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Studies of a Population of Stars:

Distances and Motions

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Venture out under a clear night sky, in city or country, bright moon or dark moon, and you will see at least a few stars. The brightest stars visible offer, fortunately, a wide variety of characteristics that can be observed or computed easily. With this activity students have the chance to see these bright stars and learn about their distances and motions.

The universe is rich with interesting phenomena. Stars, alone, offer many investigations. The results of this activity stand alone, or they may be combined with results from other “Studies of a Population of Stars” activities for more insights.

**OBJECTIVE:** Make observations and use available data and simple calculations to correlate observations and data in the characterization of stars. In this activity, the distances of bright stars are calculated and their motions, in the plane of the sky and in three dimensions are illuminated.

**APPARATUS:**

1. **Scientific calculator or computer spreadsheet** for each student, or for small groups of students to share
2. **Data tables** supplied with this lesson
3. **Star charts** supplied with this lesson

**ACTIVITIES:**

Duplicate and distribute star charts and sets of star information to the students. The specific stellar data tables for the activity’s time of year can be cut/pasted from the full set included with this activity in Appendix 1, based on the calendar-organized table in the DISCUSSION section below. The full set of stars may be analyzed even though not all will be visible at any particular time of year. Measurement units in the activities below are in [brackets]. Explanations of the terminology in the activities is found in the DISCUSSION section below. The phrases in **bold** describe the instructional activity.

More advanced students may ask why trigonometric equations aren’t being used for these calculations, and some may notice that spherical trigonometry is really applicable. The answer is that for the tiny angles being discussed, the small angle approximation is applicable: treating the calculations as plane geometry will not reduce precision in any meaningful way.

1. Students should spend an evening outdoors and **identify the stars** they will be analyzing with the data provided here. They should be encouraged to look for color differences (subtle but visible) and the distribution of the stars in the sky – are they found in all directions or “clumped” together?
2. **Calculate the distances to stars.** The parallax (PLX) in milliarcseconds (thousandths of an angular second of arc, [mas]) can be converted from an angular measure to a physical distance easily. Multiply the parallax in [mas] by 1000 and then take the reciprocal:

D = 1/(PLX ∙ 1000) [parsecs, pc] (1)

See Edberg (2005) for a *PUMAS* lesson explaining parallax.

Most students won’t have a feel for distances in parsecs so convert that to light years (Bishop, 2007):

1 pc = 3.262 [ly] (2)

1. Using the resolved directions of the stars’ proper motions (north-south and east-west, PMN-S and PME-W, respectively) vectors can be plotted on graph paper and added to **show stars’ total proper motions across the sky**. The length of the vector sum should equal the magnitude of the proper motion, calculated using:

Overall Proper Motion [mas/yr] = √{(PMN-S [mas/yr])2 + (PME-W [mas/yr])2} (3)

1. Of greater interest are **the three dimensional space velocities of the stars.** By converting the angular proper motions to physical velocities and combining those with the (physical) radial velocity, the space motion can be computed. Three dimensional parallelepiped models of individual stars’ motions can be made with pipe cleaners, scaling km/s to mm of pipe cleaner.

First, the angular rate, mas/yr can be converted to radians/yr:

[rad/yr] = {[mas/yr]/1000}/206265 (4)

where 206265 is the number of seconds of arc in a radian and 1000 converts mas to seconds of arc. Using the small angle approximation and the distance computed with equation (2), the proper motion is

PM [pc/yr] = PM[rad/yr] ∙ D [pc] (5)

which is still not easy to recognize. Use conversion factors (Bishop, 2007) of 1 parsec = 3.086x1013 km and 1 yr = 3.156x107 seconds to calculate the proper motions in km/s.

The space velocity is the square root of the sum of the squares of the proper motions and radial velocity:

Space Velocity [km/s] = √{(PMN-S[km/s])2 + (PME-W[km/s]2 + (RV[km/s])2} (6)

1. **Plot proper motion vs. distance.**

 The plot of proper motion vs. distance can be compared to the view of the motion of cars on a freeway, viewed from its side (perpendicular to the cars’ motions). If all the cars are moving at the same physical speed, the cars in the closest lane will appear to be moving faster in angular units of [degrees/second] because they are closer to the observer than cars in more distant lanes.

Stars have their individual peculiar motions (except for some prominent clusters, like the Pleiades, and other groups, like some stars in the Big Dipper, which are traveling together) but the principle still generally holds: closer stars have higher proper motions. The proper motions charts in Appendix 3 suggest that some of the bright stars being studied are close, while others are distant. Additional study of these charts shows that there are a number of faint stars that have much greater proper motions than the bright stars studied in this activity.

