(Deep-)Cryogenic IR Imagers and Multiplexers

JPL Workshop on Extreme Environments Technologies for Space Exploration

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Agenda

- Introduction & Context
- BIB Detectors
- Cryogenic Readouts
- Conclusions

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Motivation

- **Space-based infrared astronomy is in a dramatic growth phase**
- **Growth is driven by**
  - Science
    - » Further-out objects are red-shifted into the IR
    - » Lots of cool matter in the universe
    - » Infrared spectral lines
  - Enabling technology
    - » Availability of large-format, high-performance detector arrays
    - » Electronics, cryocoolers/dewars, optics etc.
    - » Access to space

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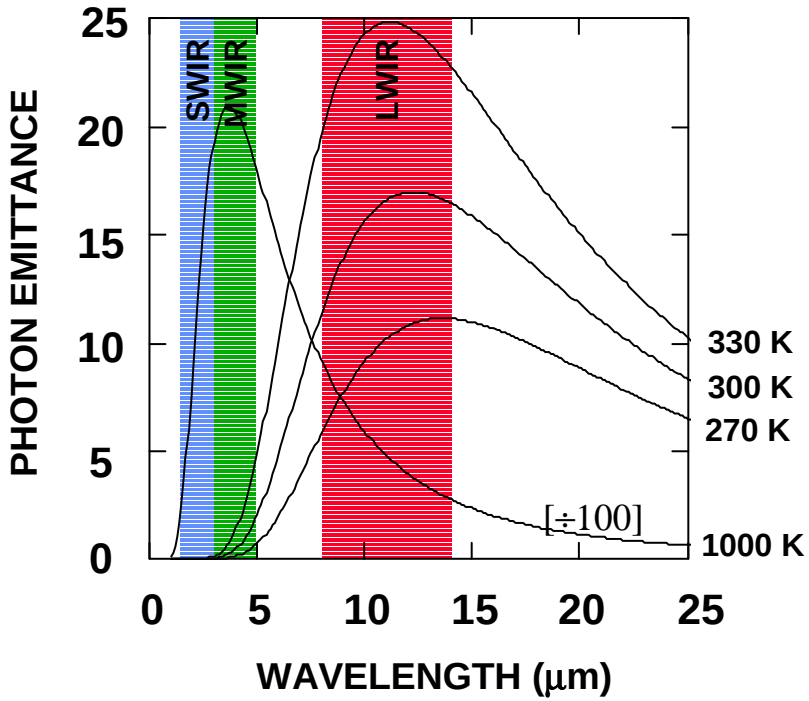
Infrared Astronomy Basics

- **All objects radiate heat waves**
  - Planck's Law
  - 300 K blackbody peaks near 12 μm
- **Mid-IR (5 - 30 μm) spectral region**
  - {LWIR to VLWIR in DoD jargon}
  - RT and colder objects
  - Line spectra
- **Very limited IR astronomy is possible from the ground**
- **The issues:**
  - Large IR background flux
    - » Atmosphere
    - » Warm telescope optics
    - » Photon noise limits detector sensitivity
  - Atmospheric transmission
    - » Limited "windows"
    - » Narrow-line absorption



