A Simulated View of the Galaxy

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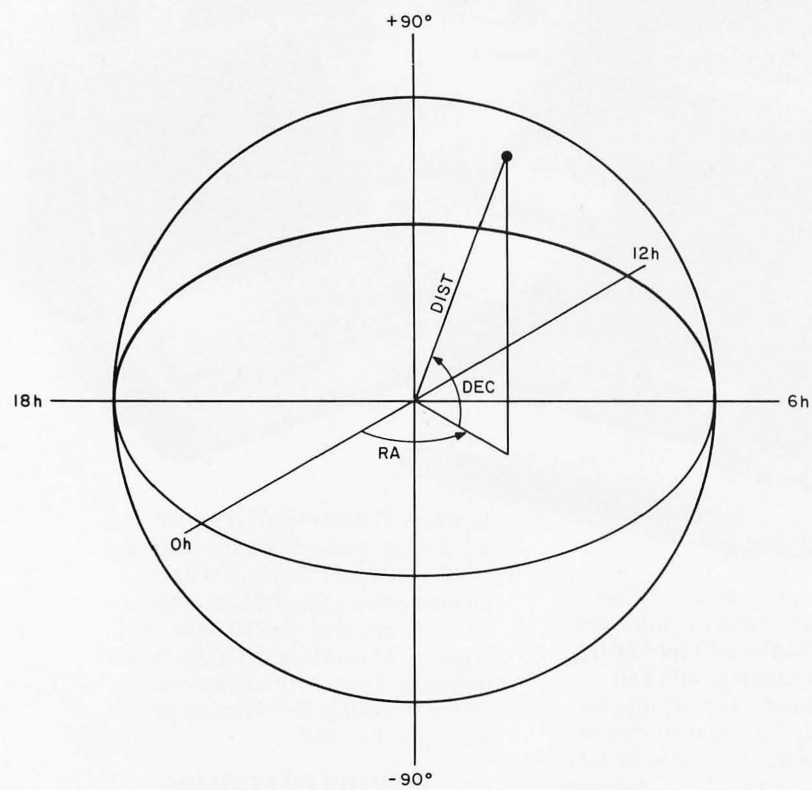

Figure 1: The celestial coordinate system.

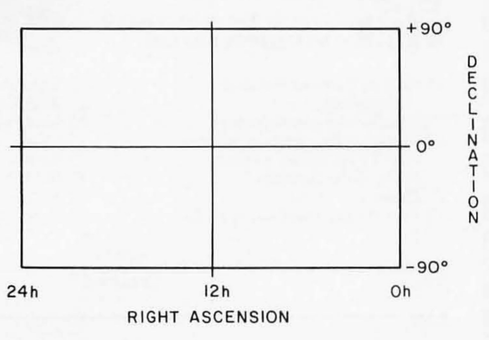

Figure 2: A Miller projection is used for plotting the data.

At one time or another, each of us lets our imagination wander; perhaps to places familiar to us, or places we have never been and can only dream about exploring. Often, my imagination leads me to the questions: "What does our sun look like from neighboring stars?" and "What do our familiar constellations look like from other points of view?" Have you ever wished that you could travel anywhere in the universe whenever you wanted to? With the help of computers and graphics displays we can begin to answer some of these questions and have fun exploring what we know about the galaxy at the same time.

Getting Started

Several things are needed to simulate the stars in our galaxy; an algorithm that will allow us to shift our position with respect to the Earth based coordinate system; actual or hypothetical coordinates of stars; and a display device on which to plot the resulting star maps. The first version of this program was written four years ago and run on an IBM 1130 computer. Output was in the form of a printer plot. 50 stars were entered, using data on the 50 brightest stars in our sky. Since positions given in star catalogs are in celestial (spherical) coordinates, right ascension (RA) corresponding to longitude (0 to 23 hours), declination (DEC) corresponding to latitude (−90 to +90 degrees), and distance in light years were entered directly into a disk file. The program then performed the necessary conversions to get values in radians. Figure 1 shows the celestial coordinate system.

The author wishes to thank TRC Photographic Specialists of Omaha NE for their help.

