Technology Splinter Report

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Far-IR Measurement Goals

1) Sub-arcsecond angular resolution is required for a meaningful understanding of star and planet formation. This requires long-baseline measurements
   - 1 km baseline -> 10 mas, 30 m baseline -> 0.3 as
2) Far-IR background contains much of the history of galaxies, nucleosynthesis and black hole accretion. We want to identify and study the dusty galaxy populations spectroscopically with our mid and far-IR toolbox
   - Imaging is underway
   - Need spectroscopy of LIRG-class galaxies at redshift of 0.5-3.
3) Peering through the far-IR background populations will reveal the earliest galaxies with the first metals at and just after reionization
   - spectroscopy of LIRG or sub-LIRGs at z~5-10
4) Molecular hydrogen is the dominant coolant of primordial and low-metallicity material via its rotational transitions.
   - Spectroscopy of clumps, filaments, galaxies at all z.

Technologies required for our scientific goals

Far-IR / submillimeter detectors and readouts

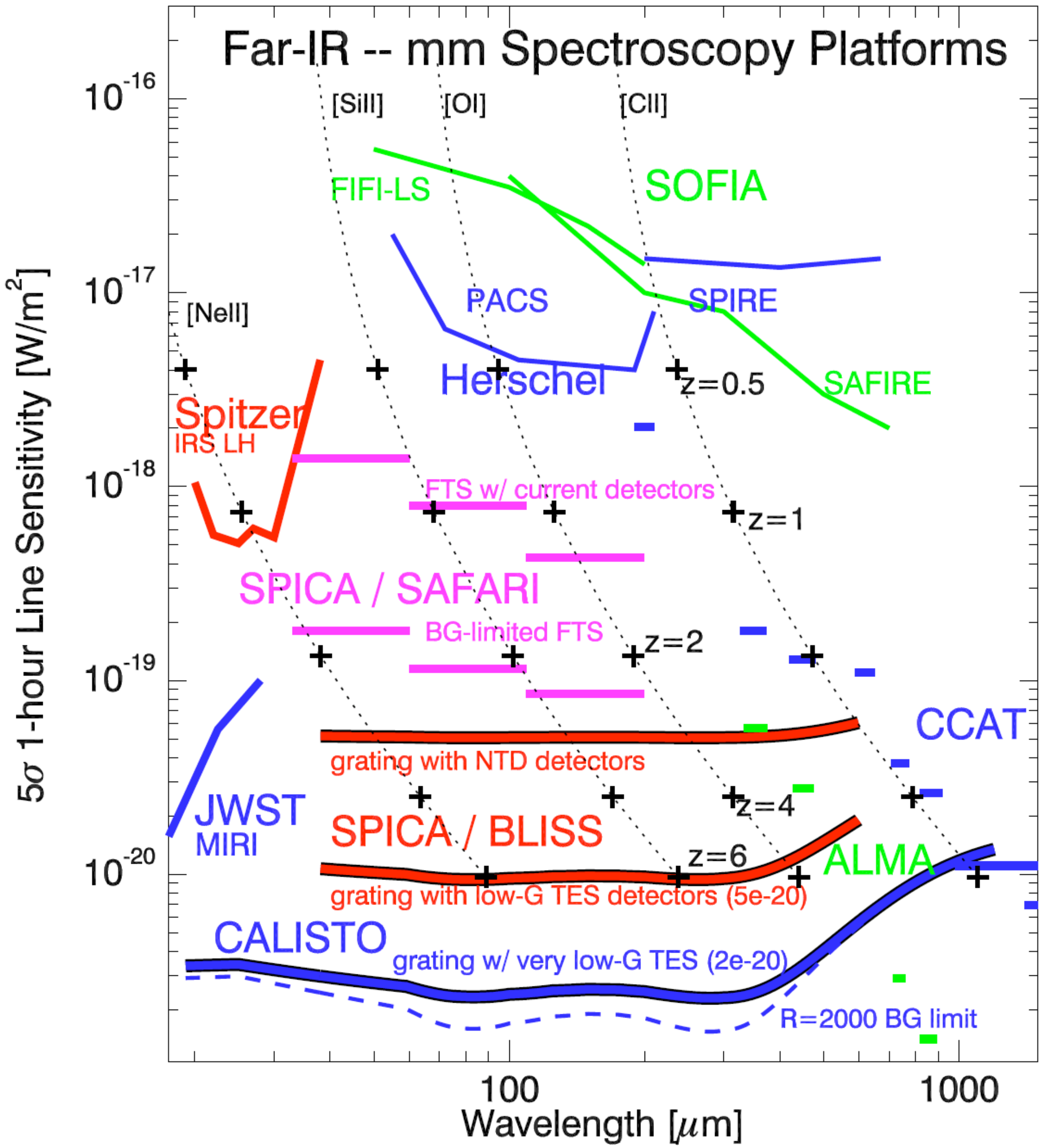
Observatory-level and sub-K cooling

Cryogenic Optics

- testing / handling
- cost control

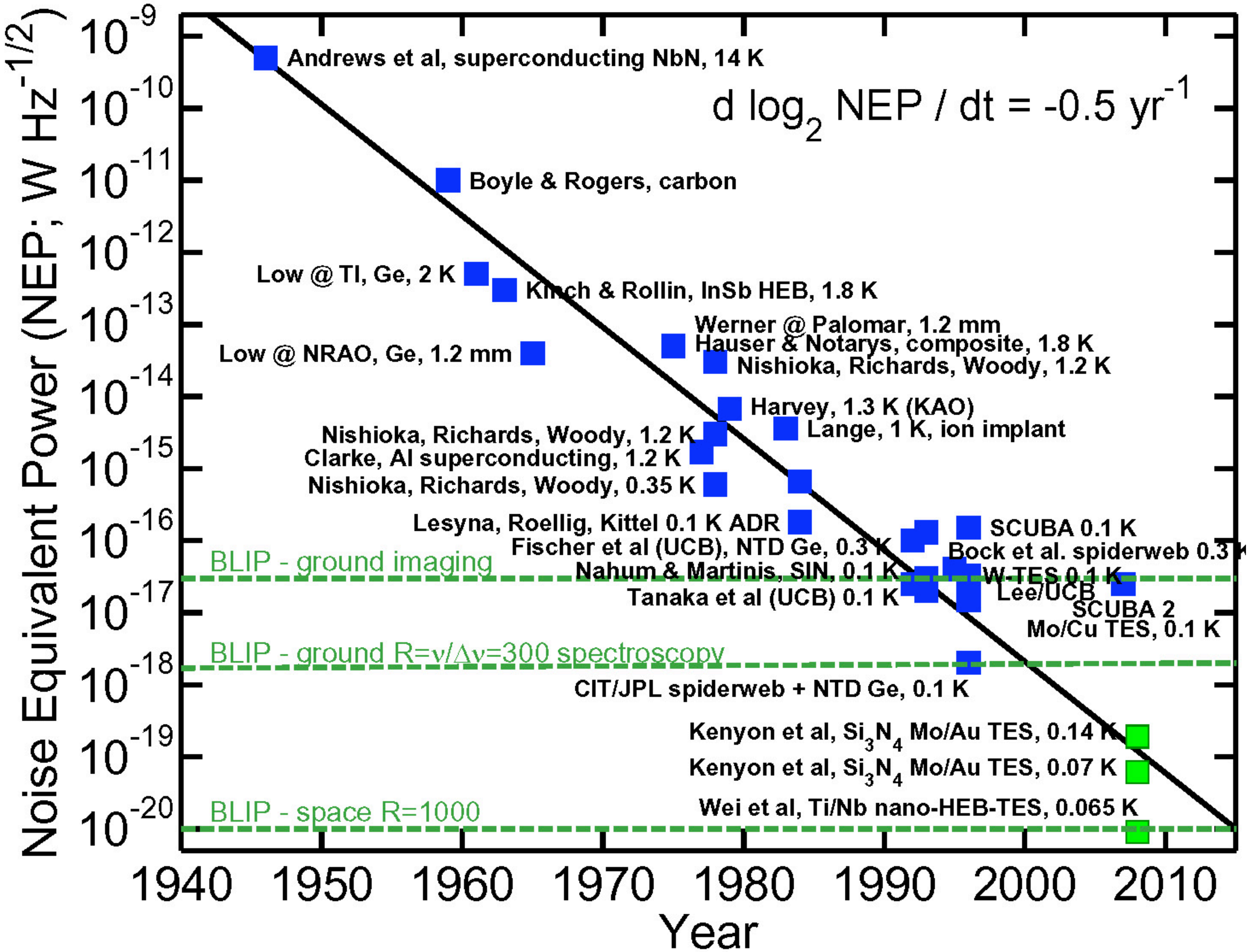
Instrument / Detector Requirements

- Far-IR galaxy populations- spectroscopy: Requirements in priority order.
  - 1e-20 W / m^2 line sensitivity with broadband spectral coverage
    - Need detector NEP ~ 5e-20 W / sqrt(Hz)
  - Resolving power: several x100 -1000
  - Spatial multiplexing: as much as possible.
