Advanced Space-Based Detector Research at the Air Force Research Laboratory

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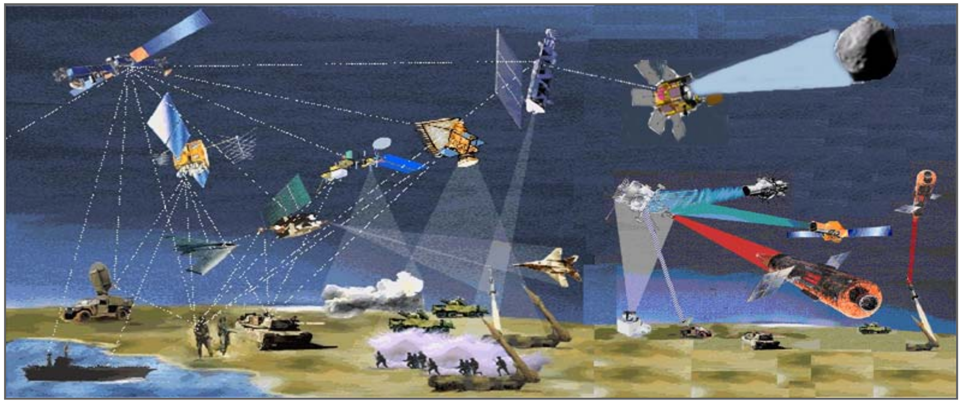
Outline

- General issues for photodetectors in space applications
- Some challenging problems
- A concept for a monolithic sensor
  - Optical signal amplification
  - Tunable detection
  - On-chip cooling
- A concept for a polarimeter in a pixel

Surveillance from Space and Space Situational Awareness



MISSIONS

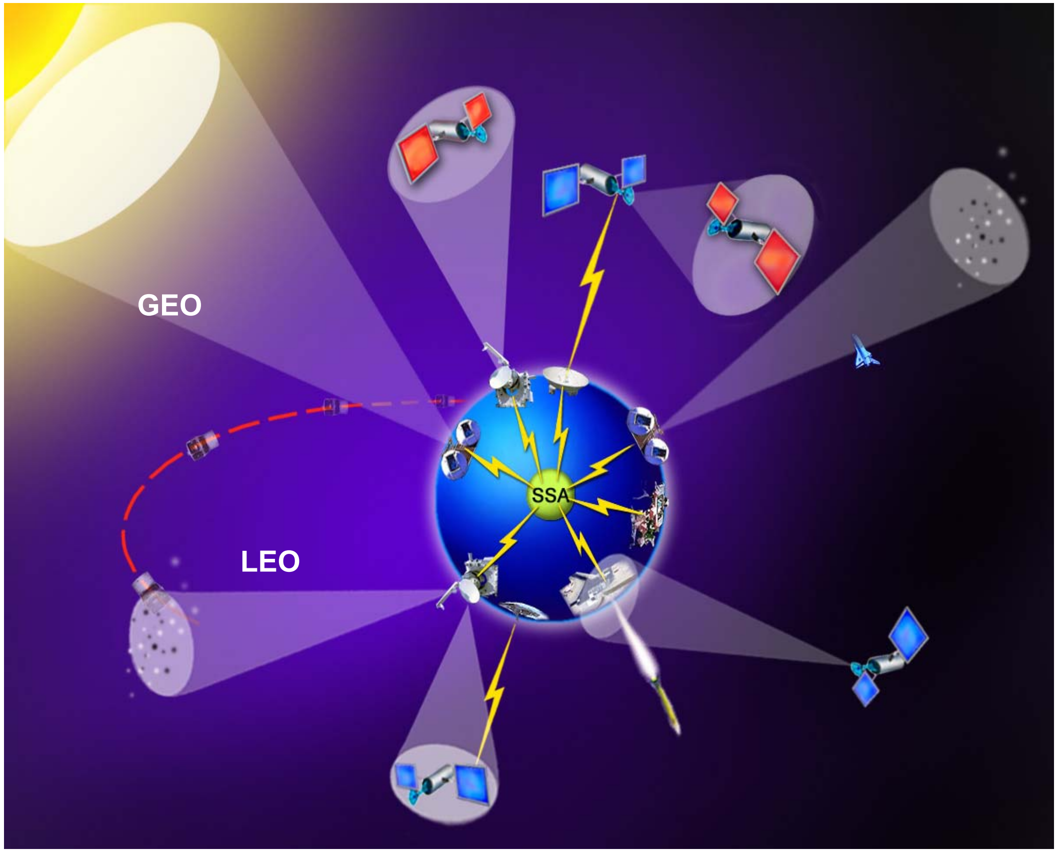
- Cold Objects
  - VLWIR and beyond
- Electronically Heated Objects
  - MWIR, LWIR
- Dim, Distant Objects
  - High efficiency detectors
  - Optical signal amplification
- Moving Objects
  - Fast detector response time
- Large Area Detection/High Resolution
  - Large format

CAPABILITIES

- Object Identification
  - Multicolor sensing
  - Polarization sensing
- Reconfigure for Multiple Missions (space background, Earth background, manmade/natural/near/far objects)
  - Tunable detector response
  - UV, VIS, IR, Far IR, THz, Radar
- Small satellites, Ultrafast processing
  - Monolithic integration of detector/electronics/cooling
- Self Protection
  - Against environment
  - Reconfigure after damage

Space Situational Awareness

Detect, track, and identify cold and hot objects from LEO to GEO with both Earth and Stellar backgrounds.
Objects can be either sunlit or in eclipse.

