# Student questions: Kristian Finlator colloquium on "Linking Galaxy Formation with Cosmic Reionization" 10/21/20

When writing and running simulations for complex subjects like this, how complex/accurate are you able to get without ending up with a code that takes too long to run?
The most honest answer is that the accuracy, complexity, and dynamic range of any numerical simulation are all adjusted so that the resulting range of applicability subtends the range we think is required for modeling the processes of interest, and the problem can be treated in a reasonable amount of time. For example, the simulations that I work with do a reasonable job of treating processes that occur on physical scales of 100 pc to 10 Mpc. This means that metal-mixing and radiative shielding processes occuring on much smaller length scales are not accounted for and that rare objects such as bright quasars are not present. Likewise, many physical processes such as cosmic rays and shocks within the interstellar medium are not accounted for directly or at all. When I write papers, I must make arguments and, if possible, use simple experiments to show that these limitations don't compromise my results.

When you said that your simulations tended to overproduce certain elements, do you know why exactly that is or do you have to just tweak different things until getting results that make sense?
I should clarify. I'm not sure that the simulations overproduce carbon (in fact they may even underproduce it), but it is possible that they put too much of it into a diffuse phase that favors the triply-ionized state. However, let's talk about supernovae. When a core-collapse supernova goes off, how much new oxygen and carbon does it produce? How much of what is produced gets released into the interstellar medium? How does this change with the star's mass and initial metallicity? These things are not known for sure. The simulation models the production of new metals by relating the rate of supernovae to the rate of new metal production in a way that makes several assumptions regarding the mass distribution of stars and the fraction of supernovae that are hypernovae (extra-powerful supernovae). These uncertainties lead to uncertainties in the rate at which new metals are released that are at the 50% level. So if all else fails, I can always argue that discrepancies with observations may owe to errors in the adopted "metal yields" that are of this order – indeed, I did consider that in my most recent paper.

Will the universe reach a point of retracting to counter its expansion?
According to the Lambda cold dark matter cosmological model, the Universe will expand indefinitely owing to what cosmologists call dark energy. Whatever that is. No one knows. All that we know is that up until about 5 billion years ago, the Universe was slowing down in its expansion in the way that anyone would expect it to owing to its own self-gravity. Then, it started accelerating in its expansion, which is amazingly weird. The 2011 Physics Nobel prize was awarded for this discovery.

With the world of technology rapid development how long will it take in your opinion for us to have faster and more detailed simulations?
They are always getting faster and more detailed. In my opinion (and not everyone would agree), there is as much progress to be made right now in learning how to draw tighter connections between cutting-edge numerical simulations and the all-important observations that can rule them out as there is in making the simulations themselves more realistic.When I was a graduate student, cosmological-scale simulations with a live radiation transport solver were a thing of the future. Now it increasingly seems normal.

Do dark matter halos still exist or were they only there at the beginning of galaxy formation?
They still exist. You live in one. There is a very lively discussion in the literature about a new and rare class of galaxies that appears not to inhabit a dark matter halo, but these are the exception.

How do present day galaxies form? Is there any mechanism other than dark matter?
Many careers are devoted to this question. Other than the exceptions alluded to above, since the seminal paper of White & Rees 1978, the reigning paradigm has held that all galaxies at all times form in dark matter halos. In the current cosmological model, 85% of matter is dark matter, so gravitationally-bound lumps of matter are always first and foremost dark matter halos. If they are massive enough, then the "baryonic" matter inside of them can collapse to form stars and galaxies. The actual process of galaxy formation involves many processes that decouple baryonic matter from dark matter – collisional and photoionization heating, radiative cooling, shocks, and all the other ways in which light, matter, and magnetic fields interact. You might say that dark matter "tells" galaxies where to form, but then steps aside and lets "gastrophysics" take care of the details.

Other than density-bounded escape, how will JWST improve these models?
So many ways! Let me mention but a few important measurements:

- The galaxy mass-metallicity relation will tell us both about how many metals galaxies create and how effectively they hold onto or disperse them;
- The ionizing escape fraction from galaxies will tell us about how they contributed to HI reionization;
- The UV and H-alpha luminosity functions will tell us about how efficiently galaxies grew;
- The rest-frame optical luminosity function will tell us about how many stars had formed by early times (sort of like a time-integral of the quantity in the previous bullet point)
- Measurements of galaxy clustering will tell us about how efficiently galaxies of different masses formed within different dark matter halos

What other environmental factors need to be considered when modeling early galaxy formation besides dark matter halo mass?
Dark matter halos are not isolated things. Something like 15% of galaxies are actually "satellite" galaxies, meaning that their parent dark matter halo has "fallen into" a larger halo and is now orbiting about within that halo. Satellite galaxies tend to be less efficient at forming stars than central galaxies even at early times because the gas in their environs that they would otherwise use to fuel further growth tends to fall toward the center of the parent halo. That means that two galaxies that were formed in halos of the same mass can have very different properties if one has since become a satellite.

