Technology Needs for Far IR, SMM, and MM Missions

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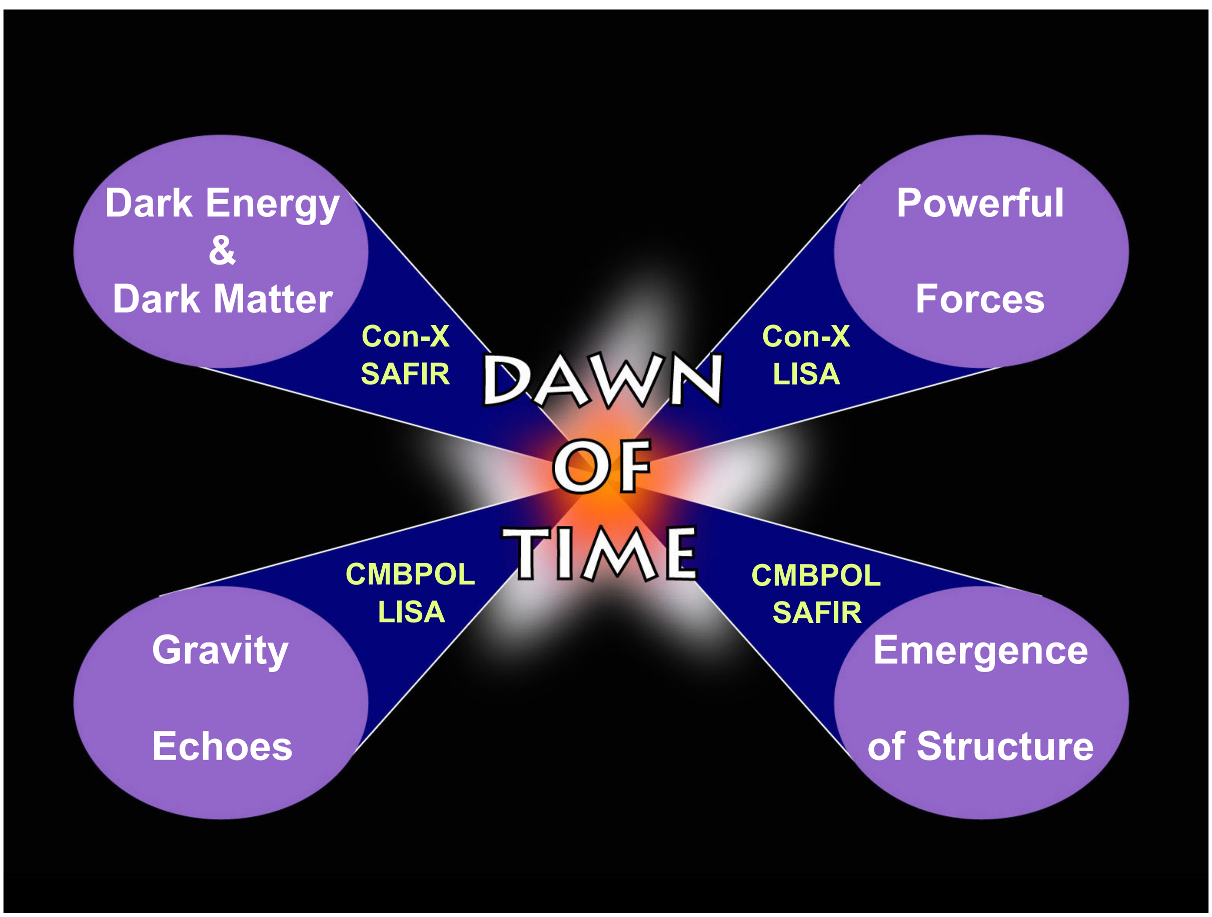
Mar. 7, 2002



SAFIR: Single Aperture Far-InfraRed Observatory

"SAFIR…will:

- Study the important and relatively unexplored region of the spectrum between 30 and 300µm.
- Enable the study of galaxy formation and the earliest stage of star formation by revealing regions too enshrouded by dust to be studied by NGST
- Be more than 100 times as sensitive as SIRTF or the European [Herschel] mission.

"The committee recommends SAFIR…

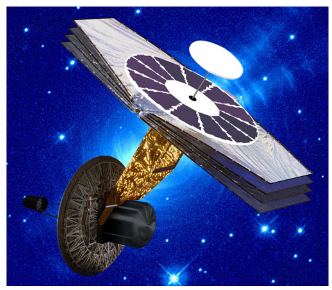
- The combination of its size, low temperature, and detector capability makes its astronomical capability about 100,000 times that of other missions
- It [has] tremendous potential to uncover new phenomena in the universe."

– pages 12, 39 & 110 of *Astronomy and Astrophysics in the New Millenium*, National Research Council, National Academy Press, 2001.

SAFIR is projected to cost around $600M total. The decadal review committee recommends that $100M be allocated in this decade to start the SAFIR project, and that additional technology developments be funded separately:

- Far-Infrared Array Development ($10M†)
- Refrigerators ($50M†)
- Large, Lightweight Optics ($80M†)

† Funding levels recommended by decadal review, page 47.



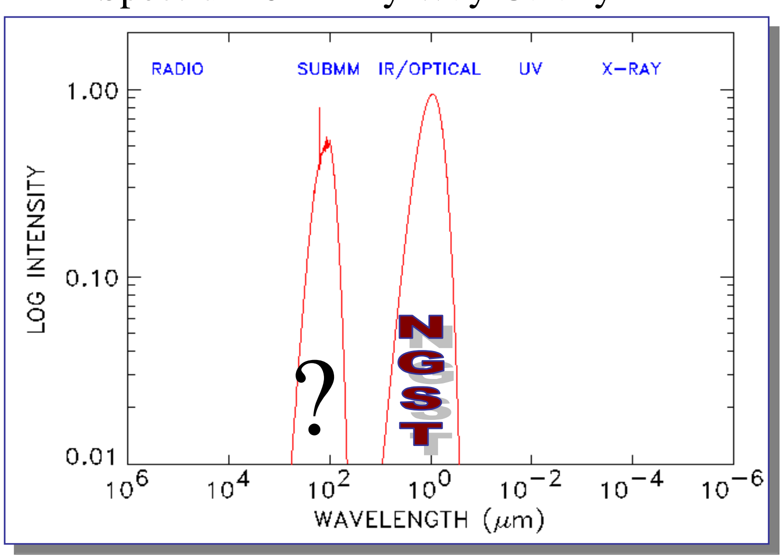
SAFIR features:
- ✓8m diameter telescope cooled to 10K
- ✓Located at L2
- ✓Lifetime 5 years
- ✓30µm-800µm wavelength range
- ✓Instrument complement including cameras and imaging spectrometers

