

Photon Detectors

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Executive Summary

The Photon Detectors Topical Group has identified two areas where focused R&D over the next decade could have a large impact in High Energy Physics Experiments. These areas described here are characterized by the convergence of a compelling scientific need and recent technological advances.

The development of detectors with the capability of counting single photons from IR to UV has been a very active area in the last decade. Demonstration for sensors based on novel semiconductor (CMOS, skipper-CCD, SiPM) and superconducting technologies (MKID, SNSPD and TES) have been performed. These sensors open a new window for HEP experiments in the low photon number regime. Several ongoing and future projects in HEP benefit from these developments (Cosmology, Dark Matter, Neutrinos) which will also have a large impact outside HEP (BES, QIS, Astronomy). The combined scientific needs and technological opportunities make photon counting an ideal area for focused R&D investment in the coming decade. Such investment will secure leadership in photon counting technologies in the US, producing a large impact in HEP, with applications outside HEP. This opportunity is summarized in Ref [245].

A technological solution for the photon detection system in the first two modules of the DUNE detector exist, based on the by now well-known Arapuca light traps, with wavelength shifters and SiPMs as the photon detector [1], [2]. However, new photon detector developments are being considered for modules 3 and 4. Some of the proposed ideas consist on novel light collectors, the so-called dichroicons which are Winston-style light concentrators made from dichroic mirrors, allowing photons to be sorted by wavelength, directing the long-wavelength end of broad-band Cherenkov light to photon sensors that have good sensitivity to those wavelengths, while directing narrow-band shortwavelength scintillation light to other sensors [3]. This technology could be used in water-based liquid scintillators thus realizing a hybrid Cerenkov/scintillator detector. Also notable are research and development efforts in new materials that could be directly sensitive to the VUV light, such as amorphous selenium (a-Se) [4] and organic semiconductors [5]. Future investment in the above technologies over the next decade will enhance the science of the DUNE project.

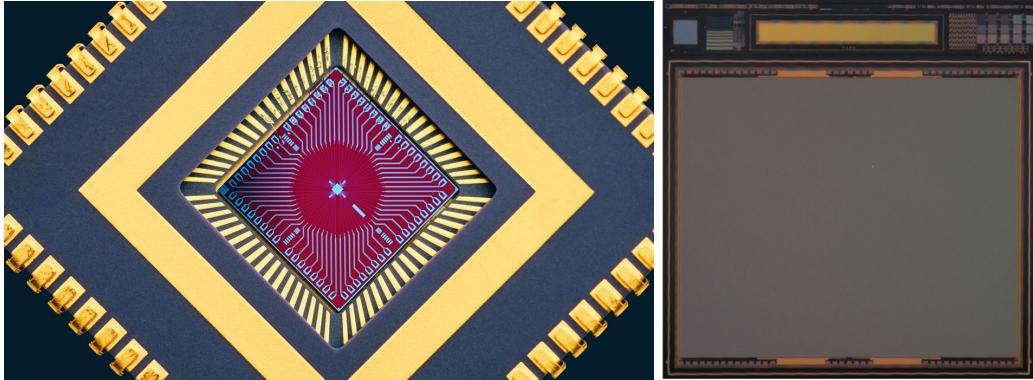


Figure 2-1. Example recently develop of superconducting and semiconducting photon counting sensors. Left) 64-pixel SNSPD array capable of counting over 1 billion photons per second with time resolution below 100 ps for Astronomy (JPL Microdevices Laboratory). Right) 1.3 Mpix skipper-CCD capable of deep sub-electron noise (LBNL Micro Systems Laboratory) developed for Astronomy and direct Dark Matter Search.

2.1 Photon Counting Sensors Enabling HEP

2.1.1 Science Needs

Several novel cosmological facilities for wide-field multi-object spectroscopy were proposed for the Astro2020 decadal review, and are being considered as part of the Snowmass process [200]. Ground-based spectroscopic observations of faint astronomical sources in the low-signal, low-background regime are currently limited by detector readout noise. Significant gains in survey efficiency can be achieved through reductions by using sensors with readout noise below 1e-. Pushing the current photon counters in the direction of mega pixel arrays with fast frame rate (10 fps) would make this possible.

Dark matter searches based on photon counting technologies currently hold the world record sensitivity for low mass electron-recoil dark matter [21] semiconductors are among the most promising detector technologies for the construction of a large multi-kg experiment for probing electron recoils from sub-GeV DM (skipper-CCDs) [16]. Significant R&D is needed to scale to scale the experiments from the relatively small pathfinders to the multi-kg experiments in the future.

Single photon counting sensors have also gained importance for their potential as CEvNS detectors. (Coherent Elastic neutrino Nucleus Scattering) [24]. The deposited energy from CEvNS is less than a few keV. Only part of this energy is converted into detectable signal in the sensor (ionization, phonons, etc.) and therefore low threshold technologies are needed. Semiconductor and superconducting technologies with eV and sub-eV energy resolution for photon counting capability in the visible and near-IR are natural candidates to reach the necessary resolution for this application.

Photon counting also enables a wide range of science outside HEP [245] including QIS, BES and applications in radiation detection.

2.1.2 Technological Opportunities

Recent advances in photon counting technology addressing the needs in Section 2.1.1 are discussed here. The advances can be grouped in three areas.

2.1.2.1 Superconducting Sensors

MKIDs (microwave kinetic inductance detector) work on the principle that incident photons change the surface impedance of a superconductor through the kinetic inductance effect [156]. The magnitude of the change in surface impedance is proportional to the amount of energy deposited in the superconductor, allowing for single photon spectroscopy on chip. Frequency multiplexed arrays 20,440 pixels with energy resolution $R=E/\Delta E \sim 9.5$ at 980 nm, and a quantum efficiency of $\sim 35\%$ have been achieved. R&D focused on larger arrays with higher QE and better energy resolution would address the need discussed in Sec. 2.1.1.

SNSPDs (Superconducting Nanowire Single Photon Detector) is a superconducting film patterned into a wire with nanometer scale dimensions (although recently devices with micrometer-scale widths have been shown to be single-photon sensitive [130]). SNSPDs have been reported with single photon sensitivity for wavelengths out to several microns, timing jitter as low as a few ps [131], dark count rates (DCR) down to 6×10^{-6} Hz [66], and detection efficiency (DE) of 0.98 [185]. They have also been shown to function in magnetic fields of up to 6T [135]. Current R&D consist on scaling to large arrays and extending the spectral range for these sensors to address the needs of HEP and Astrophysics.

TES (Transition-Edge Sensor) photon detector, which utilizes a patterned superconducting film with a sharp superconducting-to-resistive transition profile as a thermometer, is a thermal detector with a well developed theoretical understanding. When a visible or infrared photon is absorbed by a TES, the tiny electromagnetic energy of the photon increases the temperature of the TES and therefore changes its resistance. TES have been developed to measure single photons in quantum communication [191, 142, 102, 101], for axion-like particle searches [42, 85], direct detection of dark matter particles and astrophysical observations in the wavelengths between ultraviolet and infrared [53]. TES detectors can be multiplexed enabling arrays of large channel counts [44, 84, 82]. Multiplexers for detector arrays using 16,000 TESs have already been successfully implemented [44]. R&D exploiting microwave resonance techniques [82] have the potential to increase the multiplexing capacity by another factor of 10.

2.1.2.2 Semiconducting Sensors

skipper-CCDs Skipper-CCDs have an output readout stage that allows multiple non-destructive sampling of the charge packet in each pixel of the array thanks to its floating gate output sense node. This non-destructive readout has been used to achieve deep sub-electron noise in mega-pixel arrays Skipper CCDs fabricated on high resistivity silicon [116] has also demonstrated an extremely low production of dark counts. This technology as motivated to build a new generation of Dark Matter [16, 20] and neutrino experiments [169]). The R&D effort here is currently focused on faster readout (10 fps) and large gigapixel arrays.

CMOS The down scaling of CMOS technology has allowed the implementation of pixels with a very low capacity, and therefore, high sensitivity and low noise ($1\text{-}2\text{ e}^-$) at room temperature and high frame rates (50-100 fps) [149][98]. Commercial cameras with sub-electron noise at 5 fps are now available. These sensors have not yet played a big role in HEP mainly because of the small pixel size. Active R&D taking advantage of CMOS fabrication process to address the needs of HEP is ongoing to produce, including the development of new CMOS sensors with non-destructive readout (skipper-CMOS). These sensors could address the readout speed limitations of other semiconductor photon counters. The single photon avalanche diode (SPADs) have also been implemented in standard CMOS technology and integrated with on-chip quenching and recharge circuitry addressing fast timing and radiation tolerance requirements from HEP [246].

Photon-to-Digital converter In a PDC, each SPAD is coupled to its own electronic quenching circuit. This one-to-one coupling provides control on individual SPADs and signals each detected avalanche as a digital signal to a signal processing unit within the PDC. Hence, PDCs provide a direct photon to digital conversion considering that intrinsically a SPAD is a Boolean detector by design. Digital SiPMs were first reported in 1998 [35] by the MIT Lincoln Lab and many contributions followed [35, 36]. A major step came with microelectronics integration to fabricate both the SPAD and readout quenching circuit in a single commercial process [242, 127, 129, 128, 189, 187]. These innovations led to the first multi-pixel digitally read SPAD arrays [188, 172]. A recent review can be found in Ref. [183].

2.1.2.3 Extending wave length coverage

Ge semiconductor Silicon CCDs are commonly utilized for scientific imaging applications in the visible and near infrared. These devices offer numerous advantages described previously, while the skipper CCD [221] adds to these capabilities by enabling multiple samples during readout to reduce read noise to negligible levels [23, 72]. CCDs built on bulk germanium offer all of the advantages of silicon CCDs while covering an even broader spectral range. The R&D in this area will extend the photon counting capabilities of semiconductor into the IR.

UV Jet Propulsion Laboratory showed that CCD sensitivity can be increased closed to the reflection-limited quantum efficiency of silicon down [115]. This was done by blocking the surface fields and traps through the epitaxial growth of a strongly doped very thin silicon layer (delta-doping). Quantum efficiency exceeding 50% were demonstrated in CCDs down to 125 nm wavelength [173]. The method was demonstrated efficient on backside illuminated SPAD based detectors by Schuette in 2011[202]. Other methods to address the surface fields and traps issues were also demonstrated [168]. Work is being done at Caltech (D. Hitlin) to enhance SiPMs for the detection of the fast scintillation component of BaF₂ [113]. An extensive study of the delta-doping approach to enhance VUV sensitivity in frontside illuminated SPAD based detectors was done by Vachon [226].

2.2 Photon Detectors For Neutrino Experiments

A large number of outstanding questions remain to the fundamental nature of the neutrino, which can be probed through the use of higher energy ($\mathcal{O}(\text{MeV}) < E < \mathcal{O}(\text{GeV})$) neutrino sources (*e.g.*, accelerator and atmospheric neutrinos). The nature of these remaining puzzles break into the distance over which the neutrinos are allowed to propagate before being detected. Thus the future class of experiments are classified as “short-baseline” and “long-baseline” experiments.

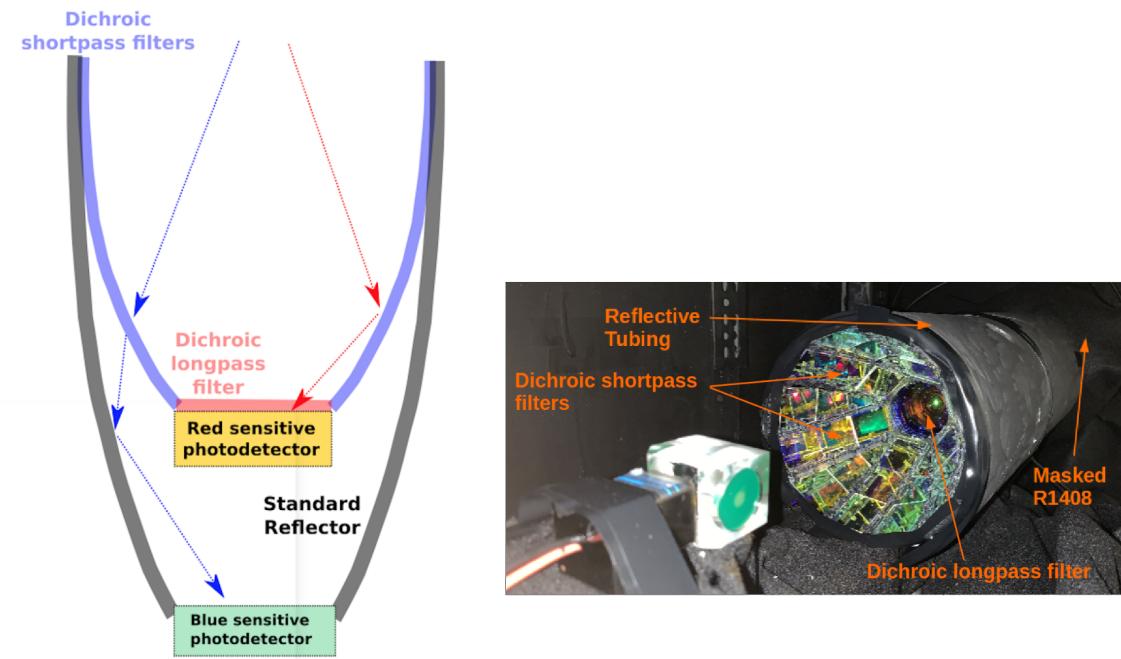


Figure 2-2. Example of photon detector development for neutrinos: the dichroicon, from arXiv:2203.07479

The next generation long-baseline neutrino experiments aim to answer the questions of the exact ordering of the neutrino mass states, known as the mass hierarchy, as well as the size of the CP-violating phase δ . These, as yet unknown quantities, remain one of the last major pieces of the Standard Model of particle physics and offer the opportunity to answer such fundamental questions as “what is the origin of the matter/antimatter asymmetry in the universe?” and “do we understand the fundamental symmetries of the universe?”. By measuring the asymmetry between appearance of electron neutrinos from a beam of muon neutrinos ($P(\nu_\mu \rightarrow \nu_e)$) compared to the appearance of electron antineutrinos from a beam of muon antineutrinos and $P(\bar{\nu}_\mu \rightarrow \bar{\nu}_e)$) as well as the precise measurement of the ν_e energy spectrum measured at the far detector, both the CP violating phase (δ_{CP}) and the mass hierarchy can be measured in the same experiment.

