Infrared Detectors for SNAP

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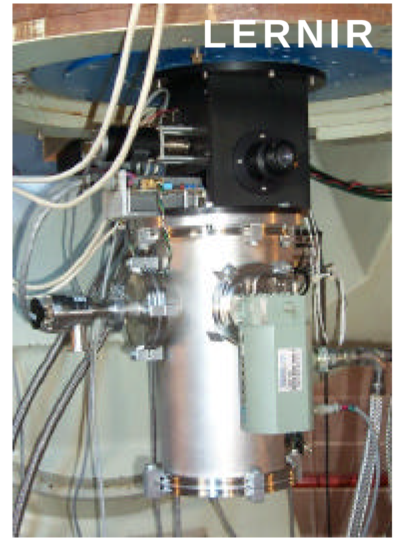
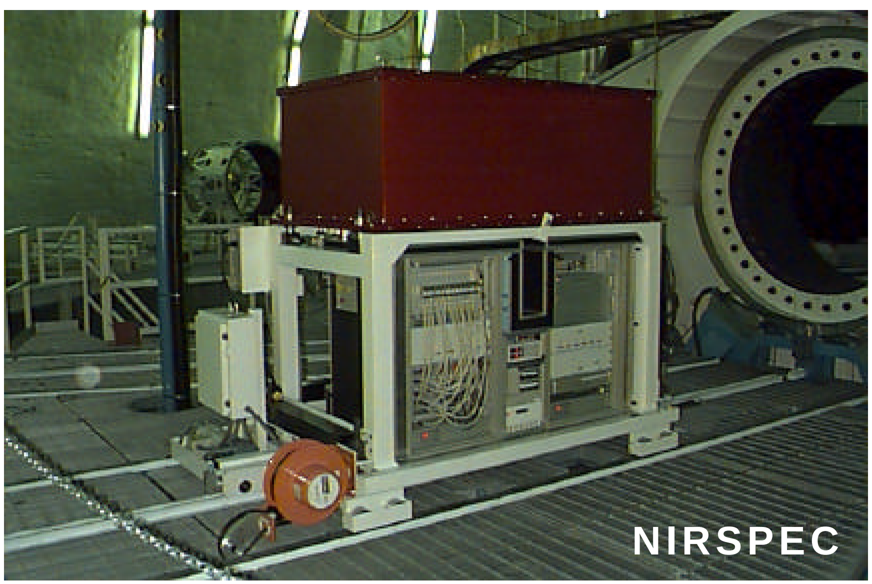
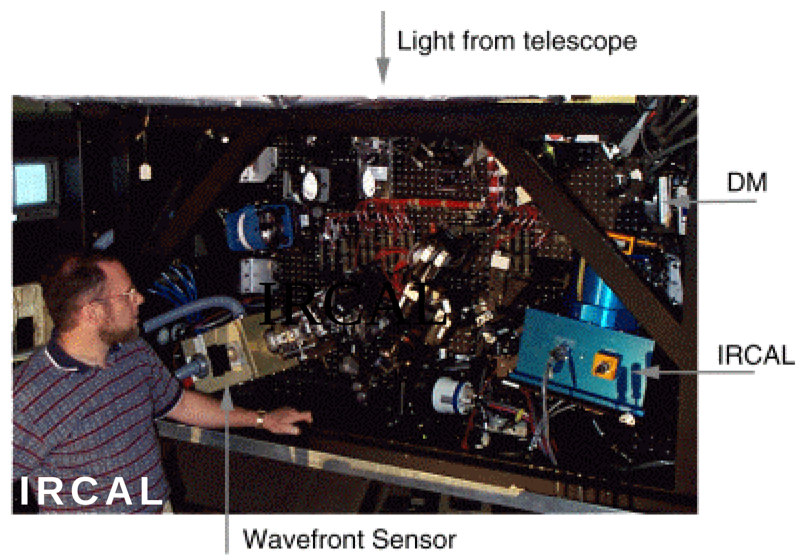
Infrared HgCdTe Detectors for SNAP

- Extensive Berkeley experience with state-of-the-art IR astronomy detector arrays
  - LERNIR
    - Leuschner Near Infrared Camera 256x256 HgCdTe PICNIC
  - IRCAL
    - Lick AO camera 256x256 HgCdTe PICNIC
  - NIRSPEC
    - Keck cryogenic echelle with 1024 x 1024 InSb ALLADIN

