The Search For Dark Matter: Rate of Rise

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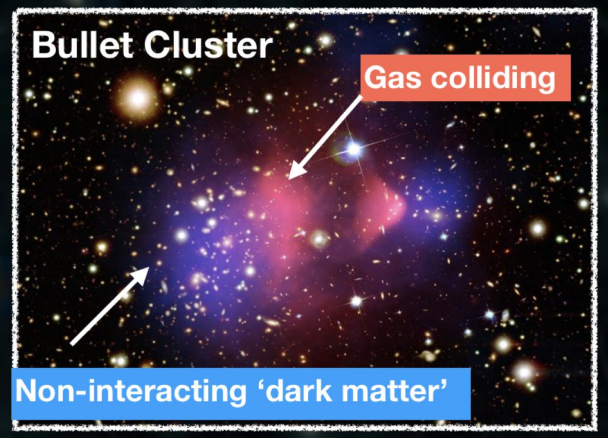
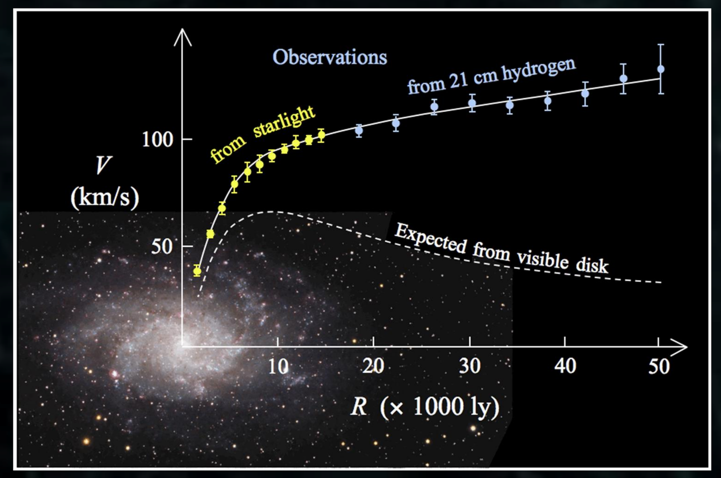
Introduction:

Astronomical observations of the last century strongly suggested the mass of galaxies to be considerably higher than previously expected.
Observed rotation curves of stars around the center of galaxies, velocity as a function of distance, revealed to be incongruent with expectations(see below) [1].

While a modified theory of gravity could attempt to explain the discrepancy, gravitational lensing is also observed as being affected by more mass present in galaxies than baryonic matter expected. An example of this the Bullet Cluster image to the right [2] where gravitational lensing can be seen. There is more "stuff" present that remains unseen and seems to only interact via the gravitational force. A further compelling point for a particle being the culprit and not just a variation in gravity was made by the Millenium Simulation at the Max Plank Institute simulating the evolution of the universe from its birth. In simulation mass clumps where galaxies cluster.





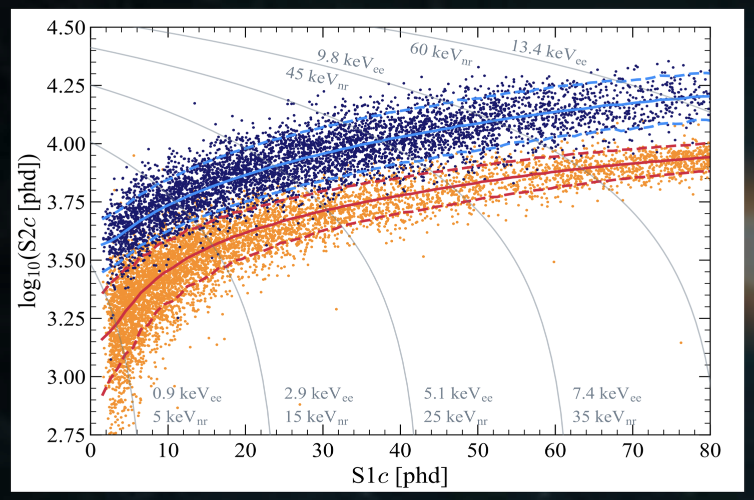
As the reality of the mass discrepancy set in, a variety of candidates for what "Dark Matter" is came along. What mass? Extinguished stars, neutrinos, axions, and modified gravity theories (MOND) were all considered. Presently a leading perspective suggests dark matter to be a Weakly Interacting Massive Particle (WIMP). Rarely interacting with matter, with high mass.