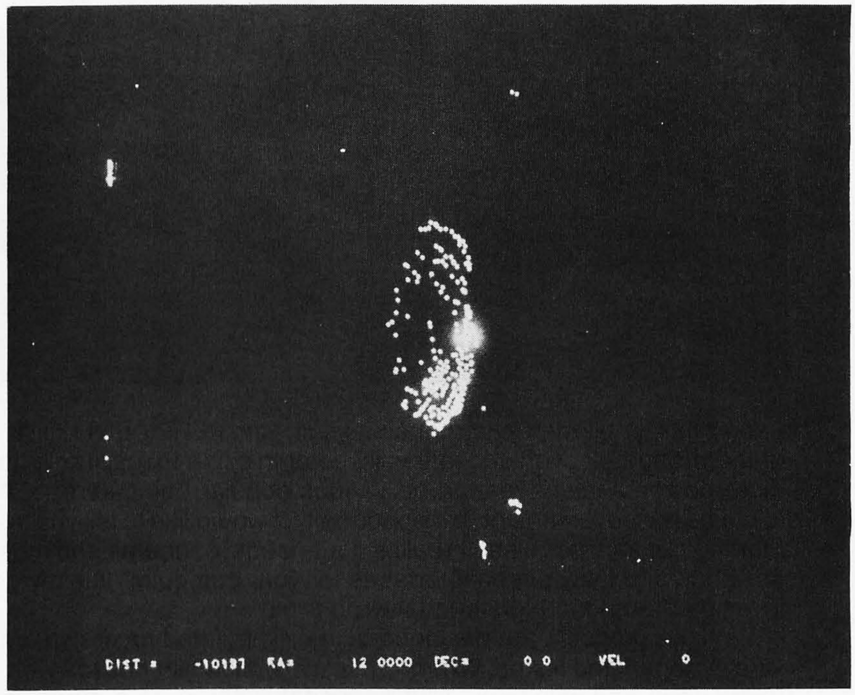

Photo 1: Side view of our galaxy from 90,987 light years.

Coordinate Transformations

In order to display the stars as they would appear from another point in space, their coordinates must be converted to a manageable form. Shifting the origin of the coordinate system appears to be the easiest way to obtain the desired results. Declination and right ascension must be converted to radians first:

$$RA = RA \times 0.261799$$
$$DEC = DEC \times 0.01745$$

where RA and DEC represent right ascension and declination, respectively. Then the celestial coordinates can be converted to rectangular coordinates:

$$X = R \times \cos(DEC) \times \cos(RA)$$
$$Y = R \times \cos(DEC) \times \sin(RA)$$
$$Z = R \times \sin(DEC)$$

The resulting rectangular coordinates are in units of light years, because of the variable R (distance). The coordinates may be kept in three arrays for easy manipulation.

Next, the origin must be shifted to the new point of view. The celestial coordinates of the destination or new origin are given by the user of the program (through console input) and converted to rectangular coordinates with the same set of equations used above. To shift the origin, the following three equations should be used:

$$X' = X - X_0,$$
$$Y' = Y - Y_0,$$
$$\text{and } Z' = Z - Z_0,$$

where X_o, Y_o, and Z_o are the rectangular coordinates of the new origin; X, Y, and Z are the old coordinates of a star in the three arrays; and X', Y' and Z' are the resulting shifted coordinates.

To display the stars, the rectangular coordinates must be converted back to celestial coordinates:

$$(R')^2 = (X')^2 + (Y')^2 + (Z')^2,$$
$$RA' = \arctan(Y'/Z'),$$
$$DEC' = \arcsin(Z'/R').$$

It is also necessary to multiply by the appropriate scale factors to be compatible with the screen or window dimensions of the display device. The current version of the program displays the stars in the form of a Miller projection, as shown in figure 2. This produces a distorted view on the top and bottom of the display but does show the entire sky. An alternate format magnifies the window to display only a 50 by 50 degree frame. This gives the impression of looking out the window of a spaceship, but makes navigation difficult.

In order to shift the window, we must introduce some new variables to indicate in the program which rotations are required. This can most easily be accomplished by altering the equations used for shifting the origin:

Text continued on page 70

A glossary is provided on page 80.

Table 1: Execution times of one iteration of the program with various numbers of stars. Times include plot or display device data transfer rates.

