Mission Dark Mattter
Teacher's guide

IDENTIFICATION OF THE GAME

Title of the game : Verification of Dark Matter
Subject : Physics
Target courses : Mechanical physics or any astronomy or astrophysics course
Program : Science or complementary course
Objectives :

- Contextualize the concepts of the dynamics of circular motion and the conservation of energy.
- Present a contemporary physics problem: the existence of dark matter.
- Compare a theoretical model with real observations.
- Learn about the observation of stars and constellations.

Content addressed :

- Conservation of energy applied to the liftoff of a rocket to an orbiting space station (material covered: kinetic translational energy, gravitational potential energy and potential energy of fuel).
- Dynamics of the circular motion of a star orbiting around a galactic nucleus.

Average length of play : 45 minutes
Average time for all activities in the pedagogical scenario : 75 to 90 minutes

Description of the game

This game uses **astronomy and the concept of dark matter** as the background for applying the **principle of the conservation of energy and the dynamics** of an object in circular motion. During the mission, the students will have to perform a series of tasks in order to **obtain data that will contradict theoretical models and justify the introduction of the concept of dark matter.**

First, they will have to **collect basic information** about the composition of the mass of the universe. These data will open the discussion about the concepts of dark matter and energy. Then the students will use the concept of the conservation of energy to **calculate the energy to provide to a rocket to get to the space station.**

Finally, the members of the team will apply the **concepts of the dynamics of circular motion to calculate the speeds reached by five stars** in a distant galaxy located in the Cygnus constellation, UGC 11748. These measurements will then be used to **compare the calculated speeds with those observed** by astronomers in order to draw conclusions about the presence of dark matter in that galaxy.

To make the game play easier, the students will do a **preparatory assignment to determine the equations** that will allow them to carry out the calculations required in the game. **The game is played in teams of three:** a **pilot**, who will use the virtual reality headset, a **mission chief** and an **engineer**. These two will see the same images as the pilot, thanks to mirroring. The mission chief and the engineer will help the pilot by **solving the puzzles and doing the calculations.**

Comment : *To simplify the calculations that have to be carried out during the game, the mass of the fuel is not considered. This can be justified by positing the future discovery of a super-light fuel. It is also possible to point out this inconsistency and to address the problem head on by using an integral calculus formula to calculate the effect of the total change in mass attributable to the fuel.*

The steps for advancing through the game are described in detail and illustrated in Appendix 1

MATERIALS AND TECHNICAL ASPECTS

Materials required

Each game requires the use of a **Meta Quest 2 or 3 headset and a tablet or computer** to mirror the image viewed in the headset. The game is designed for **teams of three.**

The students also need to have on hand the ***Equipment Introductory Guide***, the ***Mission Planning Document***, the ***Mission Chief's Document*** and the ***Engineer's Document*** in order to play the game.

The following information can be found in the ***Equipment Introductory Guide*** **:**

- How to adjust and turn on the headset
- How to define the play zone
- How to mirror the game on a computer or tablet (mirroring means casting the virtual reality headset's content to a computer or tablet screen in real time)
- How to start the game
- How to exit the game
- How to turn off the headset

The following information can be found in the ***Mission Planning Document*** :

- Context of the game
- Explanation of how to use the controllers to pick up and place objects and to teleport
- Equations and theoretical content required to solve the game's riddles; team members must communicate to solve the riddles.

The following information can be found in the ***Mission Chief's Document*** :

- Context of the game
- Instructions for playing the game
- Information required to succeed with the mission
- Visual support concerning constellations and a sky chart

The following information can be found in the ***Engineer's Document*** :

- Context of the game
- Charts for noting the quantities obtained during the mission
- Space to perform the calculations required for the success of the mission

The game documentation can be found here (https://novascience.github.io/VR/).

Technical aspects and logistics

Using virtual reality in a course requires several preparatory logistical steps, including configuring the required accounts, headsets and WiFi, and setting up a space where the game can be played. It is strongly recommended that you read the “Logistics planning for the deployment of immersive virtual reality in a college” appendix.

