

# Dark Matter, the Card Game

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Dark Matter, the Card Game (DM, tCG), is a fast paced card game for 2 to 4 players where you will join the exciting hunt for Dark Matter, one of the most elusive phenomena of Nature. You will need to operate laboratories, start research, and allocate resources to unveil the potential Dark Matter candidates. Discovering Dark Matter will have you win the Nobel prize!

## I. CONTENTS

The game is based on real science<sup>1</sup>, and you can find at the end of this rulebook references on Dark Matter and its research.

DM, tCG comes with the following cards, for a total of 108 cards:

1. 9 dark matter related cards:
  - 4 Dark Matter cards, WIMP (Weakly Interactive Massive Particle), Dark Sector, Axion, and MOND (Modified Newtonian Dynamics), that have identical front and back
  - 5 Dark Matter candidate cards: 4 negative ones (“this is NOT dark matter”), and one positive (“this is dark matter”)
2. 51 science cards grouped into 3 categories:
  - 9 laboratory cards: 4 surface laboratories, 3 underground laboratories and 2 deep underground laboratories
  - 15 research cards: each individual card describing a different research effort
  - 27 resource cards: 9 Student cards, 9 Data cards, 9 Publication cards
3. 47 grant cards:
  - 34 money cards (from 1 to 30, and 33, 42, 50 and 100 M\$)
  - 13 event cards
4. one rule card, linking to this document

## II. GAME SETUP

The game starts by putting in front of all players the 4 Dark Matter cards and shuffling the 5 dark matter candidates cards. 4 of these 5 cards are placed, face down, one below each of the 4 candidates, and the fifth one is

discarded, face down, without looking at it. After this initial setup, the “this is dark matter” card will either be the discarded one (in that case none of the 4 candidates is indeed dark matter), or be below one of the candidate, which will be dark matter for this game. The aim of the game will be to discover this dark matter.

Then 3 stacks are made for the science cards, the laboratory stack, the research stack, and the resource stack, each shuffled and face down. The first card of each stack is drawn and revealed, face up, in front of its stack. During the game whenever one of the revealed cards is taken, the next card of the pile is revealed. When no cards are available, the game may end (see end game). Laboratory, research and resource cards can be discarded at some point during the game. If so, they are removed from the game and won't be used anymore until next game.

Finally, the grant cards are prepared. When played with less than 4 players, not all cards are used. When there are 2 players, remove from the game the money cards from 21 to 30, and if there are 3 players then discard the money cards from 26 to 30. Then all the grant cards (the money and event ones) are also shuffled and each player draws 3 of them. The remaining cards are also kept as the grant stack. During the game all the grant cards will be played and placed in a played grant card pile, side up, by the side of the grant stack. When no grant card is available in the stack, this discard pile is shuffled and placed again as the grant stack. In this game, you never end up without grant<sup>2</sup>.

## III. HOW THE GAME PLAYS

Every turn the players will first play grant money cards to determine the game turn.

They will then have to build a successful research for Dark Matter from science cards: they will start by owning a laboratory, then launch a research on it, and assign the needed resources. When this is done the candidate associated with that research will be revealed, leading to winning the game if it was dark matter, or continuing the game if not.

But it won't be so easy. Only one laboratory, research or resource is available at a time, a new one being revealed only after the current one is taken by a player.

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<sup>1</sup> BTW, you probably noticed that this rulebook is written as a scientific research article

<sup>2</sup> most scientists wish this would also apply in real life

Also instead of taking one of the available science cards a player can use an event card, which may alter the game, including the ownership of laboratories and researches.

The game ends either when Dark Matter is found (and whoever found it is the winner - there can be multiple winners if they finish a dark matter search in the same turn), when all candidates are searched and are found to be negative (in that case everybody wins), or when there is no resource card available (and in that case everybody loses).

#### IV. GAME TURN

Each player must select one of its 3 grant cards with a money amount (from 1 to 100M\$) and play it face down. If the player has only 3 event cards he needs to discard all of them to the played card stack of the grant pile, face up, and draw 3 new grant cards, repeating the procedure until he/she has at least one money card. Once all players have played their cards, they are revealed, and the play order is determined by the card values, the highest playing first.