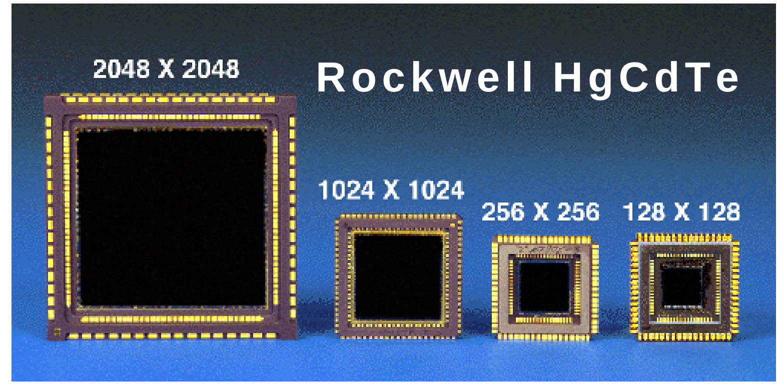






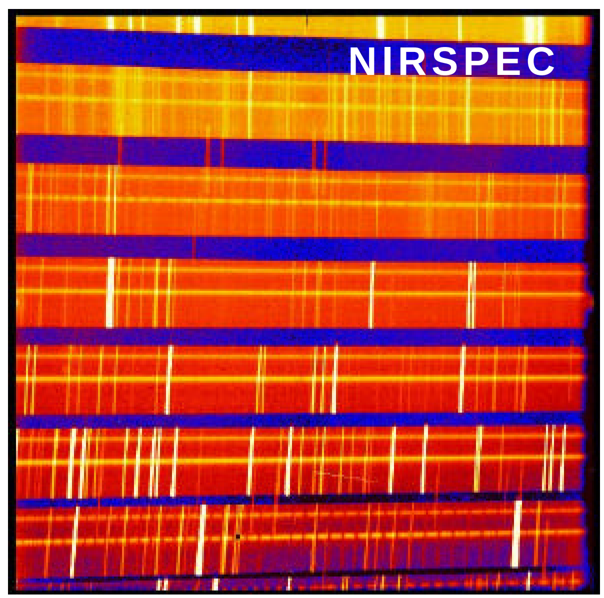
Explosive growth in IR detector technology

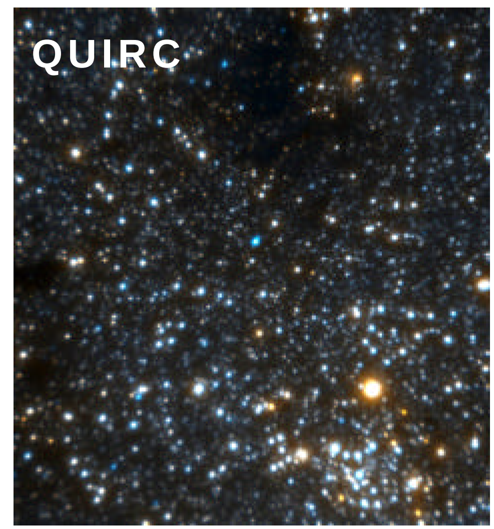
- **Revolutionary advances in near IR (1-5 micron) detectors**
  - **Growth from 58 x 62 to 2048 x 2048 pixel focal plane arrays in last decade**
  - **High performance**
    - **Low read noise: < 10 e^- rms**
    - **Low dark current: < 0.1 e^-/s**
    - **High QE: > 70 % 1 -5 mm**



- **Proliferation of InSb & HgCdTe instruments**
  - **HST/NICMOS: 256 x 256 HgCdTe**
  - **Keck/NIRSPEC: 1024 x 1024 InSb**
  - **GEMINI/QUIRC: 1024 x 1024 HgCdTe**