Careful study of many proper motions across the sky was used, as early as the 18th century by William Herschel (discoverer of Uranus), to determine the direction of the Sun’s motion through the universe. (At that time, astronomers didn’t know the solar system was a part of the Milky Way galaxy, itself only a small part of the universe.)

 The plot of space velocity vs. distance tells a different story. Is there a correlation between distance and physical velocity? **Advanced Extension:** With all the bright stars in the tables of Appendix 1, can a “flow” be identified based on proper motion directions or radial velocity? This advanced study requires geometric transformation of each vector component of the stars’ space velocities to a common origin. Such studies typically use hundreds to thousands of stars.

**THE UNDERLYING PRINCIPLES:**

Fundamental questions about stars in the sky include:

Where is it moving?

How far away is it?

These questions can be answered using the data table for each star in the collection.

Most people notice the Moon’s nightly motion against background stars and some notice the motion of planets over a few days or weeks. The motions of stars are much slower to observe and require careful measurements. A star’s motion on the plane of the sky is called Proper Motion and it is usually specified in terms of equatorial coordinates, with motion specified east-west and north-south. Stellar motion *through* the plane of the sky, towards or away from the observer, is called radial velocity and is measured in km/s. It can be measured with a telescope+spectrometer, which show a red shift or blue shift depending on whether the star is receding or approaching, respectively.

**DISCUSSION:**

The stars included in this activity are among the brightest in the sky and are easily visible with the Moon up and in light polluted cities (but not where skyscrapers or trees block the sky!). Use the orientation “rose” in the lower left of the star charts to help with using the charts at night. The stellar data presented here were downloaded from the *SIMBAD* Astronomical Database, <http://simbad.u-strasbg.fr/simbad/> .

The following sets of stars can be used, and viewed, annually from either the northern or southern hemisphere, with considerable geographic and seasonal overlap. After choosing the time of year for observing, star selection should be based on any familiar constellations first and then biased toward the hemisphere in which you reside. Stars with positive declinations will be most easily visible from the northern hemisphere; negative declinations are better seen from the southern hemisphere. (Declination is the celestial equivalent of latitude on Earth.) Some stars at higher positive (north) or negative (south) declinations will not be visible from the opposing hemisphere and others will barely skim the horizon. Stick to lower declinations when possible.

The quarters of the year used in the table are based on the assumption that the stars will be observed during evening hours. For viewing, there is considerable overlap of star availability across the quarterly boundaries (as with hemispheres) and they can often be seen for many months before the quarter given if the observer stays up later in the night or looks before dawn. Use a star chart, planisphere (“star wheel”), or planetarium software to determine which stars can be used to match the timing of your lesson plan.

The tables of star data in Appendix 1 are organized alphabetically by CONSTELLATION and then by Star Name. The tables contain a variety of information that can be extracted and used to compare and contrast these bright stars. Learning will be improved if students put together their own naked eye observations of stars with the data supplied in the tables. The space motions of many stars can be determined. The text below describes the table entries, and a summary table in the same format as the tables of stars is the first in Appendix 1. Select star data and distribute it to your students.

*Proper motions* (PMs) are the measured (when possible) motions of stars on the plane of the sky, *across* the line of sight. Celestial southbound and celestial westbound (look at the map rose on the charts in Appendix 2) are negative. Several stars’ PMs are so low that they are not presented on the Proper Motion charts. This is not surprising considering their distances or true motions (see below). Note that the modifier “celestial” in text and on the charts indicates a compass direction defined by the horizon’s direction, not a table-top map direction. (In other words, east and west are reversed in the sky compared to printed maps.)

*Radial velocity* is measured *along* the line of sight. Positive (+) is away from the observer, yielding a red shift. Negative indicates approach and produces a blue shift.

