Data From the Virtual Universe

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Stellar Data

Definition: A star is a ball of gas that shines from nuclear reactions in its interior. The story's much more complicated, but you know what one is! See any introductory astronomy text for an through explanation.

The stellar database is one of the more challenging data sets, primarily because distances can be so difficult to calculate. The distance to a star can be calculated using two methods. One method uses the trigonometric parallax, an angle we measure which is related to the star's apparent movement in the sky as we revolve around the Sun. Even for the closest stars, this is an extremely small angle and, therefore, is only measurable for stars near the Earth (and Sun). If we *can* measure the angle, the distance is calculated via the equation

$$d = \frac{1}{\pi} \; . \tag{1}$$

Here π is the trig parallax angle that we measure, and the distance, d, is in parsecs. If we can't measure the parallax, we use the brightness of the stars to get the distance using

$$d = 10^{(m-M+5)/5} \; , \tag{2}$$

where m is the apparent magnitude, the brightness of the star as seen from Earth, and M is the absolute magnitude, the intrinsic brightness of the star inferred from the spectral type.

The Hipparcos catalogue has 118,218 stars. From these, we can calculate good distances to about 25,000 stars—enough to give us the familiar view of the night sky as seen from Earth.

Examples: innumerable.

The Hipparcos and Tycho Catalogs

ESA, 1997, The Hipparcos Catalogue, ESA SP-1200
ESA, 1997, The Tycho Catalogue, ESA SP-1200
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/1/1239/`

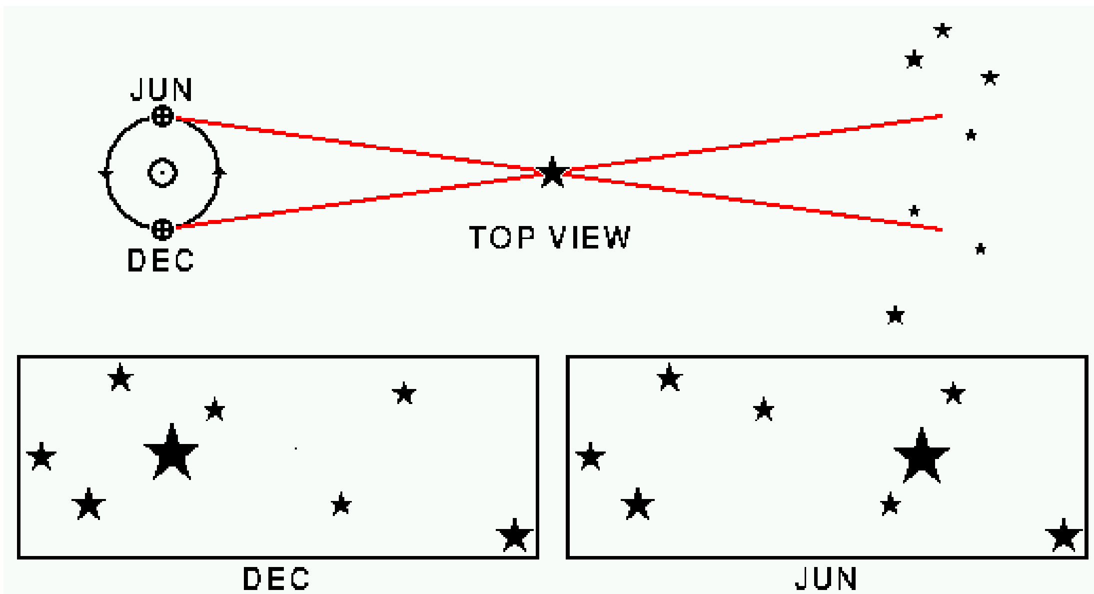

Figure 1: A diagram of the parallax method of distance determination. The parallax angle is that formed by the apparent motion of the star in the sky.

Extra-Solar Planets

Definition: Extra-solar planets, or exoplanets, are plamets that orbit stars other than our Sun. The discovery of the first confirmed extra-solar planet was in 1995 (51 Peg). Since then, there have been 71 more discovered (as of October 6, 2001). These orbiting objects are Jupiter-like planets—large, gaseous bodies that orbit their host star.

