As part of 1c you will be assessed on the completeness of your literature review outline, the completion of this feedback table and your 1c self-evaluation. Further instructions for completion can be accessed in the 1c assessment book.

**A1 milestone feedback table**

|  |  |  |
| --- | --- | --- |
| **Criteria** | ***1b: Drafting the scene* Feedback** (Feedback from tutor via track changes) | **Actions taken to improve within criteria for 1c** |
| **Topic development** | * What do you mean by “oppose”? Is there a better word(s) you can use? Are you asking if MOND is inconsistent with dark matter? Or if it removes the need for dark matter? Or something else? Choose your words carefully. Otherwise, this is a good title. * I know you restricted your investigation to rotation curves of galaxies. But that is not the full story. MOND explaining those is necessary, but it is not sufficient. It has to explain all of the data that requires dark matter if it is to be an alternative. I suggest you look into the Bullet Cluster. | * I realise that my title is unclear and lacks specificity, due to some poor choice of words. Hence, I will replace the word “oppose” with a more meaningful one. Since, my title asks if MOND can replace the theory of dark matter, I need to choose words/phrases such as ‘reject’ or ‘replace’ instead of ‘oppose’. I will also continue to further refine this topic, to make it clearer and more concise for future milestones. * I will also add Bullet Clusters to the area of comparison between these two theories, by first adding relevant information in the introduction of the review. I will also dedicate a paragraph in explaining this phenomenon and while maintaining a comparison between MOND and dark matter. This will hopefully increase relevancy of my review, as it contributes more evidence to the overall topic. |
| **Structure and organisation** | * Your introduction provides some good information. This will help the reader interpret what is to come.   I see what you are doing with this sub-heading. But it is not very good. Try to rephrase it. | * Although I need to include a sentence or two about Bullet Clusters in my introduction as an addition, I will maintain my current structure and organisation throughout my introduction. I will all try to maintain a good structure and organisation for my other paragraphs. * I will rewrite my sub-heading that is much clearer and more understandable, while trying to make it as concise as I can. I believe that formatting my sub-heading as a question by using a starting wording such as ‘how’, as well as rephrasing the rest of my sub-heading, while including relevant terms such as ‘MOND’ and ‘dark matter’ can drastically improve it. I will also replace my wording of ‘rotational observations’ with ‘observations of rotations…’, as my previous wording was unclear and confusing. |
| **Clarity of writing and language use** | * Your writing is good. There is the occasional strange choice of word, but you are off to a good start. Try and be as specific and precise as possible – people are reading your review to understand the whole picture so it’s your job to explain it to them. | * I understand that I have made poor word choices in some parts of my writing that reduce the clarity of the review. I will replace these words/phrases with much more specific and clear terms. I will also proofread my work more, in order to avoid the use of words that are irrelevant or might not make sense. I will also add more detail into my body paragraph(s), in order for the reader to understand the information in high detail. |
| **Keywords** | * Good try, but these act as additional search terms so should be different than those in your title. | * I will remove search terms that already exist in my title, as well as add one or two more keywords that are relevant. I will also ensure that these search terms stay relevant for future milestones. |
| **Acknowledgement of sources** | * Your references are very well formatted. Good work. | * I will maintain my citing format for more articles. I will also ensure that these new articles are relevant to the topic. |

