Présentation du projet DAMIC-M au Conseil scientifique de l'IN2P3

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Summary

Dark matter (DM) is a ubiquitous yet invisible presence in our universe. It dictated how galaxies formed in the first place, and now moves stars around them at puzzling speeds. The DM mass in the universe is known to be five times that of ordinary matter; yet its true nature remains elusive.

Weakly interacting massive particles (WIMPs), relics from the early universe, are a compelling explanation chased by sensitive experiments in deep underground laboratories. However, searches for heavy WIMPs (≈100 times the proton mass), the most theoretically natural candidates, have been so far unsuccessful. Nor has evidence for such heavy particles yet been found at the CERN Large Hadron Collider. Alternative scenarios are now under scrutiny, such as the existence of a hidden sector of lighter DM particles that interact, differently than WIMPs, also with electrons.

DAMIC-M (Dark Matter In CCDs at Modane) will search beyond the heavy WIMP paradigm by detecting nuclear recoils and electrons induced by light DM in charge-coupled devices (CCDs). The kg-size detector will be installed at the Laboratoire Souterrain de Modane, France. In this novel and unconventional use of CCDs, which are commonly employed for digital imaging in astronomical telescopes, the ionization charge will be detected in the most massive CCDs ever built with exquisite spatial resolution (15 µm x 15 µm pixel). The crucial innovation in these devices is the non-destructive, repetitive measurement of the pixel charge, which results in the high-resolution detection of a *single* electron and unprecedented sensitivity to light DM (≈ eV energies are enough to free an electron in silicon). By counting individual charges in a detector with extremely low leakage current – a combination unmatched by any other DM experiment – DAMIC-M will take a leap forward of *several orders of magnitude* in the exploration of the hidden sector, a jump that may be rewarded by serendipitous discovery.

1] Science objectives

There is overwhelming astrophysical and cosmological evidence for Dark Matter (DM) as a major constituent of the universe. Its gravitational influence is necessary to explain why galaxy clusters are bound together and stars move faster than expected around their galaxy, the existence of a large-scale structure in the galaxies' distribution in the universe and the features in the Cosmic Microwave Background power spectrum. Several hypotheses have been proposed to explain DM, including modifying gravity itself and the existence of new particles. Its nature, so far elusive, constitutes one of the most fundamental questions in science.

The WIMP paradigm. A compelling explanation is that DM is composed of a new class of weakly-interacting massive particles (WIMPs). In the Big Bang cosmology, WIMPs were produced together with Standard Model particles in the early universe hot bath, ultimately escaping thermal equilibrium. As relics of this "freeze-out", WIMPs would interact gravitationally with ordinary matter exerting a dramatic influence on the shaping of the Universe as we know it. For DM to be five times more abundant than ordinary matter as measured today, the WIMP self-annihilation cross section should be approximately that of a new particle in the 100s GeV mass range interacting via the electroweak force. This observation, together with the prediction of particles with these properties by super-symmetric extensions of the standard model of particle physics, has provided a strong motive for the experimental search of heavy WIMPs during the last few decades.

Direct detection of DM. The kinetic energy of a 100 GeV WIMP gravitationally bound to our galaxy is on average only 30 keV, and the WIMP is expected to interact coherently with a nucleus of ordinary matter. The detection principle is common to all experiments: a WIMP scatters off a nucleus like a billiard ball, and the recoiling nucleus leaves a tiny energy deposit in the detector. This energy deposit may be detected as ionization, scintillation light, and phonons depending on the specific detector technique. To maximize the WIMP interaction rate, the detector should be massive and have an energy threshold as low as possible since the expected recoil spectrum is exponentially decreasing. Calibration of the detector response to nuclear recoils is essential, since only part of the energy is usually converted into a detectable signal. Experiments are always located in underground laboratories, screened from cosmic rays by km of rocks. Also, special measures are implemented to reduce the radiogenic background from the environment surrounding the detector, by appropriate shielding to stop photons and neutrons from radioactive decays in the cavern walls and by using ultra-pure materials closest to the detector. Very different techniques have been developed to search for WIMPs, including scintillation crystals, noble liquids, bubble chambers and cryogenic calorimeters. The race to discover heavy WIMPs is led by noble liquids experiments, which have incrementally reached ≈100 kg to a ton of active mass - LUX, PandaX, and XENON1T with xenon, DarkSide50 with argon. The next generation of experiments employing this technique is funded to reach several tons of mass (LZ, XENONnT, DarkSide20T).