Most exoplanets are not *seen* through telescopes, they are inferred from the motion of the parent star. The action of a planet revolving around its parent star is actually both the star and the planet orbiting around a common center of mass. For the Earth-Sun orbit, the center of mass is a point on the line connecting the two bodies about 447 km (279 miles) from the center of the Sun. For Jupiter, this distance is 743,100 km from the Sun's center, just outside the Sun's "surface" (the Sun's radius is 696,000 km)! The motion of the star about the center of mass is detected in the stellar spectrum, where the spectral lines are Doppler shifted.

Examples: 51 Pegasi (first confirmed star with its own planets)

Extra-Solar Planets Catalog
Schneider J. 1998 (but discovered by many)
Unpublished
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/external/combined/E5002/`
`http://cfa-www.harvard.edu/planets/catalog.html`
`http://cfa-www.harvard.edu/planets/`

Open Clusters

Definition: An open cluster is a small group (tens to hundreds) of stars that are gravitationally bound with one another. They are young stars that have just been born. These clusters are found generally in the plane of the Galaxy, since star formation is occurring mainly in the Galactic arms.

We observe many open clusters in our Galaxy, each in a different stage of evolution. The cluster of stars in the Orion Nebula are in the birthing stage where we literally can see stars being born. The stars of the Pleiades (M45) are more evolved—only traces of the nebula from which the stars were formed can be seen. While some open clusters are much older and have swept away all the gas from which they formed.

Examples: The Pleiades (M45), the Hyades in Taurus, the Beehive (M44) in Cancer, and many, many more.

Open Cluster Data 5th Edition
Lynga G.
Lund Observatory (1987)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7092A/`

Globular Clusters

Definition: A globular cluster is a gravitationally bound group of one hundred thousand to one million stars. They are compact, spherically-symmetric "balls" of stars, with some member stars being almost as old as the universe itself! Globular clusters orbit the Milky Way galaxy (just as a comet revolves around the Sun) with orbital periods near 100 million years. They are within the Galactic Halo, a sphere centered around the Galaxy with a radius of about 100 kpc.

The distances to the clusters were inferred from the mean V magnitude (visual brightness), m_V, of the RR Lyrae stars in the cluster. RR Lyrae stars are giant, pulsating variable stars (their brightness varies periodically). We observe some RR Lyrae stars relatively close to the Sun (and the Earth)—close enough to get some of the star's fundamental properties, like its absolute magnitude, M. We can then calculate the distance to the star via the equation $m - M = 5 \log d - 5$. Since the light from the RR Lyrae star has a distinct variability, if we see one across the Galaxy, we can infer its absolute magnitude and calculate its distance. Since these stars are commonly found in globular clusters, its quite easy to derive their distance from observations.

The globular cluster data form one of the most complete data sets we have. The data we used contains 145 entries, just short of the total number we expect in the Galaxy.

Examples: M13 in Hercules, 47 Tuc in Tucana, M4 in Scorpius

Globular Clusters in the Milky Way
William E. Harris, McMaster University, Hamilton, ON, Canada
Astronomical Journal, v112, pp1487 (1997)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7202/`
`http://physun.physics.mcmaster.ca/Globular.html`

Pulsars

Definition: Pulsars are objects that give off periodic pulses of radio waves. The periods of these pulses range from 0.001 to 4.0 seconds with an average of 0.65 seconds. Physically, they are the dying remnants of stars whose initial mass was 1.4–3.0 solar masses. These stellar corpses are called neutron stars. These stars are so dense that protons and electrons are literally squeezed into neutrons, forming a neutron gas. This gas has such a high density, 10^{17} kg/m^3 (that's a 1 with 17 zeros; compare to the average density of the Earth at 5,520 kg/m^3), that one teaspoon full would weigh about a billion tons on earth. On top of this, they are only a few tens of kilometers in diameter (about the size of the NYC area).

