**Document ID**:

**Date Received**: **Date Revised**: **Date Accepted**:

**Curriculum Topic Benchmarks**: S3.3.1, S3.4.3, S15.4.4, M6.4.4, M6.4.9, M8.4.20, M8.4.22

**Grade Level**: 9-12

**Subject Keywords**: star, brightness, magnitude, distance

**Rating**:

**Studies of a Population of Stars:**

**How Bright Are the Stars, Really?**

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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 note some differences, make some eye-opening calculations, and gain a greater appreciation of the universe around them.

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 in PUMAS 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 to bright stars are calculated. The *apparent* brightness of these stars is then adjusted for distance to see which stars are intrinsically bright and which only appear bright because of their proximity to Earth.

**APPARATUS:**

1. **Computer spreadsheet** or **scientific calculator** for each student, or 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 star chart should be chosen based on the time of year and your hemisphere. Even though not all the stars will be visible, copy and distribute all of the stellar data tables included with this activity in Appendix 1. 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 calculations below are in [brackets]. Explanations of the terminology in the activities are 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 answers are that for the tiny angles being discussed, the small angle approximation is applicable and treating the calculations as plane geometry will not reduce accuracy 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 these stars in the sky – are they found in all directions or more common in some preferred direction(s)?
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. A parsec is 3.261631 light years and a light year is 9.460536x1015 m (Bishop, 2007):

1 [pc] = 3.262 [ly] (2)

1. **Compare the apparent brightnesses of stars** in relative units by comparing their magnitudes. How much brighter does the Sun look than Sirius? This and similar questions can be answered with

(b1/b2) = (2.512)m2-m1 (3)

where b1 and b2 are the apparent brightnesses of the two stars to be compared (only their ratio, b1/b2, can actually be determined) and m1 and m2 are V or B fluxes from the table.

 This equation can also be used to determine the ratio of a star’s brightness in the two color bands, V/B, by substituting B-V for m2-m1. Which stars on the list have the greatest and least flux differences?

Compare V/B or B-V with the observed colors of the stars. In the night sky, which stars show the greatest color?

Plot the stars’ distances on the x-axis and their V magnitudes on the y-axis. Notice that with the exception of the Sun, all the stars have similar magnitudes (they were chosen because they are among the brightest in the sky) but one is much more distant (and the Sun is very bright and very close). Also plot absolute V magnitude vs. distance and notice how the more distant stars are also tend to be brighter (emphasize this is not cause-effect, however).

1. **Compare the true brightnesses of stars** in relative units by comparing their magnitudes and distances. The true brightness, called the absolute magnitude, is determined with

MV = V – 5log10d + 5 or (4a)

MB = B – 5log10d + 5 (4b)

The formulas scale each star to the same distance, 10 parsecs, and retain the magnitude unit for comparison. (Note: Dust between stars can reduce the apparent brightness of a star, and if no correction is made, its absolute magnitude will be incorrect. The effect is negligible for this activity.) How bright is the Sun compared to these stars? How bright is Sirius, visually the brightest star in the sky, compared to some of the others? Use equation (3) for these comparisons.

**Plot the stars on a color-magnitude diagram** (use the chart in Appendix 3). The stars in the tables here can be plotted on a derivative of the original Hertzsprung-Russell diagram, named for astronomers Ejnar Hertzsprung and H. N. Russell, who first independently prepared plots of absolute magnitude vs. spectral type. The horizontal axis should be (B-V), color, substituted for spectral type. The vertical axis is absolute magnitude (true brightness). The stars plotted will generally fall on the upper portion of the diagram.

**Extension:**  Plot the stars’ distances on the x-axis and their magnitudes on the y-axis. Notice that the stars’ absolute magnitudes pretty smoothly cover a wide range and the brightest one is also the most distant (while the Sun is faintest and closest). Compare this plot with the magnitude vs. distance plot prepared in no. 3 above.