    - Most sources identified via continuum measurements
- Spectroscopy of earliest galaxies and H2
  - 1e-21--1e-22 W / m^2 , with broadband coverage
    - Need detector NEP ~2e-20 W / sqrt(Hz)
  - Resolving power: 1000-3000
  - Spatial multiplexing: as much as possible.

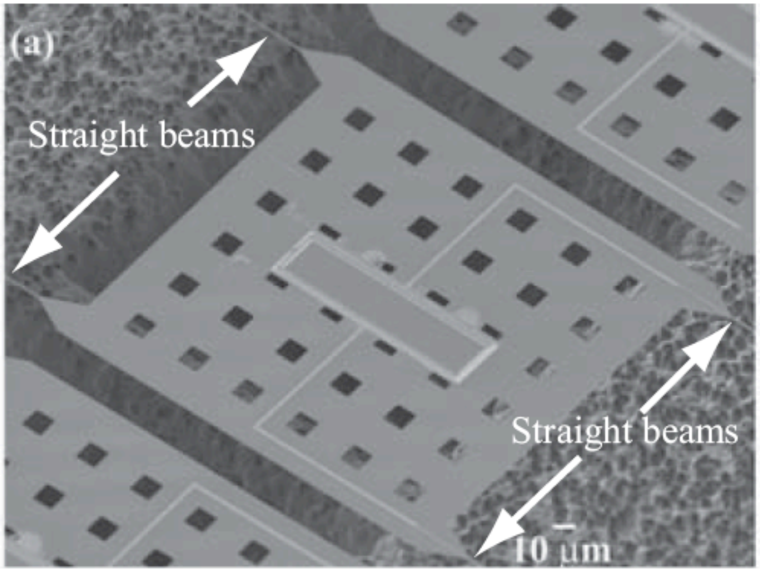


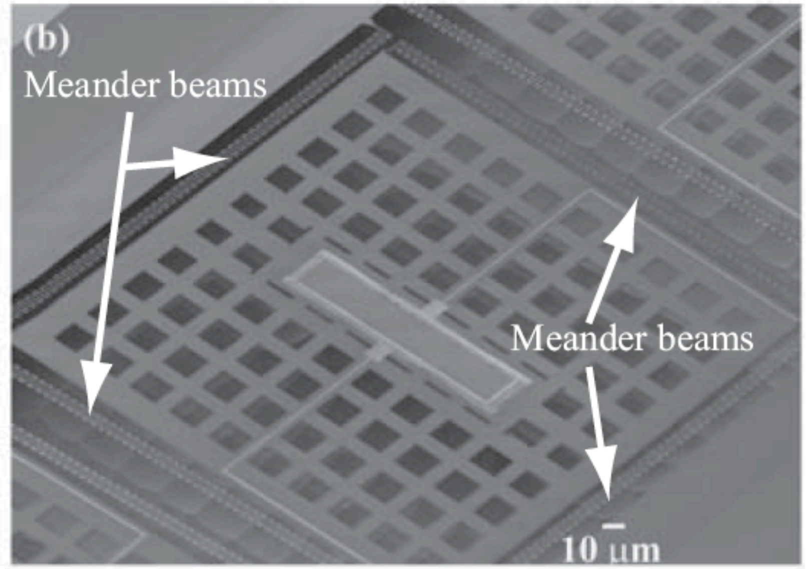
Far-IR -- mm Spectroscopy Platforms
5σ 1-hour Line Sensitivity [W/m^2]
Wavelength [μm]
10^-16
10^-17
10^-18
10^-19
10^-20
100
1000
[NeII]
[SiII]
[OI]
[CII]
FIFI-LS
SOFIA
PACS
SPIRE
SAFIRE
Herschel
z=0.5
Spitzer
IRS LH
FTS w/ current detectors
z=1
SPICA / SAFARI
BG-limited FTS
z=2
CCAT
grating with NTD detectors
JWST
MIRI
SPICA / BLISS
z=4
z=6
ALMA
grating with low-G TES detectors (5e-20)
CALISTO
grating w/ very low-G TES (2e-20)
R=2000 BG limit

