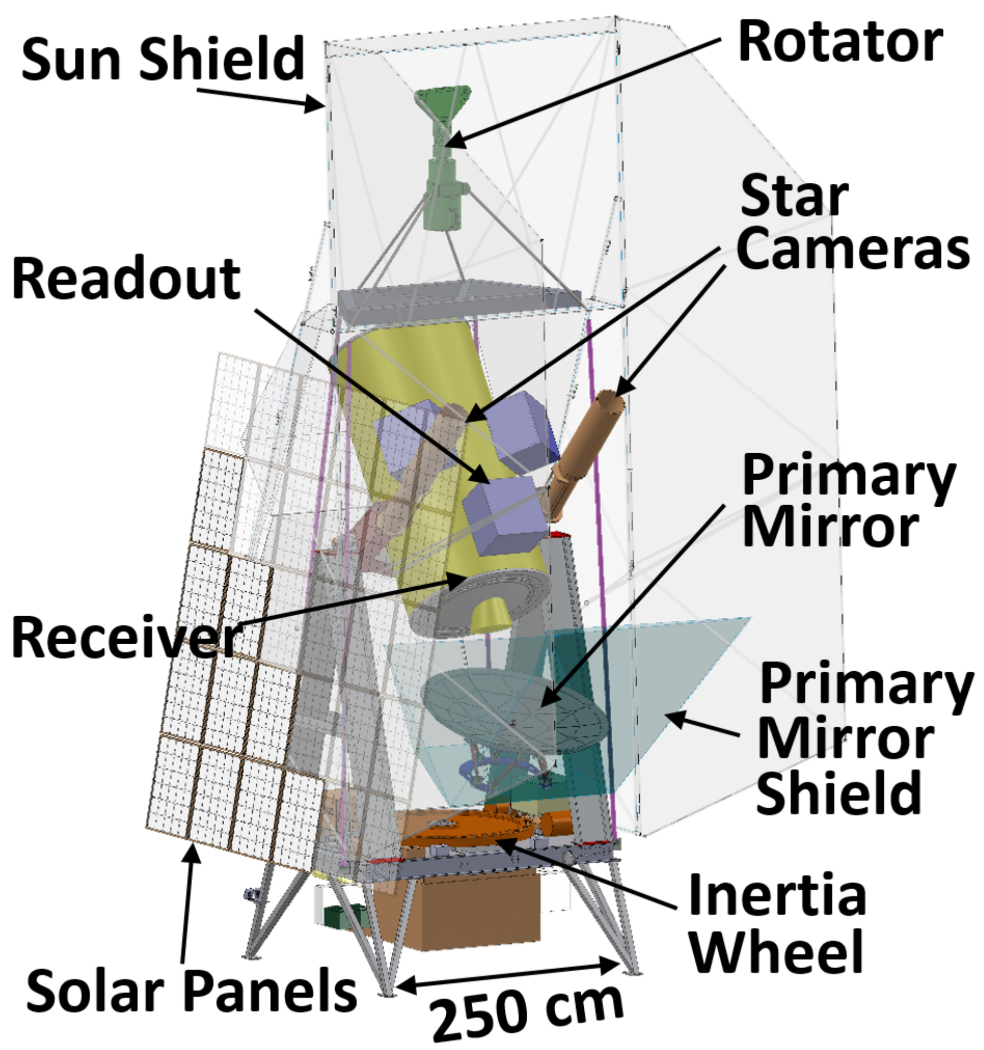
IDS - The Inflation and Dust Surveyor

Shaul Hanany
University of Minnesota

IDS Paradigm

- **Proposed Balloon Borne Experiment**

- **Design Paradigms:**
  - **Complement S3 and S4 searches for GW by giving dust information on the same patch of sky, at frequencies not accessible from the ground, with medium resolution, and with unmatched depth**
  - **Keep the implementation simple**



Balloons in the 2020s

Areas of uniqueness:

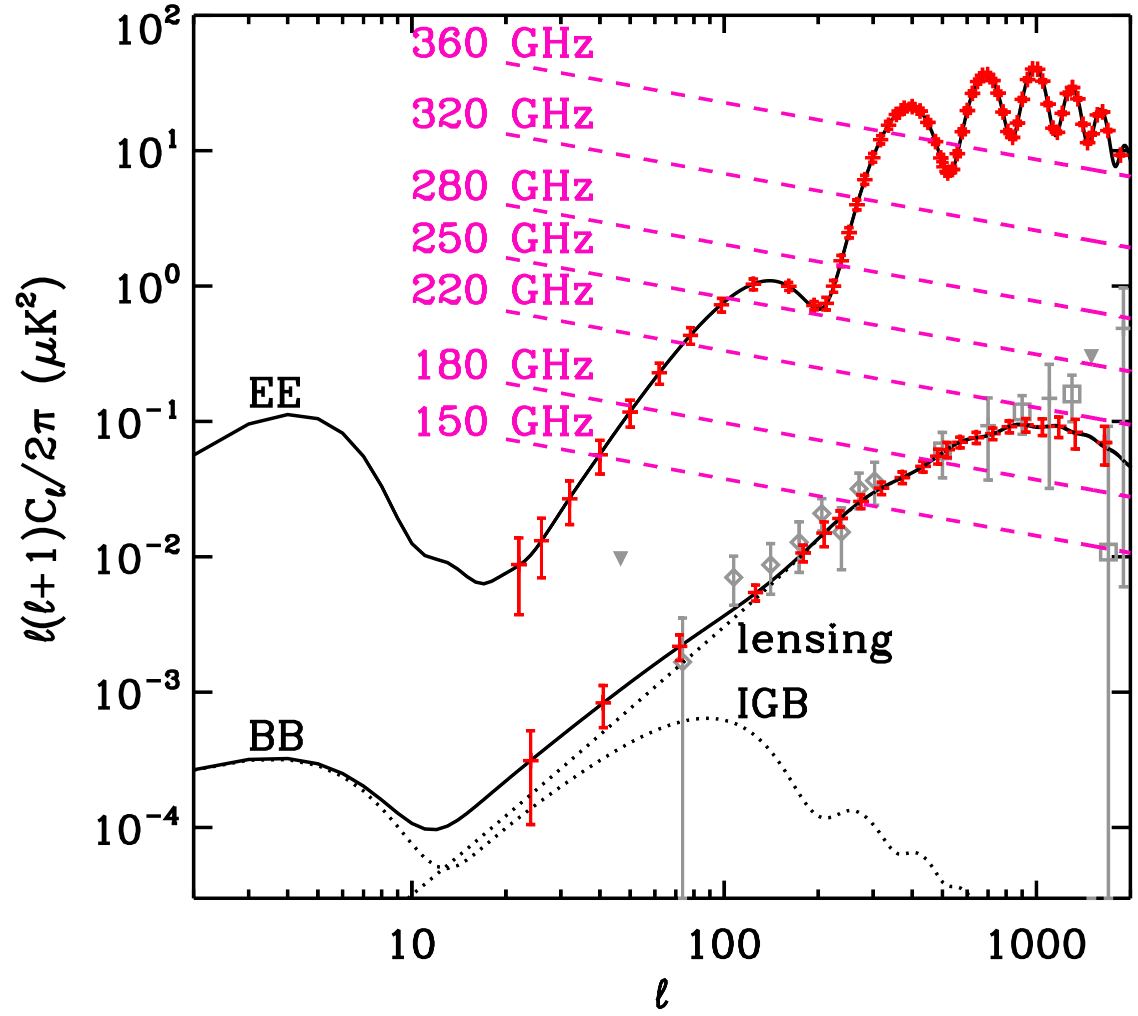
- **High frequencies, ν > 250 GHz**
- **Large angular scales,** $\ell < 50$
- **(Technology, pre-Space, Training)**

Two science targets:

- **EE-Reionization for τ and neutrino mass**
- **High resolution, higher frequency, deep observations over a small patch, for r**
  - **Give the foregrounds both for recombination peak and for lensing**
- **(BB-reionization buried in foregrounds, leave for space)**

Overall Strategy:

- **Support the depth provided by ground-based efforts for ν < 300 GHz**



Balloons in the 2020s

Areas of uniqueness:

