

Space Astrophysics Detectors and Detector Technologies

Contributed Posters (close to final)

Poster - A Wide Energy Band Compound Pixelated Photon Detector

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We present a new concept of a stacked detector that provides high spectral resolution over a wide energy band (KeV-MeV). The concept is to use detectors of appropriate energy band width to avoid saturation effects of single detectors normally used. For the energy range from sub KeV to 20 KeV we use silicon PIN detectors. To cover energies from 20 KeV to 60 KeV we use a 2-mm-thick CZT detector beneath the "SI" PIN detector. To extend the energy range above 60 KeV we incorporate another 5-mm-thick CZT. To achieve the response to MeV photons we incorporate a 2-cm-thick scintillator viewed by a PIN photo diode as the last element of the stack. The significant advantages of this concept over a single detector would be (1) charge particle rejection capability, (2) low internal noise, and (3) identification of Compton interactions.

Poster - A High-Efficiency, Multiple-Scatter Compton Telescope

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B.F. Philips and E. Wulf, George Mason Univ.

A high resolution Compton telescope has been identified by NASA's Gamma Ray Astronomy Program Working Group (GRAPWG) as the highest priority major mission in gamma ray astrophysics following GLAST. A target sensitivity of $\sim 2 \times 10^{-7} \text{ g cm}^{-2}\text{s}^{-1}$ for narrow lines from discrete sources has been established. This would provide 25-100 times improved sensitivity, relative to CGRO and INTEGRAL. Several instrumental concepts are being pursued to achieve these goals. An approach being investigated at NRL is the development and use of position-sensitive solid-state detectors (Ge, Si) for a high spectral resolution Compton telescope mission. We have shown that with only two Compton scatter interactions followed by a third interaction, the incident gamma ray energy and direction cone can be precisely determined in detectors with excellent energy and position resolution. Full energy deposition is not required. This technique enables the design for a high-efficiency Compton instrument that should meet the required sensitivities. Since only Compton interactions are required, thick silicon strip or pixel detectors are options for the detectors.

Poster - The Joule X-Ray Mission

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We have proposed the Joule x-ray astronomy mission, an orbiting observatory for high resolution x-ray spectroscopy. It is capable of addressing fundamental questions on the origin and evolution of large scale structure in the universe, life cycles of cosmic matter, and the strong gravity very near black holes. To achieve these goals, a high sensitivity, non-dispersive x-ray spectrometer with a resolution of $< 12 \text{ eV}$ is employed based on a 32 pixel

array of x-ray microcalorimeters. The high sensitivity is achieved with focusing x-ray optics based on conical-approximation foils with smooth replicated surfaces. Using an advanced cryogenic design, a mission duration of at least two years can be obtained within the SMEX envelop. The energy resolution required to address a broad range of topics is ~ 12 eV, but improvements in device fabrication could allow a resolution of ~ 6 eV to be achieved. Such a resolution would almost fully resolve the H- and He-like transitions of iron (6-7 keV) and allow emission characteristics and dynamical information to be obtained with extraordinary detail. The non-dispersive principle of the microcalorimeter allows this spectral resolving power to be readily applied to extended sources. Implementing high resolution spectroscopy out beyond 6 keV makes Joule fully complimentary to the Chandra and XMM-Newton missions, and it could be developed rapidly enough to allow simultaneous use with these observatories. The overall Joule mission is designed to support a full guest investigator program.

Poster - Development of Cryogenic Detectors for UV, X-Ray and Gamma-Ray Astronomy at LLNL.

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Our group is working on the development of STJ (superconducting tunnel junction) and TES (transition edge sensors) based cryogenic detectors which have shown better energy resolution than semiconductor detectors. Our STJ-based detectors have energy resolution between 1.7 and 8.9 eV FWHM for X-ray energies between 0.05 and 1 keV at low count rate. We have also demonstrated 8.2 eV FWHM at a rate of 20,000 counts/sec and 43eV FWHM at 55,000 counts/sec at 277eV (carbon K). For hard x-ray and gamma-ray spectroscopy we developed a detector based on Mo/Cu multi-layer TES with Sn absorber. The performance of this detector is also discussed.

This work was performed under the auspices of the U.S. Department of Energy by University of California Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48 and supported by the NASA UV Detector Development Program grant NAG5-4137, by NASA Innovative Research Program contract W-18,868, and by the NASA High Energy Astrophysics Supporting Research and Technology Program contract W-19,121.

