Document ID: 03_05_10_3
Date Received: 2010-03-05 **Date Revised**: 2013-04-05 **Date Accepted**: 2013-04-06
Curriculum Topic Benchmarks: M1.3.9, M1.4.2, M5.3.12, M6.3.6, M8.3.2, M8.3.9, M8.4.22, S15.3.3
Grade Level: High School [9-12]
Subject Keywords: star, map, celestial coordinates, Milky Way
Rating: moderate

Studies of a Population of Stars: Mapping the Positions of Stars

By: Stephen J Edberg, Jet Propulsion Laboratory, California Institute of Technology, 4800 Oak Grove Drive, M/S 183-301, Pasadena CA 91011
e-mail: Stephen.J.Edberg@jpl.nasa.gov

From: The PUMAS Collection http://pumas.nasa.gov

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. Fortunately, the brightest stars visible offer 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 that these neighbor stars plotted on the appropriate map echo the construction of the whole Milky Way galaxy.

Students will first familiarize themselves with the brighter stars in the evening sky. At first glance, the stars' positions will appear random. Moving into the classroom, students will plot the positions of the stars in two different coordinate systems. A plot prepared using the stars' positions in the "equatorial" coordinate system (essentially an expansion of latitude and longitude into the sky) will initially seem to present the apparent randomness of the stars' positions. A more careful study might belie this impression, with the emergence of a sinusoid marked by stars on the plot. A second plot of the same stars using the "galactic" coordinate system (centered on the Milky Way's core and plane) will demonstrate that the positions of these stars are not random.

The universe is rich with interesting phenomena. Stars, alone, offer many opportunities for investigation. 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 (PUMAS Examples 03_05_10_1 "Distances and Motions," and 03_05_10_2 "How Bright Are the Stars, Really?").

OBJECTIVE: Make night sky observations and use available data and simple calculations to correlate observations with the characteristics of stars. In this activity, students can discover that the positions of stars in the sky reveal information about the Milky Way galaxy.

APPARATUS:

1) **Scientific calculator or computer spreadsheet** for each student, or small groups of students to share
2) **Data tables** (Appendix 1) supplied with this example
3) **Star charts** (Appendix 2) supplied with this example
4) **Graph paper** measuring 8.5”x11”. For Activity 2, cut the paper in half widthwise and tape it together to make a 5.5”x17” strip for plotting star positions using the equatorial system. This length is desirable if the map is to be rolled into a cylinder with the map on the inside, mimicking the appearance of the sky on the inside of a hemisphere. Students should start numbering the x-axis (along the 17” length) from the far *right to the left*, at 0 hours ($0^h = 0^\circ$), continuing in one hour (15 degree) intervals to 24 hours ($24^h = 360^\circ = 0^\circ$). Use the same map scale for the y-axis, running from top to bottom starting at +45˚ continuing down to -60˚. Note that the x-axis should be offset up from the middle of the paper strip since the declinations of the stars being plotted spans only +46˚ to -63˚ (Figure 1).

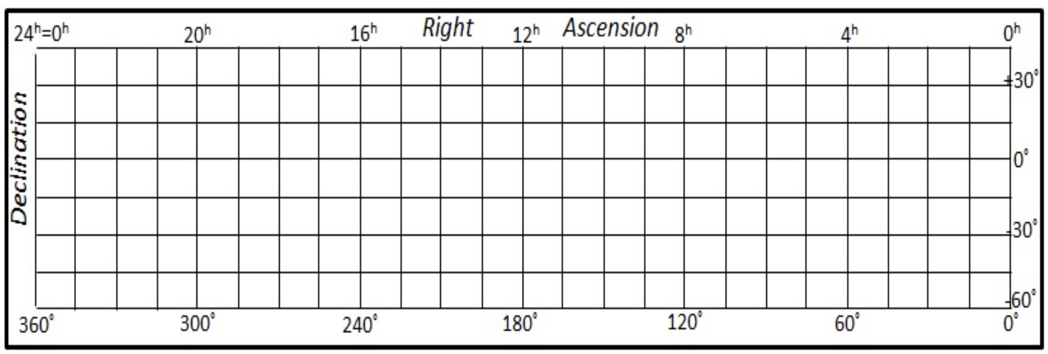


Fig. 1. The finished star-plotting chart for equatorial coordinates should look something like this. Finer spacing than the 1 hour = 15 degrees spacing illustrated will make accurate plotting easier.

For Activity 3, tape two sheets of graph paper together to construct a base for the map measuring 11”x17” for plotting star positions using galactic coordinates. Students should start numbering the x-axis from the middle of the chart (center of the Milky Way) from *right to left*, at 0˚, continuing in 10 degree intervals to the left margin at 180˚ and then continuing from the right margin toward the center from 180˚ to 360˚ = 0˚. Use the same map scale for the y-axis, running from the middle (galactic equator) to the top, 0˚ to +90˚ and from the middle to the bottom, 0˚ to -90˚ (Figure 2).