SOLUTION: COOLED SPACE TELESCOPES WITH DEEP-CRYOGENIC FOCAL PLANES

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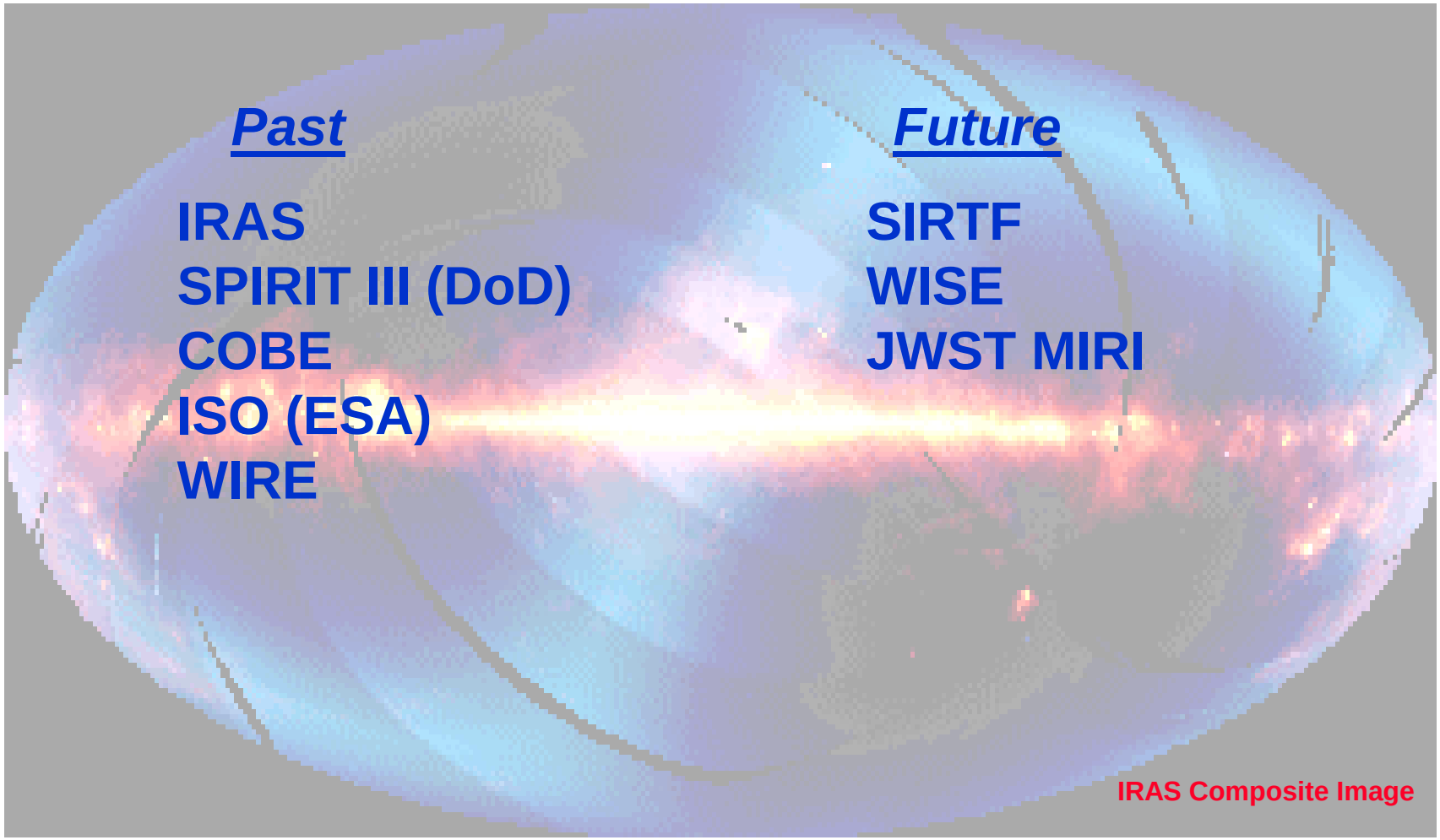
Missions with Deep-Cryogenic FPAs*



* Only missions in which we have been involved

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Blocked-Impurity-Band (BIB) Detectors

- **Blocked-Impurity-Band (BIB) detectors are the best in the Mid-IR spectral region**
  - Si:As to 28 μm; Si:Sb to ~ 40 μm
  - Excellent responsivity & response uniformity
  - Low dark currents
  - Great operability
  - Good producibility
  - Low (Deep-Cryo) operating temperature (T < ~13 K)
- **Impurity band conduction in doped silicon**
  - Si:As impurity band conducts mobile D^+ charges like a valence band conducts holes
    - » so Si:As has 3 bands and 2 forbidden gaps (at deep-cryo temperatures)
  - Valence band gap → conduction band 1.12 eV
  - Impurity band gap → conduction band ~0.05 eV