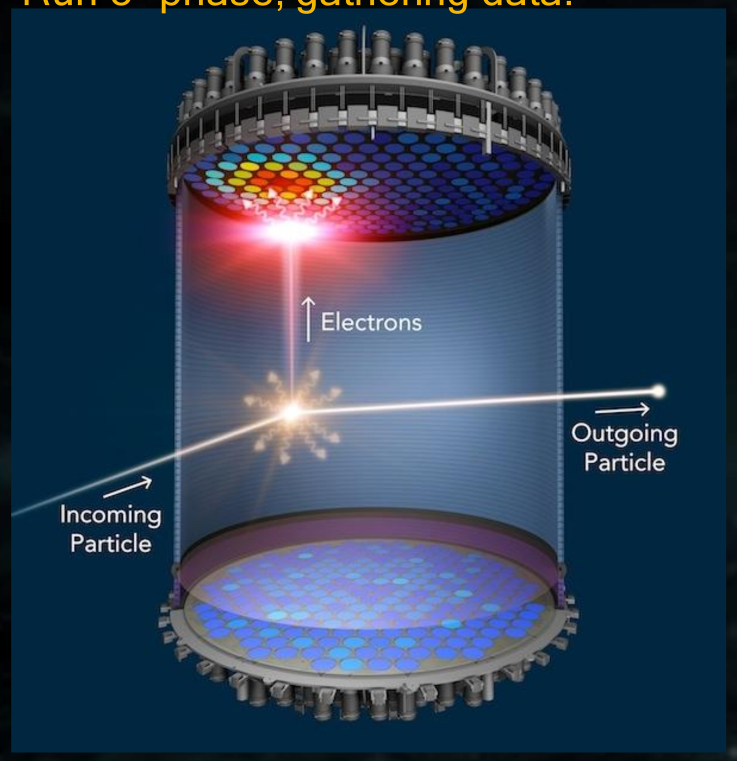
LUX-ZEPLIN (LZ) Experiment:

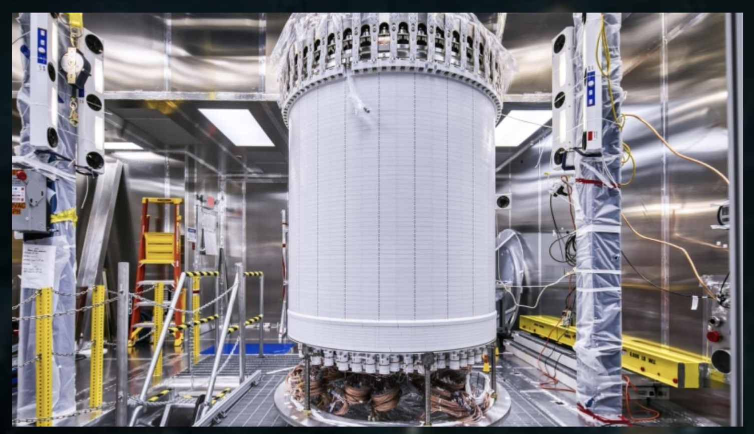
4850 feet below the surface of the Earth in Lead, South Dakota an international collaboration of physicists conduct a daily search for direct detection of Dark Matter interacting with highly pure liquid xenon at cryogenic temperatures via scintillation.