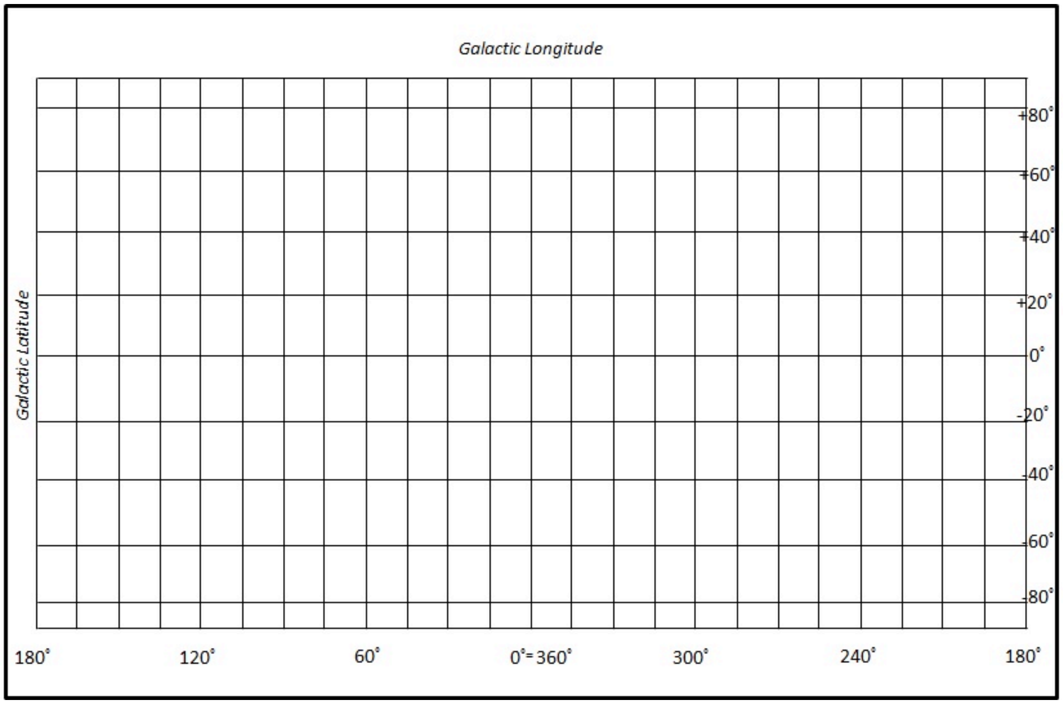


Fig. 2. The finished star-plotting chart for "galactic" coordinates should look something like this. Finer spacing than the 15-20 degree spacing illustrated will make accurate plotting easier.

ACTIVITIES:

Duplicate and distribute star charts (Appendix 2) and sets of star information (Appendix 1) to the students. One particular star chart from the set provided should be chosen based on the time of year and your hemisphere. The full set of stars should be analyzed even though not all will be visible at any particular time of year.

Measurement units in the activities below are in [brackets]. An explanation of the terminology in the activities is found in the DISCUSSION section below. The phrases in **bold** describe the instructional activity.

1. Students should spend an evening outdoors and **observe some of the stars** they will be analyzing with the data provided in Appendix 1. They should first relate the stars appearing within their star chart (pertaining to their time of year and hemisphere) to the stars listed in the data table (Appendix 1), to identify which subset of those stars will be visible in their nighttime sky (further help in DISCUSSION section). For this subset of stars, students should be encouraged to find them in the night sky and make note of their observed brightnesses, color differences (subtle but visible) and the distribution of these stars in the sky – are they found in all directions or more commonly in some preferred direction(s)?

2. **Use the equatorial coordinates to plot all the stars in this collection on graph paper showing their positions relative to the projection of Earth's equator in the sky.** It may help with visualization to make the chart into a cylinder (after

plotting) by taping right ascension (RA) $23^h59^m59^s$ to 0^h right ascension. To match the view of the sky, the map should be rolled so it is inside the cylinder.

For convenient plotting, if desired, right ascension can be converted to decimal degrees using equations (2a-c) in the DISCUSSION section or by multiplying hours [h] by 15, minutes [m] by ¼, and seconds [s] by 1/240 and summing.

Decimal degrees = [h of RA] x 15 + [m of RA] x 0.25 + [s of RA]/240 (1)

Is there any obvious grouping in bright star density on the sky? Even with the sparse distribution of bright stars on this map of the sky, a single wavelength sinusoidal pattern should be apparent. This display marks the plane of the Milky Way, as presented in equatorial coordinates. The next activity will make this obvious.

3. **Use the galactic coordinates to plot all the stars in this collection on graph paper showing their positions relative to the equator of the Milky Way.** It may help with visualization to make the chart into a cylinder (after plotting) by taping galactic longitude 360° to 0°. Is there any increase in bright star density towards the plane of the Milky Way? Yes, though with so few stars the effect is not strong and map distortion affects the appearance.

   Extensions: (1) Ecliptic coordinates are commonly used in celestial mechanics to describe the orbits of the planets in the Solar System. The 0° plane used in this system is the plane of Earth's orbit. (The intersection of this plane on the sky is called the ecliptic.) By converting equatorial coordinates to ecliptic coordinates (matrix equations are presented in Wikipedia, for example), the stars can be plotted again. What is the angular offset between the plane of the ecliptic and the plane of the Milky Way? What are the implications regarding the formation of the Solar System?

   (2) Make a three dimensional plot or model by including the stars' distances from the Sun (cf. **Studies of a Population of Stars: Distances and Motions**, PUMAS Example 03_05_10_1). Making a scale model will be interesting but finding a scale that will present the full range of distances meaningfully and also fit in a comfortable working space will be challenging.

THE UNDERLYING PRINCIPLES:

One fundamental question about stars in the sky is:

Where are they in the sky?

This question can be answered with the data table for each star in the collection.

Astronomers use several coordinate systems for the convenience of analyzing and discussing data. Equatorial coordinates are based on the view from Earth. Right ascension and declination are essentially extensions of Earth's longitude and latitude, respectively, into the sky.

The celestial sphere can be mapped by extending Earth's rotation axis into the sky. Earth's north and south poles are directly under the celestial sphere's declination points at +90° and -90°, respectively. Earth's equator projected on the sky becomes the celestial equator, declination 0°. Declination circles extend from the equator to the poles, just as latitude circles do on globes of Earth.

Meridian circles run through the north and south poles perpendicular to the equator on globes of Earth and globes of the sky. For the celestial sphere, astronomers find it more convenient to specify Right Ascension, the equivalent of longitude on Earth, in hours, minutes, and seconds of time. The sky is divided into 24 wedges, each one hour in width, that pass over an observer every 24 hours of time (one day).

(Note that latitude and longitude are presented on the outer surface of Earth's sphere, whereas right ascension and declination are projected onto the interior surface of the celestial sphere. This can lead to confusion, especially since publishers of celestial globes have not settled on one way of presenting the sky on a globe.)