Low-mass WIMPs. On the other hand, the strong limits already placed on 100s GeV WIMPs and the lack of evidence (so far) for super-symmetry from the Large Hadron Collider experiments at CERN has motivated the scientific community to take a broader look at the WIMP paradigm and explore alternative scenarios. In particular, several experiments are aggressively searching for low-mass WIMPs (<10 GeV). Low-mass WIMPs are also theoretically motivated, and the few experimental hints for DM, even if under scrutiny for their statistical or systematic uncertainties (CDMS Si, CoGeNT and DAMA), are indeed found at low-mass. Sub-keV thresholds are required to explore this mass range. In experiments employing cryogenic (≈10s mK) crystals as CRESST, EDELWEISS and SuperCDMS a low-noise measurement of the phonon signal provides an accurate estimate of the recoil energy since the kinetic energy of the recoiling nucleus is ultimately converted into phonons (also through recombination of electron-hole ionization pairs). Recently, CRESST has achieved thresholds as low as ≈ 20 eV in small (<30 g) CaWO4 and Al2O3 crystals. SuperCDMS has similar design goals for its silicon and germanium crystals.

Hidden sector DM. Going beyond the WIMP paradigm is another approach now actively pursued by the international community. In particular, DM particles arising from a hidden-sector (also called dark sector) appear as viable candidates that may have escaped so far detection. Hidden-sector particles have their own set of interaction forces and thus do not couple directly with ordinary matter. Interaction with Standard Model particles may happen via the mixing of a dark photon A' with an ordinary photon opening a portal for weak coupling of the hidden-sector with ordinary matter. In addition to acting as a mediator, the dark photon could be itself a DM particle. Hidden-sector particles could then, similarly to WIMPs, play a crucial role in the thermal history of the universe and be a dominant component of DM. The phenomenology of hidden-sector DM particles results in a much larger unexplored parameter space than that of WIMPs, in particular for DM masses $m\chi$ << GeV. This has already motivated new approaches to search for hidden particles at accelerators. For direct detection, the nuclear recoil induced by these light DM particles in a detector is so feeble to become undetectable. However, energy transfer in the elastic scattering with electrons is much more efficient, allowing direct detection experiments to probe down to $m\chi \approx$ MeV. Also, absorption of dark photon DM results in ionization for mA' as low as a few eV. The current experimental limits on DM-electron scattering cross section as a function of $m\chi$ are shown in Fig. 1.a-b for two benchmark hidden-sector scenarios with DM scattering through a heavy or light A'. Also shown are theoretical expectations when assuming that the entire DM density observed today is accounted for by the hidden-sector DM. Notably, a large area of the parameter space is still unexplored. Current limits on dark photon DM are shown in Fig. 2.a.

Independently of these theoretical motivations, it is important to recognize that current experiments have limited sensitivity to DM-electron interactions, and a light DM particle may have well escaped detection. Most of the interactions result in the production of few charges, requiring the detector to be able to resolve individual electrons. In addition, the detector's dark current – from thermal excitation, or from charge released by traps in the surface and bulk of the detector material or produced by ionizing background particles – must be extremely low for a signal to be recognizable.