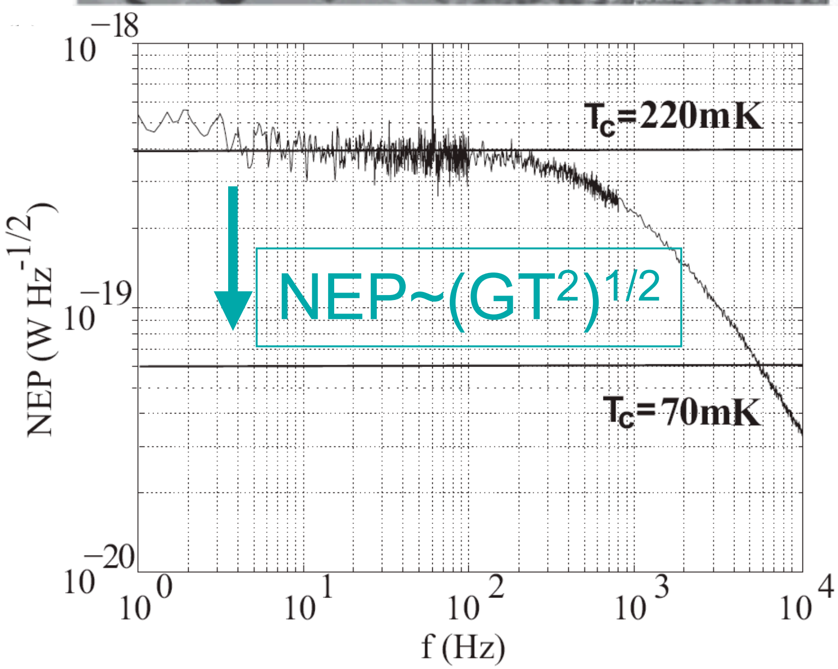
Single-device sensitivities are within reach!



Low-G TES bolometers for SPICA







Extending silicon-nitride micromesh technology:
- Reducing thermal conductance with long legs--700 µm X 0.5 µm X 0.5 µm. Suitable for 1-D or 2-D formats

Measured G corresponds to 4e-19 W Hz$^{-1/2}$ at
- 220 mK, confirmed with electrical measurements.

When cooled to 70 mK, this G corresponds to an
- NEP of 6e-20 W Hz$^{-1/2}$. (G measured, NEP measurement underway.)

Close to BLISS requirement !

(but a long way from a flight system)

Matt Kenyon et al. (see poster)

Array Formats?

Interferometers: field size is limited -> doesn’t drive array formats.

For single-dish cold telescopes, think BIG.

Cameras for CALISTO / SAFIR

conservative: 20,000 detectors in 4 bands

ambitious: 80,000 detectors in 6 bands. Either way: confusion-limited in seconds at. 100 microns, can survey the entire sky in ~1 year.

~ 1 order of magnitude more than state-of-the art ground-based arrays -> need new multiplexing scheme.

