Astronomy Information for Fun

(Tim Tasto 3/17/2018 Color Version Rev 1)

First, it is important to state that most of what is contained in this paper is the result of numerous and enthusiastic questions asked by students during astronomy labs at the CSB/SJU observatory. Many thanks to those students for their interest and questions! Included in this paper are some facts about astronomy and our universe that will hopefully give you some idea (or context) of what you are looking at when you observe the night sky. Many people think that astronomy is all about “stargazing”, but if you read through this paper I think you will find that there is a lot more to astronomy than just gazing at individual stars.

The information that follows is not intended to be too heavily detailed. Rather, brief descriptions are presented in order to provide a glimpse of each topic. The information does not have to be read in any particular order, and it is written in a conversational (rather than scientific) style, perhaps a bit like an FAQ. It is hoped that the snippets presented in what follows will inspire further study into specific areas for which you may have an interest.

The CSB/SJU observatory contains equipment that will allow you to view many of the objects described herein. In fact, the astrophotos that are included in this paper were taken with equipment that is almost identical to the equipment available at the CSB/SJU observatory. Enjoy.

Has the CSB/SJU Observatory Ever Discovered Anything?

Yes! A recent discovery involves the period of a variable star. As is demonstrated by this discovery, important scientific progress in the field of astronomy does not always require a Hubble Space Telescope. Here is my “news release” for the event:

> “Dr. Thomas Kirkman, along with a group of undergraduate researchers at the St. Johns University Observatory, have made an important discovery involving variable star TYC 1031 1262 1 (aka ASAS J182611+1212.6) in the constellation of Hercules. The star is cataloged as a "Cepheid" variable, and as such, it is expected that it's brightness would vary with a regular period. The research into this particular star is complicated by the fact that the star is both an intrinsic variable (the star itself pulsates), and it is also being eclipsed periodically by another (dimmer) star as part of a binary system. Following years of data gathering using one of the telescopes and imaging systems at the CSB/SJU observatory, and via comparison with previous data, it was discovered that the star in question is exhibiting an oscillating period. This is unusual for this type of variable star, and it will take further analysis to determine the reason for such surprising behavior. The discovery was presented at the 230th meeting of the American Astronomical Society, which was held back in June 2017 in Austin, Texas. My congratulations to Dr. Kirkman and his team of undergraduate students for their contributions to the world of science!”

If you would like to know more, the link below will open a .pdf file located on the CSB/SJU website. The file contains detailed information on the study of the star and methodology employed in measuring it's period, along with credits to the students who participated (B. Demarais, M. Ellis, D. Byrne, J. Benson, J. Hoppert, and A. Lusty):

http://www.physics.csbsju.edu/ccd/2017AAS.230.217.03K.pdf

A Little About Time and Space
Some general information about the speed of light, time, and distance in space is presented below.

* Distances in our universe are so great that we typically measure those distances in light years (the distance that a light beam travels in 1-year). The speed of light is approximately 186,000 miles per second, so in 1-year, light travels about 5.87E+12 miles.

* Our sun is about 93,000,000 miles from Earth. That means it takes about 8.33 minutes for a photon emitted by the sun to reach the Earth. Thus, we see the sun as it was 8.33 minutes ago.

* The nearest star to Earth (other than our own sun) is Proxima Centauri, which is 4.22 light-years distant. We therefore see this star as it was 4.22 years ago. If that star exploded today, it would take 4.22 years before we would see the explosion because that's how long it takes the light to reach us here on Earth.

* Whenever we look at any object, we are looking back in time. We can never see anything as it is “now”. It always takes light a finite amount of time to reach our eyes from any object. If the object is close to us (like when you turn on a light in a room), it seems that the light reaches us instantaneously. Actually, it still takes a small amount of time for the light to reach our eyes. When we look into space (as discussed above), we are looking at objects that are typically light-years away (sometimes just a few, but often thousands, millions and even billions). This means that when we observe an object such as the Andromeda Galaxy (nearest galaxy to our own), which is about 2.5 million light years distant, we are seeing it as it existed 2.5 million years ago. If a star in that galaxy exploded today, we would have to wait 2.5 million years to see it because that is how long it would take the light from the explosion to reach us. As you can see, the speed of light is not very fast at all on cosmic scales.