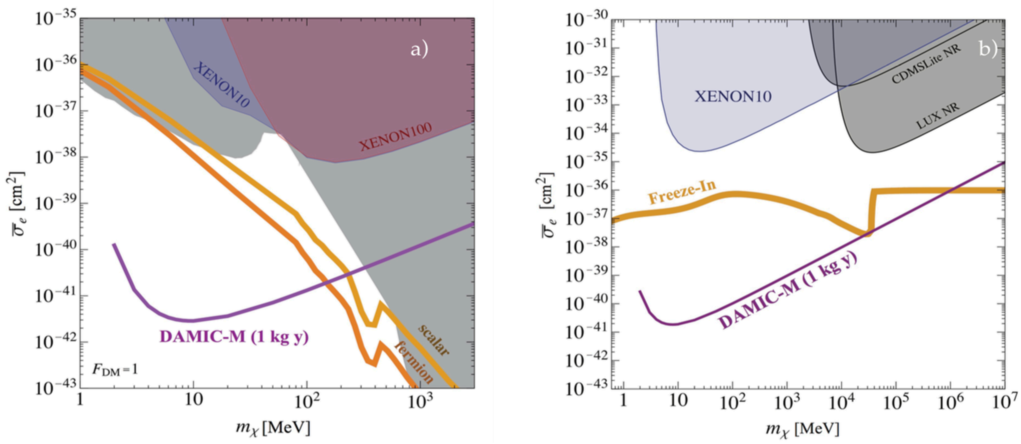


Figure 1. a) DM-electron cross section vs mχ for a heavy A' mediator (mA' >> keV). Shaded areas are excluded by current experiments (in gray those from accelerators and WIMP nuclear-recoil searches). Orange lines are theoretical expectations assuming that χ constitutes all of DM (the scalar and fermion labels refer to the possible particle nature of χ). DAMIC-M 90% C.L. sensitivity is shown as a purple line; b) same as a) for a light A' mediator (mA' << keV). In this case, the very weakly coupled χ does not reach thermal equilibrium and its relic abundance comes from a "freeze-in".

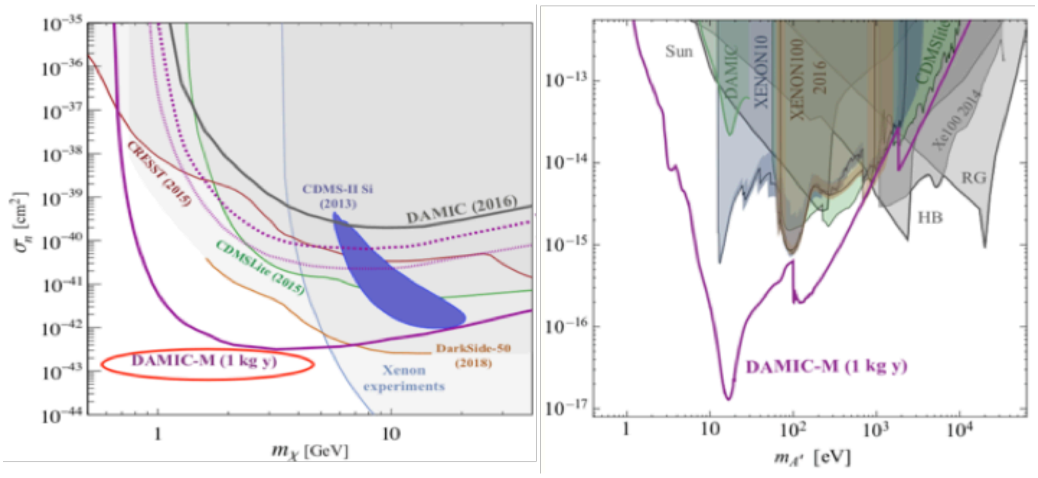


Figure 2: The potential for DM detection in a search for low-mass WIMPs (left) and for hidden-photon DM (right), the latter establishing the world-best limits for ≈ eV DM masses even with minimal exposure.

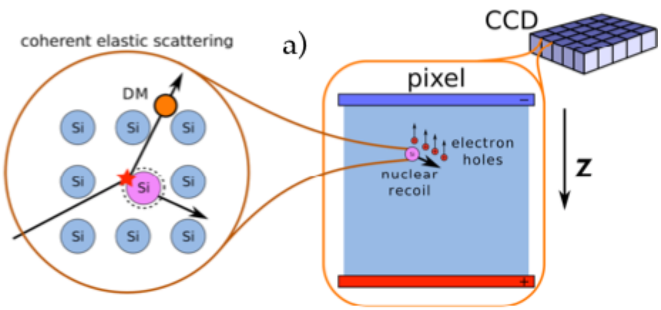
2] Project

In this context, DAMIC-M (Dark Matter in CCDs at Modane) innovative detector technology, which is capable to detect a *single* electron with high resolution, provides unprecedented sensitivity to the DM hidden sector. DAMIC has pioneered the detection of nuclear and electron recoils induced by DM particles in charge-coupled devices (CCDs). Our unconventional use of CCDs has been successfully demonstrated at the SNOLAB laboratory (located in a mine 2 km beneath Sudbury, Canada) where a 40-g prototype detector is currently operating. DAMIC-M capitalizes on this experience and, at the same time, takes a giant leap forward in sensitivity by radically innovating the detector technology. Its CCDs will be the most massive ever built, 20 g each. A novel concept for signal readout – based on non-destructive, repetitive measurements of the pixel charge – will result in the high- resolution detection of a single electron. A dark current ≤ 10^{-21}

