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Applying Dark Matter (DM)-Matter Interactions with the Atmospheric Composition of Jovian-type Exoplanets as DM Detectors

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ABSTRACT

Researching an paper by Rebecca K. Leane and Juri Smirnov (2021) on the idea of detecting dark matter (DM) particles through the increase the heat flow within exoplanets deposit annihilation energy (Leane & Smirnov 2021). In this paper we analyze the possibility of finding axion-like DM from exoplanets based on the Bethe-Bloch (BB) equation and the medium in planetary atmospheres. There advantages from using gas giant planets, both within and outside of our solar system, due to their large cross section area compared to smaller compact stars and the growing research in exoplanetary science. The Bethe-Bloch equation can provide a theoretical model on the oscillation and excess energy of axions based on SRIM (Stopping and Range of Ions in Matter) simulations. However, there are still uncertainties basically on what DM is to know what to detect. Until a widely accepted model or a confirmed detection of a DM particle is found, the parameters for the BB equation and the exoplanet detection method is huge. In either case, exoplanets can provide an opportunity to understand how DM interacts with planetary objects and insight on the density of DM within the Milky Way.

1. INTRODUCTION

One of the greatest mysteries in science is understanding the material of dark matter. Accounting for approximately 27% of the total mass-energy in the universe, DM cannot be seen through the electromagnetic spectrum due to lack of interaction with the electromagnetic (EM) field (NASA 2013). The initial way DM has been detected through astrophysical observations of its gravitational influence on missing matter in galaxies and influence in galaxies clusters. Direct methods have been purposed to measure the oscillations of DM hitting the atomic nucleus in which the elastic collision travels through atomic nuclei lattice that should emit EM radiation. Indirect methods, which this paper focuses on, are based on the observations of astrophysical objects that give indication of a dark matter annihilation and decays. First indication of DM was through astrophysicist Fritz Zwicky who applied the virial theorem to the Coma Cluster and obtained evidence of unseen mass based on the motions of galaxies near its edge. Found that gravitation attraction of dark matter was holding the cluster together (Zwicky 1937). This was further proven in observations from the 1960s and 1970s where the rotation curve of spiral galaxies appeared to be flat, indicating a hidden mass was affecting their orbital speed (Freeman 1970).

To understand what DM is made of the most accepted model are Weakly Interacting Massive Particles (WIMPs). Involving the weak nuclear force, the broad definition is a WIMP is a new elementary particle with masses in the range 1 GeV–1 TeV which interacts via gravity and any other force (or forces), potentially not part of the Standard Model itself. This would mean they have to be weak as or weaker than the weak nuclear force which would constitute cold dark matter as being slower than normal particles (Carroll & Ostlie 2017). However, no indication of WIMPs has been found that a new lead for DM particles is considered. For this paper we will focus on axions as our candidate as our sub-GeV DM particles. A low-mass boson, these particles may populate the Universe in a coherent wave-like, cold state and considered as extensions of the Standard Model (Chadha-Day et al. 2021). These axions are further explained in the section Dark Matter Axions.

In this paper, we will analyze Leane and Smirnov (2021) idea on using exoplanets as potential dark matter detectors. Discuss on what are the atmospheric conditions on what gas giants would act as medium based on those in our solar system. Understand what axion-like particles (ALPs) are and how they could be detected. Using the Bethe-Bloch equation as a theoretical mean to learn what type of excess kinetic energy would be released from DM particles, possibly using SRIM simulations. There will be many issues with this proposal that will be brought up but show an opportunity that astronomers and physicist should consider.

2. WHITE DWARFS AND NEUTRON STARS

Before we get into explaining why planets could potential DM detections, we need to understand why not observe other compact objects such as stars for indirect search methods. The logical reason is that dark matter should have some form of mass that would cause them to be gravitational pulled inward to an object. Dark matter particles would then interact with standard matter particles and cause an annihilation process. Usually, most physicists have considered neutron stars and white dwarfs as compact object targets. The advantage neutron stars possess is due to their heavy mass and high density, they should in theory gravitationally attract DM particles and trap them. Dark matter interacts only very weakly with ordinary matter and easily passes through without loss of momentum. Bell et al. 2021 suggest that since neutron stars are so dense, they may be able to capture passing DM particles as they collide, lose energy, and become gravitationally stuck. Over time, DM particles would accumulate in the core of the star and heat them up (Bell et al. 2021). Based on the NFW profile, when moving towards the galactic center, neutron stars would accumulate more dark matter that their stellar mass could decrease and perhaps reach critical value to collapse black hole (Popolo et al. 2020).

