Early Star Formation: The Radial Infall Model

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Ever since the beginning of humanity humans have pondered their existence and the universe that we exist in. As time and experience passes on, our understanding of the universe grew deeper. A big jump in that understanding occurred when the first radio antenna was used to identify an astronomical radio source. It was built by Karl Guthe Jansky, an engineer with Bell Telephone Laboratories, in 1931. This gave astronomers the ability to "see" a side of the universe previously unavailable and propelled the field of astronomy.

At the heart of every solar system is at least one star. From our own experience with our own sun we know that it is absolutely necessary for life to exist. It provides Earth with heat and light and is responsible for making all the energy we use today, such as oil, coal, and other fossil fuels. It makes sense then, as a point of intellectual curiosity, to understand everything there is to know about a star; from its initial formation to its eventual collapse and everything in between. To date we already know much about how stars evolve and how stars die[1]. Yet, not much is not about *how* stars are actually formed in the first place. Indeed the universe is the most complicated system one can imagine. So to get a first impression one must start with a simplified model.

Before one dives right into the subject of star formation, one first needs to have some background knowledge so that he or she can get a basic idea of research conducted to date, how it works and what conclusions can be drawn. When ancient astronomers looked into the sky they could only see the visible part of the electromagnetic spectrum (EM). The visible part of the EM spectrum is noted by its wavelength (λ) ranging from 400 nm (nanometers, 400 x 10^{-9} m, or .0000004m) from blue light, to 700 nm for red light. It is now known that in addition to visible light there are ultraviolet, infrared, microwave, x-rays, and gamma rays parts to the EM spectrum. Each having its own unique properties to exploit for observation.

Now modern astronomers make use of other parts of the EM spectrum to observe the known universe, in particular, the radio waves, where many molecules have excitation energies. Also radio waves are not obstructed by entering Earth's atmosphere which is necessary for land based observatories. By pointing a radio telescope into the sky astronomers can determine many parameters including but not limited to the composition, density, temperature, and distance of astronomical objects in the sky. Two principles of Physics that are necessary to make maximum use of the data from a radio telescope are the Doppler Effect and Spectroscopy.

The Doppler Effect is a wave phenomenon. The Doppler Effect is a change in frequency of a wave resulting from moving sources and or receivers. An example of this is heard every day with fire or ambulance sirens. As the siren moves towards us the frequency increases with respect to the people in the fire truck or ambulance and as the siren moves away from us the frequency decreases. Of course if the siren is at rest you hear the same sound as the people in the fire truck.

[1] There is a nice chart showing stellar evolution at the following url: http://astronomyonline.org/OurGalaxy/Images/EvolutionNormalStar.jpg

Mathematically[2] it can be described as $\Delta f = f * v / u$. Where Δf is the change in frequency, f is the source frequency, v is the relative speed at which the source and observer are moving with respect to each other, and u is the speed of the wave in the particular medium it is traveling in. In our case u will be the speed of light in a vacuum, 3×10^8 m/s.

What is true for sound waves is also true for EM waves. So if one knows what a particular wave's source frequency we can determine how far away said object is traveling towards or away from us. This brings up the obvious question, "How do we know the source frequency"? Which leads one to a brief discussion of quantum mechanics. It turns out that objects, this case molecules or atoms, emit radiation of a very specific frequency when they are lowered from a high energy state to a lower energy state. The reasons for the change of states are not a concern at this point. Only that such change occurs and that the radiation can be observed.

The compound carbon monosulfide (CS) is a good candidate for observation. First because it has a high magnetic dipole moment (μ=1.96 debye). It also has a high enough abundance in most molecular clouds and is not subject to "peculiar chemistry effects" (Mardones et. al (1997). For a particular change in energy produces a particular frequency but since the universe is expanding that frequency is Doppler shifted by some amount. By observing the same excitation in the laboratory we know what the source frequency will be. With that information we can calculate how far away the object is moving relative to Earth. For CS transitioning from J=2 to J=1 the preferred frequency is 97980.950 MHz (Caseilli et al. 1995). Observing the changes in frequency is known as spectroscopy and is a very useful tool for astronomers.

Now that one has an idea of some of the principles guiding this paper is it time to discuss star formation. In the night sky there are many dark patches. Yet when a radio telescope is pointed at it one receives radio radiation. How do we explain this? The first to explain it was Bart Bok in 1946 (Bok 1948) when he claimed that the dark nebulae are the sites of stellar birth. It turns out that we are unable to physically see these nebulae because of dust that absorb visible light and thus block all light that is on the other side of the object in our line of sight.