Possible **SAFIR** concept based on NGST

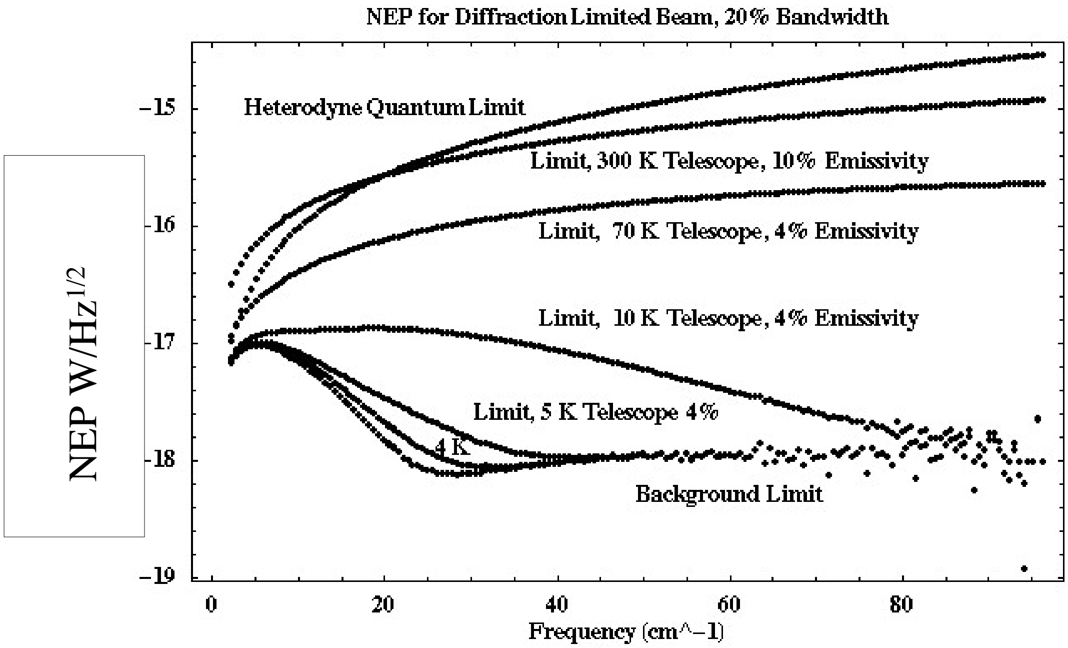
SAFIR is within reach and in need of near-term mission concept studies.

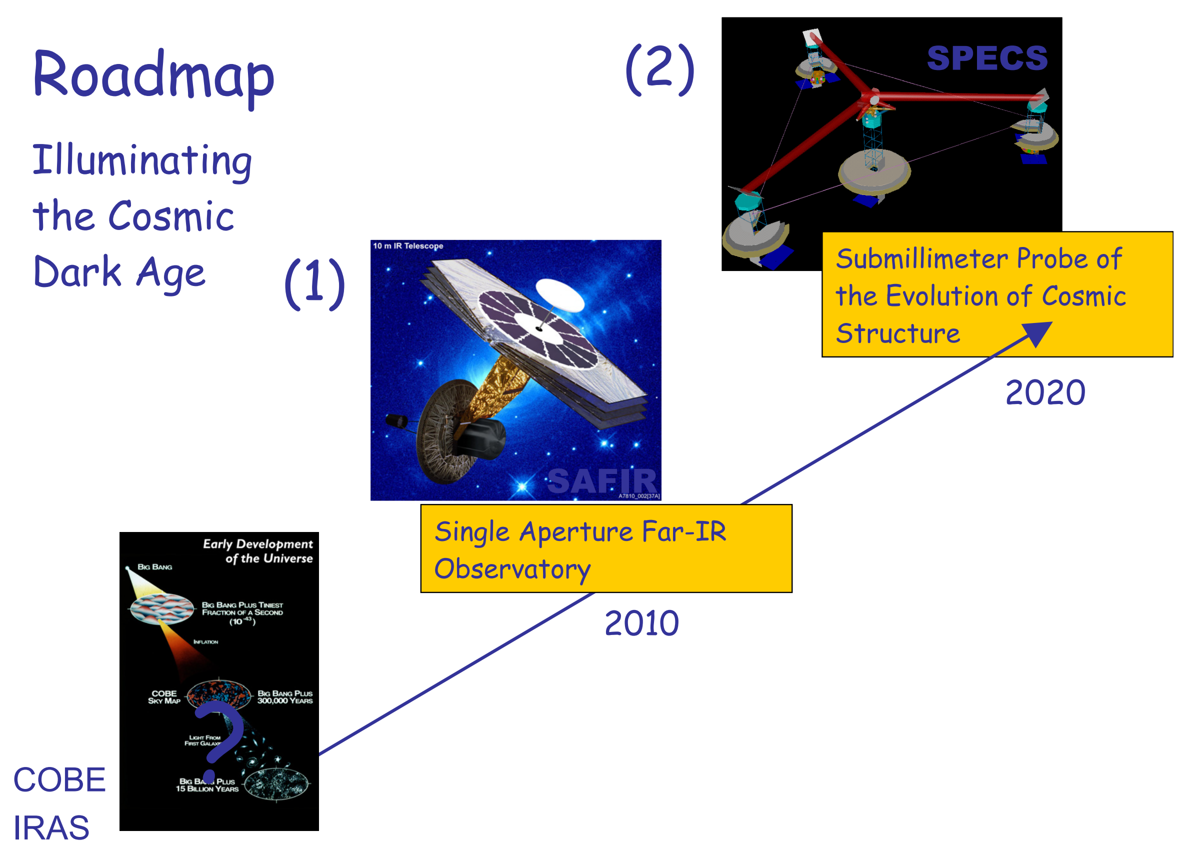
Half the luminosity and 99% of the photons in the post-Big Bang Universe are in the far-infrared and submillimeter

