Student questions: SESE Postdoc Presentations

3/17/21

Parke Loyd: "Adrift in a Tempest: Observing Space Weather Conditions for Earth-Like Planets around Red Dwarf Stars"

Aside from the perspective of view, are there other significant differences between the Coronal Mass Ejection and the Halo Coronal Mass Ejection?

- No, as far as the intrinsic properties of the CME, I believe there is no difference. It is only the perspective. However, as you might know, a halo CME looks the way it does (a halo of coronal emission surrounding the Sun) because it is heading straight at us. A halo CME is going to hit us whereas a non-halo CME might not.

I was wondering, on average, how many years does the holes left behind by the Corona mass ejection last for. or do the ejections leave permanent holes?

- The holes refill over the course of just a few hours.

Are there any problems with looking at planets that are many times more massive than Earth?

- There is scientific curiosity about planets of all masses! However, from the perspective of life, eventually planets cross a threshold to a regime where they hold on to thick atmospheres of hydrogen and helium yielding surface pressures well above Venus'. This transition occurs somewhere around 8 Earth masses. In fact, I accidentally made my green box on the plot showing planet masses vs periods too small -- the upper edge should have been higher. I was mistakenly thinking in terms of radius rather than mass when I drew it.

  A thick atmosphere does not exclude planets from supporting life, but it does make them no longer "Earth-like." So in the search for life, we will start with smaller planets.

Are there any other molecules that can act like ozone in other atmospheres?

- Almost certainly. As Jim Lyons mentioned, S8 could be a good NUV absorber. Hydrocarbon hazes could be a good NUV absorber as well, but they are also a good absorber of visible light so different than ozone in that sense.

At what maximum distance from earth can we analyze the atmospheric composition of an exoplanet with our current capabilities?

- My answer to your question requires some background that I didn't have time in my talk to explain. The most common technique to analyze atmospheric composition relies on planets with orbits that are oriented such that the planet passes in front of its star from our perspective. When that happens, we can measure how much starlight is blocked by the planet and its enveloping atmosphere. Some molecules in the atmosphere will block light at specific wavelengths more strongly than others, making the atmosphere "darker" at that wavelength. From that, we can deduce what is in the atmosphere.

  It is hard to measure very small changes in how much light is blocked, so the bigger the planet the better. Also, the smaller the star the better, because then the planet and atmosphere block a larger percentage of its light.

  The answer to your question, finally, is that "it depends." :) Both the size of the planet and the size of the star (plus more things I won't get into) will affect the maximum distance of a planet we could analyze. However, with JWST we will might be able to analyze the composition for Earth like planets orbiting red dwarf stars as far away as about 10 "parsecs" -- 40 light years.

Why is there a gap on the wavelength v. flux density graph?

- The instrument we used to measure the spectrum produces this gap. Actually, I am not sure why it was designed that way. There are other instruments we could have used that don't have that gap, but they aren't as good at detecting faint light, so we decided to deal with the gap.

How would filling in the gap in the wavelength v. flux density graph inform your interpretations of space weather around red dwarfs, if at all?

- This is important. I did not have time to go into this, but those measurements allow us to build models of the stars that we can then use to predict what is emitted in those gaps. This is actually pretty crucial to simulating the effect of that light on planets. We don't want to be leaving any of it out!

You talk about how the ozone of a planet that orbits around a red dwarf is created by the CO2 being broken up other than on Earth where the ozone was caused by some form of life. Does that necessarily mean that there can be habitable life on that planet?

- There certainly could be! If we see a planet like that in the future (the graph I showed was for a simulated planet, not a real one), then we will need to run models where we try to simulate a planet that matches the spectrum we measured. The key thing is providing the right input of ultraviolet light to that model, which is why we are measuring the ultraviolet light of these unfamiliar red dwarf stars. We could find a case where, even though the breakup of CO2 by ultraviolet light is leading to ozone, it doesn't make enough to explain the ozone we observe on the actual planet. If that happened, we might conclude that life was present (after checking a wide array of other possibilities, of course!).

What other parameters you would include besides mass, orbital period, star type, and surface temperature to find "earth-like" planets?

- It is a subjective category, of course, so open to interpretation! I hope that in the future we will eventually be able to add things like atmospheric composition, presence of land or surface oceans, and planetary magnetic field.

Is there anything that can perturb occurrence rate flares?

- Certainly. You saw that as stars age, their rate of flares declines. This is a result of their spin, which helps generate magnetic fields, slowing over time. Stars in close binaries (i.e., two stars orbiting each other) spin fast for their entire lives because of the tidal forces they exert on each other. The result is that they flare A LOT. It is also possible that a closely orbiting planet can perturb the magnetic field of a star, triggering flares. However, this has not yet been conclusively observed.

What protects us on earth from coronal mass ejections?

- At the personal level, our atmosphere protects us humans from the particle radiation of a coronal mass ejection. However, at the planetary level each coronal mass ejection (CME) that hits us messes with the chemistry of our atmosphere and, on top of that, strips some of it away. Thankfully, the effects are too small and the coronal mass ejections too infrequent to cause long term problems.

  That said, our planet's magnetic field does help prevent the charged particles from a CME from directly entering our atmosphere. Instead they get funneled toward the poles. It used to be thought that our magnetic field "protected" our planet from CMEs, but that picture is evolving. Dave Brain's colloquium from the week before mine was all about this.

  For a fun diversion down the CME rabbit hole, I suggest reading the Wikipedia article on the Carrington event, a particularly large flare and CME that happened late in the 19th century with some dramatic effects on Earth.