Detection is a 2-stage process. When a particle interaction occurs inside of the liquid xenon a primary scintillation signal (called 'S1') is produced. Ionization electrons are also created, and they are drifted under an applied electric field to the top of the detector where they produce a second scintillation signal (called 'S2'). Both light signals are detected by Photomultiplier Tubes (PMTs) at the top and bottom. The ratio of the S1 and S2 light allows LZ to distinguish nuclear recoils from electron recoils. The dark matter signal is expected to be a nuclear recoil, while most of the detector backgrounds are electron recoils [3].

There are various tasks performed on a routine basis to ensure the satisfactory performance of the LZ detector done by the onsite team, and collaborators remotely. Detector calibration with radioactive sources, online system monitoring, sampling of xenon gas, and maintenance of vacuum spaces are some of the tasks. LZ is in its "Science Run 3" phase, gathering data.







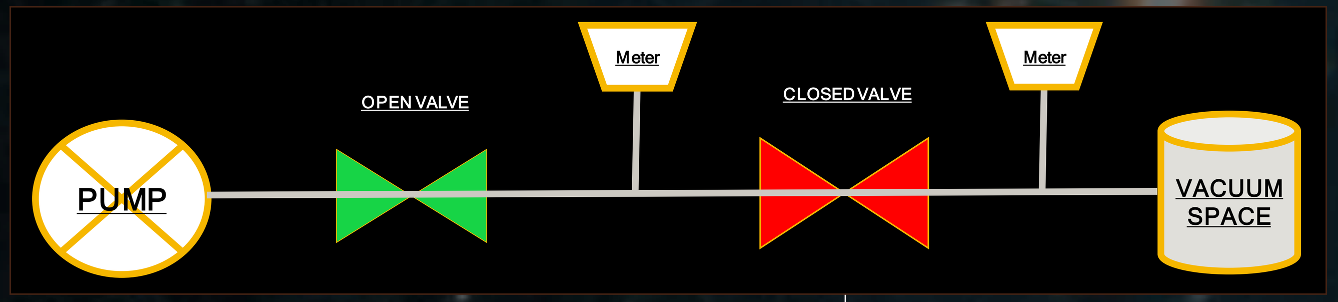
Rate of Rise Tests:

Unforeseen circumstances happen, it's important to understand the capacities of LZ in the event of loss of power or malfunction. There exists digital, and physical countermeasures to malfunction. Rate of Rise tests examine the vacuum based safety countermeasures of LZ.

In the case of unsatisfactory performance, electronic sensors alert managing LZ staff of metrics such as pressure, temperature, and rate. Upon alert staff can take digital or physical steps to remedy the alarm. In more severe incidents, overnight or sudden for example, there are sensors that will trigger devices such as physical valves, pressure pumps, alternative generators or compressors automatically.

Rate of Rise tests examine the case in which there is a total loss of electrical power to LZ systems, during which the electronic counter measures are unable to trigger any physical ones. For example, the vacuum spaces between room temperature and cryogenic environments of the experiment have a constant pump applied to keep extremely low pressure at all times. LZ staff close a valve via Ignition and thus close off the pressure pump from the vacuum and graph the rise in air pressure over the course of approximately 90 minutes to simulate how well the vacuum space can hold air outside in the absence of a pump.

