N91-14382

LWIR Detector Requirements for Low-Background Space Applications

Frank J. De Luccia
The Aerospace Corporation
P.O Box 92957
Los Angeles, CA 90009

Detection of "cold" bodies (200 - 300 K) against space backgrounds has many important applications, both military and non-military. The detector performance and design characteristics required to support low-background applications are discussed, with particular emphasis on those characteristics required for space surveillance. The status of existing detector technologies under active development for these applications is also discussed. In order to play a role in future systems, new, potentially competing detector technologies such as multiple quantum well detectors must not only meet system-derived requirements, but also offer distinct performance or other advantages over these incumbent technologies.

LWIR DETECTOR REQUIREMENTS FOR LOW-BACKGROUND SPACE APPLICATIONS

FRANK J. DE LUCCIA
THE AEROSPACE CORPORATION

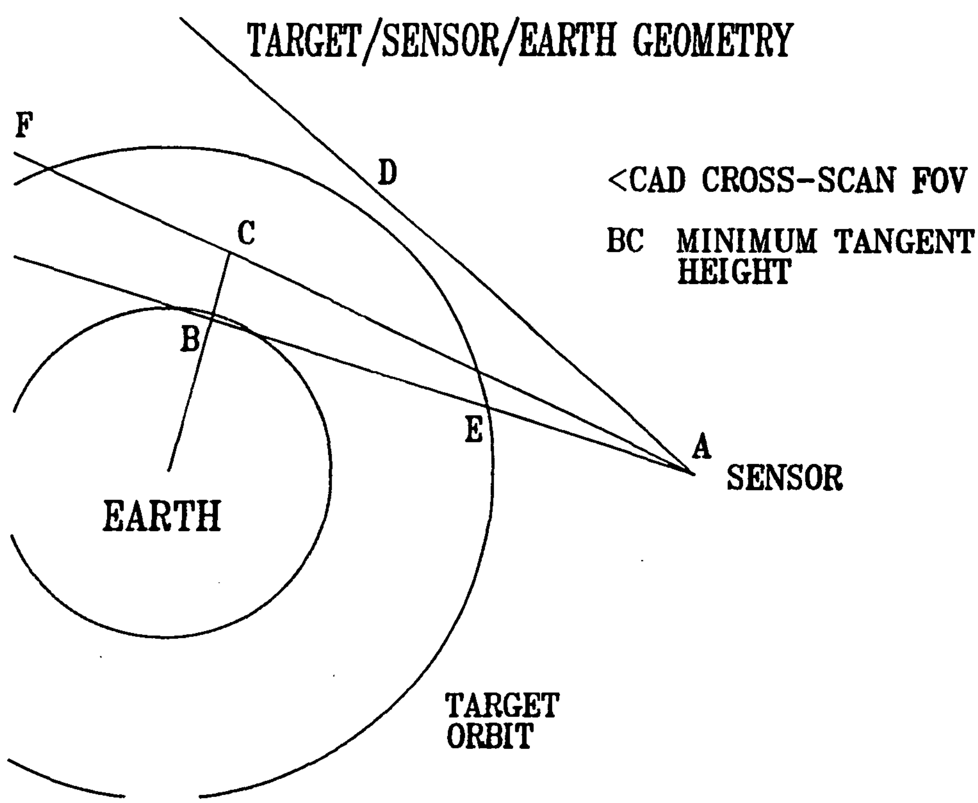
TOPICS

- APPLICATIONS OVERVIEW
  - OBJECTS OF INTEREST
  - BACKGROUNDS
  - RADIATION ENVIRONMENT
  - SENSORS
- DETECTOR REQUIREMENTS
- APPLICABLE DETECTOR TECHNOLOGIES
  - STATE OF THE ART
  - TECHNOLOGY DEVELOPMENT DIRECTIONS
- REQUIREMENTS FOR NEW, COMPETING DETECTOR TECHNOLOGIES

LOW-BACKGROUND LWIR APPLICATIONS

- STRATEGIC DEFENSE
  - SURVEILLANCE, ACQUISITION, TRACKING, DISCRIMINATION, AND KILL ASSESSMENT ("SATKA")
  - WEAPON SYSTEM SUPPORT (FIRE CONTROL, HOMING, ETC.)
- OTHER MILITARY APPLICATIONS
  - RESIDENT SPACE OBJECT SURVEILLANCE
  - DETECTION OF NEWLY LAUNCHED OBJECTS
  - TREATY MONITORING
- NON-MILITARY APPLICATIONS
  - INFRARED ASTRONOMY
  - NEAR-EARTH PHENOMENOLOGY
  - SPACE "JUNK" DETECTION AND TRACKING

TARGET/SENSOR/EARTH GEOMETRY



OBJECTS OF INTEREST

- EMISSIVITY-AREA PRODUCTS:

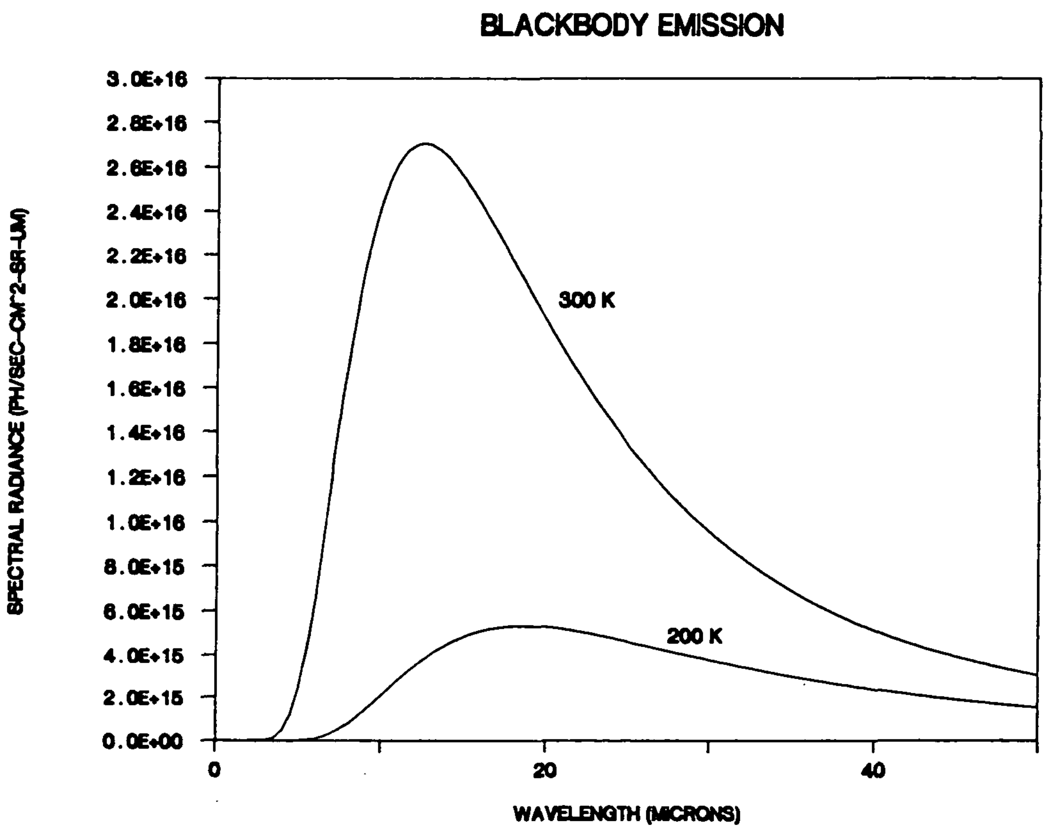
  0.1 - 10 M^2

- TEMPERATURE:

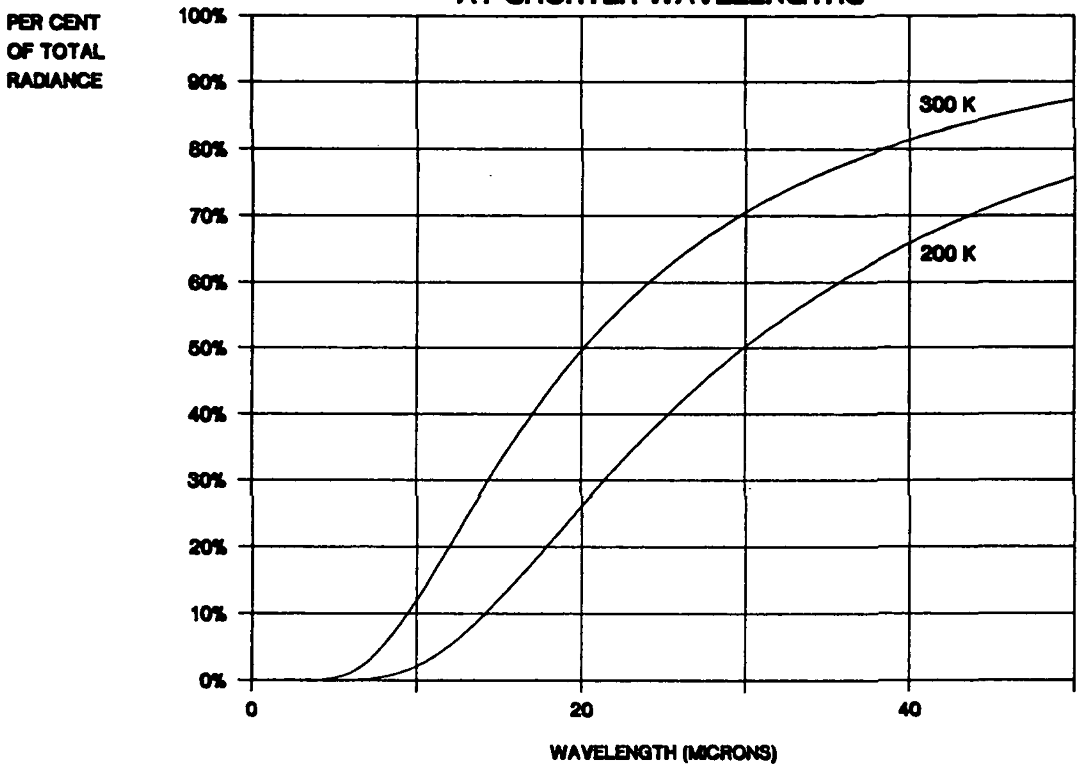
  200 - 300 K

- RANGES:

