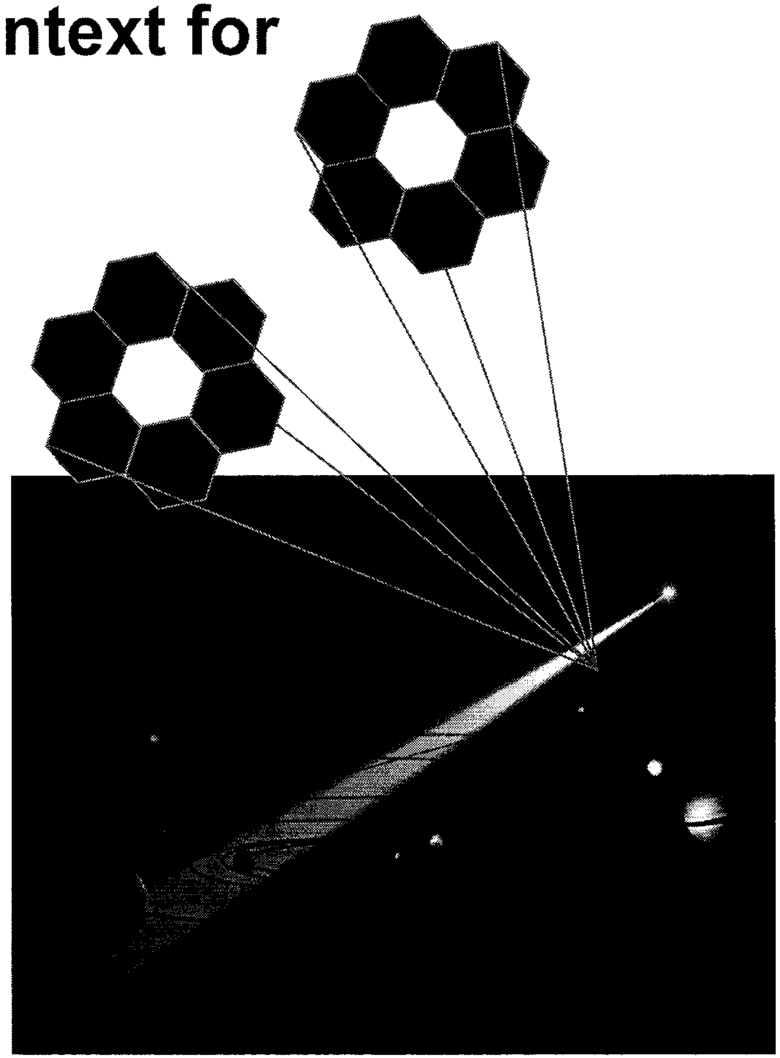
# Technology Development for Future Origins and SEU Missions

Jet Propulsion Laboratory
California Institute of Technology

## Overview of Technology Context for the SAFIR Mission

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31 July 2002

(revised 05 November 2002)

# Rationale for Technology Development

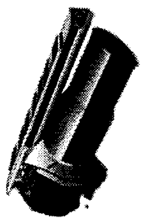
- The first wave of Origins missions ---SIRTF, SIM, NGST, TPF--- are well underway because of the previous decade's technology investments.
  - A decadal strategy for technology investment and capability development
  - Maintain technology focus on key capabilities: Cryogenic Telescopes, Detectors, Interferometer Technologies, Lightweight Deployable Optics, Ultra Lightweight Structures, ...
- From the Origins/SEU Road Maps and the Decadal survey, we now have a validated set of notional mission goals for the next generation of space observatories
  - SAFIR-- Large, single aperture IR telescopes
  - SUVO ---Large, single aperture telescope for optical/UV
  - Future Origins Missions:
    - Life Finder --- A constellation of large IR telescopes to look for spectroscopic biosignatures
    - Planet Imager --- Constellation of large optical telescopes to make resolved images of planets
- New telescope system technologies and capabilities are required to implement this vision for future large space observatories
- Future Technology Development positions NASA to continue a successful strategy
  - Continue supporting a long-term focused investment approach
  - Capture low TRL innovations while they are still fresh and exciting (no gaps)
  - Initiate early advanced development to create key mission enabling capabilities
  - Continue a systems engineering approach to the entire program, not just individual missions

Space Observatory Technologies for the Future:

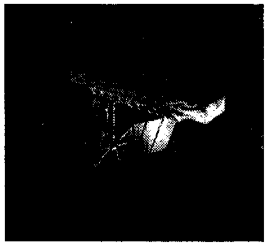
# Preparing for the Ultimate Discovery

## Are We Alone?

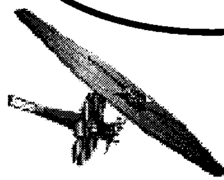
## Missions to Find The Precursors of Life



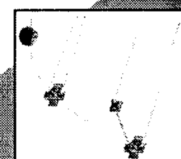
SIRTF



SIM

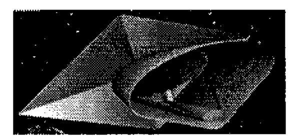


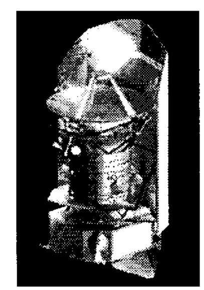
NGST



STARLIGHT

TPF





Herschel

Large Aperture Mirrors

Active Wavefront Control

Advanced Detectors

Large Telescope Cryocooling *Nuclear Solution*

**Precision Segmented Reflector**
**1986-1991 ~$20M**
- Lightweight Mirror Panels
- Segmented Aperture Control
- Lightweight Precision Structures

**Control Structures Interactions**
**1988-1996 ~$26M**
- Vibration Suppression
- Optical Delay Lines
- Precision Structures

**Telescope Technology**
**1993-1996 ~$7M**
- Cryogenic Mirrors
- High Contrast Adaptive Correction
- High Dynamic Range Testing

**Integrated Modeling**
**1992-1995 ~$2M Internal**
- Predictive Design Tools
- System Engineering Approach
- Widely Available

