

GigaCAM: A One Billion Pixel Imager for the SNAP Satellite

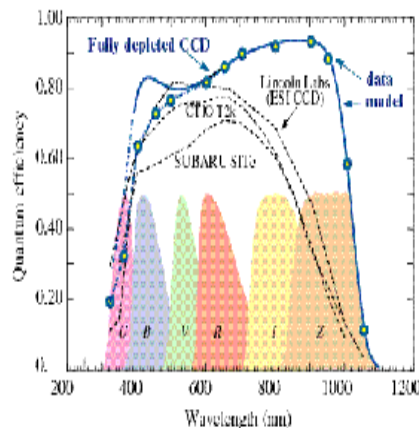
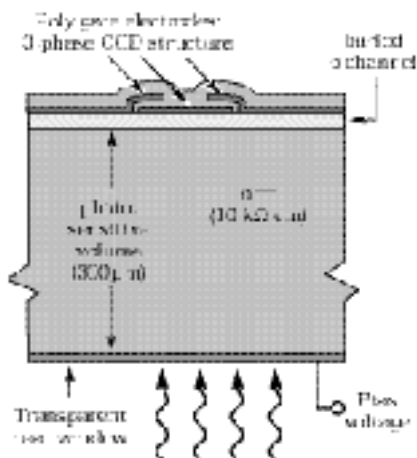
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Overview

Based on a radiation tolerant, fully-depleted, high-resistivity CCD technology, a one billion pixel imager is envisioned for the Supernova Acceleration Probe (SNAP) satellite currently in early planning [SNAP 2000]. The imager is comprised of over one hundred large format CCD's at the focal plane of a ~2-meter telescope. The diffraction-limited optics is achieved with a three-mirror anastigmat and provides a 1-square degree field of view. With a complimentary small near-IR imager and visible and near-IR spectrographs, the SNAP mission can discover over 2000 Type Ia supernovae in a year at redshifts between $z=0.1$ and 1.7, and follow their evolution with high-signal-to-noise light-curves and spectra. The resulting data set can determine the cosmological parameters with precision: mass density W_M to ± 0.02 , vacuum energy density W_L to ± 0.05 , and curvature W_k to ± 0.06 . The data set can test the nature of the "dark energy" that is apparently accelerating the expansion of the universe. In particular, a cosmological constant can be differentiated from alternatives such as "quintessence" by measuring the ratio of the dark energy pressure and density to 0.05, and by studying this ratio's time dependence. A large field imager based on CCD technology fulfills the requirement for supernova detection and photometry.

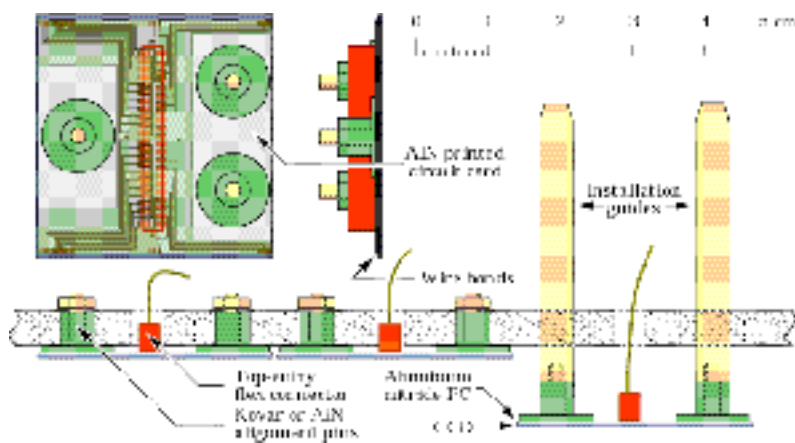
CCD's

We have successfully developed a new type of large-format CCD's on n-type high-resistivity silicon. The back-illuminated CCD's are fabricated on a 300 mm thick substrate and are fully depleted by the application of an independent voltage through an optically transparent backside contact (see [Figure 1](#)). Multiple science-grade 2k x 2k pixel (15 mm^2 pixels) CCD's have been fabricated and tested. Furthermore, devices on these wafers have shown excellent charge transfer efficiency CTE >0.999995 , read noise of $4.3e^-$, dark current of $0.003 e^-/\text{pixel}/s$, and a well depth of $300,000 e^-$. With back illumination, the QE at 1 μm is 65% (at $T=150 \text{ K}$). As shown in [Figure 2](#), commercially available CCD's with proper coatings reach 15% or less at 1000 nm at this temperature. Early measurements indicate that as expected [J. Janesick] this technology results in significantly improved radiation tolerance of the CCD. For long duration missions this could prove to be a major benefit. These are major achievements in the development of n-type high-resistivity CCD's [Groom 1999; Holland 1996, 1997, 1997, 2000; Stover 1997; 1998].



[Figure 1.](#)[Figure 2.](#)

The CCD's are self-supporting since the devices do not need to be thinned. This allows for four-sided abutment making these CCD's ideal for a wide-field mosaic array. In a packaging scheme under consideration, the edges cantilever from a 3-layer aluminum oxide structure. The first is a thin insulating layer cemented to the front of the CCD. The second is a ceramic circuit board with edge pads to which the CCD pads are wire-bonded. The traces go to a center miniature connector through which wiring is brought out perpendicular to the CCD package and through the cold plate. The third layer is an additional insulator that also captures three indexing pins. Screw-on extensions facilitate installation and removal without hitting adjacent CCD's. Four-side abutability and a certain amount of assembly jiggling are therefore automatic. This scheme is shown in [Figure 3.](#)

[Figure 3.](#)

A space-based wide-field imager taking advantage of the 4-side abutment would require much smaller

pixel sizes than ground based telescopes for reasonable cost and weight of the optics. In this context, we currently have in fabrication large-format, smaller pixel size (10.5 mm and 12 mm) devices, and we are exploring lightweight, four-side abutment packaging technologies.