White Dwarfs also present another possible compact object with interactions of DM. Graham et al. (2018) suggests that DM candidates that could interact with standard model (SM) particles (DM-SM scattering, DM-DM collisions, and DM decays) would heat through the production of high-energy (SM) particles in the stellar medium. Doing so would trigger runaway fusion within white dwarfs and ignite a type Ia supernova. Through constraints on ultra-heavy DM with masses greater than 10^{16} GeV produced by SM particles through DM-DM annihilation, these particles would cause sufficient thermalization in the white dwarf medium resulting in a supernova with sub-Chandrasekhar mass progenitor (Graham et al. 2018).

The issue with using these stars as detectors is their size, distance, and average temperature. Neutron stars and white dwarfs produce high amounts of surface heat stars due to their high luminosity with an average of $8\text{x}10^3$ K and $4\text{x}10^4$ K for white dwarfs and around 10^{11} to 10^{12} K for neutron stars(Eisenstein et al. 2006) (Lattimer 2015). This would make it rather difficult to detect any additional heating in infrared that would be produced from DM annihilation. A large portion of neutron stars that have been detected at far distances with the closest being neutron stars are RX J1856.5-3754 approximately 400 ly and PSR J0108-1431 about 424 ly (Posselt et al. 2009). The main problem is these stars have a small cross-section area where a neutron star averages in around 20 km in diameter (Britannica 2021). Cross-section is important where the size determines the number of particles caught. When particles interact, it releases energy (radiation) that the cross-section will keep as much energy interaction. Mean free path involved with cross-section and medium depending on density and temperature.

3. PLANETS

The growing research programs invested in searching for exoplanets have opened a wide range of opportunities in scientific fields. It has been assumed that their should be at least one billion neutron stars in the Milky Way (Naeye 2007), yet Cassen et al. (2012) suggest there should be around 17–30% of solar-like stars hosting a planet (Cassan et al. 2012). The Milky Way is estimated to have 100-400 billion stars(NASA 2016), meaning there could be about 30 billion planets. As of 2021-12-19, there has been 4,904 planets documented outside of our solar system (Schneider 2021). Therefore, exoplanets outnumber the amount of compact stars, making them easier to find. Infrared neutron star search requires that a sufficiently cold neutron star candidate at a distance ≤ 100 pc from Earth is found, which cannot be measured with sufficient exposure time (Baryakhtar et al. 2017). The vast amount of exoplanets provides enough candidates for possible DM detection (Leane & Smirnov 2021).

How this works is a DM particle in the galactic halo could scatter with in the galaxy and then lose energy. A passing planet in a star system or even a free-floating one would then gravitationally pull in and capture DM. As it accumulates around the planet and annihilates with planetary particles, it releases mass energy to heat exoplanets. Assuming the DM annihilation reaches equilibrium for the heating process to be maximally effective, then infrared telescopes could measure the heat of the DM scattering rate (Leane & Smirnov 2021). This is all based on a DM candidate, like axions as we will discuss, that can interact with SM particles.

The greatest advantage exoplanets have over compact stars is their cross-section area and low temperature. A typical neutron star has a radius of about 10 km, while exoplanets of interest have radii of about 50,000–200,000 km. Neutron stars are much denser and allow for higher heating rates in part due to enhancements from kinetic heating, exoplanets are much larger and may capture more DM particles (Leane & Smirnov 2021). Exoplanet temperatures can be measured much further into the galactic center (GC) with less exposure time, meaning they can provide a DM-density dependent heating signal. Exoplanets can be very cold compared to the nuclear fusion stars produce. Making it easier to detect the heat signature of the DM kinetic energy. Low core temperatures prevent DM evaporation compared to evaporation in neutron stars, providing new sensitivity to MeV DM (Adler 2009). Rogue, floating free planets would allow the heat flow stand out more without the thermal heat created from a parent star to interfere. Dark matter annihilation produces enough heat to raise planet's temperatures (Leane & Smirnov 2021).

