds to do some calculation, then prints the mass you chose, the star's spectral type, radius, and surface temperature. The computer also plots a graph with temperature on the vertical axis (in millions of degrees) and distance from the center of the star on the horizontal axis (in millions of kilometers). All stars considered are Main Sequence stars, luminosity class V.

You can learn things about stars by running this program repeatedly with different masses. Once you've seen what to expect for the sun, try masses of 2, 4, 6, 8, and 10. Watch what happens to the temperature at the center of the star. Why do you suppose this happens? Can you understand what happens to the radius? How about the surface temperature?

To gain a thorough understanding of this, you really need more background than I can give you here, but the program does allow you to experiment with the structure of stars and to learn something about the structure of stars of high or low mass compared to the sun.

O EVOLUTION OF STARS

This program allows you to study the evolution of individual stars or of whole clusters of stars.

Stars produce light and heat by means of gravitational squeezing and by nuclear reactions in their interiors. The gradual changes that take place due to this loss of light and heat energy lead over very long times to great changes in stars' structure and size. These changes are the subject of intense study by astronomers and astrophysicists, and there are still many unanswered questions that are the objects of present research. The detailed descriptions of what this program displays are beyond the scope of this short pamphlet, and I have to refer you to your textbook or your instructor for guidance.

The program first dipslays a graph called a Hertzsprung-Russell (or H-R, for short) Diagram. On the vertical axis is a quantity called "LOG L" and on the horizontal axis is "LOG T." I used the term "log" here not to panic you but as an abbreviation. The temperature scale has three numbers on it: 3, 4, and 5. These refer to temperatures of 1000, 10000, and 100000 degrees respectively. "Log" just means the number of zeros after the 1 in each case, since I didn't have room to put them all in. Notice that the highest temperature is at the LEFT, the lowest is at the RIGHT. The temperatures referred to are the surface temperatures of stars, which actually range from about 2000 to about 50000 degrees. For a simple picture of what's happening, remember that cooler stars fall to the right, hotter to the left.

The vertical axis is the luminosity, or brightness, of a star. It, too, is written as a log to save space. If "LOG L" is 4 (for example) it means a luminosity 10000 times that of the sun. A "LOG L" of -3 means a luminosity 1/1000 that of the sun. Get the idea? Most simply, brighter stars will fall near the top of the graph, dimmer ones near the bottom. On this graph, the sun as it is at present falls halfway from top to bottom and a bit to the right of the 4 on the "LOG T" axis.

The computer first asks you if you wish to see an evolving cluster of stars, the evolution of a single star, or the H-R diagram of a cluster at a single age ("cluster freeze-frame"). Press C for the evolving cluster, S for the single star evolution, and F for the "cluster freeze-frame." No RETURN is necessary.

No matter which choice you make, the computer pauses for about fifteen seconds while it does some calculations.

If you chose C, the computer produces a set of about twenty stars of various masses (ranging from .5 to 15 solar masses) for your cluster. It then places black dots on the H-R diagram at points stars of these masses occupy at a time when they are very young, before nuclear reactions have begun inside them. You may choose to follow this cluster's evolution either manually (hit M) or automatically (hit A). The cluster evolves as its age changes. The points corresponding to stars of various masses change their positions as they burn their nuclear fuel and their internal structure changes. If the dot corresponding to a particular star moves to the left, the star is getting hotter; to the right, the star is getting cooler. If the dot moves upward, the star is getting brighter, usually because it is expanding. If the dot moves downward, the star is getting dimmer, usually because it is getting smaller.

If you choose manual evolution, you are offered the choice of a "time step" -- how much the cluster's age is to increase. Your choice is a number 0-9 (no RETURN necessary). The cluster will age by a number of years equal to 1 followed by a number of zeros equal to the number you typed. For example, if you press 3, the cluster will age by 1000 years. If you press 6, the cluster will age by 1,000,000 years.

If you choose automatic evolution, the time step is always the same: 10,000,000 years, and you do not get to change it. You can observe the change in the cluster's H-R diagram as time goes on. With automatic evolution of the cluster, time in the program passes at about 1,000,000 years per second of your time. The stars whose dots move the most at each time step are the most massive stars. These eventually disappear from the graph altogether with a "beep" as the star becomes a supernova. The INSIDE STARS program shows you that more massive stars are hotter in their interiors than lighter stars. This means that they burn their fuel faster, which means that they evolve -- and die -- faster than lighter stars.

"Cluster freeze-frame" gives a result similar to the above, but you get to choose exactly what age you wish the cluster to be. You type this (DON'T USE COMMAS. 100000000 is right; 100,000,000 is wrong), then press RETURN. In this way you can attempt to produce H-R diagrams similar to those of clusters like the Pleiades, the Hyades, or an old galactic cluster like M67. The program takes about one minute to complete its run and produces points for 100 stars of masses ranging from .5 to 15 solar masses.