The SNAP Optical Imager, GigaCAM

A key technological innovation in the SNAP instrumentation is a large one billion pixel camera, GigaCAM. In order to maximize the sensitivity of SNAP to discover high redshift supernova this camera requires excellent sensitivity in the I and Z optical bands. The pixel size is chosen to be as low as attainable in science grade imagers to minimize the overall size of the device. The spatial sampling of approximately one pixel per Airy disk FWHM is sufficient to ensure accurate photometry. The high-resistivity, p-channel CCD technology provides high quantum efficiency at 1 mm since the fully-depleted devices are 300 mm thick and back-illuminated. The longest single exposure is set by cosmic ray contamination, approximately 400 to 1000 sec. Up to 24 multiple frames would be stacked and cleaned of cosmic rays prior. The longest aggregated exposure in the imager is four hours. For the parameters given in Table 1, which assumes a 2 meter primary mirror, the imager sensitivity is limited only by zodiacal light background. A possible deployment of CCD's to cover the $1^\circ \times 1^\circ$ field of view is shown in [Figure 4](#) and the location of the imager in satellite telescope is shown in [Figure 5.](#)

Table 1. Optical Imager/Photometer requirements.

Field-of-view	$1^\circ \times 1^\circ$
Plate scale	$\sim 10 \text{ mm} / 0.1 \text{ arcsec}$
Pixelization	128 CCD mosaic
Wavelength coverage	350 nm to 1000 nm
Detector type	High-resistivity, p-channel CCD's
Detector architecture	3k x 3k, 10.5 micron pixel

Detector array temperature	150 K
Quantum efficiency	65% @ 1000nm, 92% @ 900nm, >85% @ 400-800nm
Photometric accuracy	3% relative
Read noise	4 e ⁻ @100kHz
Exposure time	1 sec to 1000 sec (single exposures)
Number of frames	1 to 24
Dark current	0.08 e ⁻ /min/pixel
Readout time	20 sec
Limiting magnitude sensitivity	30th AB magnitude in Z-band
Exposure control	Mechanical shutter
Filter wheel	15 bands (U, V, R, I, Z, 10 special filters)

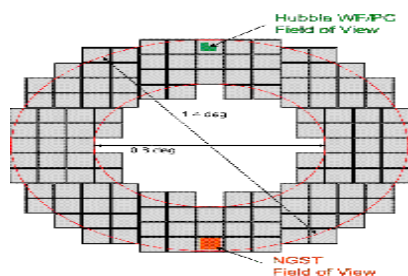


Figure 4.

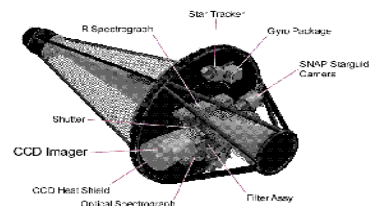


Figure 5.

Detection of supernovae is accomplished by a repeated comparison of fixed fields to reference images. The imager would obtain twenty discovery fields from dark regions around the north and south ecliptic poles. These discovery fields would have a limiting detection magnitude of $m_{AB}(1\text{mm}) < 27$. This set of discovery fields would be recorded at intervals of four days. At six day intervals detection fields would be obtained to a limiting magnitude of $m_{AB}(1\text{mm}) < 28$. At eight day intervals detection fields would be obtained to a limiting magnitude of $m_{AB}(1\text{mm}) < 28.5$. Two of these fields would have a limiting detection magnitude of $m_{AB}(1\text{mm}) < 30$ taken every eight days. This strategy is summarized in Table 2 below. For this baseline study we considered a Z-band search; higher signal-to-noise may be achieved by combining the data from several filters. These images represent the majority of the data to be transmitted. We do however expect to use follow-up images as search images as well, thereby consolidating much of the data taking and transfer.

Table 2. Observation strategy

AB mag. B-band restframe	SN flux [e ⁻ /s]	Zodiacal Light [e ⁻ /s]	Total Time [hrs]	Filter Fields	Repeat Interval [days]
27.0	0.4	0.27	0.1	Z-band	4
28.0	0.16	0.27	0.2	Z-band	6
28.5	0.06	0.27	0.3	Z-band	8
30.0	0.03	0.27	4.6	Z-band	8

The follow-up optical photometry is obtained without specific knowledge of the location of new supernovae. The optical photometer obtains wide-field frames overlapping the positions of the discovery frames. Some of the photometry frames may be taken while the satellite is taking spectra of specific supernovae. The photometer obtains frames in each of a specified list of redshifted B-band filters with exposures of sufficient

duration to obtain all the data points required to reconstruct the light curve. These total exposures will be comprised of numerous shorter exposures. These shorter exposures will be taken in dithered groups, allowing elimination of cosmic-rays without resampling of the image, while providing the subpixel offsets desirable for using resolution enhancing techniques such as DRIZZLE [Fruchter 1998] and averaging over any residual intrapixel sensitivity variations. The photometry is also obtained at regular intervals in order to obtain data points that reasonably approximate the required ten photometric points along the light curve. The B-band photometry is divided into ranges of redshift for photometry in a specific filter.

Acknowledgements

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