In regards to collecting the data, why do the simulations take so long to run?
There is always a tradeoff. The longer they run, the more detailed and accurate their predictions. However, if they take too long to run then we get impatient, or the grant runs out, or someone scoops us (though I don't tend to worry about that in practice). I am aware of cutting-edge simulations that took over a year to run, but most people use the interplay between the nature of the problem they can consider and the resources that they have to define problems that complete in under a year. In my case, never more than a couple of months.

This question is more of a point of clarification; what does it actually mean for the galaxy to be plasma, and how would the universe look otherwise if it weren't plasma?
A plasma is a lump of matter heated to maybe 10,000 K or more. At this temperature, the atoms are missing some or all of their electrons. Most of the matter in the Universe is in this state. Within galaxies, some of the matter between stars is in the form of atoms, molecules, dust, and occasionally rocks and planets. However, this is a tiny fraction of all the ordinary matter in the Universe. If the Universe were neutral, it would be opaque to ionizing radiation and hence colder than it is. Galaxies would also form more efficiently in low-mass dark matter halos than they currently do.

What is something that allows you to quickly identify the dark matter halos?
Observationally, any galaxy or evidence of metals likely traces the presence of a dark matter halo, because it is deep within halos that galaxies form and produce metals. Within simulations, one uses a piece of software called a "group finder" to find lumps that seem to belong together.

What is the most interesting thing you have discovered while looking into galaxys?
To most artists or scientists, the most interesting thing is their next project. I look forward to understanding small-scale fluctuations in the radiation field better through upcoming projects and dialogue with results from *JWST*. However, of the things I've done in the past, one that I've found particularly satisfying is the result that galaxies obey many equilibrium relations such as the tendency to process new gas into stars and outflows at the same rate that they absorb it from their environments, and the tendency to enrich themselves with new metals at the same rate that they are diluted by underenriched gas that they absorb from their surroundings. Whenever I find evidence that I can set a time derivative equal to zero and get away with it, I feel like the Universe just gave me a gift.

How do galactic cores (agns) contribute to reionization?
They are not believed to have contributed significantly to the reionization of hydrogen; there simply were not enough of them. However, they did more than half the work associated with stripping the second electron off of the helium in the Universe, a process that ended a billion years after HI reionization. Precisely how much more than half is the subject of speculation.

How can there be more metals, yet the amount of ionized species remains flat: what mechanism drives that?
I love this phenomenon. As the Universe produces more metals, it also produces more UV light. In fact, the massive stars that produce UV light generally follow through by blowing up and producing metals. So the total mass density of metals that is in neutral or nearly-neutral states such as OI or CII or SiII does not change much owing to this cancellation between enrichment and ionization. By contrast, the mass density in highly-ionized states such as CIV or SiIV increases with time owing to both effects.

How do teams go about developing tools capable of doing large, complicated computations/simulations such as yours?
Very few researchers start from scratch; I certainly didn't. For a beginning PhD or Masters-level project, most supervisors simply ask students to work directly with predictions from a calculation that has already been run. As students progress, they then learn to grow their inquiry by adding their own secret sauce to the model by improving physical and/or numerical treatments. My own student, for example, is improving my model by adding the capability to treat the effects of binary stellar evolution. It turns out that most stars are not loners the way our Sun is; they tend to be in systems of two or more stars. These stars affect each others' evolutionary tracks in ways that are probably important for reionization. Models are always being developed to do address new problems, confront new data, or take advantage of to a new computer.

Outside of JWST's capabilities, what observational data/other instruments would help verify your simulations and data and drive your next line of questioning?
*JWST* will be important, but the Roman Space Telescope will be equally important in its own way. The 30-meter class of ground-based telescopes such as the E-ELT, the GMT, and the TMT (maybe?) will quickly test the prediction that there are many weak metal absorbers at high redshifts that have not yet been observed. At the same time, they will allow much deeper measurements of the ionization state of hydrogen in the intergalactic medium, which is the most direct constraint on the progress of reionization.

