LiteBIRD focal-plane tower

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Working model

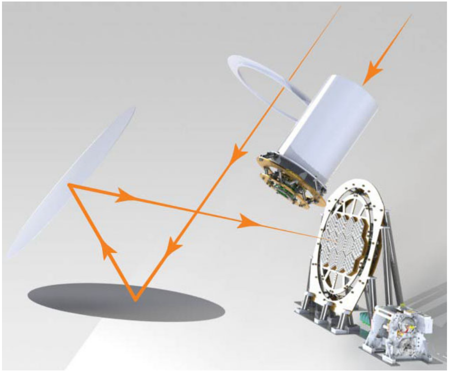
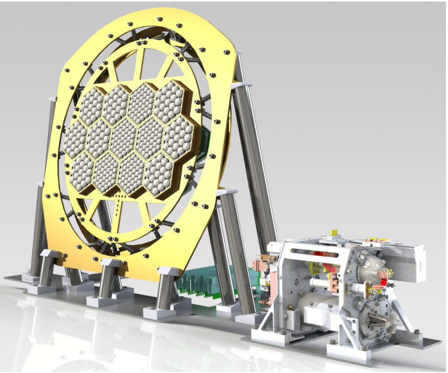


Figure: Concept drawings from NASA MO proposal

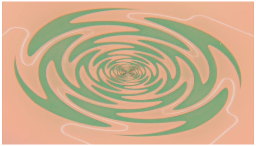
Two telescopes

- Low-frequency crossed Dragone
- High-frequency refractive

Low- and mid-freq. focal-plane unit (LMFFPU)



(a) Focal-plane tower with sub-K cooler



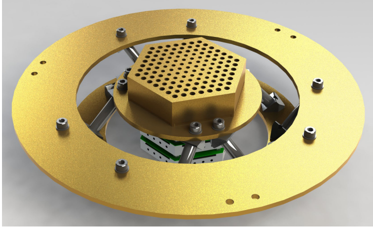
(b) Sinuous antenna

Figure: Pre-proposal LMFFPU design

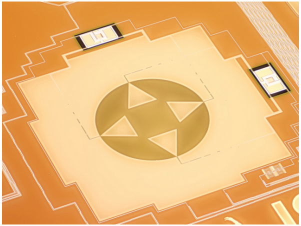
Low- and mid-frequency focal-plane unit (LMFFPU): 30-300 GHz

- Lenslet-coupled sinuous antennas
- Detector-stage diameter: $\sim$ 440 mm

High-frequency focal-plane unit (HFFPU)



(a) Focal-plane tower



(b) Orthomode transducer

Figure: Pre-proposal HFFPU design

High-frequency focal-plane unit (HFFPU): 250-450 GHz

- Feedhorn-coupled orthomode transducers
- 1 wafer ($\sim$ 80-mm diameter)

Wafer module

(a) (b)

Figure: POLARBEAR-1 wafer module

Wafer module integrates...

- Bolometer wafer
- Lenslet array
- Resonators for frequency-domain multiplexing

Baseline design builds on POLARBEAR experience

Wafer module (cont'd)

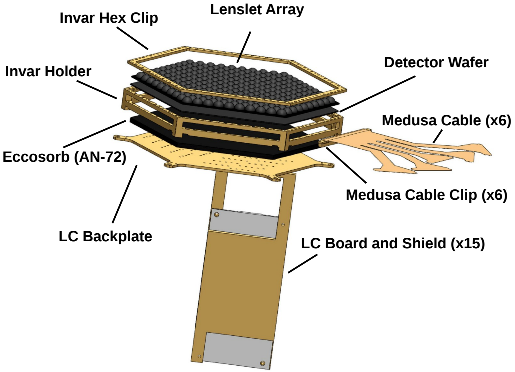


Figure: Exploded view of POLARBEAR-2 wafer module. Striplines to SQUIDs attach at bottom.