Poster - B-MINE - The Balloon-Borne Microcalorimeter Nuclear Line Explorer Mission

S.R. Bandler: for the B-MINE team, Smithsonian Astrophysical Observatory, Ball Aerospace & Technologies Corp., Lawrence Berkeley National Laboratory, University of California at Berkeley, Osservatorio Astronomico G.S., Vaiana Danish Space Research Institute, George C. Marshall Space Flight Center, University of California at Santa Cruz, Max-Planck-Institut fuer Extraterrestrische Physik, Brown University, & Univeridad de Valencia INTA/Laboratotio De Astrofisica Espacial Y Fisica Fundamental

The Balloon-borne Microcalorimeter Nuclear Line Explorer (B-MINE) brings together the advantages of a microcalorimeter array and focussing optics to the field of nuclear line emission astrophysics. This provides a substantial advance in line detection and spectroscopy capabilities. The primary science goal for B-MINE is to probe the deepest regions of a Supernova Explosion by detecting ^{44}Ti emission at 68 keV with sufficient spatial and spectral resolution to determine the extent and the velocity distribution of the Ti emitting region. Because of the concentrating power of a specifically tuned multilayered foil telescope, the active X-ray detector is very small in volume. Thus, the non-X-ray background is almost three orders of magnitude less than typically achieved in this energy range. The 3 sigma sensitivity at 68 keV is 3.3×10^{-7} ph cm⁻² s⁻¹. With a 20x20 array of microcalorimeter detectors having ~ 50 eV energy resolution we will carry out a detailed spectroscopic study of the CAS A ^{44}Ti line centroid and width in a Long Duration Balloon flight. As a secondary goal, we will study the cyclotron resonance features observed in Her X-1 around 40 keV.

Poster - New Results for the CZT drift strip Detector

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A technique -the so-called drift strip method - for improving the CdZnTe (CZT) detector energy response to hard X-ray and gamma ray is discussed. Results obtained with a 10x10x3 mm³ CZT detector demonstrated a remarkable improvement of the detector energy resolution by the method. Resolutions (FWHM) of 2.18 keV and 2.86 keV at 60 keV and 356 keV, respectively, were achieved. The energy resolution was electronic noise limited for energies below 100 keV

Poster - Development of Close-packed Microcalorimeter Arrays using Molybdenum-Gold Transition-Edge Sensors with Bismuth Absorbers

Nilesh Tralshawala, Mary Li, Carl Stahle, Code 553 NASA/GSFC

Regis Brekosky, Enectali Figueroa-Feliciano, Fred Finkbeiner, Caroline Stahle, Code 662 NASA/GSFC

We have fabricated single pixel superconducting transition edge sensors (TES) with resolution of 3 eV FWHM at 1.5 keV and 3.7 eV FWHM at 3.3 keV. Each pixel comprises a Mo/Au superconducting proximity effect bilayer on a 0.5 micron thick silicon nitride membrane. Independently, we have also successfully fabricated 10 micron thick bismuth absorbers that are designed to overhang the thermal isolation and wiring channels between sensors. This step will allow us to engineer arrays with better than 96% focal plane coverage for x-ray detection. Effort is underway to put these absorbers directly on the Mo/Au bilayers. We will discuss our design and fabrication schemes for making 2-d arrays of x-ray microcalorimeters suitable for the high resolution x-ray spectrometer on the Constellation-X mission.

Poster - Mo/Au TES X-ray Calorimeters with 3.7 eV Resolution at 3.3 keV

Enectali Figueroa-Feliciano, Caroline Stahle, Fred Finkbeiner, Richard Kelley, Mark Lindeman, Scott Porter, Code 662 NASA/GSFC

Nilesh Tralshawala, Mary Li, Carl Stahle, Code 553 NASA/GSFC

We present the latest results of our development of high resolution Mo/Au transition edge sensor (TES) calorimeters. Each calorimeter consists of a molybdenum and gold bilayer with a superconducting transition at 100 mK. The film is suspended on a nitride membrane which provides thermal decoupling from our dilution refrigerator operating at 50 mK. A SQUID array is used to measure the change in current in the device, which is voltage biased in its transition. We achieved a resolution of 3.7 eV FWHM at 3.3 keV. We have mapped the I-V characteristics as well as noise at different biases and temperatures. We will discuss our findings and future directions in this effort.

Poster - Improvements in Semiconductor Thermistor Calorimeters

In addition to investigating other thermometry techniques, the micro-calorimeter effort at GSFC and the University of Wisconsin has been pursuing improvements to the "proven" technology of micromachined silicon devices with ion-implanted, semiconductor thermistors. With hopes of improving noise performance, we are trying to increase the volumes of our thermistors, without appreciably increasing the surface areas. We will present noise measurements from some thermistors produced using diffusion to distribute the dopants across the depth of a silicon-on-insulator substrate. We plan on combining these thermistors with more robust array structures, made possible by replacing the previously used "wet" micromachining based fabrication with "dry" reactive ion etching. In our previous designs, the layer of material to absorb the xrays and to thermalize their energy was placed on the micromachined structures manually. We will describe our work to develop fabrication techniques to deposit and to form the xray absorbers directly on the silicon.

Poster - X-Ray Microcalorimeter Signal Processing System

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Extracting the best possible energy estimate from X-ray microcalorimeters requires using all the signal power available while minimizing sensitivity to whatever noise is present. The best possible estimate is provided by an optimal filter. However, the filter must be matched to the system noise, which may change after severe events such as a spacecraft launch. We describe an optimal filter system with in-situ template generation. An analog subsystem provides bias and power for the detectors and amplifies the detector signals by a factor of 20,000. A digital processor detects X-ray pulses and determines an estimate of their pulse heights by optimal filtering. The optimal filter templates are generated autonomously by determining the average noise spectrum and average pulse shape, allowing the system to adapt to varying noise conditions without any hardware adjustments. We describe the operations of pulse detection, pulse height analysis, and risetime determination. We have implemented this system in a flight-ready form, and it was part of the XRS instrument aboard Astro-E. This basic method is also applicable to future missions with higher resolution and throughput, and to other forms of microcalorimeters.