Each player, when it is his or her turn, must do one (and only one) of the following actions:

- take the visible laboratory card. The laboratory belongs to the player and is placed in front of him/her. A new laboratory card is revealed
- take the visible research card. If there is a laboratory available where this research can be conducted (see below), he/she can directly assign the research to the lab. Note that the player doesn't necessarily need to be the owner of the laboratory. If there is no laboratory available or if the player doesn't want to assign the research to the available laboratories, he/she can keep the research card, face up, by his/her side. No more than 3 cards can be kept this way. If it would be the 4th card, one card must be discarded. The next card of the research pile is revealed
- take the visible resource card. If there is a research card assigned to a laboratory needing this resource, the resource card can be applied directly to this research. If the resource card can't be assigned or the player doesn't want to assign it to the available researches, the resource card can be kept, face up, by the side of the player. No more than 3 cards can be kept this way. If it would be the 4th card, one card must be discarded. The next card of the resource pile is revealed. If the last resource game is taken, the game will end at the end of the turn (see below)
- assign cards. If the player has one or more research card and resource cards by his/her side that can be assigned, he/she can assign, in any order, any or all

of the cards he/she owns. At least one card must be assigned

- play an event card. The card is then resolved (see the Event cards section below)

Passing a turn is not allowed<sup>3</sup>. Once a player has finished his/her action, he/she discards the grant card played to the played grant card pile.

Once all players have ended their turn, fulfilled research are checked. Note that it is done after all players have finished their turn. In particular one player could finish a research, but then another would play an event card to discard the research and all cards would be discarded. Or another player could use an event card to transfer the research to one of his/her laboratories and be the owner during the fulfill phase.

All researches than are fulfilled (have the 2 or 3 required resources assigned) at this stage conclude. All cards are discarded, and the corresponding dark matter candidate cards are revealed. **If one of the candidate revealed is indeed the dark matter ("this is dark matter" card), all the players with fulfilled research for this candidate win the game.** If none of the card revealed are dark matter (all cards are "this is NOT dark matter"), then the game continues. All research for a candidate that was already revealed not to be dark matter is discarded, with all its assigned resources if it was installed in a laboratory. Research cards kept by the side of players related to this candidate are also discarded, as is any card of the research pile when it is revealed if it targets that same candidate. **If all dark matter candidates are revealed and none of them are positive, then the game ends with all players winning the game<sup>4</sup>.**

After checking the researches, the resource pile is checked. **If at this stage the resource pile (including the face up card) is empty, the game ends and all players lose.**

Then all players complete their hands to 3 grant cards drawing from the grant pile (in the same turn order). If no more grant cards are available the grant discard pile is shuffled and used as a new grant pile. As mentioned earlier, the grant pile is the only pile that never shortages. Once all players have 3 grant cards in their hand, a new turn can start.

#### V. GAME END

As described above, the game can end in 3 different ways:

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<sup>3</sup> you are always active in research, there is no dead time

<sup>4</sup> in science, a negative result is an important result

- the “this is dark matter” card is revealed. All the players that have a fulfilled research for that candidate win the game (and the Nobel prize). There can be multiple winners in such a case<sup>5</sup>
- all dark matter candidate cards are revealed and none of them is dark matter (they all are “this is NOT dark matter”). Everyone wins in this case (what a relief!)
- if at the end of a turn, after checking the fulfilled researches, there is no remaining resource card available, then the game ends and everyone loses

## VI. RESEARCH CARDS

The research cards are the most complex cards of the game. While the other cards are self explicit, the research card have some more information on them. They can only be played on specific laboratories and require specific resources.

The background color indicate in which laboratory the research can be conducted. Research with a green background need a surface laboratory (which background is also green). Research with a dual color red/black background need either an underground laboratory (red background) or a deep underground laboratory (dark background) to be operated. Finally, research with a dark background can only be run in deep underground laboratory (dark background). Only one research can be operated at a time in a laboratory. If a laboratory is already hosting a research, it cannot host a new one until the current research is fulfilled.