A/cm^2 (0,001 e$^-$/pixel/jour will enable a threshold of 2 to 3 electrons (corresponding to DM energy transfers as low as ≈ 3 eV given the silicon band gap energy of 1.1 eV). DAMIC-M consists of a kg-size detector built with this novel technology, hosted by the Laboratoire Souterrain de Modane (LSM) in France. Detector shielding, careful screening and selection of materials, proper handling of detector components to minimize cosmogenic activation and surface backgrounds, and extensive use of the CCD unique spatial resolution will limit the background to ≈ 0.1 dru[1]. The sensitivity to the hidden sector of DAMIC-M for an integrated exposure of one kg year (for one or two years of data taking) is shown in Figs. 1 and 2. DAMIC-M may discover hidden-sector DM even if it constitutes only a small fraction of all DM in the universe. DAMIC-M will also significantly advance the search for low-mass WIMPs (Fig. 2.a) in the 1 to 10 GeV range probing with the same nuclear target the potential CDMS-II Si signal; its sensitivity will be comparable to the Super-CDMS silicon detector.

This is an ambitious program where detector technology and low-background experimental techniques are brought to their cutting-edge, enabling a leap forward of *several orders of magnitude* in the exploration of the hidden sector – a jump that may be rewarded by serendipitous discovery. The program will generate numerous publications both on the various scientific objectives covered but also about the various technological innovations that the detector will implement (see below). In addition in France alone the project will host at least two PhD per year for the 5 years duration of the project and a few postdocs.

The DAMIC CCDs currently installed at SNOLAB are based on a technology developed at the Lawrence Berkeley National Laboratory (LBNL). They have a record thickness of 675 µm and active area of 6 cm x 6 cm, for a mass of 6 g each. The detectors are fabricated from *n*-type, high-resistivity (>10,000 Ω cm) silicon wafers, and are fully depleted (i.e. active over their full volume) by applying a potential (≥ 40 V) to a thin backside contact. The 15 µm x 15 µm pixels have a conventional poly-silicon 3-phase gate structure to hold and transfer the charge, arranged in an array of 4k x 4k pixels. The principle of DM detection with a CCD is illustrated on the right. The charge produced in the DM particle interaction, through absorption or a nuclear/electron recoil, drifts towards the pixels gates, where it is held in place until the readout. In the serial readout process, the charge is transferred vertically from pixel to pixel along each column by appropriate clocking of the 3-phase gates until it reaches the last row ("serial register"); higher frequency clocks move the charge horizontally until the end of the serial register where the on-chip charge-to- voltage amplifier ("output node") is located. The corresponding voltage signal ("video output") is then processed to determine the pixel charge.



When compared to other DM detectors, CCDs present some unique properties:

- *Unprecedented charge resolution*: The current version of DAMIC CCDs has reached a pixel charge r.m.s. noise of ≈ 2 e-, dominated by the noise of the readout amplifier. This allows for the positive identification (6 sigma) of as little as 40 eV of ionization energy deposited in a pixel. For comparison, ionization energy thresholds achieved by CoGeNT PPC and CDMSlite germanium detectors are 500 eV and 56 eV, respectively. DAMIC-M will have a much smaller noise (≈ 0.1 e$^-$) allowing for high-resolution detection of a *single* electron. Thus, it will be sensitive to extremely small energy transfers from a DM interaction.

[1] Differential rate unit = 1 event/keV/kg/day

- *Extremely low leakage current*: even with single-charge resolution, a signal may remain hidden in the fluctuations of the detector's dark current. DAMIC CCDs have the lowest dark current ever measured in a semiconductor detector, ≤ 10^{-21} A/cm^2 at the operating temperature of 105 K.

- *Excellent spatial resolution and 3D reconstruction*. The ionized charge diffuses transversely as it is drifted toward the pixel gates, with a spatial variance that is proportional to the transit time. Hence, there is a positive correlation between the lateral diffusion of the collected charge on the pixel array and the depth of the interaction.

- *Background identification and rejection*. Surface backgrounds, which arise from low-energy photons and electrons emitted by radioactive decay on surfaces or radiated by the surrounding materials, are efficiently rejected by 3D reconstruction. A truly unique capability of DAMIC is that background can be identified and rejected as spatially correlated events occurring at different times. DAMIC identifies and rejects the decay sequence 32Si (T1/2= 150 y, β) → 32P (T1/2= 14 days, β) by spatial correlation, reducing this background by at least a factor 100.