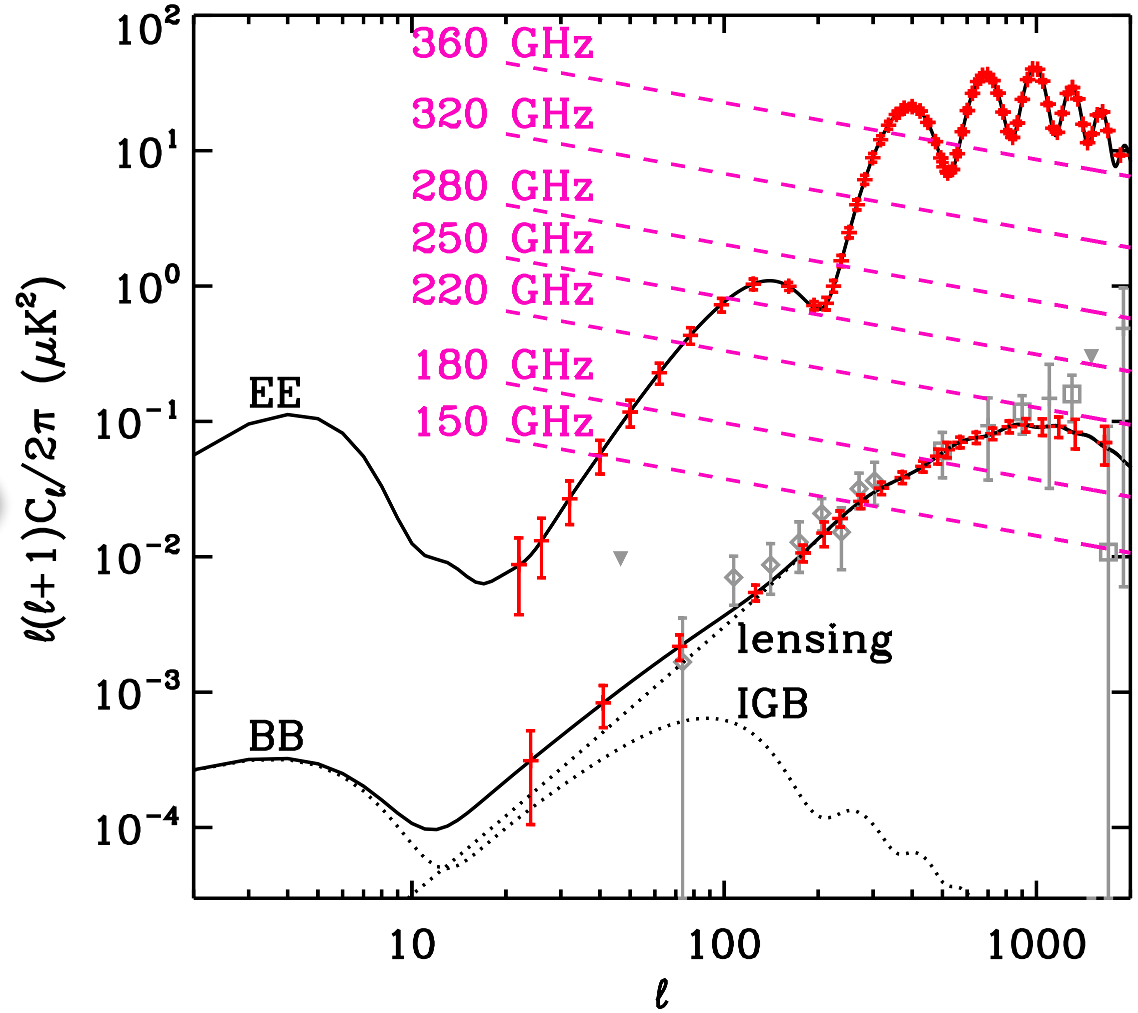
- **High frequencies, ν > 250 GHz**
- **Large angular scales,** $\ell < 50$
- **(Technology, pre-Space, Training)**

Two science targets:

- **EE-Reionization for τ and neutrino mass**
- **High resolution, higher frequency, deep observations over a small patch, for r**
  - **Give the foregrounds both for recombination peak and for lensing**
- **(BB-reionization buried in foregrounds, leave for space)**

Overall Strategy:

- **Support the depth provided by ground-based efforts for ν < 300 GHz**



Comment About Noise + Depth

MAXIMA-1 (1998, Hanany et al. 2000)

- **One warm mirror**
- **Small (thin) window, thin absorptive filter**
- **100 mK focal plane**
- **87 μK*s$^{-1/2}$; @ 150 GHz (N=3)**

Boomerang (1998, Crill et al. 2003)

- **One warm mirror**
- **Small (thin) window, thin absorptive filter**
- **250 mK focal plane**
- **140 μK*s$^{-1/2}$ @ 150 GHz (N=6)**

EBEX (2013, EBEX Collaboration et al. 2018)

- **Two warm mirrors**
- **Large (thicker) window, thicker absorptive filter**
- **250 mK focal plane**
- **Calculated: 180 μK*s$^{-1/2}$ @ 150 GHz (N=504)**

SPIDER (2015, Jones S4 talk)