The Short-Baseline Neutrino (SBN) program aims to address the anomalous neutrino results seen by the LSND and MiniBooNE which suggest the possible existence of a eV mass-scale sterile neutrino. However, the experimental landscape is perplexing since a number of other experiments utilizing a range of different neutrino sources which should have been sensitive to such a sterile neutrino have observed only the standard three neutrino oscillations. In this landscape, the conclusive assessment of the experimental hints of sterile neutrinos becomes a very high priority for the field of neutrino physics.

To address both of these areas of neutrino research, large scale noble element time projection chambers (TPC's) [236, 193] play a central role and offer an opportunity to perform discovery level measurements through the enhancement of their capabilities. In a noble element TPC, particles interact with the medium and deposit their energy into three main channels: heat, ionization, and scintillation light. Depending on the physics of interest, noble element detectors attempt to exploit one or more of these signal components. Liquid Noble TPC's produce ionization electrons and scintillation photons as charged particles traverse the bulk material. An external electric field allows the ionization electrons to drift towards the anode of the detector

and be collected on charge sensitive readout or transform energy carried by the charge into a secondary pulse of scintillation light.

A technological solution for the photon detection system in the first two modules of the DUNE detector exist, based on the by now well-known Arapuca light traps, with wavelength shifters and SiPMs as the photon detector [1], [2]. This approach is also being used in other short baseline neutrino oscillation experiments[12], but not exclusively [11]. Beyond this,new photon detector developments are being considered for modules 3 and 4 as well as for other approved or proposed experiments[3].

Going beyond DUNE’s first two modules Quoting from the executive summary of the Snowmass IF2 White Paper*Future Advances in Photon-Based Neutrino Detectors*[3], ”large-scale, monolithic detectors that use either Cherenkov or scintillation light have played major roles in nearly every discovery of neutrino oscillation phenomena or observation of astrophysical neutrinos. New detectors at even larger scales are being built right now, including JUNO [?], Hyper-Kamiokande [6], and DUNE [8].

These new technologies will lead to neutrino physics and astrophysics programs of great breadth: from high-precision accelerator neutrino oscillation measurements, to detection of reactor and solar neutrinos, and even to neutrinoless double beta decay measurements that will probe the normal hierarchy regime. They will also be valuable for neutrino applications, such as non-proliferation via reactor monitoring”.

”Of particular community interest is the development of hybrid Cherenkov/scintillation detectors, which can simultaneously exploit the advantages of Cherenkov light—reconstruction of direction and related high-energy particle identification (PID) and the advantages of scintillation light, high light-yield, low-threshold detection with low-energy PID. Hybrid Cherenkov/scintillation detectors could have an exceptionally broad dynamic range in a single experiment, allowing them to have both high-energy, accelerator-based sensitivity while also achieving a broad low-energy neutrino physics and astrophysics program. Recently the Borexino Collaboration [9] has published results showing that even in a detector with standard scintillator and no special photon sensing or collecting, Cherenkov and scintillation light can be discriminated well enough on a statistical basis that a sub-MeV solar neutrino direction peak can be seen. Thus the era of hybrid detectors has begun, and many of the enabling technologies described here will make full event-by-event direction reconstruction in such detectors possible”.

Among the new technologies of relevance for this topical group, it should be mentioned

New Photon Sensors : New advances in the science of photomultiplier tubes, including long-wavelength sensitivity, and significant improvements in timing even with devices as large as 8 inches, make hybrid Cherenkov/scintillation detectors even better, with high light yields for both Cherenkov and scintillation light with good separation between the two types of light. Large Area Picosecond Photon Detectors (LAPPDs) [10] have pushed photon timing into the picosecond regime, allowing Cherenkov/scintillation separation to be done even with standard scintillation time pro

les. The fast timing of LAPPDs also makes reconstruction of event detailed enough to track particles with the produced photons.

New Photon Collectors : Dichroicons, which are Winston-style light concentrators made from dichroic mirrors, allow photons to be sorted by wavelength thus directing the long-wavelength end of broad-band Cherenkov light to photon sensors that have good sensitivity to those wavelengths, while directing narrow-band shortwavelength scintillation light to other sensors. Dichroicons are particularly useful in high-coverage hybrid Cherenkov/scintillation detectors.

Bibliography

- [1] Machado A. A.,and Segreto E ARAPUCA a new device for liquid argon scintillation light detection. 2016 JINST 11 C02004
- [2] Paulucci L. on behalf of the DUNE Collaboration The DUNE vertical drift photon detection system. 2022 JINST 17 C01067
- [3] Tanner Kaptanoglu, Meng Luo, Benjamin Land, Amanda Bacon, and Joshua R. Klein Spectral photon sorting for large-scale Cherenkov and scintillation detectors. Phys. Rev. D 101, 072002 (2020)
- [4] S. K. Barman, M. N. Huda, J. Asaadi, E. Gramellini, D. Nygren First principles studies of the surface and opto-electronic properties of ultra-thin t-Se. arXiv:2104.14455v1
- [5] M. Febbraro Organic photosensors for detection of VUV scintillation light. Lidine 2021 this url: <https://indico.physics.ucsd.edu/event/1/>
- [6] K. Abe et al. Hyper-Kamiokande Design Report arXiv:1805.04163v2
- [7] A. Abusleme et al JUNO Physics and Detector. Progr. Part. Nucl. Phys. 123, (2022), 103927
- [8] DUNE Collaboration: B. Abi et al. Long-baseline neutrino oscillation physics potential of the DUNE experiment. Eur. Phys. J. C 80, 978 (2020)
- [9] M. Agostini et al. Borexino Coll. First Directional Measurement of sub-MeV Solar Neutrinos with Borexino. <https://doi.org/10.1103/PhysRevLett.128.091803>
- [10] A. V. Lyashenko, B. W. Adams, M. Aviles, T. Cremer, C. D. Ertley, M. R. Foley, M. J. Minot, M. A. Popecki, M. E. Stochaj, W. A. Worstell, J. W. Elam, A. U. Mane, O. H. W. Siegmund, H. J. Frisch, A. L. Elagin, E. Angelico, E. Spieglan Performance of Large Area Picosecond Photo-Detectors (LAPPD). <https://doi.org/10.1016/j.nima.2019.162834>
- [11] B. Ali-Mohammadzadeh, M. Babicz, W. Badgett, L. Bagby, V. Bellini, R. Benocci, M. Bonesini, A. Braggiotti, S. Centro, A. Chatterjee, A. G. Cocco, M. Diwan, A. Falcone, C. Farnese, A. Fava, D. Gibin, A. Guglielmi, W. Ketchum, U. Kose, A. Menegolli, G. Meng, C. Montanari, M. Nessi, F. Pietropaolo, A. Rappoldi , et al. Design and implementation of the new scintillation light detection system of ICARUS T600 <https://doi.org/10.48550/arXiv.2006.05261> Related DOI: <https://doi.org/10.1088/1748-0221/15/10/T10007>
- [12] Abratenko, P. on behalf of the SBND Collaboration Overview and Current Status of the X-ARAPUCA Light Collection System in SBND Lidine 2021 this url: <https://indico.physics.ucsd.edu/event/1/contributions/42/>
- [13] J. Scoresby, “Journals”, 1820.
- [14] A. Beale, “Surgical Writings”, 1839.
- [15] Digicam history. URL: http://www.digicamhistory.com/Evolutionary_Imagers.html.
- [16] Oscura. URL: <https://astro.fnal.gov/science/dark-matter/oscura/>, 2020.
- [17] C. E. Aalseth, S. Abdelhakim, P. Agnes, R. Ajaj, I. F. M. Albuquerque, T. Alexander, A. Alici, A. K. Alton, P. Amaudruz, F. Ameli, J. Anstey, P. Antonioli, M. Arba, S. Arcelli, R. Ardito, I. J. Arnquist, P. Arpaia, D. M. Asner, A. Asunsakis, M. Ave, H. O. Back, V. Barbaryan, A. Barrado Olmedo, G. Batignani, M. G. Bisogni, V. Bocci, A. Bondar, G. Bonifini, W. Bonivento, E. Borisova, B. Bottino,

- M. G. Boulay, R. Bunker, S. Bussino, A. Buzulutskov, M. Cadeddu, M. Cadoni, A. Caminata, N. Canci, A. Candela, C. Cantini, M. Caravati, M. Cariello, F. Carnesecchi, A. Castellani, P. Castello, P. Cavalcante, D. Cavazza, S. Cavuoti, S. Cebrian, J. M. Cela Ruiz, B. Celano, R. Cereseto, S. Chashin, W. Cheng, A. Chepurnov, C. Ciccalò, L. Cifarelli, M. Citterio, F. Coccetti, V. Cocco, M. Colocci, E. Conde Vilda, L. Consiglio, F. Cossio, G. Covone, P. Crivelli, I. D'Antone, M. D'Incecco, M. D. Da Rocha Rolo, O. Dadoun, M. Daniel, S. Davini, S. De Cecco, M. De Deo, A. De Falco, D. De Gruttola, G. De Guido, G. De Rosa, G. Dellacasa, P. Demontis, S. De Pasquale, A. V. Derbin, A. Devoto, F. Di Eusanio, L. Di Noto, G. Di Pietro, P. Di Stefano, C. Dionisi, G. Dolganov, F. Dordei, M. Downing, F. Edalatfar, A. Empl, M. Fernandez Diaz, C. Filip, G. Fiorillo, K. Fomenko, A. Franceschi, D. Franco, E. Frolov, G. E. Froudakis, N. Funicello, F. Gabriele, A. Gabrieli, C. Galbiati, M. Garbini, P. Garcia Abia, D. GascÃ³n Fora, A. Gendotti, C. Ghiano, A. Ghisi, P. Giampa, R. A. Giampaolo, C. Giganti, M. A. Giorgi, G. K. Giovanetti, M. L. Gligan, O. Gorchakov, M. Grab, R. Graciani Diaz, M. Grassi, J. W. Grate, A. Grobov, M. Gromov, M. Guan, M. B. B. Guerra, M. Guerzoni, M. Gulino, R. K. Haaland, B. R. Hackett, A. Hallin, M. Haranczyk, B. Harrop, E. W. Hoppe, S. Horikawa, B. Hosseini, F. Hubaut, P. Humble, E. V. Hungerford, An. Ianni, A. Ilyasov, V. Ippolito, C. Jillings, K. Keeter, C. L. Kendziora, I. Kochanek, K. Kondo, G. Kopp, D. Korablev, G. Korga, A. Kubankin, R. Kugathasan, M. Kuss, M. La Commara, L. La Delfa, M. Lai, M. Lebois, B. Lehner, N. Levashko, X. Li, Q. Liqiang, M. Lissia, G. U. Lodi, G. Longo, R. Lussana, L. Luzzi, A. A. Machado, I. N. Machulin, A. Mandarano, S. Manecki, L. Mapelli, A. Margotti, S. M. Mari, M. Mariani, J. Maricic, M. Marinelli, D. Marras, M. MartÃ¡nez, A. D. Martinez Rojas, M. Mascia, J. Mason, A. Masoni, A. B. McDonald, A. Messina, T. Miletic, R. Milincic, A. Moggi, S. Moioli, J. Monroe, M. Morrocchi, T. Mroz, W. Mu, V. N. Muratova, S. Murphy, C. Muscas, P. Musico, R. Nania, T. Napolitano, A. Navrer Agasson, M. Nessi, I. Nikulin, V. Nosov, J. A. Nowak, A. Oleinik, V. Oleynikov, M. Orsini, F. Ortica, L. Pagani, M. Pallavicini, S. Palmas, L. Pandola, E. Pantic, E. Paoloni, F. Pazzona, S. Peeters, P. A. Pegoraro, K. Pelczar, L. A. Pellegrini, C. Pellegrino, N. Pelliccia, F. Perotti, V. Pesudo, E. Picciano, F. Pietropaolo, A. Pocar, T. R. Pollmann, D. Portaluppi, S. S. Poudel, P. Pralavorio, D. Price, B. Radics, F. Raffaelli, F. Ragusa, M. Razeti, C. Regenfus, A. L. Renshaw, S. Rescia, M. Rescigno, F. Retiere, L. P. Rignanese, C. Ripoli, A. Rivetti, J. Rode, A. Romani, L. Romero, N. Rossi, A. Rubbia, P. Sala, P. Salatino, O. Samoylov, E. SÃ¡nchez GarcÃ¡a, E. Sandford, S. Sanfilippo, M. Sant, D. Santone, R. Santorelli, C. Savarese, E. Scapparone, B. Schlitzer, G. Scioli, E. Segreto, A. Seifert, D. A. Semenov, A. Shchagin, A. Sheshukov, S. Siddhanta, M. Simeone, P. N. Singh, P. Skensved, M. D. Skorokhvatov, O. Smirnov, G. Sobrero, A. Sokolov, A. Sotnikov, R. Stainforth, A. Steri, S. Stracka, V. Strickland, G. B. Suffritti, S. Sulis, Y. Suvorov, A. M. Szczepański, R. Tartaglia, G. Testera, T. Thorpe, A. Tonazzo, A. Tosi, M. Tuveri, E. V. Unzhakov, G. Usai, A. Vacca, E. VAjquez-JAjuregui, T. Viant, S. Viel, F. Villa, A. Vishneva, R. B. Vogelaar, J. Wahl, and J. J. Walding. Sipm-matrix readout of two-phase argon detectors using electroluminescence in the visible and near infrared range. *The European Physical Journal C*, 81(2):153, Feb 2021.
- [18] Shiva Abbaszadeh, I Karim, and K Vassili. Measurement of uv from a microplasma by a microfabricated amorphous selenium detector. *IEEE Transactions on Electron Devices*, 60:880–883, 02 2013.
- [19] A. H. Abdelhameed, P. Angloher, G. Bauer, et al. Deposition of tungsten thin films by magnetron sputtering for large-scale production of tungsten-based transition-edge sensors. *J Low Temp Phys*, 199:401–407, 2020.
- [20] O. Abramoff, L. Barak, et al. Sensei: Direct-detection constraints on sub-gev dark matter from a shallow underground run using a prototype skipper ccd. *Phys. Rev. Lett.*, 122:161801, Apr 2019.
- [21] Orr Abramoff, Liron Barak, Itay M. Bloch, Luke Chaplinsky, Michael Crisler, Dawa, Alex Drlica-Wagner, Rouven Essig, Juan Estrada, Erez Etzion, Guillermo Fernandez, Daniel Gift, Miguel Sofio-Haro, Joseph Taenzer, Javier Tiffenberg, Tomer Volansky, and Tien-Tien Yu. Sensei: Direct-detection