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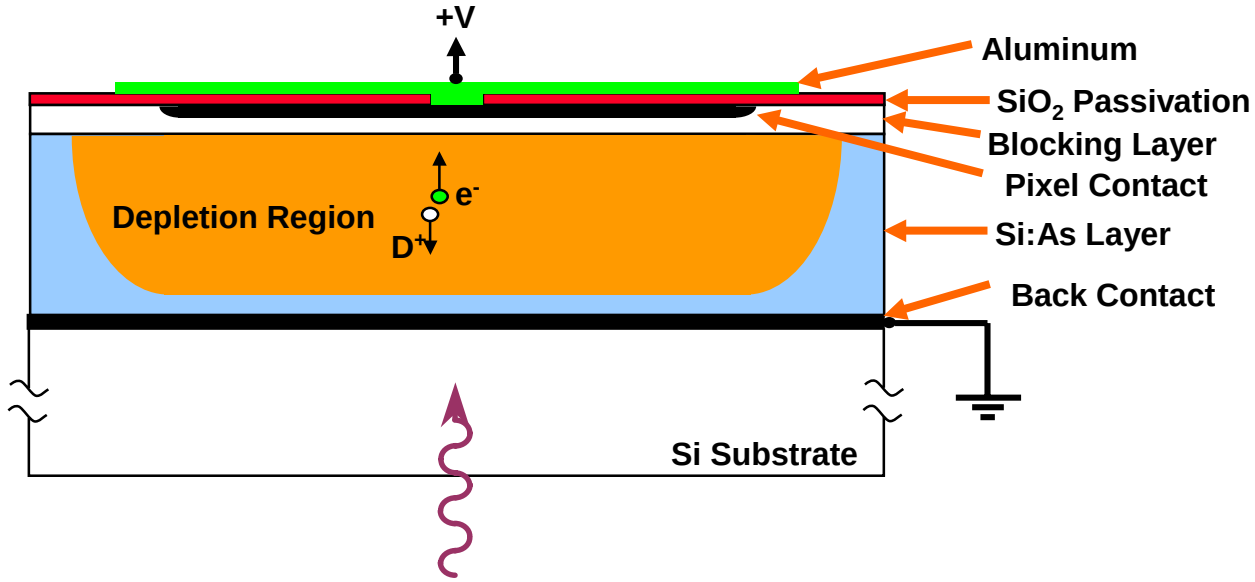
Blocked-Impurity-Band (BIB) Detector Structure



- **Undoped single-crystal silicon *substrate* transparent to IR**
- **Ion-implanted & annealed transparent *back contact***
- **Very-high-purity, epitaxially-grown, *Si:As layer* (the impurity-band layer)**