Number of Stars	IBM-1130	8080/BASIC	8080/ASM	IBM 370/158
10	4 minutes	10 seconds	0.5 seconds	0.1 seconds
100	6 minutes	100 seconds	5.0 seconds	0.3 seconds
400	8 minutes	400 seconds	20.0 seconds	1.0 seconds

Table 2: Star coordinates taken from star atlases and catalogues. Besides using real stars, the author also input 300 "imitation" stars to fill out the galaxy to what it actually looks like. The stars listed should be enough to produce interesting patterns in a reasonable amount of home computer time. Names (popular or scientific) are rough approximations in English alphabet. An asterisk represents ficticious "fill-out" stars to represent extragalactic objects.

Name	Right Ascension (hrs)	Declination (degrees)	Distance (light yrs)	Magnitude
A. CETUS	02.983	003.900	250.0	2.8
A2. LIB	14.800	−15.833	62.0	2.9
THI. ERI	02.933	−40.517	120.0	3.4
SUN	00.000	0.000	.1	−9.0
AND.GALAXY	00.667	4.100	1500000.0	7.8
AND. A	00.668	4.100	1500000.0	7.8
AND. B	00.666	4.200	1500005.0	7.8
AND. C	00.665	4.400	1500010.0	7.8
AND. D	00.668	4.300	1501000.0	7.8
AND. E	00.667	4.500	1500100.0	7.8
AND. F *	00.660	4.000	1500150.0	7.8
AND. G	00.656	4.400	1500050.0	7.8
AND. H	00.660	4.550	1510000.0	7.8
AND. I	00.661	4.500	1510001.0	7.8
AND. J	00.667	4.600	1510000.0	7.8
EG224A	00.667	041.001	1500000.0	5.0
EG224B	00.669	041.000	1500000.0	5.0
EG224C *	00.665	041.001	1500000.1	4.9
EG224D	00.666	041.002	1500001.0	5.0
EG224E	00.665	041.001	1500000.0	5.0
EG224F	00.668	040.999	1500000.0	5.0
EG225COMP	00.630	041.420	1500000.0	9.9
EG201COMP	00.667	040.600	1500000.0	9.5
PLEIADES	03.733	023.950	4300.0	4.7
SIRIUS	6.716	−16.6	8.7	−1.4
A.CENTAURI	14.600	−60.6	4.3	−.2
CANOPUS	6.380	−52.6	2300.0	−.7
VEGA	18.586	38.733	23.0	.1
CAPELLA	05.216	045.950	42.0	.2
ARCTURUS	14.223	019.450	32.0	.2
PROCYON	07.612	005.350	10.0	.5
ARCHERNAR	01.598	−57.483	70.0	.6
B CENTAURI	14.005	−60.133	130.0	.8
ALTAIR	19.805	008.733	18.0	.9
ALDEBARON	04.550	016.416	54.0	1.1
SPICA	13.376	−10.900	190.0	1.2
FORMALHAUT	22.915	−29.883	27.0	1.3
DENEB	20.662	045.100	465.0	1.3
RIGEL	05.202	−08.250	545.0	.3
BETELGEUSE	05.875	007.400	300.0	.9
BELLATRIX	05.367	006.300	230.0	1.7
E. ORION	05.567	−01.233	300.0	1.7
K. ORION	05.767	−09.683	2100.0	2.2
D. ORION	05.497	−00.333	600.0	2.5
L. ORION	05.550	009.917	1600.0	3.7
ANTARES	16.438	−26.316	170.0	1.2
REGULUS	10.095	012.216	70.0	1.3
B. LEO	11.800	014.733	43.0	2.2
G. LEO	10.300	019.983	90.0	2.6
E. LEO	09.733	023.917	100.0	3.1
TH. LEO	11.217	015.600	150.0	3.4

Table 2 continued on next page.

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$$X' = X - X_0,$$
$$Y' = Y - Y_0,$$
$$\text{and } Z' = Z - Z_0,$$

will become:

$$X' = (X - X_o)(\cos\phi)(\cos\theta) + (Y - Y_o)(\sin\theta)(\cos\phi) + (Z - Z_o)(\sin\phi)$$

$$Y' = (Y - Y_o)(\cos\theta) - (X - X_o)(\sin\theta)$$

$$Z' = (Z - Z_o)(\cos\phi) - (X - X_o)(\cos\theta)(\sin\phi) - (Y - Y_o)(\sin\theta)(\sin\phi)$$

where:

θ = rotation about the X axis on the Y,Z plane,

ϕ = rotation about the Z axis on the X,Y plane.