- constraints on sub-gev dark matter from a shallow underground run using a prototype skipper ccd. *Phys. Rev. Lett.*, 122:161801, Apr 2019.
- [22] Fabio Acerbi, Giovanni Paternoster, Alberto Gola, Nicola Zorzi, and Claudio Piemonte. Silicon photomultipliers and single-photon avalanche diodes with enhanced nir detection efficiency at fbk. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 912:309–314, 2018.
- [23] A. Aguilar-Arevalo et al. First direct-detection constraints on ev-scale hidden-photon dark matter with DAMIC at SNOLAB. *Physical Review Letters*, 118(14):141803, 2017.
- [24] D. Akimov, J. B. Albert, P. An, C. Awe, P. S. Barbeau, B. Becker, V. Belov, A. Brown, A. Bolozdynya, B. Cabrera-Palmer, M. Cervantes, J. I. Collar, R. J. Cooper, R. L. Cooper, C. Cuesta, D. J. Dean, J. A. Detwiler, A. Eberhardt, Y. Efremenko, S. R. Elliott, E. M. Erkela, L. Fabris, M. Febbraro, N. E. Fields, W. Fox, Z. Fu, A. Galindo-Uribarri, M. P. Green, M. Hai, M. R. Heath, S. Hedges, D. Hornback, T. W. Hossbach, E. B. Iverson, L. J. Kaufman, S. Ki, S. R. Klein, A. Khromov, A. Konovalov, M. Kremer, A. Kumpan, C. Leadbetter, L. Li, W. Lu, K. Mann, D. M. Markoff, K. Miller, H. Moreno, P. E. Mueller, J. Newby, J. L. Orrell, C. T. Overman, D. S. Parno, S. Penttila, G. Perumpilly, H. Ray, J. Raybern, D. Reyna, G. C. Rich, D. Rimal, D. Rudik, K. Scholberg, B. J. Scholz, G. Sinev, W. M. Snow, V. Sosnovtsev, A. Shakirov, S. Suchyta, B. Suh, R. Tayloe, R. T. Thornton, I. Tolstukhin, J. Vanderwerp, R. L. Varner, C. J. Virtue, Z. Wan, J. Yoo, C.-H. Yu, A. Zawada, J. Zettlemoyer, A. M. Zderic, and null null. Observation of coherent elastic neutrino-nucleus scattering. *Science*, 357(6356):1123–1126, 2017.
- [25] T Al Abbas, NAW Dutton, O Almer, S Pellegrini, Y Henrion, and RK Henderson. Backside illuminated spad image sensor with $7.83\text{ }\mu\text{m}$ pitch in 3d-stacked cmos technology. In *2016 IEEE International Electron Devices Meeting (IEDM)*, pages 8–1. IEEE, 2016.
- [26] Michael S Allman, Varun B Verma, M Stevens, Thomas Gerrits, Robert D Horansky, Adriana E Lita, Francesco Marsili, A Beyer, MD Shaw, D Kumor, et al. A near-infrared 64-pixel superconducting nanowire single photon detector array with integrated multiplexed readout. *Applied Physics Letters*, 106(19):192601, 2015.
- [27] J. Amaré, B. Beltrán, S. Cebrián, et al. Light yield of undoped sapphire at low temperature under particle excitation. *APPLIED PHYSICS LETTERS*, 87:264102, 2005.
- [28] Luuk J. P. Ament, Michel van Veenendaal, Thomas P. Devoreaux, John P. Hill, and Jeroen van den Brink. Resonant inelastic x-ray scattering studies of elementary excitations. *Rev. Mod. Phys.*, 83:705–767, Jun 2011.
- [29] G. Angloher, A. Bento, C. Bucci, et al. Results on light dark matter particles with a low-threshold CRESST-II detector. *Eur. Phys. J. C*, 76:1–8, 2016.
- [30] P. Antognetti, S. Cova, and A. Longoni. A study of the operation and performances of an avalanche diode as a single photon detector. In *Proceedings of 2nd ispra nuclear electronics symp.*, Stresa, Italy, 1975.
- [31] E. Aprile, A. E. Bolotnikov, A. I. Bolozdynya, and T. Doke. *Noble Gas Detectors*. John Wiley & Sons, 2006.
- [32] R. Arpaia, M. Ejrnaes, L. Parlato, F. Tafuri, R. Cristiano, D. Golubev, Roman Sobolewski, T. Bauch, F. Lombardi, and G.P. Pepe. High-temperature superconducting nanowires for photon detection. *Physica C: Superconductivity and its Applications*, 509:16–21, 2015.

- [33] A. Arvanitaki, S. Dimopoulos, and K. V. Tilburg. Resonant absorption of bosonic dark matter in molecules. *PHYSICAL REVIEW X*, 8:041001, 2018.
- [34] J. Asaadi, B. J. P. Jones, A. Tripathi, I. Parmaksiz, H. Sullivan, and Z. G. R. Williams. Emanation and bulk fluorescence in liquid argon from tetraphenyl butadiene wavelength shifting coatings. *JINST*, 14(02):P02021, 2019.
- [35] BF Aull, AH Loomis, JA Gregory, and DJ Young. Geiger-mode avalanche photodiode arrays integrated with CMOS timing circuits. In *Device research conference digest, 1998. 56th annual*, pages 58–59, Charlottesville, USA., 1998. IEEE.
- [36] Brian Aull. Geiger-mode avalanche photodiode arrays integrated to all-digital CMOS circuits. *Sensors*, 16(4), 2016.
- [37] Brian F Aull, Erik K Duerr, Jonathan P Frechette, K Alexander McIntosh, Daniel R Schuette, and Richard D Younger. Large-format geiger-mode avalanche photodiode arrays and readout circuits. *IEEE Journal of Selected Topics in Quantum Electronics*, 24(2):1–10, 2017.
- [38] Takashi Baba, Yoshihito Suzuki, Kenji Makino, Takuya Fujita, Tatsuya Hashi, Shunsuke Adachi, Shigeyuki Nakamura, and Koei Yamamoto. Development of an ingaas spad 2d array for flash lidar. In *Quantum Sensing and Nano Electronics and Photonics XV*, volume 10540, page 105400L. International Society for Optics and Photonics, 2018.
- [39] Liron Barak et al. SENSEI: Direct-Detection Results on sub-GeV Dark Matter from a New Skipper-CCD. *Phys. Rev. Lett.*, 125(17):171802, 2020.
- [40] M. Baryakhtar, J. Huang, and R. Lasenby. Axion and hidden photon dark matter detection with multilayer optical haloscopes. *PHYSICAL REVIEW D*, 98:035006, 2018.
- [41] Masha Baryakhtar, Junwu Huang, and Robert Lasenby. Axion and hidden photon dark matter detection with multilayer optical haloscopes. *Physical Review D*, 98(3):035006, 2018.
- [42] N. Bastidon, D. Horns, A. Lindner, et al. Quantum efficiency characterization and optimization of a tungsten Transition-Edge Sensor for ALPS II. *J Low Temp Phys*, 184:88–90, 2016.
- [43] Maik Beer, Charles Thattil, Jan F Haase, Jennifer Ruskowski, Werner Brockherde, and Rainer Kokozinski. Spad-based lidar sensor in $0.35\text{ }\mu\text{m}$ automotive cmos with variable background light rejection. In *Multidisciplinary Digital Publishing Institute Proceedings*, volume 2(13), page 749, 2018.
- [44] A. N. Bender, A. J. Anderson, J. S. Avva, et al. On-sky performance of the SPT-3G frequency-domain multiplexed readout. *J Low Temp. Phys.*, 199:182–191, 2020.
- [45] I Ruo Berchera and Ivo Pietro Degiovanni. Quantum imaging with sub-poissonian light: challenges and perspectives in optical metrology. *Metrologia*, 56(2):024001, 2019.
- [46] A. Bondar, A. Buzulutskov, A. Dolgov, A. Grebenuk, E. Shemyakina, and A. Sokolov. Study of infrared scintillations in gaseous and liquid argon - part i: methodology and time measurements. *JINST*, 7:06015, 2012.
- [47] A. F. Borghesani, G. Bressi, G. Carugno, E. Conti, and D. Ianuzzi. Infrared fluorescence of xe2 molecules in electron/proton beam excited pure xe gas and in an ar/xe gas mixture. *J. Chem. Phys.*, 115:6042, 2001.
- [48] Pierre Boulenc, Jo Robbelein, Linkun Wu, Luc Haspeslagh, Piet De Moor, Jonathan Borremans, and Maarten Rosmeulen. High speed tdi embedded ccd in cmos sensor. In *International Conference on Space Optics—ICSO 2016*, volume 10562, page 105622P. International Society for Optics and Photonics, 2017.

- [49] G. Bressi, G. Carugno, E. Conti, D. Ianuzzi, and A. T. Meneguzzo. A first study of the infrared emission in argon excited by ionizing particles. *Phys. Lett.*, A278:280–285, 2001.
- [50] Giorgio Brida, Ivo Pietro Degiovanni, Marco Genovese, Maria Luisa Rastello, and Ivano Ruo-Berchera. Detection of multimode spatial correlation in pdc and application to the absolute calibration of a ccd camera. *Opt. Express*, 18(20):20572–20584, Sep 2010.
- [51] Giorgio Brida, Marco Genovese, and I Ruo Berchera. Experimental realization of sub-shot-noise quantum imaging. *Nature Photonics*, 4(4):227–230, 2010.
- [52] Claudio Bruschini, Harald Homulle, Ivan Michel Antolovic, Samuel Burri, and Edoardo Charbon. Single-photon avalanche diode imagers in biophotonics: review and outlook. *Light: Science & Applications*, 8(1):1–28, 2019.
- [53] J. Burneya, T. J. Baya, J. Barral, et al. Transition-edge sensor arrays for UV-optical-IR astrophysics. *Nuclear Instruments and Methods in Physics Research A*, 559:525–527, 2006.
- [54] B. Cabrera, R. Clarke, A. Milleret, et al. Cryogenic detectors based on superconducting transition-edge sensors for time-energy-resolved single-photon counters and for dark matter searches. *Physica B*, 280:509–514, 2000.
- [55] Clinton Cahall, Kathryn L Nicolich, Nurul T Islam, Gregory P Lafyatis, Aaron J Miller, Daniel J Gauthier, and Jungsang Kim. Multi-photon detection using a conventional superconducting nanowire single-photon detector. *Optica*, 4(12):1534–1535, 2017.
- [56] A. Caldwell, B. Dvali, G. Majorovits, et al. Dielectric Haloscopes: A New Way to Detect Axion Dark Matter. *Phys. Rev. Lett.*, 118:0091801, 2017.
- [57] A. Camlica, A. El-Falou, R. Mohammadi, P. Levine, and K. Karim. Cmos-integrated single-photon-counting x-ray detector using an amorphous-selenium photoconductor with $11 \times 11 - \mu\text{m}^2$ pixels. In *2018 IEEE International Electron Devices Meeting (IEDM)*, pages 32.5.1–32.5.4, 12 2018.
- [58] Gustavo Cancelo, Claudio Chavez, Fernando Chierchie, Juan Estrada, Guillermo Fernandez Moroni, Eduardo Paolini, Miguel Sofo Haro, Angel Soto, Leandro Stefanazzi, Javier Tiffenberg, Ken Treptow, Neal Wilcer, and Ted Zmuda. Low threshold acquisition controller for Skipper charge-coupled devices. *Journal of Astronomical Telescopes, Instruments, and Systems*, 7:015001, January 2021.
- [59] Yuan Cao, Valla Fatemi, Shiang Fang, Kenji Watanabe, Takashi Taniguchi, Efthimios Kaxiras, and Pablo Jarillo-Herrero. Unconventional superconductivity in magic-angle graphene superlattices. *Nature*, 556(7699):43–50, Apr 2018.
- [60] Stephen Carr, Daniel Massatt, Shiang Fang, Paul Cazeaux, Mitchell Luskin, and Efthimios Kaxiras. Twistrronics: Manipulating the electronic properties of two-dimensional layered structures through their twist angle. *Phys. Rev. B*, 95:075420, Feb 2017.
- [61] F. W. Carter, S. A. Hertel, M. J. Rooks, et al. Calorimetric observation of single He_2^* excimers in a 100-mK He bath. *J Low Temp Phys*, 186:183–196, 2017.
- [62] Sukanya Chakrabarti et al. Snowmass2021 Cosmic Frontier White Paper: Observational Facilities to Study Dark Matter. In *Contribution to Snowmass 2021*, 2022.
- [63] Hsiang-Yu Chen, Michael K. F. Lo, Guanwen Yang, Harold G. Monbouquette, and Yang Yang. Nanoparticle-assisted high photoconductive gain in composites of polymer and fullerene. *Nature Nanotechnology*, 3(9):543–547, 2008.