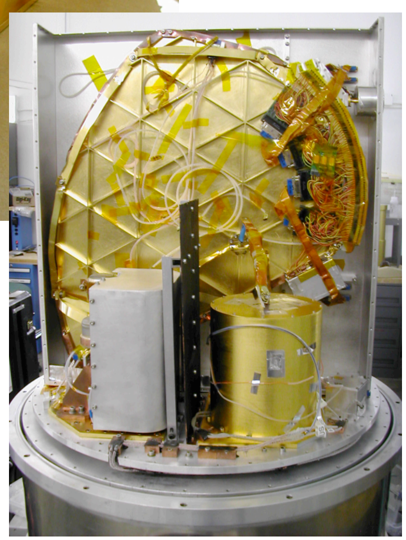
New opportunity: full-field, dispersed spectroscopy:

- large image slicers feeding slit spectrographs
- in-situ waveguide gratings

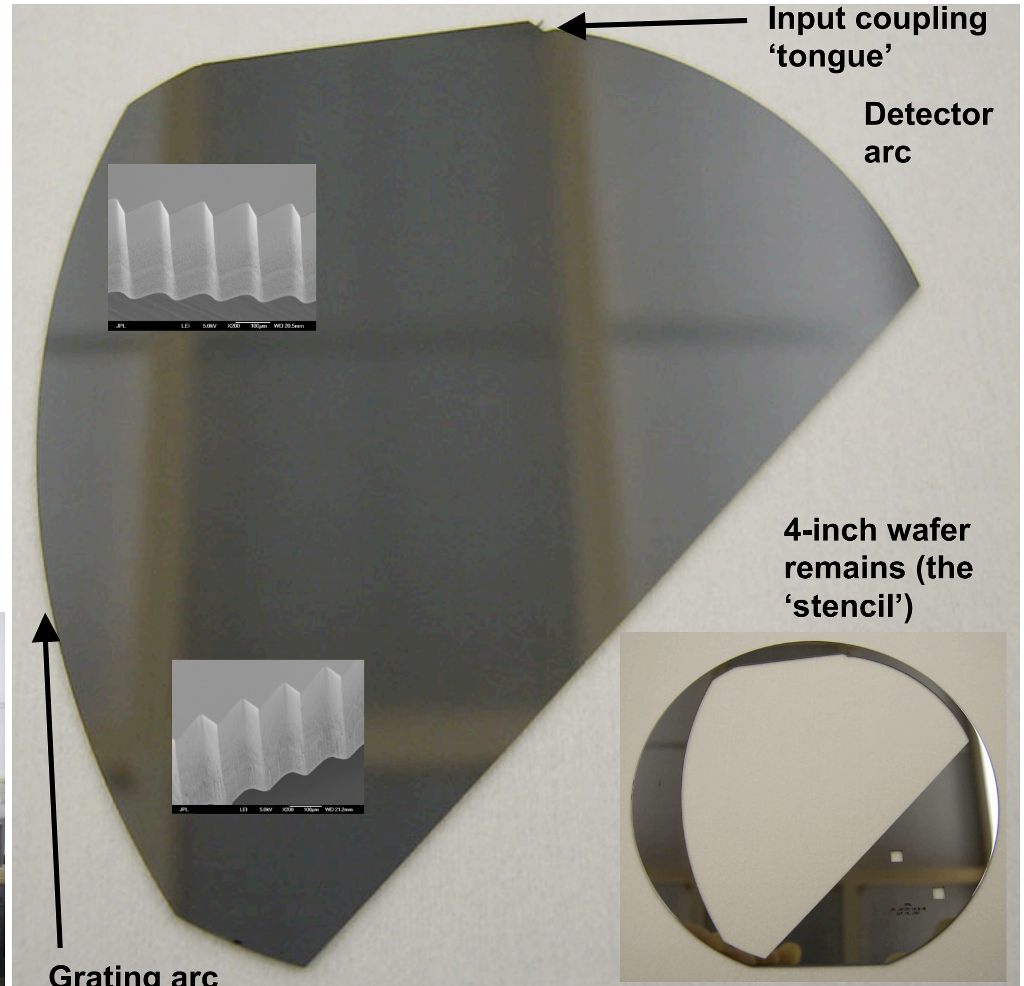
Compact in-situ spectrographs: dielectric waveguide gratings

Z-Spec waveguide grating at CSO
R=300 for λ=1-1.6 mm -> 55 cm Al.

Silicon-immersed waveguide spectrometer:
R=500 for λ=320-470 μm -> 10-cm wafer.



Large 60 mK cryostat required to get this grating cold!