While exoplanets seem to be an opportunistic method in indirect searches of DM, the type of planet for observation would likely play a role for direct observations of signatures in DM-heating. There has been research suggesting terrestrial planetary bodies could be used to detect DM from their atmospheres such as Mars to using the dark limb of the Moon to see radioisotopes caused by DM (Bramante et al. 2020) (Garani & Tinyakov 2020). Yet, gas giants such as Uranus, Jupiter and even larger would be the best candidates due to their cross-section area.

3.1. *Solar System Planets*

Jupiter and the other gas giants would work as great, local examples to know how DM interacts with large exoplanets. Jupiter and Saturn have large surface areas and a cool core temperature as well as Uranus and Neptune. Although the problem does arise if there's enough dark matter within the section of the Milky Way that the solar system inhabits in. If axion-like particles do travel across the solar system, then gas giants should be able to capture a small amount that should be detectable. Which would be the most sufficient could be based on the atmospheric composition on the elements to interact with DM particles to start an annihilation process. Even knowing the heat in the planet's atmosphere and core would be important to tell the difference between the internal heat and the excess heat from DM annihilation.

For Jupiter, most of the atmosphere is hydrogen with a fractional abundance of He relative to H, at 0.244 $\pm$ 0.005 by mass. At depths below the surface where the pressure increases $\geq 3\ M_{\rm bar}$, the hydrogen will be in the form of metallic hydrogen. In this state, the hydrogen forms an ordered lattice, and electrons move freely through the proton lattice as they do in a conducting metal. Clouds at various levels consist of ammonia and probably of NH4SH, ammonium hydrosulfide, and water (Cole & Wodfson 2013). Jupiter has an average density of $\rho = 1.3$ g/cm^3, with a radius of R = 6.99 $\times$ 10^7 m and a core with a mass in the range 10-20 M_{Earth} and at T_c = 1.5 $\times$ 10^4 K (Spohn & Johnson 2014). From the Bond albedo of Jupiter, 0.343 and the spectrum, it's possible to estimate its effective temperature as a radiator of energy with the average surface temperature 125K (Cole & Wodfson 2013). Using this information can provide an setting on what DM could be interacting with. Leane et al. 2020 has suggested Jupiter is capable of capturing and retaining lighter DM particles where the annihilation of sub-GeV DM to produce gamma rays (Leane & Linden 2021).

On Saturn, the temperatures are lower at an average of 95 K in which it radiates about twice as much radiation as it receives from the Sun. Heat generation within it is even greater per unit mass than is the case for Jupiter. This would be another advantage for DM sensitivity to be detect thermal heat in their atmosphere. Cassini spacecraft results say H abundance in Saturn's atmosphere at 0.18-0.25 by mass and He should separate more fully than on Jupiter. Saturn has low mean density (1/2 of Jupiter) and lower total mass gives much less compression of interior material than Jupiter but could produce metallic hydrogen. Other contents are below the atmospheric line of the troposphere and thermosphere where NH3, NH4, HS, and H20 is found (Cole & Wodfson 2013). While these contents are far unlike to interact with DM, it is worth note that they could depending on much DM is accumulated.