Safety measures

Using an immersive virtual reality headset entails a low risk of cybersickness, a feeling similar to motion sickness. To minimize the potential discomfort and other risks, **we recommend following these instructions :**

1. A member of the teaching staff must be present at all times when the headsets are being used.
2. The play zones must be clearly marked and free of obstacles. They must remain free of obstacles for the entire duration of play.
3. The headsets should never be used for more than 30 minutes at a time.
4. We recommend removing the headset as soon as any discomfort occurs (headache, nausea, dizziness, for example). In this situation, the player can change places with the partner who is not using the headset.
5. A virtual reality headset should not be used by anyone with any of the following conditions: **heart or blood pressure problems, anxiety, post-traumatic stress, pregnancy, epilepsy**. In these cases, the participant should play the role of the partner so they can continue to take part in the pedagogical activity. The same precaution applies to people who tend to suffer from motion sickness.

If minor symptoms occur, encourage the student to remain in the room and rest for a while, until the symptoms subside. A chair should be provided quickly to anyone who starts to feel ill.

If more serious symptoms appear, immediately contact security, which will contact the educational institution’s first aid workers or emergency services, if necessary.

PEDAGOGICAL PLANNING

Practical tips

1. This game is played in at least two parts, which the teacher can arrange as they please. First, the students must prepare for the mission by calculating two algebraic expressions that will be used in the game, based on conservation of energy concepts (kinetic energy and general formula for gravitational potential energy) and the dynamics of circular motion (centripetal acceleration and general formula for gravitational force).
2. It is important for the game to be part of a complete pedagogical scenario. A sample scenario is presented later in this document.
3. It is crucial for the teacher to be comfortable with the virtual reality headset and the game to be able to intervene if the students encounter any problems. We therefore strongly recommend thoroughly exploring the headset and game before using it.
4. The students need to receive clear, explicit instructions on the use of the headset and the game. You will need to plan time to provide these instructions and explain the visual support before having the students play the game.

Outline of the activity

1. During a class just before the students play the game or as a homework assignment, each team completes the preparation document that will be used to perform the calculations required in the game.
2. The game takes place in classtime, with teams of at least three people: a pilot, who uses the headset and performs the manoeuvres; a mission chief, who guides the pilot using a document designed for this purpose; and an engineer, who is in charge of doing the calculations.

In general, the pedagogical scenario should include the following:

<table>
<tr><td>Before the game</td><td>A preparatory activity can be planned to prepare the students for the content covered in the simulation and to activate their prior knowledge.</td></tr>
<tr><td>During the game</td><td>When the students arrive, they should be given information related to :
▪ Game objectives
▪ Session outline
▪ Instructions

The game is played in teams of three. It is important for the students to be supported (both technologically and conceptually) by a sufficient number of people during play. In the preparation room, which is the first game activity, the students will have the opportunity to get to know the controllers and the 360 gaming environment.</td></tr>
<tr><td>After the game</td><td>A debriefing should be held after the game to make sure that the students internalize and absorb the target learning. First, you can gather the participants' impressions by asking them to describe their experience. Then you can go over the mistakes and most difficult concepts. Finally, a summary should be given, ideally by the students, and feedback should be provided by the teacher.</td></tr>
</table>

You can view a sample pedagogical scenario in *Appendix 3*

APPENDIX 1 – Detailed description of the steps of the game

The game, step by step

Emergency exit

Restart the level :

- If a problem occurs during the game, you can always restart the level by holding the green button at the bottom of the screen on the player's left arm for 3 seconds.

Restart the game :

- If a problem occurs during the game, you can always exit the game or press on the red button at the bottom of the screen on the player's left arm for 3 seconds or press the Oculus button in the player's right hand.

Room 1: Preparation room

Step 1.1: Getting to know the game and the controls

- Read the chart on the left describing the mission.
- Refer to the hologram on the table, which describes how to use the controls.
  - To pick up an item, use the button controlled by the middle finger (toward the centre of the hand).
  - To teleport, use the button controlled by the index finger (toward the edge of the hand).
- Refer to the bracelet on the left arm, which provides instructions during the game.