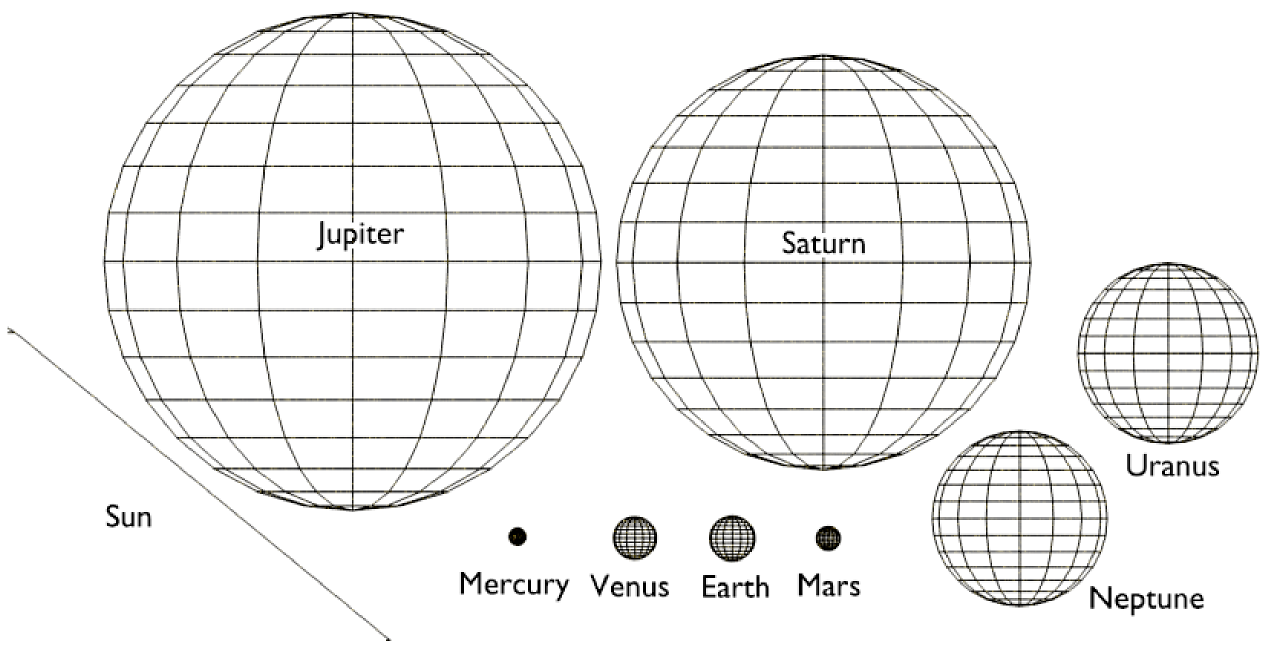
* The most distant galaxy photographed thus far (by the Hubble telescope) is galaxy GN-Z11, which is estimated to be 13,390,000,000 light years from the Earth (that's 13.39 billion light years). Thus, it took light 13,390,000,000 years to reach us from that galaxy, and we are seeing the galaxy as it appeared at that time. Looking back in time that far takes us back to nearly the beginning of the universe, the Big Bang, approximately 13.7 billion years ago.

* What existed before the Big Bang? Well, space did not exist, and time did not exist either. So, since neither space or time existed before the Big Bang, the question loses its meaning (since there is no such thing as “before” if there is no time). It's like asking “What happened before time existed?” Perhaps just a quantum field that only contained potential? We simply don't know!

Relative Sizes of the Sun and Planets in Our Solar System
Here are some size comparisons for select objects in our own solar system.

Object	Diameter (miles)	Size Compared to Earth (diameter)	Average Distance from Sun (miles)
Our Sun	864,600	109.00	0
Mercury	3,032	0.38	35,000,000
Venus	7,521	0.95	67,000,000
Earth	7,918	1.00	93,000,000
Mars	4,212	0.53	142,000,000
Jupiter	86,880	10.97	484,000,000
Saturn	72,368	9.14	889,000,000
Uranus	31,518	3.98	1,790,000,000
Neptune	30,598	3.86	2,800,000,000

The Planets (to scale)