Also, when converting back to celestial coordinates, scale factors must be introduced to produce a 50 by 50 degree field of view. The user may wish to experiment with other window formats.

Expanding the Model

Looking at the sky from various points of view in space is interesting, but I have found that animation really shows the power of the simulation technique, and of animated graphics. With the coordinates of over 400 stars (100 real stars *and* 300 that add the general shape of the Milky Way spiral arms of our own galaxy), we can begin the exploration of our universe. Unfortunately, 400 stars do not make a galaxy, or even a small

About the Author

Mark Dahmke is currently employed by the University of Nebraska Computer Network as a programmer/analyst in the Academic Computing Services section. He is also a senior computer science major. At home Mark owns an 8080 based system with 32 K bytes of memory and a floppy disk drive. His work involves graphics, electronics, writing and systems programming.

Table 2, continued:

D. LEO	11.217	021.000	140.0	3.5
Z. LEO	10.250	023.567	500.0	3.6
M. LEO	09.850	026.167	110.0	4.1
R.D SCO	15.900	−28.500	450.0	4.0
SCO	16.883	−42.317	300.0	3.8
TH. SCO	17.567	−42.967	140.0	2.0
SHAULA	17.500	−37.067	200.0	1.7
E. SCO	16.783	−34.200	75.0	2.3
K. SCO	17.650	−39.000	360.0	2.5
D. SCO	15.938	−22.533	590.0	2.5
G. SCO	16.883	−42.317	100.0	3.8
POLLUX	07.705	028.150	31.0	1.2
CASTOR	07.523	032.000	44.0	1.6
E. GEM	06.700	025.167	200.0	3.2
GEM	06.217	022.517	300.0	3.4
D. GEM	07.300	022.033	300.0	3.5
Y. CAS	00.900	060.450	200.0	2.2
A. CAS	37.833	059.267	230.0	2.4
B. CAS	00.108	058.883	45.0	2.4
D. CAS	01.400	060.083	150.0	2.8
E. CAS	01.867	063.517	100.0	3.7
D. TAURUS	05.383	28.567	130.0	1.7
TAU	05.633	021.000	350.0	4.1
HYADES	04.250	016.000	300.0	4.0
E. TAU	04.450	019.117	300.0	4.0
E URSAE MAJ	12.863	056.233	50.0	1.7
DUBHE	11.000	062.017	105.0	1.9
N. UMA	13.767	049.467	210.0	1.9
MIZAR	13.367	055.183	190.0	2.2
D. UMA	12.233	057.200	100.0	2.2
B. UMA	10.980	056.650	76.0	2.4
Y. UMA	11.867	053.967	88.0	2.5
B CRUCIS	12.746	−59.416	465.0	1.5
A CRUCIS	12.396	−62.816	150.0	1.6
E CANIS MAJ	06.945	−28.900	325.0	1.6
ACRUX	12.400	−63.150	220.0	.9
E. CARINA	08.358	−59.350	330.0	1.7
B. CARINA	09.217	−69.517	300.0	1.8
A. TRIA	16.717	−68.933	130.0	1.8
MIRFAK	03.350	049.683	270.0	1.9
Y. VEL	08.133	−47.183	100.0	1.9
ALHENA	36.583	016.450	78.0	1.9
KAUS. AUST	18.350	−34.417	160.0	1.9
AL WAZOR	07.100	−26.317	650.0	1.9
MURZIM	06.342	−17.933	300.0	1.9
D. VEL	08.717	−54.517	70.0	2.0
ALNITAK	05.633	−01.967	400.0	2.0
B. AURIGAE	05.933	044.950	84.0	2.0
PEACOCK	20.367	−56.900	160.0	2.1
POLARIS	01.817	089.033	470.0	2.1
Y. UMI	01.530	073.000	500.0	4.7
N. UMI	01.620	076.000	700.0	5.7
D. UMI	01.795	086.100	650.0	5.0
E. UMI	16.850	082.130	550.0	5.1
TH. UMI	01.572	078.100	750.0	5.0
A. OPH	17.550	012.600	67.0	2.1
NUNKI	18.867	−26.367	160.0	2.2
A. AND	00.088	028.817	120.0	2.1
ALPHARD	09.417	−08.433	200.0	2.2
AL NA'IR	22.083	−47.200	91.0	2.2
SUHAIL	09.100	−43.233	220.0	2.2
B. PER ALGOL	03.082	040.767	100.0	2.2
A. ARI	02.067	023.233	74.0	2.2
B. GRUS	22.650	−47.150	325.0	2.2
B. CETI	00.683	−18.267	57.0	2.2
B. UMI	14.850	074.367	270.0	2.2
I. CARINA	09.267	−59.067	100.0	2.2
TH CENT.	14.067	−36.117	86.0	2.2
D. PUPPIS	08.033	−39.867	800.0	2.3
Y1. AND.	02.033	042.083	400.0	2.3
ALPHECCA	15.550	026.883	67.0	2.3
Y. CYGNUS	20.333	040.100	470.0	2.3
B. AND	01.117	035.350	75.0	2.4
Y. DRA	17.917	051.500	150.0	2.4
N. CMA	07.367	−29.200	270.0	2.4
A. PHE	00.400	−42.583	76.0	2.4
E. PEG	21.700	009.650	250.0	2.5
A. PEG	23.033	014.933	100.0	2.6
N. OPH	17.125	−15.667	76.0	2.6
Y. CRV	12.217	−17.267	130.0	2.8