Poster - Laboratory Astrophysics using an XRS Microcalorimeter

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The XRS instrument on Astro-E was the first fully self-contained microcalorimeter instrument capable of acquiring, optimally filtering, and characterizing events for 32 independent pixels. We have now integrated a full engineering model detector system into a laboratory cryostat for use on the electron beam ion trap (EBIT) at Lawrence Livermore National Laboratory. The detector system contains a microcalorimeter array with 32 instrumented pixels heat sunk to 60 mK using an adiabatic demagnetization refrigerator. The instrument has a composite resolution of 8 eV at 1 keV and 12 eV at 6 keV with a minimum of 95% quantum efficiency. This will allow high spectral resolution, broadband observations of collisionally excited plasmas that are produced in the EBIT experiment. Unique to our instrument are exceptionally well characterized 1000 Angstrom thick aluminum on polyimide infrared blocking filters. The detailed transmission function including the edge fine structure of these filter has been measured in our laboratory using a variable spaced grating spectrometer. This will allow the instrument to perform absolute, broadband flux measurements with the EBIT instrument, yielding precise line strength ratios from astrophysically interesting plasmas. The instrument performance and calibration will be discussed as well as the planned July, 2000 measurement campaign. This work performed under the auspices of the U.S. D.o.E. by Lawrence Livermore National Laboratory under contract W-7405-ENG-48 and was supported by the NASA High Energy Astrophysics Supporting Research and Technology Program.

Poster - Laboratory Astrophysics Survey Of Key X-Ray Diagnostic Lines Using A Microcalorimeter On An Electron Beam Ion Trap

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Cosmic plasma conditions created in an Electron Beam Ion Trap (EBIT) make it possible to simulate the dependencies of key diagnostic X-Ray lines on density, temperature, and excitation conditions that exist in astrophysical sources. We used a microcalorimeter for such laboratory astrophysics studies because it has a resolving power greater than 1000, quantum efficiency approaching 100% and a bandwidth that spans the X-Ray energies from 0.2 keV-10 keV. Our microcalorimeter provides a significant new capability for laboratory astrophysics measurements. Broad band spectra obtained from the NIST EBIT with an energy resolution approaching that of a Bragg crystal spectrometer are presented for iron nitrogen, oxygen, neon, argon and krypton in various stages of ionization. We have compared the measured line intensities to theoretical predictions for an EBIT plasma.

Poster - Narrow Band Tunable Filters for use in the 1000 - 1500 Å region

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We present results from a research program that exploits a novel technique in the construction of high throughput, tunable, narrow-band (FWHM $\sim 20\text{\AA}$) isolation filters for use in astronomical imaging in the far ultraviolet region (1000Å - 1500Å). This technique utilizes a well-understood, but as yet unexploited, property of halide crystals (such as BaF₂, CaF₂ and LiF) in that their UV transmission varies with temperature. We present measurements of a FUV filter that is capable of high resolution imaging with a variable FUV band-width and a variable central wavelength.

Poster - Compact Imaging Spectrometers using Acousto-Optic Tunable Filters

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We describe planetary science observations made with the Goddard Space Flight Center, acousto-optic tunable filter (AOTF) cameras. This technology is a newly developed RF-tunable spectrophotometric imager. The visible-wavelength camera has a spectral bandwidth of 25 cm⁻¹ and a tuning range from 0.5 to 1.0 micron. The observations that we report here were made at the Starfire Optical Range 1.5-meter laser-beacon adaptive optics telescope facility. Observations of Jupiter and Saturn are reported. The superior spectral resolution of the AOTF camera was exploited to image these objects both in and out of molecular absorption bands, allowing us to sound to different depths in their respective atmospheres. The Jupiter and some of the Saturn observations were made during the Comet Shoemaker-Levy 9 collisions in July 1994. Saturn (and Titan) was observed again in September 1995. The enhanced spatial resolution offered by the adaptive optics facility allowed us to observe cloud and storm

activity in the atmospheres of Jupiter and Saturn that are not normally observable with conventional ground-based telescopes. Our near-IR AOTF camera operates in the 1.7-3.4 micron region. We used this camera to obtain near-IR spectral image sets of Mars over the 1.6-3.6 micron region during the April 1999 opposition. A complete image set consisted of 280 images with a spectral full-width-half-maximum of 10 wavenumber (fixed in frequency), 90 images in H-band (1.55-1.80 micron), 115 images in K-band (1.95-2.50 micron) and 75 images in L-band (2.90-3.70 micron). The short-wavelength limit is set by transmission of AOTF cell and long-wavelength limit is imposed by sensitivity of PICNIC, 256x256, HgCdTe array detector. Our newest camera which we are completing this summer (2000) will extend the spectral range over 2.5-5.2 micron. We will discuss the new array performance and provide preliminary interpretations of some of these results