Are the Northern Lights connected to space weathering?

- Yes, they are a direct result of space weather. They are a result of charged particles from coronal mass ejections entering our atmosphere and colliding with atoms and molecules in it.

According to your research so far, how do you think these different stellar behaviors affect the overall habitability of the Earth-like plants orbiting red dwarfs?

- Yes. The jury is still out, but I am beginning to suspect that planets at the right distance from a red dwarf to have an Earth-like temperature will struggle to retain any atmosphere against the erosive forces of the star's radiation, flares, and coronal mass ejections. Of course, this does not mean that life won't be possible on those planets, but it would likely have to be subsurface life. However, someone just published a paper claiming the detection of an atmosphere on a planet orbiting a red dwarf at a distance that would make it hotter than Earth, so I could already have been proven wrong! https://ui.adsabs.harvard.edu/abs/2021arXiv210305657S/abstract

Would it be detrimental for a planet to be closer to a star during a coronal mass ejection?

- Yes indeed. The coronal mass ejection expands as it travels outward, so a closer planet will get hit with a more compact cloud of gas.

As you know, last week's presentation was on magnetic fields and whether they are a requirement for a habitable world. You mentioned how the Earth's magnetic field could be protecting us from flares and CMEs. Not to put you on the spot, but can you tell us a little more about what you see in terms of CMEs and the magnetic field as they pertain to the existence of life on another planet?

- Oops, if I mentioned that I should have emphasized the "could." As Dave Brain showed us, magnetic fields might not help after all. Although they block the "front" of the planet from bearing the brunt of the CME hit, they can end up acting like a big funnel, grabbing charged particles in the CME far from our planet and directing them in toward our poles. Hence, more of those particles end up hitting our planet than would if there were no field at all.

  I didn't have time for this in my talk, but there are reasons to suspect that red dwarf stars might actually have no CMEs at all, or CMEs that are much less frequent than the Sun's. That is why figuring out a way to detect them is so important. If so, it would bode well for the planets of these stars being able to retain an atmosphere like Earth's and thus support Earth-like life.

You mention that the intensity of UV radiation from the red dwarf stars are decreasing as they age, does this mean that the more mature the stars are the more likely life could form?

- We still do not have a great sense of whether UV radiation is directly harmful to life, which is why I focused my talk more on the possibility for the radiation to cause atmospheric changes that look like life rather than affect life directly. While UV radiation is harmful to us personally, it has been suggested that the chemistry it drives in planetary atmospheres might help spark the formation of life to begin with -- serving more or less the same role that lightning served in the famous Urey-Miller experiments. On top of that, it is easy to imagine evolutionary adaptations (thick armor like skin? living in burrows?) that might protect a life form from the ill effects of direct exposure to UV radiation.

Does size of a star affect the frequency and intensity of solar flares?

- Yes. The smaller the star, the more vigorous its flares seem to be.

At what heights from the stellar surface would you roughly be with the FUV measurements?

- About 3000 km.

You discussed how you only look for certain Earth-like planets that are close to the same size as ours. Does the size of the Earth-like planet matter that much when compared to the distance that it is from its star or could a planet be two or three times the size of our Earth, but it still be at the right distance from its star?

- It does matter in terms of what kind of atmosphere that planet might have. Large planets likely hold on to atmospheres much thicker than Earth's, yielding surface pressures even higher than Venus'. There seems to be an abrupt transition from atmospheric thicknesses similar to ours to atmospheres that are much thicker around a radius of 1.8 earth radii. Hence, to look for Earth-like life, we will want to stick to the planets below 1.8 earth radii.

How do far UV's break most molecules?

- Interesting question! I am not well versed on the details of this, but I can attempt a general explanation. You probably know that molecular bonds have to do with the sharing of electrons between atoms, and electrons and ions experience forces from electric and (if they are moving) magnetic fields. A light wave is a traveling, oscillating magnetic and electric field, and it can "shake" the electrons enough to break molecular bonds.

  Another way of looking at it is that the photon of light, if absorbed, will inject more energy into the molecule than the energy of the bond, splitting it.

What are biosignatures and what does it mean for there to be a false biosignature?

- Biosignatures are signs of life on a planet. One of the earliest suggested biosignatures that would work for Earth if we were aliens observing it from a distant star is the presence of both oxygen and methane. A false biosignature is one that, under the wrong assumptions about the ultraviolet radiation from the star (among other possibilities), we might mistake as being a result of life when really it resulted from abiotic processes like the chemical effects of UV light.

Since there are many ways to see false flag biosignatures, are there any methods or processes that will allow us to be more certain on whether or not some signatures are biologically related?

- Yes, our goal if we discover a potential biosignature on an exoplanet will be to try to accumulate all the contextual information we can about that planet so we can determine whether life or some other process, like chemistry driven by ultraviolet light, is the source of the signature. Also, this field is very young and there is still much work to be done identifying gases in planetary atmospheres that could indicate life. The hope is to identify biosignatures that we can look for that have the smallest possible potential for a false positive (or false negative!).

When searching for habitable planets with the potential for life, should we be more focused on planets with similar orbital periods to Earth to ensure we are looking at candidates that have a greater 'safety' from flares and coronal mass ejections?

- Ideally, yes. However, for a variety of reasons it is harder to find these planets and it is harder to measure the composition of their atmospheres. As a result, we find ourselves in a position where the planets for which we will first be able to search for signs of life will be orbiting red dwarfs stars.

Where do you plan to go from here as far as your research is concerned?

- I plan to enthusiastically pursue techniques to measure coronal mass ejections and to measure their effects on exoplanets.