Etching courtesy Matt Dickie, Risaku Toda

Dream CALISTO spectrometer detector formats

Focal plane: telescope delivers a field of hundreds of thousands of diffraction-limited beams.

Suppose we couple: 300 spatial positions X

4000 spectral elements per, **this gives 1e6 detectors**

(our shorter-wavelength colleagues are already in this regime)

Relative to state-of-the-art ground-based facilities, we have at least 2 orders of magnitude to gain in format.

and with the spectroscopic NEPs, and potentially high-frequency response.

HOW: Not likely time-domain multiplexed TES bolometers, but perhaps via microwave-multiplexing of:

Bolometers, kinetic inductance detectors, quantum capacitance detectors, or

New ideas?

Technology development strategy (1)

- Thus we need an ongoing technology development program in this decade to prepare us for the large missions we envision for the next decade.
- APRA program provides modest funds for some low-TRL detector work at JPL, GSFC, other places. Has borne fruit.
- But increasing array formats and complexities require increasing resources to develop -> a larger, more focused program is required for far-IR detector technology maturation.
- Stay abreast of NASA management structure, continue to lobby for long-wavelength detector program.
- **Same old story.**

Technology development strategy (2)

A pure technology development program is necessary but not sufficient.

NASA's budget is tight, and CALISTO / SPIRIT / SPECS is not in front of the line.

We are at least 1 decade away from a start on either of these $1B class efforts.

Pure technology doesn't sell well to Decadal committee and NASA.

per Eric Smith.

The best approach to both advancing our technology, and maintaining our communities in preparation for our $B class cryogenic missions is scientifically-compelling, affordable technology pathfinder(s) which we can build, fly and operate in the next decade.

Low-cost pathfinders?

- SOFIA instruments
- Balloon experiments

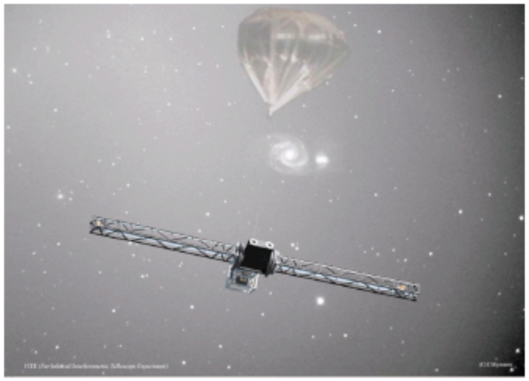
Detector backgrounds not well-matched to our cold telescope plans. 5-6 orders of magnitude higher background.

Difficult to make science case for direct-detection instruments in the face of Herschel, SPICA.

But possibly could help develop large array formats, focal plane coolers, and other systems-level aspects.

e.g. mid-IR balloon-borne interferometer testbed.

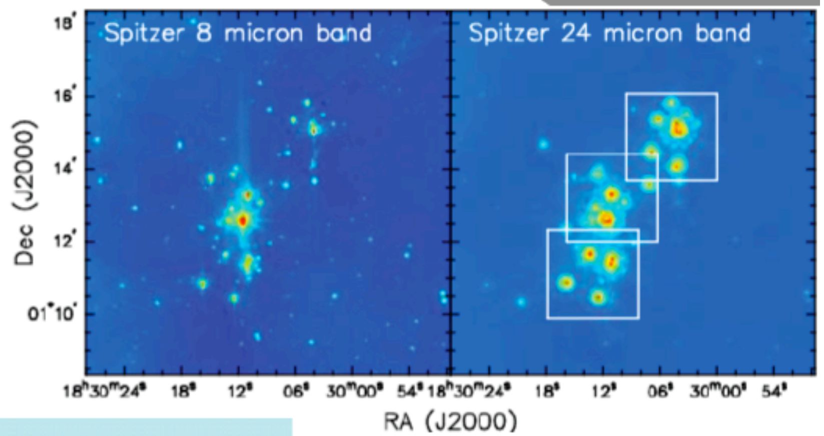
The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