Poster - Development of Epitaxial AlN/GaN/InGaN Photocathode Heterostructures for UV/Blue Scintillation and Cherenkov Radiation Detection

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The need for extending the sensitivity of photon detectors to the blue and UV wavebands comes from the fact that both Cherenkov light and scintillation light typically have an emission spectrum which is peaked at short wavelengths. Photocathode layers consisting of wide-band-gap AlN/GaN/InGaN heterostructures are being compositionally tailored on an atomic scale during the epitaxial crystal growth process to control photoelectron absorption, diffusion, and transport to the negative electron affinity cathode surface. These nitride alloy heterostructure layers are being grown directly on transparent single crystal sapphire substrates in ultra high vacuum by molecular beam epitaxy. This technology is expected to significantly enhance UV/Blue radiation detection sensitivity in single photon counting imaging and non-imaging devices.

Poster - 256 by 256 GaN Ultraviolet Imaging Array

Brent Mott, GSFC

Poster - Microchannel plate based photon counting detector system development for UV astronomy at NASA/GSFC,

Timothy Norton, Raytheon, NASA/GSFC

Visible and solar blind UV detectors based on metal oxide materials

Wei Yang, College Park, Maryland

Poster - Radiation Testing of Marconi CCDs for Wide Field Camera 3

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Laura Cawley, Space Telescope Science Institute, Baltimore, MD

Robert J. Hill, Raytheon ITSS/NASA GSFC, Greenbelt, MD

Scott D. Johnson & Gregory S. Delo, Global Science & Technology/NASA GSFC, Greenbelt, MD

The Wide Field Camera 3 (WFC3) is designed to have a UVIS channel, which will acquire images in the

Near-UV/Visible (200 to 1000 nm) spectral range with a high sensitivity and with a large (160 arcsec) field of view (FOV). The GSFC Detector Characterization Laboratory (DCL) has tested two large format Marconi CCD44 devices. These devices are 2k x 4k, backside illuminated CCDs with 15 micron pixels. Both devices performed extremely well prior to irradiation. The CTE was measured using ^{55}Fe , resulting in a parallel CTE of $.999997 \pm 1.0 \times 10^{-6}$, and a serial CTE of $.999998 \pm 1.0 \times 10^{-6}$. The readout noise was measured at a very low 2.1-2.3 electrons/pixel/readout. Dark current was well within the project performance requirements of less than 20 electrons/pixel/hour.

The devices were irradiated with the equivalent of 1 year of orbit proton damage. The post-radiation results showed normal deterioration of the CTE in both devices; the parallel CTE of $.999962 \pm 5.0 \times 10^{-6}$, and a serial CTE of $.999992 \pm 5.0 \times 10^{-6}$ are well within the expected range. The readout noise did not change, and dark current was again well within project requirements. A description of the experiment and data analysis, including the determination of CTE, readout noise, and dark current, and detailed results are provided.

Poster - Optical/UV Single Photon Imaging Spectrometers Using Superconducting Tunnel Junctions

C.M. Wilson, L. Frunzio, L. Li, K. Segall, D.E. Prober, Yale University

B. Mazin, D. Schiminovich, C. Martin, California Institute of Technology

R. Vasquez, NASA JPL

We present preliminary test results of optical/UV single photon imaging spectrometers using superconducting tunnel junctions. The detectors also have high quantum efficiency. Our devices utilize a lateral trapping geometry. Photons are absorbed in a Ta thin film, creating excess quasiparticles. Quasiparticles diffuse and are trapped by Al/Al-Ox/Al tunnel junctions located on the sides of the absorber. The Ta/Al interface does not overlap the junction area. Imaging devices have tunnel junctions on two opposite sides of the absorber. Position information is obtained from the fraction of charge collected in each junction. We have fabricated high quality junctions with a ratio of sub-gap resistance to normal state resistance greater than 100,000 at 0.22 K. We also find good material properties including quasiparticle lifetimes of 450 and 160 microseconds for Ta and Al respectively. The long Al lifetime gives the devices a tunneling multiplication of order 50. We have measured the single photon response of our devices. We have found an energy resolution of 0.4 eV (21 nm) FWHM. This corresponds to a resolving power of 12 at 4.89 eV (254 nm) and 5.7 at 2.27 eV (546 nm).

Poster - GigaCAM: A One Billion Pixel Imager for the SNAP satellite

Michael Levi, LBNL

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. The imager is comprised of over one hundred large format CCDs 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 (Ω_M) to ± 0.02 , vacuum energy density (Ω_L) to ± 0.05 , and curvature (Ω_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's pressure to its density to ± 0.05 , and by studying this ratio's time dependence.

SNAP Collaboration: G. Aldering, W. Edwards, B. Frye, D. Groom, S. Holland, D. Kasen, R. Knop, R. Lafever, M.