The candidate that is being researched is indicated in the top-right corner of the research cards. 2 cards indicate that “this is NOT dark matter”. They are non-dark matter related research, and can be used against another player to fill his/her laboratories with research that is not relevant to the game<sup>6</sup>. These researches can be fulfilled like any other, except they will not reveal any candidate. Fulfilling them will however discard the card and therefore free the laboratory for a new research.

The top-left corner of the card indicates the resources needed for completion of the research. It can be 2 or 3 resources, which are student (red circle with an “s”), data (blue circle with a “d”) or publication (green circle with a “p”).

The lower portion of the card is indicative and gives the name of the kind of research and a drawing about the topic. More about it is explained in the science section below.

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<sup>5</sup> even if extremely unlikely, 4 players could win by finding WIMP dark matter at the same time. The Nobel prizes would have to adapt to this situation, as they refuse to give it to more than 3 persons!

<sup>6</sup> but of great scientific relevance

## VII. EVENT CARDS

The effect of event cards should be quite explicit in the text description on the card. When played, the effect described has to be applied. For example, the “New Principal Investigator” implies moving a research from one laboratory to another. If this is not possible the card cannot be played and if a player tried to play it he/she has to keep the card and select another action.

After an event card is played, it is discarded for the rest of the game. The event cards are the only grant cards that do not go to the played grand card pile. This is an important rule that should not be forgotten. Played event cards are removed from the game, don’t go to the grant discard pile, and won’t be played again in the current game.

- “New lab director”: whoever plays that event card must select one laboratory in play, owned by any player, and move it to another player, together with any research it might have and all the resources the research may have (one of the involved players can of course be the one playing the card). There must be at least one laboratory in play to be able to play this card and the ownership of one (and only one) laboratory must change by the effect of this card
- “Student protest”: when the card is played, it has no effect. It is a pun to the fact that unfortunately it is frequent to see in some area of science students as cheap manpower with little to no right to protest. This is usually not the case in the Dark Matter area, but the game authors believe it is worth raising the awareness on the issue. This card is also a tribute to the great boardgame “Junta” which has a similar card.
- “Brilliant postdoc”: a postdoc is a post-doctoral researcher, one of the nerves of the scientific world. This card must be played on a research (if no research are being run the card can’t be played) and will count for one resource of any kind that is missing, meaning the research will be fulfilled with one less resource than necessary. For example, if a research needed one student, one data, and one publication, and the “Brilliant postdoc” is played on it while it has already a data card, then the research only needs one student card or one publication card to be fulfilled. There is no need to say which resource the postdoc replaces when played. The postdoc will stay on the research until it is fulfilled and play whatever resource is necessary. It is considered a generic resource, and will therefore be stolen together with the research if “New lab director” or “New PI” is played, will be affected by “COVID lockout”, but will not be affected by cards targeting grant cards. Once the research is fulfilled, the postdoc is removed from game and doesn’t go back to the grant discard pile

- “No more funds”: this card must be played on a research being conducted. The research can have resource or not, even be fulfilled (and not yet resolved as the resolution of the fulfilled research occurs after the action phase when the event card is played). The research and all its eventual resources are removed from game. The laboratory is not affected, and is now free to receive a new research. There are 2 of this event card
- “New theoretical insight”: whoever plays it can look at one of the dark matter candidate cards that was not yet revealed, in secret, and then put it back, knowing now whether this candidate is or is not dark matter
- “COVID lockdown”: when played, all resources played on all the active researches are discarded. This also includes the resources on research of whoever played the card. No one is protected from the COVID lockdown. Note that the COVID vaccine research is not affected by this card
- “Science Ministry dissolved”: whoever plays it can select another player and force him or her to discard all the grant cards, face up, to the grant discard pile. This includes all the money cards and event cards that were in the target player hand. The target player will get back to the 3 card hand at the end of the turn, normally. If he or she had not played yet this turn, he/she won’t be able to play an event card, obviously. It is a good way to put back in game (in the discard pile) powerful event cards that some players might keep
- “Friendly Agency head”: the agency is usually the governmental entity in charge of financing basic research such as dark matter search. whoever plays this card must target another player and take all his/her grant cards. Doing so one normally should go back to 3 or less cards in hand, but if in excess, then one can select which cards to discard
- “Strange feeling of Déjà vu”: by playing this card you can get to your hand one event card that has already been played and removed from the game. This is the only way to have an event card played twice during the game. The chosen card is taken to the player hand, and of course can not be played until the next turn
- “Fake news”: all players, including whoever played that card, must discard all their grant cards. At the end of the turn everybody will naturally get back to 3 grant cards, but meanwhile before the turn ends nobody will be able to play more event cards, obviously
- “Revolution!”: Every laboratory, together with any eventual research on it and resources, is moved to