I may have missed/misunderstood this, but what do you model simulated absorbers after, and how do the different simulated absorbers vary?
I'm not sure I understand this question, sorry.

How do you actually run the really computationally expensive simulations? How many CPUs, which programming language(s), etc.?
My simulations are in C+MPI. My analyses are in C too, mostly because I don't have time to learn python. I have a student who is writing an analysis in python that does what I have been doing in C. It should be much quicker and more flexible, but it is currently producing different results and we don't know why because we don't quite understand what goes on under the hood in the numpy fft package. While no one writes this sort of bottleneck into their grant, it is good – it means that we will learn something.

What causes galaxies to stop accreting gas which stops star formation?
Many careers are devoted to this question, and there are likely many answers. Here are some processes that contribute:

- Photoevaporation: The UVB can actually evaporate the gas out of low-mass halos (halos with masses of something like $10^6$ solar masses).
- Photoionization squelching: Halos less massive than $10^8$ solar masses cannot accrete new gas out of the intergalactic medium once it is heated to $10^4$ K.
- Environmental starvation: Satellite galaxies lose the ability to accrete gas and starve to death over a billion years or so.
- Quasar activity: There have been numerical models suggesting that active nuclei can expel gas from galaxies enough to quench growth. Whether this really happens remains an area of active inquiry.

Does redshift affect outflow contribution a lot, if so how much does it vary?
There are not observations that require this explicitly, but neither is it ruled out. What is observed is that most galaxies eject gas at something like the escape velocity. The escape velocity from the edge of a dark matter halo with a given mass does vary with redshift, so it is possible that there is some evolution. I am not aware of strong observational constraints on this that have separated out redshift from other influences such as the so-called specific star formation rate (that is, the ratio of star formation rate divided by stellar mass), which does evolve strongly with redshift.

What is the purpose of simulations like self-consistent continuum ionizing radiation transport?
When attempting to ask whether galaxies really ionized the Universe, there are many different approaches. One popular "bean-counting" approach is to add up all the galaxies, guess-timate how much ionizing light each one produced, and then compare that sum to what is believed to be required in order to reionize the Universe. This has been and will continue to be a central approach. However, all it really does is establish whether there were enough "criminals" (galaxies) to commit the "crime" (reionization). It does not ascertain whether they were armed (i.e., did they really create enough ionizing flux to do the deed) or whether they actually committed the crime (i.e., did they release that ionizing light into the IGM). If you want to prove that the criminal committed the crime, you want to see a photograph of her with a crowbar in one hand and the diamonds in the other. In the case of reionization, I'd like to see evidence that the Universe is "more reionized" (hotter, less neutral) near galaxies than far from them. The best way to understand what this signature should be, though, so that observers know what to look for, is to model it. There are already some tentative observations of precisely this effect, which is very exciting.

When galaxies were bright ionizing sources, why are fewer expected around strong high-ionization metal absorbers?
If high-ionization metal absorbers are highly-ionized because of the ionizing flux from nearby galaxies (which must be the case, particularly prior to the completion of helium-II reionization), then, to get a strong absorber, one requires a radiation field of a certain amplitude. If galaxies are all intrinsically brighter, then fewer of them are required to provide a field of that minimum amplitude, whereas if galaxies are intrinsically faint, then more of them are required. Astronomers do not know whether the way in which galaxies release ionizing light is more accurately approximated by the density-bounded or ionization-bounded scenarios. In the former case, galaxies were intrinsically brighter at high energies, so fewer of them are required (and hence expected) around strong absorbers.

Is it possible that there is a fundamental problem with the physics we are using to describe CIV absorbers and that is why the models are still wrong?
Something is certainly wrong. According to the Scientific Method, our goal is to propose models and then rule them out. In some sense, observations of the abundance of weak CIV absorbers at z=3 and strong ones at z=6 rule out the “vanilla” version of the model I have produced (and, to be fair, others have the same issue). The next step is to ask what might be wrong. The absence of a treatment for dust depletion? Small-scale density fluctuations? An ionizing background that is incorrect? Incorrect supernovae metal yields? All of these things must contribute as issues at some level. For example, after the end of my talk, I enjoyed a fascinating discussion with Prof. Windhorst in which he alerted me to observations indicating that AGN do not release more than half of their ionizing flux into the IGM (at least not at the energies responsible for HI reionization). The simulation assumes a fraction of 70%. Adjusting for this would decrease the amount of CIV at z=3. The discrepancy will certainly teach us something.