- [64] Sergey Cherednichenko, Narendra Acharya, Evgenii Novoselov, and Vladimir Drakinskiy. Low kinetic inductance superconducting MgB₂ nanowires with a 130 ps relaxation time for single-photon detection applications. *Superconductor Science and Technology*, 34(4):044001, feb 2021.
- [65] Fernando Chierchie, Guillermo Fernandez Moroni, Leandro Stefanazzi, Eduardo Paolini, Javier Tiffenberg, Juan Estrada, Gustavo Cancelo, and Sho Uemura. Smart readout of nondestructive image sensors with single photon-electron sensitivity. *Phys. Rev. Lett.*, 127:241101, Dec 2021.
- [66] Jeff Chiles, Ilya Charaev, Robert Lasenby, Masha Baryakhtar, Junwu Huang, Alexana Roshko, George Burton, Marco Colangelo, Ken Van Tilburg, Asimina Arvanitaki, Sae-Woo Nam, and Karl Berggren. First constraints on dark photon dark matter with superconducting nanowire detectors in an optical haloscope. *arXiv preprint arXiv:2110.01582*, 10 2021.
- [67] Veaceslav Coropceanu, Jérôme Cornil, Demetrio A. da Silva Filho, Yoann Olivier, Robert Silbey, and Jean-Luc Brédas. Charge transport in organic semiconductors. *Chemical Reviews*, 107(4):926–952, 2007. PMID: 17378615.
- [68] Hamamatsu Corporation. Orca-quest qcmos camera, technical note. URL: https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/sys/SCAS0154E-C15550-20UP_tec.pdf Hamamatsu.com, September 2021.
- [69] Hamamatsu Corporation. qcmos: Quantitative cmos technology enabled by photon number resolving, white paper. URL: https://www.hamamatsu.com/content/dam/hamamatsu-photonics/sites/documents/99_SALES_LIBRARY/sys/SCAS0149E_qCMOS_whitepaper.pdf, April 2021.
- [70] Hamamatsu Corporation. Near infrared high sensitivity mppc: S15639-1325ps. URL: https://www.hamamatsu.com/us/en/product/optical-sensors/mppc/mppc_mppc-array.html, March 2022.
- [71] Sergio Cova, Massimo Ghioni, Andrea Lacaita, Carlo Samori, and Franco Zappa. Avalanche photodiodes and quenching circuits for single-photon detection. *Applied optics*, 35(12):1956–1976, 1996.
- [72] Michael Crisler, Rouven Essig, Juan Estrada, Guillermo Fernand ez, Javier Tiffenberg, Miguel Sofo Haro, Tomer Volansky, Tien-Tien Yu, and Sensei Collaboration. SENSEI: First Direct-Detection Constraints on Sub-GeV Dark Matter from a Surface Run. *PRL*, 121(6):061803, Aug 2018.
- [73] J Crooks, B Marsh, R Turchetta, K Taylor, W Chan, A Lahav, and Amos Fenigstein. Kirana: a solid-state megapixel ucmos image sensor for ultrahigh speed imaging. In *Sensors, cameras, and systems for industrial and scientific applications XIV*, volume 8659, page 865903. International Society for Optics and Photonics, 2013.
- [74] H. Dautet, P. Deschamps, B. Dion, A. D. MacGregor, D. MacSween, R. J. McIntyre, C. Trottier, and P. P. Webb. Photon counting techniques with silicon avalanche photodiodes. *Applied Optics*, 32(21):3894–3900, 1993.
- [75] Henri Dautet, Pierre Deschamps, Bruno Dion, Andrew D MacGregor, Darleene MacSween, Robert J McIntyre, Claude Trottier, and Paul P Webb. Photon counting techniques with silicon avalanche photodiodes. *Applied optics*, 32(21):3894–3900, 1993.
- [76] Kyle Dawson, Josh Frieman, Katrin Heitmann, Bhuvnesh Jain, Steve Kahn, Rachel Mandelbaum, Saul Perlmutter, and Anže Slosar. Cosmic Visions Dark Energy: Small Projects Portfolio. *arXiv e-prints*, page arXiv:1802.07216, Feb 2018.
- [77] Kyle Dawson, Stephen Holland, and David Schlegel. Maintaining capabilities in ccd production for the astronomy community. *arXiv preprint arXiv:1907.06798*, 2019.

- [78] Peter K Day, Henry G Leduc, Benjamin A Mazin, Anastasios Vayonakis, and Jonas Zmuidzinas. A broadband superconducting detector suitable for use in large arrays. *Nature*, 425(6):817–821, October 2003.
- [79] S. Derenzo, R. Essig, A. Massari, et al. Direct detection of sub-GeV dark matter with scintillating targets. *Phys. Rev. D*, 96:016126, 2017.
- [80] Stephen Derenzo, Rouven Essig, Andrea Massari, Adrián Soto, and Tien-Tien Yu. Direct detection of sub-gev dark matter with scintillating targets. *Phys. Rev. D*, 96:016026, Jul 2017.
- [81] Micro Photon Devices. Pdm-ir. URL: <http://www.micro-photon-devices.com/MPD/media/Datasheet/PDM-IR%20Datasheet%20window.pdf>, March 2022.
- [82] B. Dober, Z. Ahmed, K. Arnold, et al. A microwave SQUID multiplexer optimized for bolometric applications. *Appl. Phys. Lett.*, 118:062601, 2021.
- [83] Joseph P Donnelly, Erik K Duerr, K Alex McIntosh, Eric A Dauler, Douglas C Oakley, Steven H Groves, Christopher J Vineis, Leonard J Mahoney, Karen M Molvar, Pablo I Hopman, et al. Design considerations for 1.06- μ m ingaasp-inp geiger-mode avalanche photodiodes. *IEEE Journal of Quantum Electronics*, 42(8):797–809, 2006.
- [84] W. B. Doriese1, K. M. Morgan1, D. A. Bennett, et al. Developments in Time-Division Multiplexing of X-ray Transition-Edge Sensors. *J Low Temp. Phys.*, 184:389–195, 2016.
- [85] J. Dreyling-Eschweiler, N. Bastidon, B. Döbrich, et al. “characterization, 1064 nm photon signals and background events of a tungsten TES detector for the ALPS experiment. *Journal of Modern Optics*, 62:1132–1140, 2015.
- [86] Alex Drlica-Wagner, Edgar Marrufo Villalpando, Judah O’Neil, Juan Estrada, Stephen Holland, Noah Kurinsky, Ting Li, Guillermo Fernandez Moroni, Javier Tiffenberg, and Sho Uemura. Characterization of skipper CCDs for cosmological applications. In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, volume 11454 of *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, page 114541A, December 2020.
- [87] E. Erdal, L. Arazi, M. L. Rappaport, S. Shchemelinin, D. Vartsky, and A. Breskin. First demonstration of VUV-photon detection in liquid xenon with THGEM and GEM-based Liquid Hole Multipliers. *Nucl. Instrum. Meth.*, A845:218–221, 2017.
- [88] R. Essig, J. Pérez-Ríos, H. Ramani, and O. Slone. Direct detection of nuclear scattering of sub-GeV dark matter using molecular excitation. *Phys. Rev. Research*, 1:033105, 2019.
- [89] G Fernandez-Moroni, R Harnik, PAN Machado, I Martinez-Soler, YF Perez-Gonzalez, D Rodrigues, and S Rosauro-Alcaraz. The physics potential of a reactor neutrino experiment with skipper-ccds: Searching for new physics with light mediators. *arXiv preprint arXiv:2108.07310*, 2021.
- [90] Guillermo Fernandez Moroni, Juan Estrada, G. Cancelo, Stephen Holland, Eduardo Paolini, and H. Diehl. Sub-electron readout noise in a skipper ccd fabricated on high resistivity silicon. *Experimental Astronomy*, 34, 07 2012.
- [91] Guillermo Fernandez-Moroni, Pedro AN Machado, Ivan Martinez-Soler, Yuber F Perez-Gonzalez, Dario Rodrigues, and Salvador Rosauro-Alcaraz. The physics potential of a reactor neutrino experiment with skipper ccds: Measuring the weak mixing angle. *Journal of High Energy Physics*, 2021(3):1–25, 2021.

- [92] Eugenio Ferrari, Carlo Spezzani, Franck Fortuna, Renaud Delaunay, Franck Vidal, Ivaylo Nikolov, Paolo Cinquegrana, Bruno Diviacco, David Gauthier, Giuseppe Penco, Primož Rebernik Ribič, Eleonore Roussel, Marco Trovò, Jean-Baptiste Moussy, Tommaso Pincelli, Lounès Lounis, Michele Manfredda, Emanuele Pedersoli, Flavio Capotondi, Cristian Svetina, Nicola Mahne, Marco Zangrando, Lorenzo Raimondi, Alexander Demidovich, Luca Giannessi, Giovanni De Ninno, Miltcho Boyanov Danailov, Enrico Allaria, and Maurizio Sacchi. Widely tunable two-colour seeded free-electron laser source for resonant-pump resonant-probe magnetic scattering. *Nature Communications*, 7(1):10343, Jan 2016.
- [93] Albert Fert, Nicolas Reyren, and Vincent Cros. Magnetic skyrmions: advances in physics and potential applications. *Nature Reviews Materials*, 2(7):17031, Jun 2017.
- [94] Keith Fife, Abbas El Gamal, and H-S Philip Wong. Design and characterization of submicron ccds in cmos. In *International Image Sensor Workshop*, 2009.
- [95] C. W. Fink, S. L. Watkins, T. Aramaki, et al. Characterizing TES power noise for future single optical-phonon and infrared-photon detectors. *AIP Advances*, 10:085221, 2020.
- [96] Eric Fossum, Jiaju Ma, Saleh Masoodian, Leo Anzagira, and Rachel Zizza. The quanta image sensor: Every photon counts. URL: <https://digitalcommons.dartmouth.edu/cgi/viewcontent.cgi?article=4432&context=facoa>, October 2016.
- [97] Eric R Fossum and Donald B Hondongwa. A review of the pinned photodiode for ccd and cmos image sensors. *IEEE Journal of the electron devices society*, 2014.
- [98] Boyd Fowler, Chiao Liu, Steve Mims, Janusz Balicki, Wang Li, Hung Do, Jeff Appelbaum, and Paul Vu. A 5.5 mpixel 100 frames/sec wide dynamic range low noise cmos image sensor for scientific applications. In *Sensors, Cameras, and Systems for Industrial/Scientific Applications XI*, volume 7536, page 753607. International Society for Optics and Photonics, 2010.
- [99] Daniel Z. Freedman. Coherent effects of a weak neutral current. *Phys. Rev. D*, 9:1389–1392, Mar 1974.
- [100] Canek Fuentes-Hernandez, Wen-Fang Chou, Talha M. Khan, Larissa Diniz, Julia Lukens, Felipe A. Larrain, Victor A. Rodriguez-Toro, and Bernard Kippelen. Large-area low-noise flexible organic photodiodes for detecting faint visible light. *Science*, 370(6517):698–701, 2020.
- [101] H. Fujino, H. Ishii, T. Itatani, et al. Titanium-based transition-edge photon number resolving detector with 98% detection efficiency with index-matched small-gap fiber coupling. *Opt. Express*, 19:870–875, 2011.
- [102] D. Fukuda, G. Fujii, T. Numata, et al. Photon number resolving detection with high speed and high quantum efficiency. *Metrologia*, 46:S288, 2009.
- [103] G. Gallina, P. Giampa, F. Retišre, J. Kroeger, G. Zhang, M. Ward, P. Margetak, G. Li, T. Tsang, L. Doria, S. Al Kharusi, M. Alfaris, G. Anton, I.J. Arnquist, I. Badhrees, P.S. Barbeau, D. Beck, V. Belov, T. Bhatta, J. Blatchford, J.P. Brodsky, E. Brown, T. Brunner, G.F. Cao, L. Cao, W.R. Cen, C. Chambers, S.A. Charlebois, M. Chiu, B. Cleveland, M. Coon, A. Craycraft, J. Dalmasson, T. Daniels, L. Darroch, S.J. Daugherty, A. De St. Croix, A. Der Mesrobian-Kabakian, R. DeVoe, J. Dilling, Y.Y. Ding, M.J. Dolinski, A. Dragone, J. Echevers, M. Elbeltagi, L. Fabris, D. Fairbank, W. Fairbank, J. Farine, S. Feyzbakhsh, R. Fontaine, P. Gautam, G. Giacomini, R. Gornea, G. Gratta, E.V. Hansen, M. Heffner, E.W. Hoppe, J. Hößl, A. House, M. Hughes, Y. Ito, A. Iverson, A. Jamil, M.J. Jewell, X.S. Jiang, A. Karelín, L.J. Kaufman, D. Kodroff, T. Koffas, R. Krücke, A. Kuchenkov, K.S. Kumar, Y. Lan, A. Larson, B.G. Lenardo, D.S. Leonard, S. Li, Z. Li, C. Licciardi, Y.H. Lin, P. Lv, R. MacLellan, T. McElroy, M. Medina-Peregrina, T. Michel, B. Mong, D.C. Moore, K. Murray, P. Nakarmi, R.J.