256 x 256

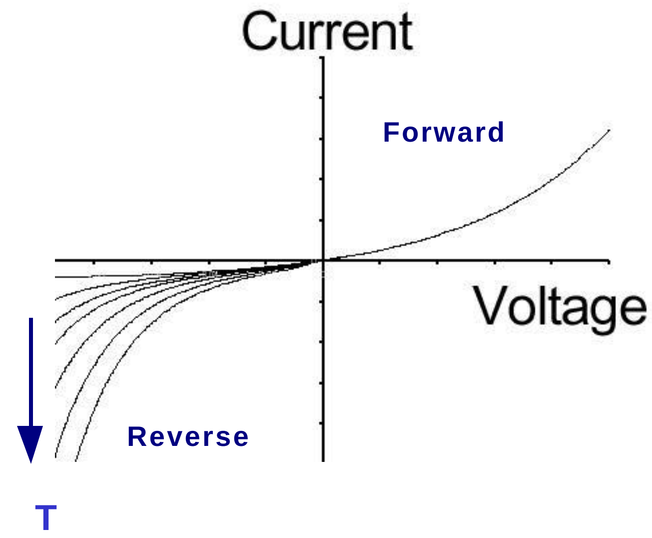




1024 x 1024

Infrared Detector Options for Astronomy

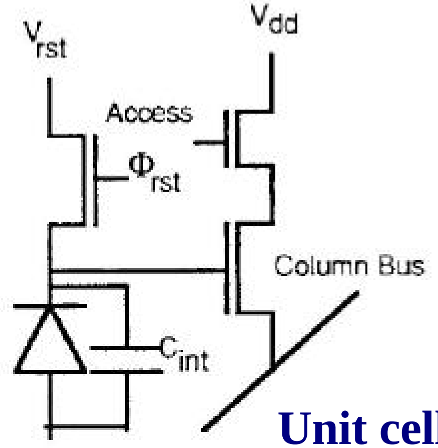
- **Common detectors are based on photovoltaic effect in a reverse biassed pn diode**
- **Detector band gap determines operating temperaure**
  - **Dark current due to thermally excited diffusion and generation-recombination has strong T dependence**
  - **IR detectors operate at lower temperatures than Si CCDs**
  - **Minimize cooling requirements by picking shortest cut-off wavelength compatible with science**
- **$Hg_{(1-x)}Cd_xTe$ --- x determines band gap**



Material	Band Gap (mm)	Operating Temp (K)
Si	1.1	140 - 300
Ge	1.8	77
InSb	5.6	4 - 77
$Hg_{(1-x)}Cd_xTe$	< 20	20 - 300

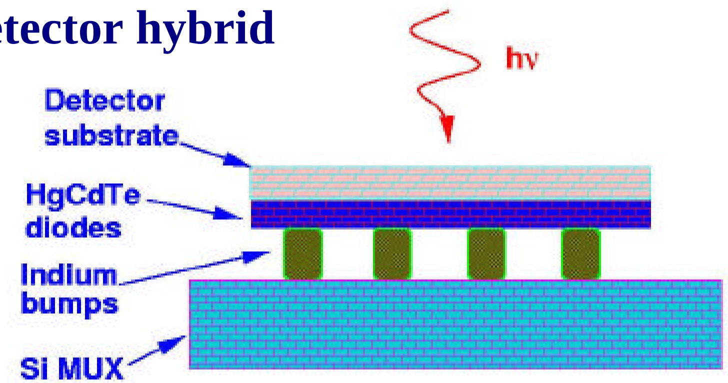
Hybrid Focal Plane Array Architecture

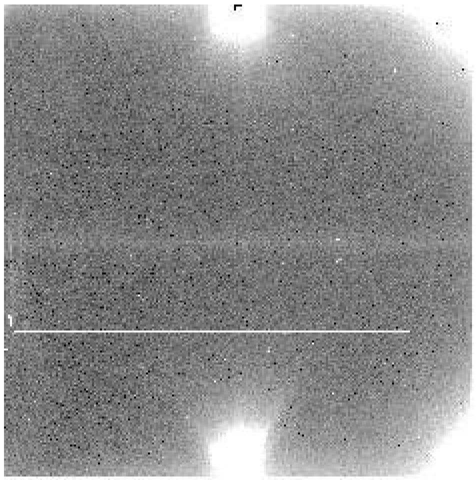
- Detector diodes bonded to a Si multiplexer for read out
  - Row & column shift registers allow sequential access to each pixel
    - Detector & readout circuit optimized separately
    - Multiple sampling
    - No charge transfer efficiency
  - Detector mechanically bonded to MUX
    - Thermal expansion mismatch effects
  - Special epitaxy technologies for growing diodes
    - PACE: Metal chemical vapor deposition of CdTe on sapphire followed by liquid epitaxy growth of HgCdTe
    - MBE: potential for improved performance