  1000 - 8000 KM

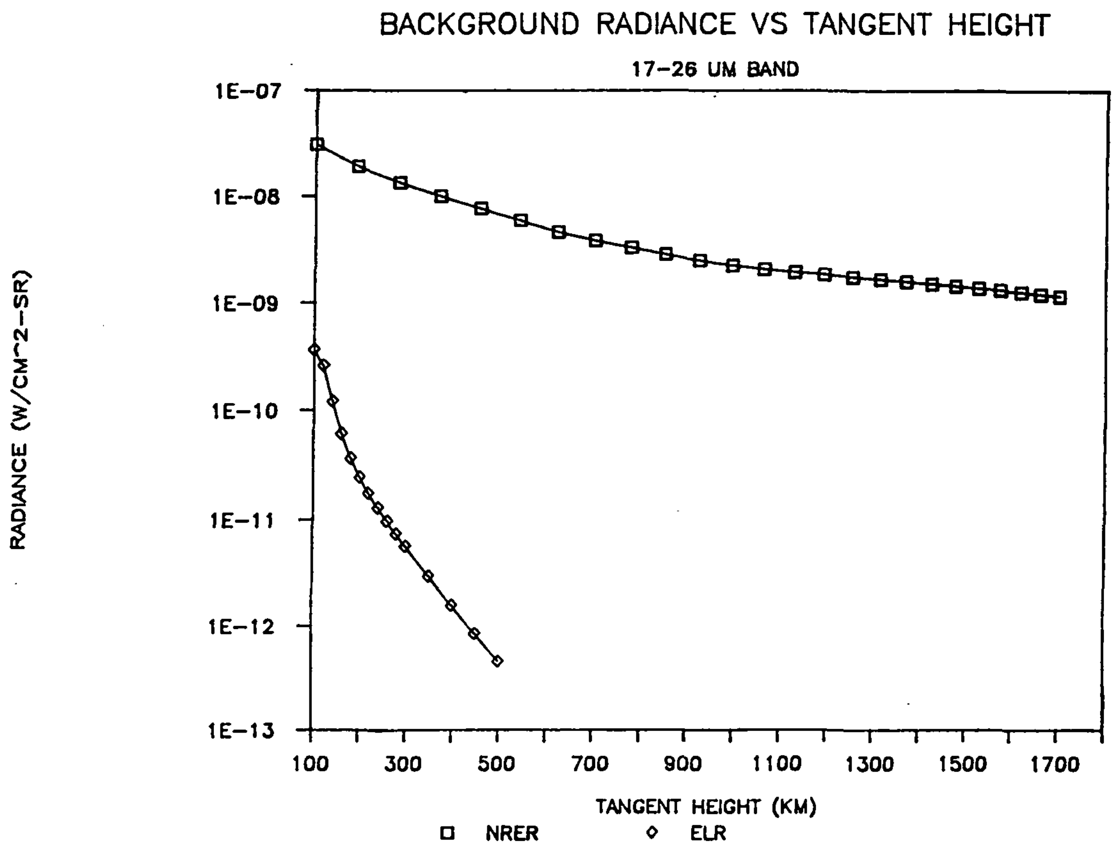


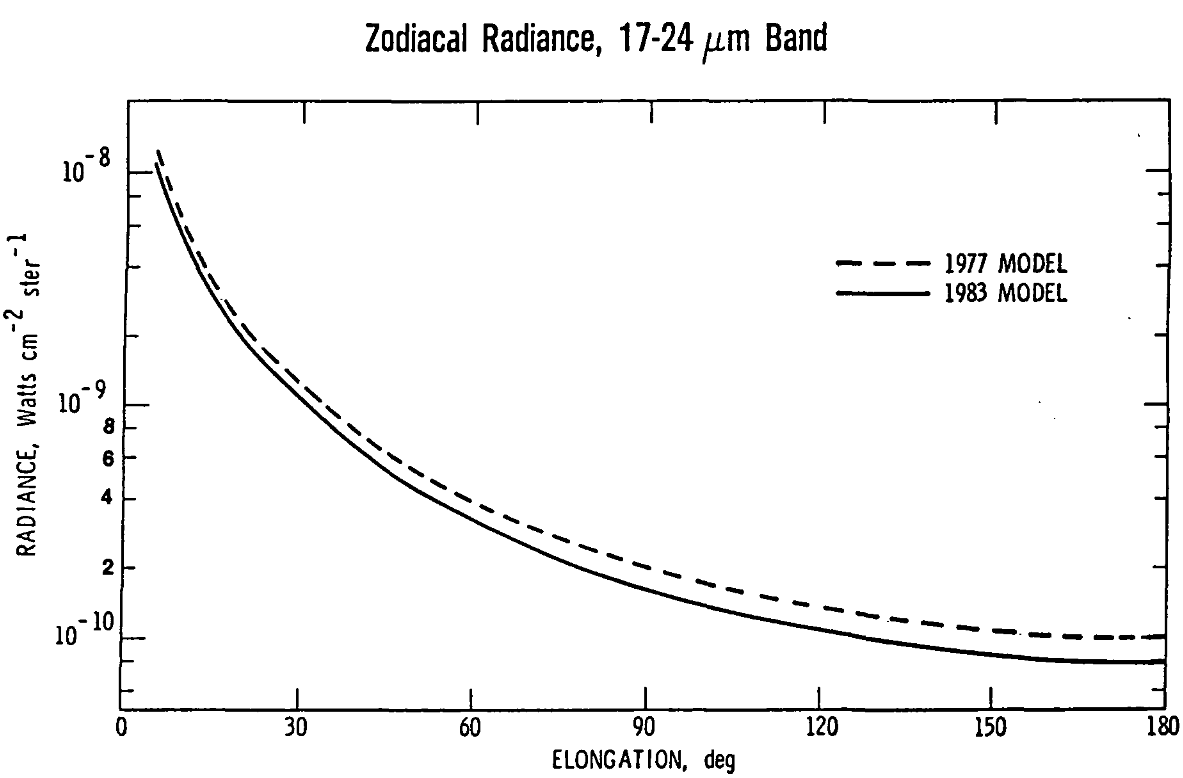
PERCENTAGE OF TOTAL RADIANCE EMITTED
AT SHORTER WAVELENGTHS



IR BACKGROUNDS

- SPACE BACKGROUNDS
  - EARTH LIMB ("ELR")
  - ZODIACAL
  - CELESTIAL
  - NON-REJECTED EARTH RADIANCE ("NRER")
  - ENHANCED (NATURAL AND NUCLEAR)
- FOR TANGENT HEIGHTS › 100 KM AND REALISTIC ASSUMPTIONS ABOUT THE LEVEL OF LIKELY OPTICS CONTAMINATION, NRER WILL BE