Nebulae: Crash Course Astronomy #36

Crash Course: Astronomy
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Astronomers have it pretty easy when we talk to the public. I may be biased, but I think astronomy is the most beautiful of all sciences. Sure, other fields of science have lots of eye candy, but all I have to do is pull out a shot of Saturn and I win because... Saturn. It's all gorgeous: planets, moons, stars, clusters. But of all of them, you just can't beat a nebula. Why? Because nebulae.

(Intro)

"Nebula" is Latin for "cloud," and for once in astronomy we have a name that actually describes the object accurately. Nebulae are clouds of gas and dust in space. I've already talked about them a bit. For example, stars form from nebulae. Our Sun did about 4.6 billion years ago. When a medium size star dies, it blows off winds of gas then lights them up as the white dwarf core of the star is revealed, creating a planetary nebula. Also, when a high-mass star explodes, it catastrophically vaporizes itself, becoming a violently expanding cloud of gas. Nebulae are literally part of the births, lives, and deaths of stars. So, besides being beautiful, they're also pretty versatile.

There are a lot of ways of categorizing nebulae. One way is by how we see them. For example, if a cloud of gas is blasted by light from a nearby massive star, the gas in it becomes excited-- the electrons in its atoms jump up to a higher energy level. When the electrons drop back down, they emit light, the gas glows, and we call this an *emission nebula*.

The color of an emission nebula depends on the gas in it and how hot it is. Hydrogen, for example, glows most strongly in the red, and we see that color in most emission nebulae. Oxygen tends to glow green, but to a lesser extent it gives off blue light too. Other elements span the spectrum in the colors they give off. And these colors are not limited to visible light. Hydrogen can emit infrared, and even radio light. And if it's energized enough, it'll emit in the ultraviolet too. That's true for many elements.

Although most emission nebulae look substantial, they're actually incredibly tenuous. A typical density in a gas nebula is only a few thousand atoms per cubic centimeter. Mind you, in the air you breathe there are about 10 to the 19 [10^19] atoms per cubic centimeter-- a thousand trillion times denser than a typical nebula.

Really, a nebula is barely more than a vacuum. The reason they look so cloudy is that they're big. Really, really big. A decent size nebula is several light years in diameter and that's a lot of centimeters. That much gas adds up, and so some nebulae can be pretty bright.

While emission nebulae glow due to their own light, *reflection nebulae* are bright because (can you guess?) they reflect the light of nearby bright massive stars. In this case though, the nebula isn't made of gas, but is instead mostly dust. I don't mean like the hair and skin flake dust bunnies you find under your couch, either. When astronomers talk about dust, they mean tiny grains a micron across. Just so you know, a human hair is 100 times wider than that.

These tiny grains contain things like silicates, aluminum oxide and calcium, and in many cases this dust is laced with complex molecules called *polycyclic aromatic hydrocarbons*. While I love that fancy name for it, you might know them better as soot. Yup, when you light a match, you're pretty much making some of the same stuff that lurks between the stars.

Dust doesn't emit visible light, but it can affect the visible light from stars if they're inside the dust cloud or nearby. Turns out, dust is very good at scattering light. That means that when light hits it, the light gets sent off in some other direction. This scattering is highly wavelength-dependent, so blue light is scattered very strongly,while red light can go right through.

We saw this in the last episode. The dust surrounding the Pleiades star cluster is a reflection nebula. The light from the stars in the Pleiades is scattered by the nearby dust, and the blue light gets sent in every direction, including toward us. The red light doesn't scatter nearly as well so we don't see it. It never gets sent toward us.

Thick dust is also very good at absorbing visible light. If a star is embedded in enough dust, the light from it is dimmed considerably. If the cloud is dense enough or big enough, the dust can completely extinguish the light seen from a star.

At the same time, if the dust is at the right density, the blue light from a star inside a dust cloud gets scattered while the red light can get through. This effect reddens starlight, and in some dust clouds it provides a striking view. Stars outside the cloud look normal enough, but closer in they get redder and redder, and then fade out entirely. The result is a fuzzy red-edged hole in space. Pretty cool.

You can see that effect in Barnard 68, a small dust cloud just half a light year in size. These are also sometimes called molecular clouds. They're cold enough that atoms can stick together to form molecules. Their cores can be hundreds of degrees below zero Celsius.

Some dust clouds like this are relatively small, but others can get downright huge. We call these giant molecular clouds because why not? These can be incredibly massive with thousands, or hundreds of thousands, of times the mass of the Sun and stretch for hundreds of light years. And that brings us to one of the most glorious objects in the sky: The Orion Nebula.

This is an emission nebula located just below Orion's belt. It's actually a naked-eye object, visible in modestly dark skies. It looks like a star by eye, but even binoculars reveal it to be fuzzy. And through a telescope or with long-exposure images, you get unmitigated majesty. The Orion Nebula is a star-forming factory; a bunch of stars have been born in it. Some of them are very massive and incredibly luminous. The entire nebula is lit by four stars located in its heart, collectively called the Trapezium. These are four brutes, huge brilliant stars that are each far more massive than the Sun. Their light is so fierce it illuminates the entire nebula, which is about 20 light years across.