Uranus and Neptune would be good candidates of internal DM heating and DM-gamma ray decay despite having a smaller surface area since their core temperature is lower than Jupiter and absorb less heat from the Sun. Internal pressures on Uranus and Neptune are too low for the metallic hydrogen transition, no seperation, He/H ratio close to the solar ratio (0.262 $\pm$ 0.048 for Uranus). The main atmospheric components of Uranus are 83% hydrogen, 15% helium, and 2% methane with small amounts of other substances, such as ammonia and various ices formed from H, N, C and O. One model indicates Uranus has a density of 1.24 x 10^{3}kg/m^3 with heat generation in Uranus is at the level of less than 20% of oncoming solar radiation. The mass of Neptune is 18% greater than that of Uranus, but its equatorial radius is about 3% less giving a density 1.638 x 10^3kg/m^3. Substantially greater than Uranus, 1.270 x 10^3kg/m^3 but the compression effects can't be explained difference, likely composition of two bodies different (Cole & Wodfson 2013). There are still unanswered questions about the ice giants, but these objects could have strong chance of interacting with DM and might be a model for potential exoplanets as well. The interactions of DM could be slightly different than Jupiter-type gas giants due to having various ice particles in their atmosphere.

3.2. *Exoplanets*

Find some info on gas exoplanet atmosphere. Gas planets bathed in axions. Considering the gas giants in our solar system have a large cross-section area, it would be logical to detect DM from exoplanets that Jovian-type planets as well. Often called "Jupiters", these planets have masses about comparable to Jupiter to up to about 10-75 $M_{\rm Jup}$, becoming "Super Jupiters" (any higher would be a brown dwarf) (Leane & Smirnov 2021). Having a large radii and lower mass compared to brown dwarfs and stars, their internal heat flow can be very low making them ideal candidates. There are many nearby Jovian planets within 100 pc, which are potential candidates for the local exoplanet search (Schneider 2021). We can assume they are primarily composed of hydrogen and helium, but it is possible they contain other volatiles like Uranus and Neptune. These can be used to test the hypothesis that DM contributes to internal heat of the gas giants in our own solar system.

Distant exoplanet searches will require that the exoplanets be such that their detection is not obscured by a parent star. Even if these distance planets have very large orbits, the further the distance is from the observer then the host star could outshine the exoplanet making temperature measurements impossible. Therefore, the best candidates for distant planets would be rogue planets that are absent of a host star and free float independently in space. To detect them would require gravitational microlensing where a distant object bends and focus light coming from a star and a passing planet passes in front of the star makes a transit (Leane & Smirnov 2021). The advantage is if excess heat is detected on these worlds, then it can already be ruled out that an external heat is the cause and is likely internal heat with a possible cause of DM.

Using this method would make it easier to detect infrared of the heat flow.

$$\Gamma_{heat}^{tot} = \Gamma_{heat}^{ext} + \Gamma_{heat}^{int} + \Gamma_{heat}^{DM} = 4\pi R^2 \sigma_{SB} T^4 \epsilon \qquad (1)$$

Total heat flow of the exoplanet Γ_{heat}^{tot} can be determined by combining potential heat power sources, including external heat Γ_{heat}^{ext}, internal heat Γ_{heat}^{int}, and DM heat Γ_{heat}^{DM}. (Leane & Smirnov 2021) The outcome is the luminosity of a spherical blackbody where have R as the exoplanet radius, the exoplanet temperature (T), the Stefan-Boltzmann constant (σ_{SB}), and the emissivity (ϵ)of the planetary heat radiation efficiency, ranging from 0 to 1. (Carroll & Ostlie 2017) In this case, the excess DM heat as a contributor to the luminosity equation while adding two other factors. In regards to rouge planets, the external heating is negligible and we are left with Γ_{heat}^{int} and Γ_{heat}^{DM} as the only factors.