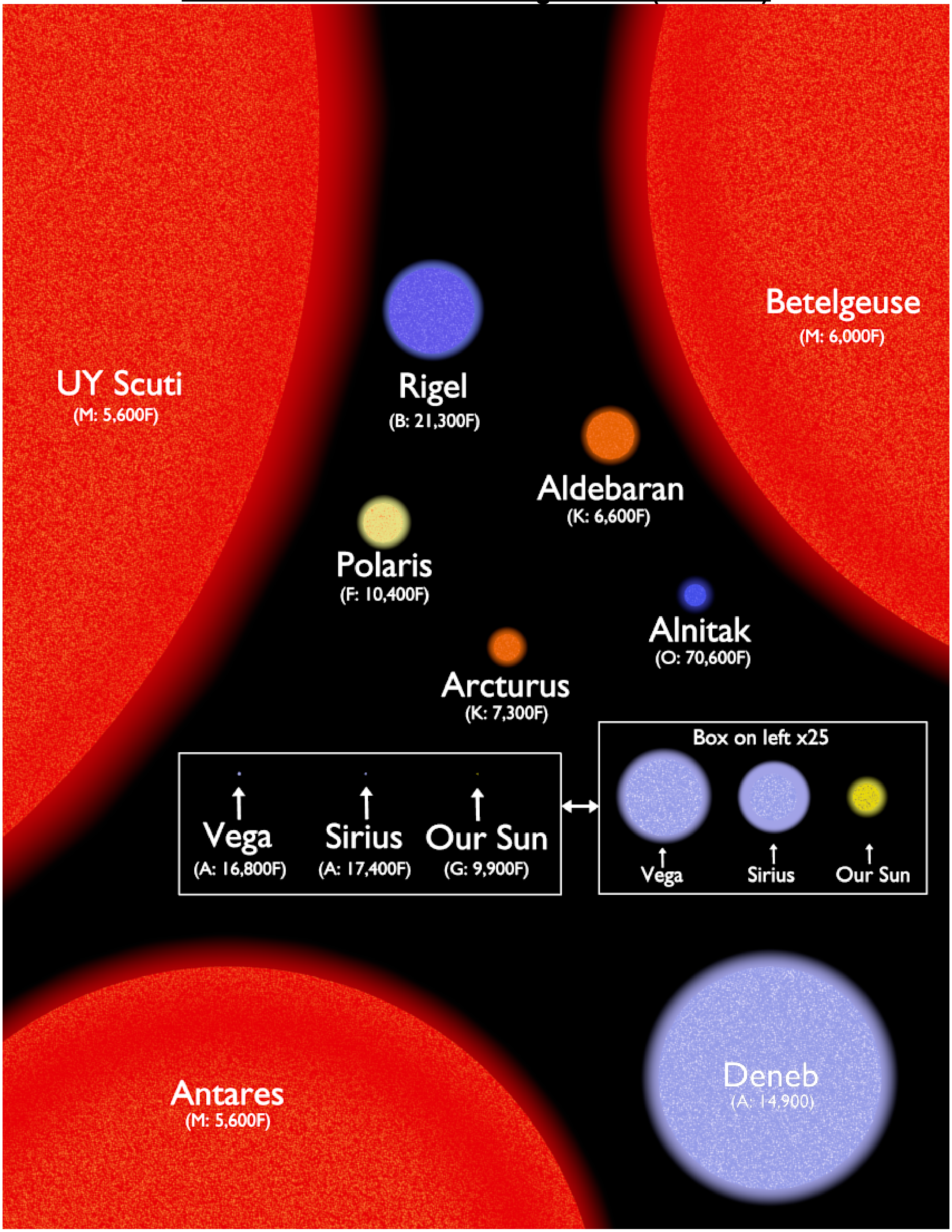
Relative Size of our Sun to Other (Larger) Stars
These size comparisons are largely estimates. For huge, distant stars, precise diameters can be difficult to determine as it is hard to know where the actual "surface" of the star is (among other things). As such, the precise diameter of large stars is arguable and can vary significantly from one study to another. However, the following estimates will give you an idea of how the size of our sun compares to the size of other, larger stars.

Star	**Diameter (miles)**	**How Many Times Larger than our Sun (diameters)**	**Distance from Earth (light years)**
Our Sun	864,600	1	-
Sirius	1,478,800	1.7	8.6
Vega	2,420,800	2.8	25
Alnitak	17,292,000	20	1260
Arcturus	21,960,000	25	36
Polaris	31,990,200	37	350
Aldebaran	38,214,300	44	65
Rigel	67,729,400	78	860
Deneb	175,513,800	203	802
Antares	587,928,000	680	550
Betelgeuse	864,600,000	1,000	222
UY Scuti	1,476,736,800	1,708	9,500

On the next page, a visual representation of the relative sizes of the stars in the table above is presented. As can be seen, it may seem like our sun is quite large from the perspective of the Earth, but when compared with other stars in the galaxy, it is actually quite small. There are also stars that are smaller than our sun, but they would not even show-up on the diagram that follows (next page).

Slight Digression - What is the most common star?
The most common type of known star is the "red dwarf". These stars are estimated to make up over 70% of the stars in our galaxy (or the universe) and are much less massive than our sun (50% of our sun's mass or even far less). They burn cool, with surface temperatures of only about 6,000 degrees F (note that our sun has a surface temperature of about 9,000 degrees F). Further, red dwarfs constantly "mix" their internal gasses while fusing hydrogen to helium, and are known as "fully convective" stars. As such, these stars avoid a large helium buildup in the core, and therefore the fusion process is greatly prolonged. For example, our sun has an expected lifetime of about 10 billion years, whereas a red dwarf can have a lifetime of around 10 trillion years due to their convective process, low gas pressure, and resulting low fusion rates and temperature. Because they are so dim, and even though they constitute a majority of all stars, no red dwarfs are known to be visible to the naked eye. One example of a red dwarf star is "Proxima Centauri", which is the nearest star to Earth (other than our sun). Proxima Centauri is only about 4.2 light years from Earth, is currently only about 15% of the size of our sun and possesses only about 12% of our sun's mass. Finally, it should be noted that the precise definition of a "red dwarf" is debatable, but the description above gives you some idea of what they are. Now, on to the diagram of the huge stars!

Relative Sizes of Select Large Stars (to scale)



How Hot are the Stars?

