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.
  - $1 \times 10^{-20}$ W / m$^2$ line sensitivity with broadband spectral coverage
    - Need detector NEP $\sim 5 \times 10^{-20}$ W / $\sqrt{\text{Hz}}$
  - Resolving power: several x100 - 1000
  - Spatial multiplexing: as much as possible.
    - Most sources identified via continuum measurements

- Spectroscopy of earliest galaxies and H2
  - $1 \times 10^{-21}$ -- $1 \times 10^{-22}$ W / m$^2$, with broadband coverage
    - Need detector NEP $\sim 2 \times 10^{-20}$ W / $\sqrt{\text{Hz}}$
  - Resolving power: 1000-3000
  - Spatial multiplexing: as much as possible.
Single-device sensitivities are within reach!

\[
d \frac{\log_2 \text{NEP}}{dt} = -0.5 \text{ yr}^{-1}
\]
Low-G TES bolometers for SPICA

Extending silicon-nitride micromesh technology:
Reducing thermal conductance with long legs--700 $\mu$m X 0.5 $\mu$m X 0.5 $\mu$m. 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 $\lambda=1$-1.6 mm -> 55 cm Al.

Silicon-immersed waveguide spectrometer: R=500 for $\lambda=320$-470 $\mu$m -> 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.

*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)

Science:
- Star formation
- AGN
- Evolved Stars

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

Technology:
- Structures
- Metrology
- FIR Filters
- Mechanisms

S. Rinehart
BETTII

May 29, 2008
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).

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**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