**Self-evaluation of your 1c**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Self-reflective evaluation 1c** | | | | **Outline your justification for your self-evaluated marks here:** | |
| **CRITERIA** | **NO EVIDENCE**  0 MARKS | **PARTIAL**  1 MARK | **COMPLETE**  2 MARKS | **MASTERY** | **COMMENTS** |
| **Research question/statement**   * Refinement of broad topic into a specific question/statement |  |  | X | * Clear refinement of broad topic into a specific question/statement that could be addressed in a 1500-word literature review. * Question/statement is well articulated. | The research topic has been refined down to be discussed in a 1500-word literature review, while maintaining enough levels of specificity, from a broad topic of dark matter.  The topic had already been developed reasonably well during 1b, but after minor changes in the selection of words to the title, the topic is well refined. |
| **Abstract and keywords**   * Appropriate number of keywords * Appropriate keywords identified * Abstract paragraph provided |  | X |  | * A complete abstract has been provided that aligns with the proposed discussion points mentioned in the detailed outline of the review. * Keywords were relevant, accurate and align with the current topic. * The abstract clearly summarises the content present and contains one to two background sentences, what research has been undertaken to date so, any obvious gaps in the literature, the aim/scope and conclusion/bigger implications. | The abstract has been mostly complete but is written in dot point format. It provides some background information and context for the review. It needs more information on relevant research that has been undertaken so far. The scope of the review has been addressed. The abstract will need to be writing in the format of a literature review, instead of dot-points. There needs to be more background information and information on the research up to date.  The number of keywords is appropriate and are relevant to the topic. |
| **Outline structure and organisation**   * Identified two to three subheadings in main body * Dot points/paragraph of arguments * Dot points/paragraph for discussion * Dot points for conclusion * Structure and linking attempted |  | X |  | * Identified subheadings and fleshed out main body arguments. Synthesis of information shown. * Structure and linking has been attempted. Relatively clear structure has been proposed. More linking between concepts may be needed in the final review. * Dot points/paragraph with discussion and conclusion, comprehensively indicate the main areas to be commented on within the final review. * Logical and defensible arguments presented. | I have chosen an additional two subheadings for my main body paragraphs, with an additional paragraph for further discussion and a general comparison. The content to be discussed in the subheadings have been stated as dot-points with arguments, which needs to be changed to make it suitable for a literature review.  The comparative-style structure in the main body paragraphs, has been attempted for this review. Although, I need to make more improvements in the overall structure and linking between paragraphs.  The arguments presented are logical but are only briefly described. They will need to be presented in more detail. Each argument has a corresponding evidence from a peer-reviewed article/journal, more evidences is required for some arguments. Some subheadings may require some rephrasing to make it clearer and more concise. Although, it does give a general idea of what the paragraph is about, from the current titles and arguments.  I used a discussion section, although it needs to be converted from dot-point format to a paragraph format in 1d. This section links together all the information covered, as well as starts to form a link to conclusion.  The conclusion is written in dot-point format, though it is slightly brief, I will need to add more relevant points. It will also need to be converted to a paragraph for the literature review. |
| **Synthesis of literature**   * At least ten peer reviewed articles * Citing within the outline against main arguments * Reference list |  |  | X | * Main body/discussion dot points acknowledged sources via citations and cited articles were provided in the reference list. * At least 10 **relevant,** primary peer-reviewed articles published between 2016 to present. * In-text citations and references appropriately used and formatted. | The evidence section of the main body paragraphs acknowledges relevant sources. Although this is only limited to one source per argument, this will need to increase before 1d.  I have found 10 relevant peer-reviewed sources that have been published within the last 5 years.  In-text citations and references are also formatted appropriately. |

**Does the Modified Newtonian Dynamics model reject the existence of Dark matter?**

**Abstract**

* Background
  + Different observations in the observable universe suggests flaws with our understanding of General Relativity.
  + MOND and Dark Matter have been used to try to justify these phenomenon’s but which of these theories is better?
* Research to date and gaps in literature
  + Dark Matter has no experimental evidence but strong theoretical evidence to justify their existence.
  + MOND works for only some of these observations.
* Aim and scope
  + To compare both these theories with different observations and phenomenon that occur in the observable universe and argue for why MOND might be a more prominent theory than Dark matter.
* Bigger picture implications
  + Finding out whether only one theory is sufficient to explain these unexpected observations in the universe. Using this to approximate data and make predictions of future events in the universe.

**Keywords:** MOND, Dark Energy, Rotational Curve, Bullet Cluster, Gravitation, Universe, Galaxy:disc

**Introduction**

Observations of the rotation motion of galaxies and the expansion universe suggests that there could be potential flaws with the theory of General Relativity. The results from these observations shows that velocity of the gases in stars does not decrease at the other edges of the galaxy and that there is a force overcoming gravity, causing an acceleration in the expansion of the universe. Thus, suggesting that there is a potential unknown force and/or matter that is modifying the force of gravity. Dark matter is an anti-luminous matter, hypothesised by many Astrophysicists and Cosmologists in order to explain these unexpected observational results. There are different proposed alternative theories that does not require the existence of non-luminous matter such as Dark Matter. The Modified Newtonian Dynamics (MOND) is the most prominent theory among those, suggesting that a modification with Newton’s equation can explain the observed rotational pattern of galaxies. Hence, the purpose of this review is to initially compare Milgrom’s hypothesis (MOND) with these two observations of the universe that lead to potential flaws with our currently used physical laws and models (Corasaniti 2020) and question the existence of Dark matter.

**How does MOND explain the observations of rotating disc galaxies in comparison to the theory of Dark matter?**

The velocities measured of different flat disc galaxies is significantly higher (Chang 2019) than what is expected from Newtonian mechanics and luminous matter. The laws of General Relativity also fail as stars and other celestial objects that are far from the centre of the galaxy move at the same angular velocity with objects closer to the centre of the galaxy (Crosta 2020), rather than it being much lower (Wilhelm 2020). This also contradicts the inverse square proportionality relationship between gravitational force and the radius of orbit (Ghari 2019). The theory of Dark matter explains these discrepancies by introducing theoretical non-luminous halo particles. These particles are said to surround all galaxies in order to contribute enough mass such that Newtonian mechanics do not fail (Crosta 2020). Using this theory, the amount of non-luminous particles (Dark matter) must be approximately 6 times as much as visible matter in the observable universe (Petersen 2020). On the other hand, Milgrom’s theory (MOND) suggests that introducing theoretical non-luminous matter is not required to explain this observation. The MOND theory suggests that there must be an unaccounted factor in our current gravitational laws, as general relativity can explain the motion of planets in our Solar System accurately. Thus, Milgrom proposed that the force of gravity must behave differently depending on whether a given celestial body has a high or a low acceleration, that is some critical value of acceleration (Ghari 2019). This modification of gravity states that the inverse square rule between the gravitational force and orbital radius is only valid at higher values of acceleration. At lower accelerations, they must be inversely proportional (Wilhelm 2020). Though the application of MOND, the obtained data fits correctly for dozens of observed galaxies.