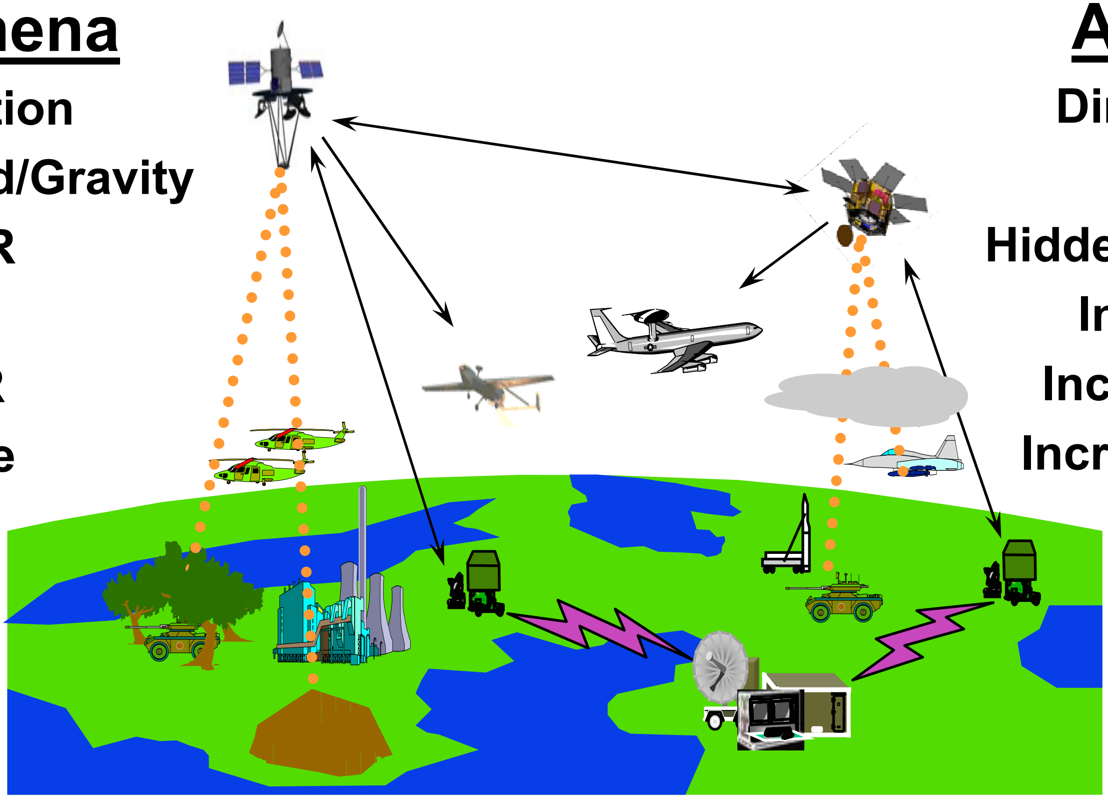


Surveillance from Space

Develop sensors that can reconfigure themselves for persistent surveillance day or night, through all weather, through all vegetation, below or above the ground in a timely manner at a reduced cost

Phenomena

Polarization
Magnetic Field/Gravity
VLWIR
LWIR
MWIR
Visible



Applications

Dim/Distant Object
Object ID
Hidden Object Detection
Increased Range
Increased Coverage
Increased Resolution

Requirements for Space Applications

Distant Objects (>100 km)

High Sensitivity for Dim Sources

High Uniformity for Tracking of Single-Pixel Objects

Cannot Image Single-Pixel Objects

Low Background (~10^9 photons/cm^2/s)

Low Noise

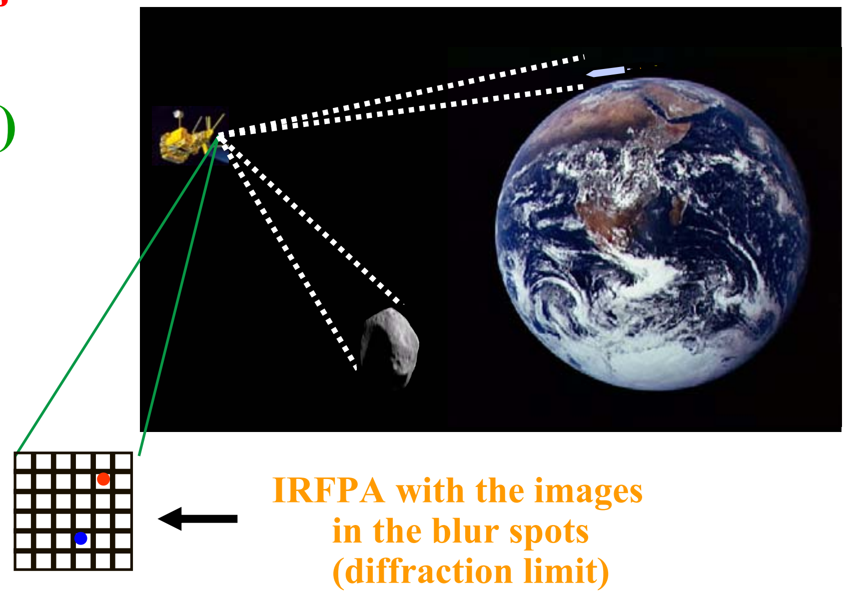
Low Temperature Operation (~40K)

Low Power Consumption

Satellite electric power is limited

Low Weight Requirement

Lower launch cost

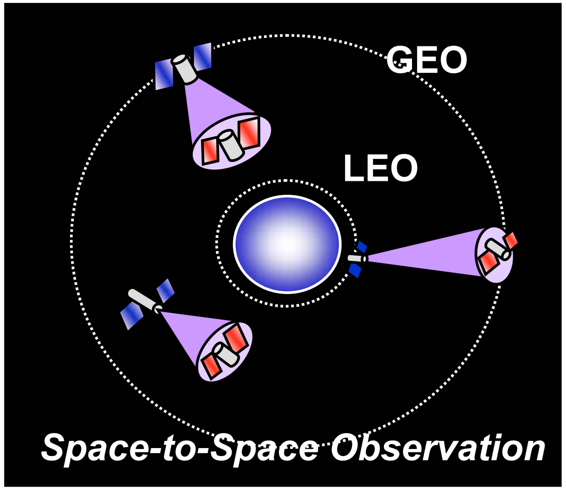


Radiation Environment

Radiation Hard to protons, gamma rays, etc.