**Bright Evening Stars**

**CONSTELLATION-Hemisphere; Star Name**

|  |  |  |  |
| --- | --- | --- | --- |
| **Jan.-Feb.-Mar.** | **Apr.-May-June** | **July-Aug.-Sep.** | **Oct.-Nov.-Dec.** |
| AURIGA – N Capella | AURIGA – NCapella | AQUILA – N Altair | AQUILA – N Altair |
| CANIS MAJOR – S Sirius | BOOTES – N Arcturus | BOOTES – N Arcturus | AURIGA – N Capella |
| CANIS MINOR – N Procyon | CANIS MINOR – N Procyon | CENTAURUS – SAlpha Centauri | CYGNUS – N Deneb |
| CARINA – SCanopus | CARINA – SCanopus | CENTAURUS – SBeta Centauri | ERIDANUS – SAchernar |
| ERIDANUS – S Achernar | CENTAURUS – SAlpha Centauri  | CRUX – SAcrux | LYRA – NVega |
| GEMINI – NCastor | CENTAURUS – SBeta Centauri | CRUX – SMimosa | PISCIS AUSTRINUS – S Fomalhaut |
| GEMINI – NPollux | CRUX – SAcrux | CRUX – SGacrux | TAURUS – NAldebaran |
| ORION – Equator Betelgeuse | CRUX – SMimosa | CYGNUS – NDeneb |  |
| ORION – EquatorRigel | CRUX – SGacrux | LYRA – NVega |  |
| TAURUS – N Aldebaran | GEMINI – NCastor | PISCIS AUSTRINUS – S Fomalhaut |  |
|  | GEMINI – N Pollux | SCORPIUS – SAntares |  |
|  | LEO – N Regulus |  |  |
|  | VIRGO – EquatorSpica |  |  |

The combination of proper motion and radial velocity gives the space velocity in three dimensions. Actually computing that motion (square root of the sum of the squares of the velocities in km/s) requires knowledge of the distance, which can be computed using the parallax.

*Parallax* is the angular change in position a closer star would have against very distant background stars across the radius of Earth’s orbit. (To see this, hold up a finger at arm’s length and alternately close your eyes. Your finger seems to move against objects in the background, by twice the parallax angle [since your eyes are separated by twice their separation from your nose, equivalent to two radii]. Visit [http://pumas.jpl.nasa.gov](http://pumas.jpl.nasa.gov/) for a lesson on parallax [Edberg, 2005].)

To convert parallax in milliarcseconds [mas] to distance, first multiply mas by 1000 to get the parallax in seconds of arc [as]. The distance in the units of parsecs [pc, parallax seconds] is the reciprocal of the parallax in [as]:

distance = 1/(parallax [as]). (8)

A parsec is 3.261631 light years and a light year is 9.460536x1015 m (Bishop, 2007).

Simple trigonometry can now be used to convert the proper motions in [mas/yr] to (fractions of) [lightyears/year], and then to [km/s].

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The star and constellation charts were generated by TheSky6 © Software Bisque, Inc. All rights reserved. [www.bisque.com](http://www.bisque.com/).

The star charts were prepared using *TheSky6* and the proper motion charts were prepared with *Starry Nights Pro* Ver. 3.

The proper motion star chart graphics are courtesy of Starry Nights® Pro Version 3, Imaginova® Corp.

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**APPENDIX 1: Star Tables**

|  |  |
| --- | --- |
| *KEY TO THE STAR INFORMATION TABLES BELOW. THE TABLES ARE ALPHABETIZED BY CONSTELLATION.* |  |
| **CONSTELLATION** |   |
| **Star name** – Brief description or other designator  |   |
| **Radial velocity** km/s and uncertainty; negative sign indicates approach = blueshift. | **km/s**  |
| Proper motions *milliarcseconds/yr*: | **Motion on plane of the sky with sign indicating celestial direction: N-S (south is negative) is listed first followed by E-W (west is negative).** |
| **Parallax** milliarcseconds is one-half the angular change in position of a star seen against a background of more distant stars across the diameter of Earth’s orbit around the Sun. | **Can be converted to distance**  |
|  |  |
|  |  |
| **AQUILA** |   |
| **Altair** -- Variable Star of delta Sct type  |   |
| Proper motions *mas/yr* [error ellipse]: | **536.87 385.57**  |
| Radial velocity / Redshift / cz : | **km/s -26.1 [0.9]**  |
| parallax mas: | Not available |
|  |  |
| **AURIGA** |   |
| **Capella** -- Variable of RS CVn type  |   |
| Proper motions *mas/yr* [error ellipse]: | **75.52 -427.11**  |
| Radial velocity / Redshift / cz : | **km/s 30.2 [0.9]** |
| parallax mas: | **77.29 [0.89]**  |
|  |  |
| **Arcturus** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **-1093.43 -1999.43** |
| Radial velocity / Redshift / cz : | **km/s -5.2 [0.9]**  |
| parallax mas: | **88.85 [0.74]**  |
|  |  |
| **CANIS MINOR** |   |
| **Procyon** -- Spectroscopic binary  |   |
| Proper motions *mas/yr* [error ellipse]: | **-716.58 -1034.6** |
| Radial velocity / Redshift / cz : | **km/s -3.2 [0.9]**  |
| parallax mas: | **285.93 [0.88]**  |
|  |  |
| **CANIS MAJOR** |   |
| **Sirius** -- Spectroscopic binary  |   |
| Proper motions *mas/yr* [error ellipse]: | **-546.05 -1223.14** |
| Radial velocity / Redshift / cz : | **km/s -7.6 [0.9]**  |
| parallax mas: | **285.93 [0.88]** |
|  |  |
|  |  |

