DJORGOVSKI: Let's first talk about the interstellar medium in our galaxy. And here is one of the pretty pictures from the Hubble that shows a reasonably typical combination of interstellar clouds.

So simply it is the gas and dust between the stars. And it is generally mostly concentrated in the galactic disk, but not entirely. It's stuff from which stars are made, for galaxies for that matter. All of the baryons in the universe, you know protons, neutrons, and electrons go on with them, were originally in the form of a gas. And now we think that in fact maybe 90% of all ordinary matter in the universe is in the form of gas, not stars.

So starts are in sort of an ecological equilibrium with the interstellar medium. They form from interstellar medium, from gas clouds that condense, we'll talk about that in a moment. They live their lives. Then some of them explode. Others lose their envelopes. And thus they contribute back to the interstellar medium. But the material that comes out of them was enriched by heavier chemical elements that were cooped up in stars. And then new stars form.

Stars also interact with interstellar medium. They can change it. They can ionize it. They can be the mechanical effects of shock waves. And so it's a fairly complex system. And there isn't the continuum of properties. But it does fall into several different categories that I'll define in a moment.

So there are three basic forms of interstellar gas that are associated at least with the galactic disk. First young stars emit lots of UV radiation, and that means they will pump up internal energy levels of atoms or ions to higher energies. Which occasionally they will lose electrons. And they will recombine. And when they do this they shine emission lines. You'll see the red color tends to go with these. And anybody has a guess what is the spectroscopic line that dominates this?

Let's try this way, what chemical element is it likely to be from?

STUDENT: Hydrogen.

DJORGOVSKI: Yes, hydrogen. And so anybody care to guess what's the spectroscopic line? Which line series of hydrogen is in the visible part of the spectrum?

STUDENT: Balmer Series.

DJORGOVSKI: Balmer series, that's right. And the strongest of those will be the first line, alpha. So this is H alpha, as it's called. There are others, of course. But that's what tends to carry most of the energy in these recombination nebulae, at least in the visible part of the spectrum. And that's what gives them this reddish color.

What about the blue stuff? Do you think that's also ionized gas? Sometimes a little bit. But mostly that's just star light reflected from interstellar dust. Now you don't think of dust as a mirror, or a little dust grains. But they will reflect some fractional of photons that come up them. And the reason why it tends to look blue is that youngest stars, young stars, the most luminous ones are the hottest ones. And does most of the starlight in the vicinity of star forming regions tend to be dominated by very blue continuum light. So you see a reflection of it off of dust clouds.

And then there are dust clouds, which usually appear as shadows on the optical picture hiding stuff behind them. But if you were to take a look in far-infrared, you will see them shining bright in thermal infrared. They absorb visible light from starlight. Then they get heated up to temperatures of tens, sometimes a couple hundred degrees Kelvin. But usually, it's tens. And they meet in mid to far-infrared.

You probably remember Wien's law, which connects temperature with the peak wavelength. So for solar type radiation temperature of the sun is 6,000 degrees roughly speaking. Where does the spectrum peak? Around which wavelength? You have eyes that see in the visible part of the spectrum. And so what could it possibly be? Yeah?

STUDENT: [INAUDIBLE].

DJORGOVSKI: Well, yeah very smart. Now where exactly? Well, kind of in the middle. It's more like yellowish light is about 5,000, 5,500 angstroms.

OK so the sun is 6,000 degrees. And let's say an interstellar dust cloud is at 60 degrees Kelvin. What would be the peak wave length of that? Starting with say 500 nanometers? I'll let you figure this one out for yourselves. But it would be in far-infrared, maybe even submillimeter regime.

So I've said that there are several different components. Two of them were captured in that picture, the cold and the warm gas, Cod gas and dust tend to be the lowest temperatures of some 10's of Kelvin. Molecules tend to be well mixed with dust grains. And only a small fraction of full volume, but maybe a lot of mass, is contained inside these cold clouds. They are all exclusively in the thin disk of the Milky Way. And that's where stars are formed. They're obviously not well ionized because they're cold. And their primary importance is that this is what stars are made from. Stars are made exclusively from cold interstellar gas and dust.

Warm is the one that makes pretty pictures. It is the ionized gas, mostly hydrogen. Has temperatures of some thousands of degrees, typically maybe around 10,000 degrees Kelvin. And all of it is ionized, not necessarily all. And it shines in these nice recombination lines. So that tends to fill most of the volume around clouds of the cold gas.