the player on the left. The same effect could be obtained if all players would change chairs one step to the right, but this is not how it is done. Revolutions move things to the left, right?

- “New Principal Investigator”: the PI is usually the person in charge of a research. Playing this card allows you to take one research, together with its allocated resources, and move it to another laboratory. You must move a research to be able to play this card. If there is no laboratory able to receive the research (must be empty and of the correct depth), then this card cannot be played

Remember the event cards are resolved immediately upon being played, before the end of turn (fulfilling researches, getting new grant cards). In particular one can win the game by “stealing” a fulfilled research from another player (via “New PI”, “New lab director” or “Revolution!”), or prevent someone from winning by playing “No more funds” on a fulfilled research before it can be resolved.

## VIII. TIPS

The Dark Matter cards have green/red/dark circles which corresponds to the research cards that look for each candidate. Axion and MOND have 3 green circle, remembering that the 3 research cards that look for them are operated in a surface laboratory. WIMP for example is researched by 2 experiments needing a deep underground laboratory, and 2 than can run in an underground laboratory or a deep one. It is also the only candidate with 4 research proposals looking for it. This information can be useful to plan the game.

While having strong grants (large values in M\$) can be good to get first the card you need, it may also be dangerous to finish a research while many other players still have to play if all event cards like “New Principal Investigator”, “New lab Director” or “Revolution!” have not been played. You could very well end the turn not being anymore the owner of that research and provide victory to another player.

Laboratories are much limited in number and play an important part of the game. When planning your game, always take into account the effects of “Revolution!” and “New lab Director” event cards.

Be careful when you have event cards in hand. If you don’t have money card at the start of a turn you will need to discard your 3 event cards to draw 3 new grant cards. It would be a shame to discard all these event cards. Keeping 2 event cards in hand can be dangerous if a third one is drawn at the end of the turn, forcing you to discard them all.

## IX. GAME EXAMPLE

Mark, Jamie and Sarah are playing. They sit around the table, and put in front of them the 4 Dark Matter cards, WIMP, Dark Sector, Axion and MOND. They then shuffle the 5 dark matter candidate cards and assign one face down below each of the 4 dark matter cards. They then discard the fifth without looking at it.

They then prepare the science card piles, laboratory, research and resource, shuffling each of them. They then remove from the game the money cards 26 to 30 from the grant cards (as they play as 3 players) and shuffle the cards, and draw 3 cards. Mark draws 3 money cards, 12, 24 and 42 M\$. Jamie has 2 money cards, 1 and 8 M\$ and the “No more funds” event card. Sarah gets only one money card, 18 M\$, and 2 event cards, “Revolution!” and “Student protest”. They are ready to play.

The first turn starts. The first card of each of the 3 piles is swapped, revealing a surface laboratory, the “Shine through the wall experiment” research, and a student resource card. Mark plays face down his 24 M\$ card, Jamie the 8 M\$, and Sarah has no choice but play the 18 M\$. All cards are revealed and the order is determined: Mark will play first, then Sarah, then Jamie.

Mark takes the surface laboratory and places it in front of him. Then he flips the first card of the laboratory pile and reveals another surface laboratory. Sarah takes the newly revealed surface laboratory and flips the first card of the laboratory pile revealing a deep underground laboratory. Jamie takes the deep underground laboratory and reveals the next card in the pile: an underground laboratory.

The first turn is over. The 3 grant cards played (24, 8 and 18 M\$) are discarded to the grant discard pile and Mark, Sarah and Jamie (in the same play order) draw one card each from the pile. Mark gets a 2 M\$ card, Sarah a “Brilliant postdoc” event card and Jamie a 7 M\$ card.