Usually, star temperatures utilize units of Kelvin, but temperatures in the table below are presented in degrees Fahrenheit because those units are more familiar to most people. The Spectral Class indicates both the overall color and temperature of the star. The "Effective Temperature" presented below is often used as an estimate of the surface temperature of the star (but not the much hotter core temperature), and is technically related to "Black Body" emission of electromagnetic radiation (we won't go into that here). Note that the core temperature of our sun can reach more than 27 million degrees Fahrenheit (where hydrogen is fusing to helium), whereas the surface temperature is only about 9,900 degrees F. It can take over a million years for the heat generated by nuclear fusion in the core of our Sun to reach the upper layers (or surface) of the Sun.

Spectral Class	**Effective Temperature Degrees F**	**Color**	**Example Stars (approximate surface temperatures in degrees F)**
O	> 53,540	Blue	Alnitak (70,600F)
B	17,540 - 53,540	Blue - White	Rigel (21,300F)
A	13,040 - 17,540	White	Sirius (17,400F), Vega (16,800F), Deneb (14,900F)
F	10,340 - 13,040	Yellow-White	Polaris (10,400F)
G	8,900 - 10,340	Yellow	**Our Sun** (9,900F)
K	6,200 - 8,900	Orange	Arcturus (7,300F), Aldebaran (6,600F)
M	3,860 - 6,200	Red	**Red Giants:** Betelgeuse (6,000F), Antares (6,000F), UY Scuti (5,600F), **Red Dwarf:** Proxima Centauri (6,000F)

What Else is Out There?

There's a lot more out there than just individual stars. Information on some other interesting things in our universe that are known as "Deep Space Objects", or DSO's, is provided below. There are literally thousands of DSO's cataloged.

The images that follow are included in a couple different astronomical catalogs. The "M" designation stands for "Messier" catalog of deep space objects. The "NGC" designation stands for the "New General Catalog" of deep space objects. There are many, many more objects cataloged than are presented below.

Most of the DSO's below can be seen in smaller telescopes (3"), or sometimes even with binoculars. Note, however, that moonlight "washes out" the background sky and lowers contrast to the point where the object can be difficult or impossible to see, even in a telescope. Clear, moonless nights are best for observing these objects as many are very faint.

M31 - Andromeda Galaxy: This galaxy is somewhat similar to our own, but is a bit larger. The Andromeda Galaxy spans about 220,000 light years in diameter, whereas our galaxy, the Milky Way, is estimated to be about 125,000 light years in diameter. The Andromeda Galaxy contains an estimated 1 trillion stars, compared to our Milky Way Galaxy, which is estimated to contain about 400 billion stars.

The Andromeda Galaxy is also the closest galaxy to ours at a distance of about 2.5 million light years. On a clear, moonless night, you can sometimes see the faint, fuzzy glow of this galaxy with the naked eye if you know where to look. It's easy with binoculars. One of the problems with observing this object is that it is it is actually quite large. In fact, it is about five times larger than a full moon (lengthwise). It doesn't stand out in the night sky because even though it is large, it is too dim to be easily visible with the naked eye. Most telescopes will magnify it to the point where you can usually only see the core of the galaxy. The other two fuzzy patches in the photo are also galaxies (M32 and M110).

Now prepare to run for your life, because our own galaxy (the Milky Way) and the Andromeda Galaxy are on a collision course. The collision is expected to occur in about 4 billion years. Plan ahead!

M51 - Whirlpool Galaxy: This galaxy lies about 23 million light years from us and is about 80,000 light years in diameter (just a little smaller than our galaxy, which is about 125,000 light years in diameter). M51 is a type “Sa” galaxy, as is our Milky Way. So our own galaxy would look similar to M51 if viewed from a great distance and at the same angle as shown the image below. Note also the companion galaxy (NGC5195) at the top of the image.