**1986-1996**
**Code R Investments**
**To Enable**
**Large Space Observatories**

# Future Core Technologies

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## Large Aperture Mirror Technology

- Key Technology Motivation
  - Affordable Manufacturing and Launch Cost
- Goal Metrics
  - -Diameter ≥10 meters
  - -Deployable or Erectable Mirror & Structure
  - -Total Mass < 1,000 kg  <1 kg/$m^2$
  - -Production Rate > 125 $m^2$ per year
- Precursor - Gossamer S/C Initiative

## Large Telescope Cryocooling

- Key Technology Motivation
  - FIR Science Performance
- Goal Metrics
  - -Optics Temperature < 10K
  - -No additional stray light background
  - -Mass < 100kg, Power < 100W
- Precursor - Active Cooler - FIRST
  - Stored Cryogen – SIRTF
- Nuclear Initiative May Ease Requirements

## Active Wavefront Metrology and Control

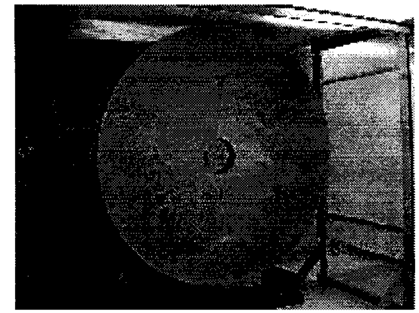
- Key Technology Motivation
  - Adequate Optical Performance
- Goal Metrics
  - -Full Time, Full Aperture Correction
  - -Diff. Limited at visible and IR wavelengths
  - -Mass < 30kg, Power < 20W
- Precursor - NGST Wavefront Control

## Advanced UV and FIR Detector Arrays

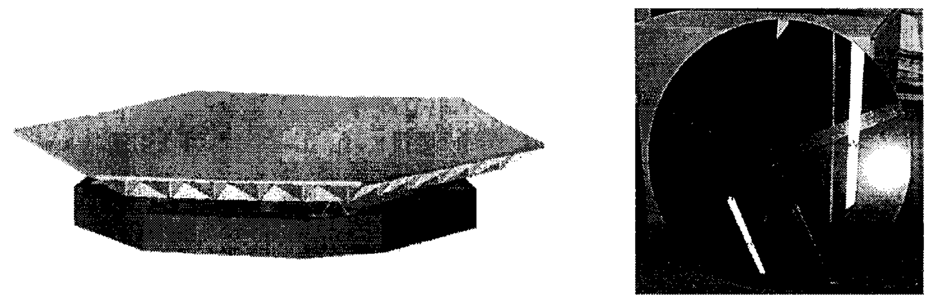
- Key Technology Motivation
  - UV and FIR Science Performance
- Goal Metrics
  - -UV QE > .2, FIR Array > 500x500
  - -Photon counting noise statistics
  - -Ancillary cooler mass < 2kg, Power < 10W
- Precursor - CETDP Advanced Sensors
  - NGST/TPF Instrument Cryocooler

# Beyond NGST - Mirror Technologies for 5-10 $kg/m^2$

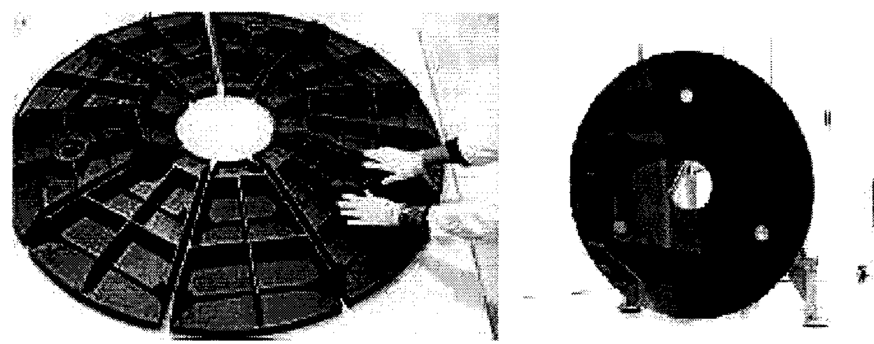
- ESA/FIRST Telescope
  - 2 meter composite prototype by COI
  - Cryogenic performance at FIR wavelengths
  - Demonstrated 9 $kg/m^2$
- Carbon/Silicon Carbide - CSiC
  - IABG (German) Product
  - 0.5 meter prototype demonstrated
  - Projected capability below 10 kg/m2
- Sintered Silicon Carbide
  - Astrium & BOOSTEC
  - New Technology, 1.3 meter demonstrated
  - Licensed in US
  - Projected capability below 10 $kg/m^2$
- COI Ion Figured Cyanate Ester
  - Concept for visible light optics
  - Projected 5 $kg/m^2$
- **Aside from the FIRST telescope, these candidate 5-10 $kg/m^2$ technologies have no NASA-specific development support**