- Newby, Z. Ning, O. Njoya, F. Nolet, O. Nusair, K. Odgers, A. Odian, M. Oriunno, J.L. Orrell, G.S. Ortega, I. Ostrovskiy, C.T. Overman, S. Parent, A. Piepke, A. Pocar, J.-F. Pratte, D. Qiu, V. Radeka, E. Raguzin, S. Rescia, M. Richman, A. Robinson, T. Rossignol, P.C. Rowson, N. Roy, R. Saldanha, S. Sangiorgio, K. Skarpaas, A.K. Soma, G. St-Hilaire, V. Stekhanov, T. Stiegler, X.L. Sun, M. Tarka, J. Todd, T. Tolba, T.I. Totev, R. Tsang, F. Vachon, V. Veeraraghavan, G. Visser, J.-L. Vuilleumier, M. Wagenpfeil, M. Walent, Q. Wang, J. Watkins, M. Weber, W. Wei, L.J. Wen, U. Wicher, S.X. Wu, W.H. Wu, X. Wu, Q. Xia, H. Yang, L. Yang, Y.-R. Yen, O. Zeldovich, J. Zhao, Y. Zhou, and T. Ziegler. Characterization of the hamamatsu vuv4 mppcs for nexo. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 940:371–379, 2019.
- [104] F. Giazotto, T. T. Heikkilä, A. Luukanen, et al. Opportunities for mesoscopics in thermometry and refrigeration: Physics and applications. *Rev. Mod. Phys.*, 78:217, 2006.
- [105] V Giovannetti, S Lloyd, and L Maccone. Advances in quantum metrology. *Nature Photonics*, 5(4):222–229, 2011.
- [106] John B. Goodenough and Youngsik Kim. Challenges for rechargeable li batteries. *Chemistry of Materials*, 22(3):587–603, Feb 2010.
- [107] Angelo Gulinatti, Ivan Rech, Francesco Panzeri, Corrado Cammi, P Maccagnani, M Ghioni, and Sergio Cova. New silicon spad technology for enhanced red-sensitivity, high-resolution timing and system integration. *Journal of Modern Optics*, 59(17):1489–1499, 2012.
- [108] Robert H Hadfield. Single-photon detectors for optical quantum information applications. *Nature photonics*, 3(12):696–705, 2009.
- [109] M. He, Y. Li, J. Cai, Y. Liu, K. Watanabe, X. Xu, and M. Yankowitz. Symmetry breaking in twisted double bilayer graphene. *Nature Physics*, 17:26–30, 2020.
- [110] T. Heindl, T. Dandl, M. Hofmann, R. Krücken, L. Oberauer, W. Potzel, J. Wieser, and A. Ulrich. The scintillation of liquid argon. *EPL*, 91(6):6002, 2010.
- [111] R Henning-Yeomans, C. L. Chang, J. Ding, et al. Controlling Tc of iridium films using the proximity effect. *Journal of Applied Physics*, 128:154501, 2020.
- [112] S. A. Hertel, A. Biekert, J. Lin, V. Velan, and D. N. McKinsey. Direct detection of sub-GeV dark matter using a superfluid ^4He target. *Phys. Rev. D*, 100:092007, 2019.
- [113] David Hitlin. Progress on a photosensor for the readout of the fast scintillation light component of BaF₂. In *CPAD Instrumentation Frontier Workshop*, Stony Brook, NY, May 2021.
- [114] Yonit Hochberg, Ilya Charaev, Sae-Woo Nam, Varun Verma, Marco Colangelo, and Karl K. Berggren. Detecting sub-gev dark matter with superconducting nanowires. *Phys. Rev. Lett.*, 123:151802, Oct 2019.
- [115] Michael E. Hoenk, Paula J. Grunthaner, Frank J. Grunthaner, R. W. Terhune, Masoud Fattahai, and Hsin-Fu Tseng. Growth of a delta-doped silicon layer by molecular beam epitaxy on a charge-coupled device for reflection-limited ultraviolet quantum efficiency. *Applied Physics Letters*, 61(9):1084–1086, 1992.
- [116] S. E. Holland, D. E. Groom, N. P. Palaio, R. J. Stover, and Mingzhi Wei. Fully depleted, back-illuminated charge-coupled devices fabricated on high-resistivity silicon. *IEEE Transactions on Electron Devices*, 50(1):225–238, 2003.

- [117] D. Horns, J. Jaeckel, A. Lindner, et al. Searching for WISPy cold dark matter with a dish antenna. *JCAP*, 04:016, 2013.
- [118] T. Igarashi, M. Tanaka, T. Washimi, and K. Yorita. Performance of VUV-sensitive MPPC for Liquid Argon Scintillation Light. *Nucl. Instrum. Meth.*, A833:239–244, 2016.
- [119] Broadcom Inc. Broadcom’s nir sipm technology sets new performance standards for lidar. URL: <https://www.broadcom.com/blog/broadcoms-nir-sipm-technology-sets-performance-standards-for-lidar>, February 2020.
- [120] K. D. Irwin and G. C. Hilton. “*Transition-Edge Sensors*” in *Cryoogenic Particle Detection*, Edited by C. Enss. Springer, 2005.
- [121] Mark A Itzler, Mark Entwistle, Mark Owens, Ketan Patel, Xudong Jiang, Krystyna Slomkowski, Sabbir Rangwala, Peter F Zalud, Tom Senko, John Tower, et al. Design and performance of single photon apd focal plane arrays for 3-d ladar imaging. In *Detectors and Imaging Devices: Infrared, Focal Plane, Single Photon*, volume 7780, page 77801M. International Society for Optics and Photonics, 2010.
- [122] Ihor I. Izhnin, Kirill A. Lozovoy, Andrey P. Kokhanenko, Kristina I. Khomyakova, Rahaf M. H. Douhan, Vladimir V. Dirk, Alexander V. Voitsekhovskii, Olena I. Fitsych, and Nataliya Yu. Akimenko. Single-photon avalanche diode detectors based on group IV materials. *Applied Nanoscience*, February 2021.
- [123] A. Jamil, T. Ziegler, P. Hufschmidt, G. Li, L. Lupin-Jimenez, T. Michel, I. Ostrovskiy, F. Retière, J. Schneider, M. Wagenpfel, A. Alamre, J. B. Albert, G. Anton, I. J. Arnquist, I. Badhrees, P. S. Barbeau, D. Beck, V. Belov, T. Bhatta, F. Bourque, J. P. Brodsky, E. Brown, T. Brunner, A. Burenkov, G. F. Cao, L. Cao, W. R. Cen, C. Chambers, S. A. Charlebois, M. Chiu, B. Cleveland, M. Coon, M. Côté, A. Craycraft, W. Cree, J. Dalmasson, T. Daniels, L. Darroch, S. J. Daugherty, J. Daughhetee, S. Delaquis, A. Der Mesrobian-Kabakian, R. DeVoe, J. Dilling, Y. Y. Ding, M. J. Dolinski, A. Dragone, J. Echevers, L. Fabris, D. Fairbank, W. Fairbank, J. Farine, S. Feyzbakhsh, R. Fontaine, D. Fudenberg, G. Gallina, G. Giacomini, R. Gornea, G. Gratta, E. V. Hansen, D. Harris, M. Hasan, M. Heffner, J. Hößl, E. W. Hoppe, A. House, M. Hughes, Y. Ito, A. Iverson, C. Jessiman, M. J. Jewell, X. S. Jiang, A. Karel, L. J. Kaufman, T. Koffas, S. Kravitz, R. Krücken, A. Kuchenkov, K. S. Kumar, Y. Lan, A. Larson, D. S. Leonard, S. Li, Z. Li, C. Licciardi, Y. H. Lin, P. Lv, R. MacLellan, B. Mong, D. C. Moore, K. Murray, R. J. Newby, Z. Ning, O. Njoya, F. Nolet, O. Nusair, K. Odgers, A. Odian, M. Oriunno, J. L. Orrell, G. S. Ortega, C. T. Overman, S. Parent, A. Piepke, A. Pocar, J.-F. Pratte, D. Qiu, V. Radeka, E. Raguzin, T. Rao, S. Rescia, A. Robinson, T. Rossignol, P. C. Rowson, N. Roy, R. Saldanha, S. Sangiorgio, S. Schmidt, A. Schubert, D. Sinclair, K. Skarpaas, A. K. Soma, G. St-Hilaire, V. Stekhanov, T. Stiegler, X. L. Sun, M. Tarka, J. Todd, T. Tolba, T. I. Totev, R. Tsang, T. Tsang, F. Vachon, B. Veenstra, V. Veeraraghavan, G. Visser, J.-L. Vuilleumier, Q. Wang, J. Watkins, M. Weber, W. Wei, L. J. Wen, U. Wichojski, G. Wrede, S. X. Wu, W. H. Wu, Q. Xia, L. Yang, Y.-R. Yen, O. Zeldovich, X. Zhang, J. Zhao, and Y. Zhou. Vuv-sensitive silicon photomultipliers for xenon scintillation light detection in nexo. *IEEE Transactions on Nuclear Science*, 65(11):2823–2833, 2018.
- [124] James Janesick, Tom Elliott, Richard Bredthauer, Charles Chandler, and Barry Burke. Fano-Noise-Limited CCDs. In Leon Golub, editor, *X-Ray Instrumentation in Astronomy II*, volume 0982, pages 70 – 95. International Society for Optics and Photonics, SPIE, 1988.
- [125] Safa Kasap, Joel B. Frey, George Belev, Olivier Tousignant, Habib Mani, Jonathan Greenspan, Luc Lapierre, Oleksandr Bubon, Alla Reznik, Giovanni DeCrescenzo, and et al. Amorphous and polycrystalline photoconductors for direct conversion flat panel x-ray image sensors. *Sensors*, 11(5):5112–5157, May 2011.

- [126] B. Keimer, S. A. Kivelson, M. R. Norman, S. Uchida, and J. Zaanen. From quantum matter to high-temperature superconductivity in copper oxides. *Nature*, 518(7538):179–186, Feb 2015.
- [127] W. J. Kindt and H. W. van Zeijl. Fabrication of Geiger mode avalanche photodiodes. In *1997 IEEE nuclear science symposium conference record*, pages 334–338 vol.1, Albuquerque, USA, 1997.
- [128] W.J. Kindt. *Geiger mode avalanche photodiode arrays: For spatially resolved single photon counting*. Delft University Press, 1999.
- [129] W.J. Kindt and H.W. van Zeijl. Modelling and fabrication of Geiger mode avalanche photodiodes. *IEEE Transactions on Nuclear Science*, 45:715–719, 1998.
- [130] Yu. P. Korneeva, D. Yu. Vodolazov, A. V. Semenov, I. N. Florya, N. Simonov, E. Baeva, A. A. Korneev, G. N. Goltsman, and T. M. Klapwijk. Optical single-photon detection in micrometer-scale nbn bridges. *Phys. Rev. Applied*, 9:064037, Jun 2018.
- [131] B. Korzh, Qingyuan Zhao, Simone Frasca, J. Allmaras, T. Autry, Eric Bersin, Marco Colangelo, G. Crouch, Andrew Dane, T. Gerrits, F. Marsili, Galan Moody, E. Ramirez, J. Rezac, Martin Stevens, E. Wollman, D. Zhu, P. Hale, Kevin Silverman, and Karl Berggren. Demonstrating sub-3 ps temporal resolution in a superconducting nanowire single-photon detector. *Nat. Photonics*, 14:250–255, 04 2018.
- [132] Kateryna Kuzmenko, Peter Vines, Abderrahim Halimi, Robert J. Collins, Aurora Maccarone, Angus McCarthy, Zoë M. Greener, Jarosław Kirdoda, Derek C. S. Dumas, Lourdes Ferre Llin, Muhammad M. Mirza, Ross W. Millar, Douglas J. Paul, and Gerald S. Buller. 3d lidar imaging using ge-on-si single-photon avalanche diode detectors. *Opt. Express*, 28(2):1330–1344, Jan 2020.
- [133] Andy LaBella, Jann Stavro, Sébastien Léveillé, Wei Zhao, and Amir H. Goldan. Picosecond time resolution with avalanche amorphous selenium. *ACS Photonics*, 6(6):1338–1344, 2019.
- [134] A. Lacaia, S. Cova, C. Samori, and M. Ghioni. Performance optimization of active quenching circuits for picosecond timing with single photon avalanche diodes. *Review of scientific instruments*, 66(8):4289–4295, 1995.
- [135] Benjamin J. Lawrie, Claire E. Marvinney, Yun-Yi Pai, Matthew A. Feldman, Jie Zhang, Aaron J. Miller, Chengyun Hua, Eugene Dumitrescu, and Gábor B. Halász. Multifunctional superconducting nanowire quantum sensors. *Phys. Rev. Applied*, 16:064059, Dec 2021.
- [136] M-J Lee, AR Ximenes, P Padmanabhan, TJ Wang, KC Huang, Y Yamashita, DN Yaung, and E Charbon. A back-illuminated 3d-stacked single-photon avalanche diode in 45nm cmos technology. In *2017 IEEE International Electron Devices Meeting (IEDM)*, pages 16–6. IEEE, 2017.
- [137] C. Leitz et al. Development of germanium charge-coupled devices. In Andrew D. Holland and James Beletic, editors, *High Energy, Optical, and Infrared Detectors for Astronomy VIII, SPIE Astronomical Telescopes + Instrumentation, 2018, Austin, Texas, United States*, volume 10709, pages 1070908–1–7. International Society for Optics and Photonics, SPIE, 2018.
- [138] C. Leitz et al. Towards megapixel-class germanium charge-coupled devices for broadband x-ray detectors. In Oswald H. Siegmund, editor, *UV, X-Ray, and Gamma-Ray Space Instrumentation for Astronomy XXI*, volume 11118, pages 111802–2–8. International Society for Optics and Photonics, SPIE, 2019.
- [139] C. Leitz et al. Germanium charge-coupled devices for hard x-ray astronomy. In Andrew D. Holland and James Beletic, editors, *X-Ray, Optical, and Infrared Detectors for Astronomy IX, SPIE Astronomical Telescopes + Instrumentation, 2020, Online Only*, volume 11454, pages 114541B–1–8. International Society for Optics and Photonics, SPIE, 2020.