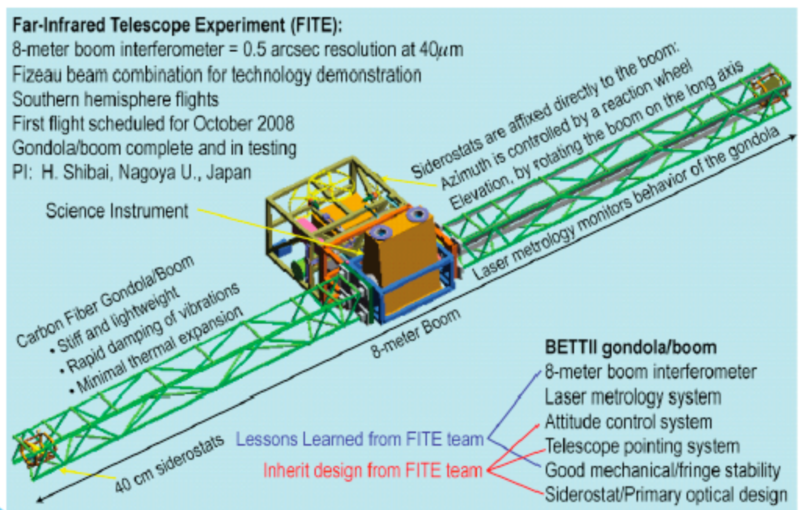


BETTII provides unique and powerful scientific data while proving technologies for future space interferometers

Science:

- Star formation
- AGN
- Evolved Stars

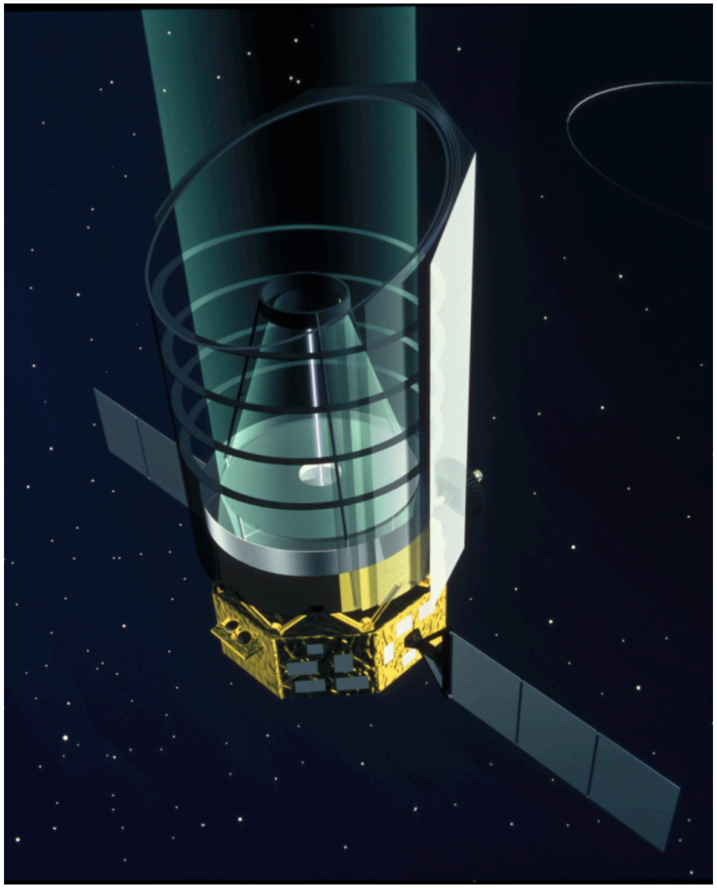




Technology:

- Structures
- Metrology
- FIR Filters
- Mechanisms

SPICA: *The World's First Large, Cryogenic Far-IR Space Telescope*



US participation in SPICA?

NASA is well-poised to contribute, especially critical focal-plane aspects -- detectors, readouts.

SPICA team is keen to have US support, but mission does not require it.

Best approach for our technology program is to deliver a focal-plane instrument.

For example, BLISS, a broadband spectrograph with superconducting bolometers.

Cost on the scale of an Explorer (but not a MoO).

BLISS

- full 38-430 μm coverage in 5 bands, R=700
- 4200 superconducting bolometers with sensitivity approaching the background limit.
- cooled to 50 mK with magnetic refrigerator
- two beam on the sky, modulated by cold chopper