Now introduce logarithms. Make two other plots by computing log10(distance) and either plotting on cartesian graph paper or plotting the distance on semi-log paper. Distance is again on the x-axis with V magnitude and absolute V magnitude on the y-axes. The scattered V magnitudes settle down into a fairly tight line on the absolute magnitude plot: this demonstrates the logarithmic nature of the magnitude system. Additional thought leads to the conclusions that (1) the brighter stars seen in the sky tend to be intrinsically brighter and more distant and (2) that brighter stars are much rarer, per unit volume, than fainter stars.

**THE UNDERLYING PRINCIPLES:**

A fundamental question about stars in the sky is:

How bright are they?

This question, both in appearance and in reality, can be answered with the data table for each star in the collection.

Bright stars are bright enough to trigger the color receptors in our eyes. While stars are often described as red or blue, the words usually exaggerate what is really a range of tints that run from pale orange through yellow and white to pale blue. These colors, though, indicate surface temperatures that range from less than 3000K to over 100,000K, a component of star classification by spectral type. Spectral type also indicates the evolutionary state of a star. Stars with the same color can be youthful dwarfs (= on the “Main Sequence”) or evolved giants approaching the ends of their lives.

A star’s surface temperature can be estimated based on its brightness (flux) in two or more color bands. Determining the surface temperature requires the (usually good) assumption that the star’s emission follows the distinctive shape of the blackbody curve. The ratio of brightness in two color bands varies with temperature. (As mentioned earlier, interstellar dust can confound this generalization by reddening starlight.)

[Reminder: A blackbody perfectly absorbs and emits all wavelengths of electromagnetic radiation. The spectrum of a blackbody, that is, a plot of intensity vs. wavelength (or frequency), has a distinctive “hump” shape: at short wavelengths intensity rises rapidly to a peak before more slowly dropping down again towards longer wavelengths. The height and wavelength of the peak change with temperature. For additional background, the basic properties of a blackbody are explained in most encyclopedias and introductory physics texts.]

Since time immemorial, the brightness of stars has been estimated by observers using their eyes. This led to a system that is sometimes mystifying and inconvenient. Brighter objects in the sky have *lower* values, including negative values in the system called “magnitude”. The Sun has a magnitude of -26.8, the full moon is magnitude -12.7, the brightest star, Sirius, is about -1.4, the faintest star visible with the unaided eye is about +6, and the faintest objects recorded by the Hubble Space Telescope are about +29.5.

Every difference of one magnitude corresponds to a difference in brightness by a factor of 2.512 (the fifth root of 100; a result of the way our eye-brain combination works and the creation, in the 19th century, of a standardized definition of stellar magnitude). The difference in brightness between an average bright star in this collection (mag. 1) and the naked eye limit (mag. 6) is 2.512(6-1) = 2.512(5) ≈ 100.

Astronomers now measure stellar brightness with standard color filters to enable the determination of characteristics like temperature. Filters designated B (blue) and V (visual) were used to determine the brightness of all the stars in the table.

**DISCUSSION:**

The stars included in this activity are among the visually 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 near the celestial equator 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 schedule of your syllabus. October through June (convenient for a typical school year in the northern hemisphere) offers a greater variety of star types (see “Spectral type” in the Appendix 1 tables and explained below), which will make the results more interesting.

**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 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. Examples will be found of close bright stars actually being greatly outshone by more distant stars that appear somewhat fainter. 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.

*Parallax* is one-half the angular change in position a closer star would have measured against very distant background stars across the diameter 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 a radius]. See Edberg (2005) at [http://pumas.jpl.nasa.gov](http://pumas.jpl.nasa.gov/) for an activity on parallax.)