3] Genesis and Calendar

This novel experimental technique has been demonstrated in a successful R&D carried out at SNOLAB during the last years in which the LPNHE group has been very active since 2015. Stringent limits on intrinsic radioactive contaminants in the silicon bulk of the CCDs, including the first measurement of 32Si activity in ultra-pure silicon using the spatial correlation method, show the power of DAMIC background identification and rejection. The seven-CCD 40-g detector which will operate until the end of 2018 at SNOLAB has achieved background rates as low as 5 dru, a level comparable to other low-mass dark matter experiments like CRESST and CDMSLite.

Former publications of the DAMIC collaboration includes:

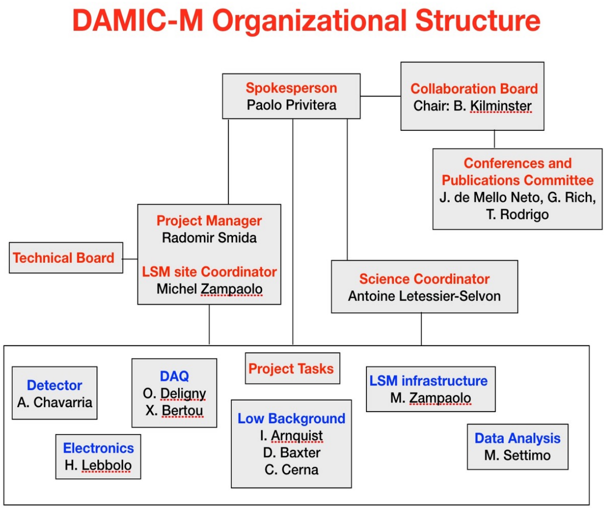
- Aguilar-Arevalo et al. (DAMIC Collaboration), *"First Direct-Detection Constraints on eV-Scale Hidden-Photon Dark Matter with DAMIC at SNOLAB,"* Phys. Rev. Lett. 118 (2017) 141803.
- Aguilar-Arevalo et al. (DAMIC Collaboration), *"Search for low-mass WIMPs in a 0.6 kg day exposure of the DAMIC experiment at SNOLAB,"* Phys. Rev. D 94 (2016) 082006.
- Aguilar-Arevalo et al. (DAMIC Collaboration), *"Measurement of radioactive contamination in the high-resistivity silicon CCDs of the DAMIC experiment,"* J. Instrum. 10 (2015) P08014.

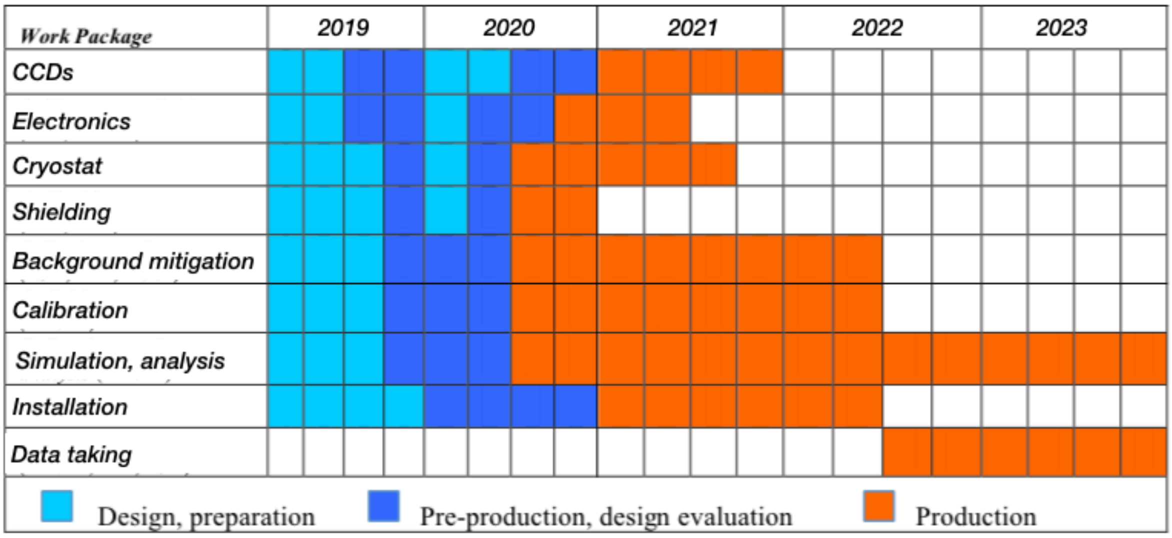
Several theses on DAMIC at SNOLAB are underway, including two at LPNHE Paris. Two new students will join the Paris group in the fall of 2018 to prepare a thesis on the DAMIC-M project. More students are expected to join in the various groups in France and abroad.