**Comparing how these theories explain the phenomenon of Bullet clusters**

Argument 1: MOND and MOG theories can be used to describe bullet clusters without the need to invoke dark matter.

Evidence 1: Using Jeans analysis in MOND and comparing the kinematics of orbits can explain the occurrences of bullet clusters (Haghi 2019).

Argument 2: Dark matter provides a clear explanation for the collision of galaxies.

Evidence 2: Collision of dark matter and stars, will cause the gases within stars to clash at high speeds and hence result in a Bullet Cluster of galaxies (Madau 2020).

**How does the expansion of the universe link with these theories?**

Argument 1: Dark Matter provides strong theoretical evidence regarding the expansion of the universe.

Evidence 1: Scalar dark matter fields create vacuum energy causing the universe to exponentially grow (Kang 2020).

Argument 2: Using MOND and under assumptions such that the gravitational constant varies, and the radius of the universe is very large, the acceleration due to dark matter approaches 0.

Evidence 2: This results in the exponential expansion of the universe, without the need to consider dark matter (Christodoulou 2019).

**Discussion**

* State which theory explains each of the observations discussed about the best.
  + Rotation of disc galaxies – better explained by MOND
  + Accelerated expansion of the universe - better explained by Dark matter
  + Bullet clusters – better explained by Dark matter.
* Discuss a possible combination of the two theories.
  + Consider different possibilities? Can the theories be overlapped? Is one better than the other?
  + Conclude which one of the above provides the most accurate results.

**Conclusion**

* The current MOND theory does not relate with some of these observations, thus the theory of Dark matter cannot be rejected.
* Although MOND cannot reject existence of Dark matter, that doesn’t mean they are confirmed to exist. It just shows that our current understanding of the universe is not sufficient to explain these events through observations.
* Conclude with a “No”, as MOND can only explain some of these theories, while dark matter has a theory for all.

**References**

Corasaniti PS, Giocoli C, Baldi M (2020) Dark matter halo sparsity of modified gravity scenarios. *Physical Review D* **102**, 1-7. doi: 10.1103/PhysRevD.102.043501

Petersen J, Frandsen MT (2020) A method for discriminating between dark matter models and MOND modified inertia via galactic rotation curves. *Monthly Notices Of The Royal Astronomical Society* **496**, 1077-1081. doi: 10.1093/mnras/staa1541

Wilhelm K, Dwivedi BN (2020) On the radial acceleration of disc galaxies. *Monthly Notices Of The Royal Astronomical Society* **494**, 4015-4025. doi: 10.1093/mnras/staa967

Ghari A,Haghi H, Zonoozi AH (2019) The radial acceleration relation and dark baryons in MOND. *Monthly Notices Of The Royal Astronomical Society* **487**,2148-2165. doi: 10.1093/mnras/stz1272

Chang Z, Zhou Y (2019) Is there a fundamental acceleration scale in galaxies?. *Monthly Notices Of The Royal Astronomical Society* **486**, 1658-1666. doi: 10.1093/mnras/stz961

Crosta M, Giammaria M, Lattanzi MG, Poggio E (2020) On testing CDM and geometry-driven Milky Way rotation curve models with Gaia DR2. *Monthly Notices Of The Royal Astronomical Society* **496**, 2107-2122. doi: 10.1093/mnras/staa1511

Madau P, Lupi A, Diemand J, Burkert A, Lin DNC (2019) Globular Cluster Formation from Colliding SubStructure. *Astrophysical Journal* **890**, 1-12 18. doi: 10.3847/1538-4357/ab66c6

Haghi H, Amiri V, Zonoozi AH, Banik I, Kroupa P, Haslbauer M (2019) The Star Formation History and Dynamics of the Ultra-diffuse Galaxy Dragonfly 44 in MOND and MOG. *Astrophysical Journal Letters* **884**, L25. doi: 10.3847/2041-8213/ab4517

Kang ZF, Zhu J (2020) Scale genesis by dark matter and its gravitational wave signal. *Physical Review D* **102**, 053011. doi: 10.1103/PhysRevD.102.053011

Christodoulou DM, Kazanas D (2019) Universal expansion with spatially varying G. *Monthly Notices Of The Royal Astronomical Society* **487**, L53-L57