fraction of it, but with a little imagination (which was all we had in the first place) we can mentally fill the gaps in the model. The current version of the simulation runs on an IBM 370-158 with a 2250 graphics display unit. The 2250 has a resolution of 4096 by 4096 points. With a slight modification to the program, it will run in a continuous loop, starting with a direction vector and velocity in light years per iteration. The effect is that of a space craft with almost unlimited velocity. With a fast processor, the impression of speed is dramatic. Velocities of 10,000 light years per second have been simulated. There are no relativistic effects, but it might be interesting to add the necessary equations—especially if color graphics are available. The Doppler shifts would be most striking. The stars in the direction of travel would be intensely blue, while those receding from the observer would be a deep red.

Adding More Stars

As my desire to travel outward increased, I soon realized that I would have to have something to travel to. Additions to the model included the Andromeda galaxy (approximately 1.5 million light years away), the Magellanic clouds (our nearest intergalactic neighbors) and several other extragalactic objects. One problem with adding more stars is that the execution time goes up proportionately. When experimenting with computer based simulations, this soon becomes apparent. Note that in listing 1, the algorithms have been optimized to the extreme, to cut down on the execution time. Comparison tests were run on several systems with the results shown in table 1.

The IBM-1130 was slowed down by its printer, used to generate a printer plot of the star map. The 8080 is almost fast enough to compete with the 370, if it didn't have to do the floating point calculations in software. A floating point hardware board would probably decrease the times given for the 8080 by a factor of 10. The 370 is a multiprogramming system—running several other programs at the same time. Thus, the simulation has to compete with other programs and is also slowed down by competition for peripheral devices such as video terminals, the 2250 graphics display, printers, and card readers.

Implementation

The details of implementation depend on the computer, display device, and language used. The original IBM-1130 version used a printer plot because that was the only output device available. Since the available memory was limited (8 K words), the program was written to make heavy use of disk files for storage of the starting coordinates and intermediate results. The last phase of the program scanned the disk file containing the shifted coordinates and produced a printer plot.

The second version ran on an IBM/360-65 and plotted on a Tektronix 4013 graphics display terminal. Although neither of these first two versions was animated, single star maps could be obtained.

The 2250 version required considerably more programming effort. Since the 2250 is a high speed device, true animation was finally possible. The 2250 refreshes its display from a core buffer loaded from the processor. Coordinates are plotted and mapped into the buffer; subroutine EXEC is then called and the entire buffer is sent to the display. Unfortunately the buffer must be cleared before another iteration can take place—but clearing the buffer also clears the screen. The solution is to maintain two separate buffers. One can be displayed on the screen while the other is being cleared and loaded. If this is not done, the display will flicker with a duty cycle of about 10 percent on, 90 percent off, since the calculation time is greater than the intermediate display time.