While the JWST is supposed to launch next year, it has been delayed so many times already, so are there other possible sources of observations to support the models?
Of course! There are very interesting published observations of the relationship between galaxies, CIV absorbers, and the IGM that I have not yet tested the model against. Meanwhile, as alluded to before, there are other facilities such as the 30-meter ground-based telescopes and the Nancy Grace Roman observatory that I look forward to.

How would you quality control these cosmological models to determine if the model is underproducing or overproducing a certain element, material etc.?
Broadly, metals are visible either in the interstellar medium of galaxies via the emission lines of star-forming regions or in the circumgalactic medium in absorption. By testing the model against observations of the galaxy mass-metallicity relation as well as against the observed column density distributions of as many ions as I can realistically predict, I learn something about whether the correct number of metals is produced. At the same time, comparison against the observed number of stars that the Universe has produced via a statistic called the stellar mass function (basically just a histogram of all galaxies' stellar masses normalized by the cosmological volume in the survey or the simulation), I can test whether the model generated the right number of stars. If the model generated the right number of stars and the right number of metals in every available ionizing species, that supports the assumptions. Such a result would be surprising though. I have seen papers in which well-regarded theorists ran a simulation of galaxy formation and then divided all the predicted metallicities by 2 in order to close a gap with observations. There is nothing wrong with this; it is an acknowledgment of the underlying uncertainties (or could even be regarded as a "measurement").

You mentioned these models were computationally expensive, but how much monetary cost goes into these models and do you need any specific or expensive equipment to run them?
My simulations each need ten to a few hundred thousand core hours of computation time. My most recent calculation required 256,000 core hours. It was run on 384 cores that communicated over an infiniband network, so that means about 27 days from start to finish. This is not really much. Many cutting-edge astrophysical calculations require over a million core hours.

Do the properties of dark matter halos change much/if at all after their formation besides galaxy and star formation?
Up until the Universe was about half its current age, they continued to grow unless they became satellite halos. More recently, however, the Universe's low density and the onset of accelerated expansion has begun to choke of the growth of structure formation, so dark matter halos are not growing very quickly any more.

Since the epoch of ionization was the progeniture of the CMB, have you ever considered doing cross-correlations between galaxy density distributions and the energy intensity map of the CMB?
The CMB consists of light that was "released" from being coupled with matter when the Universe was a few hundred thousand years old. Reionization occurred 500 million to a billion years later. Therefore, the structures that we see in the CMB are not the same structures as the ones eventually formed the galaxies that we see; those galaxies are in the foreground. However, about 5% of the CMB light does interact with gas in those structures via a broad variety of effects such as Thomson scattering off of free electrons as well as the kinetic and thermal Sunyaev-Zel'dovich Effects, so cross-correlating the background CMB with foreground structures is an immensely productive approach for this reason.

In your study of the absorption lines from triple-ionized Carbon, has there been any relationship between z-shift and density implying earlier/later galaxies produce this odd element?
Broadly, the simulations reproduce the evolution of the cosmic abundance of CIV, indicating that the model produces roughly the right amount of carbon at roughly the right times. However, it might not be producing it (or placing it) in quite the right places.

When the JWST can count the galaxies that you mentioned, will that answer which model is correct in terms of the Si and C?
It will help! The number of neighboring galaxies around strong absorbers depends both on the metal yield (discussed above) and the ionizing emissivity from galaxies. Boosting either one boosts the CIV production. It will be necessary to consider many complementary observables simultaneously such as the galaxy mass-metallicity relation and the simultaneous abundances of CII and CIV to put the most pressure on the models.

Can the ionization of all hydrogen in the universe tell us anything about the underlying structure connecting galaxies, galactic clusters, and superclusters?
Not directly. It contains more information about which sources released ionizing light than about how those sources were related to each other spatially.

Why does light escaping favor Hard UV? This concept was a little confusing to me when Dr. Finlator was presenting several graph in the "Absorber Abundance Reflects UVB Hardness" slide.
This is not an easy concept. Imagine a string of islands in the middle of the sea, and imagine three kinds of waves heading for that archipelago. One wave is comparable in size to the individual islands and the spaces between them, one is much smaller, and one is much larger. The one consisting of very small ripples will be able to “sneak” between the islands, the one that is enormous compared to the islands will overrun them, while the one whose size is comparable to the islands will scatter off of them. It is similar with light: light waves with very short wavelengths (like hard UV and x-rays) tend to get past hydrogen atoms more easily than those whose wavelength is matched to what is required to ionize them. Hard UV consists of light with high energy and therefore short wavelengths, so it is more likely to escape through a translucent medium. This also explains why sunsets are red (red light has longer wavelengths than dust and gas in the atmosphere) and in turn why the “Blood Moon” is red.