Galactic coordinates are designed to describe the positions of objects in the Milky Way galaxy, as seen from the Sun (Figure 3). The origin of the coordinate system is the Sun. The center of the Milky Way, in the constellation Sagittarius where the Milky Way's central black hole resides, marks the zero point for galactic longitude and the Milky Way's plane marks the zero point for galactic latitude. Note that both the equatorial and galactic coordinate systems are two dimensional, in the sense that positions are measured on the "plane" of the sky (which is actually a spherical surface) and distance from the origin is ignored.

Three-dimensional galactic coordinate systems specify a position in two coordinates and distance in a third, from the origin (Figure 4).

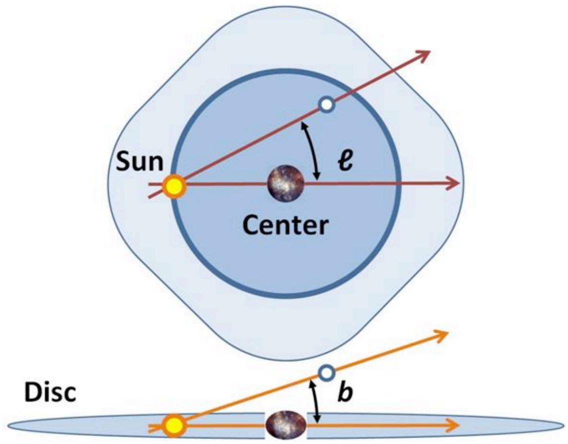


Fig. 3. The flat map in Figure 2 is based on the geometry presented here. The Milky Way can be described as a very flat (a few thousand light years), large diameter (100,000 light years) cylinder. Galactic coordinates use the Sun as their origin. The azimuthal angle, called galactic longitude (ℓ), is measured from the position of the galactic center as 0° and the altitude angle, called galactic latitude (*b*), is measured from the plane of the Milky Way. (Source: Wikimedia Commons)

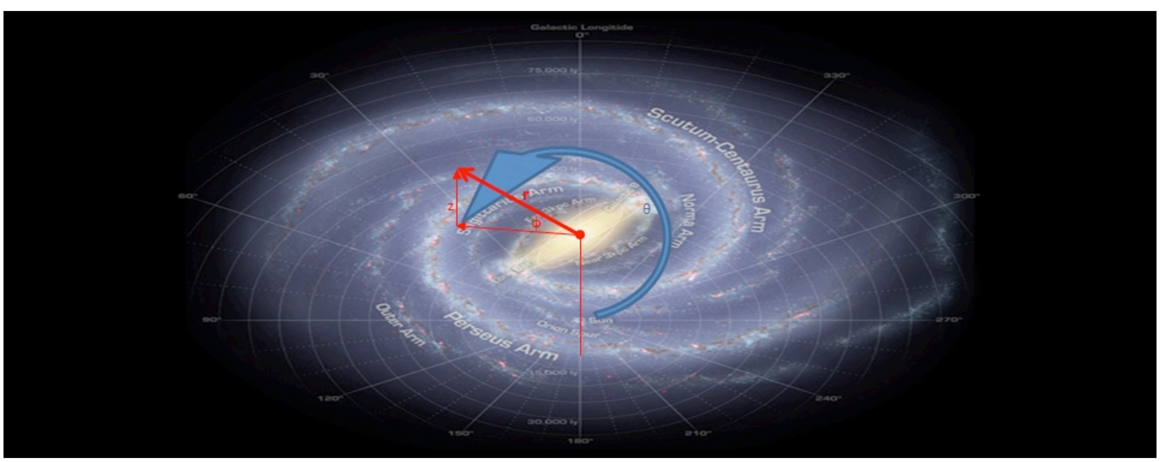


Fig. 4. A cylindrical (**r**, θ, z) or spherical (**r**, θ, φ) coordinate system centered on the Milky Way's nucleus is illustrated here, with the direction of the Sun from the core serving as the zero point for the azimuthal angle θ (blue). The position of an object anywhere around the Milky Way (the bold red arrow) can be specified with just three numbers. Alternatively, as presented on the original image, the galactic coordinate system (grey, only azimuthal angles (ℓ) illustrated) can be specified centered on the Sun, as has been used by the United Federation of Planets in the *Star Trek* television and movie series. This figure

has been distorted to more easily illustrate three dimensions. The original image, found at http://solarsystem.nasa.gov/multimedia/display.cfm?IM_ID=8083, shows the current best understanding of the layout of the Milky Way.

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!). 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. Choose the time of year for the students to observe but they will be using all the stars on the list for this activity. 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; examine the **equatorial** coordinates in the tables in Appendix 1, which are explained below.) 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.

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

Bright Evening Stars

CONSTELLATION-Hemisphere; Star Name

Jan.-Feb.-Mar.	**Apr.-May-June**	**July-Aug.-Sep.**	**Oct.-Nov.-Dec.**
AURIGA – N Capella	AURIGA – N Capella	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 – S Alpha Centauri	CYGNUS – N Deneb
CARINA – S Canopus	CARINA – S Canopus	CENTAURUS – S Beta Centauri	ERIDANUS – S Achernar
ERIDANUS – S Achernar	CENTAURUS – S Alpha Centauri	CRUX – S Acrux	LYRA – N Vega
GEMINI – N Castor	CENTAURUS – S Beta Centauri	CRUX – S Mimosa	PISCIS AUSTRINUS – S Fomalhaut
GEMINI – N Pollux	CRUX – S Acrux	CRUX – S Gacrux	TAURUS – N Aldebaran
ORION – Equator Betelgeuse	CRUX – S Mimosa	CYGNUS – N Deneb	
ORION – Equator Rigel	CRUX – S Gacrux	LYRA – N Vega	
TAURUS – N Aldebaran	GEMINI – N Castor	PISCIS AUSTRINUS – S Fomalhaut	
	GEMINI – N Pollux	SCORPIUS – S Antares	
	LEO – N Regulus		
	VIRGO – Equator Spica		

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 syllabus.

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. Students should put together their own naked eye observations of stars with the data supplied in the tables. Figure 5 illustrates a table entry and the text below describes the table entries. A glossary/summary table in the same format as the tables of stars is the first in Appendix 1.