And here's a funny thing about Orion, what you're seeing is not just a gas cloud in space. It's actually just a bubble sitting on the edge of a much, much larger molecular cloud hundreds of light-years across. That cloud is cold and dark, so we don't see it by eye. The Trapezium stars formed inside that cloud, very near the edge. When they turned on, fusing hydrogen into helium, they started blasting out a mind-numbing amount of ultraviolet light, which began eating away at the gas and dust. Eventually, they blew a hole in the side of the cloud like a weak spot in a bicycle tire blowing out. What we see as the magnificent Orion Nebula is just a dimple, a cavity in the side of the cloud, filled with gas heated to glowing by the stars.

There are still stars forming there today too. I mean literally right now. We can see it happening. In Episode 9, I talked about the Solar System and how it starts off as a flattened disk of gas and dust. When we look at the Orion Nebula with Hubble, we see those disks. They're called *protoplanetary disks*, and they're so dense that they absorb almost all the light from the stars forming inside them. So they're dark, and we see them in silhouette inside the brighter gas of the nebula

Unless you look in the infrared. That kind of light can pierce the

dark disk, and when we use infrared telescopes, we can see the protostars forming in the centers of those disks. Take a good look, those are baby stars. Literally stars that are forming right this very minute. They're still hot due to their contraction, but in a few million years they'll ignite fusion in their cores and become real stars. They'll blow away the remaining material around them, revealing themselves and perhaps any planets orbiting them as well.

In fact, once stars start forming inside a nebula, its days are numbered. The Eagle Nebula is another star factory with active star birth going on inside of it. Some of these are massive luminous stars and give off so much ultraviolet light, it erodes away at the surrounding nebula in a process called photo-evaporation. However, dense knots of material forming new stars can resist that erosion better and protect the material behind them, in essence, shadowing it. This results in long fingers of material we see in silhouette against the hotter gas, like sandbars in a stream. Observing their infrared light, we can also see the stars embedded inside them.

There are several of these giant towers in the Eagle Nebula, three of which have been called the Pillars of Creation. Stars are forming at their tips. Eventually though, the light from the massive stars will win, zapping away at the structures, dissolving them. There's also some very hot gas in the nebula that might be the result of a star that has already exploded. If so, then the pillars really don't have long to live. In a few thousand years they won't be eroded away, they'll be blasted away.

In a lot of nebulae there's no sharp edge, they just kind of fade away. Sometimes that's because the gas thins out so there's not enough stuff there to get lit and see. Other times it's because there's just one, or maybe a few stars lighting up the whole cloud, and at some distance from them the starlight fades and can't illuminate the gas anymore.

But sometimes nebulae do have sharp edges. That usually happens when a gas cloud is expanding, like in a planetary nebula or supernova. The gas slams into the much thinner gas that is strewn between the stars--what we call the interstellar medium. The expanding gas piles up like snow in a snow plow, getting denser and glowing more brightly.

Gas inside a nebula can be in turmoil too. Winds from stars compress the gas, shockwaves form when stars explode and when they're born. These can create lovely sheets, tendrils, and filaments in nebulae as well. All of these factors can come together to create great beauty.

Not too far from the Orion Nebula in the sky is another dark nebula superposed on a bright emission nebula. By coincidence, the dense dark material is shaped like a gigantic chess piece and it's called the Horsehead Nebula. It's being eroded by a star called Sigma Orionis off the top of the frame here, and that's also making the gas behind it glow in that sharp ridge.

One of my favorite nebulae in the sky is Barnard's Loop - a huge arc of material that's formed either by the expanding gas from supernovae or the winds of all the massive stars being born in the Orion Complex. It's also the outer edge of a huge bubble surrounding a substantial amount of real estate in the constellation Orion. In this image, you can see both the Orion and the Horsehead Nebulae. The Loop is so big you could fit 25 full moons across it.

One more thing, I've been talking about bright and dark nebulae but that's an old fashioned way of thinking of them. I've also mentioned that infrared light can get through them. But remember from Episode 24 that the kind of light an object gives off depends on its temperature. Clouds of dust that look dark to the human eye are actually glowing if you observe them in the far infrared, well outside the colors our eyes can detect. But we have telescopes that can see at these much longer wavelengths.

In Orion, there's a reflection nebula called M78. Between M78 and Earth, are long filaments of very cold and dark dust blocking the light from the reflection nebula behind, and looking like dark rivers running through it. But when you use a telescope that can see light with a wavelength of a millimeter or so, that dust glows brightly, threading through M78 like ribbons of fire. Like so much else in life, what you see really depends on how you see it. If there's a life lesson there, feel free to take it.

Today you learned that nebulae are clouds of gas and dust in space. They can glow on their own or reflect light from nearby stars. When they glow, it's usually predominantly red from hydrogen and green from oxygen. And when they reflect and scatter light, it's from massive hot stars, so they look blue. Stars are born in some nebulae and create new ones as they die. Some nebulae are small and dense; others can be dozens or hundreds of light-years across. Also, they're incredibly beautiful.

Crash Course: Astronomy is produced in association with PBS Digital Studios. Head over to their YouTube channel to catch even more awesome videos. This episode was written by me, Phil Plait. The script was edited by Blake de Pastino and our consultant is Dr. Michelle Thaller. It was directed by Nicholas Jenkins, edited by Nicole Sweeney, the sound designer is Michael Aranda, and the graphics team is Thought Café.