COI FIRST Prototype



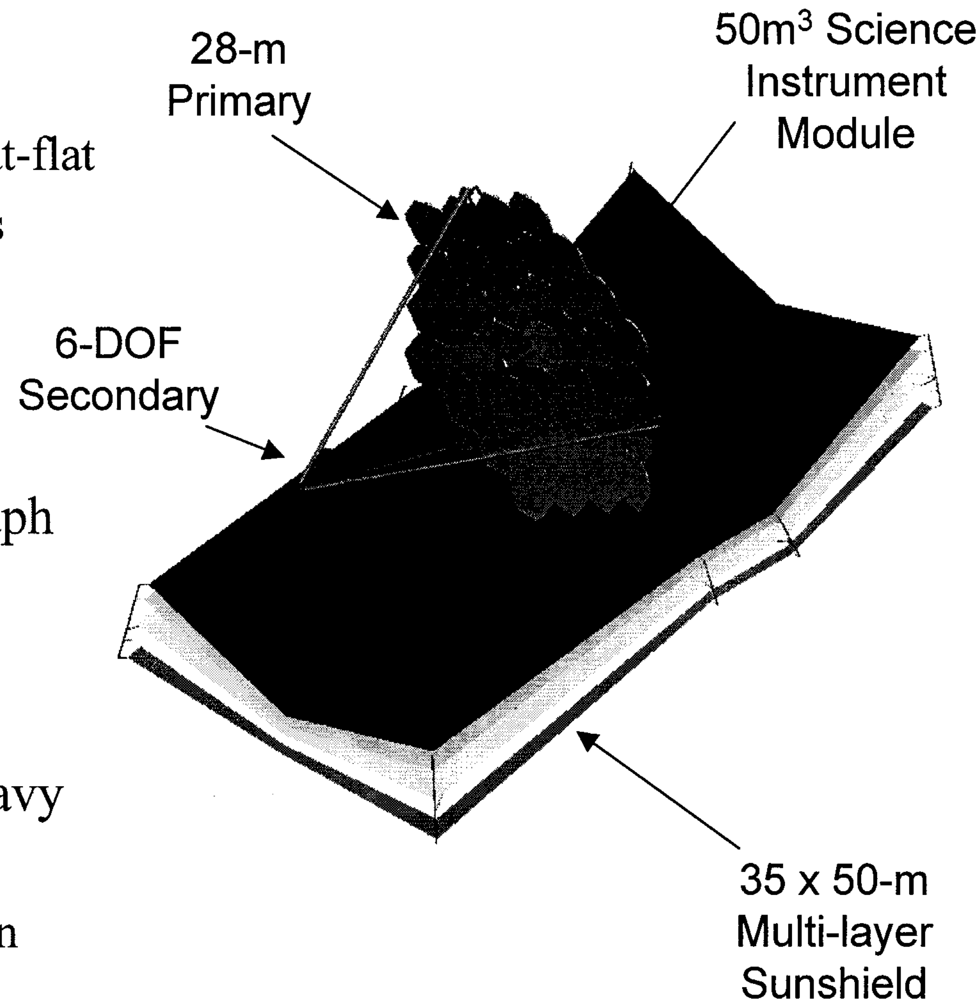
IABG CSiC



MMS/BOOSTEC Sintered SiC
1.3 m Brazed Mirror Assembly

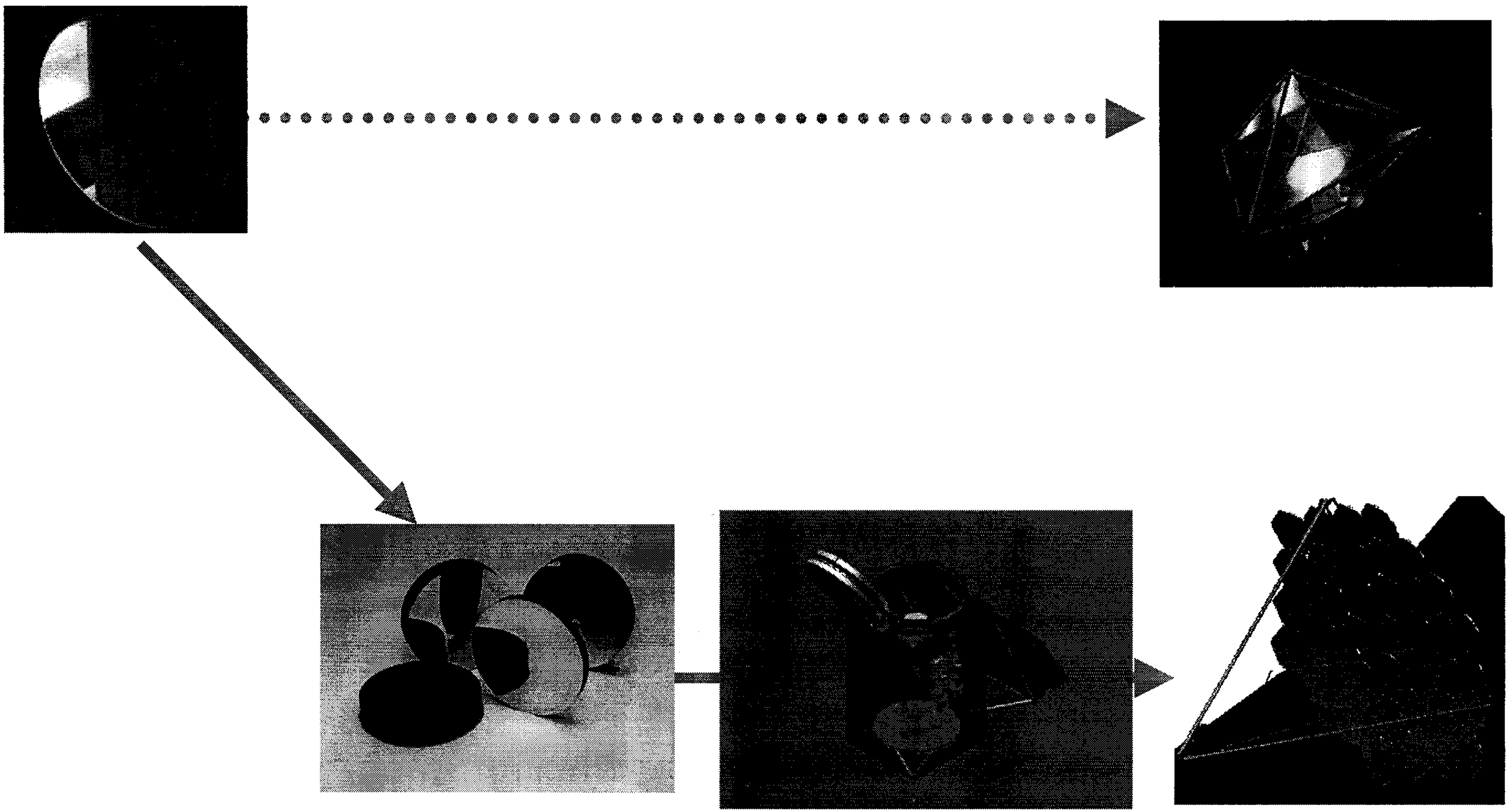
# SAFIR Design Concept (TRW TPF IR imager)