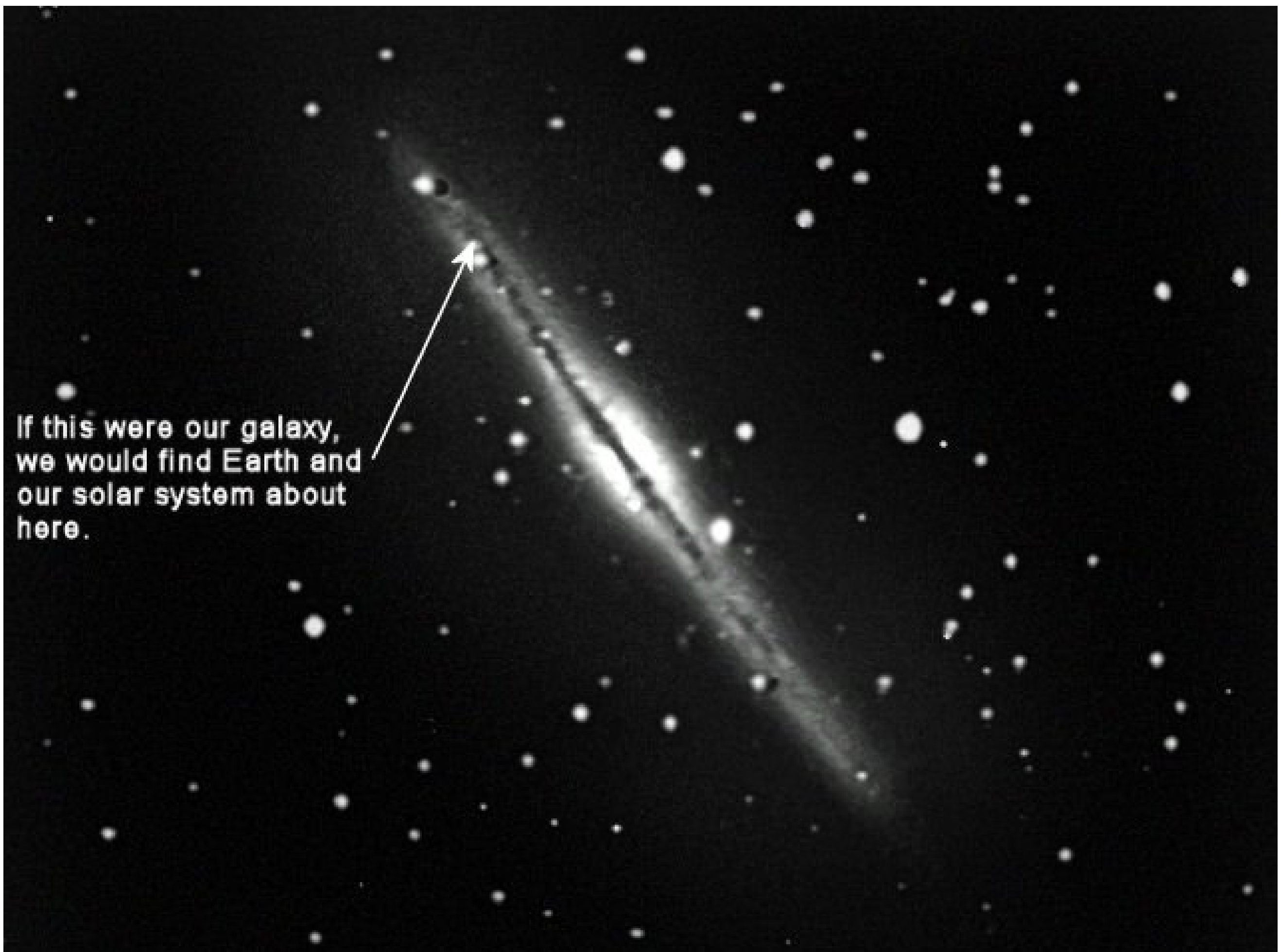
Although M51 is technically listed as being in the constellation of Canes Venatici, it actually resides very close to the first star (Alkaid) in the handle of the Big Dipper.

M51 (NGC-5194) and NGC-5195 in Canes Venatici. Size 10.8' x 6.6'. Mag:8.4. Surf Brt: 12.9
10" LX200GPS at f/6.3. SAC Focal Reducer. SAC-8 at 640x480. Gain 50%. Bright/Contrast 100%
Mosaic [30x40sec central]+[10x40sec periphery]. Temp 30F.
Original Image 5/14/04. Reprocessed 09/12/04 using Stellar Magic DDP. Tim and Becky Tasto.

NGC891 - View of a Galaxy Edgewise: This galaxy lies about 27 million light years from us and is also of type “Sa”. If we could view our own galaxy from the side, it would look similar to the image below. The image of M51 (above) and the side-view image of NGC891 below should give you a pretty good idea of what our own galaxy would look like from a great distance and at different viewing positions (i.e. front and side).

The Earth and our solar system are located, very roughly, about 2/3 of the way towards the edge of our galaxy from the center. We cannot take a picture of our own galaxy from the outside (since we are obviously inside it). So, because NGC891 is similar to how our own galaxy would look if viewed from the side, we can use the image to illustrate about where we are located in our own galaxy. See image below.

NGC891 needs at least a 6” telescope and clear, moonless night too see. It is far too dim for the naked eye or binoculars.



NGC-891 in Andromeda. Size: 13.1' x 2.8'. Mag: 9.9. Surface Brightness: 13.6.
SAC-8 at 640x480. 10" LX200GPS at f/3.3. SAC Focal Reducer. 50 x 30sec.
Tim and Becky Tasto. Taken at Jims house 08/21/04.

M57 and M27 - Planetary Nebulae: These nebulae are the result of a star that suddenly emits a shell of hot gas. The emission typically occurs when the core temperature of an old star decreases (as hydrogen fuel is depleted by fusion to helium) and outward pressure from the core fusion process also decreases. When this happens, gravity overrides outward pressure from fusion and causes the star to contract rather rapidly. This contraction, in turn, causes the fusion reaction in the core to suddenly increase rapidly, and this increase is accompanied by a spike in core temperature and outward pressure. When the outward pressure overrides gravitational forces of contraction, a “bubble” or shell of hot gas is emitted by the star. The two planetary nebula shown below are M57 (the Ring Nebula in Lyra) and M27 (the Dumbbell Nebula in Vulpecula). They are both about 2.8 light years in diameter and still expanding. Neither are visible with the naked eye, but are easy targets for the telescopes at CSB/SJU.