The current DAMIC-M collaboration is formed by 62 members (including technical staff and students) from 14 institutions distributed over 8 different countries (France-24, USA-18, Switzerland-6 Brazil-5, Spain-5, Argentina-1, Denmark-2, Canada-1).

The French collaboration (24 members) is currently the largest one in particular due to the technical investment foreseen for the design and test of the front-end electronics, the background control, the shielding design and the installation of the experiment at the LSM.

The collaboration structure is shown on the right. Important responsibilities are shared among the French component of the collaboration. This includes the LSM site coordination, the science coordination, and various task leaders (data acquisition, electronics, low background, LSM infrastructures, data analysis). The project is to be completed over a period of 5 years starting at the end of 2018. A preliminary calendar is shown below, depicting the various phases and staging of the work packages. This is a relatively tight but reasonable schedule that fits well within the time constraint of the ERC finance (5 years).





4] Resources

As stated above the collaboration is composed of about 60 members including students and technical staff. The largest group (24+1 persons[2] or 40%) comes from France and is distributed among 5 sites (Bordeaux (CENBG), Modane (LSM), Nantes (SUBATECH), Orsay (LAL, IPNO) and Paris (LPNHE)). In total there are 7 staff scientists, 2 PhDs and 16 engineers. The number of PhD students and Post-docs will increase in the coming years with 5 positions already financed by the ERC (3 PhD, 2 3-year postdocs). Two new PhD students will start at LPNHE in October 2018 (one in co-tutelle with Chicago on American finance, the other one on the ERC).

In terms of investment money the project is fully funded on the French side with a 3.35 M€ contribution from the ERC advanced grant of Paolo Privitera. Additionally a 4 MUSD NSF grant has been obtained by Paolo Privitera for the US contribution. Other funding opportunities in Switzerland, Spain and Denmark for the respective group are under processing. Note that the ERC budget includes funds for the salaries of Paolo Privitera and part of Antoine Letessier Selvon. Since those salaries are now covered directly by CNRS/IN2P3 this represent an indirect contribution of 0,5 M€ from IN2P3 made available as investment money for the project.

[2] Counting Paolo Privitera who is also 50% at University of Chicago

Beyond the investment money well covered by the ERC and NSF funds it is expected that IN2P3 will cover the running expenses of the French groups and the corresponding running cost of the experiment which should be of the order of 100 000 € per year for the next 5 years.

The total budget of the project is therefore 7,5 M€ with an expected direct contribution from IN2P3 of about 0,5 M€ (6,7 %) for the operating cost of the French groups over the 5 years duration of the project.

French Scientist staff list: Pierre Billoir, Olivier Deligny, Romain Gaior, Antoine Letessier Selvon, Fabrice Piquemal, Paolo Privitera[3], Mariangela Settimo.

Engineers (number/FTE): Orsay (4/1.5), Paris (7/3), Nantes (1/0,3), Bordeaux (1/0,5), LSM (3,1.5)

5] State of the art and technical developments

DAMIC-M will be held at the Laboratoire Souterrain de Modane which offers several advantages when compared to SNOLAB. Its horizontal access through the Frejus tunnel greatly simplifies the logistics to perform detector packaging, test and assembly underground. Supply of radon-free air, crucial to minimize surface backgrounds, is already part of the laboratory infrastructure. France will be involved in many of the technical aspects of DAMIC-M. These include the development and test of the front-end electronics in Orsay and Paris. Nantes will focus on mechanics and software while Bordeaux and Modane on background mitigation and LSM site preparation and operation. Test and calibrations will also be performed both in Paris and in Modane.

The DAMIC-M system will comprise a cryostat vessel to house the CCDs, closely packed in a box surrounded by two infrared (IR) shields. Cooling is provided by a liquid nitrogen dewar located outside the shielding. The vacuum cryostat, IR shields, and CCD box are made of electroformed copper to minimize radiogenic background. The cryostat is enclosed in a 20-cm thick lead shielding to stop high-energy radiogenic photons from the external environment. To reduce surface backgrounds, the experiment will be located in a class 100 clean room supplied with radon-free air from the radon trapping facility of LSM.