- **0 warm mirrors**
- **250 mK focal plane**
- **154 μK*s$^{-1/2}$ @ 150 GHz (N=818)**

BICEP (Ade et al. PRL 2014)

- **0 warm mirrors**
- **250 mK focal plane**
- **300 μK*s$^{-1/2}$ @ 150 GHz (N=512)**

Balloons in the 2020s

Areas of uniqueness:

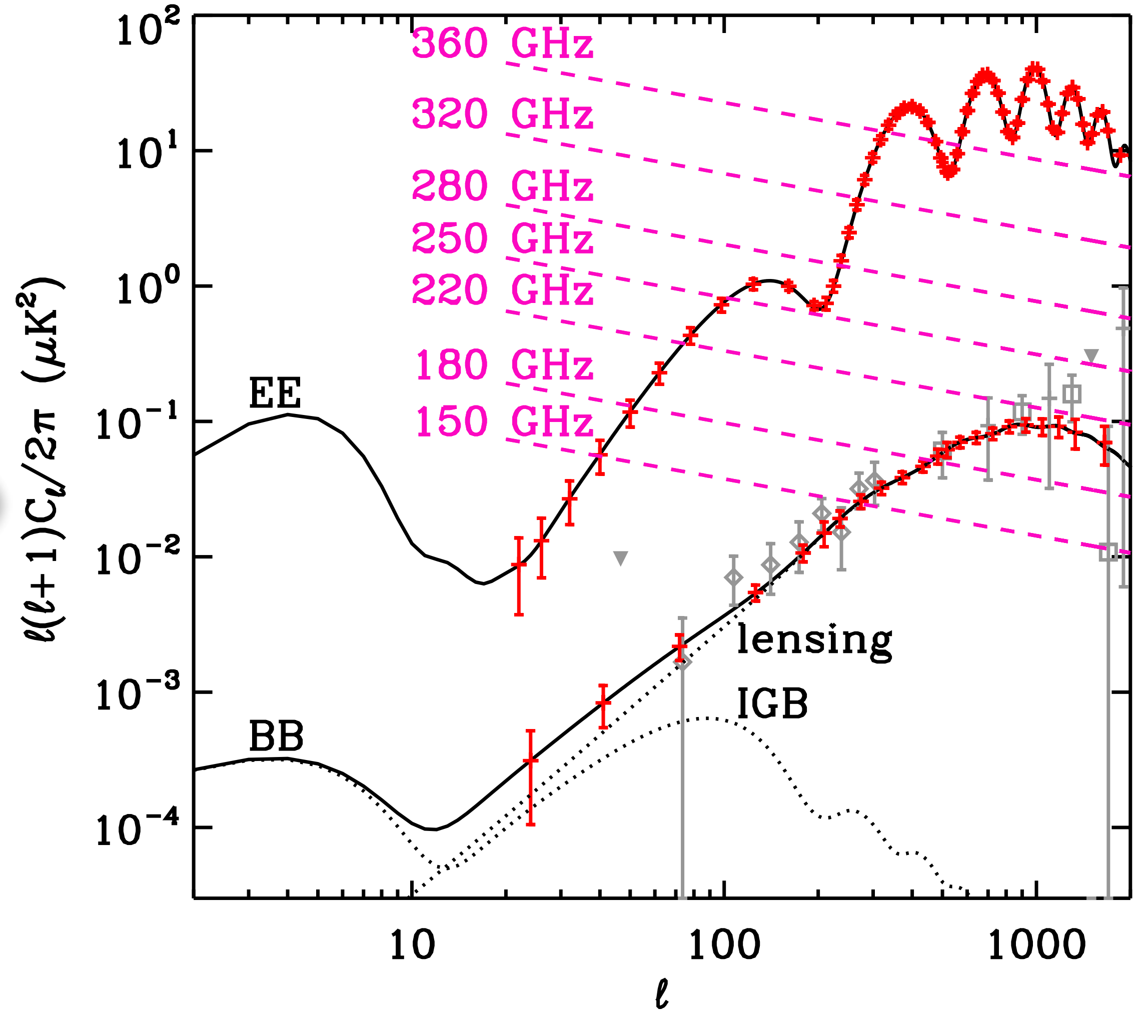
- **High frequencies, ν > 250 GHz**
- **Large angular scales,** $\ell < 50$
- **(Technology, pre-Space, Training)**

Two science targets:

- **EE-Reionization for τ and neutrino mass**
- **High resolution, higher frequency, deep observations over a small patch, for r**
  - **Give the foregrounds both for recombination peak and for lensing**
- **(BB-reionization buried in foregrounds, leave for space)**