THE DOMINANT NON-ENHANCED BACKGROUND FOR NEAR-EARTH LINES OF SIGHT


BACKGROUND RADIANCE VS TANGENT HEIGHT
17-26 UM BAND
RADIANCE (W/CM^2-SR)
1E-07
1E-08
1E-09
1E-10
1E-11
1E-12
1E-13
100
300
500
700
900
1100
1300
1500
1700
TANGENT HEIGHT (KM)
NRER
ELR

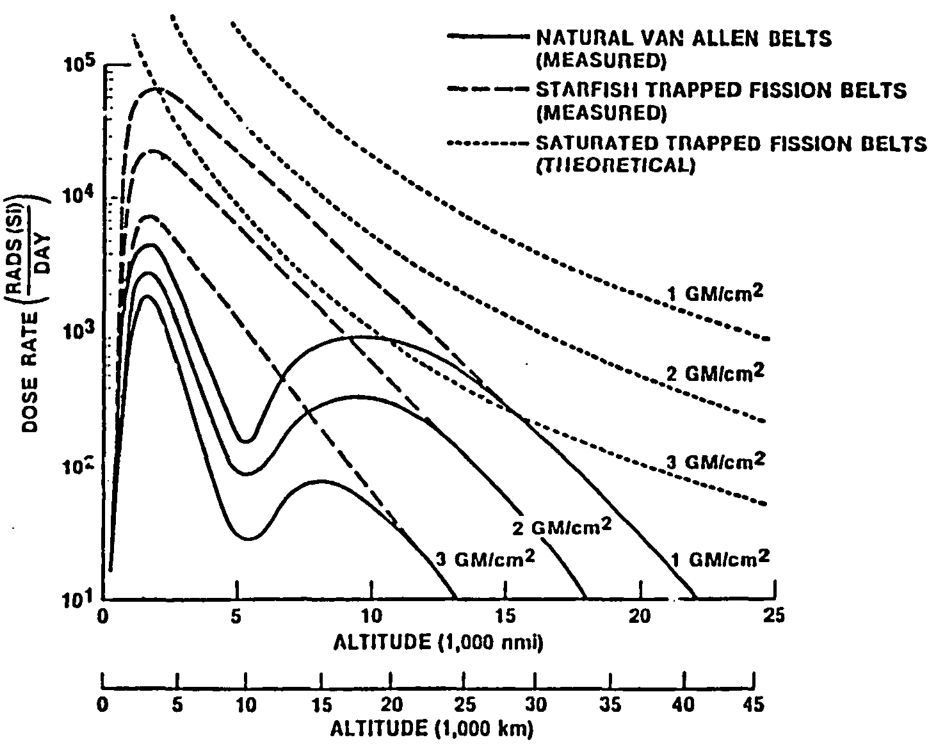

Zodiacal Radiance, 17-24 μm Band
RADIANCE, Watts cm-2 ster-1
10-8
10-9
8
6
4
2
10-10
1977 MODEL
1983 MODEL
0
30
60
90
120
150
180
ELONGATION, deg