Positions for the stars are given based on the *ICRS*, International Celestial Reference System of coordinates. The *equatorial coordinate* "Right Ascension" (RA) is the celestial equivalent of longitude on Earth, but is measured in hours, minutes, and seconds. If desired, it can be converted to degrees by first converting to decimal hours, dividing by 24, and multiplying by 360:

$$[\text{decimal hours}] = \text{hours} + (\text{minutes}/60) + (\text{seconds}/3600) \quad (2a)$$
$$[\text{decimal days}] = (\text{decimal hours}/24) \quad (2b)$$
$$[\text{degrees of RA}] = (\text{decimal days}) \times 360 \quad (2c)$$

The *equatorial coordinate* Declination is the celestial equivalent of latitude on Earth, south indicated by a minus sign.

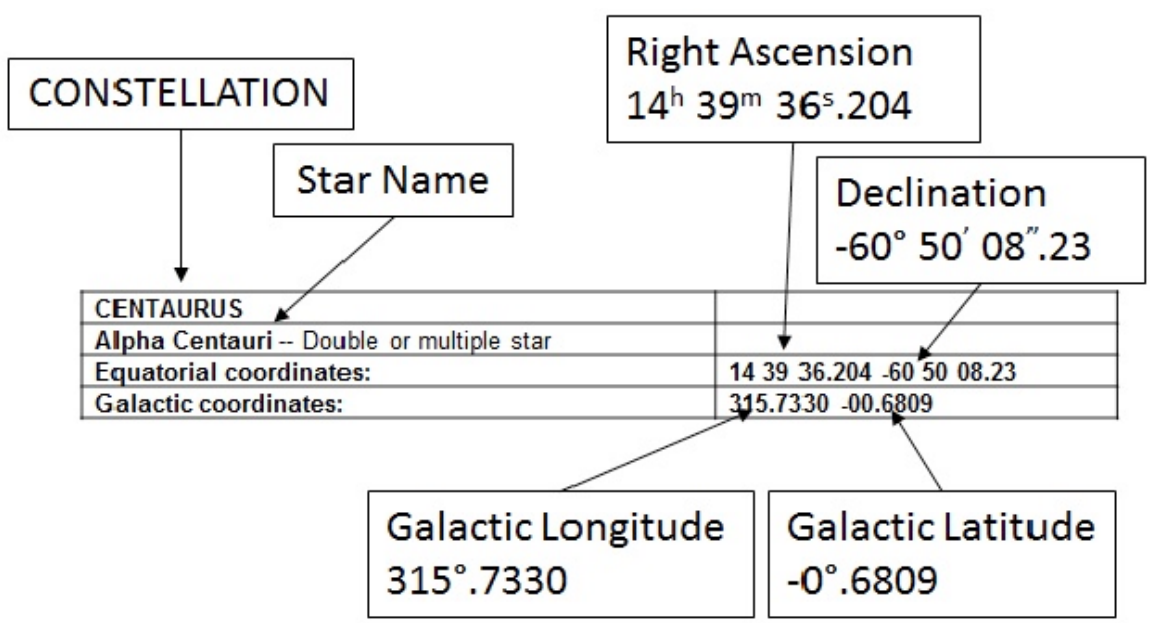


Fig. 5. This is an example of the entries made for stars in Appendix 1.

Galactic coordinates use the Milky Way center, as seen from Earth, as the origin, with position measured "around" the Milky Way and "above" (north of) or "below" (south of) the plane of the Milky Way. These coordinates are somewhat similar to the system used in *Star Trek*, which might be pedagogically helpful to mention.

FOR MORE INFORMATION:

Kelly, P., 2007, *Observer's Handbook 2008*, Toronto: Royal Astronomical Society of Canada.

Starry Nights Pro. (Ver. 3, 1997 was used; Ver. 6 is now available) [Computer software]. New York, New York: Imaginova.

TheSky6 Professional Edition Version 6 for Windows. (2004). [Computer software]. Golden, Colorado: Software Bisque.

ACKNOWLEDGMENTS:

I am grateful to Dr. Larry Lebofsky, two anonymous reviewers, and PUMAS Editor Dr. Ralph Kahn for many fine edits and advice that improved the clarity and completeness of the discussions in this activity.

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

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

APPENDIX 1: Star Table

Key to the star information tables below. The tables are alphabetized by constellation. Star data are from the SIMBAD database, operated at CDS, Strasbourg, France, http://simbad.u-strasbg.fr/simbad/.

CONSTELLATION name	
Star name -- Brief description or other designator	
Equatorial coordinates:	Right Ascension, similar to longitude on Earth, is measured in hours/minutes/seconds *hh mm ss.ssss*. Declination, similar to latitude on Earth, is measured in (sign)degrees minutes, seconds <u>+</u>*dd mm ss.sss* where a "-" sign indicates south.
Galactic coordinates:	Galactic longitude is measured towards celestial east from the center of the Milky Way in Sagittarius; measured in degrees.decimals, *ddd.dddd*. Galactic latitude is measured north or south (south is negative) from the plane of the Milky Way in (sign)degrees.decimals <u>+</u>*dd.dddd*

AQUILA	
Altair -- Variable Star of delta Sct type	
Equatorial coordinates:	**19 50 46.9990 +08 52 05.959**
Galactic coordinates:	**047.7441 -08.9092**

AURIGA	
Capella -- Variable of RS CVn type	
Equatorial coordinates:	**05 16 41.3591 +45 59 52.768**
Galactic coordinates:	**162.5885 +04.5664**

BOOTES	
Arcturus -- Variable Star	
Equatorial coordinates:	**14 15 39.6720 +19 10 56.677**
Galactic coordinates:	**015.0501 +69.1113**

CANIS MINOR	
Procyon -- Spectroscopic binary	
Equatorial coordinates:	**07 39 18.1183 +05 13 29.975**
Galactic coordinates:	**213.7022 +13.0194**