Overall Strategy:

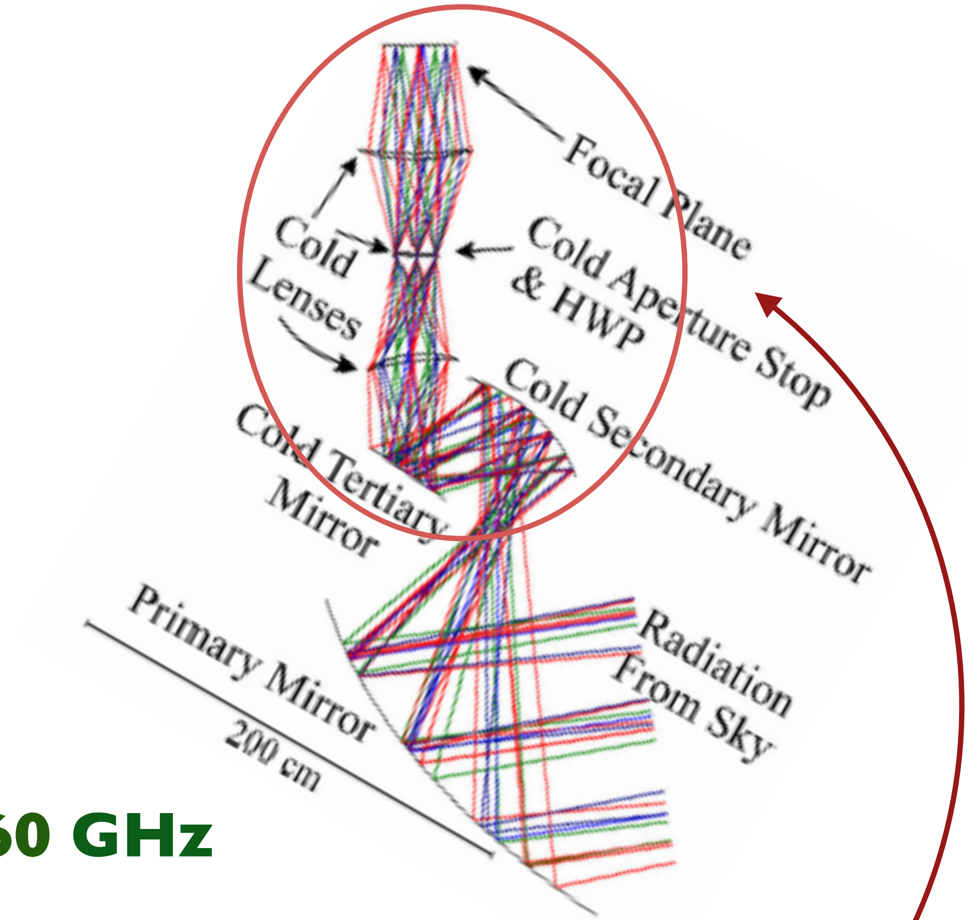
- **Support the depth provided by ground-based efforts for ν < 300 GHz**