There are many mechanisms that initiate star formation in these dark nebulas, though all have the same affect of bringing loosely connected matter closer together until there is enough matter closely packed to undergo fusion. These main mechanisms include: ram pressure, magnetic forces and gravity. Gravity has the biggest influence in star formation and as a subject of Physics is well understood. We known that gravity brings any two particles closer together but when dealing with a massive body such as a dark nebula the way in which gravity works is not as simple as a two particle example.

As with any complex system we must first break down the complex nature by making certain assumptions and then test those with recorded observations. One such model is the De Vries & Myers Model (De Vries 2005). This model assumes a spherical molecular cloud where the matter infalls radialy (fig 1). This has the particular advantage that no matter where we are observing from we would record similar data because of the symmetry of the system. Say for example that a particular molecular cloud had a spiral infall (fig 2), then an observer on earth would receive different data than from an observer in another star system. When in the end what the

[2] This is true only in the case where $v << u$. The full relativistic Doppler Effect is unnecessary for speeds we will consider. For further analysis of this principle see Modern Physics 3rd Ed. By Thornton and Rex Pg. 53.

particular molecular cloud is doing *is* independent of the observer.

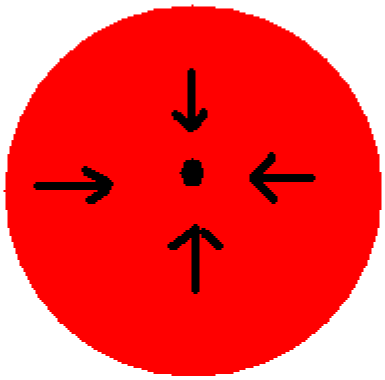
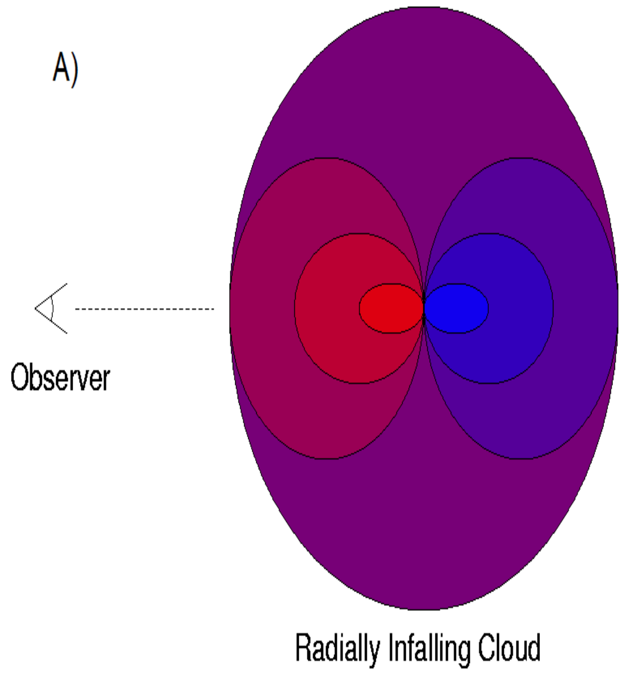
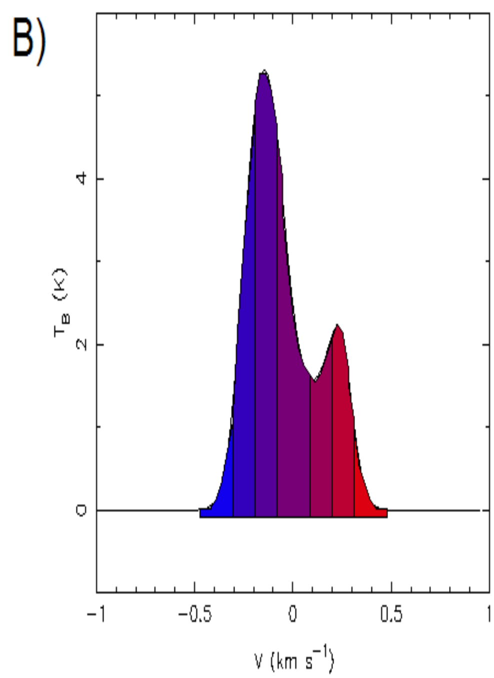


Figure 1

All the mass is falling radially into a central core.