*Spectral type* indicates the surface temperature and size of a star. The temperatures range from high to low as the sequence O, B, A, F, G, K, M is followed. Supergiant stars are indicated by I, Bright Giants by II, Giants by III, Subgiants by IV, and Dwarfs (= “main sequence” stars) by V. The “main sequence” is the collection of stars that are quietly “burning” their core hydrogen into helium; the main sequence is where a star spends the bulk of its life when nuclear reactions are taking place. Stars off the main sequence (subgiants and larger) are expanding or have already expanded due to changes in where their nuclear burning is occurring or in what elements are being burned. These evolutionary changes do not have a long duration compared to the duration of the main sequence phase of a star’s life.

There are no white dwarfs in this collection of stars (though some of the stars listed are binaries, with white dwarf companions visible in a telescope). White dwarfs persist for durations much longer than the main sequence stage. They are just too faint to be seen with the unaided eye at their distances from Earth. (Astronomers use “dwarfs”, not “dwarves”, in their usage. I don’t know why.)

The stars in this lesson are bright enough that you can see their colors, which indicate their temperatures: pairs for comparison are (cooler, then hotter) salmon-orange Betelgeuse and electric blue Rigel (both in ORION), Arcturus (BOOTES) and Spica (VIRGO), Antares (SCORPIUS) and Altair (AQUILA), Aldebaran (TAURUS) and Fomalhaut (PISCIS AUSTRINUS), and Alpha Centauri and Beta Centauri (both in CENTAURUS). Other letters and symbols with spectral type indicate other properties of the star.

*Flux* is an indication of the luminosity of the star, in this case, as measured from Earth with no account of the difference in distances of the stars or any dust that might be between Earth and the star. Flux in the V (visual) filter closely matches the eye’s response. The other flux given is in B (blue filter). The numbers are in “magnitudes”, the system astronomers use to measure brightness. Brighter stars have lower, sometimes even negative, magnitudes and fainter stars have larger positive magnitudes. Stars range from bright magnitude -1.5 (Sirius) through 0, 1.5, 2.5 ... 5.5, 6.5 (approximate unaided eye limit) ... to very faint +29 (near the detection limits of the Hubble Space Telescope and the Keck Telescopes on Mauna Kea, Hawaii) and beyond.

The temperatures of stars can be gauged by comparing the B and V fluxes. If B-V>0 the star is cooler than a white star (B-V=0, “surface” temperature about 10000K) and has a reddish tint. If a star has B-V<0 it indicates the star is warmer than a white star and has a bluish tint. The colors of some stars (not in the group used in this activity) are reddened by large amounts of dust between Earth and the stars.

The true luminosity of stars can be calculated using the inverse square law and the distances computed from the parallaxes. Stars like Deneb, Rigel, and Betelgeuse are enormously brighter than some other stars on the list, if they are compared at the same distance.

Students may find it interesting to compare their luminosity results with the proper motions discussed in **Studies of a Population of Stars: Distances and Motions**.

**REFERENCES:**

Bishop, R., 2008, “Some Astronomical and Physical Data” in *Observer’s Handbook 2008***,** P. Kelly, ed., Royal Astronomical Society of Canada, Toronto.

Edberg, S. J., 2005, “When A Ruler Is Too Short,” *Practical Uses of Math and Science*, an on-line refereed journal at [http://pumas.jpl.nasa.gov](http://pumas.jpl.nasa.gov/) , accepted 2005 August 25.

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**ACKNOWLEDGMENTS:**

This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France, <http://simbad.u-strasbg.fr/simbad/> .

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

The color-magnitude diagram is from Wikipedia, <http://en.wikipedia.org/wiki/Main_sequence> , where a color version may be found.

This publication was prepared by the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration.