A drawback of these tests is they were previously not automated. When an ROR (Rate of Rise) test was performed, the team would have to manually go through database and input the time of day the test occurred for a visual graph of how the space performed. LZ needed a function (see below) that can be called on




```python
def ror_Timestamps(days_Ago):
    #Define tags we want to retrieve:
    tags = ['8100PV', '8101PV', '8102PV', '8103PV', '8116PV', '8111PV', '1084SV', '2084SV']

    end = datetime.datetime.fromtimestamp(time.time()) # Time of daily "if test was ran" check
    start = end - datetime.timedelta(days=days_Ago)  # Assuming no tests were ran at night, 'start' will happen at 0730 MT, daily.
    end = end.isoformat()                            # Convert to correct format
    start = start.isoformat()

    #Standard Procedure for working with the LZ stat kernel. idbi object.
    idbi = IDBIWrapper(known_tags_file='/global/homes/a/aaronflo/sensor_tag_map.json')
    idbi.select(tags, start, end)
    data = idbi.resolve(dateformat='unix')
    local_Time = pytz.timezone('US/Mountain')

    #empty array that we will push all of our time data to in the below for loop.
    time_Data_For_All_Tags = []

    #STEP 1 DATA GATHERING: Pushes an array with the time data for a tag (if closed)
    for i in tags:
        valve_Off_Times = []
        index_Count = 0
        closed_Count = 0

        #For every piece of data, for each tag, if its zero (closed) append the time to the array we will return.
        for j in data[i]['vals']:
            if j == 0.0:
                closed_Count += 1
                valve_Off_Times.append(data[i]['times'][index_Count])
            index_Count += 1

        #For every element in our array (a time value) convert it to milliseconds, put in format, and replace in array.
        for k in valve_Off_Times:
            index = valve_Off_Times.index(k)
            k = k/1000.0
            k = datetime.datetime.fromtimestamp(k, local_Time).strftime('%Y-%m-%d %H:%M:%S.%f') #Converts time to a string type.
            valve_Off_Times[index] = k
        #Append array of nice, formatted data for this specific tag to central array containing data for all tags.
        time_Data_For_All_Tags.append(valve_Off_Times)

    #STEP 2 DATA PROCESSING: We start with an array of arrays. We go through each subarray and scan for test positive criteria.
    index_For_Tags = 0
    dictionary_Of_Tests = {} #This will be our final output!
    for i in time_Data_For_All_Tags:
        if not time_Data_For_All_Tags[time_Data_For_All_Tags.index(i)]: #If valve wasn't closed in the last day, just skip to next tag.
            index_For_Tags += 1
        else:
            minute_Counter = 0
            minute_One_Timestamp = datetime.datetime.strptime(time_Data_For_All_Tags[time_Data_For_All_Tags.index(i)][0],'%Y-%m-%d %H:%M:%S.%f')
            minute_One = int(time_Data_For_All_Tags[time_Data_For_All_Tags.index(i)][0][14:16])
            minute_Two = minute_One + 1

            while minute_Two == minute_One + 1:
                minute_Counter += 1
                minute_Three = minute_Two + 1
                minute_One = minute_Two
                minute_Two = minute_One + 1

                if minute_Counter == 30:
                    test_Array = []
                    last_Minute_Timestamp = datetime.datetime.strptime(time_Data_For_All_Tags[time_Data_For_All_Tags.index(i)]
                                                                       [len(time_Data_For_All_Tags[time_Data_For_All_Tags.index(i)]) - 1],
                                                                       '%Y-%m-%d %H:%M:%S.%f')
                    test_Array.append(minute_One_Timestamp)
                    test_Array.append(last_Minute_Timestamp)
                    dictionary_Of_Tests.__setitem__(tags[index_For_Tags], test_Array)
                    break
            index_For_Tags += 1

    #If this were a function this would be the return of the function. Instead of 'print', it would be 'return'.
    if not dictionary_Of_Tests:
        return 'There were no tests today.'
    else:
        return dictionary_Of_Tests

ror_Timestamps(7)
```

a daily basis and return the times an ROR test started, and ended, for a predefined set of valves under the 'tags' python list. This result can be used by staff to automatically send reports/graphs of ROR performance to managing staff without having to manually inquire. A process that may not happen for days after the test, this ensures daily reports.

LZ utilizes approximately 110-150 million dollars' worth of xenon gas. Ensuring vacuum spaces aren't compromised easily ensures the temperature of the cryogenic xenon-space at 173 K and liquid.

Maintaining all subsystems working properly with adequate countermeasures in place is of the highest priority for such a sensitive environment!

Remote Monitoring Shifts:

A critical aspect of managing LZ is stopping potential problems before they are observed. Collaborators utilize software to remotely control and monitor the detector systems in 8-hour shifts. As part of my REU I monitored the LZ detector systems and controlled data acquisition to run the experiment.