- **Very-high-purity, epitaxially-grown, undoped *blocking layer***
- **Ion-implanted & annealed *pixel contact***
- **Deposited *SiO_2 passivation***
- ***Aluminum* metalization**

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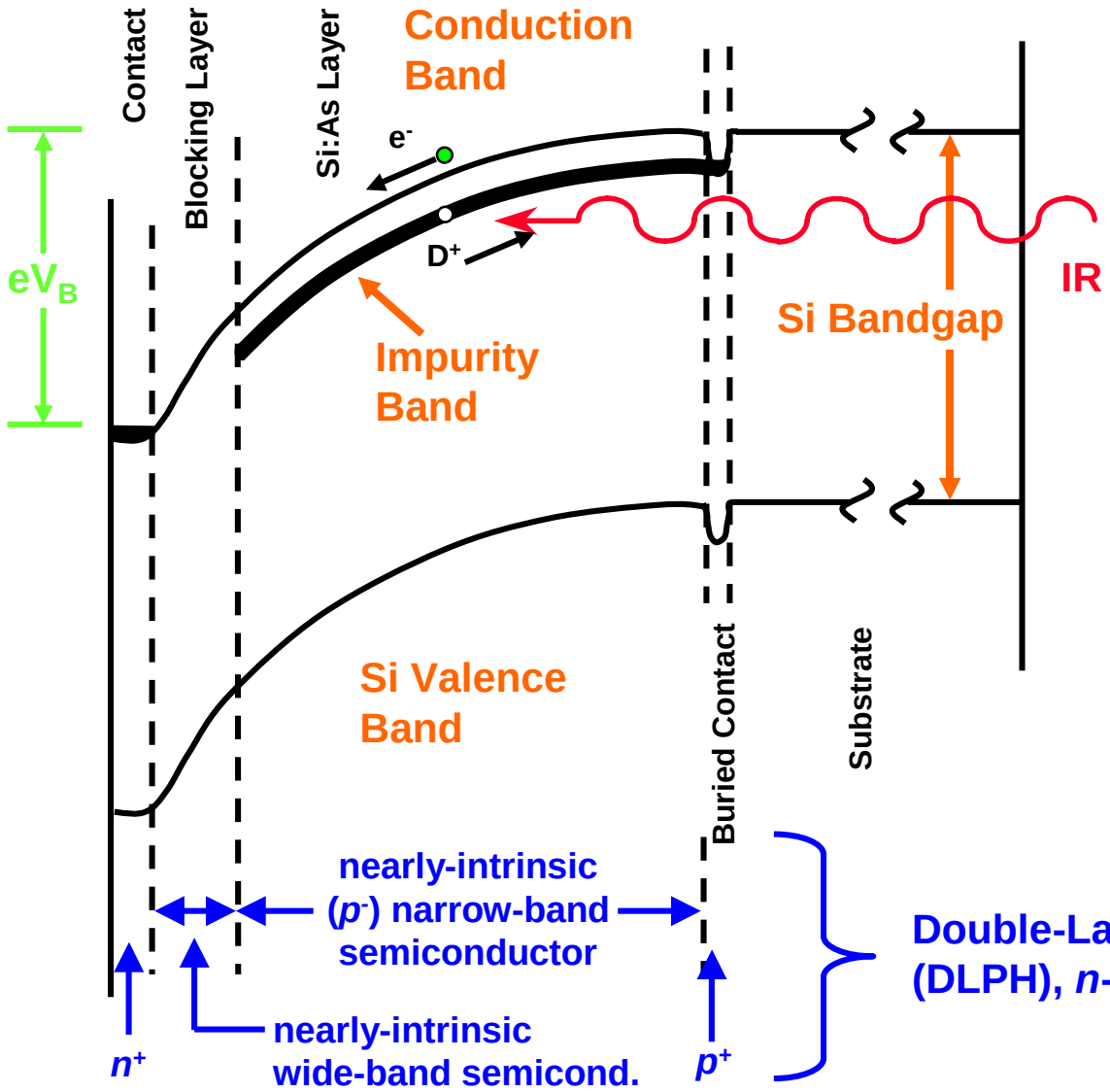
BIB Detector Energy Band Diagram



