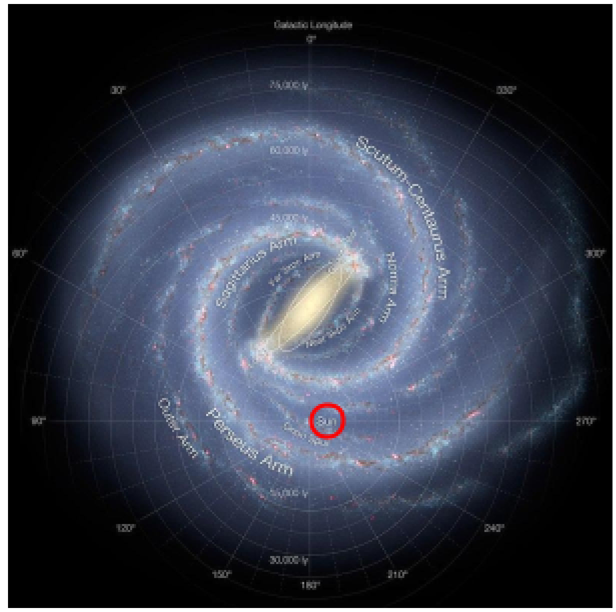
# THE NEBULAR THEORY

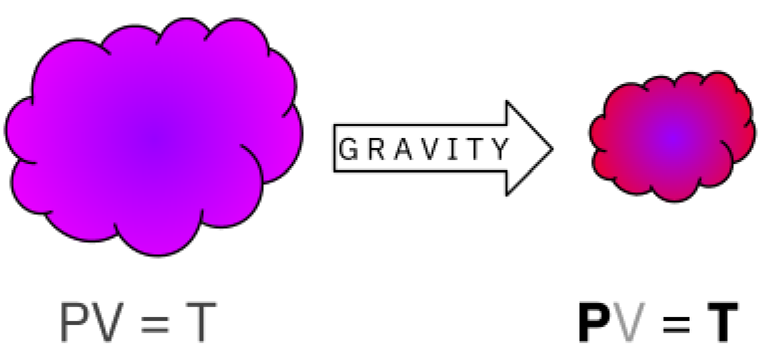
The Milky Way Galaxy is our home in the Universe. The Milky Way galaxy is one of about 125 billion other galaxies and itself contains 200 billion stars. When you do the math, this translates to 100-200 billion trillion (1,000,000,000,000,000,000,000) stars in the observable Universe. These stars may vary in size, temperature, and luminosity, but they were all created the same way. This is that story of creation.




Focusing in on the Milky Way Galaxy, you will see a high density of clusters of stars that form bright spiral arms, areas of relatively fewer stars that appear darker in contrast, and large clouds of gas and dust that we call nebulas. If undisturbed, these nebulas (made mostly of hydrogen gas) will remain peacefully floating in space unless disturbed by an outside force. This outside force usually comes in the form of a shockwave from a nearby star that goes supernova. These are some of the most violent explosions in the Universe and the energy they release is enough to start mixing up the gas cloud.

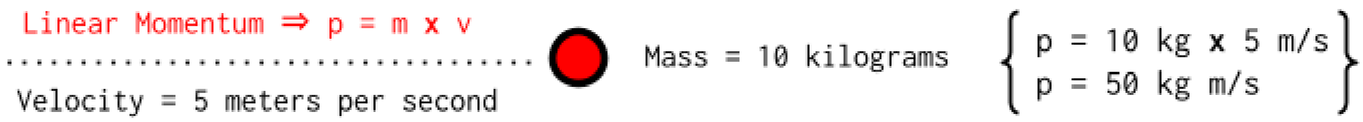
4.5 billion years ago, a supernova exploded and disturbed a nebula in the Orion Spur of the galaxy (circled in red). As the gas and dust in the nebula began to move due to the shockwave of the supernova, some areas began to increase in density as gas and dust particles were attracted to each other. This process of objects coming together under the force of gravity is called accretion and drives the entire process of star and planet formation. As small pockets of gas and dust accrete, so does their overall mass and as a result they exert a greater force of gravity on surrounding objects.

With the nebula beginning to contract under the force of gravity, the temperature in this once freezing region of space began to heat up tremendously. The reason for this increase in temperature is that as particles move closer together their chances of hitting and interacting with other particles increases significantly. Each of these interactions produces friction that in turn gives off heat. The physics that dictates this is called the Ideal Gas Law. This diagram on the left demonstrates how this process works on a fundamental level.