The 3 central piles have an underground laboratory, the “Shine through the wall experiment” research, and a student resource card exposed. Mark and Sarah have a surface laboratory played in front of them, while Jamie has a deep underground laboratory.

The second turn starts and Sarah has no money card in hand, having 3 event cards. She must discard them, face up, to the grant discard pile. Mark and Jamie are happy to see Sarah had to discard event cards. She then draws 3 new cards, 4, 13 M\$ and a “New theoretical insight”.

Mark plays his 12 M\$ card, Jamie the 7 M\$ and Sarah the 13 M\$. Sarah picks first the “Shine through the wall experiment” and assigns it to her surface laboratory. She reveals the next research card, which is the “Scintillator crystals”. Mark moans as he also wanted the Shine experiment for his surface laboratory, while the available research doesn’t match his laboratory. He decides to take the underground laboratory, places it in front of him and reveals the next laboratory card, a surface laboratory. Jamie then picks the “Scintillator crystals” and assigns it to the deep underground laboratory, revealing

the next card, the “Neutrino observatory”. The second turn is over, the grant cards plays (13, 12 and 7 M\$) go to the discard pile and each player draws a new grant card. Sarah draws the 33 M\$, Mark the 3 M\$, and Jamie the 100 M\$.

Mark has in front of him 2 laboratories, a surface one and an underground one, Jamie has a deep underground laboratory with the “Scintillator crystals” operating. Sarah has a surface laboratory running the “Shine through the wall experiment”.

The third turn can start. The available cards are a surface laboratory, the “Neutrino observatory” and a student resource card.

Mark plays a 3 M\$, Sarah the 33 M\$ and Jamie the 100 M\$. Jamie takes the student resource and assigns it to the “Scintillator crystals”, revealing a publication resource. Sarah then plays the “New theoretical insight card” and looks in secret at the dark matter candidate below the WIMP card. It is a “This is NOT dark matter” card and knows she shouldn’t worry about the “Scintillator crystals” research of Jamie. Mark is again unhappy as the research available, the “Neutrino observatory”, is not looking for dark matter. He decides to take the publication for later and keeps the card to his side, knowing he can keep 2 more cards this way. He reveals another publication card.

The third turn ends, and Jamie draws a “New principal investigator” from the grant pile, while Sarah must draw 2 cards (she only has one remaining card), a 21 and 22 M\$. Mark finally draw one card, a 25 M\$.

Mark still has his 2 laboratories, a surface one and an underground one, and one publication kept. Jamie has a deep underground laboratory with the “Scintillator crystals” operating and a student resource on it (still needing a data and a publication to fulfill the research), and Sarah has a surface laboratory running the “Shine through the wall experiment”. The 3 available cards are a surface laboratory, the “Neutrino observatory” and a publication resource card.

The fourth turn starts. Mark plays the 2 M\$, Jamie the 1 M\$ and Sarah the 21 M\$. Sarah starts and picks the “Neutrino Observatory” to play it on Mark underground laboratory. Mark seems quite unhappy with how the game has started for him. The “Cryogenic calorimeter” is revealed. Mark complains a lot. The available “Cryogenic calorimeter” cannot run on his available surface laboratory. The available resource publication cannot help him to get rid of the “Neutrino Observatory”, and the resource he has kept from the previous turn is also a publication. He decides to take the surface laboratory, his second one, and reveals a deep underground laboratory. Jamie then assigns the visible publication to the “Scintillator crystals”, which is by now only missing a data resource. The next resource card is revealed and is a student.

Sarah, Mark and Jamie each draw a card from the grant pile to get back to 3 cards, 9 M\$ for Sarah, 50 M\$ for Mark and 10 M\$ for Jamie.

The fifth turn starts with a deep underground laboratory, the “Cryogenic calorimeter” research and a data resource as available. Mark has 3 laboratories, 2 surface and one underground in which the “Neutrino Observatory” research is running. Jamie has a deep underground laboratory running the “Scintillator crystals” with a student and a publication resource, only missing a data. Sarah still has her surface laboratory running the “Shine through the wall experiment”.