- Dark current from D^+ charge transport eliminated by blocking layer
- Long carrier lifetime in the depleted region
- Both electron and D^+ charge collected
  - No recombination noise
  - Gain = 1 (at low bias)

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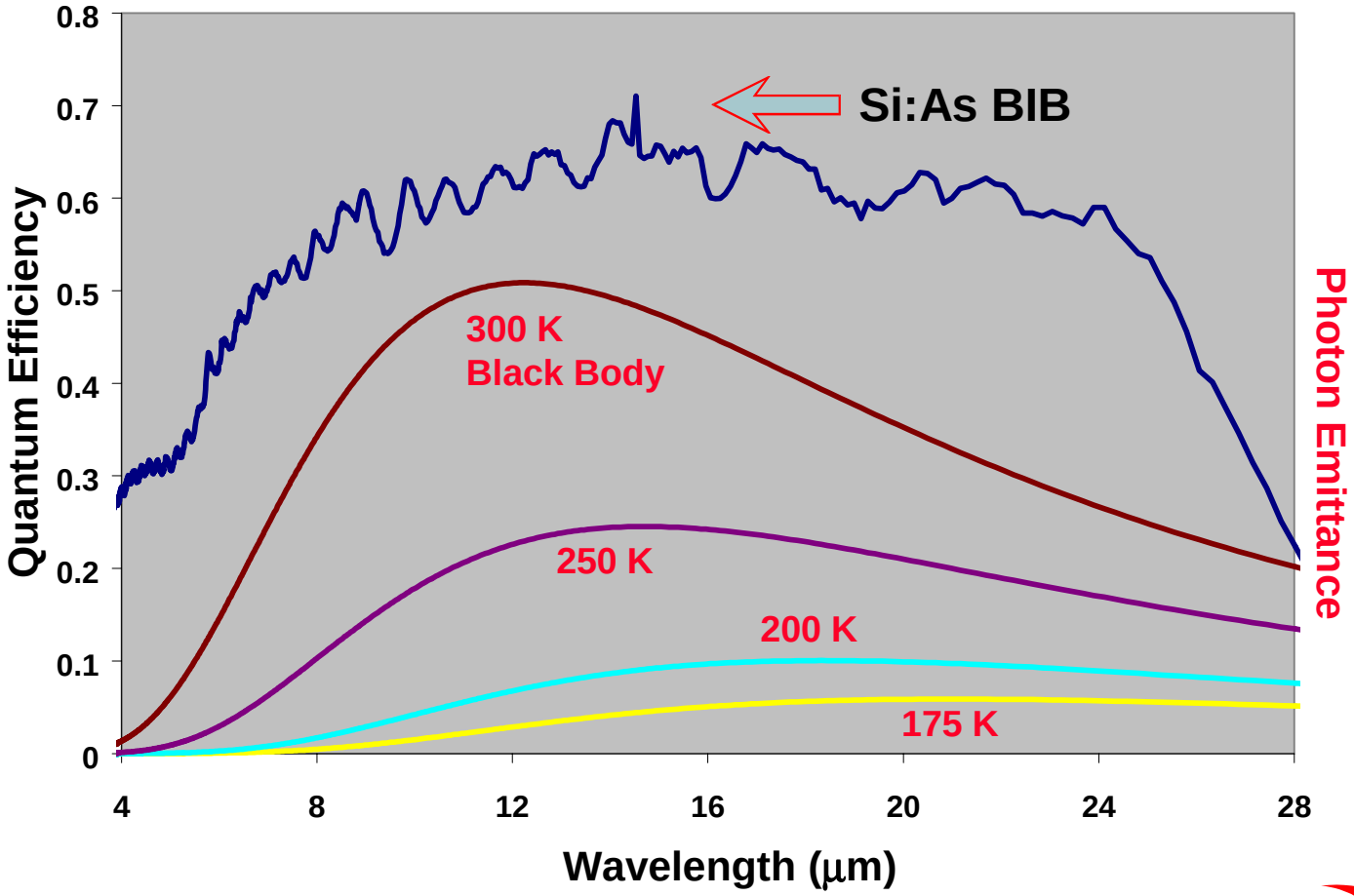
BIB Detector Spectral Response