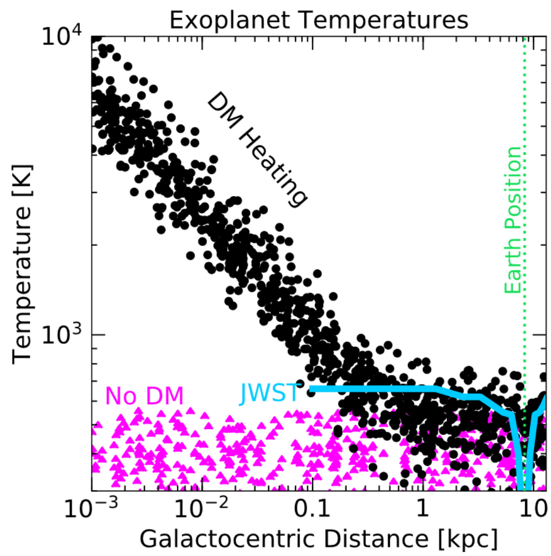

Figure 1. A model of temperature distribution of 20–50 $M_{\rm Jup}$ exoplanets over Galactocentric distances. Black dots are DM-heated exoplanets, magenta triangles are those without DM heating. The blue line represents the minimum telescope sensitivity of the JWST. Dashed green line is the Earth's distance to the galactic center. (Leane & Smirnov 2021)

In Figure 1, taken from the work of Leane and Smirnov (2021), both searches in local and distant are shown as an example distribution of exoplanets with masses of about 20–50 $M_{\rm Jup}$ with and without DM heating. The James Webb Space Telescope (JWST) is used as an example of an infrared telescope where the line represents the estimated minimum telescope sensitivity in 105 seconds of exposure considering the spectral flux density with the minimal temperature above about 650 K. Both are based on a new DM parameter space, probing the DM-proton and DM-electron scattering cross sections to unprecedented sensitivities (Leane & Smirnov 2021). What is shown that with DM heating, an exoplanet will have an increase in heat the closer it gets to the galactic center. If true, exoplanets could provide a potential method to map out the distribution and density of DM in the Milky Way.

Further in-depth on the DM density is another graph provided by Leane and Smirnov (2021) that considered three theoretical models. Using the Navarro-Frenk-White (NFW) profile (Navarro et al. 1996), a generalized Navarro-Frenk-White (gNFW) profile, and a Burkert profile (Burkert 1995) (with the local DM density 0.42 GeV/cm^3 (Pato et al. 2015)), Figure 2 illustrates the distribution of DM-heating exoplanet temperature as a function of Galactocentric distance. Exoplanets are based on a mass between 1-14 $M_{\rm Jup}$ and all in the range of 1 $R_{\rm Jup}$ radius where the shaded region for a given DM profile represents the range of heating possibilities for the indicated mass range. From the heaviest exoplanets at the upper boundary to the lightest in the lower region, the shape of the curves over galactic distances show the effective capture radius of the exoplanet based the DM density and velocity profiles (Leane & Smirnov 2021). Both figures show using an infrared telescope with minimum temperature sensitivity ($\leq$ 650 K) and exoplanets all the way into about 0.1 kpc of the inner Galaxy, it is possible to measure DM-heating of distant and local exoplanets. Leane and Smirnov determined that DM with masses above about an MeV can be probed with exoplanets, with DM-proton scattering cross sections down to about 10^{-37}cm^2 and DM mass sensitivity lighter than many other celestial body searches for DM heat flow.

Based on the three DM density profile, likely candidates closer into the galactic center or inner area of the Milky Way's disk. Another great area would be the galactic halo. An advantage of using these planets would provide astronomers a way to map the galactic dark matter density of the Milky Way. Tolos et al. (2020) has even considered a model of dark compact planets where planetary bodies are admixed with dark matter material. Weakly interacting DM for Earth-like mass and radii to strong interacting DM for Jupiter-like mass and radii (Tolos & Schaffner-Bielich 2015). The next question to the research on this subject is looking into the DM interactions on exoplanets at the microscopic level.

4. DARK MATTER AXIONS

As stated, we can assume the DM particles that would interact with planetary bodies would be axions. A type of WIMP candidate, axions have no charge and the like at a scattering of an uncharged particle like a neutron. Currently, they have started to become a leading candidate for DM (Chadha-Day et al. 2021). The reason is they seem to fit in the puzzle on why quantum chromodynamics (QCD) seems to preserve Charge and Parity (CP)-symmetry know has the strong CP problem (Kobayashi & Maskawa 1973). The Peccei-Quinn theory provides an anomalous symmetry to the Standard Model in which a scalar field spontaneously breaks the symmetry at low energies and an axion suppresses the CP-violation (Peccei & Quinn 1977). The axion field in the Standard Model couples to gluons in which the axion mass can be computed in terms of the strong nuclear force. The axion mixes with a neutral pion in which the interactions with the neutral pion mean that the pion's mass generates a small mass for the axion. QCD effects produce an effective periodic potential in which the axion field moves. The oscillations of the axion field about the minimum of the effective potential generate a cosmological population of cold axions with an abundance depending on the mass of the axion. With a mass above 10-11 times the electron mass, axions could account for dark matter making it a likely candidate (Chadha-Day et al. 2021).