Spectrum of Milky Way Galaxy



Ultimate Performance Requires Cold Telescope





"Astronomy and Astrophysics in the New Millennium"
Astronomy and Astrophysics Survey Committee

Gravitational waves excited during the first instants after the Big Bang should have produced effects that polarized the background radiation. More precise measurements of the properties of this polarization—to be made by the generation of CMB missions beyond Planck—will **enable a direct test of the current paradigm of inflationary cosmology**, and at the same time they will shed light on the physics of processes that occurred in the early universe at energies far above those accessible to Earth-bound accelerators.

Future microwave background experiments, such as measuring the polarization, are of great importance, but the committee recommends that prioritization of such experiments await the results from MAP…

"Astronomy and Astrophysics in the New Millennium"
Astronomy and Astrophysics Survey Committee

…NASA's MAP mission, to be launched in spring 2001, will revolutionize knowledge of the microwave background, and the committee believes that no decision on the next major or moderate microwave background project should be made until the results from that mission are available. ESA's Planck mission later in the decade will also provide important information, but **it will be possible to decide on the next step before its results are available**. Together, MAP and Planck will test the most promising ideas about the very early universe as well as determine cosmological parameters to high precision. **The next frontier is to measure the polarization of the cosmic microwave background, which has the potential of probing even earlier times, close to the Big Bang itself**.

Technologies for Far IR/mm Missions

- Cryogenic Cooling
  - Efficient use of radiative cooling
    - Choose a good orbit
  - Refrigerator for cooling to ~10 K
  - ADR or Dilution Fridge for lower temps required by detectors
- Lightweight large optics
  - Less demanding figure compared to (SIRTF and NGST)
  - Colder
  - Lighter

Mission Technologies (cont.)

- Large Format background limited arrays
  - 10^3 to 10^4 or more elements
  - Integrated low power, low temperature readout
- Coherent receivers will have a role for high resolution spectroscopy

Current Developments

- SIRTF
  - Long-life cryostat with efficient radiative cooling
  - Cryo-friendly orbit
  - Large format Far IR detector arrays.
- MAP
  - Radiative cooling in good environment

Current Developments

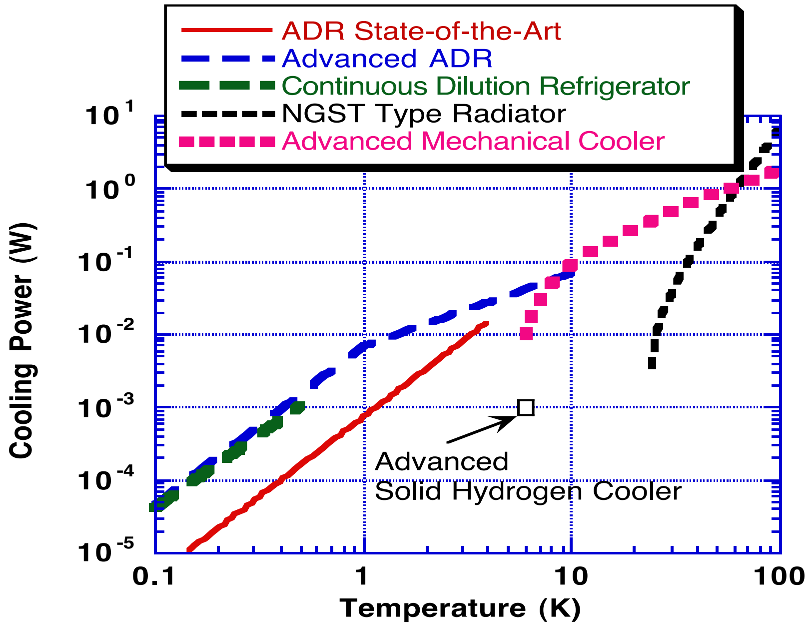
- NGST
  - Low mass deployable mirrors with figure control
  - Deployable sunshield
- Herschel
  - SiC mirror
  - Bolometer Arrays

Current Developments

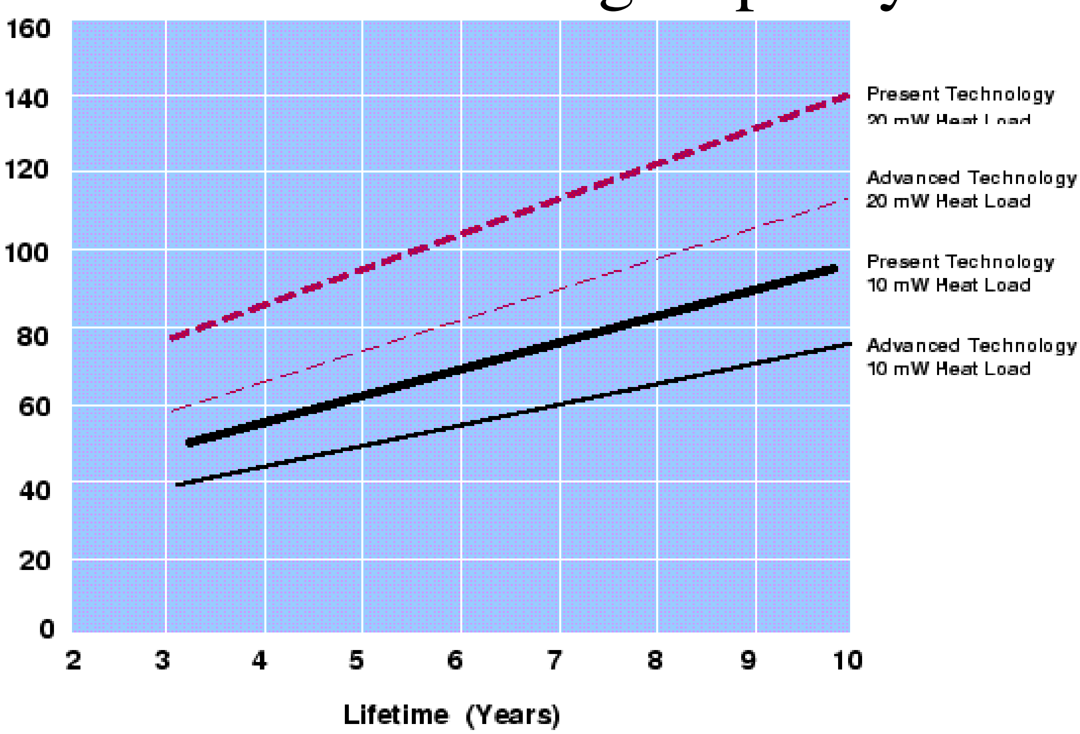
- SOFIA and Suborbital
  - Instruments and detectors
- Constellation-X
  - The Con X detector requirements are very similar to, and perhaps more difficult than, those of SAFIR or CMBPOL.
    - We must watch and participate in this development so we are prepared to transfer it to our missions.