Photo 2: Our galaxy from —5983 light years.

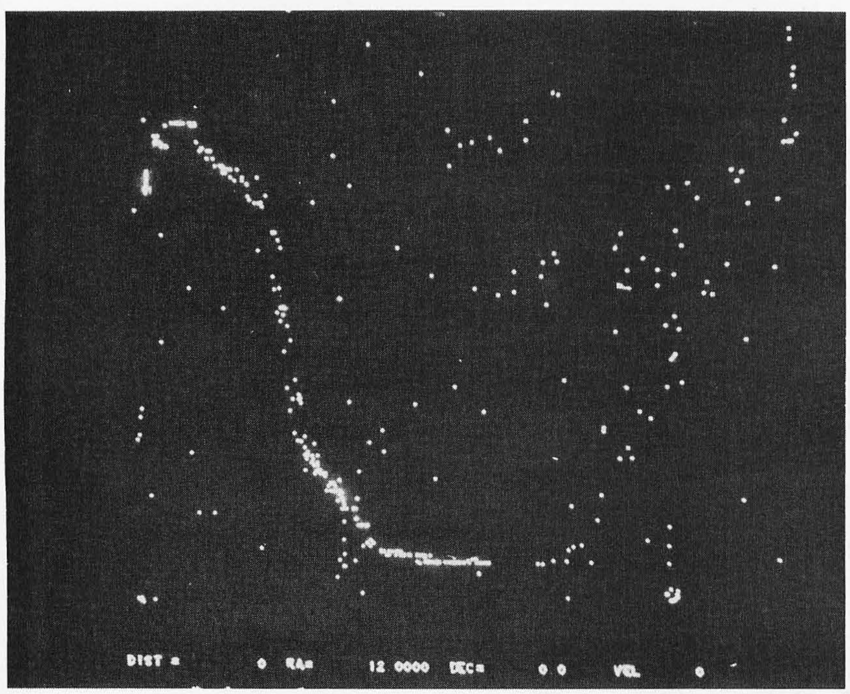

Photo 3: The night sky as seen from the Northern Hemisphere of Earth. Note the Big Dipper in the upper center, Leo just above and right of center, and the Milky Way down the left and across the middle.

Sample Output

Photo 1 is a side view of our galaxy from 90,987 light years. As you can see, the model is not accurate because the middle of the galaxy is almost empty. Also, the large bright spot on the right side of the galaxy represents the tight group of 100 stars that form our local constellations. At the bottom of the screen distance, right ascension, declination, and velocity have been displayed for reference. The minus sign on the distance means that the direction of travel is opposite the direction the right ascension/declination vector. Photo 2 is a view of our galaxy from -5983 light years. Photo 3 shows the sky from Earth (note the Big Dipper in the upper center, Leo just above and right of center, and the Milky Way down the left side and across the bottom). Photo 4 shows our local constellations from 2937 light years, against the background of the Milky Way. Photo 5 is another side view of the Milky Way from one million light years (viewed with the 50 by 50 degree window). The two small objects just below and to the right of the galaxy are the large and small Magellanic Clouds. They are approximately 100,000 light years from the Milky Way.