CANIS MAJOR	
Sirius -- Spectroscopic binary	
Equatorial coordinates:	**06 45 08.9173 -16 42 58.017**
Galactic coordinates:	**227.2303 -08.8903**

CARINA	
Canopus -- Star	
Equatorial coordinates:	**06 23 57.1099 -52 41 44.378**
Galactic coordinates:	**261.2121 -25.2922**

CENTAURUS	
Alpha Centauri -- Double or multiple star	
Equatorial coordinates:	**14 39 36.204 -60 50 08.23**
Galactic coordinates:	**315.7330 -00.6809**

CENTAURUS	
Beta Centauri -- Variable Star of beta Cep type	
Equatorial coordinates:	**14 03 49.4045 -60 22 22.942**
Galactic coordinates:	**311.7670 +01.2511**

CRUX	
Acrux -- Spectroscopic binary	
Equatorial coordinates:	**12 26 35.871 -63 05 56.58**
Galactic coordinates:	**300.1265 -00.3627**

CRUX	
Mimosa = Beta Cru -- Variable Star of beta Cep type	
Equatorial coordinates:	**12 47 43.2631 -59 41 19.549**
Galactic coordinates:	**302.4622 +03.1796**

CRUX	
Gamma Crucis -- Variable Star	
Equatorial coordinates:	**12 31 09.9593 -57 06 47.562**
Galactic coordinates:	**300.1692 +05.6498**

CYGNUS	
Deneb -- Alpha Cyg -- Variable Star	
Equatorial coordinates:	**20 41 25.9147 +45 16 49.217**
Galactic coordinates:	**084.2847 +01.9975**

ERIDANUS	
Achernar -- Be Star	
Equatorial coordinates:	**01 37 42.8466 -57 14 12.327**
Galactic coordinates:	**290.8412 -58.7920**

GEMINI	
Castor -- LTT 12038 -- High proper-motion Star	
Equatorial coordinates:	**07 34 35.8628 +31 53 17.795**
Galactic coordinates:	**187.4410 +22.4792**

GEMINI	
Pollux -- Variable Star	
Equatorial coordinates:	**07 45 18.9503 +28 01 34.315**
Galactic coordinates:	**192.2293 +23.4063**

LEO	
Regulus -- Variable Star	
Equatorial coordinates:	**10 08 22.3107 +11 58 01.945**
Galactic coordinates:	**226.4273 +48.9342**

LYRA	
Vega -- Alpha Lyr -- Variable Star	
Equatorial coordinates:	**18 36 56.3364 +38 47 01.291**
Galactic coordinates:	**067.4482 +19.2373**

ORION	
Betelgeuse --V* alf Ori -- Semi-regular pulsating Star	
Equatorial coordinates:	**05 55 10.3053 +07 24 25.426**
Galactic coordinates:	**199.7872 -08.9586**

ORION	
RIGEL -- Emission-line Star	
Equatorial coordinates:	**05 14 32.2723 -08 12 05.906**
Galactic coordinates:	**209.2412 -25.2454**

PISCIS AUSTRINUS	
Fomalhaut -- Variable Star	
Equatorial coordinates:	**22 57 39.0465 -29 37 20.050**
Galactic coordinates:	**020.4881 -64.9096**

SCORPIUS	
Antares -- Alpha Sco -- Semi-regular pulsating Star	
Equatorial coordinates:	**16 29 24.4609 -26 25 55.209**
Galactic coordinates:	**351.9471 +15.0643**

TAURUS	
Aldebaran -- Alpha Tau -- Variable Star	
Equatorial coordinates:	**04 35 55.2387 +16 30 33.485**
Galactic coordinates:	**180.9719 -20.2483**

VIRGO	
Spica -- 67 Vir -- Variable Star of beta Cep type	
Equatorial coordinates:	**13 25 11.5793 -11 09 40.759**
Galactic coordinates:	**316.1123 +50.8446**

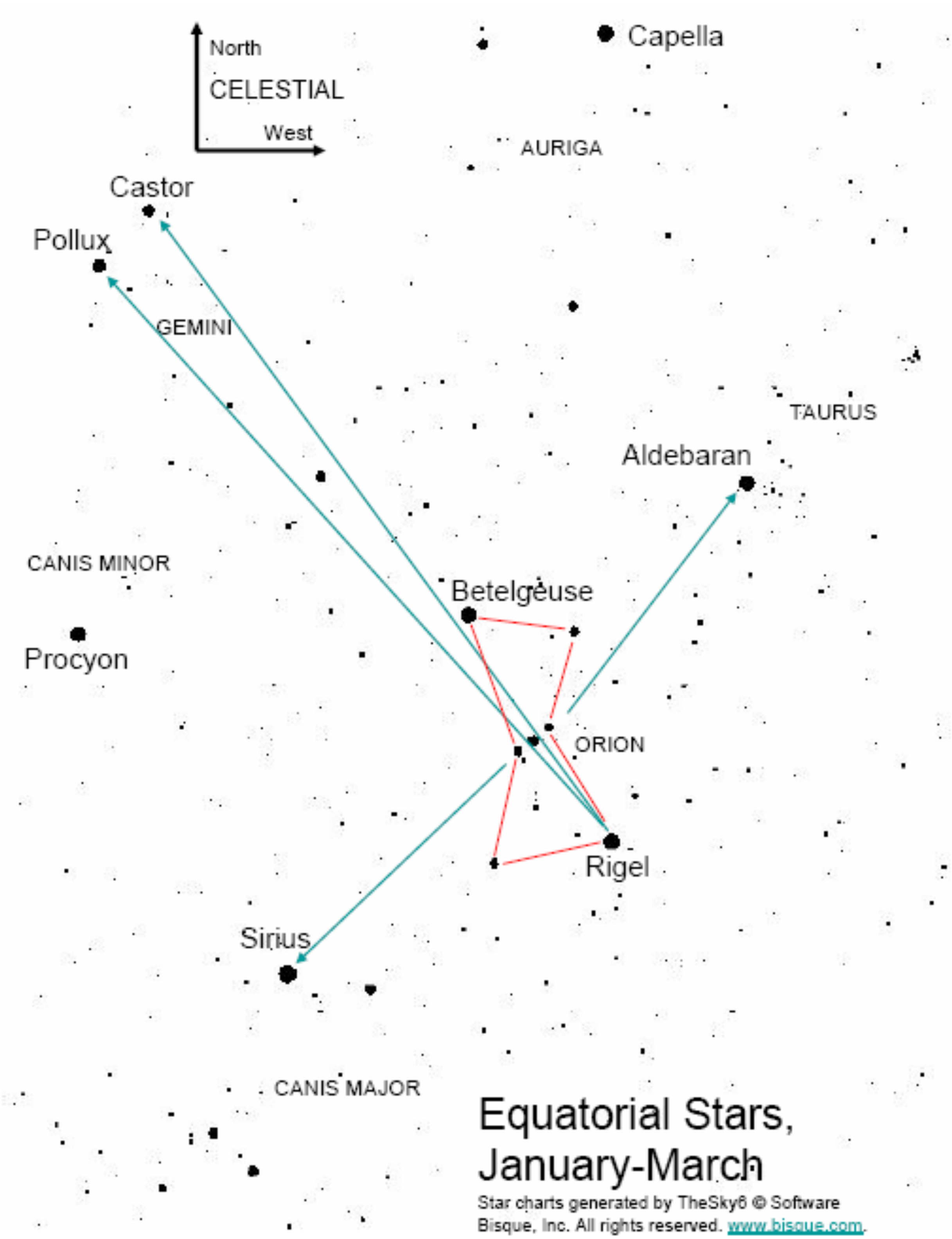
APPENDIX 2: Star and Constellation Charts