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Poster - Development of a Hybrid CMOS Visible Focal Plane Array for Space Based Applications

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Rockwell Science Center is developing a hybrid CMOS visible focal plane array (FPA) technology for high-end scientific applications that require a broad band spectral response, high quantum efficiency, high speed, low noise, highly-integrated functionality and radiation hardness. As a high performance alternative to advanced monolithic detector arrays, such as CCD and APS, the hybrid design enables independent optimizations of the detector array and readout electronics. It also offers an attractive readout commonality with the instrument's IR channels for integrators of sensor suites such as for hyperspectral spectrometers. In this presentation, the development of Rockwell's CMOS-based hybrid visible FPAs are described, including key detector performance aspects, interface electronics requirements, radiation hardness and concomitant implications for space applications. We will present the latest results of large format hybrid focal plane arrays with ~100% optical fill factor, high broadband QE spanning ultraviolet (UV) through near infrared (NIR), wide dynamic range, and high pixel operability. Specifically, dark current of $\sim 0.01 e^-/\text{sec}$ and read noise $\sim 6e^-$ have been measured on a 1024x1024 FPA that uses Hawaii readout integrated circuit. Initial radiation data indicate a total ionization dose (TID) tolerance greater than 35Krad for our standard CMOS process.

Poster - Dark current measurements on a state of the art near-IR HgCdTe 1024x1024 array

Scott D. Johnson, Elizabeth Polidan, Augustyn Waczynski, Robert J. Hill, Gregory S. Delo, GSFC,

Massimo Robberto, Carey M. Lisse, and Laura Cawley, STScI

The NASA/GSFC Detector Characterization Laboratory (DCL) has acquired, for the HST Wide Field Camera 3 project, a preliminary engineering HgCdTe, 1024x1024, 18.5 μm pitch array manufactured by Rockwell Science Center. The device is designed for the near infrared with a cut-off at approximately 1.73 μm and a dark current at 150K of 0.2 e^-/sec . We have made measurements at the DCL to confirm that this preliminary device meets the design specifications. In order to achieve the most reliable results for the dark current, three techniques were used that mitigated non-linear drift problems. We discuss the viability of these methods for determining dark current and the results of the measurements on the device.

Poster - Pop-up Bolometric Detectors for the High Resolution Airborne Wideband Camera (HAWC) on SOFIA

Minoru M. Freund, GSFC

Here we report on the measured performance characteristics of HAWC prototype detectors. HAWC is a far-infrared camera for SOFIA, designed to cover the 50-220 micron spectral range in four bands at diffraction limited resolution. Its purpose is to provide a sensitive and reliable facility-imaging capability for SOFIA during its first operational years. HAWC will be the first flight instrument to utilize a bolometric 12x32 pixel array of ion-implanted silicon pop-up detectors (PUDs). This technology was developed at Goddard Space Flight Center,

and it enables the construction of close-packed, two-dimensional arrays of bolometers with high quantum efficiency and >95% area filling factors. The array will be cooled by an adiabatic demagnetization refrigerator and operated at ~0.2K.

Poster - The Stressed Ge:Ga 160 Micron Focal Plane for SIRTf

E. T. Young, R. Schnurr, J. W. Beeman, J. Cadien, L. Davidson, J. T. Davis, K. A. Ennico, K. D. Gordon, E. E. Haller, T. Horne, D. M. Kelly, D. Knight, G. H. Rieke, G. Rivlis, J. A. Stansberry, and G. Winters, University of Arizona.

Stressed Ge:Ga is currently the most suitable detector type for very low background operation in the 115 to 200 micron range. We have built a 2x20 array of these detectors, qualified it, and tested it both in the laboratory and in the Multiband Imaging Photometer for SIRTf (MIPS). The array has been delivered along with the instrument for integration into the SIRTf Observatory. This device has detective quantum efficiency of 15%, average responsivity of 15 A/W, and a read noise of ~300 electrons rms. As a result, it can reach the natural background limit for imaging in space in just a few seconds of integration.

Poster - The Ge:Ga 70 Micron Focal Plane for SIRTf

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The first high performance large format far infrared focal plane has been built for the Multiband Imaging Photometer for SIRTf (MIPS). The device is qualified, tested in the flight instrument, and delivered with it for integration into the SIRTf Observatory. The array is 32x32 pixels in size, and is 99.8% operative. It has an average detective quantum efficiency of 18%, responsivity of 7 A/W, and read noise of 150 electrons rms. The construction approach allows for a virtually 100% fill factor. It can reach the natural background limit for imaging in space in a few seconds of integration. The design approach could be expanded to larger formats for future missions.

Poster - Deep Cryogenic Ge JFETs for Detector Readout

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We are developing JFETs, based on Ge, that operate down to the lowest cryogenic temperatures (down to liquid-helium temperatures) with very low noise and stable dc characteristics. Our intent is to fill the gap that has so far not been filled by available Si JFETs, Si MOSFETs, GaAs MESFETs, or GaAs JFETs.

We have obtained good dc characteristics down to liquid-helium temperature for both n- and p-channel Ge JFETs. Transconductance increases continuously when cooling from 300 K to 4 K; typical values are approximately 5 mS/mm at 77 K and 7 mS/mm at 4 K.