|  |  |
| --- | --- |
| **CARINA** |   |
| **Canopus** -- Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **19.99 23.67**  |
| Radial velocity / Redshift / cz : | **km/s 20.5 [0.9]**  |
| parallax mas: | **10.43 [0.53]**  |
|  |  |
| **CENTARUS** |   |
| **Alpha Centauri** -- Double or multiple star  |   |
| Proper motions *mas/yr* [error ellipse]: | **-3608 686**  |
| Radial velocity / Redshift / cz : | **km/s -22.3 [0.9]**  |
| parallax mas: | **742** |
|  |  |
| **CENTARUS**  |   |
| **Beta Centauri** -- Variable Star of beta Cep type  |   |
| Proper motions *mas/yr* [error ellipse]: | **-33.96 -25.06** |
| Radial velocity / Redshift / cz : | **km/s 5.9 [5]**  |
| parallax mas: | **6.21 [0.56]**  |
|  |  |
| **CRUX** |   |
| **Acrux** -- Spectroscopic binary  |   |
| Proper motions *mas/yr* [error ellipse]: | **-35.3 -12** |
| Radial velocity / Redshift / cz : | **km/s -11.2 [2]**  |
| parallax mas: | Not available |
|  |  |
| **CRUX**  |   |
| **Mimosa = Beta Cru** -- Variable Star of beta Cep type  |   |
| Proper motions *mas/yr* [error ellipse]: | **-48.24 -12.82** |
| Radial velocity / Redshift / cz : | **km/s 15.6 [0.9]**  |
| parallax mas: | **9.25 [0.61]**  |
|  |  |
| **CRUX** |   |
| **Gamma Crucis** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **27.94 -264.33**  |
| Radial velocity / Redshift / cz : | **km/s 21.4 [0.9]** |
| parallax mas: | **37.09 [0.67]**  |
|  |  |
| **CYGNUS** |   |
| **Deneb -- Alpha Cyg** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **1.56 1.55**  |
| Radial velocity / Redshift / cz : | **km/s -4.5 [0.9]**  |
| parallax mas: | **1.01 [0.57]**  |
|  |  |
| **ERIDANUS** |   |
| **Achernar** -- Be Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **88.02 -40.08**  |
| Radial velocity / Redshift / cz : | **km/s 16 [5]**  |
| parallax mas: | **22.68** |

|  |  |
| --- | --- |
|   |  |
| **GEMINI** |   |
| **Castor -- LTT 12038** -- High proper-motion Star  |   |
| Proper motions *mas/yr*: | **-354.51** |
| Radial velocity / Redshift / cz: | Not available |
| parallax mas: | **63.27** |
|  |  |
| **GEMINI** |   |
| **Pollux** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **-625.69 -45.96** |
| Radial velocity / Redshift / cz : | **km/s 3.3 [0.9]**  |
| parallax mas: | **96.74** |
|  |  |
| **LEO** |   |
| **Regulus** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **-249.40 4.91**  |
| Radial velocity / Redshift / cz : | **km/s 5.9 [2]** |
| parallax mas: | **42.09 [0.79]**  |
|  |  |
| **LYRA** |   |
| **Vega -- Alpha Lyr** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **201.03 287.47**  |
| Radial velocity / Redshift / cz : | **km/s -13.9 [0.9]** |
| parallax mas: | **128.93 [0.55]**  |
|  |  |
| **ORION** |   |
| **Betelgeuse --V\* alf Ori** -- Semi-regular pulsating Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **27.33 10.86**  |
| Radial velocity / Redshift / cz : | **km/s 21.0 [0.9]** |
| parallax mas: | **7.63** |
|  |  |
| **ORION** |   |
| **Rigel** -- Emission-line Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **1.87 -0.56**  |
| Radial velocity / Redshift / cz : | **km/s 20.7 [0.9]**  |
| parallax mas: | **4.22** |
|  |  |
| **PISCIS AUSTRINUS** |   |
| **Fomalhaut** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **329.22 -164.21**  |
| Radial velocity / Redshift / cz : | **km/s 6.5 [0.9]** |
| parallax mas: | **130.08 [0.92]**  |
|  |  |
| **SCORPIUS** |   |
| **Antares -- Alpha Sco** -- Semi-regular pulsating Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **-10.16 -23.21** |
| Radial velocity / Redshift / cz : | **km/s -3.4 [0.9]**  |
| parallax mas: | **5.40 [1.68]**  |
|  |  |
| **TAURUS** |   |
| **Aldebaran -- Alpha Tau** -- Variable Star  |   |
| Proper motions *mas/yr* [error ellipse]: | **62.78 -189.35**  |
| Radial velocity / Redshift / cz : | **km/s 54.3 [0.9]** |
| parallax mas: | **50.09 [0.95]**  |
|  |  |
| **VIRGO** |   |
| **Spica -- 67 Vir** -- Variable Star of beta Cep type  |   |
| Proper motions *mas/yr* [error ellipse]: | **-42.50 -31.73 A**  |
| Radial velocity / Redshift / cz : | **km/s 1.0 [0.9]** |
| parallax mas: | **12.44 [0.86]**  |