Ideal for Detecting Objects at RT or Below



Si:As BIB

Measured Data w/o AR Coating

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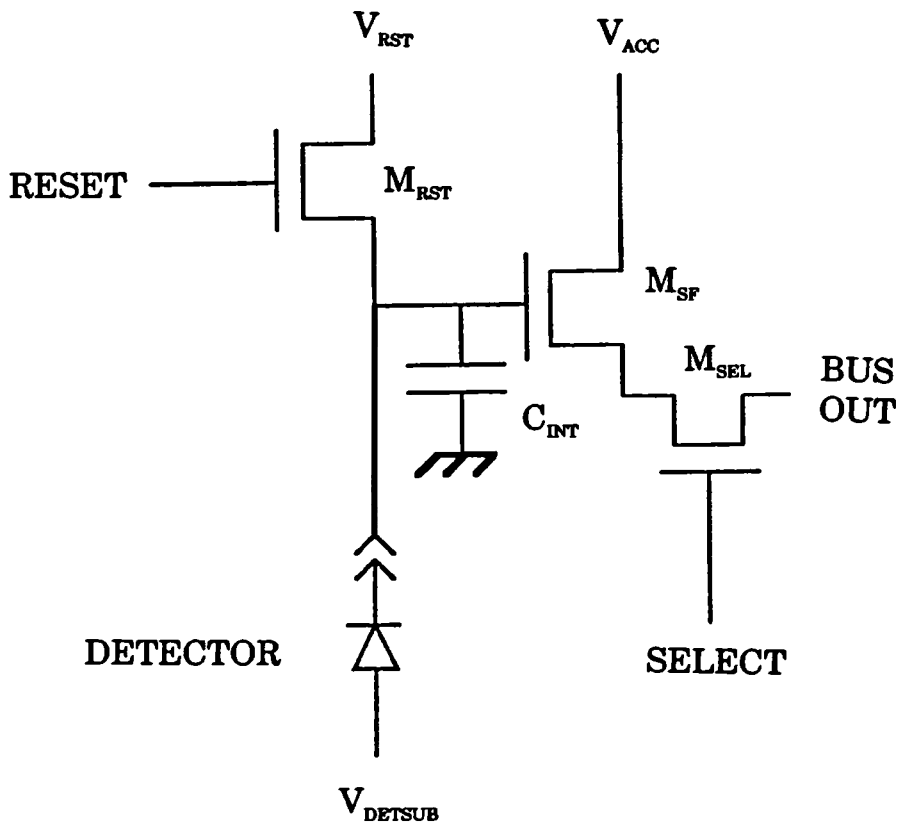
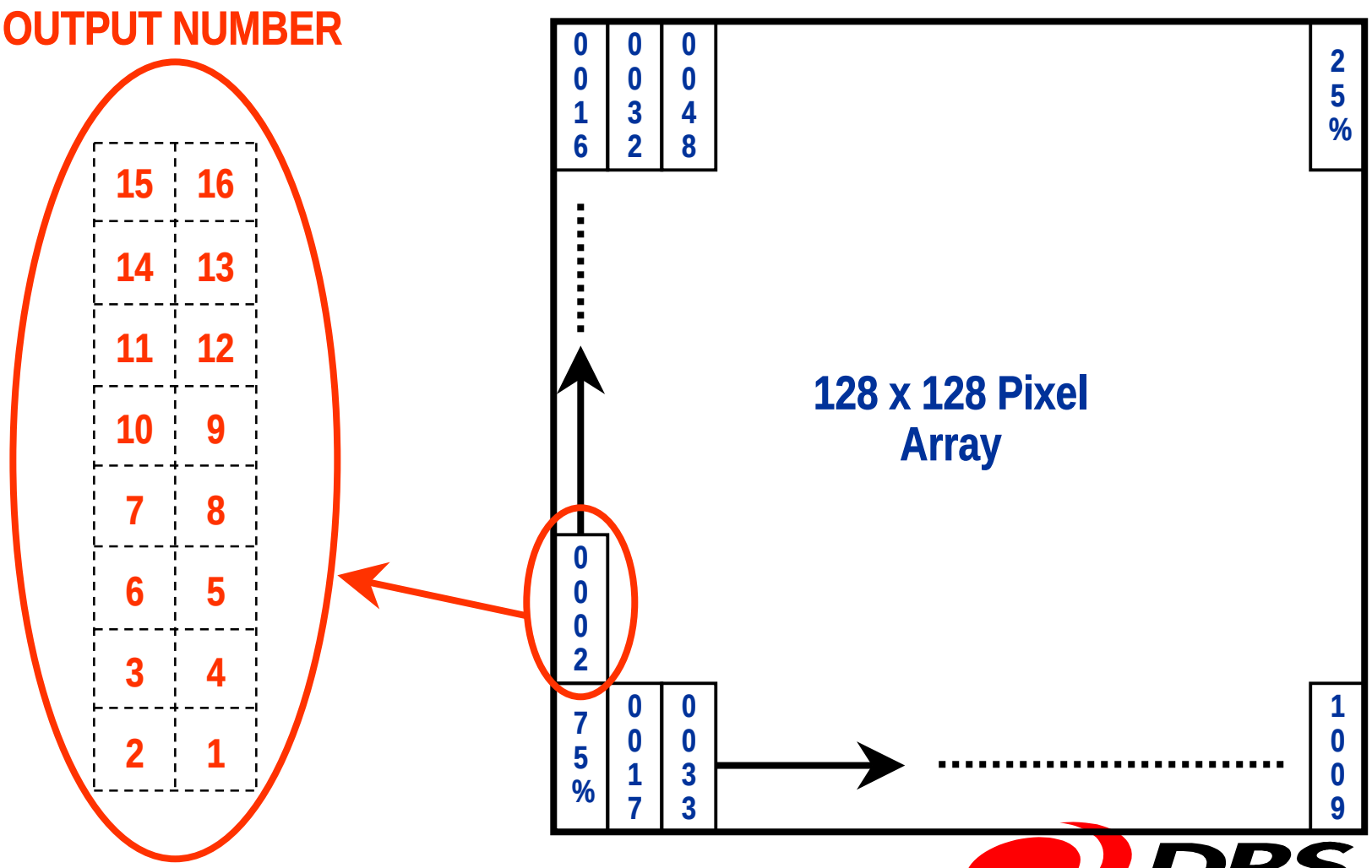
Simple Source Follower per Detector (SFD) Unit Cell Design