M57 (Ring Nebula, below, is about 2,300 light years from Earth)

M27 (Dumbbell Nebula, below, is about 1,400 light years from Earth)

M1 - Supernova Explosion: This “mess” is about all that is left of a star that exploded in the constellation of Taurus the Bull thousands of years ago. It lies about 6,500 light years from us and the expanding supernova remnants are about 11 light years across. The remnants are expanding at an estimated rate of about 930 miles per second (0.50% light speed). At the center of the expanding remnants are what is left of the original star that exploded, and also a neutron star (about 20 miles in diameter) that is spinning (a “pulsar”) at about 1,800 revolutions per minute. (Neutron stars and Pulsars are discussed a little bit in another part of this short paper. Note that the compressed matter in a neutron star is so dense that 1-teaspoon of the star can weigh as much as 6 billion tons!) When the light from the exploding star first reached the Earth in about 1054 AD, it is said that it could be seen in the daytime. At night it was nearly as bright as the full moon, and is recorded as being the brightest object in the night sky at the time (except for the full moon itself).

M1 Crab Nebula . Size: 8.0' x 4.0'. Mag: 8.4. Surf Bright: 11.0.
10" LX200GPS. Meade Focal Reducer at f/3.3. [20 x 20sec] + [20 x 10sec]. SAC-8 at 640 x 480.
Tim and Becky Tasto. 02/11/05

M42 - Great Nebula in Orion (star factory): This is a huge cloud of gas that is about 24 light years across and about 1,400 light years away from Earth. Much of the gas consists of ionized hydrogen (HII). Since stars are formed from contracting hydrogen gas, it is no surprise that M42 is a “star factory”, as new stars are being born in the white region of the nebula (below) as the gas contracts due to gravity. When the gas contracts, it heats up. If the pressure (and resulting temperature increase) from the contracting hydrogen gas becomes great enough, nuclear fusion of the hydrogen begins and a new star is born. It is estimated that there are about 700 new, young stars in the “HII” region shown below, which is about 2.5 light years in diameter. The HII gas in this region of M42 is believed to have a temperature of about 14,000 degrees F. M42 easily seen in binoculars or any telescope by looking at the middle star in the sword of the constellation Orion.

And now...a gratuitous, shameless, and self-serving web page pump: These images and more can be viewed at: **http://users.cloudnet.com/dsastro/index.htm**

Einstein's Theory (Theories) of Relativity

No discussion of space can presented without recognizing the contributions of this famous theory. The "Theory of Relativity" actually consists of two parts. First, there is the Special Theory of Relativity which deals with constant, high speed motion and the speed of light. Secondly, there is the General Theory of Relativity, which is an extension/generalization of the Special Theory which includes gravity. The General Theory addresses both gravity and high speed motion. Einstein's theories are important for the study of space and time (e.g. astrophysics, cosmology), as the theories address the overall large scale structure of our universe. Here, then, is Einstein's equation for the structure of our universe:

$$G_{uv} = T_{uv}$$

The equation above is known as the Einstein Field Equation. The left side, G_{uv}, represents the "spacetime metric". It tells us about the shape/structure of spacetime. The right side, T_{uv}, is the distribution of matter/energy in the universe (it is called the "stress-energy tensor"). The equation is very difficult to solve as the G_{uv} and T_{uv} break down into many different components and includes entities called "tensors". As such, it is called a "tensor equation" We won't get into that here. For now, the equation can be understood by visualizing the G_{uv} as the structure/shape of spacetime (i.e. curvature), and T_{uv} as the matter/energy distribution in the universe. In simpler words, the equation states the following:

"Matter and energy tell space and time how to curve, and that curvature tells matter how to move."

* The famous $E=mc^2$ equation is a result of Einstein's study of matter, energy, space and time. It tells us that matter and energy are equivalent. This equation is responsible for nuclear reactors used in the production of electricity and, unfortunately, nuclear bombs as well.

* One basis for the Special Theory of Relativity is that no object that possesses rest mass (i.e. matter) can be accelerated to match (or exceed) the speed of light (186,000 miles per second). It is the speed limit of our universe. You can get closer and closer to light speed (i.e. asymptotically approach it), but you can never actually "get there" because it would take an infinite amount of energy to do so. As such, it is also true that nothing that possesses mass can go faster than light. In many science fiction stories, people go back in time by exceeding the speed of light. There is also the proposal of "warp" drives that would allow us to exceed light speed. However, the reality is that there is currently no known way to do any of this and the equations of relativity will produce a "divide by zero" error as soon as you reach the speed of light. If you try to solve the equations for going faster than light, you end up taking the square root of a negative number (resulting in use of imaginary numbers) and the result is not physically real.