Text continued on page 80

```
      DIMENSION FX (400), FY(400), FZ (400)
      REAL NRA, NDEC, NEWR
C     READ IN AND STORE RECTANGULAR COORDINATES FOR STARS IN FX,
C     FY, AND FZ ARRAYS.
      DO 1 I = 1, 400
            READ (5, 100) CRA, CDEC, CDIST
C     FIRST, CONVERT CRA, AND CDEC TO RADIANS
            CRA  = CRA  * .261799
            CDEC = CDEC * .01745

            CXY   = DIST * COS (CDEC)
            FX (I) = CXY * COS (CRA)
            FY (I) = CXY * SIN (CRA)
            FZ (I) = DIST * SIN (CDEC)
  1         CONTINUE
100   FORMAT ( 3( 10F7.3) )
C     RA, DEC, AND DIST REPRESENT THE POLAR COORDINATES FOR THE
C     DIRECTION VECTOR. VEL IS THE VELOCITY OR RATE OF CHANGEOVER
C     EACH ITERATION OF THE ALGORITHM.
      DIST = 0.
      RA   = 3.1415927
      DEC  = 0.
      VEL  = 0.
C     ADVANCE THE DISTANCE COUNTER BY ADDING THE VELOCITY FOR ONE
C     ITERATION.
 10   DIST = DIST + VEL
C     NOW COMPUTE THE NEW LOCATION IN SPACE FROM RA, DEC, DIST.
      AXY = DIST * COS (DEC)
      AX   = AXY * COS (RA)
      AY   = AXY * SIN (RA)
      AZ   = DIST * SIN (DEC)
C     NOW ENTER THE INNER DO LOOP WHERE THE SHIFTED COORDINATES
C     ARE FOUND, CONVERTED TO CELESTIAL COORDINATES AND PLOTTED.
      DO 20 I = 1, 400
            XP = FX (I) - AX
            YP = FY (I) - AY
            ZP  = FZ (I) - AZ

            NRA   = ATAN (YP / XP)
            NEWR = SQRT (XP * XP + YP * YP + ZP * ZP)
            NDEC  = ARSIN (ZP / NEWR)
C TEST FOR QUADRANTS MESSED UP BY THE ARCTANGENT FUNCTION.
            IF  (XP .LT. 0.) NRA = NRA + 12.
            IF ((XP .GT. 0.) .AND. (YP .LT. 0.)) NRA = NRA + 24.
C TEST FOR SCREEN LIMITS.
            IF (NRA .GT. 24.) NRA = NRA - 24.
            IF (NRA .LT. 0.  ) NRA = NRA + 24.
C PLOT POINTS HERE, USING THE APPROPRIATE SUBROUTINE CALLS FOR THE
C AVAILABLE DISPLAY DEVICE.
            CALL P POINT ( -NRA, NDEC)
 20         CONTINUE
C     CLEAR SCREEN; PREPARE FOR NEXT ITERATION.
C     TEST FOR CONSOLE INPUT; CHANGES IN DIRECTION, VELOCITY, SCREEN
C     WINDOW FRAMING, ETC.
      GO TO 10
      STOP
      END
```

Listing 1: Generalized FORTRAN version of galaxy simulation. This program can be converted almost directly into BASIC. Note: for those people not having an arcsin function: arcsin function: arcsin (x) = arctan $(x/\sqrt{1-x^2})$.

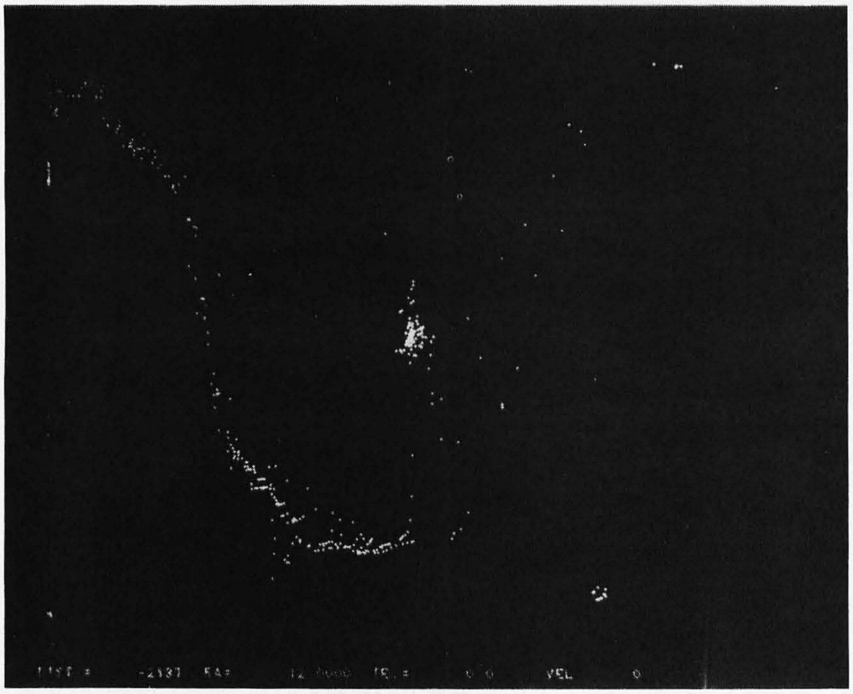

Photo 4: The local constellations from 2937 light years against the background of the Milky Way.