CMOS Multiplexer Organization



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ROIC/Multiplexer Issues for Deep Cryo

- **Degraded MOSFET characteristics at low temperatures**
  - Carrier freezout
  - Threshold shifts
  - Increased noise below 30 K
  - “Kink” effect in NFETs
  - Poor transfer characteristics
- **Solution (“in the old days”) – Maintain a custom deep-cryo process at a foundry**
  - Process rarely exercised
  - Low yield
  - Not very dense
  - Obsolescence
- **Current solution (in my view) – Deep-cryo by design**
  - Use a well-maintained commercial process
  - State-of-the-art design rules
  - High yield
  - Reproducible

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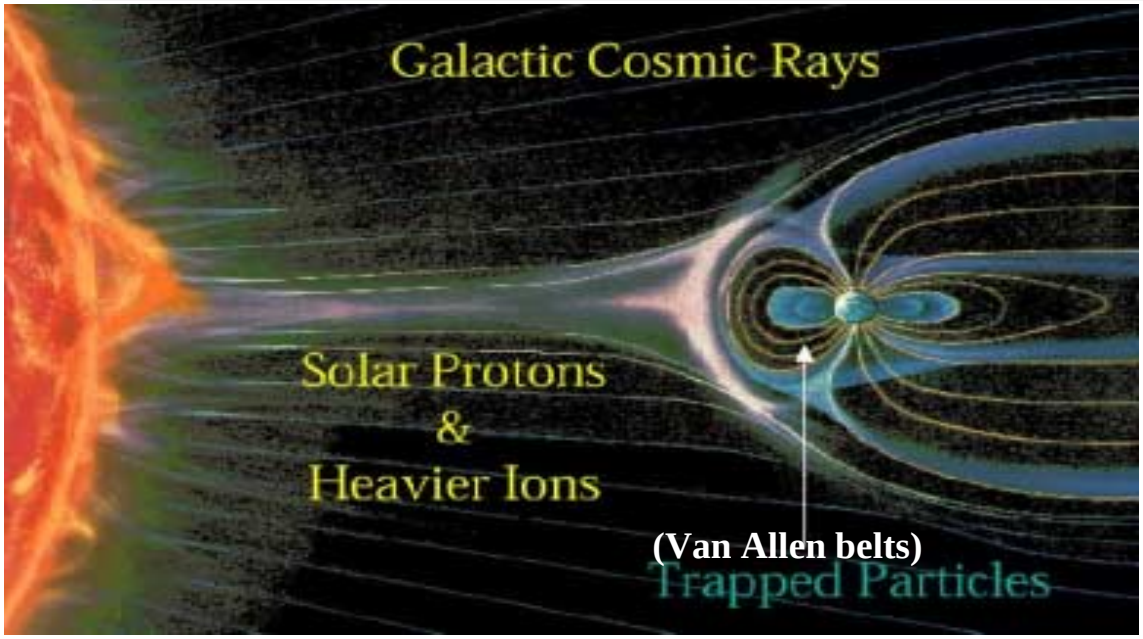
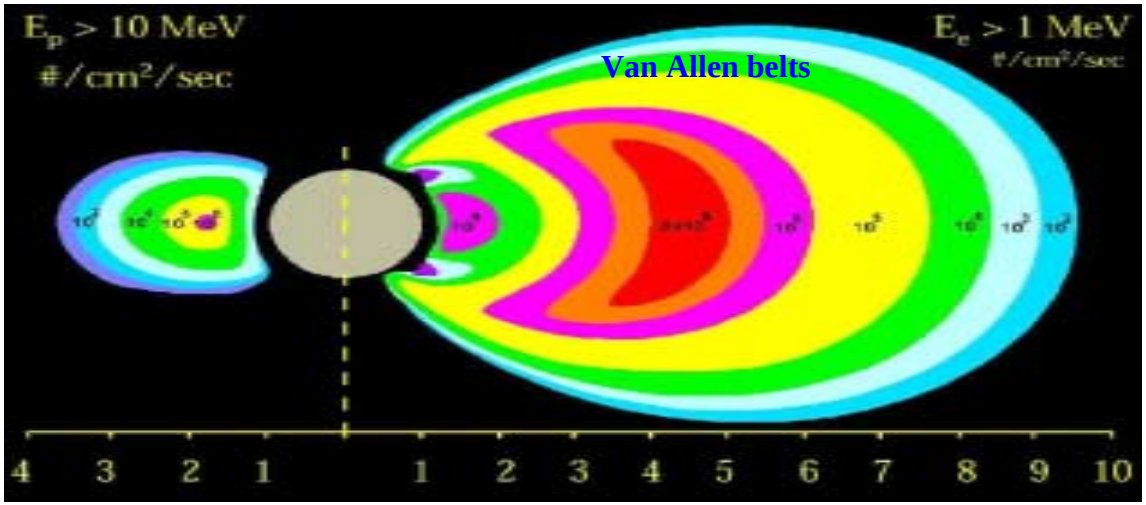
Space Radiation Environments





Earth Orbit

- **Total Dose**

~2.2 krad(Si) / year @ 500 km, 35°
~2.0 Mrad(Si) / year @ 35,786 km, 35°

- **Single Event Effects**

Much higher radiation doses in other interesting places!