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; sometimes stars or constellations will be below the horizon or blocked by local landmarks. 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.

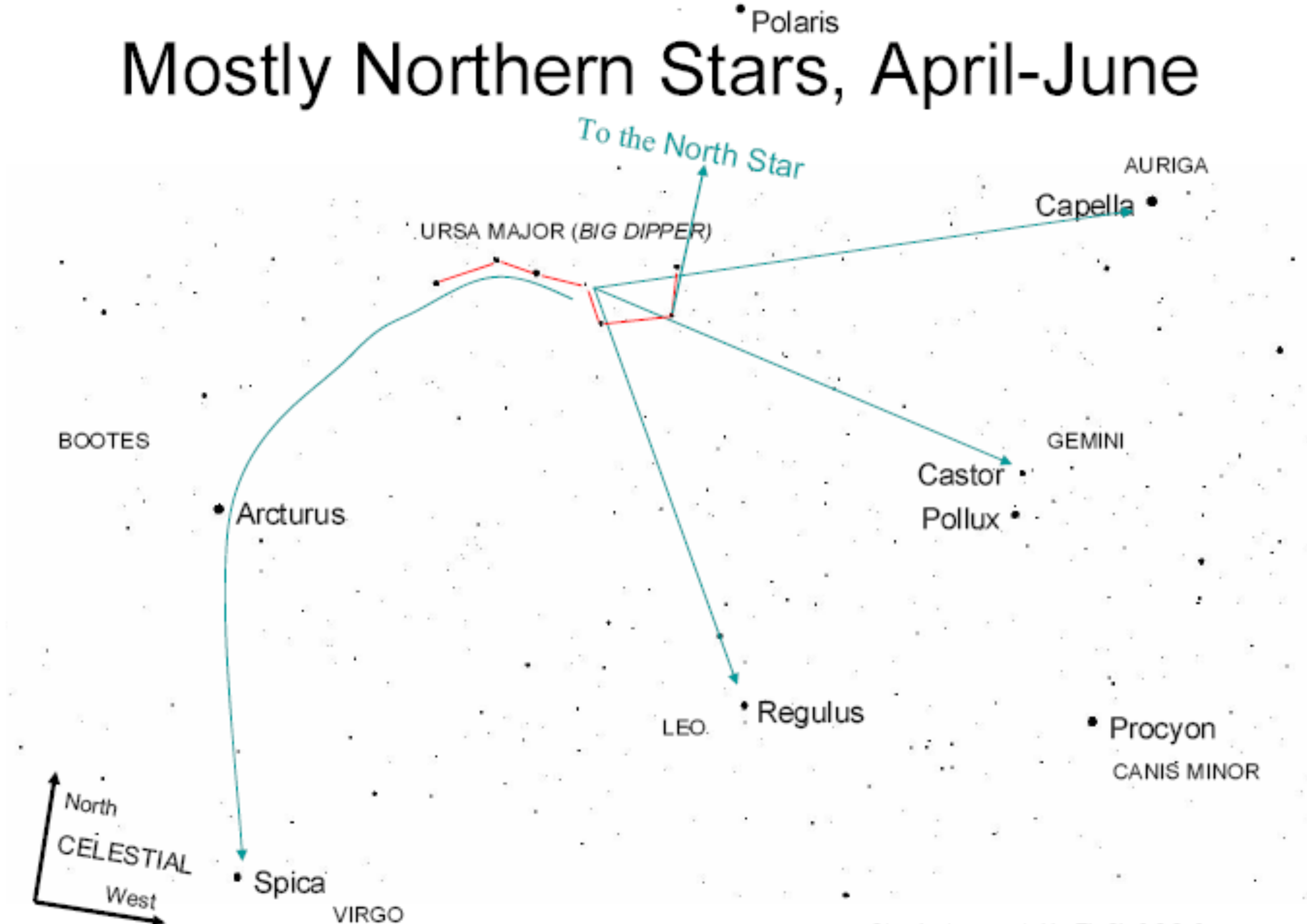
As a general rule, facing south is best, but some neck-craning (and/or facing a different direction and rotating the chart) will be necessary to go from the starting point to the target stars at the ends of the arrows. The font convention for the charts is that **CONSTELLATIONS** are fully capitalized 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: Choose a familiar group of stars, recognizable on a chart, and "star hop" from there.