- [140] BF Levine, CG Bethea, and JC Campbell. Near room temperature $1.3\text{ }\mu\text{m}$ single photon counting with a ingaas avalanche photodiode. *Electronics Letters*, 20(14):596–598, 1984.
- [141] P. Lindblom and A. Solin. Atomic near-infrared noble gas scintillation i optical spectra. *Nucl. Instr. Meth.*, A268:204–208, 1988.
- [142] A. E. Lita, A. J. Miller, and S. W. Nam. Counting near-infrared single-photons with 95% efficiency. *Opt. Express*, 16:3032–3040, 2008.
- [143] J. Liu, K. Dona, G. Hoshino, et al. Broadband solenoidal haloscope for terahertz axion detection. arXiv:2111.12103, 2021.
- [144] Jesse Liu, Kristin Dona, Gabe Hoshino, Stefan Knirck, Noah Kurinsky, Matthew Malaker, David Miller, Andrew Sonnenschein, Pete Barry, Karl K Berggren, et al. Broadband solenoidal haloscope for terahertz axion detection. *arXiv preprint arXiv:2111.12103*, 2021.
- [145] Lourdes Ferre Llin, Jarosław Kirdoda, Fiona Thorburn, Laura L. Huddleston, Zoë M. Greener, Kateryna Kuzmenko, Peter Vines, Derek C. S. Dumas, Ross W. Millar, Gerald S. Buller, and Douglas J. Paul. High sensitivity ge-on-si single-photon avalanche diode detectors. *Opt. Lett.*, 45(23):6406–6409, Dec 2020.
- [146] Lourdes Ferre Llin, Jarosław Kirdoda, Fiona Thorburn, Laura L Huddleston, Zoë M Greener, Kateryna Kuzmenko, Peter Vines, Derek CS Dumas, Ross W Millar, Gerald S Buller, et al. High sensitivity ge-on-si single-photon avalanche diode detectors. *Optics Letters*, 45(23):6406–6409, 2020.
- [147] Elena Losero, Ivano Ruo-Berchera, Alice Meda, Alessio Avella, and Marco Genovese. Unbiased estimation of an optical loss at the ultimate quantum limit with twin-beams. *Scientific reports*, 8(1):1–11, 2018.
- [148] Zhiwen Lu, Yimin Kang, Chong Hu, Qiugui Zhou, Han-Din Liu, and Joe C Campbell. Geiger-mode operation of ge-on-si avalanche photodiodes. *IEEE Journal of Quantum Electronics*, 47(5):731–735, 2011.
- [149] Cheng Ma, Yang Liu, Jing Li, Quan Zhou, Yuchun Chang, and Xinyang Wang. A 4mp high-dynamic-range, low-noise cmos image sensor. In *Image Sensors and Imaging Systems 2015*, volume 9403, page 940305. International Society for Optics and Photonics, 2015.
- [150] Jiaju Ma, Saleh Masoodian, Yue Song, Kofi Odame, Eric Fossum, and Donald Hondongwa. Quanta image sensor (qis): Early research progress. In *Optics InfoBase Conference Papers*, 06 2013.
- [151] Jiaju Ma, Dexue Zhang, Omar A. Elgendi, and Saleh Masoodian. A 0.19e- rms read noise 16.7mpixel stacked quanta image sensor with $1.1\text{ }\mu\text{m}$ -pitch backside illuminated pixels. *IEEE Electron Device Letters*, 42(6):891–894, 2021.
- [152] Agustina G. Magnoni, Muriel Bonetto, Juan Estrada, Miguel A. Larotonda, and Dario Rodrigues. Sub-shot noise absorption measurements using a skipper-ccd and twin-beams: a work in progress. In *Quantum Information and Measurement VI 2021*, page W2B.5. Optical Society of America, 2021.
- [153] Olivier Marcelot, Magali Etribeau, Vincent Goiffon, Philippe Martin-Gonthier, Franck Corbière, Romain Molina, Sébastien Rolando, and Pierre Magnan. Study of ccd transport on cmos imaging technology: Comparison between sccd and bccd, and ramp effect on the cti. *IEEE Transactions on Electron Devices*, 61(3):844–849, 2014.

- [154] Jennifer Marshall, Adam Bolton, James Bullock, Adam Burgasser, Ken Chambers, Darren DePoy, Arjun Dey, Nicolas Flagey, Alexis Hill, Lynne Hillenbrand, Daniel Huber, Ting Li, Stephanie Juneau, Manoj Kaplinghat, Mario Mateo, Alan McConnachie, Jeffrey Newman, Andreea Petric, David Schlegel, Andrew Sheinis, Yue Shen, Doug Simons, Michael Strauss, Kei Szeto, Kim-Vy Tran, and Christophe Yèche. The Maunakea Spectroscopic Explorer. In *Bulletin of the American Astronomical Society*, volume 51, page 126, September 2019.
- [155] Nicholas JD Martinez, Michael Gehl, Christopher T Derose, Andrew L Starbuck, Andrew T Pomerene, Anthony L Lentine, Douglas C Trotter, and Paul S Davids. Single photon detection in a waveguide-coupled ge-on-si lateral avalanche photodiode. *Optics express*, 25(14):16130–16139, 2017.
- [156] D C Mattis and J Bardeen. Theory of the Anomalous Skin Effect in Normal and Superconducting Metals. *Physical Review*, 111(2):412–417, 1958.
- [157] Massimo Mazzillo, Anatoly Ronzhin, Sergey Los, Salvatore Abbissio, Delfo Sanfilippo, Giusy Valvo, Beatrice Carbone, Angelo Piana, Giorgio Fallica, Michael Albrow, et al. Electro-optical performances of p-on-n and n-on-p silicon photomultipliers. *IEEE transactions on electron devices*, 59(12):3419–3425, 2012.
- [158] Sean McHugh, Benjamin A Mazin, Bruno Serfass, Seth Meeker, Kieran O’Brien, Ran Duan, Rick Raffanti, and Dan Werthimer. A readout for large arrays of microwave kinetic inductance detectors. *Review of Scientific Instruments*, 83(4):4702, April 2012.
- [159] KA McIntosh, JP Donnelly, DC Oakley, A Napoleone, SD Calawa, LJ Mahoney, KM Molvar, EK Duerr, SH Groves, and DC Shaver. Ingaasp/inp avalanche photodiodes for photon counting at 1.06 μm . *Applied Physics Letters*, 81(14):2505–2507, 2002.
- [160] KA McIntosh, JP Donnelly, DC Oakley, A Napoleone, SD Calawa, LJ Mahoney, KM Molvar, J Mahan, RJ Molnar, EK Duerr, et al. Arrays of iii-v semiconductor geiger-mode avalanche photodiodes. In *The 16th Annual Meeting of the IEEE Lasers and Electro-Optics Society, 2003. LEOS 2003.*, volume 2, pages 686–687. IEEE, 2003.
- [161] Bertrand Mennesson, Scott Gaudi, Sara Seager, Alina Kiessling, and Keith Warfield. The Habitable Exoplanet Observatory mission concept. In *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, volume 11443 of *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*, page 1144320, December 2020.
- [162] Matteo Mitrano, Sangjun Lee, Ali A. Husain, Luca Delacretaz, Minhui Zhu, Gilberto de la Peña Munoz, Stella X.-L. Sun, Young Il Joe, Alexander H. Reid, Scott F. Wandel, Giacomo Coslovich, William Schlotter, Tim van Driel, John Schneeloch, G. D. Gu, Sean Hartnoll, Nigel Goldenfeld, and Peter Abbamonte. Ultrafast time-resolved x-ray scattering reveals diffusive charge order dynamics in $\text{La}_{2-x}\text{Sr}_x\text{CuO}_4$. *Science Advances*, 5(8):eaax3346, 2019.
- [163] Paul-Antoine Moreau, Ermes Toninelli, Thomas Gregory, and Miles J Padgett. Imaging with quantum states of light. *Nature Reviews Physics*, 1(6):367–380, 2019.
- [164] P. C. Nagler, M. A. Greenhouse, S. H. Moseley, et al. Development of transition edge sensor detectors optimized for single-photon spectroscopy in the optical and near-infrared. *Proc. SPIE*, 10709:1070931, 2018.
- [165] P. C. Nagler, J. E. Sadleir, and E. J. Wollack. Transition-edge sensor detectors for the origins space telescope. *J. of Astronomical Telescopes, Instruments, and Systems*, 7(1):011005, 2021.

- [166] S. Nakano, Y. Takeuchi, T. Kaneko, and M. Kondo. Influence of surface treatments on crystalline germanium heterojunction solar cell characteristics. *Journal of Non-Crystalline Solids*, 358(17):2249–2252, 2012.
- [167] P. Nakarmi, I. Ostrovskiy, A.K. Soma, F. Retière, S. Al Kharusi, M. Alfaris, G. Anton, I.J. Arnquist, I. Badhrees, P.S. Barbeau, D. Beck, V. Belov, T. Bhatta, J. Blatchford, P.A. Breur, J.P. Brodsky, E. Brown, T. Brunner, S. Byrne Mamahit, E. Caden, G.F. Cao, L. Cao, C. Chambers, B. Chana, S.A. Charlebois, M. Chiu, B. Cleveland, M. Coon, A. Craycraft, J. Dalmasson, T. Daniels, L. Darroch, A. De St. Croix, A. Der Mesrobian-Kabakian, R. DeVoe, M.L. Di Vacri, J. Dilling, Y.Y. Ding, M.J. Dolinski, L. Doria, A. Dragone, J. Echevers, F. Edaltafar, M. Elbeltagi, L. Fabris, D. Fairbank, W. Fairbank, J. Farine, S. Ferrara, S. Feyzbakhsh, R. Fontaine, A. Fucarino, G. Gallina, P. Gautam, G. Giacomini, D. Goeldi, R. Gornea, G. Gratta, E.V. Hansen, M. Heffner, E.W. Hoppe, J. Hößl, A. House, M. Hughes, A. Iverson, A. Jamil, M.J. Jewell, X.S. Jiang, A. Karelín, L.J. Kaufman, T. Koffas, R. Krückken, A. Kuchenkov, K.S. Kumar, Y. Lan, A. Larson, K.G. Leach, B.G. Lenardo, D.S. Leonard, G. Li, S. Li, Z. Li, C. Licciardi, P. Lv, R. MacLellan, N. Massacret, T. McElroy, M. Medina-Peregrina, T. Michel, B. Mong, D.C. Moore, K. Murray, C.R. Natzke, R.J. Newby, Z. Ning, O. Njoya, F. Nolet, O. Nusair, K. Odgers, A. Odian, M. Oriunno, J.L. Orrell, G.S. Ortega, C.T. Overman, S. Parent, A. Piepke, A. Pocar, J.-F. Pratte, V. Radeka, E. Raguzin, S. Rescia, M. Richman, A. Robinson, T. Rossignol, P.C. Rowson, N. Roy, J. Runge, R. Saldanha, S. Sangiorgio, K. Skarpaas VIII, G. St-Hilaire, V. Stekhanov, T. Stiegler, X.L. Sun, M. Tarka, J. Todd, T.I. Totev, R. Tsang, T. Tsang, F. Vachon, V. Veeraraghavan, S. Viel, G. Visser, C. Vivo-Vilches, J.-L. Vuilleumier, M. Wagenpfeil, T. Wager, M. Walent, Q. Wang, M. Ward, J. Watkins, M. Weber, W. Wei, L.J. Wen, U. Wichoski, S.X. Wu, W.H. Wu, X. Wu, Q. Xia, H. Yang, L. Yang, O. Zeldovich, J. Zhao, Y. Zhou, and T. Ziegler. Reflectivity and PDE of VUV4 hamamatsu SiPMs in liquid xenon. *Journal of Instrumentation*, 15(01):P01019–P01019, jan 2020.
- [168] Lis K Nanver, Lin Qi, Vahid Mohammadi, KRM Mok, Wiebe B de Boer, Negin Golshani, Amir Sammak, Thomas LM Scholtes, Alexander Gottwald, Udo Kroth, et al. Robust uv/vuv/euv pureb photodiode detector technology with high cmos compatibility. *IEEE Journal of Selected Topics in Quantum Electronics*, 20(6):306–316, 2014.
- [169] Irina Nasteva. Low-energy reactor neutrino physics with the connie experiment. *Journal of Physics: Conference Series*, 2156(1):012115, Dec 2021.
- [170] National Academies of Sciences, Engineering, and Medicine. *Pathways to Discovery in Astronomy and Astrophysics for the 2020s*. 2021.
- [171] A. Neumeier, T. Dandl, T. Heindl, A. Himpsl, L. Oberauer, W. Potzel, S. Roth, S. Schönert, J. Wieser, and A. Ulrich. Intense vacuum-ultraviolet and infrared scintillation of liquid ar-xe mixtures. *EPL*, 109(1):12001, 2015.
- [172] Cristiano Niclass, Alexis Rochas, Pierre-Andre Besse, and Edoardo Charbon. Design and characterization of a CMOS 3-D image sensor based on single photon avalanche diodes. *IEEE Journal of Solid-State Circuits*, 40(9):1847–1854, 2005.
- [173] Shouleh Nikzad, Michael E Hoenk, Frank Greer, Blake Jacquot, Steve Monacos, Todd J Jones, Jordana Blacksberg, Erika Hamden, David Schiminovich, Chris Martin, et al. Delta-doped electron-multiplied ccd with absolute quantum efficiency over 50% in the near to far ultraviolet range for single photon counting applications. *Applied Optics*, 51(3):365–369, 2012.
- [174] U.S. Department of Energy. Basic research needs for dark-matter small projects new initiatives. <https://www.osti.gov/servlets/purl/1659757>, 2019.