- 28-meter filled aperture telescope
  - Three-mirror anastigmat
  - 36 segments, 4-meter flat-flat
  - Composite replica optics
  - Gold mirror coatings
- Multi-layer sunshade
  - Passive cooling to ~30K
- IR camera and spectrograph for general imaging/spectroscopy
  - 2 x 2 arcmin FOV
- Launched with EELV heavy to L2
  - On-orbit assembly option

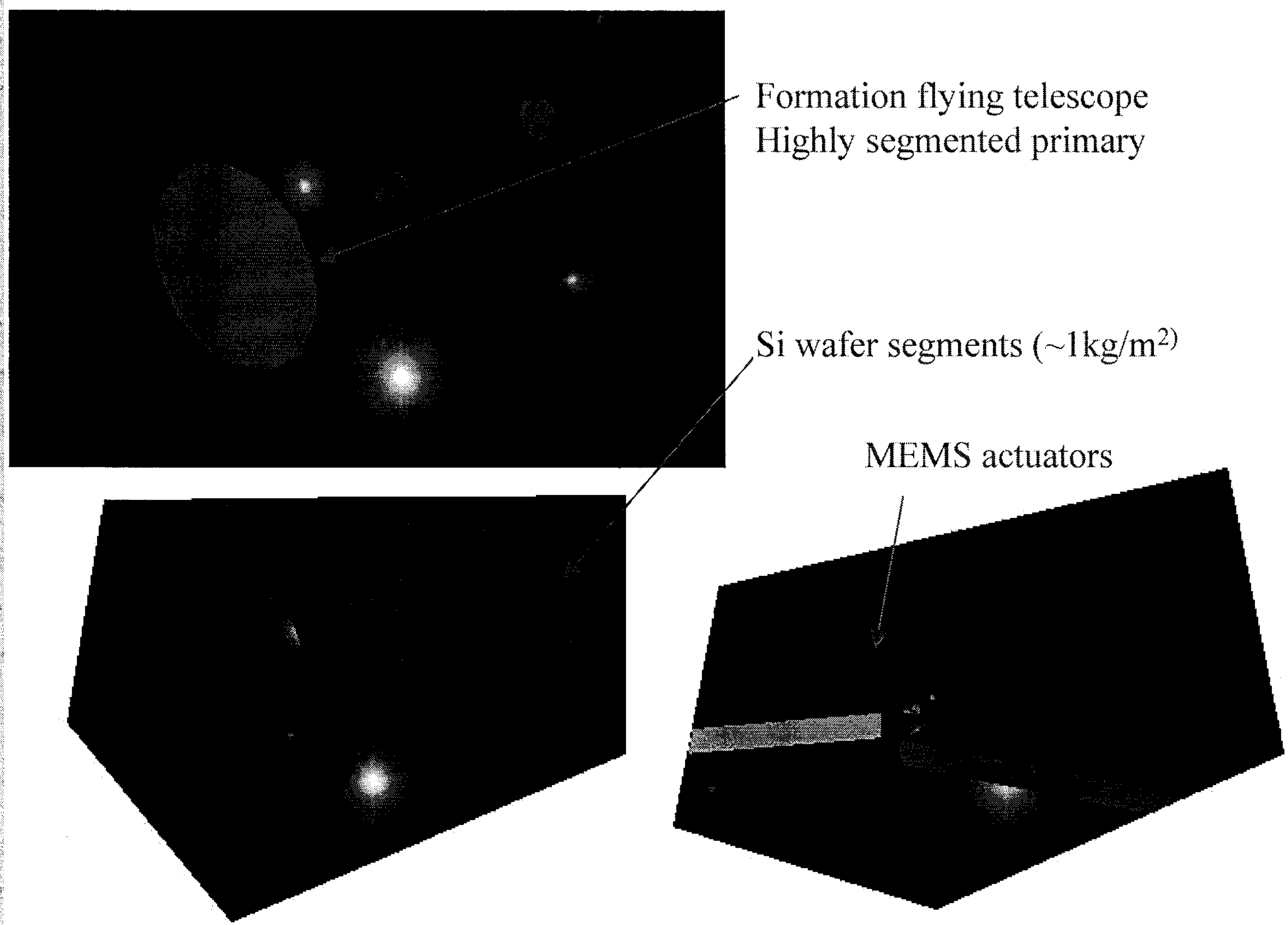


# Gossamer Aperture Technology

- Concepts to Enable 1 kg/m$^2$ Systems