Cooler Technologies

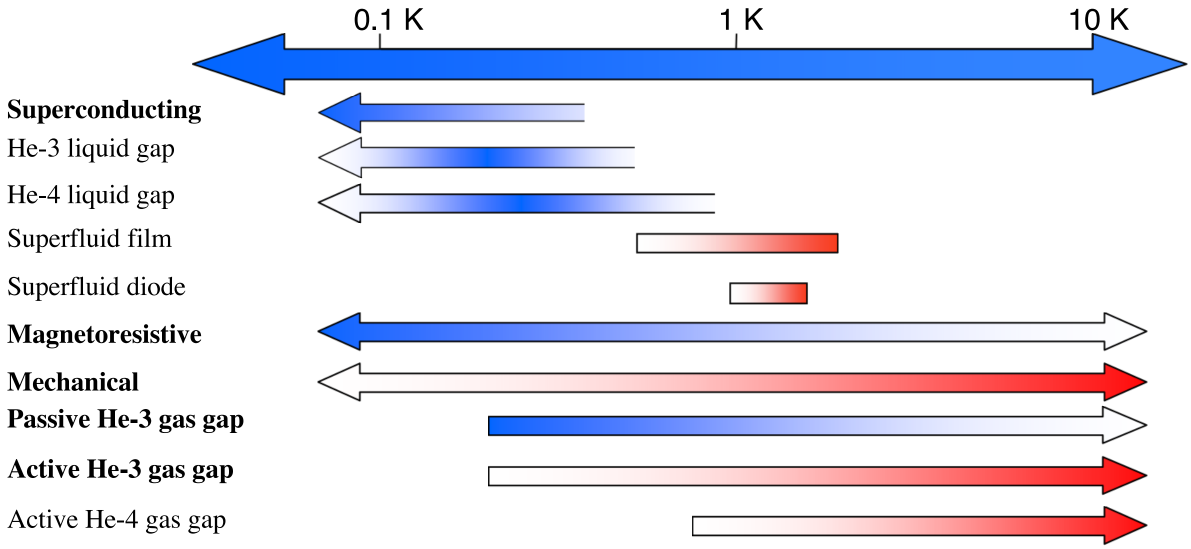
Cooler Performance, Circa 2002

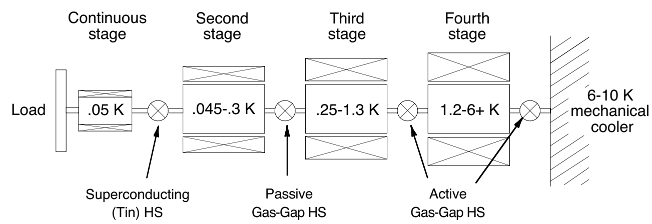


Cryostats Can Provide Long Life, Modest Cooling Capacity

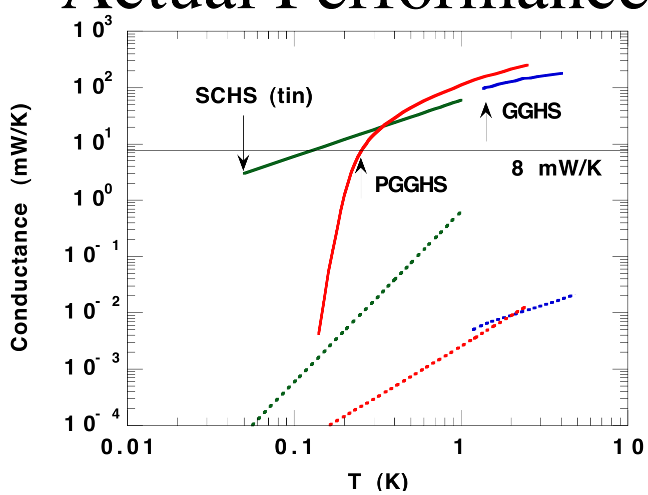


Heat Switch Options





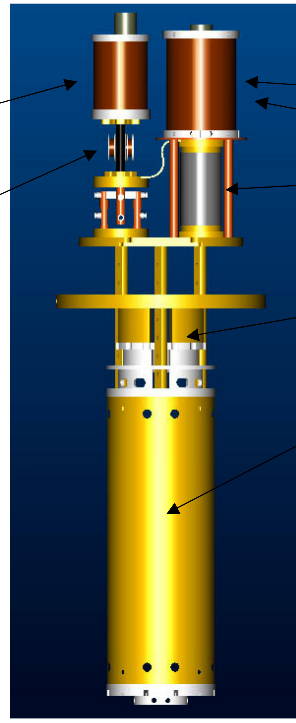
Actual Performance



- Superconducting switch is 2x less conductive than desired
  - Limits present system to proportionally lower cooling power

3-Stage ADR

- Continuous Stage
  - 42 g CPA salt pill
  - .1 T magnet
  - .05 cm thick magnetic shield
  - Superconducting heat switch