Step 1.2: Complete the chart on the composition of the mass of the universe.

- Pick up each item on the table and put it in the correct place on the chart.
- To pick up a lozenge, use the button controlled by the middle finger (toward the centre of the hand).
- The numbers should be placed on the shapes that display a percentage sign.
- The correct answers are as follows:
  - "Atoms" and "4.6%" for the yellow section.
  - "Dark matter" and "24%" for the blue section.
  - "Dark energy" and "71.4%" for the grey section.
- Once the exercise has been successfully completed, the chart will disappear.

Step 1.3: Pick up the access card

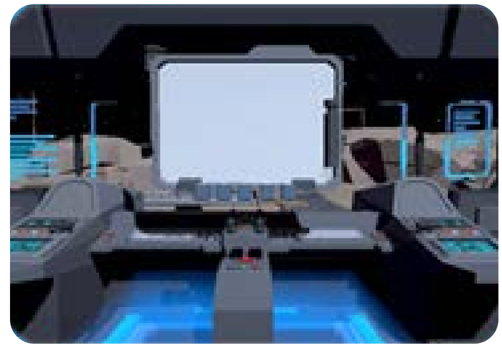
- Teleport to the rectangular key located near the lab machine.
- To teleport, press the button controlled by the index finger (toward the edge of the hand) until a blue laser appears and then point the laser at the area outlined in blue (point the laser toward the floor) and then let go.
- To pick up the card, use the button controlled by the middle finger (toward the centre of the hand).

Step 1.4: Open the door to move into Room 2

- Teleport to the door by pointing the laser at the area outlined in blue.
- Place the card in the slot in the machine under the red button, with the black part facing out.
- Press the red button. The door will open and the game will automatically pass into the next room.

Room 2: Control base

Step 2.1: Confirm the energy formula required to launch the rocket.



- Teleport to the verification station (in the back centre).
- Select the correct mathematical formula to use to calculate the energy required by the rocket.
  - The answers are placed at random.
  - Pay attention to the mass of the kinetic energy term. It should be the mass of the rocket.
  - Pay attention to the sign of the gravitational energy term. The Earth's radius term should be positive.
  - Correct equation: : $W_{nc} = \frac{1}{2} m_r (s_{ISS}^2 - s_E^2) + Gm_E m_r \left(\frac{1}{r_E} - \frac{1}{r_{ISS}} \right)$
- Once this step has been completed, check the pilot's left hand for instructions.

Note that Steps 2.2 and 2.3 can be carried out in either order.

Step 2.2: Piloting simulation station (station on the right).

- The goal is to find the three constellations on the chart (Lyra, Aries, Fornax) by turning the vessel using the joystick.
- Note that it is possible to recentre the simulation using the button on the left.
- Here are some pointers for finding the constellations from the initial position by pressing on the "Recentre vessel" button:
  - Lyra: Pivot right, following the astrological signs from Aquarius to Capricorn and all the way to Sagittarius and then go directly up, passing two or three constellations.
  - Aries: The constellation is almost visible from the start. It is in the upper left corner.
  - Fornax: The constellation is at the bottom left, just outside of the field of vision when the simulation is centred.

- Once the three constellations have been found, the screen on the left will display the required information.
  - Speed of the space station: v_{ISS} = 7,196 m/s
  - Radius of the Earth: r_E = 6,371,000 m
  - Mass of the rocket: $m_r = 2.8 \times 10^6$ kg

Step 2.3: Celestial analysis station (station on the left).