# ASSiST overview (Dekaney et. al.)



# DART Concept for SAFIR

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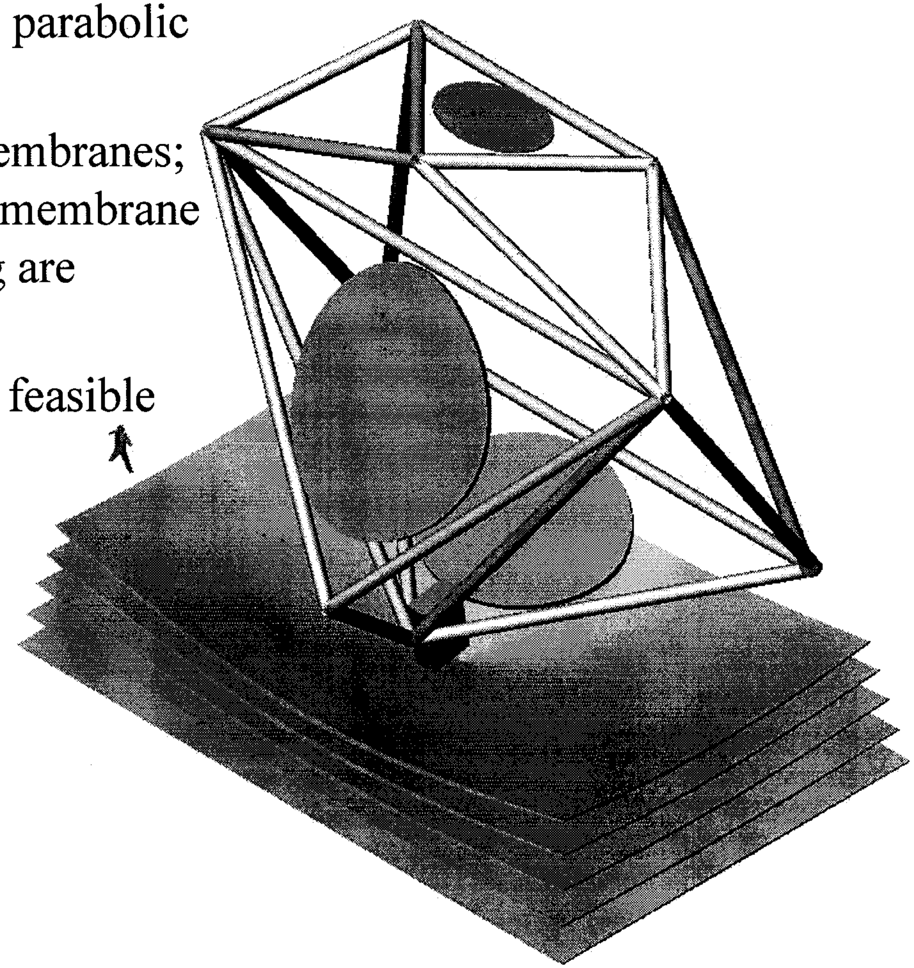
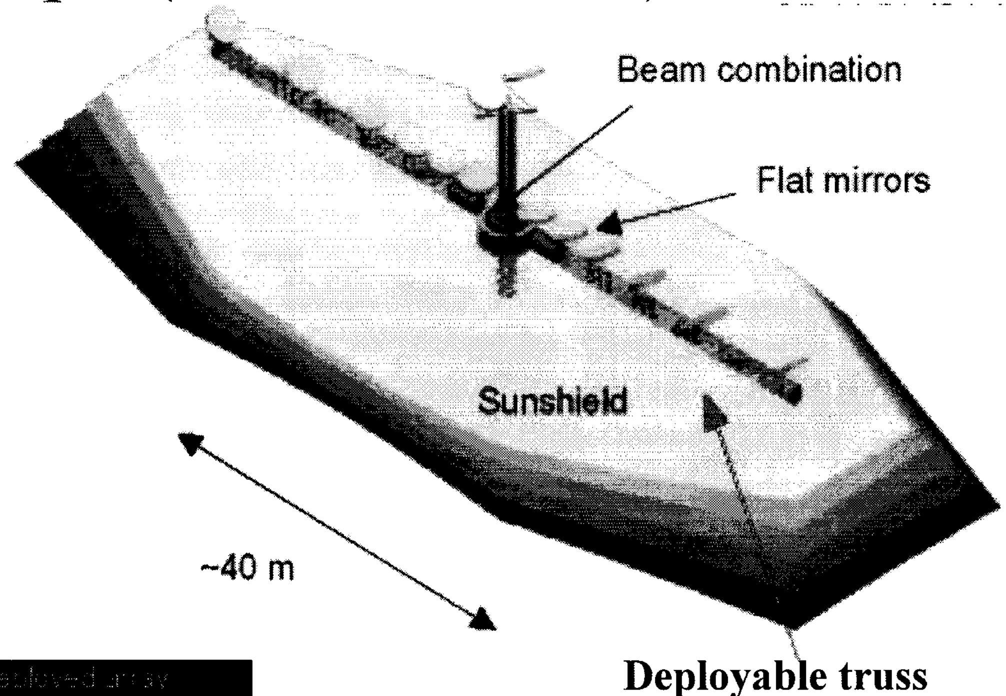
DART

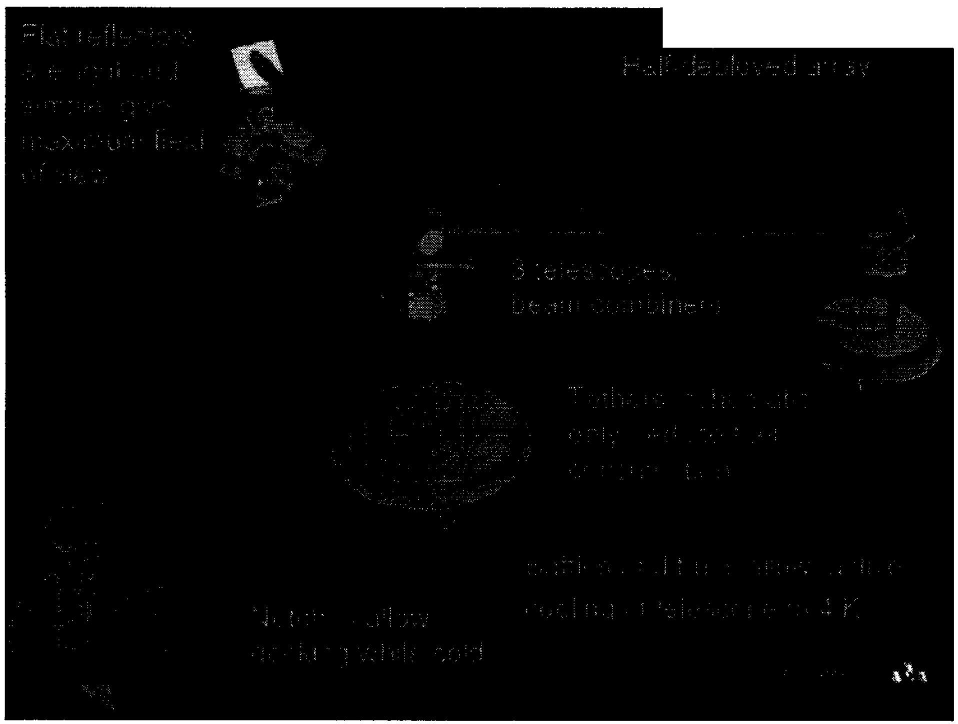
- DART-Dual Anamorphic Aperture Telescope
  - Enables 25-40m apertures
  - Reflectors are two cylindrical parabolic reflectors
  - 2D geometry is natural for membranes; problems associated with 3D membrane dish manufacture and shaping are avoided
  - Areal densities of < 1 1kg/m$^2$ feasible