Mark plays the 50, Jamie 10 and Sarah 22 M\$. Mark takes the data for his “Neutrino Observatory” and reveals another data. Sarah takes the deep underground laboratory and reveals an underground laboratory. Jamie takes the data for the “Scintillator crystals” and reveals a student resource.

The turn ends first by solving the fulfilled “Scintillator crystals” research. The dark matter card candidate card below the WIMP card is revealed, and to the surprise of no one, especially Sarah, it is not dark matter. The “Scintillator crystals” research and the 3 resources associated are discarded from the game, leaving Jamie’s deep underground laboratory available for a new research. The “Cryogenic calorimeter”, the visible research card from the research pile, is also a research for WIMP, so it is discarded and a new research is revealed, the “Noble gas TPC”. It is also a WIMP research so it is discarded again, and reveals a “Quantum Gravity theory”. All players then draw grant cards to get back to 3 cards and the game continues with only 3 dark matter candidates left...

## X. THE SCIENCE BEHIND DM, TCG

This game is inspired by the large international effort of a thriving community to search for Dark Matter.

Of course, a lot of information on Dark Matter and the specific candidates we selected for the game can be found on Wikipedia, and is as usual perfectly accurate. We will in this part describe very briefly Dark Matter, the 4 candidates we chose, and what is behind the different game cards.

Dark Matter is what is supposed to be 85% of the matter in the Universe. Looking at how the Universe behaves, we find many clues that there is more matter than it seems. The stars in galaxies move too fast as one goes away from the center. They should fly away from the galaxy into the unknown, and yet they don’t, they keep rotating around the galaxy center. We believe this is because there is more in the galaxy than what meets the eye. In addition to the stars and the interstellar gas, there may be an extra form of matter, 6 times more present than our known normal matter: the Dark Matter.

While it may seem like a bit of a stretch to postulate the existence of a new form of matter “just” because stars don’t rotate as we expect them, this is not the only hint we have. When we look at how groups of galaxies move one with respect of another, we find the same movement anomalies, and the same solution seems to fix

the anomaly: add 6 times more matter, an invisible matter. Then when galaxy collides we also need more matter to explain what we see. And as we know matter (when there is a lot of it) can bend light, we can also measure the amount of matter by looking at how light is deflected, what we call gravitational lenses. And again, guess what? We need 6 times more matter than the normal matter we observe to explain the lensing observations. Finally, looking at the Universe as a whole, the remnants from its first instants (the so-called Cosmological Microwave Background), we also find patterns that we can only explain by adding more matter. How much? 6 times more. All this cannot be a coincidence. Can it?

Something interesting (or annoying) about Dark Matter is that we know it cannot interact much with regular matter, else we would see these interactions and Dark Matter wouldn’t therefore be dark. This means that if the Dark Matter was made of particle, these could for example cross the Earth without any issue. This is very interesting because if we build a detector for a specific Dark Matter particle candidate, and turn it on, we will start seeing a lot of signals, not produced by Dark Matter but produced by normal matter particles. There are a lot of them, produced by natural radioactive processes, and other from the so-called cosmic radiation. Turning on any detector on Earth results in detecting these particles.

Now, if one goes underground, the rock slowly absorbs the cosmic radiation and the rate of events detected go down. Fast. While a typical detector of  $1\text{ m}^3$  would detect hundreds of particles per second on the surface, it would only detect one per hour 1 km below ground, and one per day 2 km deep. This is why a significant part of the search for Dark Matter happens underground, or deep underground, and why many of the experiments mentioned in the game need to be operated in underground laboratories, or deep underground laboratories. The denomination is not clear-cut, but one can consider laboratories below 1.5 km deep to be called deep laboratories. In this game, the surface laboratories could be any scientific institution with research groups in particle physics, theoretical or experimental.