- The team has to identify the four constellations shown on the screen in order to choose the right group of variables in the instruction document.
- Use the arrows to move from one constellation to the next.
- It is possible to point at stars using the right hand to compare them with the lists of stars presented for each constellation in the instruction document.
  - Constellation 1: Centaur
  - Constellation 2: Canis Major
  - Constellation 3: Andromeda
  - Constellation 4: Cassiopeia
- Variables to use from the instruction document:
  - Mass of the Earth: $m_E = 5.972 \times 10^{24}$ kg
  - Orbital radius of the space station: r_{ISS} = 6,779,000 m
  - Speed of the Earth at the equator: v_E = 7,196 m/s

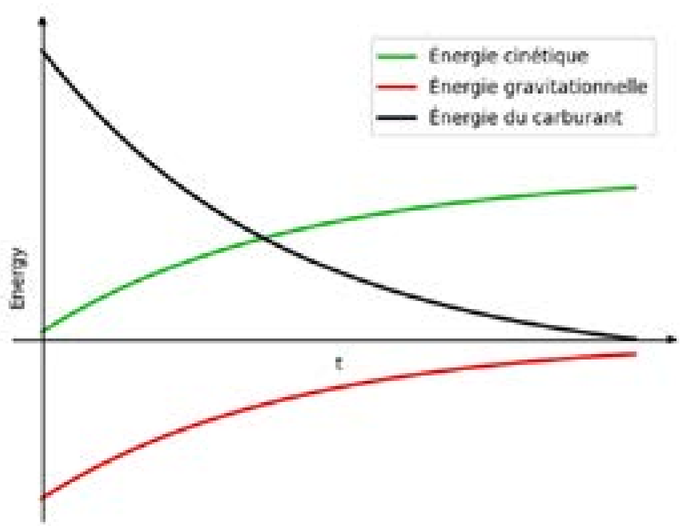
Step 2.4: Return to the verification station.

- Verify the amount of energy the rocket needs.
- Use the equation for the quantity of energy the rocket needs for the trip to the space station.
- **Equation:**
  - $W_{nc} = \frac{1}{2} m_r (v_{ISS}^2 - v_E^2) + G m_E m_r \left(\frac{1}{r_E} - \frac{1}{r_{ISS}} \right)$
- **Data :**
  - Speed of the space station: v_{ISS} = 7,196 m/s
  - Radius of the Earth: r_E = 6,371,000 m
  - Mass of the rocket: m_R = 2.8×10^6 kg
  - Mass of the Earth: m_E = 5.972×10^{24} kg
  - Orbital radius of the space station: r_{ISS} = 6,779,000 m
  - Speed of the Earth at the equator: v_E = 7,196 m/s
- **Response :**
  - Energy required by the rocket : 8.27×10^{13} J
- Once the answer is confirmed, the pilot will automatically move to the next room.

Room 3: Trip inside the rocket

Step 3.1: Launch the rocket.

- Activate the rocket launch by grabbing the joystick.
- Note the appearance of graphics showing energy as a function of time.
  - Graph on the left: Fuel energy
  - Graph in the centre: Gravitational potential energy
  - Graph on the right: Kinetic energy



Step 3.2: Start the docking sequence.

- When the graphics have finished, use the green button on the right to start docking. The instructions provided on the screen on the pilot's right arm will confirm that it is time to continue.
- After pressing the button, look straight ahead to watch the rocket dock!

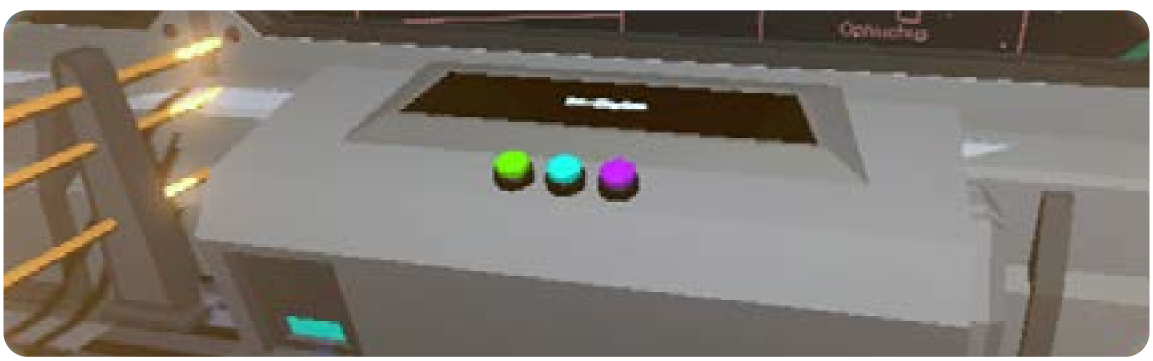
Room 4: Space station

Note that the station on the left (artificial gravity) is not used.