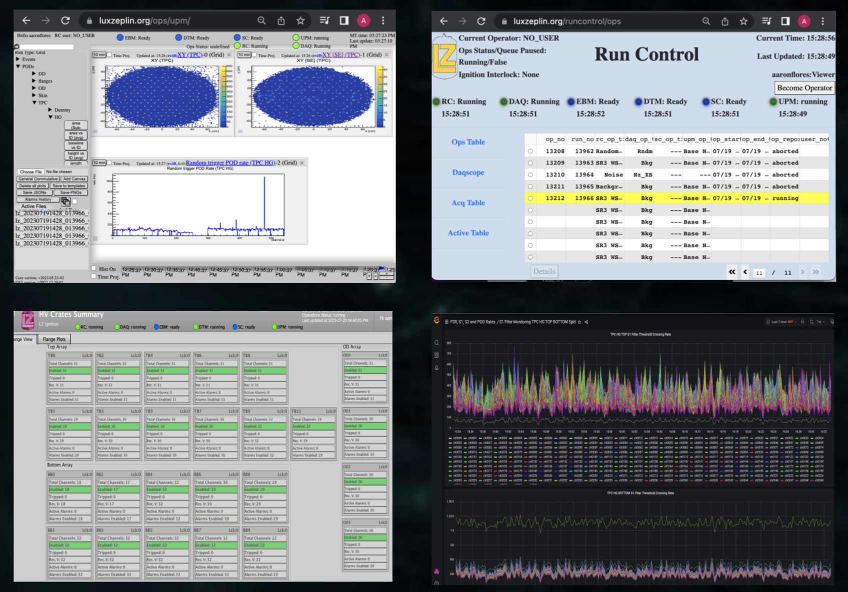
XLZD and Forward:

Currently LUX-ZEPLIN is conducting its third run of data collection, "Science Run 3." Collected data is "salted," where fictitious data is mixed with real data in order to prevent bias when analyzing. At the end of SR3 the results will be "unsalted," to show what data was acquired. The goal is to acquire data congruent with a proper proportion of S1 and S2 nuclear recoil signals. Currently there has been no conclusive evidence for direct detection [3].

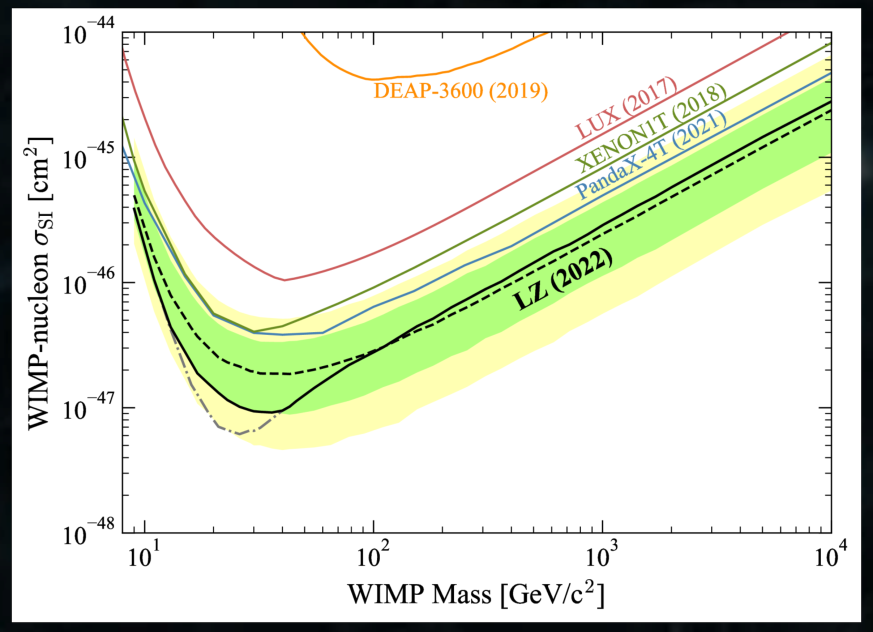
LZ will operate for the next few years. Preparation for a next-generation dark matter experiment has started under a consortium named XENON/LUX-ZEPLIN/DARWIN (XLZD).