- Second stage
  - 100 g CPA salt pill
  - .5 T magnet
  - Passive gas-gap HS
- Third stage
  - Connected to 1.2 K helium bath by an active gas-gap HS
  - 730 g FAA salt pill
  - 0.8 T magnet (not shown)

SIRTF Demonstrates Key Technologies for Future Missions

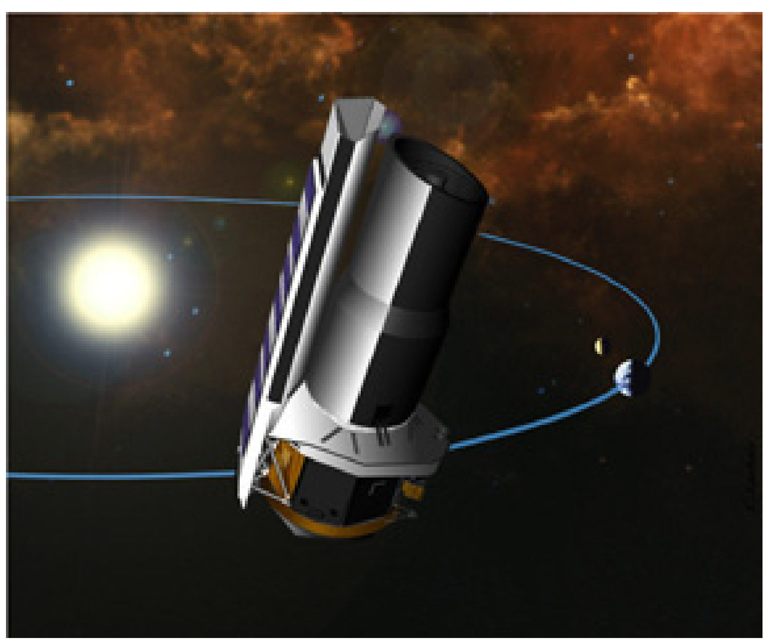
Warm launch

Efficient radiative design (dewar shell 40 K)

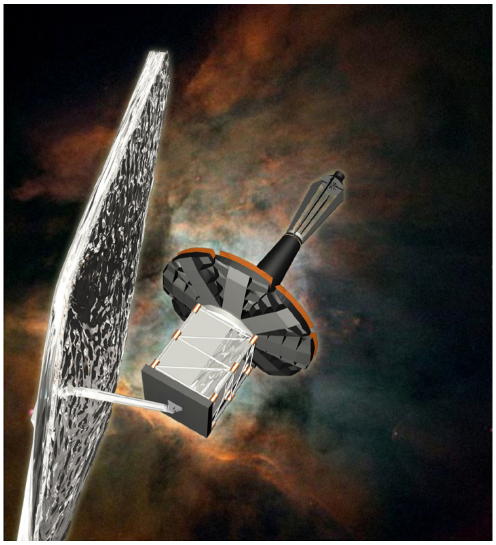
Earth-trailing Solar orbit

Long life cryostat

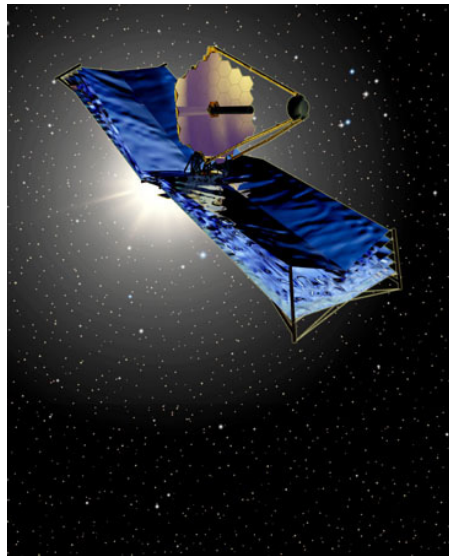
Large format far IR array



NGST Sunshield Development Status



Lockheed Martin NGST Concept



TRW/Ball NGST Concept

NGST Passive Cooling Development Status

Key requirements

- Telescope optics less then 50 K passively
- Instrument near infrared detectors < 30 K passively
- Heat loads on mid infrared instrument compatible with volume and mass allocation for 10 year cryogen lifetime
- Passive cooling heat load margins > 50 %

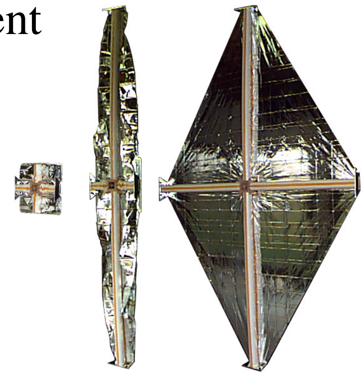
Key passive cooling technologies

1. Sunshield utilizing deployed multiple separated membranes for sunshield

2. Large 30 K radiator (>8 m^2) and thermal strap system for cooling of detector arrays

Sunshield Technology Development

Sunshield stowage, deployment & film management approaches have been explored and demonstrated using numerous models of 1/12 to >1/2 scale



NGST 2-m Sunshield Model

NGST Yardstick 1/2-Scale Sunshield

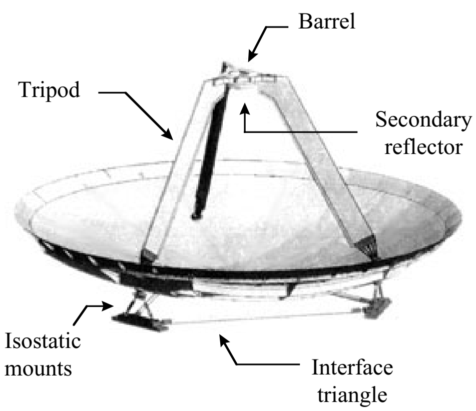
- **4 film layers**
- **Inflatable deployment booms**
- **Film launch restraint & tensioning mechanisms**