Step 4.1: Identify the five stars.

- The initial goal is to identify, in the sky, the five stars mentioned in the instruction document.
- Each time a star is found, data will appear on the analysis station screen.
- To point, use the index finger button.
- Finding five stars without help is hard. To make the identification easier, you can display information about the celestial sphere at the sectorization station.

Step 4.2: Sectorization station



- Teleport to the sectorization station in the middle of the vessel.
- The sectorization station allows you to choose the level of difficulty of identify the stars by changing the quantity of information displayed.
  - Green button: No additional information.
  - Blue button: Names of stars displayed on the celestial sphere.
  - Purple button: Names of constellations displayed on the celestial sphere.
- You can change your choice during play.
- Some stars will not be visible due to the orientation of the space station. The pilot has to go to the piloting station in order to change the orientation of the space station.

Step 4.3: Piloting station

- Teleport to the back of the room, where the piloting station is.
- Some stars will not be visible due to the orientation of the space station.
- Use the joystick to change the orientation of the vessel. This is the same process used for the piloting simulation.
- You can recentre the vessel using the button on the left.
- Here are some pointers for finding the stars from the initial position (you can press the "Recentre vessel" button at any time):
  - Schedar: Visible from the initial position by looking straight ahead, midway between the horizon and the zenith.
  - Hamal: Visible from the initial position by looking just above the vessel, around 11 o'clock.
  - Spica: Pivot the vessel so that Earth is straight down and Andromeda is visible in the middle window. Spica will be visible at 5 o'clock just above the horizon.
  - Vega: Visible from the initial position by looking just above the vessel, around 3 o'clock.
  - Sirius: Pivot the vessel so that Earth is in the first window on the right, starting in the middle and slightly exceeding the top of the vessel. Sirius will be visible just above the horizon, at 11 o'clock.

Step 4.4: Transfer the data.

- Each time a star is found, the data about a star in galaxy UGC 11748 will appear on the analysis station screen.

- When all five stars have been found, teleport to the analysis station.

- The pilot must communicate the data about the five stars to the team. Here is the information that should be displayed:
    - **Star A**
    - Observed speed: 2.47×10^5 m/s
    - Orbital radius: 1.85×10^{20} m
    - **Star B**
    - Observed speed: 2.40×10^5 m/s
    - Orbital radius: 2.75×10^{20} m
    - **Star C**
    - Observed speed: 2.37×10^5 m/s
    - Orbital radius: 3.18×10^{20} m
    - **Star D**
    - Observed speed: 2.25×10^5 m/s
    - Orbital radius: 4.26×10^{20} m
    - **Star E**
    - Observed speed: 2.47×10^5 m/s
    - Orbital radius: 6.48×10^{20} m

Step 4.5: Calculate the theoretical speeds.

- Teleport to the second part of the analysis station, under the graph.
- Using the keypad, enter the calculated speeds for each of the five stars in galaxy UGC 11748.
- Do the calculation using the equation obtained in the Preparatory Document.
  - **Equation :**
    - $s=\sqrt{\left(\frac{Gm_G}{r}\right)}$
    - The equation below assumes that about 95% of the mass of the galaxy is contained in a central sphere of the galaxy, which has a mass of $m_G = 1.54 \times 10^{41}$ kg.
  - **Calculated speed :**
    - Star A : 236 km/s
    - Star B : 193 km/s
    - Star C : 179 km/s
    - Star D : 155 km/s
    - Star E : 126 km/s
- If the wrong value is entered, a notification will appear on the screen on the pilot's left arm.
- Once the five values are correctly entered, the graph will show the calculated speeds in green and the observed speeds in red.
- *Note that the observed speeds do not seem to change based on the orbital radius. This is contrary to what is expected. One possible explanation is the presence of a significant quantity of matter that is not identifiable by luminosity and that is not concentrated in the centre of the galaxy.*

Step 4.6: View the dark matter hologram.