Focal-plane heritage

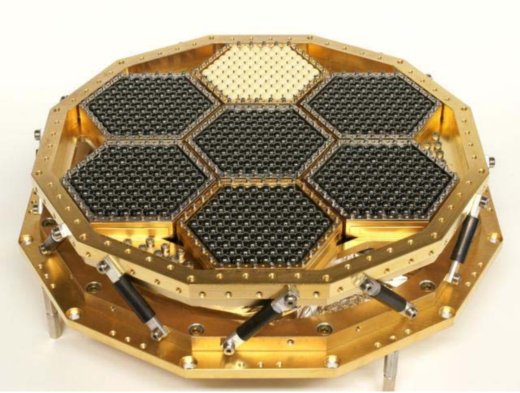


Figure: POLARBEAR-1 focal-plane tower

Concentric temperature stages separated by insulating struts

Cryogenics overview

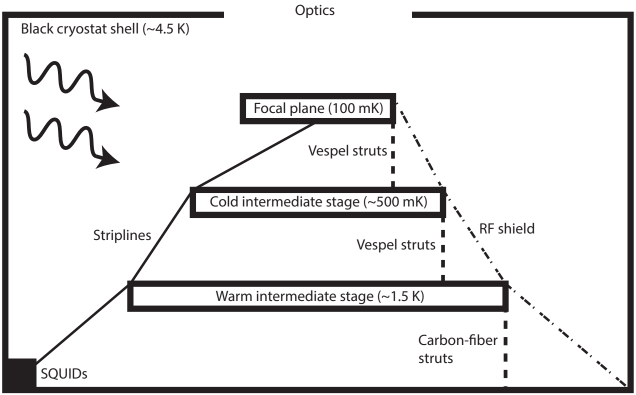


Figure: Cryogenic block diagram.

Focal-plane tower of decreasing temperatures

- 100 mK at focal plane
- Other temperatures may vary through design process

Cryogenics overview (cont'd)

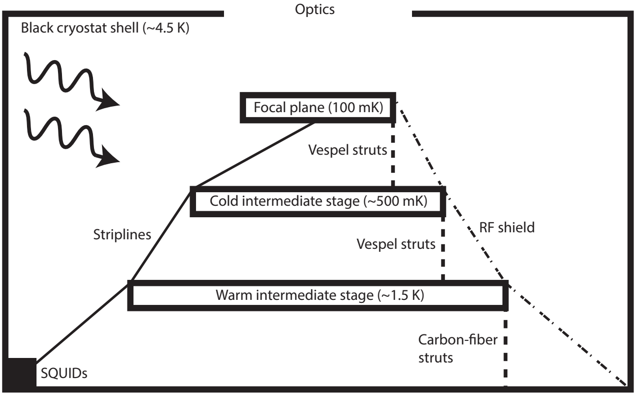


Figure: Cryogenic block diagram.

Cryostat shell is black

- Suppresses multiple reflections
- Crossed Dragone is susceptible to such reflections
- But creates large radiative load ($\sim 4.5\ \mathrm{K}$, $\epsilon = 100\%$)

Cryogenics overview (cont'd)

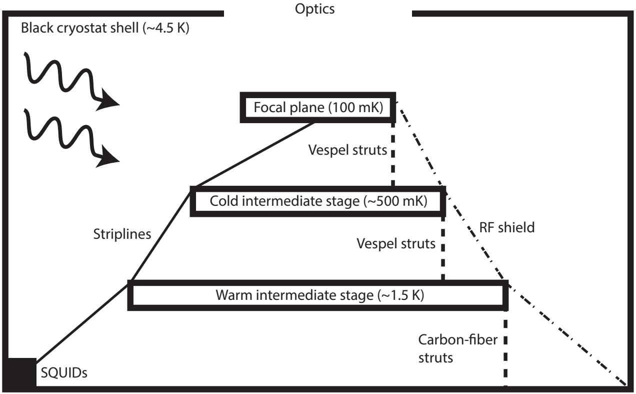
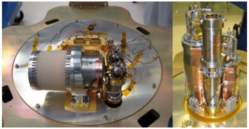


Figure: Cryogenic block diagram.

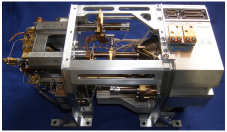
Strut material should be studied/optimized

- Vespel is common for ground-based; carbon fiber becoming more popular
- Other options: Ti 15-3-3-3, NbTi
  - Higher thermal conductivity than Vespel
  - Tradeoff between thermal and mechanical requirements

ADR options



(a) Astro-H (GSFC)



(b) SPICA-SAFARI (CEA)

(c) SHI

Studying 3 ADRs

- All provide similar sub-K temps.: 100 and $\sim 500\ \mathrm{mK}$
  - CEA requires $\sim 2\ \mathrm{K}$ and $\sim 4\ \mathrm{K}$
  - Goddard, SHI require $\sim 4\ \mathrm{K}$

Thermal loading

Known contributions

- Radiative
  - Most severe from $\sim 4.5\text{-}\mathrm{K}$ black cryostat shell
  - Metal-mesh filters
    - Lenslets are significantly absorptive ($\sim 30\%$)
    - POLARBEAR places metal-mesh (low-pass) filters directly above wafers
- Structural
  - Balance mechanical strength and thermal insulation
- Wiring
  - Striplines from SQUIDs to bolometers
  - Balance parasitic inductance and thermal insulation
- RF shielding
  - Protects SQUIDs
  - Extra conductive thermal path between stages

Thermal loading (cont'd)