Optics Technologies

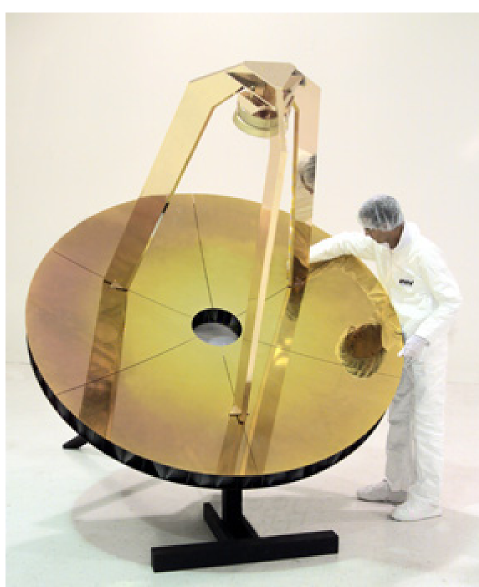
Herschel Telescope

3.5 m diameter
Collecting area > 9m^2
FOV +/-15arcmin
f/# 8.68
Mass 280 kg

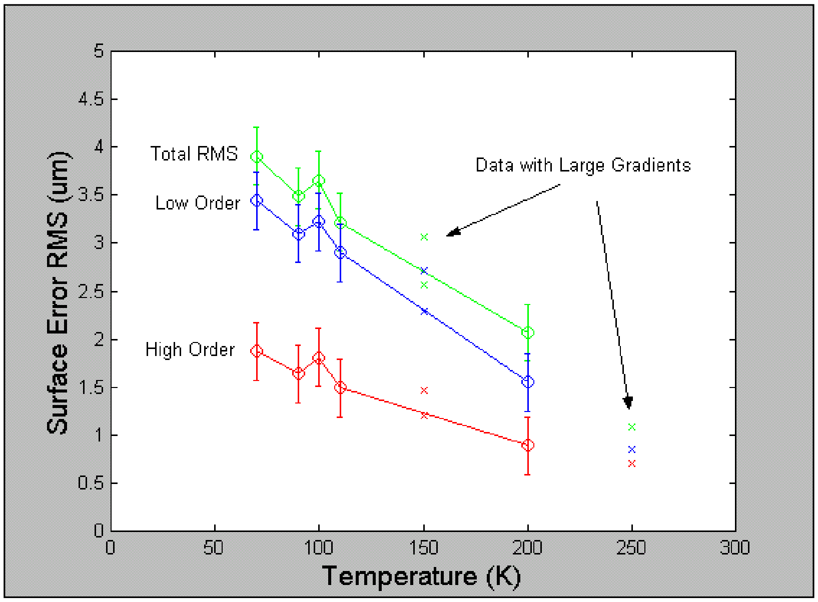
Fabrication is in progress
SiC green bodies (blocks of SiC) are being cold pressed
Machining of green bodies will start later this month



2-Meter Lightweight Mirror Demonstrator and FIRST Telescope Mock-Up

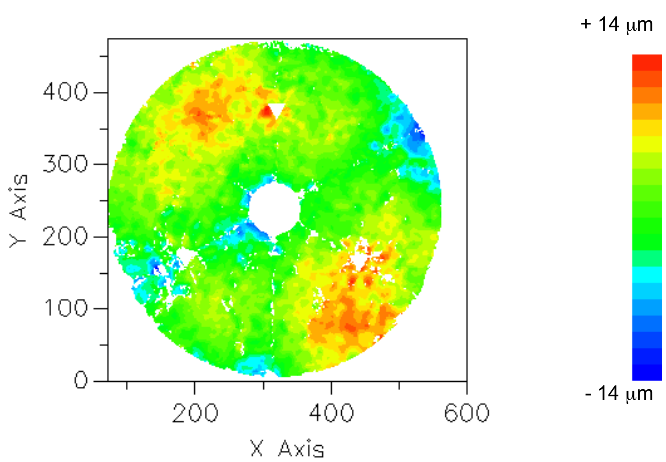


Evolution of Figure vs. Temp



Modest Variation Over Operating Temperature

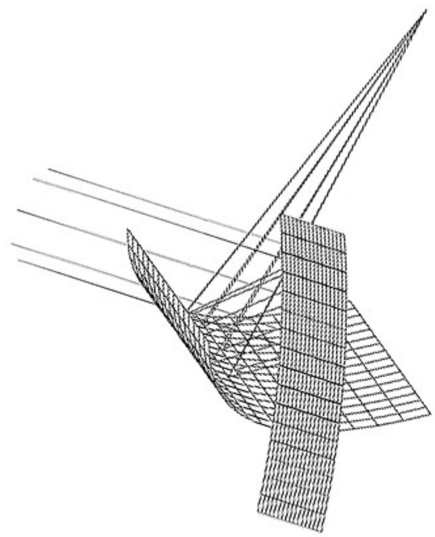
Delta Figure: 293K to 70K



- $S_5 - S_2$
- 3.9 µm RMS

New Ideas Can Change Optimization

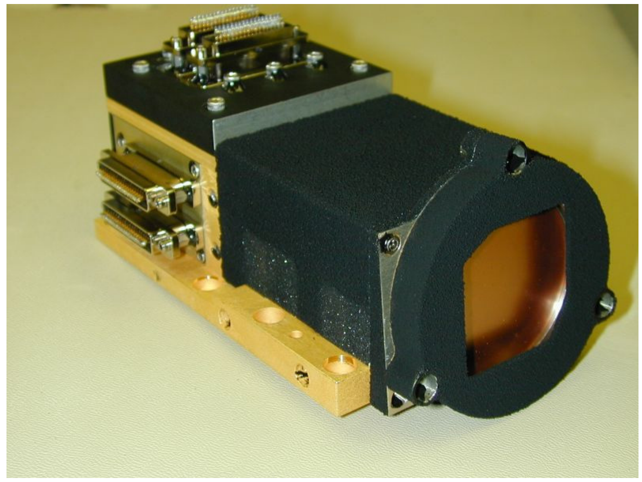
DART telescope, Dragovan et al., provides imaging over a 100 x 100 beam area using crossed cylindrical mirrors.