Unit cell

Detector hybrid



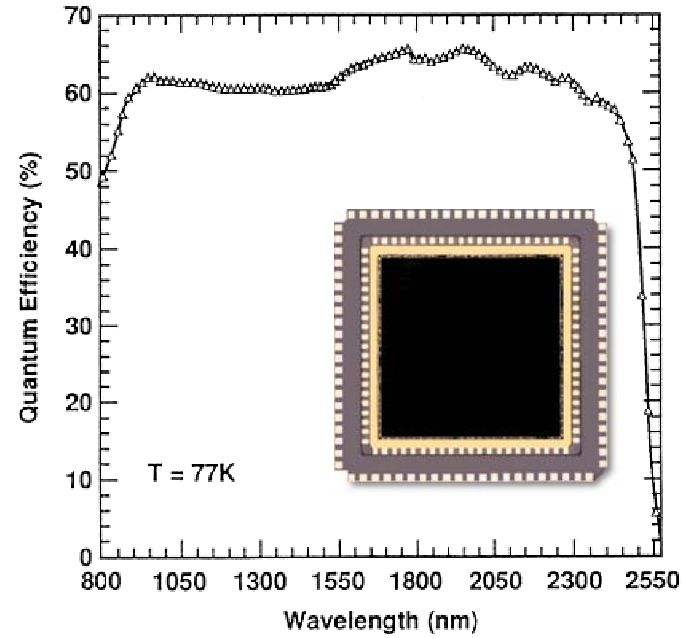


Hawaii-1 glow

State-of-the-Art Large Format HgCdTe

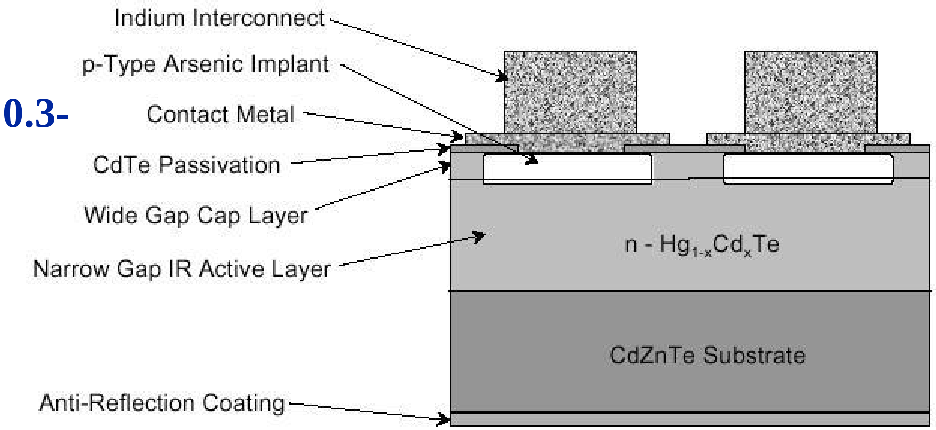
- Rockwell HAWAII family
  - 1024 x 1024 HAWAII-1 2.5 mm PACE HgCdTe
    - 18.5 mm pixel pitch
    - 25 devices delivered and in use
    - PACE technology
      - Dark current
      - Uniformity
      - Residual images
    - Read noise 3.5 e- rms achieved (10 e- rms CDS)
    - Dark current < 0.1 e- achieved at T ~ 60 K
    - Power < 2 mW
    - Average QE ~ 65%
    - Four-quadrant/four output MUX
      - Read noise
      - Amplifier glow
  - 2048 x 2048 HAWAII-2 2.5 mm PACE HgCdTe
    - 18 micron pixels - 40 mm x 40 mm device
    - 4/8/16/32 readout MUX for improved output-FET glow
    - Improved MFT
    - Twenty fabricated
      - Devices delivered to UH, ESO, & SUBARU
  - 1024 x 1024 HAWAII-1 5 mm PACE HgCdTe