We have obtained excellent low-frequency noise voltage: At 77 K it is below 30 nV/rtHz at 1 Hz, corresponding to K_f approximately 30 $\mu\text{V}^2\text{-}\mu\text{m}^2$, with a white level of approximately 1.3 nV/rtHz for a JFET gate area of 62,400 μm^2 and power dissipation of 400 μW . The noise remains low for power dissipation down to 10 μW . In variable-temperature measurements (at 400 μW) the noise remains low down to 30 K, increasing less than a factor of 2 at 1 Hz. The temperature range for lowest noise appears to be 30-80 K, much lower than the low-noise range for Si JFETs. At liquid-helium temperatures we have so far obtained noise voltage of approximately 100-200 nV/rtHz at 1 Hz, with a white level of approximately 5 nV/rtHz. However, we expect to decrease this noise level substantially in the near future.

Poster - Cryocoolers for Space

Peter Kittel, Jeff Lee and Pat Roach, NASA Ames Research Center

Ali Kashani and Ben Helvensteijn, Atlas Scientific

Many of the detectors for space telescopes require cooling to increase sensitivity and reduce thermal noise. For space applications, such cooling requires reliable, long-life coolers that are relatively compact and light weight and have low vibration. We have developed or are developing coolers that meet these requirements over a wide range of temperatures. These include pulse tube coolers cooling from 300 K to below 10 K, a magnetic cooler cooling from 10 K to 2 K, a He3 sorption cooler cooling from 2 K to 0.3 K and a helium dilution cooler cooling from 0.3 K to 0.05 K. Details of these coolers and their advantages and disadvantages will be presented.

Poster - Multiplexed RF-SET Readout Amplifiers for Superconducting Detector Arrays

Thomas Stevenson, Orbital & NASA/GSFC, Fernando Pellerano, NASA/GSFC, Robert Schoelkopf, Yale University, Ken Segall, Yale University, Carl Stahle, NASA/GSFC

We report progress on multiplexing a new type of amplifier, the Radio-Frequency Single-Electron Transistor (RF-SET), to develop multi-channel fast and sensitive readout of high impedance cryogenic photodetectors, such as Superconducting Tunnel Junctions and Single Quasiparticle Photon Counters. RF-SETs, very high performance electrometers which use an rf readout technique to provide large bandwidth, are well-suited for this application. Small size, low power, and cryogenic operation allow direct integration with detectors, and using multiple rf carrier frequencies permits simultaneous readout of many amplifiers with a common electrical connection. We describe both the first 2-channel demonstration of this wavelength division multiplexing technique for RF-SETs, and work at Goddard Space Flight Center on increasing the number of channels.

Poster - Fabrication Technology for Single Electron Transistors and Submillimeter Detectors

Carl Stahle, NASA/GSFC, Abdelhanin Aassime, Chalmers University, Per Delsing, Chalmers University, Mary Li, Raytheon ITSS & NASA/GSFC, Robert Schoelkopf, Yale University, Ken Segall, Yale University, Thomas Stevenson, Orbital & NASA/GSFC

We describe efforts to develop a robust fabrication technology for making submillimeter detectors integrated with single electron transistors as readout amplifiers. This work will make a fundamental and critical contribution to the development of new classes of imaging detector arrays with photon-counting sensitivity in the submillimeter, and intrinsic energy resolution in the UV/optical and x-ray.

Poster - SQUID Multiplexers for Large Transition Edge Sensor (TES) Detector Arrays

S. Nam, J. Chervenak, E. Grossman, K. Irwin, J. Martinis, National Institute of Standards and Technology, H. Moseley, R. Shafer, Goddard Space Flight Center

As any multi-channel detector technology matures, the desire for progressively larger formats requires the development of a multiplexed read out. We have developed a SQUID multiplexer which has been used to read out a small array of IR-submillimeter Transition Edge Sensor (TES) bolometers. With careful optimization, an array of microcalorimeters (e.g. X-ray, optical) can also be multiplexed. The basic elements of the SQUID multiplexer will be reviewed. We will also present results from a multiplexed IR bolometer array and describe progress on the development of a SQUID multiplexer system for TES microcalorimeters.

Poster - Aluminum sub-micron superconducting hot-electron bolometer mixers

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A. Skalare, B.S. Karasik, W.R. McGrath, P. Echternach, and H.G. LeDuc, Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91109

We report on microwave measurements of superconducting aluminum hot-electron bolometers (Al HEBs). Diffusion-cooled Al HEB mixers are ideal candidates for space-borne and terrestrial remote-sensing applications in the Terahertz frequency range since they are predicted to have small local oscillator (LO) power requirements, intermediate frequency (IF) bandwidths / 10 GHz, and a noise temperature lower than that of Nb and NbN HEBs. Mixer measurements were made at an LO frequency ~30 GHz LO, with an IF in the range 0.1-7.3 GHz. For $T < 0.8$ K, a magnetic field $H=0.1-0.3$ T was applied to suppress the superconductivity in the contact pads, and partly in the bridge. For a 0.6 μ m long Al HEB, we measure an IF bandwidth of 4 GHz, a conversion efficiency $\cdot = -8$ dB, and a mixer noise temperature $T_m / 4$ K, DSB ($T_{\text{mixer}}=T_{\text{output noise}}/2$). These results are shown to be in quantitative agreement with simple theoretical predictions.