Notable improvements over DAMIC at SNOLAB are the extensive use of electroformed copper and the operation in a radon-free air clean room environment, which will result in a large background reduction. Other improvements include the installation of IR shields for a lower CCD dark current and the LN2 cooling which eliminates the electronic noise associated to the use of a cryocooler.

Large-size CCDs with sub-electron resolution: ***(PARIS/ORSAY)***
The DAMIC-M CCDs are based on the LBNL design but will be much bigger and with a novel readout scheme for sub-electron noise.

Large size. The device will feature 6k x 6k pixels over a 9 cm x 9 cm area and a thickness of 1 mm, for 20 g of mass. This will be the heaviest CCD ever built, more than three times heavier than that at SNOLAB. Teledyne/DALSA, the foundry that produced DAMIC CCDs, has already confirmed the capability to fabricate these thicker devices.

Conventional readout. The crucial innovation in DAMIC-M is the integration on these large-size, massive devices of a novel on-chip readout scheme to achieve sub-electron resolution. In the conventional readout, a reset pulse is first applied to remove the previous pixel's charge; the reference voltage of the output node is then measured, then the new pixel charge is transferred on the node and the corresponding signal voltage is measured. The difference between the signal and the reference voltage, usually performed in an analog circuit, provides a low-noise measurement of

[3] Also at University of Chicago

the pixel charge. This Correlated Double Sampling (CDS) technique cancels the reset noise and its accuracy increases with the integration time (T) used to measure the reference and the pixel charge voltages. An optimal integration time T must be found to minimize the measurement noise without being dominated by the 1/f noise of the amplifier. In DAMIC, a noise of ≈ 2e- is obtained for T=20µs.

Sub-electron resolution with Skipper readout:
To reach sub-electron noise, DAMIC-M will feature a *non- destructive*, *multiple* measurement of the pixel charge. A fast CDS sequence is repeated many times, moving the pixel charge back and forth on the output node. Taking the average of these measurements the noise is reduced by √N. Most importantly, the effect of low- frequency 1/f noise is drastically reduced, since the integration time of each measurement is much shorter than in the conventional readout. A charge resolution of 0.2 e- was obtained for T = 5 µs and N ≈ few hundreds, which corresponds to a few ms pixel readout time. The target goal for DAMIC-M is a charge resolution of 0.1 e^- for ≤ 1 ms pixel readout time. Further optimization of the sense node will be done in connection with Steve Holland from LBNL. For optimal detector performance CCD operating parameters like clocks and DC voltage biases will be independently adjusted. Thus, each DAMIC-M CCD is readout and controlled by an independent module. An ASIC chip will be designed for the front-end readout, building on the experience with a CCD readout chip developed at LPNHE/LAL for the LSST camera. The chip will be placed inside the cryostat, as close as possible to the CCD for optimal noise performance. The design goal is a contribution to the readout noise of ≤ 0.2 e-, this is negligible with respect to the several electrons equivalent noise of a single CDS sequence in the Skipper amplifier.

The CCD controller board will be placed outside the DAMIC-M shield. CABAC chips originally developed for LSST (LPNHE/LAL) will be used for the clocks and DC voltage biases. The board will host four ADCs (≥18 bits and ≥2MHz sampling rate) to digitize the video signals and a Gigabit Ethernet interface for the data transfer. A Field Programmable Gate Array (FPGA) will exert the overall control. The CDS algorithm will be implemented in the FPGA, which will also calculate the average and variance of the N Skipper measurements (Section b.3). More elaborated digital filtering algorithms will be evaluated to reduce the noise. Time synchronization between boards will be implemented for simultaneous readout of multiple CCDs.

Background mitigation (Bordeaux/Nantes/Modane)
A background level of ≈ 0.1 dru – corresponding to ≈ 0.1 pixel with 2 electrons in one kg year exposure – is required to fully exploit DAMIC-M scientific reach. This is a challenging requirement, but a similar background level at low energy has already been reached by EDELWEISS and is also a design goal for SuperCDMS. Careful screening and selection of materials, proper handling of detector components to minimize cosmogenic activation and surface backgrounds, and detector shielding will be extensively employed in DAMIC-M for this purpose. An accurate estimate of background requires a detailed detector design which is not available at this stage. Preliminary Geant4 simulations indicate that the goal of ≈ 0.1 dru is reachable, with cosmogenic tritium being the dominant background component.