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**APPENDIX 1: Star Tables**

|  |
| --- |
| ***Key to the star information tables below. The tables are alphabetized by constellation. Solar data are from Bishop, R., 2008, “Some Astronomical and Physical Data” in Observer’s Handbook 2008, P. Kelly, ed. and other sources. Star data are from the SIMBAD database, operated at CDS, Strasbourg, France, http://simbad.u-strasbg.fr/simbad/ .*** |
| **CONSTELLATION** |  |
| **Star name** – Brief description or other designator  |   |
| Parallax *milliarcseconds* [mas]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**  |
| Spectral type: Star surface temperature is indicated with a letter designation (O, B, A, F, G, K, M, L, & T, very hot to cool) with a number (0-9) that subdivides the letter groups. A Roman numeral (Ia or b, II, III, IV, V) indicates supergiant, bright giant, giant, subgiant, or main sequence, respectively. Classes !-IV have evolved off of the main sequence (V). | **Indicates temperature and evolutionary state** |
| Fluxes (2) in [magnitude]: indicate brightness in various filters (**B**lue, **V**isual). Larger positive numbers mean fainter (astronomical magnitude system). | **B**  |
|   | **V** |
|  |  |
| **ECLIPTIC CONSTELLATIONS** |  |
| **Sun** |  |
| parallax mas: | **8794.143** |
| Spectral type: | **G2V**  |
| Fluxes: | **B -26.10**   |
|   | **V -26.75** |
|  |  |
|  |  |
| **AQUILA** |   |
| **Altair** -- Variable Star of delta Sct type  |   |
| parallax mas: | Not available |
| Spectral type: | **A7V**  |
| Fluxes: | **B 0.99**   |
|   | **V 0.77**   |
|  |  |
| **AURIGA** |   |
| **Capella** -- Variable of RS CVn type  |   |
| parallax mas: | **77.29 [0.89]**  |
| Spectral type: | **G5IIIe+...**  |
| Fluxes: | **B 0.88**   |
|   | **V 0.08**  |
|  |  |
| **BOOTES** |   |
| **Arcturus** -- Variable Star  |   |
| parallax mas: | **88.85 [0.74]**  |
| Spectral type: | **K1.5III**  |
| Fluxes: | **B 1.19**   |
|   | **V -0.04**  |
|  |  |
| **CANIS MINOR** |   |
| **Procyon** -- Spectroscopic binary  |   |
| parallax mas: | **285.93 [0.88]**  |
| Spectral type: | **F5IV-V**  |
| Fluxes: | **B 0.74**   |
|   | **V 0.34**   |
|  |  |
| **CANIS MAJOR** |   |
| **Sirius** -- Spectroscopic binary  |   |
| parallax mas: | **379.21** |
| Spectral type: | **A1V**  |
| Fluxes: | **B -1.46**   |
|   | **V -1.47**  |
|  |  |
| **CARINA** |   |
| **Canopus** -- Star  |   |
| parallax mas: | **10.43 [0.53]**  |
| Spectral type: | **F0II**  |
| Fluxes: | **B -0.57**  |
|   | **V -0.72**  |
|  |  |
| **CENTAURUS** |   |
| **Alpha Centauri** -- Double or multiple star  |   |
| parallax mas: | **742** |
| Spectral type: | **G+...**  |
| Fluxes: | **B 0.4**  |
|   | **V -0.1**  |
|  |  |
| **CENTAURUS**  |   |
| **Beta Centauri** -- Variable Star of beta Cep type  |   |
| parallax mas: | **6.21 [0.56]**  |
| Spectral type: | **B1III**  |
| Fluxes: | **B 0.38**  |
|   | **V 0.60**  |
|  |  |
| **CRUX** |   |
| **Acrux** -- Spectroscopic binary  |   |
| parallax mas: | Not available |
| Spectral type: | **B0.5IV**  |
| Fluxes: | **B 1.32**  |
|   | **V 1.4**  |
|  |  |
| **CRUX**  |   |