SSA Challenges for Advanced Detectors

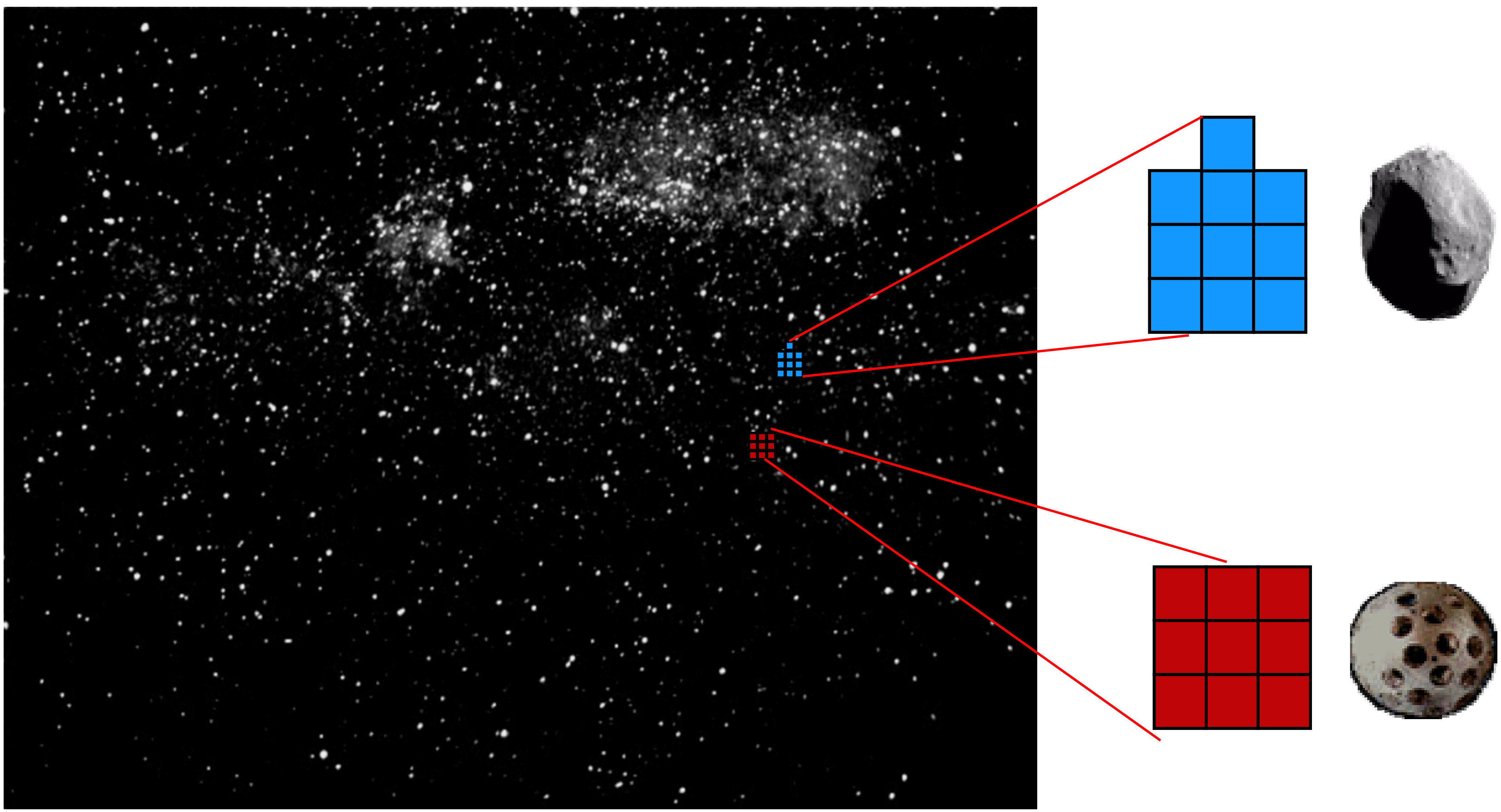
- **Provide timely and accurate object awareness data:**
  - **Provide day and night remote sensing of objects located in LEO, MEO and GEO.**
  - **Provide 4π steradians faint object detection and identification.**
  - **Provide small feature discrimination.**
  - **Determine object status based on spectral, temporal, and polarimetric signatures:**
    - Location, orientation, spin-rate, relative motion, mass
    - Components and material temperatures
    - other indicators of interest …



Object Identification

What if we could better identify objects?

Tunable multispectral detection will do that
- more colors ==> better ID

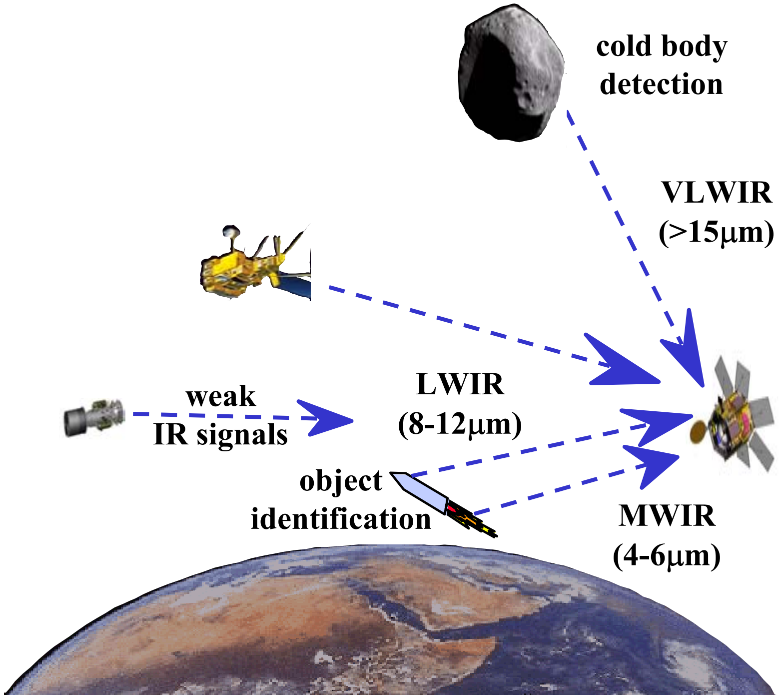


Tunable Multicolor Sensors

To reduce size, cost, weight, and complexity of a sensor system, we would like to be able to see any color we want, any time we want, within a single pixel of a sensor