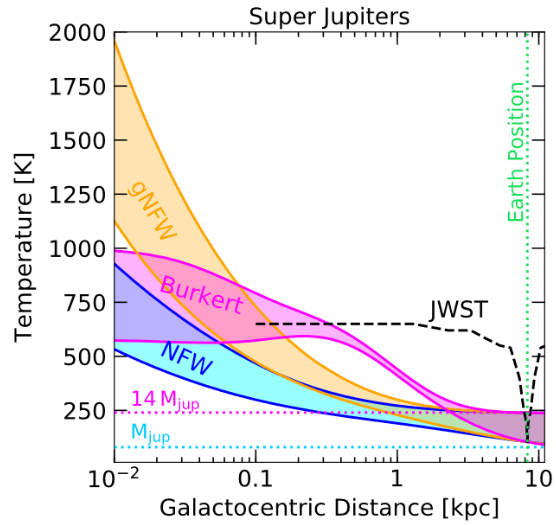

Figure 2. The labeled DM density profiles are included to model the exoplanet temperatures over Galactocentric distances of super Jupiters (1 - 14 M_{Jup}). The dotted lines show the range of minimum temperatures for a 10 Giga-year-old exoplanet without DM. The black line represents the minimum telescope sensitivity of the JWST (Leane & Smirnov 2021).

In doing so, when searching for DM interactions on exoplanets then axion-like particles (ALPs) should be considered. With photons and matter particles through its interaction with $\vec{E} \cdot \vec{B}$ (electric and magentic field), axion (DM) would look like an additional electrical current or anomalous magnetic field with Maxwell's equations modified by the addition of the axion field. In coupling to nuclear spins, axion Dark Matter would cause these spins to undergo precession (precess) in the electric field, as they would in a magnetic field. The coupling between axions and photons would also allow axions to be copiously produced in stars (Chadha-Day et al. 2021). If these ALPs can couple with the elements in planetary atmospheres such as hydrogen or helium, it should be possible to cause oscillations.

It would be important to understand how to detect DM in direct searches in order to know what kind of signature these particles create. Yonit Hochberg et al. (2021) suggests the inclusion of dark Compton scattering where an incoming bosonic DM particle interacts with the electrons in the detector and a photon is emitted in the final state. Through axion-like particles (ALPs) using the free-electron approximation (FEA),the rate for a slow-moving DM flux is given by (Hochberg et al. 2021)

$$R = \frac{n_e \rho_{DM}}{\rho_T} \frac{e^2 g_{aee}^2 m_a (m_a + 2m_e)^2}{16\pi m_e^2 (m_a + m_e)^4} \quad (2)$$

Here an ALP, a, of mass m_a, couples to the electron with strength g_{aee} and undergoes a dark Compton scattering. The electron recoil spectrum is a delta function centered at the same value as for a dark photon, at $T = \frac{m_a^2}{2(m_a+m_e)}$. Dark Compton scattering that can occur in the detector becomes prominent at high masses above $\geq$ 100 keV (Hochberg et al. 2021). If this is true, than ALPs should be able to interact with charged particles and create an excess heat that infrared detectors detect in indirect searches.