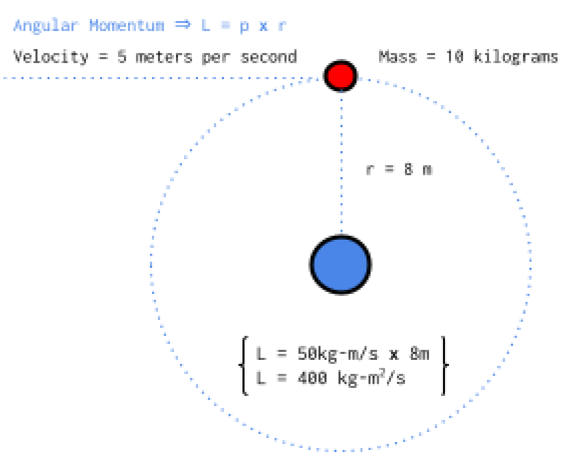



Ideal Gas Law → PV = nRT. We ignore n and R here because they remain constant. As gravity contracts the nebula Volume (V) decreases. This is offset by a massive increase in Pressure (P) and this leads to an overall increase in temperature due to particle friction.

As the nebula contracted under the force of gravity and its temperature increased, another interesting thing happened. The nebula began to spin and as its volume decreased the rate at which it spun also increased. To explain this behavior, we have to look at the concept of momentum. This is something you've seen before when a figure skater brings their arms in to spin faster...but why? To answer this we will look at an object moving a straight line. We refer to this as its linear momentum, or the rate at which it is traveling in a straight line. To calculate the linear momentum we multiply mass by velocity...

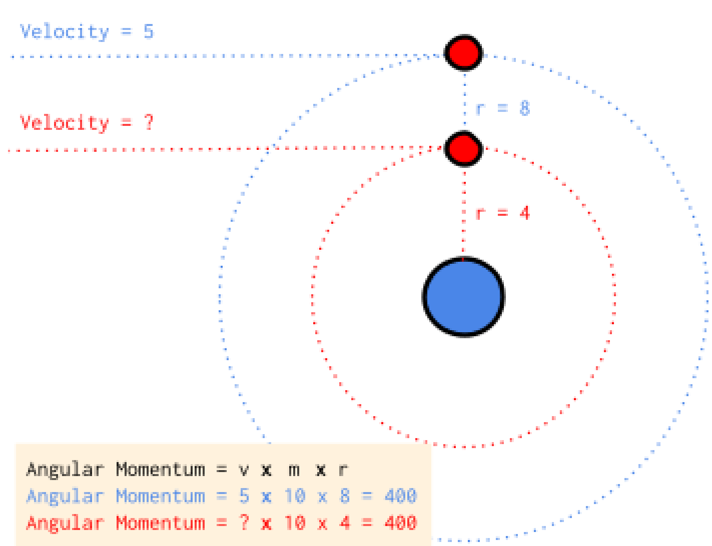



As demonstrated in the diagram above, this applies to objects moving in straight lines, but the material in the nebula is moving in a circular motion and so the math changes slightly and one major law comes into play. This is the Law of Conservation of Angular Momentum. Before we talk about this law, we need to establish how it works and for this you can refer to the diagram below.