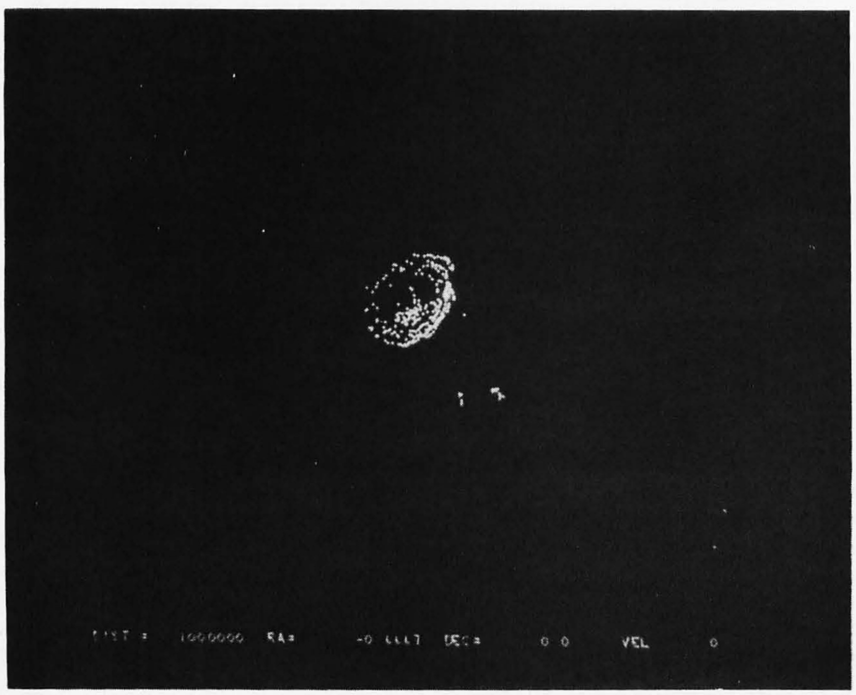

Photo 5: Another side view of the Milky Way galaxy from 1 million light years. The two small objects just below and to the right of the galaxy are the large and small Magellanic Clouds.

Text continued from page 74.

Other Possibilities

Computer enthusiasts who are also interested in astronomy or physics might want to experiment with the Doppler shift effect mentioned earlier—requiring a color graphics display. Also, giving the stars colors related to their surface temperatures might be interesting. Another possibility would be the addition of magnitude (brightness). The IBM-1130 version calculated magnitudes and used different printer characters to indicate stars, but the 2250 does not have a programmable intensity control.

Another interesting possibility lies in the three-dimensional nature of the model. If two images were plotted side by side on the screen at slightly different viewing angles, a pair of stereoscopic viewing glasses would permit a truly three-dimensional view. I have experimented with the stereo three-dimensional effect by placing similar Gould hard copy plots side by side. The sense of depth produced gives one a feeling of vertigo.

Since the model is animated, navigation experiments are possible. Perhaps the algorithms presented here could be written into a game program producing the ultimate celestial exploration game.■

GLOSSARY

Buffer: Temporary storage area in main memory, usually used to prepare or receive data from input or to output devices.

Declination: The angle from the celestial equator to the star. Equivalent to latitude (−90 to 90 degrees).

Doppler shift: Apparent changes in frequency due to direction of travel and speed. For example, if you are moving towards an object that is emitting light, the frequency of the observed light is higher. The reverse is true for the opposite direction of travel.

Extragalactic objects: Objects outside the domain of a galaxy.

Light year: The distance light will travel in one year at 186,284 miles per second (300,000 kilometers per second) – about 5,870,000,000,000 miles.

Magnitude: The brightness of a star. Each unit of magnitude signifies a difference in brightness factor of 2.512.

Right ascension: The arc measured along the equator, from 0 hours to the base of the star's vertical declination circle.