XLZD is will be a Time Projection Chamber (TPC) design with 40-80 tonnes of active mass. Having a higher mass detector allows for searches at theoretically lower WIMP-nucleon cross-sections, the higher the volume on the detector the lower the theoretical cross-section of dark matter that can be scanned for. The lower bound of the proposed XLZD detector will be nearing the estimated "neutrino fog" limit, where differentiation between dark matter and neutrino signals becomes difficult and unreliable. The noble liquid TPC detector approach would near its maximum potential in searching for dark matter [4].

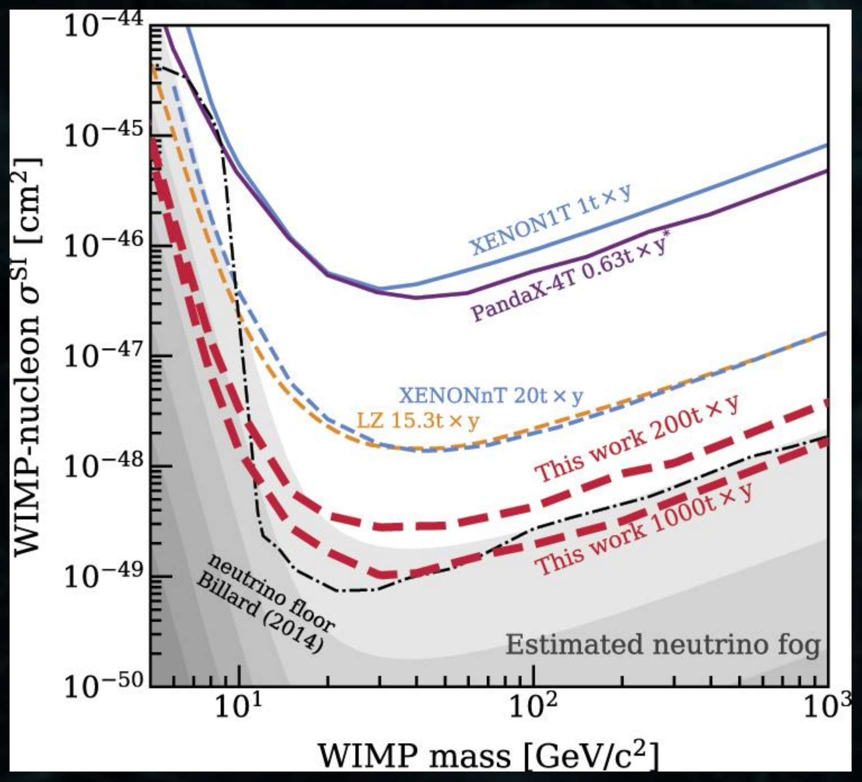
Undoubtedly our efforts to understand this gravitationally interacting discrepancy will occupy a central place in physics for the foreseeable future. A recent topic of interest that has developed within me is the intersection of theoretical dark matter research with the idea of Kaluza-Klein particles and alternative spaces. Is elusive Dark Matter associated with other spaces than our own? Does direct detection require induction, not just observation?
We must find it. We will find it.



Monitoring Tools LZ uses for shifts: Underground Performance Monitor (UPM), Run Control, Ignition, and Grafana.



LZ WIMP search cross section.



Projected XLZD WIMP search cross section. Nearing "neutrino fog."

Acknowledgements:
I, Aaron Flores, would like to acknowledge the Research Experience for Undergraduates (REU) program from Black Hills State University for this summer opportunity. Principle Investigator, and organizer, Dr Brianna Mount for her role in the REU. On the LZ side, Dr David Woodward for his role as my advisor for this (REU) and facilitating a healthy work environment this summer, and the LZ onsite team.

This work experience was funded partially by NSF award 2150517.

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