- Teleport back to the piloting station (in the centre).
- Press the button to display the hologram showing the galaxy as its luminosity allows it to be seen as well as the sphere attributable to dark matter.

Step 4.7: End of the game.

- Return to the space station door to view the congratulations animation.
- Teleport to the podium and press the green button to end the game.
- Bravo!

APPENDIX 2 – Logistics planning for the deployment of immersive virtual reality in a college

To do before the first use

Purchase headsets	You will need a set of Oculus Quest 2 or 3 headsets, enough for one for every two people. **Plan to have 14 to 15 headsets.**
Transport and charge the headsets	You will need a **cart** to transport and charge the headsets.
Set up Meta accounts	To use mirroring, which allows the students who do not have a headset to see the image, each headset must be linked to a separate Meta account. You therefore need to create as many institutional (or other) email addresses as there are headsets and **create a Meta account for each of these addresses**. Creating pseudonyms on an institutional email server may simplify email management. For example: metaheadset1@dawsoncollege.qc.ca; metaheadset2@dawsoncollege.qc.ca, etc. The procedure for creating a Meta account from an email address can be found **ici**.
Configure the headsets	Each new headset must be configured before linking it to the corresponding Meta account and connecting it to the right WiFi network.
Install the game	To install the game, you have to download the Meta app on a mobile device and log in using the identifiers for the Meta account linked to the headset. Then select Search and enter Novascience in the search tool. Then click on the image of the game and select Download. The detailed procedure can be found **ici.**
Configure the WiFi network	The institution's WiFi network must permit mirroring on multiple headsets simultaneously on a tablet, computer or phone. These permissions are generally managed by the institution's IT team, so it is important to check with them in advance.
Prepare for mirroring (tablet or cell phone)	If the mirroring is done on a tablet or phone, the Meta Quest app must be installed on it and connected to the same account as the corresponding headset. The device must be connected to the same WiFi network as the headset.
Prepare for mirroring (computer)	If the mirroring is done on a computer, it must be connected to the Meta account that corresponds to the address oculus.com/casting. The computer must be connected to the same WiFi network as the headset.

To do for every session

Reserve a room	To have enough space to safely run the game, every team must have a space measuring 1.5 m by 2.1 m with no furniture and no obstructions other than the equipment required for the students not using the headsets. Please ensure with your institution's IT services that the WiFi allows headset mirroring in that room.
Provide equipment for mirroring	Provide the equipment required for headset mirroring: computers, tablets or phones. If you will be using tablets or phones, make sure that the Meta app is already installed on them.
Provide support	Make sure to have enough qualified people to support the students technologically and conceptually. These people must be able to help the students use the headsets, choose the application and set up the mirroring at the beginning. From then on, the assistance may relate to technical support, but ideally the assistants will know the content of the game well enough to be able to answer questions about content that is challenging for the students or at least to point them in the direction of solutions.
Recharge the headsets	Make sure the headsets are recharged after every use.
Recharge the controller batteries	Make sure the controller batteries are recharged.
Update	Make sure the headsets and the game are updated before use.
Distribute the preparatory documents	Give the students the preparatory documents in advance, so they can familiarize themselves with the game and the equipment.
Cleaning	Provide wet wipes to clean the outside of the headsets and a microfibre cloth to clean the lenses, if necessary.
Safety	Provide a space where participants who are feeling ill can sit down.
Answers	Make sure that the responses to the game questions (or riddles) are easily accessible.

APPENDIX 3 – Sample pedagogical scenario

[Clic here to open link]