How would you go about testing which of your hypotheses for the overproduction of carbon in your model is the correct one?
Conceptually, this would follow a two-step process. At first, I (or more likely a PhD student) would treat a number of different possibilities in what is called “post-processing;” that is, I would adjust the predictions of the model in a way that attempts to get at what would have happened had the model made this modified assumption. The results from that experiment constitute a proof of concept, but are simplified in that they would not have taken into account the many nonlinear ways in which different physical processes couple to one another. The most promising possibilities would then be tested by implementing them directly into the model and re-running it.

How would you approach the problem of identifying the wavelength-dependence of the ionizing escape fraction?
I wrote a proposal to do this. The project consisted of a pen-and-paper theory aspect, a part in which we actually computed how light escaped from numerically-simulated galaxies using what is called radiation transport calculations, and a part in which we tested the results of that part on larger scales. I was very excited about this idea. It was not funded. I'll have to improve it and try again!

What other reasons may spatial fluctuations in the UVB differ from the normal CBR?
The CMB is isotropic: That means it is uniform on the sky to one part in 100,000. It is uniform because the entire Universe was when the light was released. That result was from the COBE satellite. The UVB was made by galaxies and quasars much later. It is spatially inhomogeneous for the same reason that the lighting in a theater is: wherever the light bulbs (galaxies) are, it is bright; in the shadows (molecular clouds), it is dark.

What are examples of harder types of ionization than QSO's?
On small scales, there are the gamma-ray bursts and accreting neutron stars. However, these are believed to be subdominant contributors to H and He reionization.

What things are considered weaker absorbers than CIV, SiIV, and OI?
A strong absorber is a lump of gas that produces a great deal of absorption (like a dark shadow that covers only a very specific range of colors of light) owing to any one of these ions. So you can speak of a strong or a weak CIV absorber, or a strong or a weak SiIV absorber, or a strong or a weak MgII absorber, and so on.

Does the spatial distribution of dark matter halos in observations play a role in modeling parameters to account for coupled forces between them?
No. dark matter halos interact with one another only through gravity. Dark matter interacts with other matter only via gravity (that's why it's dark). In the standard scenario. The recent EDGES result has had people questioning that, though.

Do you believe there is a lower limit to the observation relevance of halos by mass in galaxy formation, or will improvements in observational technologies continue to make increasingly low mass observations relevant?
Good question. There is a lower limit to the halo mass where galaxies can form in an intergalactic medium that is cold, and that is believed to be around $10^6$ solar masses. However, those lower-mass halos can do something else even if they never have gas, namely they can produce gravitational lensing, at least in principle, so I would not say that even the featherweights don't have their place in the literature.

Why are dark matter regions referred to as halos rather than spheres?
On a technical level, they are not spherical. In general, they are triaxial. However, I don't know the history well enough to say who first called them halos and why. It would be fun to know that.

How well does metallicity correlate to redshift?
The Universe is constantly producing more metals, so, when averaged over a cosmological volume, the Universe's metallicity increases as redshift decreases. This is probably true when averaged over dark matter halos as well. However, when restricting attention to galaxies, it does not evolve as rapidly because galaxies seem disposed to expel a lot of their metals into the CGM.

So dark matter halos are responsible for the development of galaxies, what is responsible for the development of the dark matter halos themselves?
Gravity! The CMB teaches us that, when the Universe was about 370,000 years old, the Universe had density fluctuations at the level of about 1 in 100,000. Those tiny fluctuations could only grow under gravity, so they did, and the first thing that they did was to form dark matter halos.

When it comes to examining galaxies with a redshift of over 5, which are of course early galaxies, how much does the effect of gravitational lensing affect your observations of such quantities of Carbon 4 and Silicon 4, especially considering the predicted affect that the gas cloud has on the photons getting out into the open intergalactic medium.
Very good question. Gravitational lensing has a tendency to make things brighter, so it can make galaxies appear 20 or more times brighter than they really are. However, absorbers are measured as a fraction of the light from the background source – whatever that is—that is missing. So it does not matter if a sightline happens to pass through a lensed region. That makes the background source brighter, enabling better observations, but the fraction of light that is absorbed is not changed. Astronomers are concerned that lensing will affect measurements of the number of bright (and faint) galaxies at early times because, the farther you look, the more likely your sightline is to pass over a lump of matter that would produce lensing. But I'm not aware that this affects absorber statistics, though admittedly that may reflect a lack of creativity.