Dark Matter search is definitely an extremely active research field, and there are hundreds of different candidates for this missing matter. We chose for this game 4 of them:

- WIMP, the Weakly Interactive Massive Particle. It has been the star of the show for decades, the most likely candidate for Dark Matter. There were many good theoretical models that predicted ways for the Universe to create a WIMP, a particle that would interact weakly (meaning it would be invisible as it doesn’t interact much), but be massive (and therefore could affect gravity in all the ways described above). While it was and still is the star of the show, the most “natural” models (this means the most simple ones, the most easily justified ones) have already been excluded by large Dark Matter

search experiments and while one can always adjust parameters to create a model just at the edge of the current detection limits, a significant fraction of the scientific community is starting to diversify the activity in search for other candidates. However, in the game, the WIMP is the only candidate which has 4 research cards for it, reflecting the current status of the Dark Matter hunt.

- **Dark Sector.** In the Dark Sector theories there is a whole dark world together with our normal world, but they just don't interact much. Many models propose communication between both worlds but these would likely imply lower masses Dark Matter particles. This implies usually that the detectors need to be more precise (and therefore often need to be operated deeper), but don't need to be that big (we know there is 6 times more Dark Matter than regular matter. If its particles are "light" we need more particles than if they are "heavy" to get the same amount of mass. So if they are "light", there are many, and we may not need too large a detector). These models have been becoming more looked after in the community given the non discovery of WIMPs.
- **Axion.** The axion is a theoretical particle that has been proposed to solve another issue in particle physics (the so-called strong CP problem), but it may also be a great candidate for Dark Matter, if its mass and density are in the proper range. It has been getting a lot of attention in the community as a well motivated candidate than could solve two long standing physics problems at once. It is a much lighter particle than what was discussed previously, millions of millions of times lighter. So lighter than in practice we rarely search them the same way. While for WIMP and Dark Sector we expect for a particle of dark matter to scatter in our detector and move/break something, the axion is considered as a wave more than a particle, and detected as an interference appearing in specific frequencies, or light coming out of nowhere. Not only the detection methods are totally different, but also cosmic ray are no longer an issue, meaning the experiments can be run on the surface.
- **MOND.** The last candidate is a bit different than the previous ones. Here, the idea is that the physics law we know and use may not be valid at large scales. There is a variety of modifications to the gravity laws that aim at explaining the different discrepancies in the observations that lead to the introduction of Dark Matter. MOND is one of this models, and is sometimes used as a generic way of describing these theories. While many of these models can properly explain a discrepancy (for example the galaxy curve rotation), none has managed to give a comprehensive view of all the obser-

vations. The particle Dark Matter is usually preferred in the community given the fact that a single particle may explain (almost) all the observations. Nevertheless, a lot of theoretical efforts are done in order to prove the community wrong and solve the Dark Matter problem with a new theory for gravity. Obviously, whoever works in this topic doesn't need to go underground and (luckily) works on the surface.

Finally, the 15 research cards were chosen to be a broad description of the research in the area. For each research the drawing illustrated the card was inspired by real research and experiments:

- **Noble gas TPC.** This is the most efficient Dark Matter experiment, looking for WIMPs, mostly. The drawing is based on the XENON experiment, the first of its kind and still leading the way together with other similar experiments, together with LUX/LZ and Panda-X, all of them using xenon in liquid and gas form to operate tons of target volume in which a dark matter particle could interact. As the leading experiments, it is the only one to need only 2 resources to check for WIMPs. Also in this category are experiments using argon as noble gas, in liquid and gas form too, such as the Dark Side experiment.
- **Scintillator crystals.** These crystals are used in many particle physics experiment to observe the passage of particles. The drawing is of the DAMA/LIBRA experiment, the only experiment to claim a positive signal for Dark Matter. The observed signal (an indirect one) is in contradiction with the absence of signal of other experiments, especially (but not only) the Noble gas TPC ones. These are exciting times...
- **Cryogenic calorimeter.** One way to look for dark matter is to have a very (very) cold material (as close as possible to the absolute zero) and wait for a dark matter particle to hit it and heat it (no pun intended). Operating at milikelvin temperatures, these experiments are sensitive to extremely small temperature change, ie extremely small knock of dark matter. The drawing is based on the CRESST dark matter experiment, the leading of its kind.
- **Bubble chamber.** These are interesting detectors as they were used in the early days of particle physics in accelerators, but then left over due to the fact they can't react fast enough to many particles. In these chambers the trace of a particle is visualised by bubbles (using out of equilibrium liquids), but when many particle interaction occur there is not enough time to prepare again the liquid for the next interaction. While this is has been an issue for a while in particle physics done at accelerators, in dark matter searches most of the time nothing

happens. This allowed these detectors to actually be brought back from retirement. The drawing is based on the PICO experiment.