Unknown contributions

- Mechanical resonances (vibrational heating)
  - Actively pursuing through simulation and vibration tests
- Cosmic-ray heating
  - Preliminary estimates show negligible heat load

Focal-plane stage

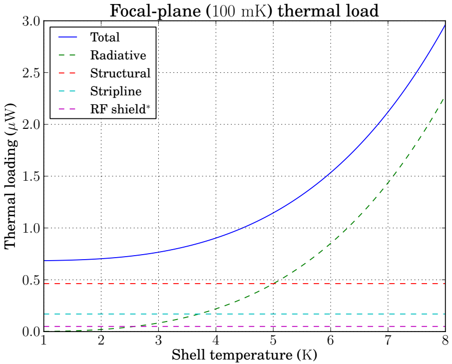


Figure: Thermal load on focal plane (100 mK). Expect $T_{\text{shell}} \sim 5$ K.

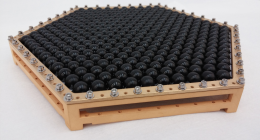
Radiative and structural loading dominate

- Radiative is more variable
  - Sensitive to shell temperature

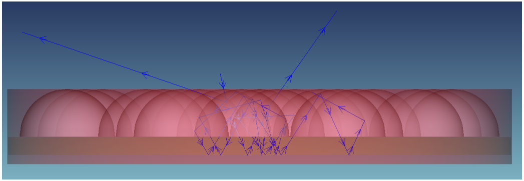
Expect $\sim 1\ \mu\text{W}$

- Fine for all ADR options

Lenslet emissivity



(a) POLARBEAR-2 lenslet array



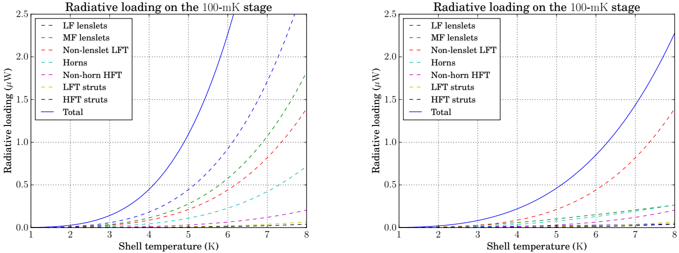
(b) Raytracing

Figure: Lenslet array

Rays are trapped by total internal reflection

- "Greenhouse effect"
- Simulations suggest $\sim$ 30% *effective* emissivity

Radiative loading



(a) Without low-pass (b) With low-pass

Figure: Improvement from low-pass filtering.

Low-pass filter reduces radiative loading by $> 2\times$

- Metal-mesh filter is an obvious choice
  - Implemented successfully in POLARBEAR

Cold intermediate stage

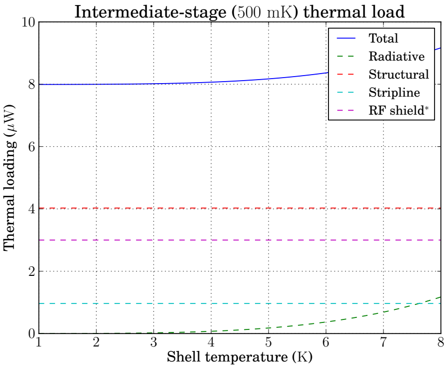


Figure: Thermal load on cold intermediate stage. Expect $T_{\mathrm{shell}} \sim 5$ K.

Structural and RF-shield loading dominate

Expect $\sim 8\ \mu\mathrm{W}$: fine for all ADR options

Warm intermediate stage

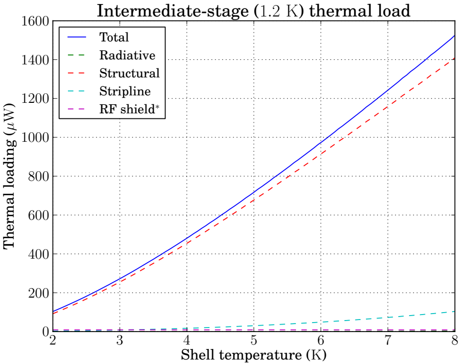


Figure: Thermal load on warm intermediate stage. Expect $T_{\mathrm{shell}} \sim 5\ \mathrm{K}$.