HAWAII-1 QE



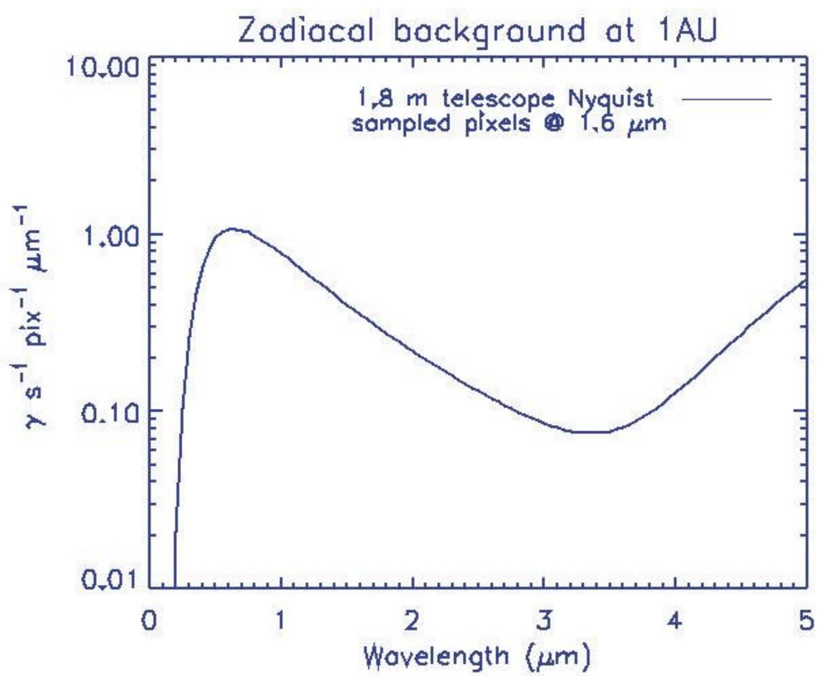
HgCdTe Technology Development

- **Molecular beam epitaxy diode fabrication**
  - **HgCdTe is grown by MBE on CdZnTe**
    - **Improved lattice match between HgCdTe & CdZnTe vs. Al_2O_3**
    - **Fewer lattice defects - dark current approaching 0.001 e^-/s**
    - **Dramatically reduced residual images 0.3-0.5% after saturation**
      - **None detectable after one read**
    - **Better uniformity**
    - **Worse CTE mismatch to CdZnTe**
    - **CdZnTe available in small wafers**
      - **One device 2048 x 2048 per wafer**
    - **Driven by NGST 5.0 mm program**
- **Multiplexer design**
  - **HAWAII-1R MUX**
    - **Reference pixels**
    - **Output FET glow mitigation**
    - **Mated to 1.7, 2.5 or 5.0 mm HgCdTe**
- **Short wavelength cut-off HgCdTe**
  - **QE limited by AR coating**