Poster - Aluminum hot-electron bolometers for heterodyne THz receivers

Anders Skalare, William R. McGrath, Pierre M. Echternach, Henry G. LeDuc, Center for Space Microelectronics Technology, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Irfan Siddiqi, Aleksandr Verevkin, Daniel E. Prober, Dept. of Applied Physics, Yale University, New Haven, CT 06520-8482

Superconducting hot-electron bolometer (HEB) mixers are of significant interest for low-noise, high-resolution spectroscopy in the submillimeter and far-infrared wavelength regimes. The most significant advantage compared to competing superconductor-insulator-superconductor (SIS) mixers is that the gap-frequency of the superconductor, about 1 THz for relevant niobium alloys, does not impose an operational upper frequency limit on the HEB mixer. These mixers also achieve considerably lower noise temperatures and require 10⁴-times lower local oscillator power than receivers using Schottky diode mixers. Bolometers made from aluminum rather than the more common niobium, are expected to offer even lower noise temperatures and lower local oscillator (LO) power requirements. Theoretical studies show that the mixer noise should scale as the superconducting transition temperature T_c , while the LO power scales as T_c^2 , which gives aluminum ($T_c=1.5-2$ K) a significant advantage over Nb ($T_c=5-6$ K). The reduction in LO power is especially important for THz applications since tunable compact sources such as frequency-multipliers that will become available in the next few years are likely to yield only limited output power levels.

In this presentation we will report the first mixing experiments at submillimeter wavelengths (frequency = 618 GHz)

with superconducting diffusion-cooled aluminum HEB devices. These initial measurements show conversion bandwidths of up to 3 GHz (for a 1 μm long device), and absorbed local oscillator (LO) powers of only 0.5 to 6 nW. This is already an improvement over Nb mixers. A mixer noise temperature of about 1000 K DSB (double sideband) and a receiver noise temperature of about 3100 K DSB were inferred from measurements of conversion efficiency and intermediate frequency output noise.

Poster - Tunable Terahertz Source

Rolf A. Wyss, Suzanne C. Martin, Barbara J. Nakamura, and Peter H. Siegel, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA 91109

Christoph Kadow and Arthur C. Gossard, Materials Department, University of California, Santa Barbara, CA 93106

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Several future NASA and ESA missions have observational targets that require heterodyne receivers operating in the submillimeter frequency regime (300 GHz to 3 THz). Very capable low-noise heterodyne mixers have been identified for many of these applications, but the current lack of solid-state local oscillator sources prohibits compact instrument implementations at present. A promising technique, submillimeter-wave generation by means of optical-heterodyne mixing, known as photomixing, has been pursued for a number of years. This approach is capable of achieving output power levels on the order of hundreds of nanowatts over an extremely wide frequency range. While this power level is as yet insufficient for use as a THz local oscillator drive, the potential is enormous.

We have initiated a development effort at JPL, in collaboration with UCSB and Caltech, to pursue a new class of photomixers, which alleviates some of the key shortcomings of earlier designs. The primary focus of our activity is in the following areas:

Introduce a distributed gain region and low-loss GaAs membrane/planar antenna technology to increase the output power of the device above 1 THz.

Synthesize novel material structures (ErAs islands in GaAs, InGaAs and InAlAs) which can be used at longer IR wavelengths (1.1 to 1.55 microns) and thus take advantage of a wide range of commercial fiber-optic components.

We will present our ongoing research in this field, and its future directions.

Poster - Hot electron microbolometers for space cryogenic submillimeter telescope.

Vladimir Gromov (Astro Space Center, Russia), Leonid Kuzmin (Chalmers University, Sweden)

Advance in submillimeter-wave detectors sensitivity is necessary for many astrophysical tasks. One of them is the deep sky survey of distant extragalactic sources in submillimeter region with cryogenically cooled telescope at International Space Station (project Submillimetron). The faint sources detection need wide-band continuum observation with direct detectors (bolometers), not restricted by quantum noises of indirect, particularly heterodyne receivers. Theoretical considerations and experiments made with laboratory samples of detectors shows possibility to realize necessary for space telescope sensitivity 10^{-18} - 10^{-19} W/Hz^{1/2} with microbolometers using heating of electrons in normal (not superconducting) metal absorber of submicron dimensions at temperature 0.1 K. Two types of bolometers are chosen as most perspective: NHEB - bolometer with Andreev mirrors thermal insulation from superconducting leads and antenna, and CC-NHEB with capacitive coupling of antenna and absorber.

Poster - SIS mixer development for THz frequency

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The THz range molecular spectroscopy is an important part of the space astrophysics instrumentation development for the understanding of the star forming process. Due to the severe opacity of the Earth atmosphere at the far infrared wavelength this spectroscopic study of the star forming regions is possible only from space or from the stratospheric platforms.