5. BETHE-BLOCHE EQUATION

To measure the excess heat from DM annihilation based on the material it interacts with, one suggestion would be to use the Bethe-Bloch (BB) equation. As a way to calculate the mean energy loss per centimeters for a particle of momentum p and mass m in material of density (ρ), the BB equation could be applied to an axion-like DM particle. It can be used to explain the excess heat from DM annihilation on microscopic scale. Represented in ($-dE/dx$), the excess energy indicates the distance travelled of swift charged particles traversing (or stopping) material (Sundaresan 2001).

$$-\frac{dE}{dx} = z^2 C \frac{Z}{A} \frac{\rho}{2\beta^2} [\ln \frac{2m_e \beta^2 \gamma^2 E_{max}}{I^2(Z)} - 2\beta^2] \quad (3)$$

$$E_{max} = \frac{2m_e \beta^2 \gamma^2}{[1 + (m_e/m)^2 + (2m_e \gamma/m)]} \quad (4)$$

$$C = 4\pi N r_e^2 m_e \quad (5)$$

In the BB equation, the energy lose over distance is calculated from the charge of the incident particle (z) (in units of the electron charge) traveling through a medium of the atomic number (Z) and atomic weight (A). If we are considering that the charged particles or even ALPs are moving at or near the speed of light, then we have to consider c = 1 in terms of relavitiy. $\beta = p/\sqrt{p^2 + m^2}$ is the velocity of the incident particle in units of the speed of light in a vacuum (c = 1), $\gamma^2 = 1/(1 - \beta^2)$, and m_e is the rest mass energy of the electron (or could be the mass of the DM particle). E_{max}, equation (4), is the maximum kinetic energy that is transferred to a free particle after collision. The incident particle with mass m and momentum p collides with the particle of m_e. *I(Z)* is the average ionization energy of an atom of the atomic number. Equation (5) takes in consideration Avogadro's number (N) and the classical electron radius $r_e = \alpha/m_e$ where $\alpha = 1/137$ (Sundaresan 2001) (Grimes et al. 2017).

Fast charged particles moving through matter interact with the electrons of atoms in the material. The interaction excites or ionizes the atoms, leading to an energy loss of the traveling particle. However, the BB equation is initial made for charged particles and would need to consider how to account for DM that lacks interaction with EM. Neutron scattering could be a suggestion since they do penetrate further into matter than electrically charged particles of comparable kinetic energy (Sundaresan 2001). Leane and Smirnov (2021) use a hypothetical concept of DM-electron scattering for hydrogen dense exoplanets on the assumption that the proton number density is identical to the electron number density.

5.1. *SRIM*

The Stopping and Range of Ions in Matter (SRIM) software uses the BB equation to measure the excess energy from the mean free path and oscillations of particles through a medium. The energy loss of ions in matter are calculated in SRIM in quick calculations that produce tables of stopping powers, range and straggling distributions for any ion at any energy in any elemental target. Stopping power is the expression for the average energy loss by ionization, corrected for the density effect, is found to be valid for most charged particles over a wide range of energies, from a few MeV to several GeV. The TRIM (Transport of Ions in Matter) program in the software describes the range of ions into matte and provides details on many other aspects of the damage done to the target during the slowing-down process.

These are measured and plotted through the calculations of high energy stopping by the Bethe-Bloch equation (Ziegler et al. 2010). Several examples from SRIM could be seen as applications to the use of DM. Even a growing new idea on DM is perhaps it is not in the GeV range but lower to MeV or less (Berlin & Blinov 2018).

Mohammadi et al. (2017) used SRIM to compute the radiation damage from neutron irradiation in structural changes by the displacement cascades initiated by nuclear reaction. The modeling of neutron induced displacement damage was focused on reactor structural materials, including stainless steel composed of iron, nickel and chromium. The Interface Mixing program looks into the transport of atoms from one layer of a target into another layer in mixed gaseuous substances (Mohammadi et al. 2017). This could be suggested on how particles move in planetary atmospheres that are composed of multiple elements considering gas giants such as Uranus and Neptune have other elements deep inside.

6. ISSUES ON DM-PLANET DETECTION

While ALPs look like a likelihood on what DM could be and applied to the detection of them on exoplanets, there are a lot of uncertainties left unanswered. To start, axions and other models of what DM particles are need to be proven first. Scientists need to be certain that DM can interact with charged particles in order to be applied to the BB equation. The concept of DM having charges themselves would be contradictory since DM is to be assumed to not interact with the electromagnetic spectrum (CERN 2012). Although nuclear physics can be used, it does leave a lot of concepts to work with in simulations on what signatures DM could leave based on the type of particle. The BB equation would be left with a guessing game on the excess energy results.