- Solid state detector. These detectors are a variant of the cryogenic detectors, operating also at low temperature, but can use semi-conductors to exploit interactions of dark matter particles with electrons. This opens a new window for “lighter” dark matter as it is easier to knock on an electron than an atom, and therefore maybe open the Dark Sector. The drawing is based on the SuperCDMS experiment.
- Segmented camera. Similar to the previous ones, these detectors are just a big camera sensor that takes empty pictures in the dark, hoping to see dark matter interactions as small dots appearing out of nowhere. The latest version of these cameras take hours to read an image, but they are so precise they can see individual electrons and this makes them the best Dark Sector hunters to date. The drawing is based on the DAMIC experiment.
- Superconductive Nanowire. These are not yet ready for mainstream search of dark matter but are prototypes of future experiments. Different designs and materials in nanowires open the window to even more sensitive detectors than semi-conductors. It is a proof of concept of what Dark Sector hunters might be in the near future. The drawing is based on SNSPD (superconducting-nanowire single-photon detectors) related work.
- Axion Telescope. Axions could be produced in the sun, and one way of finding them would be to look at the sun with a telescope, but inside a closed building! While no light could be seen, an axion would go through the wall without issue. The difficulty is in making the axion visible inside the telescope. For that extremely strong magnetic fields are produced by superconductive magnets in the telescope. The drawing is based in the design of IAXO, the future of such experiments.
- Shine through the wall experiment. Similar to the previous axion telescope, another idea is to produce light, convert it to axion in, again, large superconductive magnets, put a wall, and then put another superconductive magnets to turn an axion back to light again and see if one could get light out of the wall... The drawing is based in the ALPSII experiment.
- Axion microwave experiment. Another way to look for axions is to have a microwave cavity optimized for picking up a specific frequency of light, that would be produced by an axion turning to light in a strong magnetic field magnet, as previously. The cavity has to be optimized to pick up very small signals, not your typical microwave oven. The drawing is based on ADMX, the pioneering experiment in the area.
- 5th force. When new particles can’t be found, and the 4 forces we know of in Nature can’t explain what we observe, then maybe it is time to push forward and add a 5th force into the equation. There are here and there some anomalies in particle physics that may hint at a 5th force. Maybe?
- New Gravity theory. That’s the standard MOND solution, the Modified Newtonian dynamics. Changing the gravity is not easy, because Newtonian dynamics work quite well, and General Relativity seems flawless up to now. Finding a modified theory that works as the usual one at solar scale, then operates as observed at galactic scale, and still doesn’t blow away when going at intergalactic scales, or at the full scale of the Universe, properly describing galactic collisions and other effects is far from being an easy task.
- Quantum Gravity theory. The holy grail of theoretical physics. Quantum mechanics is a wonder of modern physics, but has no gravity in it. General relativity has passed all the tests it has been up to, and even lead to the discovery of gravitational waves. Yet they don’t speak to each other. Will it be possible to have them naturally part of a big “theory of everything”?
- Neutrino Observatory. Neutrino science is the other main science done in underground laboratories. Neutrinos interact only weakly and can therefore go through the Earth without issue, meaning observing them is a similar task to hunting dark matter. They may actually even start to be an issue when dark matter detectors start observing the neutrinos. In the meanwhile, they are a sister science to the dark matter one. The observatory drawn is SuperKamiokande, a star in the neutrino observation science.
- COVID-19 vaccine. Finally, we couldn’t release a game based on science today without COVID being present. It did impact the dark matter search community like any other being on Earth, and clearly developing a vaccine has been and still is one of the most important activities run in laboratories.

As everything in science, something is considered valid until proof of the contrary is obtained. If you found any inaccuracy in this document, want to know more about any of the topics of the game, or just want to say hi, please drop us a message at [pff@labdpr.org](mailto:pff@labdpr.org).