If you choose to examine the evolution of a single star, you are once again presented with two choices: manual (hit M) or automatic (hit A) time steps. In either case you get to choose the mass of the star you wish to see evolve. This has to be a number between .5 and 15. After you type it, press RETURN. As in the case of cluster evolution, the computer begins by placing a dot on the diagram at a point whose temperature and luminosity correspond to what a star of this mass is like when it is very young, before nuclear reactions begin inside it. If you are using manual time steps, the program produces a beep and asks you to type a number 0-9 (no RETURN necessary). If you type 4, for example, the computer allows 10,000 years to pass (1 followed by 4 zeros) and then plots a black point corresponding to the star's temperature and luminosity 10,000 years after the last temperature and luminosity. If you type 8, the time step is 100,000,000 years (1 followed by eight zeros), and so forth. Time steps of 0 (1 year), 1 (10 years), or 2 (100 years) are probably too short ever to be useful. In the single star evolution, the computer leaves the points corresponding to earlier combinations of temperature and luminosity so you can get some idea of what happens to these quantities as time passes.

If you are using automatic time steps with the single star evolution, you get to choose the size of the automatic time step, once again by typing a number 0-9 (no RETURN necessary). Once you choose this, the computer starts with a very young star of your desired mass and evolves it by your chosen size of time step automatically at about two steps per second of real time.

The EVOLUTION OF STARS program can be ended at any time by pressing the CTRL key (on the left side of the keyboard) and while holding it down, pressing the C. This automatically stops the program and allows you to return to the menu. You will probably wish to make use of this feature fairly often, as the programs will otherwise not stop until they reach an age of 12,000,000,000 years.

A good way to start using this program is to choose to evolve a single star with a mass of 1 (the same as the sun). Choose an automatic time step of 7 (10,000,000 years) and watch what happens. The point on the H-R Diagram will move quite rapidly at first, but then the sun's age will reach the time when hydrogen begins to undergo nuclear fusion reactions to produce helium in its core. The sun is then said to be a "Main Sequence" star. Its structure continues to change, but much more slowly. When its age reaches about 1,000,000,000 years you may wish to stop by pressing CTRL and C at the same time. You should then run the single star evolution with the same automatic time step (7, which means 10,000,000 years) and a mass of 2 (twice the sun's mass). Notice any differences? Try again with 3, 4, and 5 solar mass stars, and finally with one of .5 solar masses. You'll see an interesting pattern begin to emerge.

Once you think you understand single stars you can experiment with clusters, which are just collections of a lot of single stars of different masses. Much of what we know about stellar evolution comes from measurements of luminosities and temperatures of stars in clusters. Since all the stars are fairly close together, they are all at about the same distance from us and it is suspected that they all formed at about the same time. This simplifies a lot of considerations for astrophysicists.

P SPIRAL GALAXIES

This program allows you to produce a picture of a spiral galaxy seen from any inclination angle you wish.

Spiral galaxies are enormous groups of tens or hundreds of billions of stars. Our sun is part of one called the Milky Way. Although not all galaxies are spirals, these have the most interesting structure. This program displays three prominent features of these objects: core, spiral arms, and nebulae. The region where stars are closest together is near the center; this is called the galactic core. It is more or less elliptical in shape. Even here the stars are a light-year or so apart, so don't get the idea they are packed shoulder-to-shoulder or anything. Surrounding the core is a region shaped like a coin called the disk of the galaxy. Within this region are the spiral arms, composed largely of young stars, and the dark clouds of gas and dust called nebulae which are the birthplaces of new stars.

You first get to choose the type of spiral you wish to see. The three types are A (tightly wound spiral arms), B (intermediate winding), and C (loosely wound spiral arms). Our own galaxy is type B. Press A, B, or C. No RETURN is necessary.

The computer allows you to choose any inclination angle you wish between 0 and 90 degrees. Spiral galaxies are arranged at random in the universe, so from our vantage point here on earth they can be tipped at any angle at all. An inclination of 0 degrees shows the galaxy "face-on," so you can see the spiral arms in greatest detail. An inclination of 90 degrees shows you the galaxy "edge-on," making the spiral structure impossible to see (but still showing some interesting effects). Intermediate angles show you what most spiral galaxies look like through our telescopes.

After you type the inclination angle, press RETURN. The computer first produces the core in white; the stars are close enough together here that it is impossible to see individual ones at our window's distance from the galaxy (about a million lgiht years). Next, the computer draws in some of the very brightest stars of the spiral arms, the most prominent of which are spectral types O and B. Along with these it produces the regions of thick nebulosity. These look black because they block out the light of stars behind them, and can best be seen when they are projected against the bright core, at inclinations near 90 degrees.

The entire process of drawing the galaxy takes about forty seconds. At the end of this time, the computer offers you the usual options of running again (press A) or returning to the menu (press M).

THE END

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Double Stars displays the motion of both stars in a binary system for which you choose the stars' masses and their orbits

Inside Stars shows you how the internal structure of stars is influenced by their masses

Evolution of Stars uses an H–R diagram to display the changing properties of individual stars or whole star clusters as the stars age

Spiral Galaxies allows you to display a spiral of any type as seen from an angle of your choice

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