Astrophysicists use the lighthouse model to describe the pulse of radiation we see. As the star rotates, the source of the "pulse" comes in and out of our view like a light from a lighthouse. But why do they pulse? Neutron stars have a strong magnetic field which is typically not aligned with the axis of rotation, as it is on Earth where the North Magnetic Pole is in the tundra of Canada. Charged particles, or electrons, escaping from the star travel up the magnetic field lines, giving off radiation in the process. We see this radiation in radio wavelengths (the first pulsar was discovered in 1967 at a frequency of 81.5 MHz, just below the FM range which begins at 87.5 MHz). The source of the radio emission is constant and is directed in a cone from the magnetic poles, but we only see this emission when it rotates into view. Therefore, the period of the pulsar allows us to determine its rotation rate.

Deducing the distance to a pulsar is not trivial. If pulses of two different frequencies f_1 and f_2 are emitted at some time t_0, the times when they arrive at earth will be different. This is because of the material (electrons) in the line of sight slowing the light signal down, just as glass slows light down (described by its index of refraction). As we look at lower frequency pulses of radio emission, the signal takes longer and longer to reach the Earth. Therefore, the times these two pulses f_1 and f_2 reach Earth will be $t_1 - t_0 = d/v_1$ and $t_2 - t_0 = d/v_2$. We don't know t_0 but we can measure $t_2 - t_1$ and so the two equations above become

$$t_2 - t_1 = \left(\frac{1}{v_2} - \frac{1}{v_1}\right) d \, . \tag{3}$$

The velocities, v_1 and v_2, depend on the density of electrons between us and the pulsar. The quality of the calculated distance is then subject to this density measurement. So, if we know the electron density and measure the times between two pulses of different frequencies, we can calculate the pulsar's distance.

Examples: The Crab pulsar (PSR 0531+21), the Vela pulsar (PSR 0833-45), PSR 1937+21, the fastest pulsar at 1.56 milliseconds (or 640 times per second!).

Taylor: Catalog of 558 Pulsars
Updated May 1995 to 706 pulsars
Taylor J. H., Manchester R. N., Lyne A. G.
Astrophysical Journal Supplement Series, v88, pp529 (1993)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7156A/`

Dark Nebulae

Definition: Dark nebulae are clouds of dust in the interstellar medium which obscure the light behind them. The Coal Sack in the southern hemisphere, the Great Rift in Cygnus, and the Horsehead Nebulae in Orion are all good examples. Dust is produced in the atmospheres of cooler giant stars or dense clouds where the temperatures are low enough to allow for the condensation of silicates. These dust grains are not the ordinary household dust we're used to seeing, these particles are so small you would need a microscope to see them.

These data are very spotty. Based on the Lynds catalogue of 1962, Palomar plates (observed from the Palomar Observatory in California) were used to map dark nebulae in the sky. However, one cannot see the southern sky from California so there is little or no coverage in the southern sky. While Lynds mapped the dark nebulae in two dimensions, it was Hilton and Lahulla in the 1990s who searched the literature to find distances to each of them. Many are found using the light from stars in the line of sight. The light from closer stars are affected less than the light from stars farther away (and closer to the dust cloud). If the distances to the stars are known, then the dark nebula can be placed among them.

Examples: Horsehead Nebula in Orion, the Coal Sack in Crux (Southern Cross).

The Lynds Catalogue of Dark Nebulae
Lynds B. T.
Astrophysical Journal Supplement Series, v7, pp1 (updated version) (1962)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7007A/`

Distance measurements of Lynds galactic dark nebulae
Hilton J., Lahulla J. F.
Astronomy & Astrophysics Supplement, v113, pp325 (1995)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/journal_tables/A+AS/113/325/`

H II Regions

Definition: An H II region is an area of glowing, ionized hydrogen gas surrounding young, hot stars. Ionized gas is so hot that the hydrogen atoms have been stripped of their electron. They have a temperature of about 10,000 Kelvin and a density of about 5000 particles/m^3. The star's light (or radiation) illuminates the hydrogen gas, causing it to glow, like the Orion Nebula. Further away from the star, the light is "used up" in exciting the nearby gas and, the hydrogen is in it's non-glowing, non-ionized state called neutral hydrogen, or H I.

H II regions can be seen in many parts of the electromagnetic spectrum. The Orion Nebula provides us with a good example. We observe H II gas in the visible, star formation in the infrared, and hot stellar winds in the X-ray part of the spectrum. However, an H II region is just a small part of the cloud.