| **Mimosa = Beta Cru** -- Variable Star of beta Cep type  |   |
| parallax mas: | **9.25 [0.61]**  |
| Spectral type: | **B0.5IV**  |
| Fluxes: | **B 1.145**  |
|   | **V 1.297**  |
|  |  |
|  |  |
| **CRUX** |   |
| **Gamma Crucis** -- Variable Star  |   |
| parallax mas: | **37.09 [0.67]**  |
| Spectral type: | **M3.5III**  |
| Fluxes: | **B 3.22**  |
|   | **V 1.63** |
|  |  |
| **CYGNUS** |   |
| **Deneb -- Alpha Cyg** -- Variable Star  |   |
| parallax mas: | **1.01 [0.57]**  |
| Spectral type: | **A2Iae**  |
| Fluxes: | **B 1.34**   |
|   | **V 1.25**   |
|  |  |
| **ERIDANUS** |   |
| **Achernar** -- Be Star  |   |
| parallax mas: | **22.68** |
| Spectral type: | **B3Ve**  |
| Fluxes: | **B 0.30 [~] C** ~ |
|   | **V 0.50 [~] C** ~ |
|   |  |
| **GEMINI** |   |
| **Castor -- LTT 12038** -- High proper-motion Star  |   |
| parallax mas: | **63.27** |
| Spectral type: | **A2Vm**  |
| Fluxes: | **B 1.63**   |
|   | **V 1.59**  |
|  |  |
| **GEMINI** |   |
| **Pollux** -- Variable Star  |   |
| parallax mas: | **96.74** |
| Spectral type: | **K0IIIb**  |
| Fluxes: | **B 2.15**   |
|   | **V 1.15**   |
|  |  |
| **LEO** |   |
| **Regulus** -- Variable Star  |   |
| parallax mas: | **42.09 [0.79]**  |
| Spectral type: | **B7V**  |
| Fluxes: | **B 1.24**   |
|   | **V 1.35**   |
|  |  |
| **LYRA** |   |
| **Vega -- Alpha Lyr** -- Variable Star  |   |
| parallax mas: | **128.93 [0.55]**  |
| Spectral type: | **A0V**  |
| Fluxes: | **B 0.03**   |
|   | **V 0.03**  |
|  |  |
|  |  |
| **ORION** |   |
| **Betelgeuse --V\* alf Ori** -- Semi-regular pulsating Star  |   |
| parallax mas: | **7.63** |
| Spectral type: | **M2Iab:**  |
| Fluxes: | **B 2.35**   |
|   | **V 0.58**  |
|  |  |
| **ORION** |   |
| **Rigel** -- Emission-line Star  |   |
| parallax mas: | **4.22** |
| Spectral type: | **B8Iab:**  |
| Fluxes: | **B 0.09**   |
|   | **V 0.12**   |
|  |  |
| **PISCIS AUSTRINUS** |   |
| **Fomalhaut** -- Variable Star  |   |
| parallax mas: | **130.08 [0.92]**  |
| Spectral type: | **A3V**  |
| Fluxes: | **B 1.25**   |
|   | **V 1.16**  |
|  |  |
| **SCORPIUS** |   |
| **Antares -- Alpha Sco** -- Semi-regular pulsating Star  |   |
| parallax mas: | **5.40 [1.68]**  |
| Spectral type: | **M1.5Iab-b**  |
| Fluxes: | **B 2.96**   |
|   | **V 1.09**  |
|  |  |
| **TAURUS** |   |
| **Aldebaran -- Alpha Tau** -- Variable Star  |   |
| parallax mas: | **50.09 [0.95]**  |
| Spectral type: | **K5III**  |
| Fluxes: | **B 2.39**   |
|   | **V 0.85**  |
|  |  |
| **VIRGO** |   |
| **Spica -- 67 Vir** -- Variable Star of beta Cep type  |   |
| parallax mas: | **12.44 [0.86]**  |
| Spectral type: | **B1III-IV+...**  |
| Fluxes: | **B 0.91**   |
|   | **V 1.04**   |

**APPENDIX 2: Star and Constellation Charts**

The following collection of charts is designed to make it easy to 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 a familiar group of stars, recognizable on a chart, and “star hop” 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.

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**APPENDIX 3: Color-Magnitude Diagram**



Diagram from Wikipedia: *Main Sequence*, created

by Looxix. A color version is also available.