Snowmass2021 - Letter of Interest

Development of R&D platform for astronomical instrumentation in visible and near-IR

Thematic Areas:

■ (CF4) Dark Energy and Cosmic Acceleration: The Modern Universe
■ (CF6) Dark Energy and Cosmic Acceleration: Complementarity of Probes and New Facilities
■ (IF2) Instrumentation Frontier: Photon Detectors

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Abstract: The next generation of astronomical instruments for cosmic surveys will require the development of new technology. Examples of such developments include novel sensors, mechanisms for multi-fiber positioning systems, and electronic readout systems. These efforts are often started at instrumentation development facilities that do not have a direct access to telescopes for on-sky testing. Recently, NOIRLab was formed by amalgamation of Gemini Observatory, NOAO, and Rubin Observatory, and part of its strategic vision is enabling breakthrough discoveries via collaborations with other institutions. The current letter describes the interest in establishing a partnership between National Physical Laboratories, Universities, and NOIRLab to accelerate on-sky testing of new technologies.

1 New technologies under development

This list identifies areas of mutual interest where collaboration would result in the advancement of technology and the application of that technology to provide mutual benefit to the partners. The technological areas listed below are currently areas of active investigation and development. Collaboration between the organizations would take advantage of the unique facilities and infrastructure of the collaborating partners.

Skipper-CCD

The main difference between conventional scientific CCDs and Skipper-CCDs lies in the non-destructive readout system of the latter, which allows to repeatedly measure the charge in each pixel. For uncorrelated samples, this capability results in the reduction of the readout noise in a factor equal to the square root of the number of samples[1]. This feature enhances the signal to noise ratio to the point of enabling the precise determination of the number of electrons in each pixel, which means that single photon counting is possible in the low energy region (optical and near-infrared). There is an ongoing R&D effort to implement skipper-CCDs in astronomical instruments.

Germanium CCD

Building CCDs on bulk germanium could realize all of the advantages of standard CCDs while covering an even broader spectral range, notably including the short-wave infrared (SWIR) and hard X-ray bands. There is an ongoing effort to develop these sensors at MIT Lincoln Laboratory[2] and LBNL[3].

CMOS imagers

Over the last years the performance of CMOS imaging sensors has been improving constantly. Mainly due to the introduction of back-side illuminated CMOS devices of scientific grade these detectors are now competing with traditional CCDs in areas of low noise and low signal applications. One of the big advantages of CMOS over CCDS is the extremely high frame rate that can be achieved, being very well suited for high time resolution applications. But the CMOS technology keeps evolving, and through careful testing of new incoming devices it would be possible to enable more and newer astronomical applications in VIS and NIR bands.

Kinetic Inductance Detectors

Optical and IR Kinetic Inductance Detectors (KIDs) are superconducting photon counting detectors capable of measuring the energy and arrival time of photons without read noise or dark current. These sensors are already being implemented in some astronomical instruments[4] and have been identified as a very promising technology for future cosmic surveys. Significant R&D is still required to reach the full potential of this technology.

Superconduting nanowires single photon detectors (SNSPD)

SNSPDs are among the highest-performing photon counters in terms of efficiency, speed, dark counts, and range of wavelength sensitivity. These sensors are the detector of choise for several quantum information science applications. More recently the scientific community is considering taking advantage of SNSPDs' in astronomy, where large arrays of time-resolved single-photon detectors in the optical and near-IR are currently lacking.[5]. Astronomical applications can certainly take advantage of the SNSPD ultra-low dark count rates - which can be below 10-4 counts/s - and their sensitivity to mid-infrared wavelengths. These devices offer high-efficiency single photon detection of low-flux signals.

Multi fiber positioners

The unique qualities of optical fibers makes them extremely important in many fields of modern astronomical observation. One of the most widely used applications is as optical feeds on multi-object spectroscopy instrumentation. The massive number of fibers used by latest-generation spectrographs like DESI present a real challenge to the mechanics, control electronics and software involved in manipulating them. Problems involving robot geometries, the cost and limits to the number of fibers, serial and/or parallel positioning, clustering, adaptation to curved surfaces, etc. require ongoing investigation and design effort to solve for future instrumentation. Having the facility and opportunity of testing these mechanism on the sky is of great value to validate and improve novel designs in both software and hardware.

Readout electronics

The volume and velocity of pixel data collected in cameras used for particle physics experiments and astronomical observations is ever increasing. The newer generations of giant, mega-pixel instrumentation presents an ongoing challenge for the readout electronics used in the instrumentation in terms of the number of channels, power dissipation, the readout speed, and the noise and stability of the data. These factors directly affect the scientific gains obtained from the data due to the performance of the cameras. From both, massive multi-channel external camera electronics to individual, per-detector integrated circuits - including hybrids of both - are being continuously designed, produced and tested to meet these challenges. The ability to perform on-sky testing not only enables the validation of the detector technology itself, but also of novel readout and control electronics designed for newer generations of instruments and experiments. The application of these novel electronic designs for cameras and detectors is a common area to both particle physics experiments and to astronomical applications.

2 NOIRLab

NSF's NOIRLab (formally named the National Optical-Infrared Astronomy Research Laboratory) is the preeminent US national center for ground-based, nighttime optical and infrared astronomy. The mission of NOIRLab is to enable breakthrough discoveries in astrophysics by developing and operating state-of-the-art ground-based observatories

Through its five programs — Cerro Tololo Inter-American Observatory (CTIO), the Community Science and Data Center (CSDC), Gemini Observatory, Kitt Peak National Observatory (KPNO) and the Vera C. Rubin Observatory once operational — NOIRLab serves as a focal point for community development of innovative scientific programs, the exchange of ideas, and creative development. The lab's infrastructure enables the astronomy community to advance humanity's understanding of the Universe by exploring significant areas of astrophysics, including dark energy and dark matter, galaxies and quasars, the Milky Way, exoplanets, and small bodies in our own Solar System.

In collaboration with the astronomical community, partner organizations, other US optical and infrared system operators, and NSF, NOIRLab develops and advances a strategic vision for NSF-funded future optical and infrared facilities.

NOIRLab has world-class facilities (mechanical shops, electronics, optical and detector labs) and very experienced professionals with a long history on instrument development, so it is an institutions well-placed to make a strong contribution to joint instrumentation projects.

3 Collaboration Plan

TBD later in white paper

References

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