RADIATION ENVIRONMENT

- NATURAL ENVIRONMENT
  - WORST CASE DOSE RATE AT FPA, ASSUMING 0.5 INCH ALUMINUM SHIELDING:
    0.02 RAD(SI)/SEC (5 x 10^7 GAMMAS/CM^2-SEC)
  - WORST CASE TOTAL DOSE AFTER 5 YEARS ON ORBIT:
    3 x 10^6 RAD(SI)

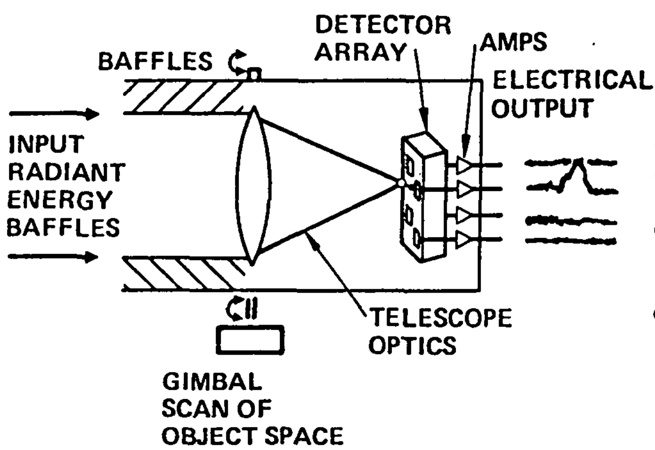
- ENHANCED NUCLEAR ENVIRONMENT
  - TRANSIENT DOSE RATE DUE TO NUCLEAR DETONATIONS CAN BE ORDERS OF MAGNITUDE HIGHER
  - SUSTAINED DOSE RATE DUE TO SATURATED BELT CONDITION CAN BE 1 RAD(SI)/SEC, WORST CASE
  - WORST CASE TOTAL DOSE DUE TO SATURATED BELTS:
    › 10^7 ACCUMULATED OVER 10–300 DAYS

EARTH'S VAN ALLEN BELTS VERSUS ALTITUDE AT 0°



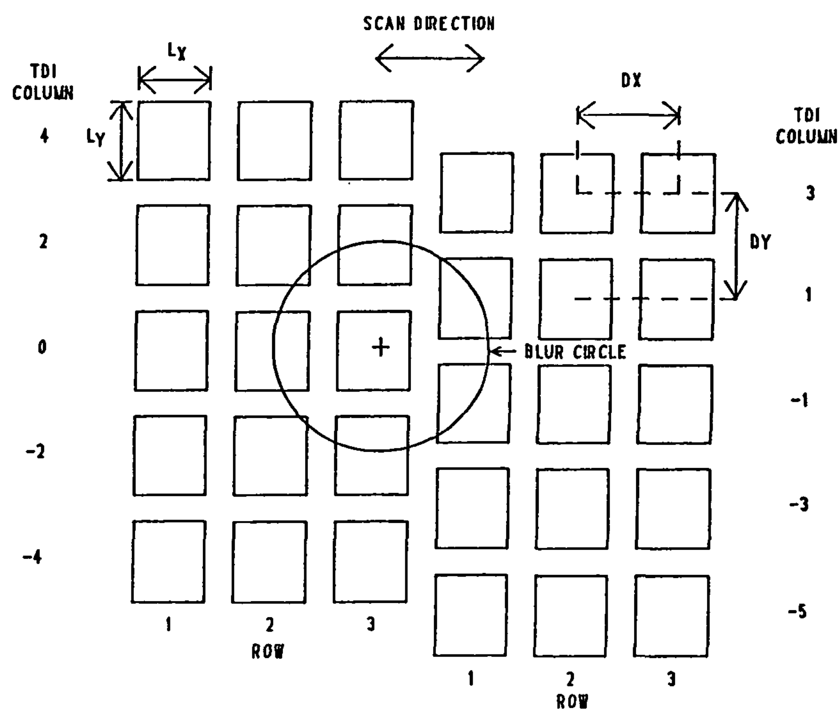
ORIGINAL PAGE IS OF POOR QUALITY

SENSOR SYSTEM OPERATION



- BAFFLES REJECT OFF-AXIS RADIATION
- OPTICS FOCUS TARGET AND BACKGROUND ENERGY
- GIMBAL SCANS SCENE ACROSS DETECTORS
- DETECTORS CONVERT PHOTON SCENE TO ELECTRICAL SIGNAL