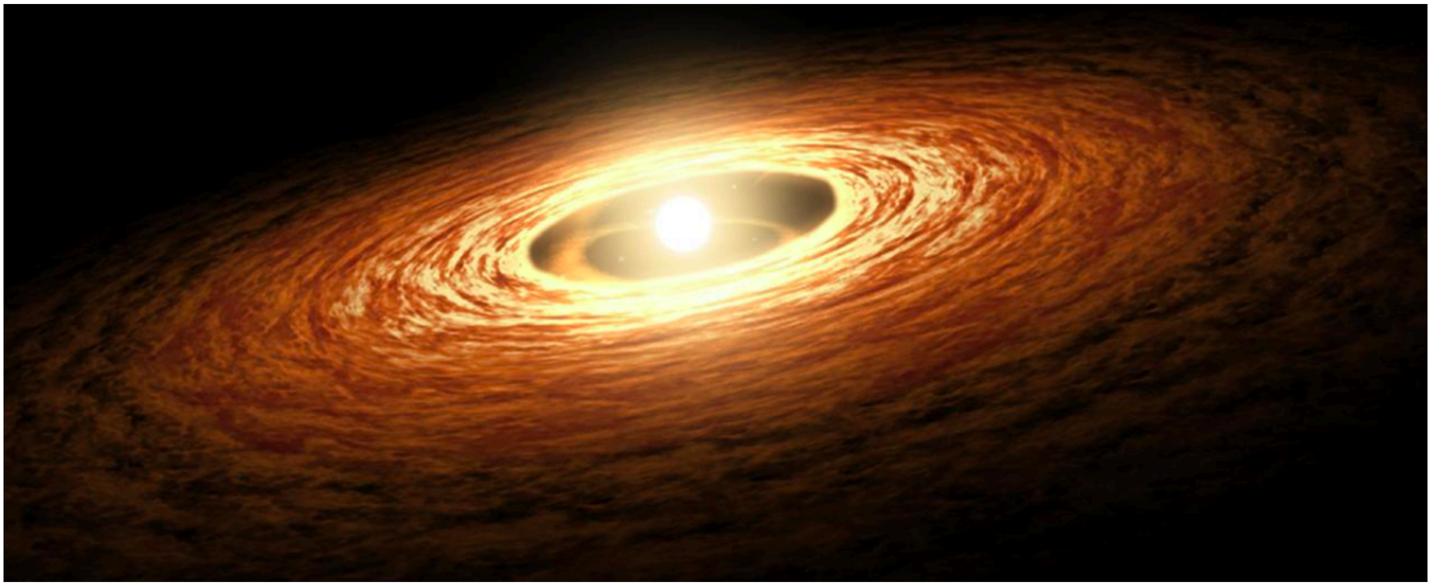

If we have an object rotating at a distance about its axis or an object traveling around a focal point like the blue circle, we are able to calculate the Linear Momentum by multiplying the Angular Momentum by the radius the object is rotating about its axis or revolving around another object. Here is the tricky part, while we can change our linear momentum, angular momentum must always be conserved (remain constant). This is why the nebula will spin faster because the radius of the nebula is getting lower so another variable must increase to conserve the Angular Momentum.

To illustrate this process clearly, we will pretend that the diagram above shows a top down view of a spinning nebula with L = 400 kg-m$^2$/s. We will simulate the contraction and see how this changes the velocity of its rotation.

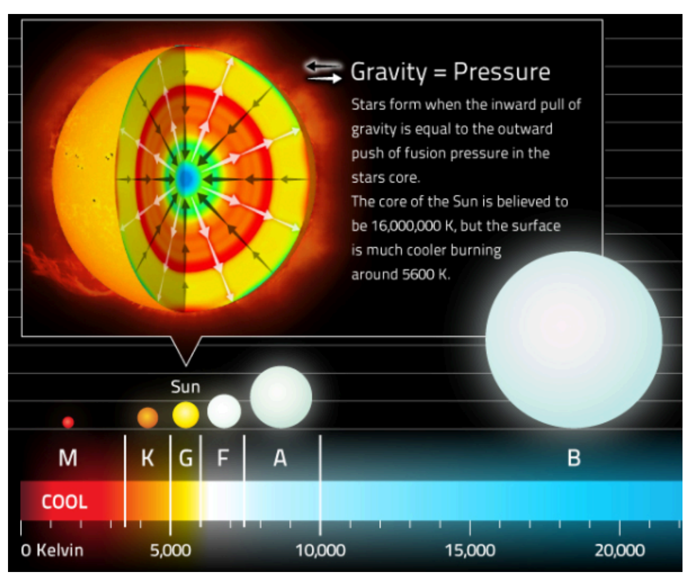



As you can see, as the radius decreases, a change to either the mass or the velocity must be increased to conserve the original Linear Momentum. Since the mass of the nebula is not changing, it must therefore increase its velocity to conserve momentum, and this is why not just nebulas but all objects closer to the point of rotation or revolution move faster.

Now that we understand how the Ideal Gas Law and Conservation of Angular Momentum contributed to the heating and motion of the nebula, we can now observe what our solar system once looked like at this moment in the process.



The rapidly spinning nebula began to flatten out into an accretion disk with the majority (over 99%) of the matter accreting in the center and the rest fanning out for millions upon millions of kilometers. Where the mass was greatest in the center, so was the force of gravity and this contributed to even greater levels of pressure and much higher temperatures. The growing object in the center would one day transform into our star but with insufficient heat to undergo nuclear fusion at this point it was classified as a protostar. Out in the disk, a similar process of accretion was occurring and here, objects that would someday become the planets (called planetesimals) and other bodies in our solar system were taking shape.




At this time, approximately 100,000 years had passed and our solar system was one important event away from its birth. That event was the transformation of our protostar into the sun and for this to happen, a temperature of 15 million degrees celsius would need to be reached to initiate nuclear fusion. Fortunately, gravity was still increasing the pressure on the protostar, steadily raising its temperature as per the Ideal Gas Law. When the temperature was reached, hydrogen atoms in the core of the sun were able to collide with such force that their nuclei fused into heavier elements, simultaneously releasing huge amounts of energy.

This initial fusion also released solar wind, a violent storm of highly charged electrons that left the sun traveling over 1.5 million kilometers per hour. This solar wind blew the gas in the accretion disk towards the outer solar system and stripped the inner planets of large amounts of gas in their atmosphere. The temperature of the inner solar system was also hot enough that stable gas planets could not form and this is the primary reason the inner planets (terrestrial) are small, rocky bodies whereas the outer solar system is dominated by gas giants (jovian planets).