The SIS receiver technology using Nb devices, allowing one to reach the sensitivity close to the heterodyne spectrometer quantum limit, was until recently delimited around 1 THz by the gap frequency of Nb. For the spectroscopy at the higher frequencies now are used Hot Electron Bolometer (HEB) or Schottky mixer technologies allows building receivers 40 times less sensitive than the quantum limit. This is leaving a room for the improvement of the THz spectrometers sensitivity using the SIS mixers with a higher gap frequency.

We present the development of SIS mixer for the band 1.1-1.25 THz of the FIRST heterodyne receiver. The choice of the SIS mixer for the THz frequency receiver is motivated by a relatively low output mixer noise of 20-30 K and by a low intrinsic conversion loss of about 3-5 dB at the frequency of interest. This allows one to consider a possibility to build an SIS receiver with equivalent DSB receiver noise temperature close to 2-3 hn/k in the 1-1.3 THz band.

The SIS mixer is using a quasi-optical design with Si hyper hemispherical lens and with a planar twin slot antenna. The two NbN/AlN/Nb 0.7 mm² area junctions are used in the mixer. The Josephson critical current is close to 40 kA/cm² and in the middle of the band $R_w C \gg 5$.

The ground plane of the mixer circuit is made of NbTiN. The critical temperature of the NbTiN film deposited at the Si substrate is close to 16 K. The tuning circuit of the junctions is made of a normal metal.

The expected loss in the junction tuning circuit is about 1 dB and the overall receiver conversion loss is expected to be close to 7 dB.

Poster - Compact Ambient Submillimeter Heterodyne Receivers using Schottky Diodes

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This presentation will discuss recent research at the University of Virginia on the development of compact heterodyne receivers based on Schottky diodes. Heterodyne mixers based on Schottky diodes are used to build sensitive, room temperature receivers for use in a broad range of applications, including spectroscopy, passive imaging, and radio astronomy. This presentation will focus on new techniques that have been developed to scientifically design integrated planar Schottky diode mixers that are robust, easy to assemble, have large fixed tuned bandwidth and achieve state-of-the-art sensitivity.

As a demonstration of the power of these techniques, the design and analysis of a fixed-tuned 600 GHz integrated mixer will be presented. This mixer has achieved record sensitivity ($T_{\text{mix}}=1,150\text{K}$ (DSB)) and bandwidth for a room temperature detector in this frequency range, outdoing even the best whisker-contacted mixers. The mixer design has been shown to be not only mechanically robust but also easy to assemble and reproduce. The integration of the diode with the mixer circuitry allows for precise control of the circuit geometry and a reduction of parasitic elements, allowing greater accuracy of computer simulations and therefore better high frequency performance and bandwidth. In addition to the 600 GHz mixer, the fabrication and design of a 1.6 THz fundamental mixer design has been completed, and test results will be presented at the workshop.

The design and testing of a state-of-the-art 400 GHz subharmonic mixer using anti-parallel integrated Schottky barrier diodes will also be presented. The initial testing of the mixer has yielded a double-sideband mixer noise temperature of 850 K and a mixer conversion loss of 8.5 dB at 380 GHz. The mixer was pumped by an all-solid-state LO source. The mixer block was fabricated by standard split-block machining techniques, but was specifically designed to be compatible with micromachining and molding technologies and to be readily scalable to higher frequencies. The IF impedance of the mixer is approximately 100 Ω , and the IF bandwidth of the mixer extends to 12 GHz with good sensitivity. The simulation techniques used to design this mixer will be discussed, including the nonlinear and linear analyses of the anti-parallel diode structure.

This research has enabled us to efficiently design and build submillimeter wavelength mixers that are not only highly sensitive, but also have enhanced mechanical robustness and large fixed tuned bandwidth. The coupling of these new analysis techniques and the new integrated diode technology can be easily extended to other circuit designs such as balanced and subharmonic mixers and frequency multipliers, and will allow the development of a new generation of SubMillimeter-wave Integrated Circuits (SMICs) for the wide range of scientific, military and commercial applications that is now envisioned.

Poster - Monolithic Silicon Bolometer Coupled to Waveguide

P. Timbie, S. Cordone, K. Farooqui, J. Gundersen, G. Wilson, J-W. Zhou, UW-Madison, C. A. Allen, T. Chen, S. H. Moseley, D. B. Mott, NASA/GSFC

We have measured the performance of ion-implanted silicon bolometers developed for observations of faint astrophysical sources at millimeter wavelengths. These devices are mounted in waveguide to couple to a single mode and single polarization of electromagnetic radiation. We measure optical coupling efficiencies of $\sim 90\%$. When cooled to 0.1 K and operated under low background conditions, the devices have a time constant of ~ 5 mS and an NEP $\sim 1 \times 10^{-17}$ W/Hz^{1/2}. They have a small cross-section to cosmic rays. We will describe an application of these bolometers to a balloon-borne measurement of the 2.7 K cosmic microwave background radiation at frequencies between 65 and 170 GHz.