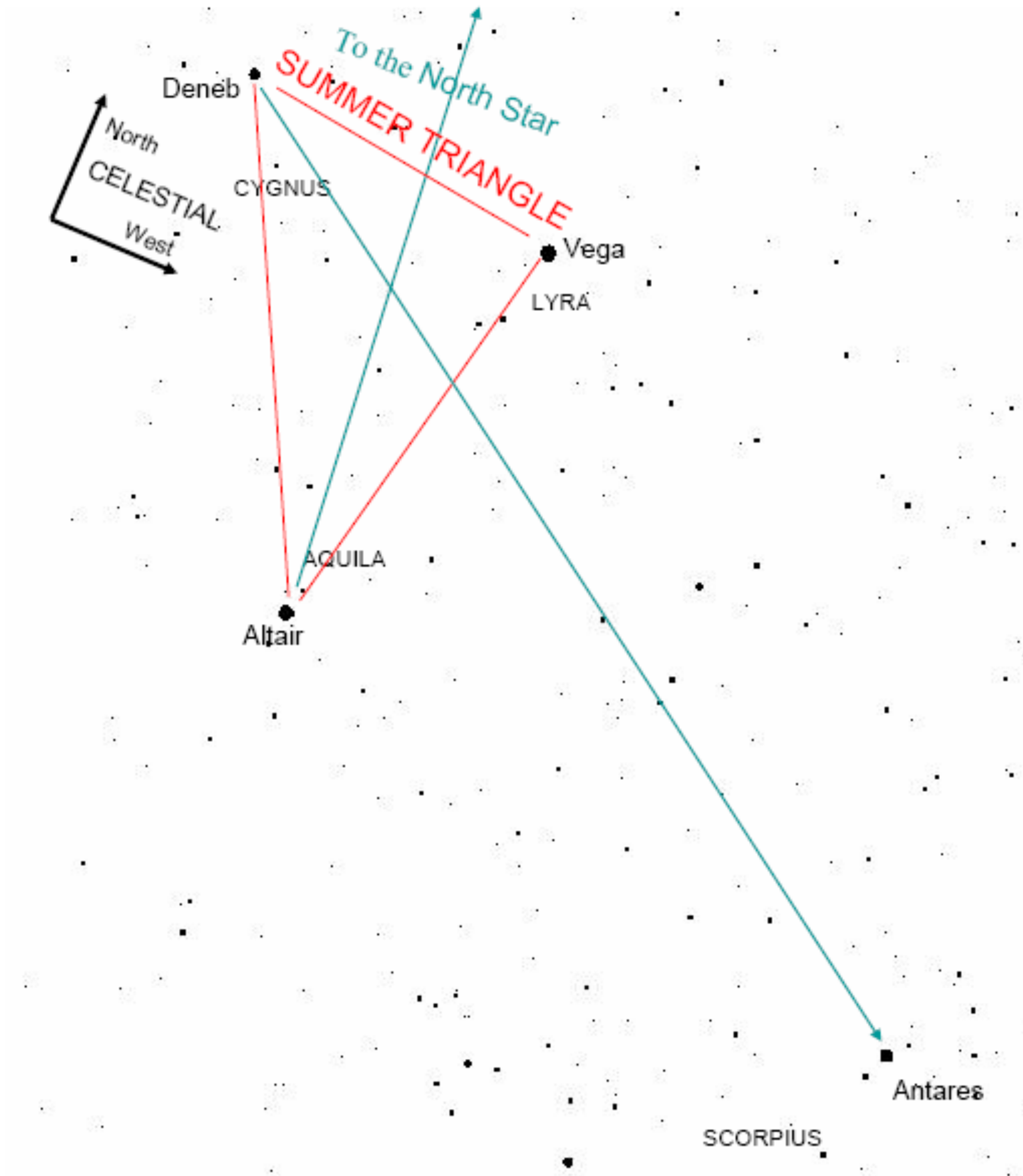
Use the orientation "rose" on each star chart to help with orienting the charts at night. At night, some observers find it is easier to use printed star charts with black stars on a white background rather than white stars on a black background. Black on white saves copier toner as well. The charts can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