* It is often stated that Einstein proved that "everything is relative." The statement is <u>not</u> true. In fact, the situation is just the opposite. Einstein showed that there is an absolute known as "ds" in spacetime equations. The value of "ds" must be <u>the same for all observers</u> and is NOT relative. This "absolute" assures that the laws of physics are the same for all observers in any state of constant motion (from the Special Theory). In order for "ds" to be the same for all observers, space and time must be "flexible". In short, the faster you move through space, the slower you move through time, and vice-versa.

* Before Einstein, many people believed that space and time were completely separate entities. It seemed intuitively obvious that time passed at the same rate for everybody, events that are simultaneous for one observer are simultaneous for all observers, and the measurements of the length of objects is the same for everyone regardless of how they are moving or whether or not they are in a

gravitational field. Einstein's theories changed all of this by unifying time and space into a single mathematical object. By doing so, he contradicted almost everything that most people believed about space and time. Under Einstein's theories, time can pass at different rates for different observers, what is simultaneous for one observer may not be simultaneous for another observer, and lengths of objects can be measured as different for different observers. These effects are related to how fast an object is moving (how close to the speed of light) and/or how strong the gravity is in the vicinity of an observer.

* Einstein's theory of Special Relativity tells us that as an object approaches the speed of light, time slows down, mass (i.e. total energy) increases, the length of the object contracts in the direction of motion, and that events that are simultaneous for one person are not necessarily simultaneous when observed by another person.

* Einstein's theory of General Relativity tells us all the things that Special Relativity (above) tells us, and also that time slows down in a gravitational field. The stronger the field, the slower time passes. Clocks on the surface of the Earth run slower than those that are, for example, 50,000 miles above the Earth's surface. It is from this theory that the concept of a "black hole" emerged. If you are very near to a black hole, time can actually come nearly to (but not quite) a complete stop. In addition, the GPS system that we find so useful would become highly inaccurate (i.e. "fail") if the time dilation effect of relativity theory was not incorporated into calculations performed by the system.

* Contrary to what most of us were taught in school about the "force" of gravity, Einstein showed that <u>gravity is not really a force at all</u>. The General Theory of Relativity tells us that if an object is falling in a gravitational field, there is <u>no force acting on it</u>. Rather, the object is simply following the natural curvature of the spacetime in which is embedded.

* Einstein's theories were considered to be so bizarre and counter intuitive to people (even scientists) of his time that he never received a Nobel Prize for the theories (the Nobel Prize he did receive was for his explanation of the "photoelectric effect" and NOT relativity theory).

<u>Quantum Physics</u>

Most of this paper is about things that are very large. However, we cannot ignore the small even when studying the large. On the small end of things, we are talking about sub-atomic particles such as protons, neutrons, electrons (and even smaller). It is important to study the small because it too helps us understand the universe at large. The study of how matter and energy behave at these levels is called Quantum Physics. The topic is much too huge to fairly describe in this short paper. However, in order to understand more about stars, nebulae, how our universe began and how it might end, we need to understand how the universe "manages" energy on a subatomic level. Below, I will briefly describe just a couple of interesting things we have learned from Quantum Physics.

* Wave-Particle Duality. For a long time, it was believed that subatomic particles (like electrons) were small balls of matter (like a billiard ball). It turns out that this is not exactly true. Somewhere around the year 1905 (or so), Einstein proposed that electromagnetic energy, such as light waves, could also behave like particles (you can look up the "Photoelectric Effect" on the internet). Then, in about 1924, Louis DeBroglie wrote a PhD thesis where he proposed the opposite. If electromagnetic waves could behave as particles, <u>should not particles also possess properties of waves</u>? It sounds preposterous...how could a particle be a wave? Well, in 1929, DeBroglie was awarded a Nobel Prize for his strange proposal because an experiment performed in 1927 showed that matter indeed can (and does) behave like a wave. The shortest way I can think of to explain this is called the "Double Slit Experiment".

To understand the famous Double Slit Experiment, picture electrons being fired, one at a time, at a screen that contains two slits that are parallel to each other. Behind that screen is a piece of film that detects where the photon hits after passing through one or the other of the slits (one electron can only go through one slit at a a time, right? It's either one or the other, or so it would seem.) Not so. The pattern that emerged on the film was an interference pattern, like you would get if a wave had passed through the slits. But to get that pattern, each single electron would have to go through both slits. This would be impossible if the electron is a little billiard ball, so the only solution was to acknowledge that the electron is actually a wave. Each electron is interfering with itself. Yet, when the electron wave arrives at the photographic plate behind the double slits, it collapses to a point. How this happens remains a mystery to this day. What we do know is that matter on all scales exhibits characteristics of both waves and particles. The wave nature of matter is not readily evident on macroscopic scales because the wave nature is too “small” to be noticed. On subatomic scales, however, the wave nature of matter is quite evident. So, matter is now known to possess both the characteristics of particles and waves.

* Atoms are typically shown as electrons orbiting a nucleus of protons and neutrons like planets orbit the sun in the solar system. In reality, Quantum Physics has shown that an atom actually resembles a standing wave pattern (i.e. a “fuzzy blob”), much more than it resembles a miniature solar system.