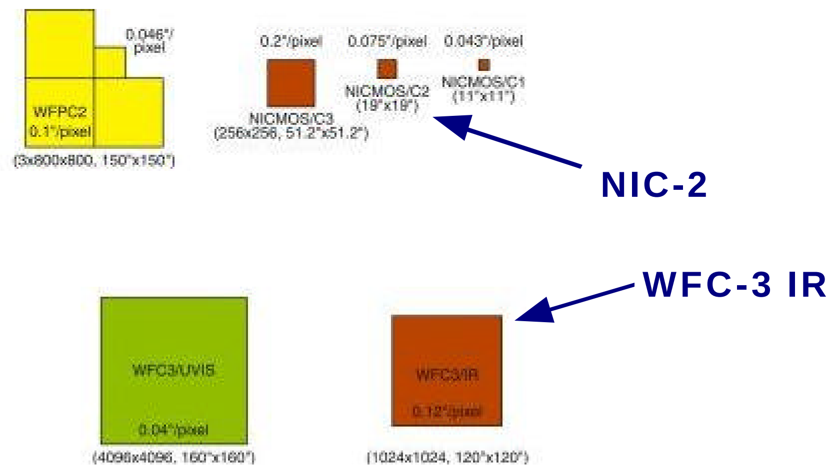
Shortwave HgCdTe Arrays for SNAP

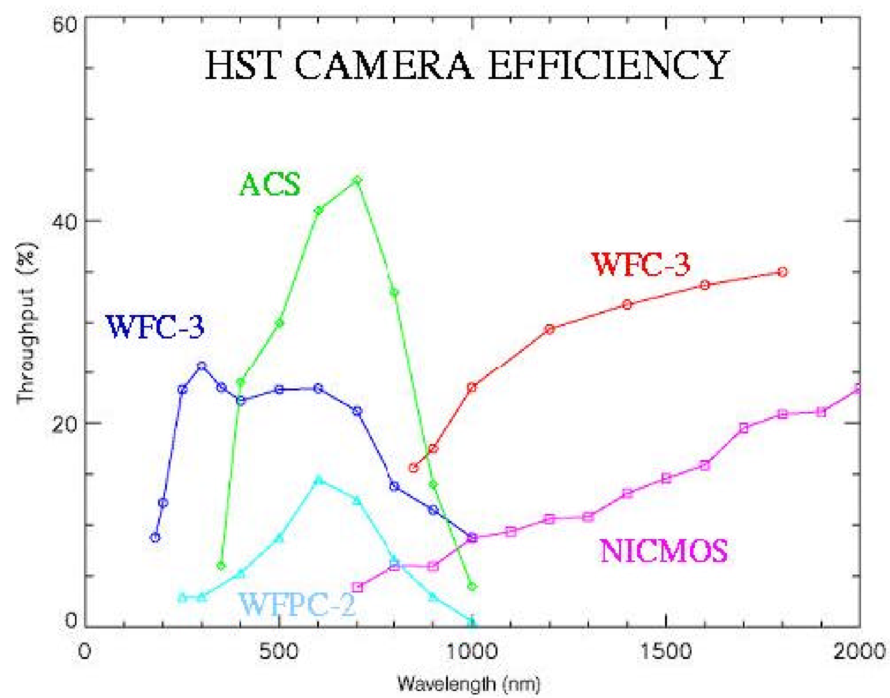
- **Short wave cut-off (< 2 mm) HgCdTe can yield low dark current at CCD operating temperature**
  - **Option for CCDs & IR arrays to share 140-150 K thermal environment**
  - **Dark current < 0.1 e^-/s for zodi-limited operation requires MBE**
- **No commercial short wave HgCdTe**
- **HgCdTe development programs**
  - **HST/WFC-3 1.7 *m*m MBE HgCdTe**
    - **1024 x 1024**
    - **HAWAII-1R MUX**
  - **VLT/NIRMOS 1.9 *m*m MBE HgCdTe**
    - **2048 x 2028**
    - **Four devices**
    - **HAWAII-2 MUX**



Shortwave HdCdTe Development

- *Hubble Space Telescope* Wide Field Camera 3
  - WFC-3 replaces WFPC-2
    - CCDs & IR HgCdTe array
    - Ready for flight July 2003
  - 1.7 mm cut off
  - 18 mm pixel
  - 1024 x 1024 format
    - Hawaii-1R MUX
  - Dark current consistent with thermoelectric cooling
    - < 0.5 e/s at 150 K
    - <0.05 e-/s at 140 K
  - Expected QE > 50% 0.9-1.7 mm
  - Individual diodes show good QE
    - Effective CdZnTe AR coating
    - No hybrid device with simultaneous good dark current & QE





Conclusion & Recommendations

- Clear technology choice for the forseeable future
  - HgCdTe
    - Short wave cut off HgCdTe on MBE is within reach
    - Zodi limited performance
    - Compatible with Si CCD thermal environment
    - Leverage national (NASA HST/NGST) and international development programs (ESO VLT)
  - Ge, InSb, InGaAs, PtSi
    - Immature technology
    - Significant performance penalty
    - Incompatible with Si CCD thermal environment
- Rockwell has mastered component technologies for large format, high performance HgCdTe
  - Satisfies requirements of baseline IR camera
  - HST/WFC-3 devices represent the state-of-the-art for IR flight detectors
    - Goddard SFC takes delivery of science grade devices 1/31/2001
    - Select flight array Fall 2001
- Evaluate performance, cost, & risk trade of
  - 2048 x 2048
  - Evolution of MUX from HAWAII-1/2/1R to Hawaii-2R MUX
  - Buttable architecture to reach 4096 x 4096