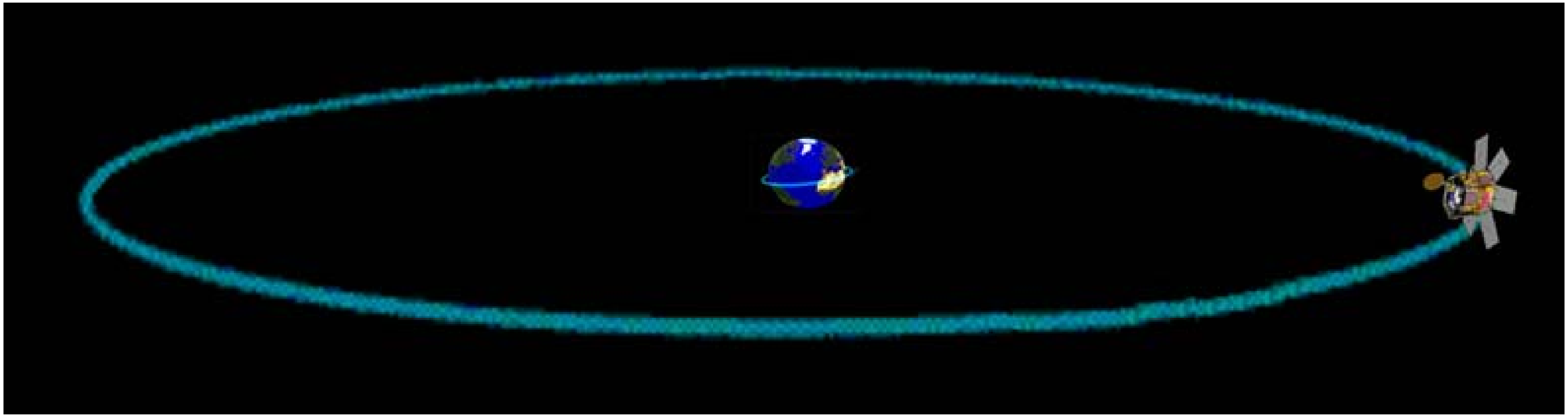
Tunable detection

- **discrete enery levels**
- **Qwells**
- **Qdots**
- **Superlattices**



Dim/Distant Objects

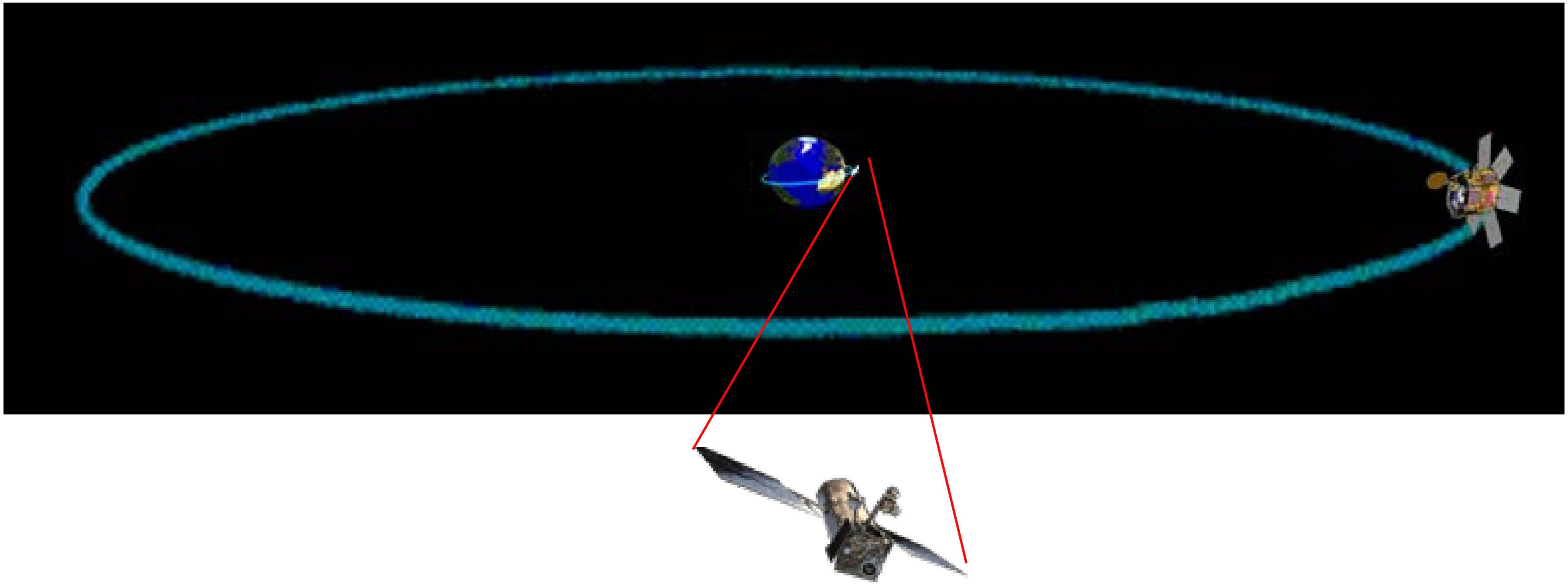
What if we could locate distant/dim objects?



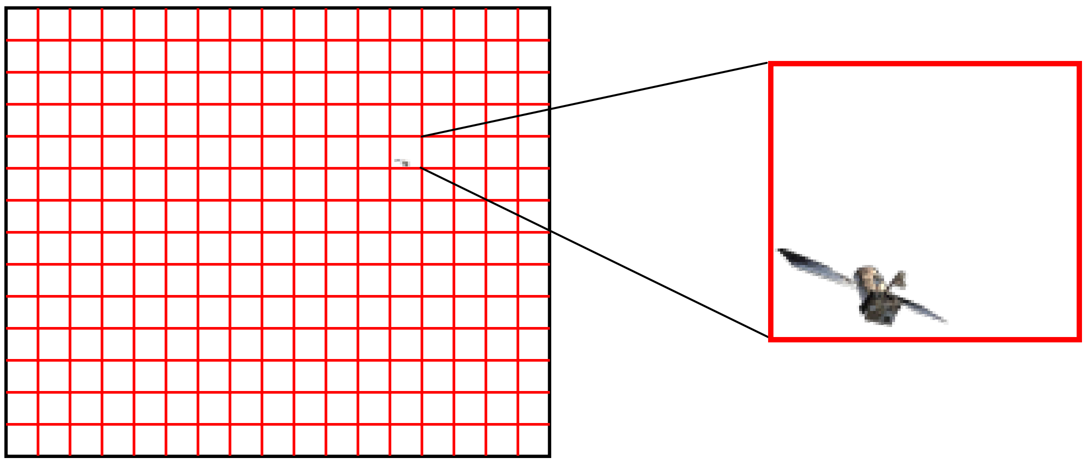
From LEO to GEO is approximately 35,000km.

Objects are dim.
Images are subpixel to only a few pixels across.

Optical amplification will do that
- greater amplification & greater optical sensitivity ==> dimmer objects

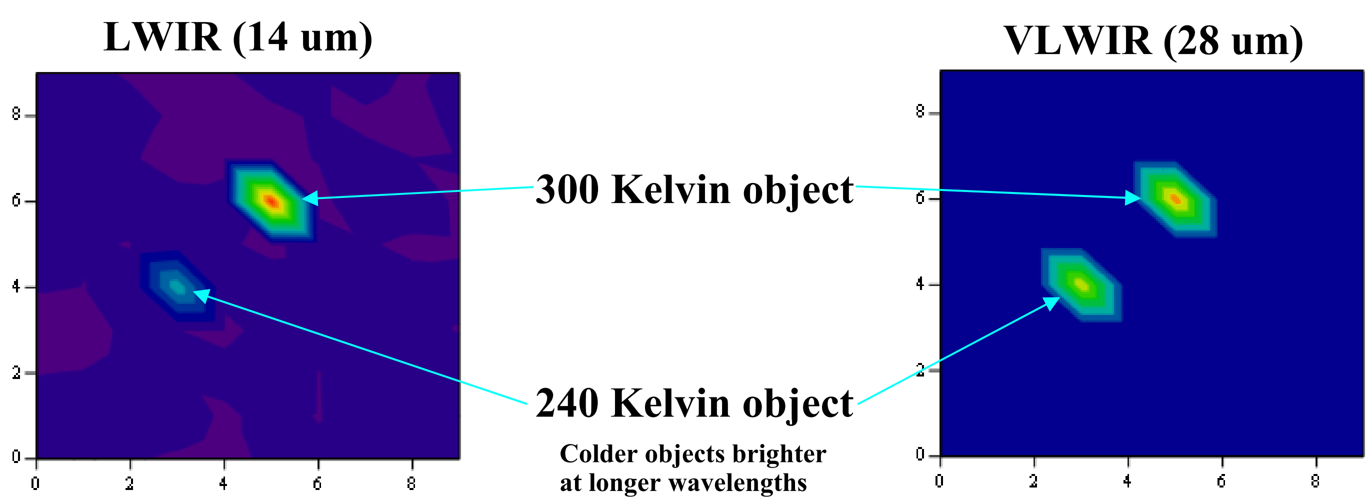


Higher Resolution and/or Longer Wavelength Detection



Sub-Pixel Resolution or Decreased Pixel Size for sub-pixel images

LWIR vs. VLWIR for Cold-body Acquisition Range



Calculations due to Dr. Paul LeVan

Status Determination

What if we could determine the following about objects:

- ***Is it alive, dead, on standby?***
- ***What are its functional capabilities?***
- ***What is its operational intent?***
- ***If malfunctioning, what is wrong?***
- ***What is its mass?***
- ***Etc.***

Close observation in multiple phenomenologies will do that

Need small satellite, with multifunctional capabilities

- *UV*
- *Vis*
- *IR*
- *THz*
- *Magnetic Field*
- *Gravitational Field*
- *Polarization*

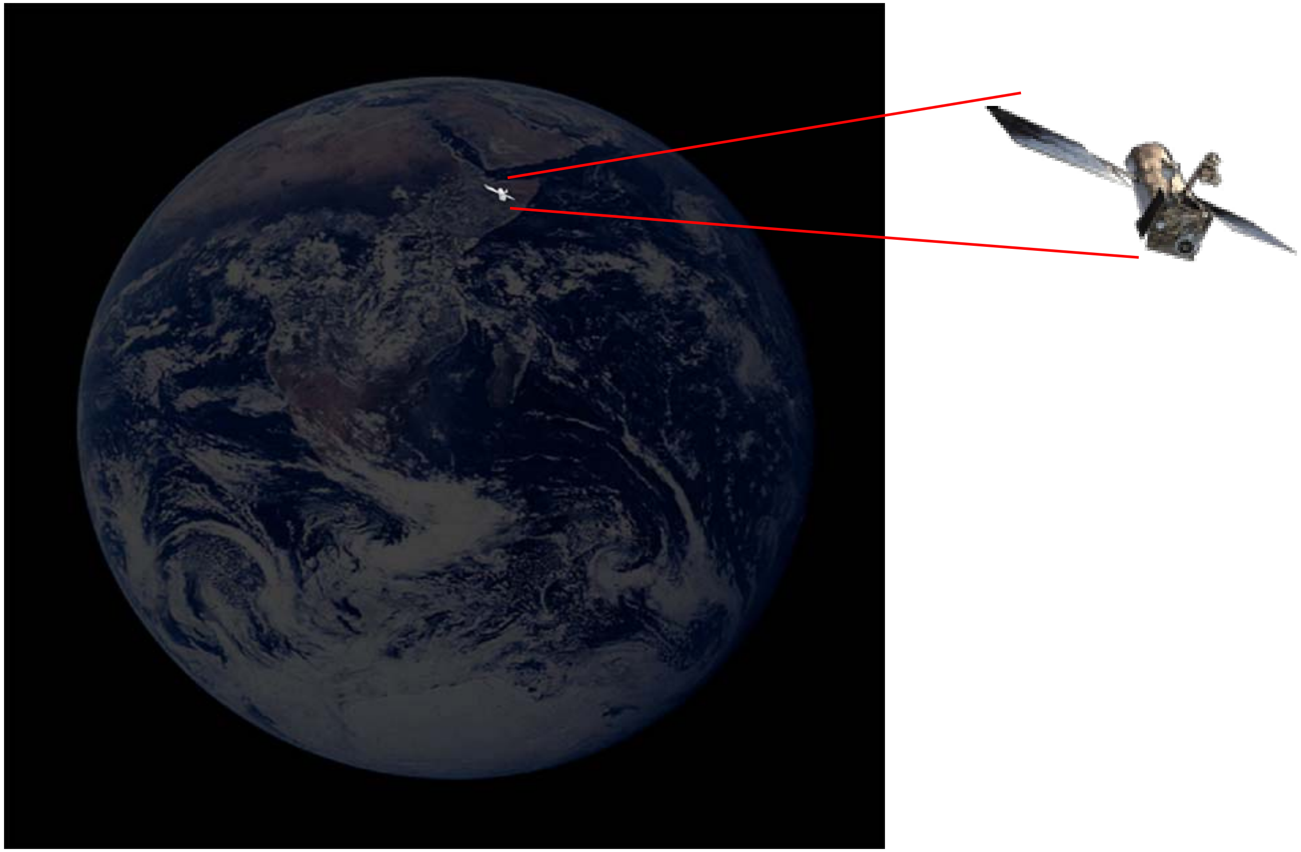
Multiple Phenomenologies

- UV for improved resolution (if sunlit)
- Visible for overall look
- IR for temperature sensing
- THz for electronics and communications sensing
- Magnetic Field for power determination
- Gravitational Field for mass determination
- Polarization for contrast enhancement and/or shape determination

Earth Background

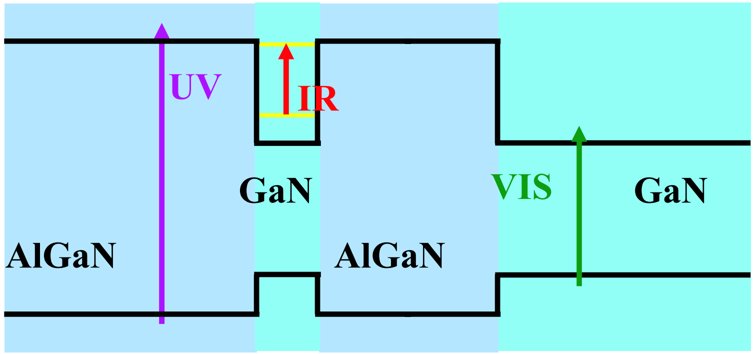
What if we could locate objects with Earth as the background?

Detecting in the solar blind UV, where the Earth is dim, will do that

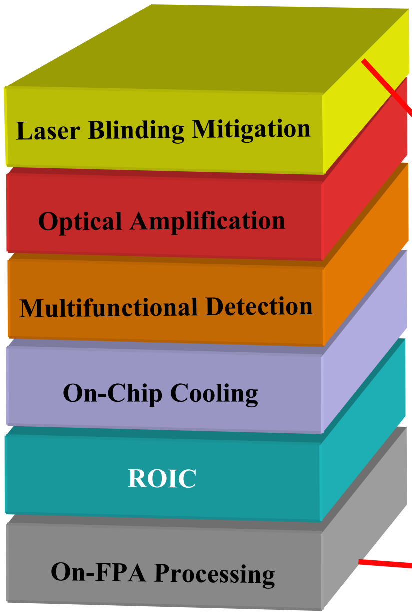


UV/Vis/IR Detection

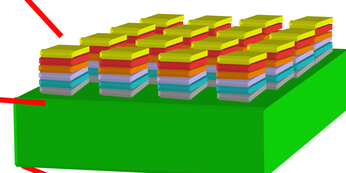
- Increased resolution
- Increased discrimination
- Materials identification