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The Future for Deep-Cryo ROICs

- **Bigger chips, smaller unit cells, more transistors**
- **Smaller feature sizes**
- **Increased susceptibility to single event upset problems**
- **Technology scaling to reduce total dose problem**
- **Move towards digital designs**
- **DRS future**
  - Deep-cryo by design
  - Rad-hard by design

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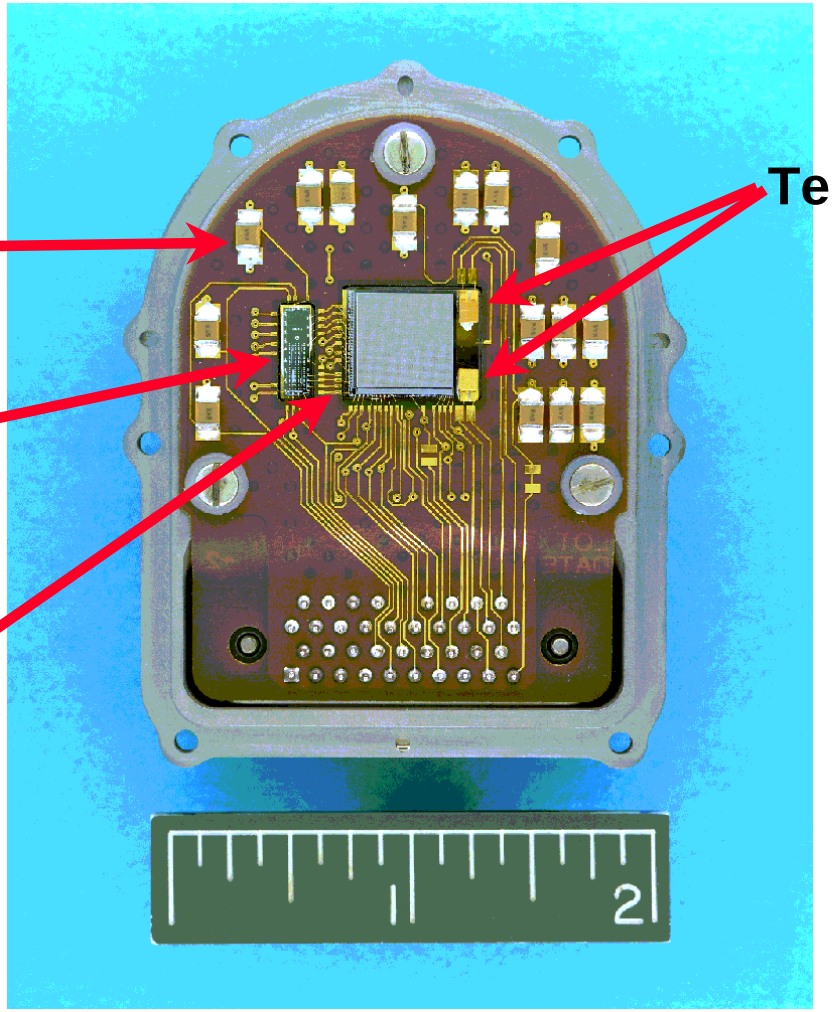
A Representative Focal Plane Module Assembly



WIRE FPMA

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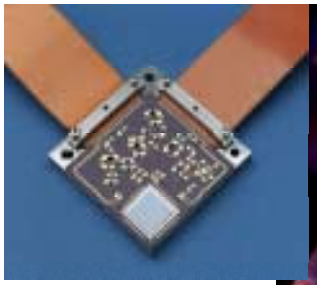
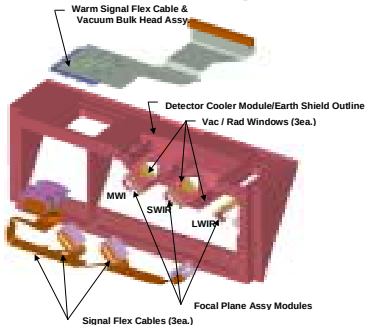
DRS "Strategic" Focal Plane Products & Programs

Science Programs



NICMOS
WIRE
SIRTF
WISE
JWST
TES

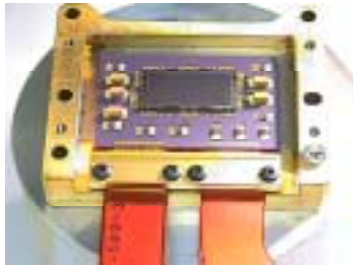
Remote Sensing Programs



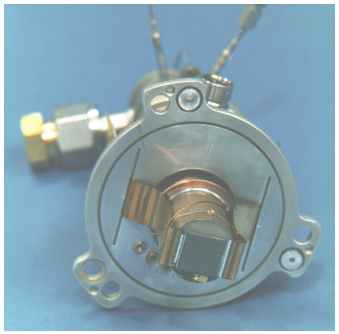
SBIRS
DSP
HSI
Sandia
EKV

Proprietary
SPIRIT III / MSX
CrIS
GOES ABI, HES
RAMOS

TES



LADS (SBIRS)



GBI
EKV

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