# Interferometric Concepts (Leisawitz et. al.)

- SPIRIT (Space Infrared Telescope)
  - ~40m baseline for λ=800μm resolution
  - 3m mirrors at ~4K
  - Cryogenic delay line




- SPECS (Submm)
  - Tethered formation
  - 4m mirrors at ~ 4K
  - Cryogenic delay line

# Summary

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- Origins and SEU have scientific goals that extend far beyond our present technological reach, well into the 21st century.
- Future Technology creates the infrastructure needed to make critical astrophysical measurements for missions that have already been identified as needed during the next decade.
- The technology will develop the breakthrough capabilities needed for UV to far-IR astrophysics by:
  - making telescopes an order of magnitude more lightweight using new materials and concepts
  - on-orbit deployment
  - advanced wavefront metrology and advanced micro-electronic mechanical (MEMS) devices for precision wavefront control.
  - developing the detectors and cooling needed to take full advantage of the low background space environment.

# Backup charts on component technology development

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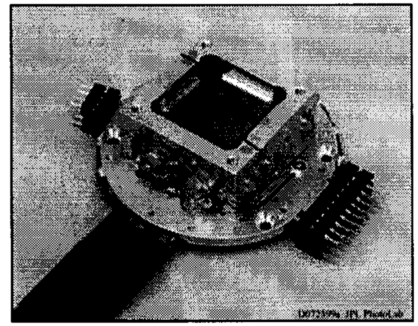
# Active Wavefront Metrology & Control Technology

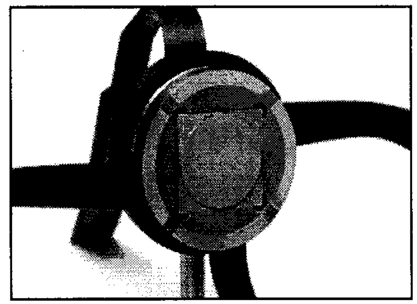
- NGST will be the first application of this technology in a major space system
  - Imaged based phasing and wavefront sensing
  - Will compensate for deployment, alignment and fabrication errors to provide diffraction limited performance at 2μm.
  - Essentially DC (0 Hz) control bandwidth enabling lower power, lower mass electronics
  - Rigid body actuation for positioning of segments and secondary mirror
  - Deformable primary mirror segments provide modest wavefront correction
    - Cryogenic deformable tertiary mirror in early development (TRL= 2) as backup technology

# Deformable Mirror Technology Beyond NGST

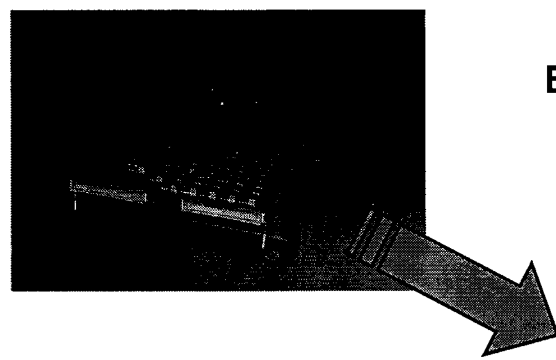
- Developed technique to manufacture deformable mirrors with 1mm actuator spacing.
- Compatible with tailored low temperature ceramic formulations developed by NGST
- Demonstrated 1Å rms stability for single actuators
- Fabricated 4 module 1750 actuator mirror for test.
- Developed benchtop multiplexed drive electronics with 2 orders of magnitude mass reduction and >1 order of magnitude power reduction
  - Designed ASIC drive circuitry
- Capable of expansion to 20,000 or more actuators as a result of modular construction
- Capable of providing high density small stroke control for very large apertures



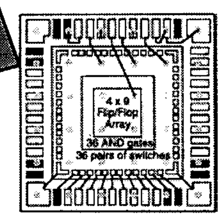
**Single 441 actuator mirror module wired to multiplexer**



**1750 actuator mirror module wired to multiplexer**



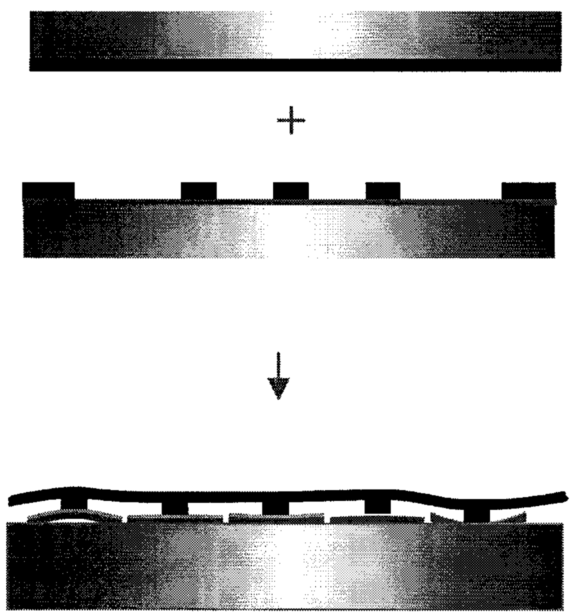
**Benchtop Drive Electronics**




**ASIC Module**

# **Wafer Transfer Process*** for MEMS Deformable Mirrors, E.H. Yang, JPL, PI

*Patent pending



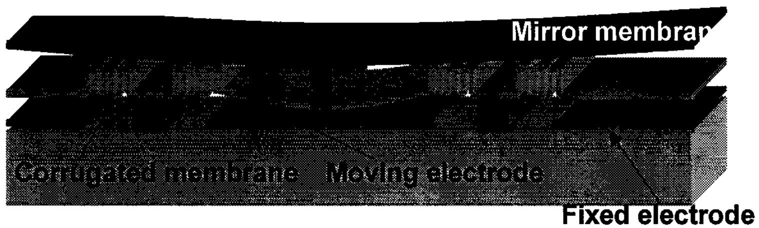
- Transfer of a mirror membrane from one wafer to another for optical quality mirror

- Surface quality: Transferred membrane is a replica of the carrier wafer.