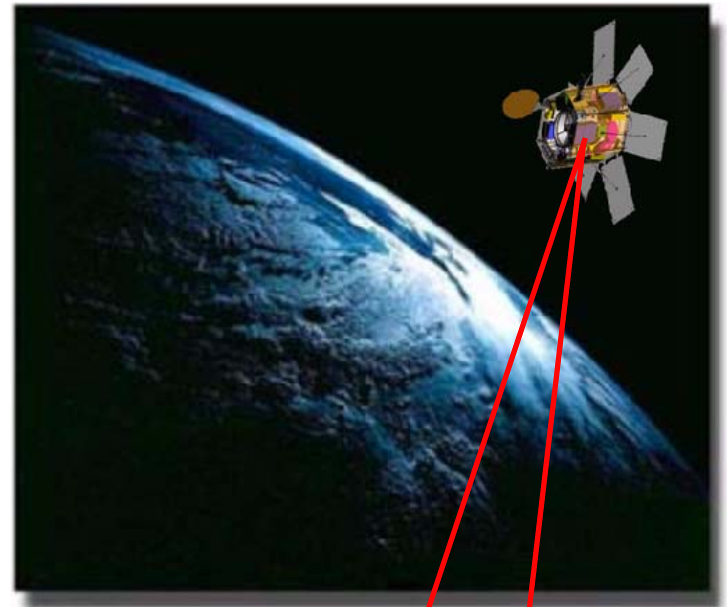


A Concept for an Intelligent Multifunctional Sensor

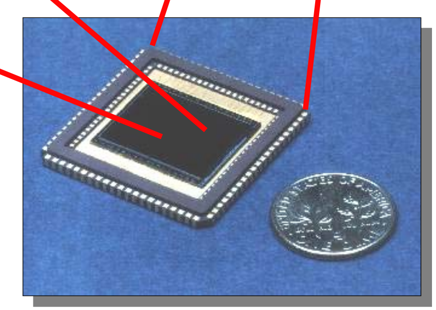


Self-Contained Intelligent Multifunctional Monolithically-Integrated Sensor System

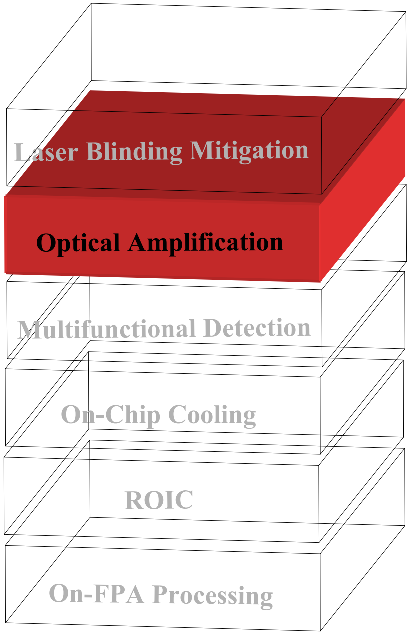




- Self protection
- Improved detection efficiency
- Increased functionality
- Reduced volume/weight
- Increased reliability and speed
- Autonomous reconfiguration
- Reduced cost