- [175] J. O'Meara and Luvoir Mission Concept Study Team. The LUVOIR Mission Concept: Telling the Story of Life in the Universe. In *American Astronomical Society Meeting Abstracts #235*, volume 235 of *American Astronomical Society Meeting Abstracts*, page 447.04, January 2020.
- [176] onsemi. Rb-series sipm: Silicon photomultipliers, nir-enhanced. URL: <https://www.onsemi.com/products/sensors/photodetectors-sipm-spad/silicon-photomultipliers-sipm/rb-series-sipm>, March 2022.
- [177] Paolo Organtini, Alberto Gola, Giovanni Paternoster, Fabio Acerbi, Giovanni Margutti, and Roberto Bez. Industrial exploitation of sipm technology developed for basic research. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 978:164410, 2020.
- [178] F. Paolucci, V. Buccheri, G. Germanese, et al. Development of highly sensitive nanoscale transition edge sensors for gigahertz astronomy and dark matter search. *J. Appl. Phys.*, 128:194502, 2020.
- [179] Giovanni Paternoster, Lorenza Ferrario, Fabio Acerbi, Alberto Giacomo Gola, and Pierluigi Bellutti. Silicon photomultipliers technology at fondazione bruno kessler and 3d integration perspectives. In *ESSDERC 2019-49th European Solid-State Device Research Conference (ESSDERC)*, pages 50–53. IEEE, 2019.
- [180] H Podmore, I D'Souza, J Cain, T Jennewein, BL Higgins, YS Lee, A Koujelev, D Hudson, and A McColgan. Qkd terminal for canada's quantum encryption and science satellite (qeyssat). In *International Conference on Space Optics—ICSO 2020*, volume 11852, page 118520H. International Society for Optics and Photonics, 2021.
- [181] Tomas Polakovic, Whitney Armstrong, Volodymyr Yefremenko, John E. Pearson, Kawtar Hafidi, Goran Karapetrov, Zein-Eddine Meziani, and Valentyn Novosad. Superconducting nanowires as high-rate photon detectors in strong magnetic fields. *Nuclear Instruments & Methods in Physics Research Section A-accelerators Spectrometers Detectors and Associated Equipment*, 959:163543, 2020.
- [182] N.E. Posthuma, G. Flamand, and J. Poortmans. Development of standalone germanium solar cells for application in space using spin-on diffusants. In *Proceedings 3rd World Conference Photovoltaic Energy Conversion, Osaka, Japan*, volume 1, page 777–780, 2003.
- [183] Jean-François Pratte, Frédéric Nolet, Samuel Parent, Frédéric Vachon, Nicolas Roy, Tommy Rossignol, Keven Deslandes, Henri Dautet, Réjean Fontaine, and Serge A Charlebois. 3d photon-to-digital converter for radiation instrumentation: Motivation and future works. *Sensors*, 21(2), 2021.
- [184] Prasana Ravindran, Risheng Cheng, Hong Tang, and Joseph C Bardin. Active quenching of superconducting nanowire single photon detectors. *Optics express*, 28(3):4099–4114, 2020.
- [185] Dileep V. Reddy, Robert R. Nerem, Sae Woo Nam, Richard P. Mirin, and Varun B. Verma. Superconducting nanowire single-photon detectors with 98% system detection efficiency at 1550nm. *Optica*, 7(12):1649–1653, Dec 2020.
- [186] Michael W. Richmond, Masaomi Tanaka, Tomoki Morokuma, Shigeyuki Sako, Ryou Ohsawa, Noriaki Arima, Nozomu Tominaga, Mamoru Doi, Tsutomu Aoki, Ko Arimatsu, Makoto Ichiki, Shiro Ikeda, Yoshifusa Ita, Toshihiro Kasuga, Koji S. Kawabata, Hideyo Kawakita, Naoto Kobayashi, Mitsuru Kokubo, Masahiro Konishi, Hiroyuki Maehara, Hiroyuki Mito, Takashi Miyata, Yuki Mori, Mikio Morii, Kentaro Motohara, Yoshikazu Nakada, Shin-Ichiro Okumura, Hiroki Onozato, Yuki Sarugaku, Mikiya Sato, Toshikazu Shigeyama, Takao Soyano, Hidenori Takahashi, Ataru Tanikawa, Ken'ichi Tarusawa, Seitaro Urakawa, Fumihiko Usui, Junichi Watanabe, Takuya Yamashita, and Makoto Yoshikawa. An

- optical search for transients lasting a few seconds. *Publications of the Astronomical Society of Japan*, 72(1):3, February 2020.
- [187] A. Rochas, M. Gani, B. Furrer, P.A. Besse, R.S. Popovic, G. Ribordy, and N. Gisin. Single photon detector fabricated in a complementary metal-oxide-semiconductor high-voltage technology. *Review of Scientific Instruments*, 74(7):3263–3270, 2003.
 - [188] A. Rochas, M. Gosch, A. Serov, P. A. Besse, R. S. Popovic, T. Lasser, and R. Rigler. First fully integrated 2-D array of single-photon detectors in standard CMOS technology. *IEEE Photonics Technology Letters*, 15(7):963–965, 2003.
 - [189] Alexis Rochas. *Single photon avalanche diodes in CMOS technology*. EPFL, Lausanne, 2003.
 - [190] Dario Rodrigues, Kevin Andersson, Mariano Cababie, Andre Donadon, Gustavo Cancelo, Juan Estrada, Guillermo Fernandez-Moroni, Ricardo Piegaia, Matias Senger, Miguel Sofo Haro, et al. Absolute measurement of the fano factor using a skipper-ccd. *arXiv preprint arXiv:2004.11499*, 2020.
 - [191] D. Rosenberg, J. W. Harrington, P. R. Rice, et al. Long-distance decoy-state quantum key distribution in optical fiber. *Phys. Rev. Lett.*, 98:010503, 2007.
 - [192] J. Rothe, P. Angloher, G. Bauer, et al. TES-based light detectors for the CRESST direct dark matter search. *J Low Temp Phys*, 193:1160–1166, 2018.
 - [193] Carlo Rubbia. The liquid argon time projection chamber: a new concept for neutrino detectors. Technical report, CERN, 1977.
 - [194] T. Saab. *Searching for Weakly Interacting Particles with the Cryogenic Dark Matter Experiment*. PhD thesis, Stanford University, 2002.
 - [195] Ichitaro Saito, Wataru Miyazaki, Masanori Onishi, Yuki Kudo, Tomoaki Masuzawa, Takatoshi Yamada, Angel Koh, Daniel Chua, Kenichi Soga, Mauro Overend, Masami Aono, Gehan A. J. Amaralunga, and Ken Okano. A transparent ultraviolet triggered amorphous selenium p-n junction. *Applied Physics Letters*, 98(15):152102, 2011.
 - [196] Nigam Samantaray, Ivano Ruo-Berchera, Alice Meda, and Marco Genovese. Realization of the first sub-shot-noise wide field microscope. *Light: Science & Applications*, 6(7):e17005–e17005, 2017.
 - [197] V Saveliev and V Golovin. Silicon avalanche photodiodes on the base of metal-resistor-semiconductor (MRS) structures. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 442(1):223–229, 2000.
 - [198] Carmelo Scarella, Gianluca Boso, Alessandro Ruggeri, and Alberto Tosi. Ingaas/inp single-photon detector gated at 1.3 ghz with 1.5% afterpulsing. *IEEE Journal of selected topics in quantum electronics*, 21(3):17–22, 2014.
 - [199] Dennis R Schaart, Edoardo Charbon, Thomas Frach, and Volkmar Schulz. Advances in digital SiPMs and their application in biomedical imaging. *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, 809:31–52, 2016.
 - [200] David Schlegel, Juna A. Kollmeier, and Simone Ferraro. The MegaMapper: a $z > 2$ spectroscopic instrument for the study of Inflation and Dark Energy. In *Bulletin of the American Astronomical Society*, volume 51, page 229, September 2019.
 - [201] D. K. Schroder. A two-phase germanium charge-coupled device. *Applied Physics Letters*, 25:747, 1974.

- [202] Daniel R Schuette, Richard C Westhoff, Joseph S Ciampi, Gayatri E Perlin, Douglas J Young, Brian F Aull, Robert K Reich, and David C Shaver. Mbe back-illuminated silicon geiger-mode avalanche photodiodes for enhanced ultraviolet response. In *Advanced Photon Counting Techniques V*, volume 8033, page 80330D. International Society for Optics and Photonics, 2011.
- [203] M. H. Seaberg, B. Holladay, J. C. T. Lee, M. Sikorski, A. H. Reid, S. A. Montoya, G. L. Dakovski, J. D. Koralek, G. Coslovich, S. Moeller, W. F. Schlatter, R. Streubel, S. D. Kevan, P. Fischer, E. E. Fullerton, J. L. Turner, F.-J. Decker, S. K. Sinha, S. Roy, and J. J. Turner. Nanosecond x-ray photon correlation spectroscopy on magnetic skyrmions. *Phys. Rev. Lett.*, 119:067403, Aug 2017.
- [204] Hokuto Seo, Satoshi Aihara, Toshihisa Watabe, Hiroshi Ohtake, Misao Kubota, and Norifumi Egami. Color sensors with three vertically stacked organic photodetectors. *Japanese Journal of Applied Physics*, 46(No. 49):L1240–L1242, dec 2007.
- [205] L. Shen, M. Seaberg, E. Blackburn, and J. J. Turner. A snapshot review—fluctuations in quantum materials: from skyrmions to superconductivity. *MRS Advances*, 6(8):221–233, May 2021.
- [206] Fabio Signorelli, Fabio Telesca, Enrico Conca, Adriano Della Frera, Alessandro Ruggeri, Andrea Giudice, and Alberto Tosi. Low-noise ingaas/inp single-photon avalanche diodes for fiber-based and free-space applications. *IEEE Journal of Selected Topics in Quantum Electronics*, 28(2):1–10, 2021.
- [207] T.H.R. Skyrme. A unified field theory of mesons and baryons. *Nuclear Physics*, 31:556 – 569, 1962.
- [208] SONY. Sony develops next-generation back-illuminated CMOS image sensor which embodies the continuous evolution of the camera.
- [209] Konstantin D Stefanov, Martin J Prest, Mark Downing, Elizabeth George, Naidu Bezawada, and Andrew D Holland. Simulations and design of a single-photon cmos imaging pixel using multiple non-destructive signal sampling. *Sensors*, 20(7):2031, 2020.
- [210] S. M. Sze and Kwok K. NG. *Physics and Properties of Semiconductors*, chapter 1. John Wiley & Sons, Ltd, 2006.
- [211] P Szypryt, S R Meeker, G Coiffard, N Fruitwala, B Bumble, G Ulbricht, A B Walter, M Daal, C Bockstiegel, G Collura, N Zobrist, I Lipartito, and B A Mazin. Large-format platinum silicide microwave kinetic inductance detectors for optical to near-IR astronomy. *Optics Express*, 25(21):25894–25909, 2017.
- [212] Isamu Takai, Hiroyuki Matsubara, Mineki Soga, Mitsuhiro Ohta, Masaru Ogawa, and Tatsuya Yamashita. Single-photon avalanche diode with enhanced nir-sensitivity for automotive lidar systems. *Sensors*, 16(4):459, 2016.
- [213] Michael A Taylor and Warwick P Bowen. Quantum metrology and its application in biology. *Physics Reports*, 615:1–59, 2016.
- [214] Michael A Taylor, Jiri Janousek, Vincent Daria, Joachim Knittel, Boris Hage, Hans-A Bachor, and Warwick P Bowen. Biological measurement beyond the quantum limit. *Nature Photonics*, 7(3):229–233, 2013.
- [215] Excelitas Technologies. Spcm-aqrh. URL: <https://www.excelitas.com/product/spcm-aqrh>, March 2022.
- [216] Teledyne-DALSA. CCD foundry services. URL: <https://www.teledynedalsa.com/en/products/foundry/ccd/>, 2019.