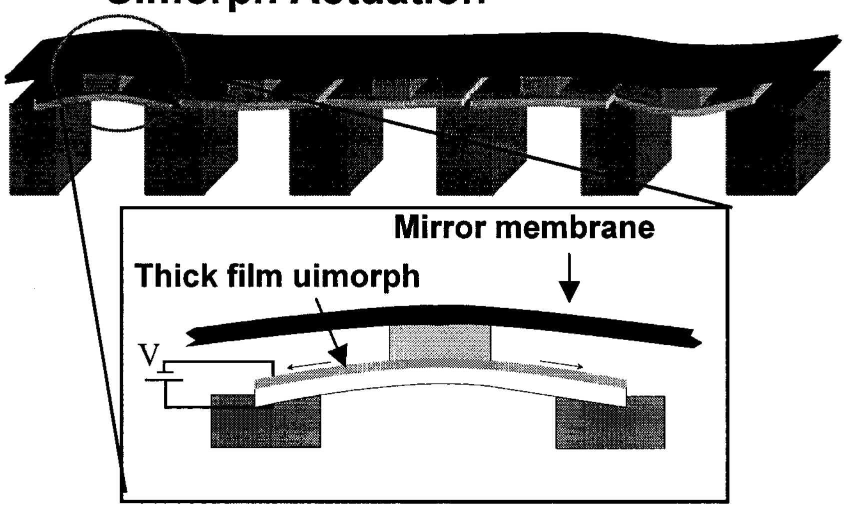
- Various optical materials can be transferred.

# JPL's MEMS Deformable Mirror Concepts

## Electrostatic Actuation




## Uimorph Actuation




- Transferred mirror membranes for optical quality deformable mirrors

- Electrostatic actuation for precision operation

- Uimorph actuation for large stroke actuation

- Large stroke actuator array would be a critical component in wavefront compensation for large aperture instruments as well as ophthalmic instruments.

# Cryo-cooling

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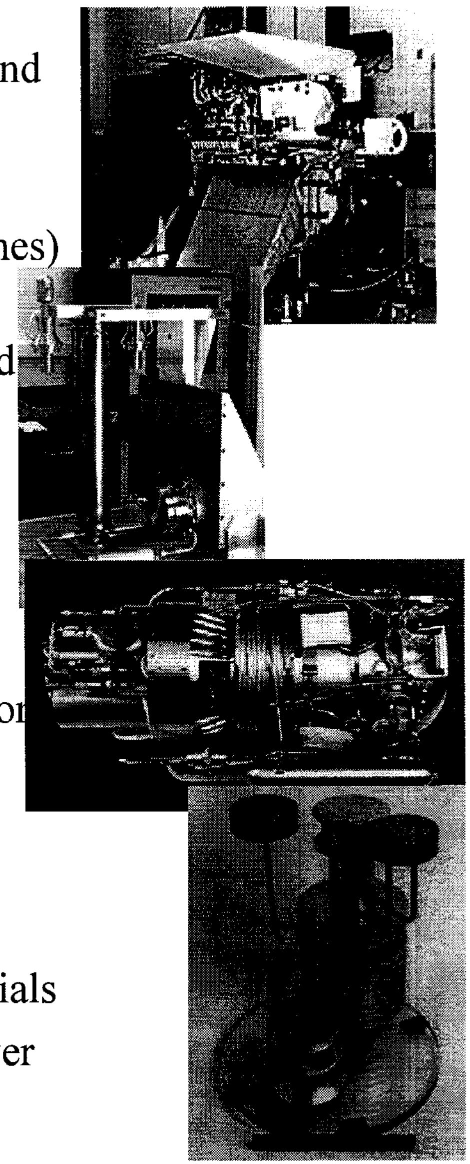
- Possibly the most difficult technology challenge
  - Cooling the full aperture (>10meters) to achieve zodiacal background limited IR/FIR performance requires cooling to ~ 10K
    - Equivalent to scaling SIRTF to 15 meters
  - Passive cooling with current technology (SIRTF & NGST approaches) limited to 35K-40K at 1AU
    - Sunshield backside reradiation (90K) dominates NGST beyond 10μm
- Current cryocooler technologies offer a point of departure for technology investments.
  - Stored/Recycled Cryogens - Today's state-of-practice
  - 20K JPL sorption/J-T cooler in production for ESA Herschel mission
  - Demonstrate 6 Kelvin turboalternator and/or turbo-Brayton coolers
- Future directions
  - More effective sunshield concepts
  - High efficiency cryogenic heat transfer in gossamer aperture materials
  - More efficient coolers to enable mirror cooling with low input power
  - Demonstrate <10K cooling
  - Demonstrate sub K cooling



# Advanced Cryocooler Technology Development Program (ACTDP)

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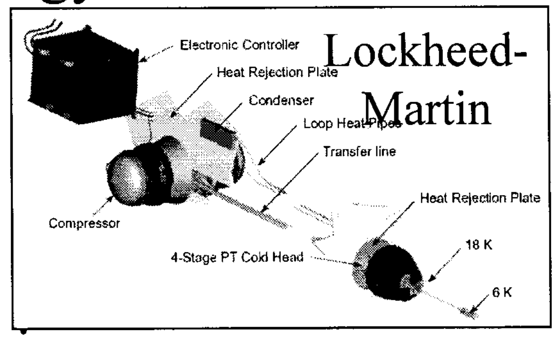
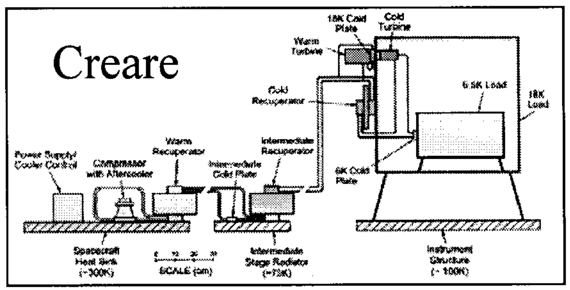
- Goal: Develop sub-10K cryocooler technology to enable long life astrophysics missions
  - NGST, Con-X, TPF, ...