Structural dominates

- Next design iteration can aim to suppress this

Expect $\sim 0.8\ \mathrm{mW}$: large but manageable

- May need (quasi-)continuous operation

Fridge cycle and hold time

Require 85% observation efficiency

- Astro-H SXS and SPICA-SAFARI satisfy this requirement
  - But thermal loads and heat capacities are different for LiteBIRD
- Keep thermal loads low to increase hold time
- Keep heat capacities low to decrease cycle time
  - And to maintain cooling capacity
- Study of cycle and hold time is underway

Mechanical robustness

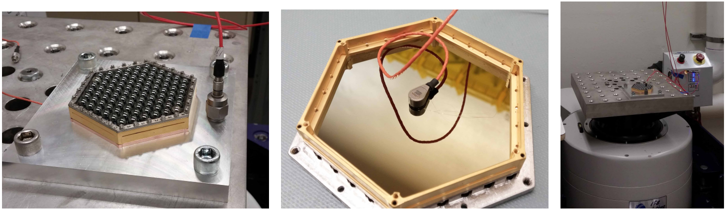
Two regimes:

- Launch
  - Large accelerations, broad frequency profile
  - But focal plane just needs to survive
- Observation
  - Much gentler
  - But tolerances are much tighter
    - Focal-plane heating can destroy sensitivity

Want to avoid mechanical resonances

- Combination of simulation and measurement

Vibration testing



(a) Reference accelerometer

(b) Accelerometer on wafer

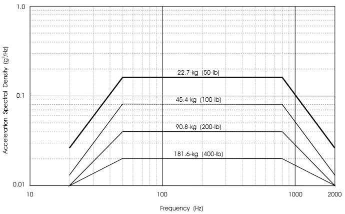
(c) Shake table

Figure: SSL shake-table testing

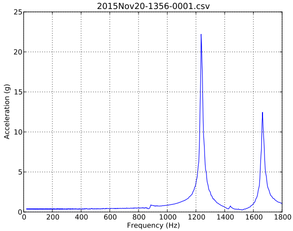
Look for mechanical resonances through vibration testing

- Preliminary tests done at the Space Sciences Laboratory (SSL) in Berkeley
- Silicon wafer is brittle
    - Check for drumhead modes from launch vibrations

Vibration testing (cont'd)



(a) NASA recommended vibration test levels



(b) Wafer-module results

Figure: Acceleration spectral density.

Resonances at ~ 1.2 and $\sim 1.7\ \mathrm{kHz}$

- Past roll-off of NASA recommendations
- Promising start
  - Work to push resonances above $2\ \mathrm{kHz}$
  - Thicker lenslet wafer ($\sim 4\times$ for LiteBIRD) will help

Future tests

More realistic and complete hardware

- E.g., lenslet array should be $\sim 5\times$ thicker
- Mutual coupling of focal-plane components
  - Ideally test/simulate full focal-plane tower

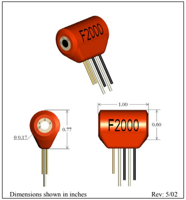
Large-amplitude vibration test

- Random vibration test ($14g$ RMS)
- Typically design to withstand 5σ fluctuations, i.e., $70g$

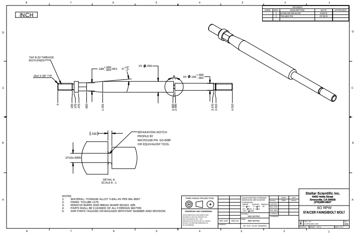
Acoustic test

- Sound waves
  - Important, unless launching under vaccum
- Wafers (large, unsupported area) may be susceptible
- This is a common NASA pre-launch test

Launch locks



(a) Actuator



(b) Frangibolt

Figure: Frangibolt is a type of launch lock.

Add mechanical support during launch

- Break supports in orbit to achieve thermal isolation
- Separates launch and observation designs

Launch locks

- Shape-memory alloy (NiTi) expands on heating (90° C)
- Breaks bolt and creates gap
- Can be reset in a hydraulic press
- Used routinely for mission-critical procedures

Launch locks (cont'd)

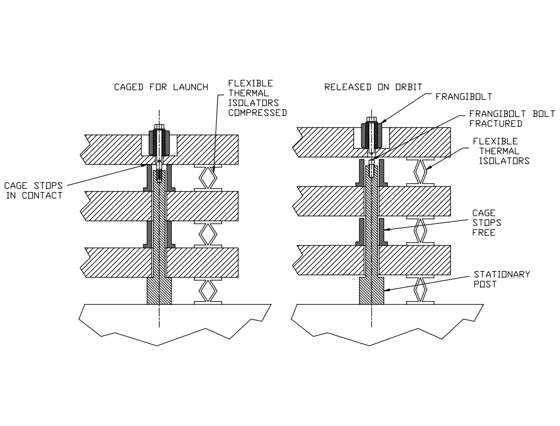


Figure: Possible launch-lock scheme (P. Turin, SSL).

Ongoing activities

Refine/improve design

- Iterate with JAXA

Mechanical simulations, vibration testing

- Part of iterative design process

ADR study

- Study is on-going
- Can we use existing designs (with small perturbations)?
  - Preliminary answer is yes

Study successful past designs

- Incorporate lessons learned from other experiments