Detector Technologies

MIPS 70 μm Flight Array

- Wavelength Coverage: 50 - 115 μm
- Detector Material: Ge:Ga
- Format: 32 x 32
- Pixel Size: 750 x 750 μm
- Readout Technology: Cryogenic CTIA
- Read Noise: 92 electrons
- Dark Current: <190 e/s
- NEP: 1.2 x 10^{-18} W $Hz^{-1/2}$



SPIRE Uses Arrays of Spider Web Bolometers for Submillimeter Imaging and Spectroscopy

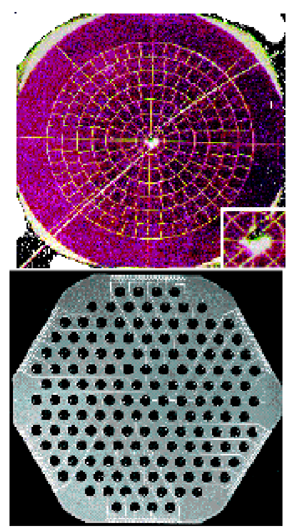
Feedhorn coupled

NTD Ge thermometer

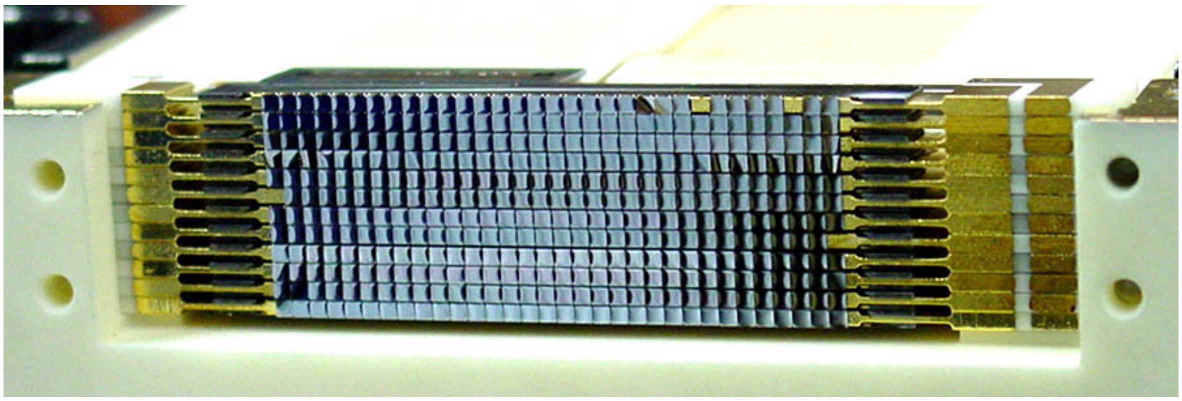
Silicon Nitride Structure

Si backing wafer

AC biased detectors read out by JFET preamps for low 1/f noise



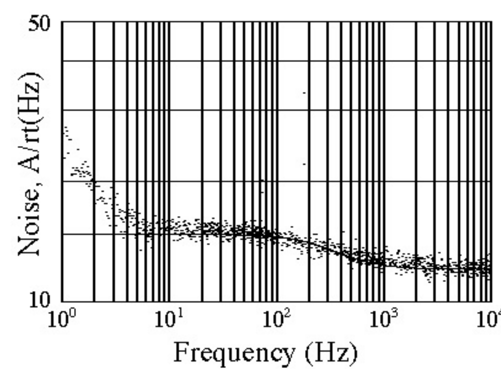
Large Format Far IR Arrays for SOFIA



12 x 32 pop up array, prototype for HAWC, to be demonstrated in the SHARC II instrument at 350 μm on the CSO.

Superconducting TES Bolometers

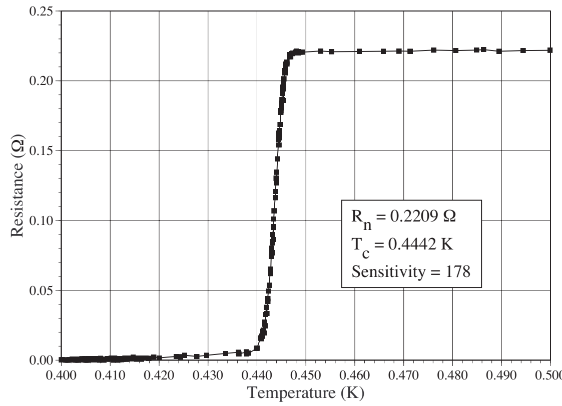
- TES detectors and SQUID amplifiers offer significant benefits for large format arrays.
  - High performance thermometer
  - Couples naturally to SQUID amps
  - Possibility of multiplexing
- Several groups have demonstrated near-ideal noise in "IR" type TES detectors
  - Irwin et al., Lee et al., Bock et al.
- Multiplexed TES array operation demonstrated in lab and FIBRE instrument
  - First light on CSO in the May 2001 (Benford et al.)
- Pop-up versions planned for SAFIRE on SOFIA, SPIFI, and other applications
- Array technology development
  - First arrays built in pop-up architecture
  - Planar arrays mid-term goal (SCUBA II, Con-X, and GSFC/Penn (GBT) developing such devices with TDM mux)