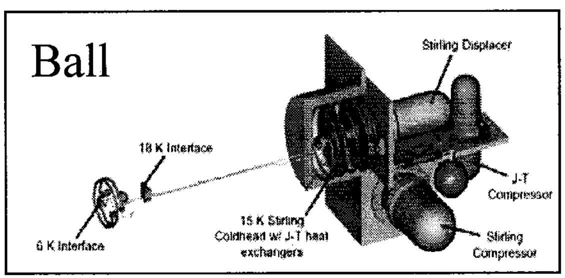



Pulse Tube

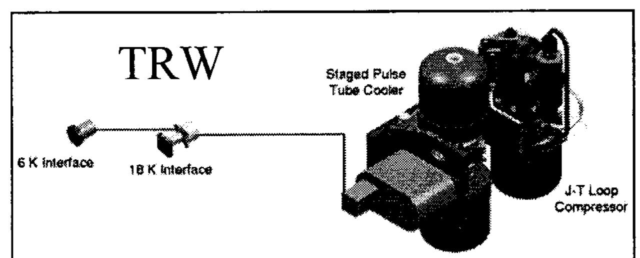
- Objective: Demonstrate engineering model cryocooler(s) consistent with customer mission needs and schedules




Turbo Brayton




Hybrid Stirling/Joule-Thomson



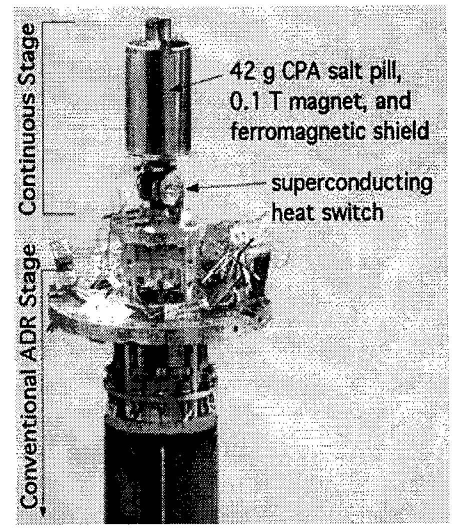

Hybrid Pulse Tube/Joule-Thomson

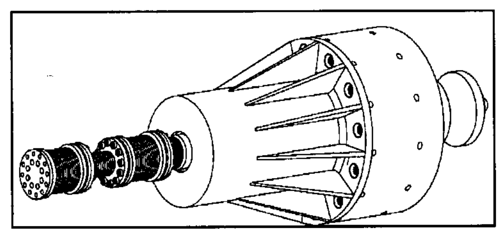
# Ancillary Sub-Kelvin Detector Coolers

- Most of the advanced UV and FIR detector concepts operate at temperatures well below 1K
  - Cooler must be power efficient and vibration free

- Sub-Kelvin Cooler Technology Candidates
  - Helium-3 evaporation
    - Start at 2 - 3 K, reach 0.25 K
  - Continuous Adiabatic Demagnetization Refrigerator
    - Start at 4 - 8 K, reach 0.05 K in 3 stages
  - Helium-3 Dilution Refrigerator
    - ESA designs exist for space, but haven't flown yet (FIRST/Herschel)
    - Start at 0.3 K, can reach 0.02 K in lab
  - Superconducting Peltier effect
    - Very small cooling power
    - Start at 0.5 K, reach 0.02 K

**Today:**
**100 mK proof-of-principle continuous sub-Kelvin cooler**



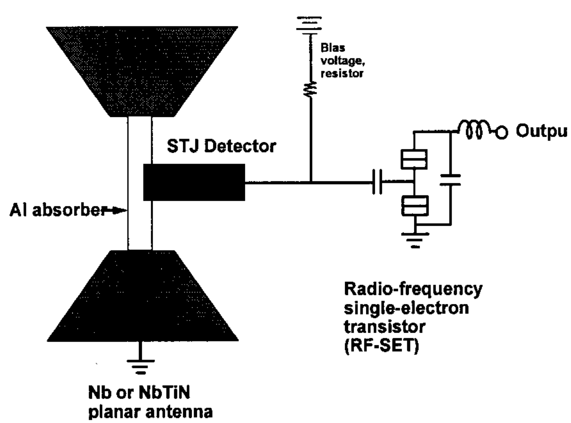



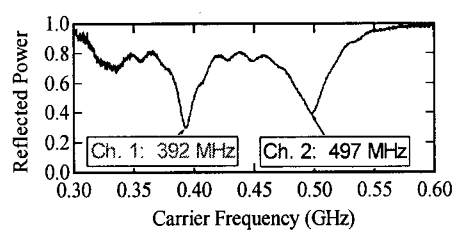
**3-5 years:**
**10 Kelvin to 50 milliKelvin Continuous Cooling**

# Advanced Detector Expectations

- Initial emphasis on promising new sensor technologies for wavelengths where current performance is farthest from theoretical limits - UV and FIR Imaging and spectroscopy
  - Photon conversion to superconducting quasiparticles (direct counting) or phonons (temperature sensors)
  - UV/X-ray position sensing, energy resolving photon counters
  - IR background photon limited arrays for all IR/FIR wavelengths
  - Single electron transistor amplifiers, SQUIDs (superconducting quantum interference devices), multiplexers, digitizers
  - RF conversion multiplexers for large format FIR imaging arrays

**STJ Detector with RF-SET Read**




**Linear Arrays of Superconducting Energy Resolving Detectors (X, λ) with QE>70%**

**Solar Blind CCD's (GaN, SiC, etc.)**