The larger question remains if these particles can caused an annihilation process on planetary bodies. Gas giants do feel to be the best bet for interstellar observations due to having lower temperatures and a large cross section area. Just as mentioned before, without knowing what type of particle DM exists, there could be a large amount of astrophysical objects where infrared telescopes could detect excess heat caused by nuclear physics means but might not be DM. Still, the growing push for planetary research on exoplanets should not be looked over as an opportunity to be applied in the understanding of dark matter. If an unusual heat signature is found, there will be a series of examinations and simulations to rule any other cause of the excess heat until a better understanding of DM is applied. Even the type of planet would need to be considered since there has been a variety of planets discovered not found in our solar system. Their atmospheric composition could be different making the medium for which DM particles travel through have different outcomes.

7. CONCLUSION

Overall, the proposal that Leane and Smirnov (2021) give on using exoplanets as DM detectors is an intriguing possibility. The idea that DM annihilation on atmospheric particles causing excess heat would mean that it can be observed through infrared telescopes. The upcoming James Webb Space Telescope (JWST) would be best option and the Nancy Grace Roman Space Telescope (NGRST) is designed to look for signs of dark matter and observe exoplanets as well.

Launched in 2021 December 25, the JWST presents a major opportunity for a vast array of scientific endeavors as it will collect infrared (IR) light across a broad range of wavelengths. One of its main uses will be to study the atmospheres of exoplanets using spectroscopy. During the transit method as a planet passes in front of its star, JWST can measure the spectra of the planet and in turn determine the planetary heating. With the Mid-Infrared Instrument (MIRI) providing imaging and spectroscopic observing modes from 4.9 to 28.8 μm (Wright et al. 2015), JWST can be ideally suited to studying DM-heated exoplanets in infrared. As shown in the previous figures 1 and 2, the general sensitivity of JWST to exoplanet heating can be found by considering the spectral flux density. JWST would be able to observe Jovian-sized planets and probe new DM parameter space. Nearby Jupiters, especially if DM heated, would be within reach of direct imaging with JWST.

Another potential, upcoming space telescope would be the NGRST which plans on studying exoplanets along three complementary fronts: gravitational microlensing, direct imaging, and transit method. The Galactic Bulge Time Domain Survey is one of the surveys NGRST will provide in a census of extrasolar planets detected by gravitational microlensing of background stars (NASA 2020). The NGRST is expected to find about 2200 new cold planets towards the galactic bulge (Green et al. 2012), and hundreds of free-floating planets in which provides large statistical samples (Johnson et al. 2020). It aims to perform a deep near-infrared survey of the Galactic sky, and upon identifying candidates, can inform infrared telescopes such as JWST and ground-based telescopes where to measure the temperature of the candidate planet. Alternatively, if a K-filter is added to NGRST (allowing it to see further into the infrared), then itself may be able to measure the temperature of colder, distant exoplanets (Stauffer et al. 2018). Both telescopes would provide the opportunity to test if these DM-heating exoplanets are detectable if DM particles do interact with enough matter to create excess heat.

The expanding horizons that exoplanets have presented to astronomy and other fields of science present many opportunities. Right now, physicists appear to be limited on where to detect and observe dark matter from detectors on Earth to looking at the gravitational behaviors on intergalactic celestial objects. Yet there seems to be little thought into looking for dark matter in our own galaxy. While that rest on what the NFW profile is on the density and dispersion of DM in our galaxy and, most importantly, what type of particle DM is, this should be considered. The BB equation and SMIR simulation can provide an insight on DM interacts with Standard Model particles and what type of signature physicist need to look for. Studying our own Jovian type planets would allow us to see how DM is contained in our own solar system. Exoplanets can then be used to study on DM interacts with different mediums and how DM is mapped out with the Milky Way. Combining these two fields of astronomy and physics would open a new door in astrophysics on understanding the mechanisms of the cosmos.

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