How do you differentiate "regular" galaxies from true faint galaxies that have been magnified?
In the case of strong magnification, such as the one in the image I showed to motivate the discussion of metals, the galaxy will be highly deformed in appearance. Many such systems are known that happen to lie behind massive galaxy clusters in the so-called Hubble Frontier Fields. Galaxy clusters are giant gravitational magnifying glasses, so there it's clear. If a distorted-looking galaxy is discovered that is not behind a cluster, it can be more difficult to work out whether it is strongly-lensed by some faint but massive foreground system.

What is different about JWST (as compared to HST) that will enable you to distinguish between efficient/inefficient UV absorbers?
JWST's primary mirror will have a diameter of 6.5 meters. Hubble's is 2.4 meters. 'Nuff said.

How were parsecs established (does 3 light years equal to anything specific, or just easier for calculations)?
Parsec is short for "parallax second." It is the distance from Earth of a star that appears to wobble back and forth annually on the sky by 1/3600th of one degree (1 arcsecond) on the sky owing to Earth's orbital motion. It is fun to know the history of parallax – books have been written about it. Among other things, it was during an attempt to detect parallax that William Herschel discovered Uranus.

Are the measurements of wavelength taken with specialty equipment?
Yes: A spectrograph. Conceptually, it's a camera with a prism in front of it.

Is there a possibility that there are systematic errors in observations rather than the model?
Always! One example involves efforts to determine how metal-rich a galaxy's gas is. One usually determins that by looking for "emission lines" of glowing metals such as singly- and doubly-ionized oxygen. However, working out how what metallicity gives what sort of emission lines is not easy, and usually uncertain at the factor-of-2 level. It's always best to have multiple independent measurements to make progress with this problem.

What is the significance of CIV?
Triply-ionized carbon is easy to observe because it happens to cast a very dark pair of shadows in the UV, and it is easy to model because it occurs in diffuse gas that is not too subject to complicated radiative transfer effects. It is also sensitive to more energetic light than OI or SiIV are, so its presence tells astronomers about higher temperatures and more intense (or I should say spectrally-hard) radiation fields than they do.

Metal productions are from the interior of stars. I guess the compositions and masses of stars were different in the past. Considering your simulation timescale, how does your simulation account for this variable?
The simulation does account for the possibility that the metal yields and ionizing emissivities of stellar populations depend on metallicity because these things have been modeled separately. In astronomer-speak, the stellar nucleosynthetic yield tables were computed for a wide range of metallicities, as were the stellar population synthesis models. However, the possibility that stars form with a distribution of *masses* that differs depending on their metallicity is not accounted for. There are good arguments that this distribution may indeed vary with metallicity in the sense that lower-metallicity systems have more massive stars, but we have not introduced this extra level of complexity. It would not be too difficult computationally, but I always prefer to wait with introducing new complexity until I am sure that observations require it.

Why does light have one less medium than baryonic matter?
The IGM, CGM, and ISM are really just somewhat artificial distinctions based heavily on their observational presentations. As for the background radiation field, it consists basically of the CMB + everything else, where by everything else one means stars, quasars, supernovae, gamma-ray bursts, cataclysmic variables, shocks,…everything else.

What causes carbon IV to cast such "dark shadows"?
It has a resonant transition that is particularly easy for UV light to excite and scatter off of. In astronomer-speak, it has an unusually large "oscillator strength" and also happens to be quite abundant.

Does dust have an effect on the escaping ionizing photons of hydrogen?
Yes! About half of all light produced by star-forming regions gets absorbed by dust. In fact astronomers like measuring this re-emitted light and using it to estimate how much star formation is occurring.

What do dark matter halos of <2 x 109 Mo do if they don't produce galaxies?
I believe that they do form galaxies. However, observations at redshift >= 6 do not yet *require* that they did so. However, there is certainly some mass limit below which dark matter halos cannot form stars. For whatever mass turns out to be that limit, the even lower-mass halos do not form galaxies because they cannot acquire gas from their surroundings. They may have some stars left over from before reionization completed, but probably not many. It is possible that some of the satellite galaxies in our local group are such systems.

Why are higher redshift halos harder to eliminate with a minimum mass?
The observations are shallower because, as the galaxies are farther away, they are harder to see for a given intrinsic luminosity. This means that the limit on dark matter halo mass that are enabled by the data are also shallower.