Equatorial Stars, January-March

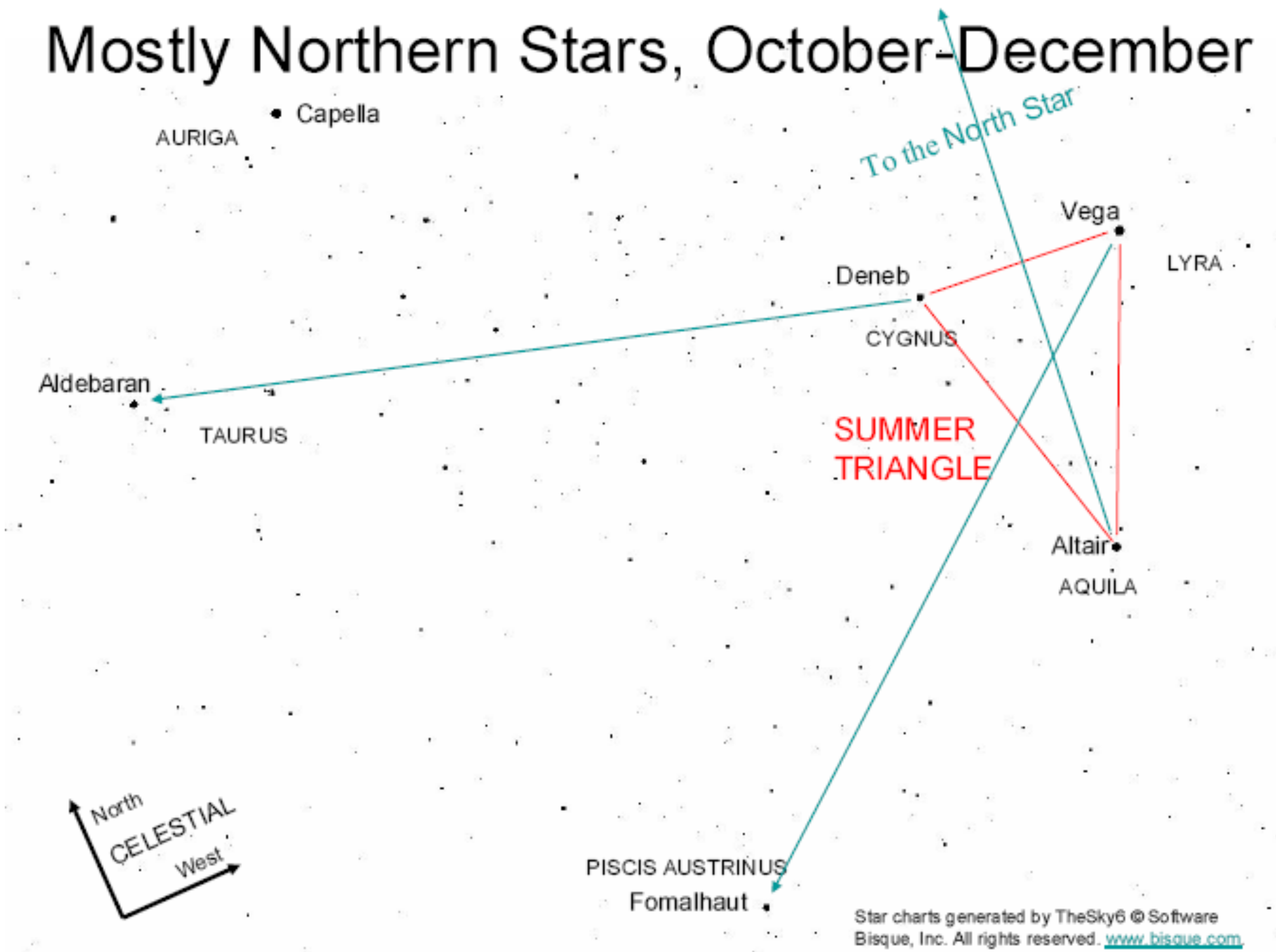
Mostly Northern Stars, April-June



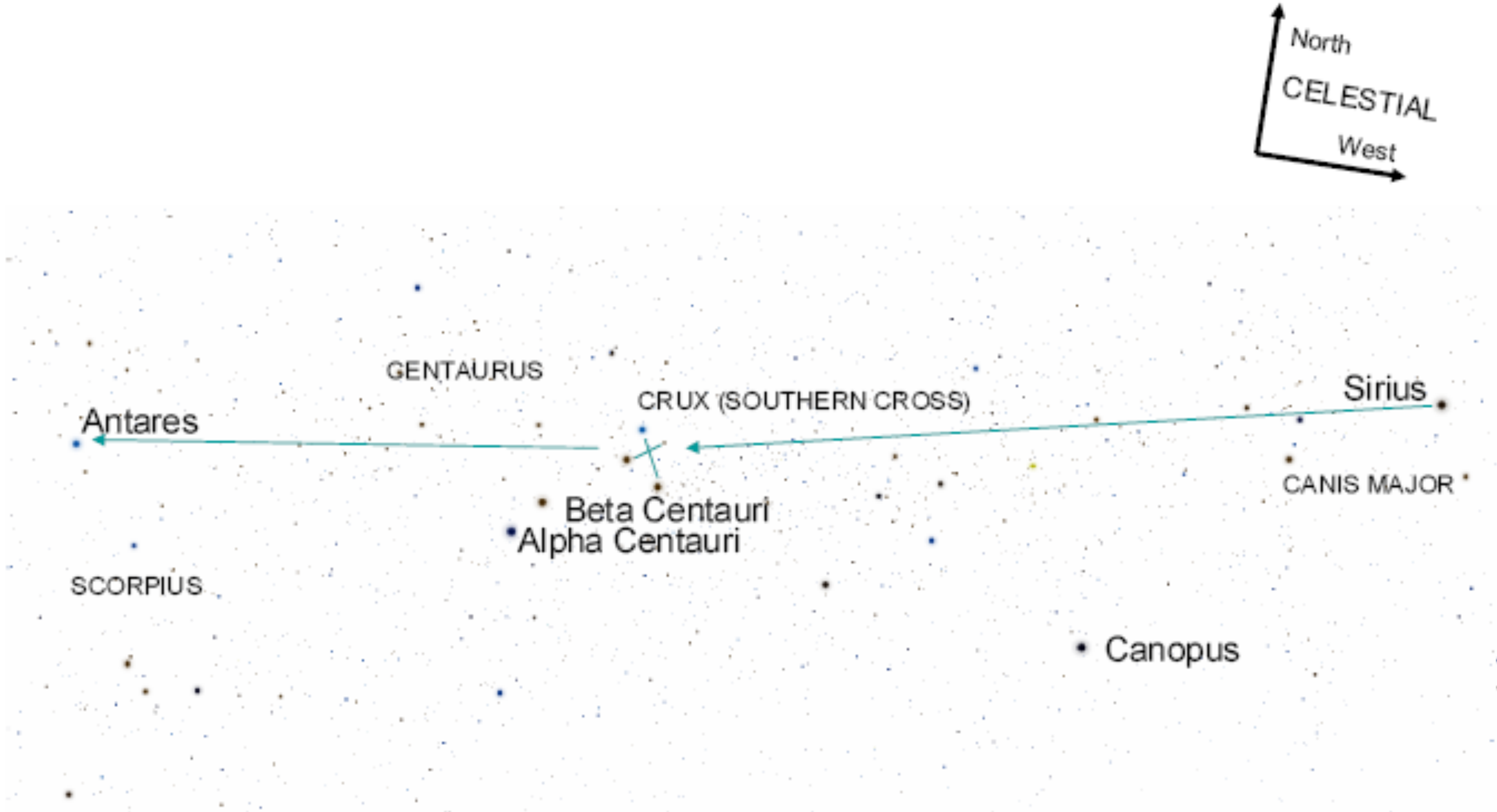


Mostly Northern Stars, July-September

Mostly Northern Stars, October-December



Southern Stars, April-June



Equatorial & Southern Stars, November-January