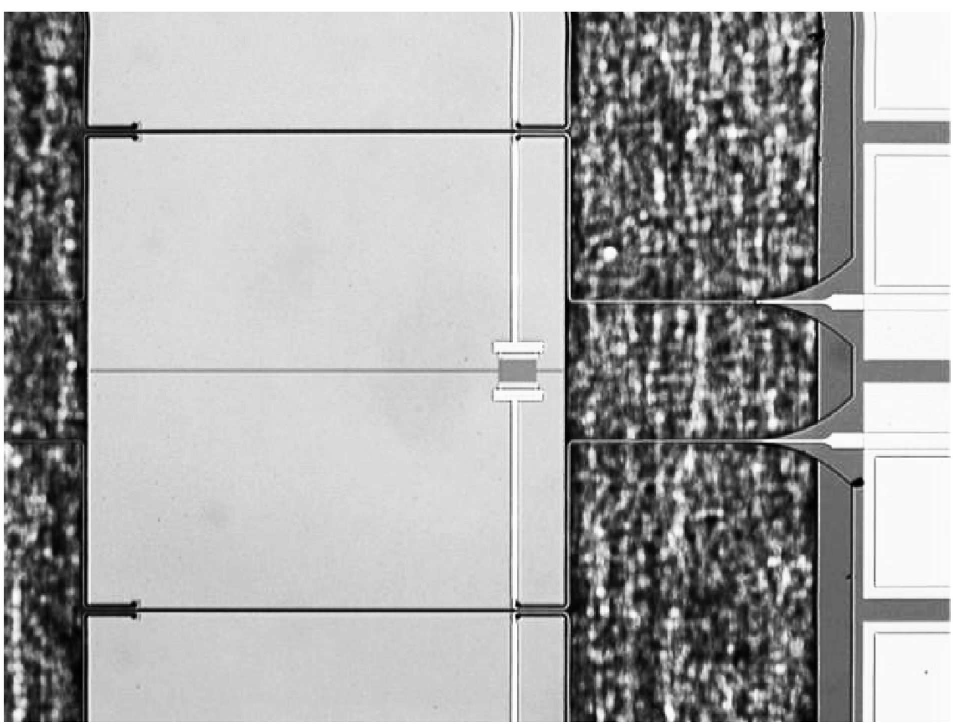
NIST measurement of AlAg Bilayer

Superconducting Transition in Bilayer

- Transitions remain sharp, but transition temperature changes with relative thickness of normal metals and superconductors.

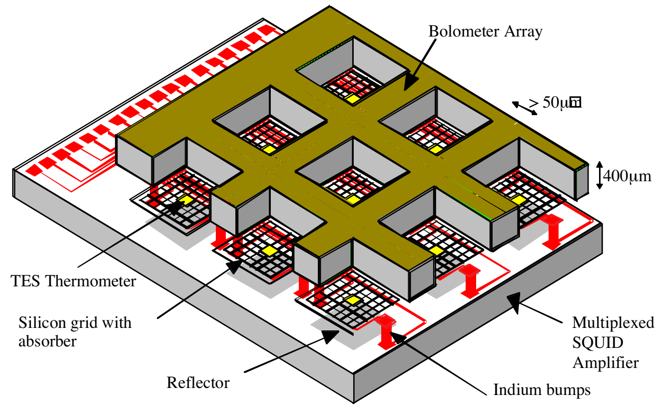


Unfolded TES Pop-up

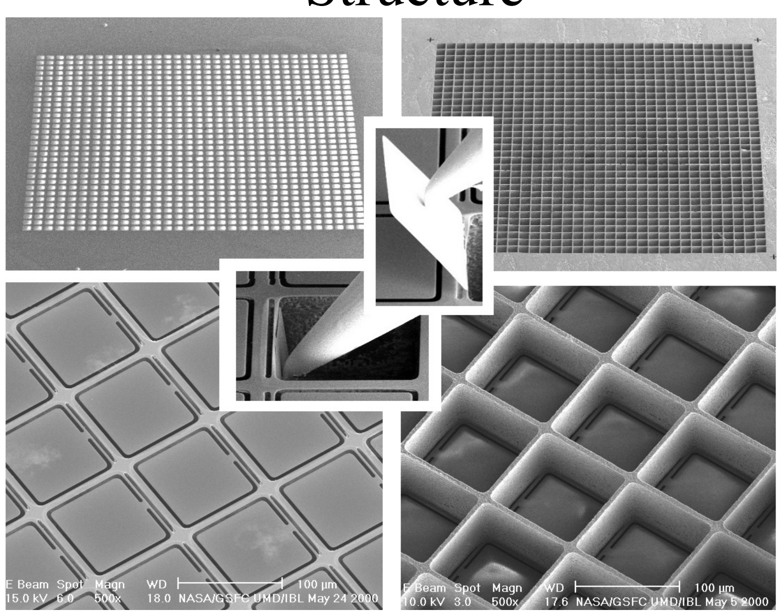


Alternative Configurations Are Under Study for Large Format Arrays

- Superconducting version of Saclay/CEA detector shows promise for scaling to large arrays
- Front end SQUIDs can operate at detector temperature

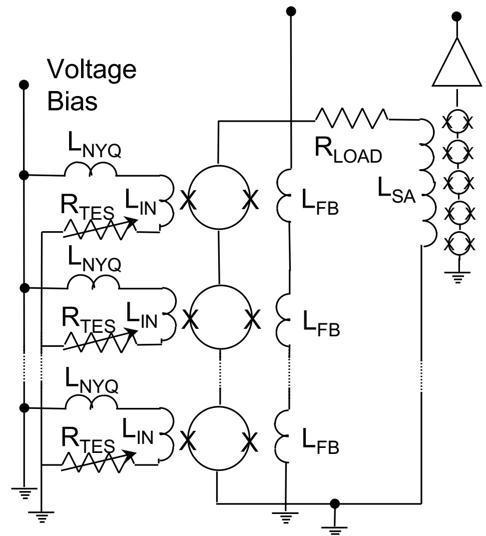


First Steps Towards Mechanical Structure



Multiplexing Concept

- Multiplexing is effected by sequential sampling of individual input SQUIDS
- We see full noise of SQUID, band limited noise from detectors



Steps to Required Technologies

- Long term industrial development on refrigerators, optics, and cryogenic systems must continue with community involvement
- We must identify unique needs for Far IR/ SMM missions that we must do ourselves
  - HQ-chartered detector panel is doing this in our most critical area, detectors
- Establish close connections with other relevant development programs (NGST, Con X, Herschel)
  - Avoid duplication, save time

Technology Concerns

- Basic concepts for SAFIR, e.g., are established. Significant engineering effort is required to make progress
  - Detailed engineering is typically only done after performance requirements are established.
  - Much important (and schedule-risky) work must be done after initiation of project.
  - We need to make progress on critical elements, such as detectors, before "meter is running" to lower cost risk on missions.

Summary

- We need to refine mission concepts, agree on science goals and requirements
- We need to identify performance requirements and pursue them to demonstrate readiness
- Far IR, SMM, and CMB science is so compelling that given a clear community voice and concerted technical effort in critical areas, it will compete successfully with other fields.