And then there is a hot component that you didn't see in the previous picture because it doesn't shine much in visible light. It is a gas that is heated it maybe a million degrees Kelvin. And therefore it shines in x-rays. That gas is filling up the galactic halo. It's not a dark matter halo. Its regular matter mixed in. But it's no longer confined to the disk. Can you guess how did it get there? And why did it get hot? If it's hot, what does that mean in terms of the kinetic energy? Low kinetic energy or high kinetic energy? Well what's the relation between kinetic energy and temperature for a gas?

STUDENT: High kinetic energy?

DJORGOVSKI: Well, that's right. It's proportion between kinetic energy and temperature. So if this gas is high temperature that means those atoms or ions have received all the kinetic energy from somewhere. And to spare you the agony of having to answer the question, they got there largely due to supernova explosions. Which obviously impart a lot of kinetic energy into the interstellar medium. At the same time they can heat up the gas. So because of the gas's law of kinetic energy it flies high above the galactic disk. And just like any gravitational system would work.

OK so where is the gas? This is an actual picture of the Milky Way, from here. And we are in disk, and this is a mosaic of near infrared imagery from the two microns sky survey. And almost all of the gas is concentrated in this very thin disk. And then there is this corona which has some of the hot gas, which really is a negligible component by mass. But it's interesting physically.

So in studying a interstellar medium you may recall there is this hyper fine structure line of neutral hydrogen that happens when the spin of the electron relative to the proton flips. And that tends to happen once every 10 million years or so per hydrogen atom. But there are a lot of hydrogen atoms. And so it tends to be the dominant radiation from the cold gas. Now if this hydrogen wasn't cold, if it wasn't the temperatures of 10's of degrees Kelvin, sometimes it's barely more than microwave background, a few Kelvin. Do you think that this would be an important line? Let's say with a gas this makes those nice shiny nebulae also shining 21 centimeter line.

Well, since I'm asking the question the answer is obviously no. Because that gas will be first ionized, by in large. And second even if it's not the energy levels that are populated will be way higher than these. Although this can happen at many different energy levels.

So the main advantage of observing interstellar hydrogen using this radio emission line is that radio waves to zip through dust clouds as if they didn't exist. And that way we can actually see throughout the Milky Way galaxy, and same thing outer galaxies. So we can study parts of the Milky Way that are hidden from view in visible light. That unfortunately does not include protostellar clouds and protostellar course. The gas there is actually dominated, the emission is dominated by molecular lines.

But that's fine. We can study those as well.

So this is a picture of the Milky Way, again from here in 21 centimeter line. You can see most of it really is concentrated in the galactic plane. But there is hydrogen at high galactic latitudes as well. Some of it is really near us. And so it's no wonder we can see it up. But other parts of it got there is some interesting fashion. You can see there are kind of arches, almost bubbles. Anybody have an idea where do those come from? You see something that's probably kind of spherical up there.

Well they too must come from supernova explosions. And the shock wave of supernova will push the interstellar medium even when it's not ionizing. But you'll still have kinetic energy. It will make these shells of hydrogen, and just expand for a while before they're dissolved and fall back.

All right, so it's interesting to look how different components of the interstellar medium correlate among each other. And the top is a side picture of the Milky Way in visible light. And there is obviously a big seller disk and a bulge. But there are shadows in the front. And those are the dust clouds. Now if you look in millimeter wavelengths the carbon monoxide, you'll find out that the molecular gas, which you cannot see in visible light one way or together, goes more or less exactly where the dust grains are. So molecular gas clouds and dust clouds tend to be well mixed together.

Also it turns out that there is a reasonably good correlation between neutral hydrogen, atomic cold gas, and dust emission as well. And the reason for this is well it's just simply gravity. That you have denser spots, say giant molecular clouds that would attract hydrogen as well. And so there'll be some correlation, broadly speaking. But not a perfect one. The molecular clouds are colder. Therefore they tend to be more condensed than just generic hydrogen clouds. But in terms of gravity it doesn't matter.

And one last portrait of the interstellar medium. This one is a large scale picture of most, not the entire, galactic plane as seen in the light of ionized hydrogen, the H alpha line. And you can easily see there are these bubbles that were produced by supernova explosions. There are some spots it's hotter. Those are the regions where there's some star formation that ionizes the gas.