H I clouds which surround H II regions are observed primarily in the radio part of the electromagnetic spectrum. Because radio waves penetrate the interstellar dust and gas, it is really the neutral hydrogen, H I, that aids us in seeing the clouds in which the H II region lies. Information from these radio observations give us the general properties of the hydrogen cloud, its density, and its motion in the galaxy. In this way, we can observe the rotation of our own galaxy and, using both H I and H II data, we can map its spiral structure.

Examples: Orion Nebula (M42), Lagoon Nebula (M8) in Sagittarius

CO Radial Velocities Toward Galactic H II Regions (Blitz+ 1982)

Catalog of CO Radial Velocities toward Galactic H II Regions
Blitz L., Fich M., Stark A.A.
Astrophysical Journal Supplement Series, v49, pp183 (1982)

CO Observations of Southern Hemisphere H II Regions
Gillespie A.R., et al
Astronomy & Astrophysics, v60, pp221 (1977)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7050/`

Georgelin & Georgelin on the spiral structure of our Galaxy
Georgelin, Y. M. & Georgelin, Y. P.
Astronomy & Astrophysics, v49, pp57 (1976)
Not published in electronic form.

Planetary Nebulae

Definition: A planetary nebula is a shell of expanding gas illuminated by a central star. While H II regions are the sign of stellar birth, planetary nebulae are a signature of stellar death. As a star similar to our Sun evolves, it eventually will run out of nuclear fuel (hydrogen) in the core and will begin burning helium. The core will eventually become all helium which will then be converted into carbon as it burns. Once the core is pure carbon, the star will become unstable and blow out its outer layers. A spherical shell of gas forms around what is now the exposed core of the central star. The core will quickly become a white dwarf—a small, dense star that no longer shines by nuclear burning but stored residual energy. This is the fate of stars that have a mass less than 1.4 solar masses (like our Sun). The star will continue to radiate this energy sparingly for billions of years. We call the spherical shell of gas a planetary nebula.

Planetary nebulae are found mainly in the disk and the center of the Galaxy. However, their orbits are elongated around the Galactic center. In addition, some are found above the plane, and one in a globular cluster even.

Examples: The Ring Nebula (M57) in Lyra, Helix Nebula (NGC 7293) in Aquarius, the Dumbbell Nebula (M27) in Vulpecula

Strasbourg-ESO Catalogue of Galactic Planetary Nebulae
Acker A., Ochsenbein F., Stenholm B., Tylenda R., Marcout J., Schohn C.
European Southern Observatory—ISBN 3-923524-41-2 (1992)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/5/5084/`

Galaxies

Definition: A galaxy is a huge assemblage of stars (our Milky Way has about 10^{12} stars), gas, and dust that is held together by gravity. All of what we see in the sky with our naked eye, with the exception of the Andromeda galaxy (M31), is in our Galaxy.

This data set has been provided to us directly via the author, Brent Tully of the University of Hawaii. These data consist of over 28,000 galaxies that surround our Milky Way. In it, we see the structure of the local universe—filaments of galaxies that intersect to form clusters of galaxies. These data form two lobes on either side of the Galaxy. The entire data set is about 300 million light-years across a side (i.e., the data forms a cube-like structure with each side being about 300 million light-years). In the middle is the Milky Way, in what is called the Zone of Obscuration. This zone forms the empty space in between the two lobes. What this zone represents is the plane of our own Galaxy. Because we cannot see through our Galaxy, there is no data on either side of the Milky Way, only above and below the plane of the Galaxy. This relates to the forest through the trees argument, there are just too many trees in the Milky Way to see through it and out into the universe.

Each galaxy has been given a color based on which cluster or filament they belong to. The color code is simply a way to see more structure as we move through it in three dimensions. As we pull away from the Milky Way, we can see the Local Group cluster members and we can see that the Local Group galaxies are a member of the Virgo Cluster. As we open our eyes to more galaxies, we see the web-like structure of the Universe. The distances to these galaxies are measured by redshift of their spectral lines, which will be discussed next week.

Examples: Any galaxy outside our own Milky Way

Nearby Galaxies Catalogue
Tully, R. B., University of Hawaii
Cambridge University Press (1988)
`http://adc.gsfc.nasa.gov/adc-cgi/cat.pl?/catalogs/7/7145/`