* The equations of quantum physics involve a great deal of statistical probabilities, rather than single outcomes.

* Because of Quantum Physics we have semiconductor technology, CD's, DVD's, transistors, lasers and so much more. The possibility of multiple universes has also emerged from Quantum Physics, along with other deep philosophical questions. The consequences of Quantum Physics, like Relativity Theory, are far reaching.

* The topic of Quantum Physics is much too large and complex to try to explain here. The attempt to describe the theory here in a brief manner, quite frankly, fails. However, the theory must be mentioned because of it's importance in understanding how our universe works on all levels.

* To close this inadequate discussion of Quantum Physics, I will simply state that I do not believe that there is any fictional story ever written that is as strange as Quantum Physics. It is “weirder” than one can imagine and in my opinion, no one could even make up anything as strange as how our universe works on a subatomic level. If you don't believe me, look it up and I think you will be convinced that reality is truly stranger than *any* fiction.

Size and Age of our Universe
* Our universe is estimated to be about 13.7 billion years old (since the “Big Bang” occurred). This is only an average estimate however, as the General Theory of Relativity tells us that time passes at different rates in different parts of the universe, depending upon the strengths of gravitational fields and relative motion of objects contained therein.

* The diameter of our observable universe is estimated to be about 99 billion light years. The actual size is very difficult to determine as our universe is observed to be expanding. Also, the “shape” of our universe is uncertain. Some current proposals tend to favor a “flat”, infinite spacetime manifold. However, there are also a couple of other possible shapes. The first involves negative curvature of spacetime (looks like the saddle of a horse), which is also infinite in extent. The other is a spherical shape (like a baseball), which has no boundaries and has finite, but unbounded surface. For the spherical model, you can try to visualize a 3-dimensional surface of a 4-dimensional sphere (just like a baseball has a 2-dimensional surface on a 3-dimensional sphere).

But Wait... There's Still More!
* In the summer, the Earth is positioned such that when you look in the direction of the constellation Sagittarius, you are looking directly toward the center of our own galaxy (the "Milky Way").

* In the winter, the Earth is positioned such that when you look in the direction of the constellation Orion, you are looking out into deep space, away from the center of our galaxy.

* **Pulsars** are rotating neutron stars. Neutron stars are the cores of "dead" large stars (more massive than our sun by 10 to 29 times) that have collapsed to a diameter of maybe 6 to 20 miles, but did not compress to the point of forming a black hole. The compressed matter in these stars is so dense that 1-teaspoon of the star can weigh as much as 6 billion tons! Now, consider the fact that the fastest spinning pulsar (known at this time) is rotating at an amazing 43,000 revolutions per minute (PSR J1748-2446ad). The surface speed is almost one-quarter the speed of light. The gravitational field of a typical neutron star can be as much as 2E+11 times as strong as the gravitational field of the Earth. Because of the intensity of the gravitational field, the time dilation effect described by Relativity (General Theory) can become significant to the point where for every 8 years that pass on the surface of a neutron star, 10 years pass on earth.

* **Gamma Ray Bursts (GRBs)** are extremely energetic bursts of electromagnetic energy (i.e. gamma rays) that are believed to originate from the material of an exploding star which is spinning and collapsing into a potential neutron star or black hole. GRBs have been observed to occur in distant galaxies (billions of light years) and can last from milliseconds to hours. Following the initial high-energy burst, a relatively long-lived "afterglow" consisting of lower energy electromagnetic waves such as x-rays, visible light (even radio waves) remain available for study.

<u>Dr. Sarah Yost</u> is the CSB/SJU resident expert in the area of GRBs. Dr. Yost's publications on this subject include the following:

1) Yost, S. A.; Moore, T. M. "A search for correlations between gamma-ray burst variability and afterglow onset", MNRAS 454, 3567 (2015)

2) Yost, S. A. et. al. "The Dark Side of ROTSE-III Prompt GRB Observations", ApJ 669, 1107 (2007)

* **Black holes**. Just about everyone has heard of these. Anything that falls into a black hole will never come out, including light. If the mass of our sun could be compressed down to fit in a diameter of about 3.6 miles, a black hole would result. However, because of the physics involved, collapsing stars require masses over about 20 times the mass of our sun to actually have the possibility of compressing/collapsing to the point where a black hole is created. Einstein's theory of General Relativity predicts that these objects could exist in our universe. Even though a black hole cannot be directly observed, they have been discovered by observing the effects of the black hole on surrounding objects. There is so much information available on the internet about black holes that it is not necessary to elaborate further here.

In Closing
This paper has already become 16 pages long, so it is time to stop. When you study the sky during your astronomy classes and labs, (or if you are just outside admiring the universe on a clear night) please keep in mind some of the information contained in this paper and realize that the study of the universe goes far beyond memorizing constellations and names of stars. The really amazing mystery begins when you put it all into context and have some understanding of what you are looking at in the sky. Hopefully that will inspire further study, or at least a sense of wonder at the beautiful and often bizarre universe in which we live.