Using the radial infall model we can deduce several things. First the mass that is on the side closer to us will be redshifted. Redshifted is a term used to describe a result of the Doppler Effect when an object is relatively moving away from its receiver. The mass on the far side of the molecular cloud will be blueshifted because it will be closer relatively closer to earth (fig 3 A)[3]. In addition we get a blueshifted asymmetric line profile. What this means is that when we observe the emission of radiation from a molecular cloud we get more blueshifted radiation than we do redshifted. The reason for this is that molecules on the far side of the molecular cloud (blueshifted) are unabsorbed as they pass through the core due to the high excitation temperature at the center of the core and again unabsorbed as it passes through the front. Whereas the molecules one the near side of the molecular cloud (redshifted) are absorbed by nearby molecules because there is a lower excitation temperature away from the core of the molecular cloud (fig 3 B)[3]. This blueshifted asymmetry is a useful parameter in studying the infall of molecular clouds.

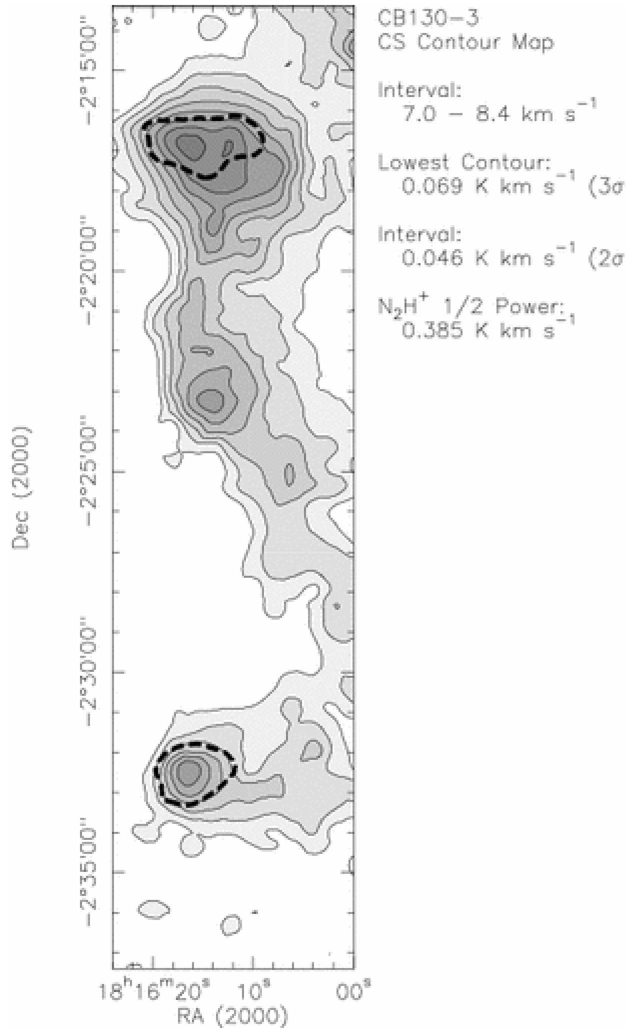




[3] From: http://kepler.csustan.edu/astrowiki/ResearchPages

The work I am conducting consists of analyzing data from observations of molecular clouds to deduce if there are any candidates for star formation. The data has already been compiled and is ready to be analyzed. I will be analyzing line profiles similar to what you saw in figure 3-B. I encourage all who read this to go to http://kepler.csustan.edu/astrowiki for updates concerning my latest research findings.

One such cloud that I have already looked briefly into is CB 130-3 located at a declination of -2° 18min and right ascension of 18 hours 16 minutes 20 seconds. Figure 4 shows a contour map of CB 130-3 with respect to CS. The areas with more color show regions with higher densities of carbon monosulfide and are excellent places to start my investigation into the infall model.



To reiterate, much information has been gathered to date on star formation, yet there are still many uncertainties. This research will help to show that such a model can be used to accurately predict star formation in molecular clouds. Eventually we can predict star formation in other molecular clouds. Our solar system was once a molecular cloud and it condensed into a star and ejected mass that later became Earth and all the other planets and asteroids in our system. So by understanding star formation we are in a sense better understanding where we as a species originated

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References

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