Natural radioactivity in materials: the radioactive isotopes 238U and 232Th and their decay chain daughters are found in small concentrations in many materials. 40K and 60Co are also commonly present. Photons, beta electrons and alphas (which produce neutrons by (α,n) reactions) from natural radioactivity constitute a potential background. All materials to be used in DAMIC-M will be radioassayed with facilities available at the LSM (HPGe) and externally (e.g. neutron activation and ICP-MS). Outgassing of radon will also be measured (CENBG). This screening campaign will drive the selection of materials for DAMIC-M construction, and at the same time provide quantitative input to the background model for data analysis (SUBATECH). Critical items, due to proximity to the detector or large mass, include the CCD packaging, copper parts (vacuum vessel, IR shield, cold finger and CCD box) and shielding. The CCD itself is made of extremely pure silicon and strong limits have been placed by DAMIC on the presence of radioactivity in the CCD bulk.

Cosmogenic activation: tritium (3H) is produced as a spallation product in the interaction of cosmic-ray secondaries (neutrons, protons, and muons) with silicon nuclei in the CCDs, with a rate of ≈ 80 atoms/kg of Si/day at ground level. Due to its long half-life (t1/2 = 12.5 years), tritium will accumulate in the CCD bulk during exposure to cosmic rays and then slowly decay once the detectors are placed underground, producing low energy electrons (endpoint energy = 18.6 keV.) To reduce this background, exposure to cosmic rays must be minimized. Thus, the silicon wafers and CCDs will be shipped in a shielded container reducing the 3H production rate by a factor ten. The total ground-level equivalent exposure of the silicon (including CCD fabrication) will be less than two months. No additional activation will occur during the CCD packaging and test since they will be performed underground at the LSM.

Natural 32Si: this radioactive isotope of silicon is produced by neutron spallation on atmospheric argon, and then brought to ground by rain. The amount of 32Si present in a detector ultimately depends on the history of the silica sand used to make the silicon boule, which is very difficult to track given the complexity of the silicon industry. The 32Si concentration in a CCDs can be measured by identifying the two spatially correlated betas from the decay sequence 32Si-32P (see Section b.1). This unique capability will be used to minimize the 32Si background in DAMIC-M.

Surface backgrounds: exposure to air results in the deposit of 222Rn decay daughters onto material surfaces, ultimately building up the long-lived 210Pb. Its decay products – X-rays, betas and alphas – are a potential source of background, particularly when originating from the surfaces of the CCDs and of materials close by. Surface background will be minimized by aggressively reducing the exposure to radon: CCDs will be stored in a nitrogen atmosphere until arrival to the LSM; etching and cleaning of surfaces (e.g. lead and copper), CCD packaging and test, assembly and operation of DAMIC-M will be performed in a radon-free clean room environment at the LSM, where air with radon activity of 20 mBq/m3 is provided (a factor 1000 lower than standard air.)

LSM backgrounds: The polyethylene and lead shielding surrounding the detector will reduce by several orders of magnitudes the flux of gamma rays and neutrons from the natural radioactivity in the rock and concrete wall of the LSM cavern. The corresponding background is estimated to be negligible by simulations, validated by measurements performed removing the shielding of DAMIC at SNOLAB.

Calibration (Paris/Modane/USA)
CCD characterization underground. Standard characterization procedures with optical photons and radioactive sources have already been successfully implemented in the quality control of CCD arrays of a similar size to DAMIC-M. The test stations at the LSM will feature easy-access vacuum chambers with single-CCD electronics and appropriate CCD fixtures that are thermally coupled to a cold-tip. The single-electron resolution of DAMIC-M CCDs simplifies the calibration since the number of collected electrons per pixel will be directly counted. Radioactive sources as 3H and 241Am will be used to illuminate the front and the back of the device over its full area. These sources have already been deployed in the calibration of the current DAMIC CCDs with great success. Finally, due to the low background in the underground site, dark images will allow to measure the dark current of each device, and to identify defects in the silicon lattice or the CCD gate structure with much higher sensitivity than in a test station located at ground surface.

More information on the DAMIC-M project can be found on the collaboration web page at:
https://damic.uchicago.edu