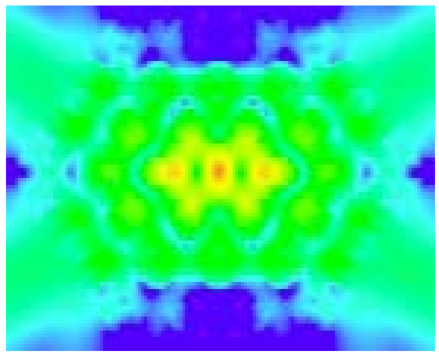


Optical Signal Amplification



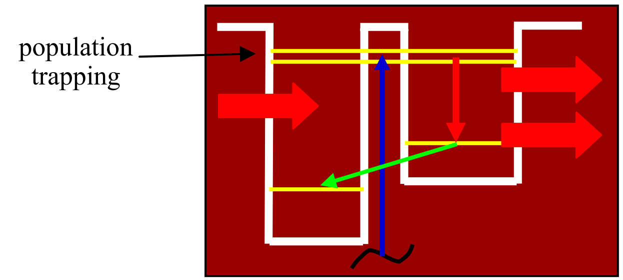
Electromagnetic Field Enhancement

Photonic Crystal Microcavities

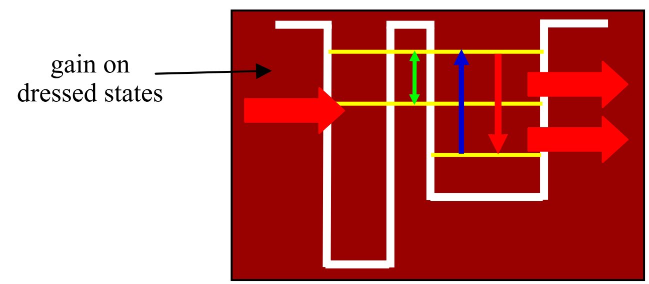


Put quantum dots in the cavity-enhanced field

Quantum Interference in QWs

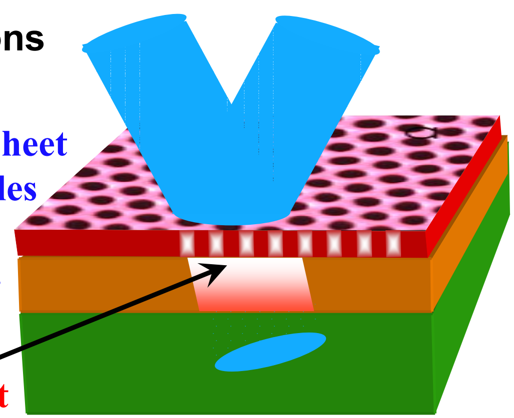


Using off-diagonal coupling

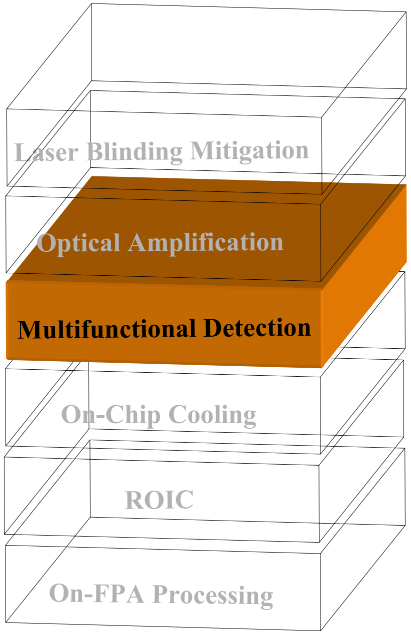


Using microwave coupling

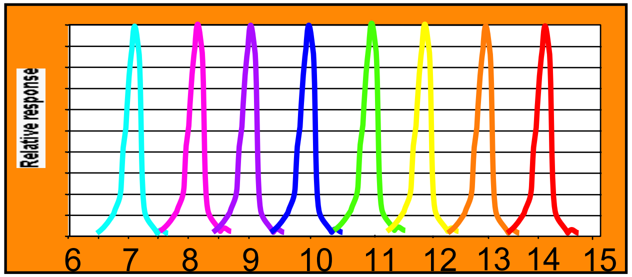
Plasmonic Interactions

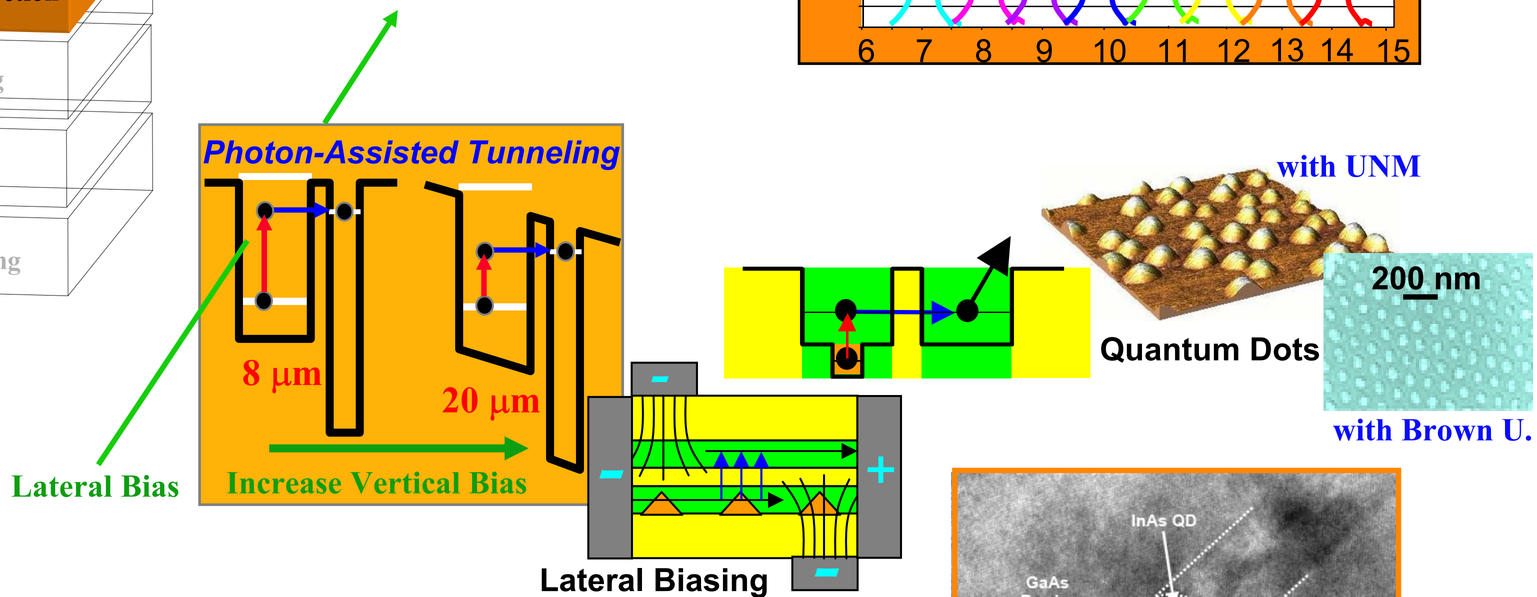


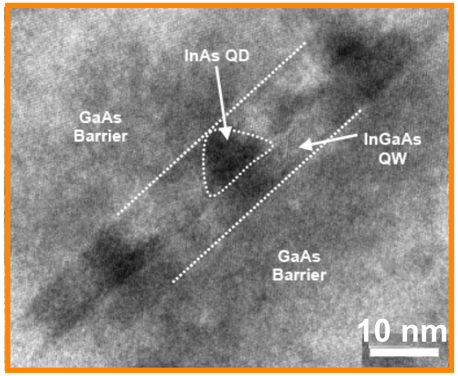
Frequency-Agile Detection



Tunable Detector Response



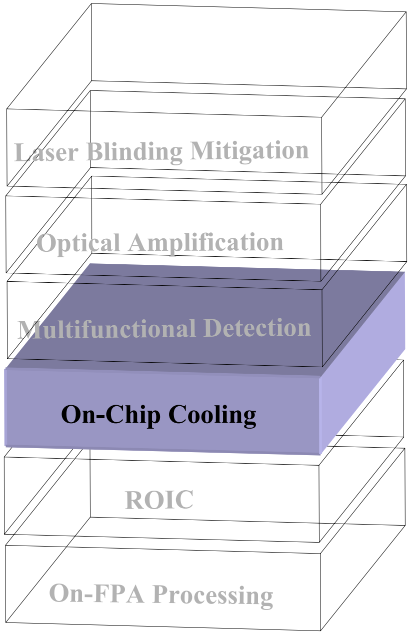




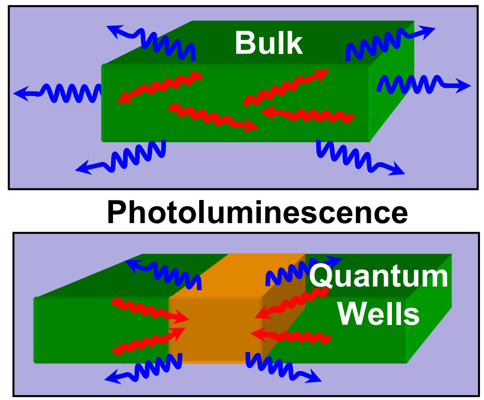
Quantum Dots buried in Quantum Wells

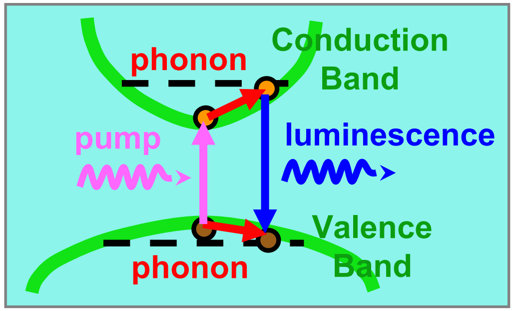
with UNM

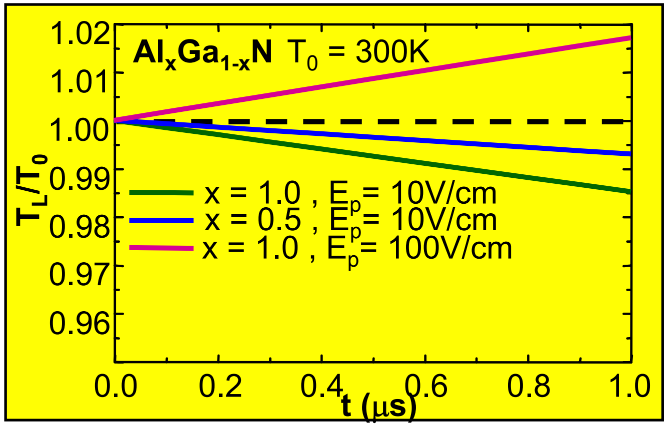
Quantum-Electronic Refrigeration



Pixel-By-Pixel Cooling

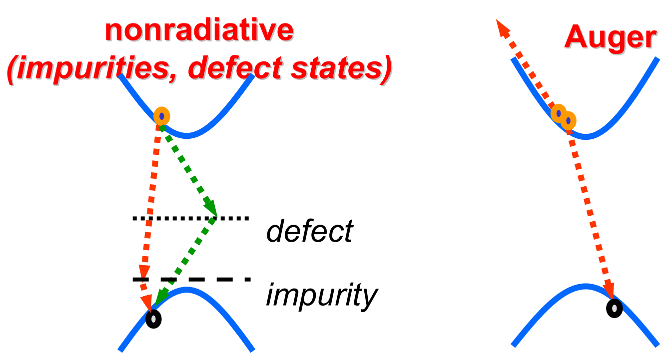




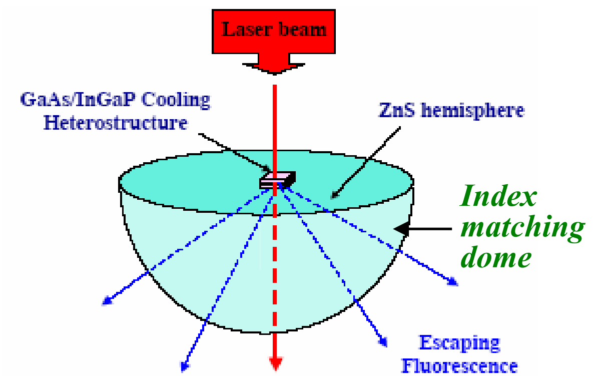


Some Practical Issues

1. Non-Radiative Decay



2. Enhancement of Photon Escape

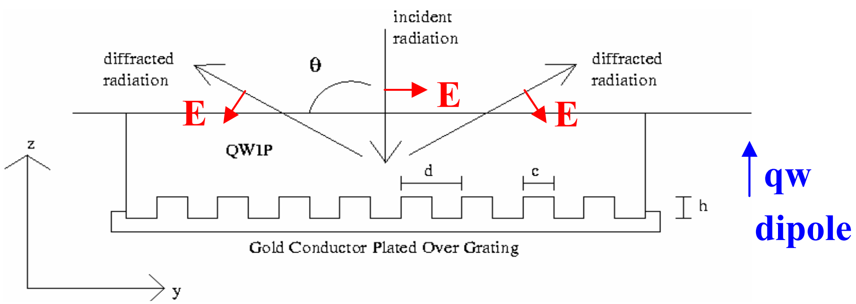


Polarimeter Application of Quantum Wells

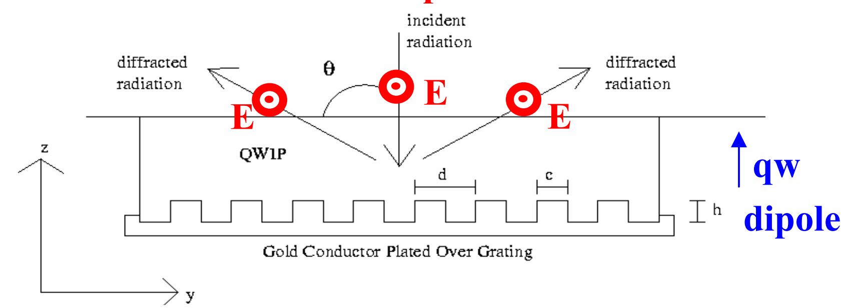
Quantum Wells only absorb IR light polarized parallel to growth direction.

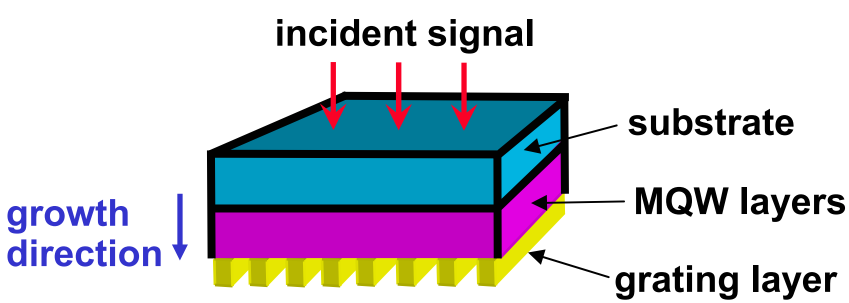
