The First Good Look At The Coolest Stars In Our Universe

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- Title: The First JWST Spectral Energy Distribution of a Y Dwarf
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Stars form from large clouds of gas that slowly collapse together under gravity. Once enough gas gathers close together, gravity forces the atoms at the core of this cloud close enough to start combining together. This is the process of fusion, generating the energy that causes every star to emit heat and light. However, if there is not enough gas in the cloud, the new object will not be massive enough to fuse most elements, like the Sun does. This forms what is called a brown dwarf star. These stars are about the same size as the largest planet in our solar system, Jupiter, but are about 15-80 times as massive. Compared to the Sun, they are about one tenth the size and have about 1.5-7.5% the mass. Despite being so small compared to the Sun, they are big enough to fuse some special versions of hydrogen, called isotopes, into helium, generating some heat. There are several different types of brown dwarfs, separated based on their size. Here, we will focus on the smallest brown dwarfs: Y dwarfs.

First, however, a detour into talking about light. Visible light is a part of what we call the electromagnetic spectrum, alongside radio waves, microwaves, and x-rays. As can be seen in some of their names these are all waves, meaning that they move through space oscillating at some frequency, like sound waves or water waves. If you look at the same point in the ocean, a wave will pass by, and then some time will pass, and then another wave will pass by. This is the frequency of those waves, and unlike with ocean waves, light waves have the same size every time they pass. For sound waves, the frequency of the wave is related to the pitch of the sound we hear, but for light the frequency is related to the color we see it as! In fact, there are many frequencies of light that are outside what we can see, such as infrared or ultraviolet light, or radio waves and microwaves as mentioned above. We can see the specific range of frequencies that are visible to us because the cells in our eyes absorb those frequencies and no other ones!

When we look at distant stars, we know what frequencies of light they should emit in what is known as their emission spectrum. This is because stars let off light based on how hot they are, just like when metal is glowing red-hot. However, when we look at these stars, we do not see a perfect emission spectrum like we might naively expect. To explain this, we need to talk about how molecules interact with light. Molecules don't absorb every frequency of light, just like our eyes. In fact every type of molecule (like oxygen, or helium) has a unique way they absorb light, which is called their absorption spectrum. As the light makes its way out of the star, the molecules in the outer layers of the star absorb the light they want, leaving the emission spectrum missing those frequencies. Since we know what frequencies molecules absorb, we can compare the missing frequencies from our ideal case emission spectrum to the one we see, and take a very solid guess of what molecules there are in the star!

This paper does exactly this with a Y dwarf, for the first time ever due to the unprecedented accuracy granted by the James Webb Space Telescope. Looking at the figure on the next page, we can see some of their results. The x-axis is measured in wavelength, which is just another way to talk about the frequency or color of light like we have before. The y-axis is just how bright that specific wavelength of light is. The black line is the emission spectrum we see from the star, while the colored lines are the absorption spectra of various molecules that they believe are in the star. By comparing the colored lines and the black line with just our eyes, we can see that the dips and rises in the lines do appear connected to the dips and rises in the black line, in some areas more obviously than others. This is most notable in the bottom graph, where the emission spectrum of the Y dwarf takes a very big drop exactly where the yellow line does. The yellow line represents the spectrum of NH3, better known as ammonia, telling us that it is very certain ammonia is in the star! The other molecules they note are H20 (water), CH4 (methane), and CO (carbon monoxide).

The question is, what does seeing these patters even mean? The first interesting thing to note is that Y dwarfs are not hot enough to fuse heavier elements like oxygen, nitrogen, and carbon, and yet they have molecules made from those inside it. This means that they most likely formed from the debris left by dead stars. The second thing to notice is that these molecules must be near the surface of the star to have their effects be seen, but these are pretty heavy elements. We'd expect them to sink to the middle of the star beneath the lighter elements like hydrogen and helium, like a rock dropped into water. This means that there must be something more happening here! The paper

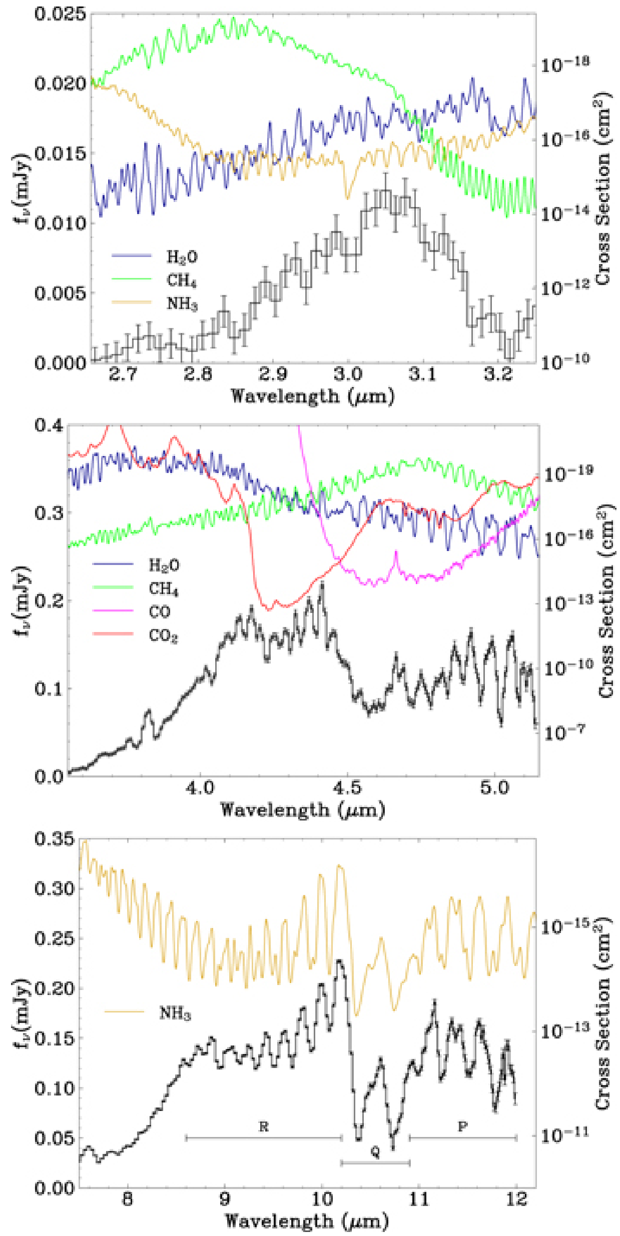

FIG. 1. Luminosity vs. wavelength for the spectrum of the Y dwarf examined, in black, and the absorption spectrum for several elements thought to be in the star, in different colors [1]

tried a ton of different models to explain the emission spectrum they saw, and the ones that fit best were ones that included disequilibrium. If the star is in equilibrium, it would be like a smooth pond, where we'd expect the heavier elements to sink like rocks. Disequilibrium is more similar to a rapid river, where a rock dropped in would be swept around and away, and not necessarily settle to the bottom.

This model is not definitive, but it gives us a big clue into what is going on in these dwarf stars. As we learn more about Y dwarfs, we learn more about stars. As we learn more about stars, we learn even more about how our universe works!

[1] S. A. Beiler, J. D. K. M. C. Cushing, A. C. Schneider, S. Mukherjee, and M. S. Marley, The first jwst spectral energy distribution of a y dwarf, The Astrophysical Journal Letters **951** (2023).