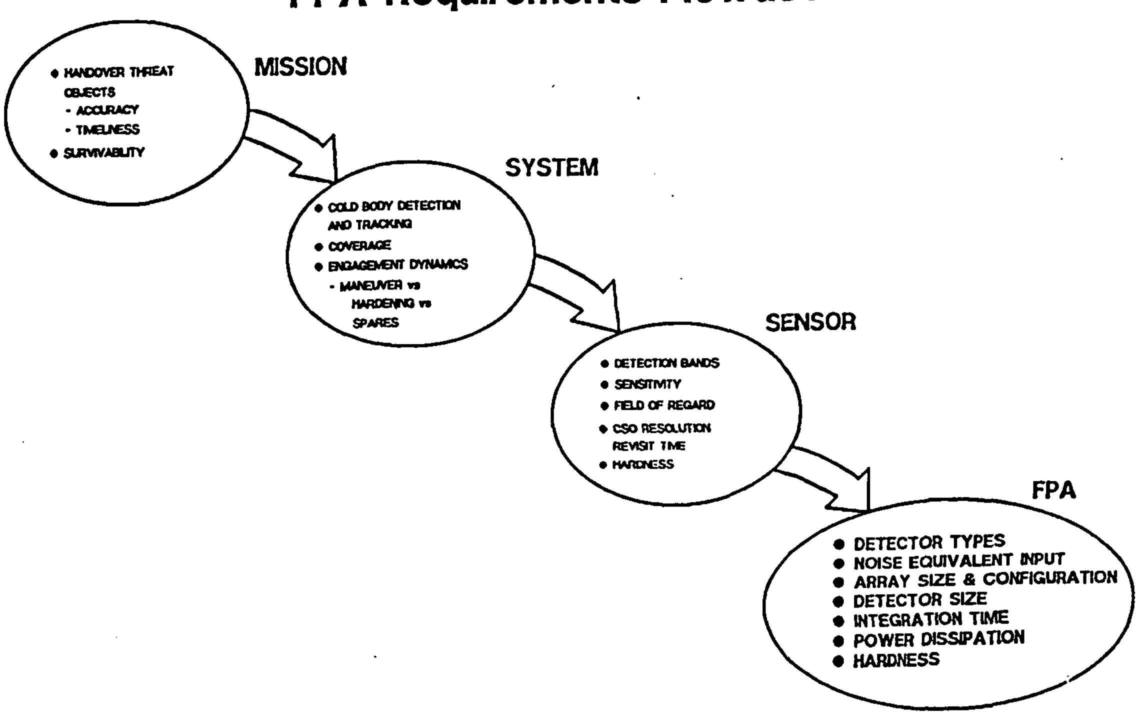
SAMPLE FPA DESIGN CONFIGURATION
THREE TDI STAGES, TWO STAGGERED SUBARRAYS



SIGNAL PROCESSING CHAIN

- o Detector Bias/ Photocurrent Integration
- o Charge-to-Voltage Conversion/ Buffer Amplifier
- o First Stage Multiplexing
- o Analog-to-Digital Conversion
- o Gain & Offset Correction
- o TDI
- o BG Subtraction/ Clutter Suppression
- o Matched Filtering/ Centroiding/ Track Formation ...