**APPENDIX 2: Star and Constellation Charts**

The following collection of charts is designed to make it easy find and identify bright stars. In the charts, prominent and/or well-known stars or groups of stars, constellations, or super-constellations are used to point to other prominent stars. If desired, once a prominent star is found, other charts can be used to identify other stars in a constellation until the full constellation is recognized.

These charts are useful over large areas of Earth’s northern and southern hemispheres. They place a significant fraction of a celestial hemisphere on a small, flat piece of paper. Use separations between recognized stars (especially those paired to make “pointers” to gauge the distance to the desired target star. In the northern hemisphere, April-June, the ***BIG DIPPER*** asterism (part of the constellation **URSA MAJOR**) visible high in the north is particularly good for learning the sky. **ORION** is good from November-January in the southern hemisphere and January-March in the northern hemisphere. Though the charts are labeled to indicate a hemisphere, many of the stars will be visible from the opposing hemisphere, depending on your latitude.

As a general rule, facing south is best but some neck-craning (and/or facing a different direction and rotating the chart) will be necessary to go from the starting point to the target stars at the ends of the arrows. The font convention for the charts is that **CONSTELLATIONS** are fully capitalized and Star Names are larger and first-letter capitalized. Celestial North and West refer to the direction to those points on the horizon as seen on the sky. (In other words, east and west on the sky and on the charts are reversed compared to maps of features on Earth.) Most important: Pick something familiar and go from there.

At night, some observers find it is easier to use printed star charts with black stars on a white background rather than white stars on a black background. Black on white saves copier toner as well. The charts can be copied from this document and easily reversed with your image viewing and manipulation software if desired.

These star charts were generated by TheSky6 © Software Bisque, Inc. All rights reserved. [www.bisque.com](http://www.bisque.com/).













**Appendix 3: Proper Motion Charts**

The following collection of charts shows the proper motions, i.e., the motions on the plane of the sky of naked-eye stars. They are divided among four quarters of the year and both celestial hemispheres, as the star and constellation finder charts are. Only Star Names are shown. Celestial North and West refer to the direction to those points on the horizon as seen on the sky. (In other words, east and west on the sky and on the charts are reversed compared to maps of features on Earth.) Remember, though, that the compass rose would change orientation across the chart since a large area of the curved sky is being reproduced on flat paper.

In these charts, only the prominent stars are called out. The call-outs of named stars are in similar positions with respect to the stars on the finder charts and on the proper motion charts. Both charts can be used together to locate stars on the proper motion charts when necessary.

Proper motions are indicated on the charts with line segments. The length of the line is an indication of the speed of the star across the sky. It’s orientation shows the direction of overall motion.

The proper motions indicated are not limited to the brightest stars. The pattern of line segments comes from both the stars discussed in this activity and from numerous other stars visible to the naked eye on a dark, clear night. Looking at the charts, one’s eyes will be drawn to the named stars and to the longest lines. Very often these are not paired together, hinting at discoveries to be made from the companion activity **Studies of a Population of Stars: How Bright Are the Stars, Really?**

These graphics are courtesy of Starry Nights® Pro Version 3, Imaginova® Corp.

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