- [217] The MSE Science Team, Carine Babusiaux, Maria Bergemann, Adam Burgasser, Sara Ellison, Daryl Haggard, Daniel Huber, Manoj Kaplinghat, Ting Li, Jennifer Marshall, Sarah Martell, Alan McConnachie, Will Percival, Aaron Robotham, Yue Shen, Sivarani Thirupathi, Kim-Vy Tran, Christophe Yeche, David Yong, Vardan Adibekyan, Victor Silva Aguirre, George Angelou, Martin Asplund, Michael Balogh, Projjwal Banerjee, Michele Bannister, Daniela Barría, Giuseppina Battaglia, Amelia Bayo, Keith Bechtol, Paul G. Beck, Timothy C. Beers, Earl P. Bellinger, Trystyn Berg, Joachim M. Bestenlehner, Maciej Bilicki, Bertram Bitsch, Joss Bland-Hawthorn, Adam S. Bolton, Alessandro Boselli, Jo Bovy, Angela Bragaglia, Derek Buzasi, Elisabetta Caffau, Jan Cami, Timothy Carleton, Luca Casagrande, Santi Cassisi, Márcio Catelan, Chihway Chang, Luca Cortese, Ivana Damjanov, Luke J. M. Davies, Richard de Grijs, Gisella de Rosa, Alis Deason, Paola di Matteo, Alex Drlica-Wagner, Denis Erkal, Ana Escorza, Laura Ferrarese, Scott W. Fleming, Andreu Font-Ribera, Ken Freeman, Boris T. Gänsicke, Maksim Gabdeev, Sarah Gallagher, Davide Gandolfi, Rafael A. García, Patrick Gaulme, Marla Geha, Mario Gennaro, Mark Gieles, Karoline Gilbert, Yjan Gordon, Aruna Goswami, Johnny P. Greco, Carl Grillmair, Guillaume Guiglion, Vincent Hénault-Brunet, Patrick Hall, Gerald Handler, Terese Hansen, Nimish Hathi, Despina Hatzidimitriou, Misha Haywood, Juan V. Hernández Santisteban, Lynne Hillenbrand, Andrew M. Hopkins, Cullan Howlett, Michael J. Hudson, Rodrigo Ibata, Dragana Ilić, Pascale Jablonka, Alexander Ji, Linhua Jiang, Stephanie Juneau, Amanda Karakas, Drisya Karinkuzhi, Stacy Y. Kim, Xu Kong, Iraklis Konstantopoulos, Jens-Kristian Krogager, Claudia Lagos, Rosine Lallement, Chervin Laporte, Yveline Lebreton, Khee-Gan Lee, Geraint F. Lewis, Sophia Lianou, Xin Liu, Nicolas Lodieu, Jon Loveday, Szabolcs Mészáros, Martin Makler, Yao-Yuan Mao, Danilo Marchesini, Nicolas Martin, Mario Mateo, Carl Melis, Thibault Merle, Andrea Miglio, Faizan Gohar Mohammad, Karan Molaverdikhani, Richard Monier, Thierry Morel, Benoit Mosser, David Nataf, Lina Necib, Hilding R. Neilson, Jeffrey A. Newman, A. M. Nierenberg, Brian Nord, Pasquier Noterdaeme, Chris O'Dea, Mahmoudreza Oshagh, Andrew B. Pace, Nathalie Palanque-Delabrouille, Gajendra Pandey, Laura C. Parker, Marcel S. Pawłowski, Annika H. G. Peter, Patrick Petitjean, Andreea Petric, Vinicius Placco, Luka Č. Popović, Adrian M. Price-Whelan, Andrej Prsa, Swara Ravindranath, R. Michael Rich, John Ruan, Jan Rybizki, Charli Sakari, Robyn E. Sanderson, Ricardo Schiavon, Carlo Schimd, Aldo Serenelli, Arnaud Siebert, Malgorzata Siudek, Rodolfo Smiljanic, Daniel Smith, Jennifer Sobeck, Else Starkenburg, Dennis Stello, Gyula M. Szabó, Robert Szabo, Matthew A. Taylor, Karun Thanjavur, Guillaume Thomas, Erik Tollerud, Silvia Toonen, Pier-Emmanuel Tremblay, Laurence Tresse, Maria Tsantaki, Marica Valentini, Sophie Van Eck, Andrei Variu, Kim Venn, Eva Villaver, Matthew G. Walker, Yiping Wang, Yuting Wang, Michael J. Wilson, Nicolas Wright, Siyi Xu, Mutlu Yıldız, Huawei Zhang, Konstanze Zwintz, Borja Anguiano, Megan Bedell, William Chaplin, Remo Collet, Jean-Charles Cuillandre, Pierre-Alain Duc, Nicolas Flagey, JJ Hermes, Alexis Hill, Devika Kamath, Mary Beth Laychak, Katarzyna Małek, Mark Marley, Andy Sheinis, Doug Simons, Sérgio G. Sousa, Kei Szeto, Yuan-Sen Ting, Simona Vegetti, Lisa Wells, Ferdinand Babas, Steve Bauman, Alessandro Bosselli, Pat Côté, Matthew Colless, Johan Comparat, Helene Courtois, David Crampton, Scott Croom, Luke Davies, Richard de Grijs, Kelly Denny, Daniel Devost, Paola di Matteo, Simon Driver, Mirian Fernandez-Lorenzo, Raja Guhathakurta, Zhanwen Han, Clare Higgs, Vanessa Hill, Kevin Ho, Andrew Hopkins, Mike Hudson, Rodrigo Ibata, Sidik Isani, Matt Jarvis, Andrew Johnson, Eric Jullo, Nick Kaiser, Jean-Paul Kneib, Jun Koda, George Koshy, Shan Mignot, Rick Murowinski, Jeff Newman, Adi Nusser, Anna Pancoast, Eric Peng, Celine Peroux, Christophe Pichon, Bianca Poggianti, Johan Richard, Derrick Salmon, Arnaud Seibert, Prajval Shastri, Dan Smith, Firoza Sutaria, Charling Tao, Edwar Taylor, Brent Tully, Ludovic van Waerbeke, Tom Vermeulen, Matthew Walker, Jon Willis, Chris Willot, and Kanoa Withington. The Detailed Science Case for the Maunakea Spectroscopic Explorer, 2019 edition. *arXiv e-prints*, page arXiv:1904.04907, Apr 2019.
- [218] G. S. Thekkadath, S. Sempere-Llagostera, B. A. Bell, et al. Single-shot discrimination of coherent states beyond the standard quantum limit. *Optics Letters*, 46(11):2565–2568, 2021.

- [219] Fiona Thorburn, Xin Yi, Zoë M Greener, Jaroslaw Kirdoda, Ross W Millar, Laura L Huddleston, Douglas J Paul, and Gerald S Boller. Ge-on-si single-photon avalanche diode detectors for short-wave infrared wavelengths. *Journal of Physics: Photonics*, 4(1):012001, 2021.
- [220] Javier Tiffenberg, Miguel Sofo-Haro, Alex Drlica-Wagner, Rouven Essig, Yann Guardincerri, Steve Holland, Tomer Volansky, and Tien-Tien Yu. Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD. *PRL*, 119(13):131802, Sep 2017.
- [221] Javier Tiffenberg, Miguel Sofo-Haro, Alex Drlica-Wagner, Rouven Essig, Yann Guardincerri, Steve Holland, Tomer Volansky, and Tien-Tien Yu. Single-Electron and Single-Photon Sensitivity with a Silicon Skipper CCD. *Phys. Rev. Lett.*, 119:131802, Sep 2017.
- [222] Steven Tingay. High-cadence optical transient searches using drift scan imaging I: Proof of concept with a pre-prototype system. *Publications of the Astronomical Society of Australia*, 37:e015, April 2020.
- [223] S. Tisa, F. Zappa, A. Tosi, and S. Cova. Electronics for single photon avalanche diode arrays. *Sensors and Actuators A: Physical*, 140(1):113–122, 2007.
- [224] Alberto Tosi, Adriano Della Frera, Andrea Bahgat Shehata, and Carmelo Scarella. Fully programmable single-photon detection module for ingaas/inp single-photon avalanche diodes with clean and sub-nanosecond gating transitions. *Review of Scientific Instruments*, 83(1):013104, 2012.
- [225] Frédéric Vachon, Samuel Parent, Frédéric Nolet, Henri Dautet, Jean-Francois Pratte, and Serge A Charlebois. Measuring count rates free from correlated noise in digital silicon photomultipliers. *Measurement Science and Technology*, 2020.
- [226] Frédéric Vachon. Conception de photodiodes à avalanche monophotonique sensibles aux photons ultraviolets pour les détecteurs de la physique des particules dans les gaz nobles liquéfiés. Master’s thesis, Université de Sherbrooke, Canada, May 2021. URL: <http://hdl.handle.net/11143/18350>.
- [227] S. Vasiukov, F. Chirossi, C. Braggio, G. Carugno, F. Moretti, E. Bourret, and S. Derenzo. GaAs as a bright cryogenic scintillator for the direct dark matter detection. 4 2019.
- [228] S Verghese, DM Cohen, EA Dauler, JP Donnelly, EK Duerr, SH Groves, PI Hopman, KE Jensen, Z-L Liau, LJ Mahoney, et al. Geiger-mode avalanche photodiodes for photon-counting communications. In *Digest of the LEOS Summer Topical Meetings, 2005.*, pages 15–16. IEEE, 2005.
- [229] Varun V Verma, Boris Korzh, Alexander B Walter, Adriana E Lita, Ryan M Briggs, Marco Colangelo, Yao Zhai, Emma E Wollman, Andrew D Beyer, Jason P Allmaras, Heli Vora, Di Zhu, Ekkehart Schmidt, Alexander G Kozorezov, Karl K Berggren, Richard P Mirin, Sae Woo Nam, and Matthew D Shaw. Single-photon detection in the mid-infrared up to $10 \mu\text{m}$ wavelength using tungsten silicide superconducting nanowire detectors. *APL Photonics*, 6:056101, 2021.
- [230] Peter Vines, Kateryna Kuzmenko, Jarosław Kirdoda, Derek Dumas, Muhammad M Mirza, Ross W Millar, Douglas J Paul, and Gerald S Boller. High performance planar germanium-on-silicon single-photon avalanche diode detectors. *Nature communications*, 10(1):1–9, 2019.
- [231] Alexander B Walter, Neelay Fruitwala, Sarah Steiger, John I III Bailey, Nicholas Zobrist, Noah Swimmer, Isabel Lipartito, Jennifer Pearl Smith, Seth R Meeker, Clint Bockstiegel, Grégoire Coiffard, Rupert Dodkins, Paul Szypryt, Kristina K Davis, Miguel Daal, Bruce Bumble, Giulia Collura, Olivier Guyon, Julien Lozi, Sébastien Vievard, Nemanja Jovanovic, Frantz Martinache, Thayne Currie, and Benjamin A Mazin. The MKID Exoplanet Camera for Subaru SCExAO. *Publications of the Astronomical Society of the Pacific*, 132(1):125005, December 2020.

- [232] G. Wang, C. L. Chang, M. Lisovenko, et al. Light dark matter detection with hydrogen-rich crystals and low-Tc TES detectors. *arXiv:2201.04219*, 2022.
- [233] Ryan E Warburton, Giuseppe Interomite, Maksym Myronov, Phil Allred, David R Leadley, Kevin Gallacher, Douglas J Paul, Neil J Pilgrim, Leon JM Lever, Zoran Ikonic, et al. Ge-on-si single-photon avalanche diode detectors: design, modeling, fabrication, and characterization at wavelengths 1310 and 1550 nm. *IEEE Transactions on Electron Devices*, 60(11):3807–3813, 2013.
- [234] D. Wei, J. Olaya, B. S. Karasik, et al. Ultrasensitive hot-electron nanobolometers for terahertz astrophysics. *Nature nanotechnology*, 3(8):496–500, 2008.
- [235] David S. Weiss and Martin Abkowitz. *Organic Photoconductors*, pages 1–1. Springer International Publishing, Cham, 2017.
- [236] W.J. Willis and V. Radeka. Liquid-argon ionization chambers as total-absorption detectors. *Nucl. Instrum. Meth.*, 120(2):221 – 236, 1974.
- [237] Emma E. Wollman, Varun B. Verma, Adriana E. Lita, William H. Farr, Matthew D. Shaw, Richard P. Mirin, and Sae Woo Nam. Kilopixel array of superconducting nanowire single-photon detectors. *Opt. Express*, 27(24):35279–35289, Nov 2019.
- [238] Emma E Wollman, Varun B Verma, Adriana E Lita, William H Farr, Matthew D Shaw, Richard P Mirin, and Sae Woo Nam. Kilopixel array of superconducting nanowire single-photon detectors. *Optics express*, 27(24):35279–35289, 2019.
- [239] V. Zabrodskii et al. SiPM prototype for direct VUV registration. *Nucl. Instrum. Meth.*, A787:348–352, 2015.
- [240] Franco Zappa, A Lacaita, Sergio Cova, and P Webb. Nanosecond single-photon timing with ingaas/inp photodiodes. *Optics letters*, 19(11):846–848, 1994.
- [241] Franco Zappa, P Lovati, and A Lacaita. Temperature dependence of electron and hole ionization coefficients in inp. In *Proceedings of 8th International Conference on Indium Phosphide and Related Materials*, pages 628–631. IEEE, 1996.
- [242] P. Zappa, M. Ghioni, S. Cova, L. Varisco, B. Sinnis, A. Morrison, and A. Mathewson. Integrated array of avalanche photodiodes for single-photon counting. In *27th european solid-state device research conference*, pages 600–603, Stuttgart, Germany, 1997.
- [243] Bo Zhao and Wei Zhao. Imaging performance of an amorphous selenium digital mammography detector in a breast tomosynthesis system. *Medical Physics*, 35(5):1978–1987, 2008.
- [244] Nicholas Zobrist, Byeong Ho Eom, Peter Day, Benjamin A Mazin, Seth R Meeker, Bruce Bumble, Henry G Leduc, Grégoire Coiffard, Paul Szypryt, Neelay Fruitwala, Isabel Lipartito, and Clint Bockstiegel. Wide-band parametric amplifier readout and resolution of optical microwave kinetic inductance detectors. *Applied Physics Letters*, 115(4):042601, July 2019.
- [245] Jonathan Asaadi et al. Photon counting from the vacuum ultraviolet to the short wavelength infrared using semiconductor and superconducting technologies. *arXiv preprint arXiv:2203.12542*, 2022.
- [246] Francesco Gramuglia et al. Sub-10 ps Minimum Ionizing Particle Detection with Geiger-Mode APDs. *arXiv preprint arXiv:2111.09998* , 2021.