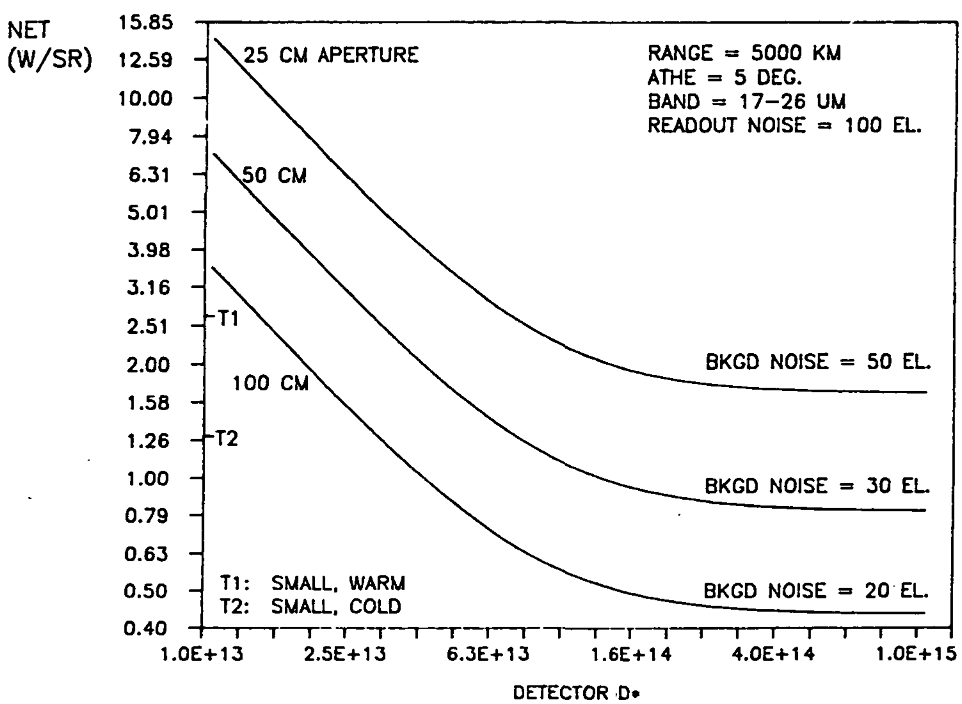
FPA Requirements Flowdown

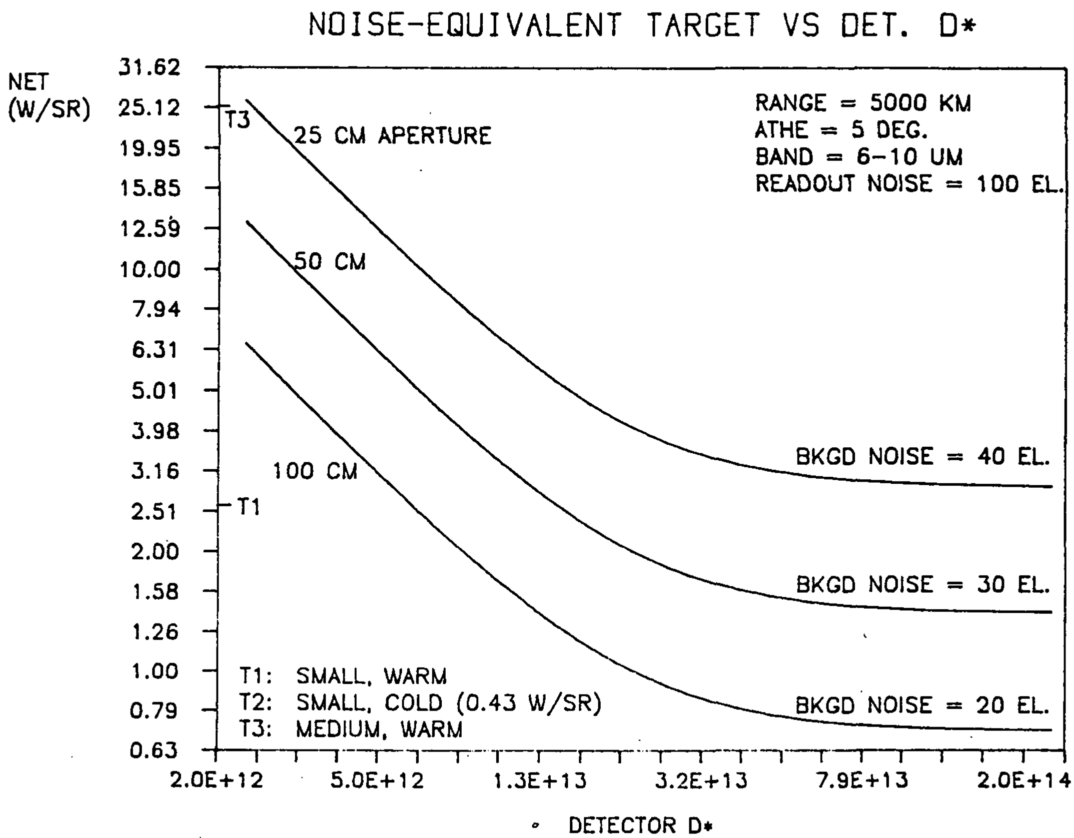


SENSOR PERFORMANCE LIMITED BY NOISE

- **DETECTOR NOISE**
  - MAY BE REDUCED BY COOLING
- **READOUT NOISE**
  - DEPENDS STRONGLY ON COUPLING CIRCUIT DESIGN AND DEVICE CHARACTERISTICS
- **IR BACKGROUND NOISE**
  - RANDOM FLUCTUATIONS OF IN-FOV SOURCES
    - FUNDAMENTAL LIMIT ON SENSOR PERFORMANCE DUE TO NRER VIEWING NEAR EARTH, ZODIACAL RADIANCE VIEWING AWAY FROM EARTH
  - SPATIAL STRUCTURE ("CLUTTER")
  - OPTICS THERMAL EMISSION
    - CAN BE RENDERED NEGLIGIBLE BY COOLING

NOISE-EQUIVALENT TARGET VS DETECTOR D*





KEY DETECTOR REQUIREMENTS FOR LOW-BACKGROUND SPACE APPLICATIONS

- **SPECTRAL COVERAGE:**

  SIGNIFICANT BROAD-BAND RESPONSE WITHIN 6-30 UM REGION, E.G., QUANTUM EFFICIENCY › 40% OVER A 5 UM SUB-BAND

- **SENSITIVITY:**

  D* › 1E14 CM-HZ /W AT 20 UM

  D* › 5E13 CM-HZ /W AT 10 UM

- **FREQUENCY RESPONSE:**

  BANDPASS › 10 KHZ, NO ANOMALIES

- **DYNAMIC RANGE:**

  LINEAR RESPONSE FROM NOISE LEVEL TO 1E4 TIMES THE NOISE LEVEL

KEY DETECTOR REQUIREMENTS FOR LOW-BACKGROUND SPACE APPLICATIONS (CONT.)

- **POWER DISSIPATION:**

  POWER DISSIPATED ON FPA < 10 UW/DETECTOR

- **RADIATION HARDNESS:**

  TOTAL DOSE HARDNESS > 1E6 RAD(SI)

  EFFECTIVE GAMMA AREA < 1E-6 CM (100 UM DET.)