Therefore, use gratings to distinguish various polarizations.

TM Polarization: Absorption

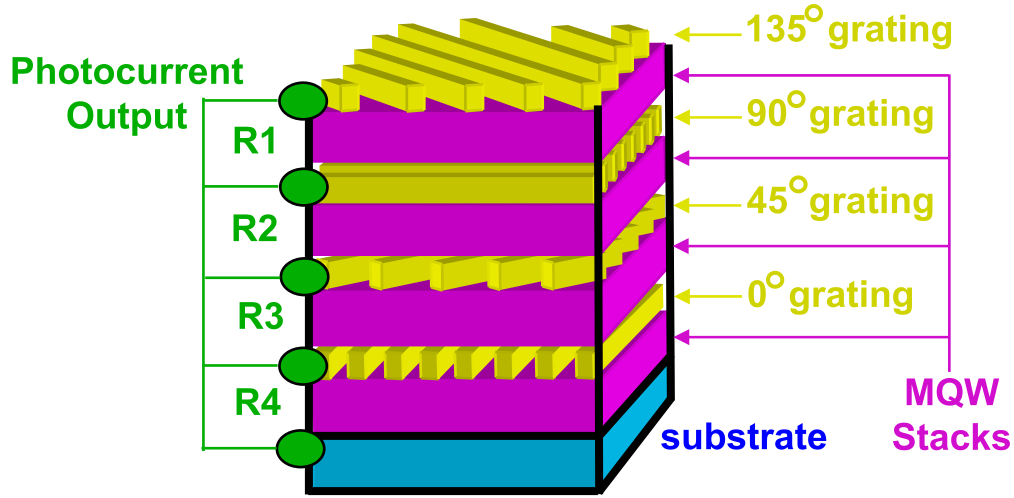


TE Polarization: No Absorption





Single-Pixel Polarimeter

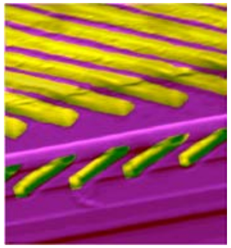


Opportunities:

- **Improved contrast enhancement**
- **Sub-pixel resolution**
- **Materials discrimination**

With simultaneous, co-registered detection of complete polarization

Polarization-Dependent Absorption Within QW Layers	+	**Interference Between Multiply-Diffracted Light Paths**	+	**TE & TM Mixing by the Gratings**	=	**Fully Polarization Dependent Readouts**



First Two-Layer Demo

Goal:

Simultaneous detection of total polarization vector within single pixel

Research Challenges/Topics:

- dielectric grating model
- wafer fusion
- quantum well optimization

Summary

- The requirements for use in space sometimes rule out the use of sensors that are fine in a 300K Earth environment

- We are investigating several technologies to amplify the incoming signal to a photodetector

- We are investigating a method to tune the spectral response of a photodetector

- We are investigating an optical method for on-chip cryogenic cooling of focal plane arrays

- We are looking into the possibilities of using quantum wells to detect the full polarization vector within a single pixel