- **PIXEL SIZE:**

  50-150 UM (SQUARE)

- **CONFIGURATION:**

  TWO-DIMENSIONAL MOSAIC ARRAYS, E.G., 10-20 X 50 DETECTORS PER CHIP

APPLICABLE TECHNOLOGIES

- **DETECTORS**

	SPECTRAL CUTOFF (UM)	OPERATING TEMPERATURE (K)
Si:As IBC	26	12
Si:Ga IBC	17	18
PV HgCdTe	10	40

- **READOUTS**

  - MATERIALS: SILICON, GERMANIUM, GaAs

  - VERY LOW NOISE, RADIATION HARD DEVICES ARE UNDER DEVELOPMENT

TECHNOLOGY ASSESSMENT

- Si:As IBC
  - MEETS PERFORMANCE REQUIREMENTS
  - LOW OPERATING TEMPERATURE REQUIRES ADVANCED 3-STAGE CRYOCOOLERS FOR SPACE-BASED SYSTEMS
  - PRODUCIBILITY DEMONSTRATION PLANNED
- Si:Ga IBC
  - REQUIRES DEVELOPMENT
  - OPERATING TEMPERATURE NOT HIGH ENOUGH TO ALLEVIATE CRYOCOOLER PROBLEM (3 STAGES STILL REQUIRED)
- LWIR PV HgCdTe
  - INDIVIDUAL DETECTORS WITHIN ARRAYS MEET REQUIREMENTS
  - OPERATING TEMPERATURE COULD BE SUPPORTED BY A 2- STAGE COOLER
  - SEVERE NON-UNIFORMITY PROBLEM
  - UNSUITABLE FOR SOME STRATEGIC DEFENSE SURVEILLANCE MISSIONS
    - TRACKING COLD TARGETS
    - DISCRIMINATION

TECHNOLOGY DEVELOPMENT DIRECTIONS

- GREATER SENSITIVITY
  - ULTRA-LOW NOISE READOUTS
  - IMPROVED RoA UNIFORMITY OF HgCdTe DETECTORS
- GREATER TOTAL DOSE HARDNESS
  - ULTRA-RAD HARD READOUTS
  - IMPROVED HARDNESS OF HgCdTe DETECTORS
- GREATER OPERABILITY IN GAMMA ENVIRONMENTS
  - DEVELOPMENT OF "INTRINSIC EVENT DISCRIMINATION" (IED) CONCEPTS
- GREATER PRODUCIBILITY
  - PILOT LINE DEMONSTRATION FOR Si:As IBC HYBRIDS IS PLANNED

REQUIREMENTS FOR NEW, COMPETING TECHNOLOGIES

ASSUMPTION: NEW TECHNOLOGY HAS PERFORMANCE EQUIVALENT TO OR SUPERIOR TO THAT OF THE INCUMBENT TECHNOLOGY WITH WHICH IT COMPETES

SPECTRAL BAND: 6 - N UM	OPERATING TEMPERATURE < 25 K	OPERATING TEMPERATURE > 25 K
N = 10	R — NOT COMPETITIVE WITH EITHER HgCdTe OR Si:As.	G — COMPETITIVE WITH HgCdTe, ESPECIALLY IF HARDER OR MORE UNIFORM.
N = 25	G — COMPETITIVE WITH Si:As, ESPECIALLY IF OPERABILITY IN A GAMMA ENVIRONMENT IS SUPERIOR.	B — COULD DISPLACE Si:As— ONLY A 2-STAGE COOLER REQUIRED.
N = 30	G — COULD DISPLACE Si:As IN APPLICATIONS REQUIRING VERY COLD BODY DETECTION.	B — COULD DISPLACE Si:As. ADDITIONAL SPECTRAL COVERAGE MAY BE USEFUL.

R = LITTLE OR NO UTILITY   G = MODERATE UTILITY   B = GREAT UTILITY

SUMMARY

- DETECTOR SENSITIVITY REQUIREMENTS FOR LOW BACKGROUND SPACE APPLICATIONS ARE STRINGENT AND ARE DRIVEN BY:
  - STRESSING MISSIONS, E.G., DIM TARGETS, LONG RANGES
  - LOW BACKGROUND NOISE LIMIT
  - AVAILABILITY OF LOW NOISE READOUTS
- DETECTOR RADIATION HARDNESS REQUIREMENTS ARE ALSO STRINGENT:
  - SPACE BASING MAKES HIGH TOTAL DOSE HARDNESS ESSENTIAL
  - STRATEGIC DEFENSE SURVIVAL AND OPERABILITY REQUIREMENTS ARE EXTREMELY STRESSING
- NEW TECHNOLOGIES SUCH AS MQW DETECTORS CAN COMPETE WITH THE BETTER DEVELOPED EXISTING TECHNOLOGIES ONLY IF THEY:
  - MEET PERFORMANCE REQUIREMENTS
  - OFFER A SUBSTANTIAL ADVANTAGE OVER AN EXISTING TECHNOLOGY
    - □ HIGHER OPERATING TEMPERATURES (> 25 K) WITH SPECTRAL COVERAGE TO 25-30 UM
    - □ HIGHER PERFORMANCE OR PRODUCIBILITY THAN HgCdTe WITH COMPARABLE SPECTRAL COVERAGE AT A COMPARABLE OPERATING TEMPERATURE