IDS - Telescope and Focal Plane

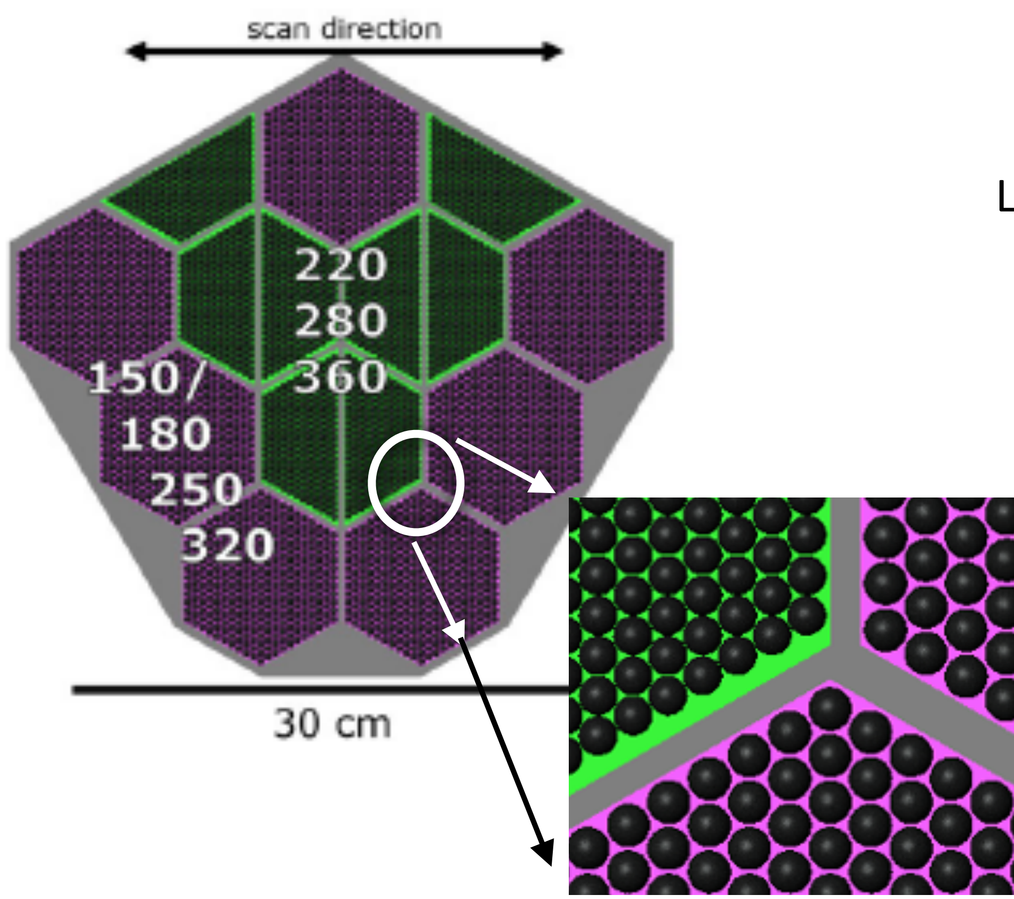
Optics

- **3-mirror telescope; two 2 at 4 K**
  - **1.5 m primary (Archeops, EBEX)**
  - **7’ at 150 GHz; 3.2’ at 360 GHz**
- **3 anti-reflection coated silicon lenses**
- **Internal, cold aperture stop + stepped AHWP**

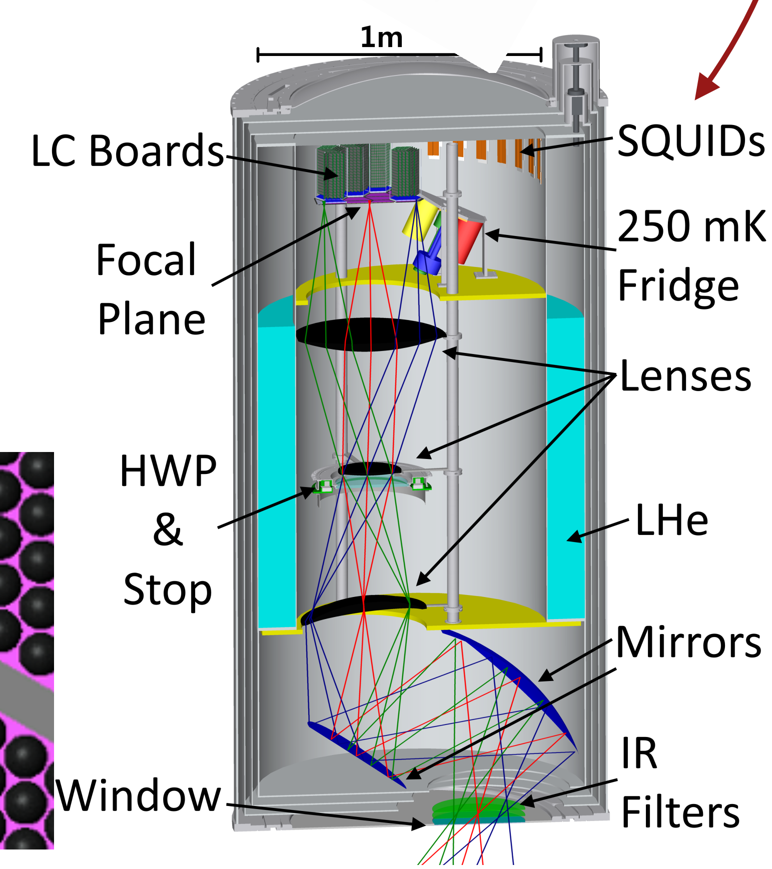


Focal Plane

- **Sinuous-Antenna based, 3-color pixels**
- **7 frequency bands: 150/180, 220, 250, 280, 320, 360 GHz**

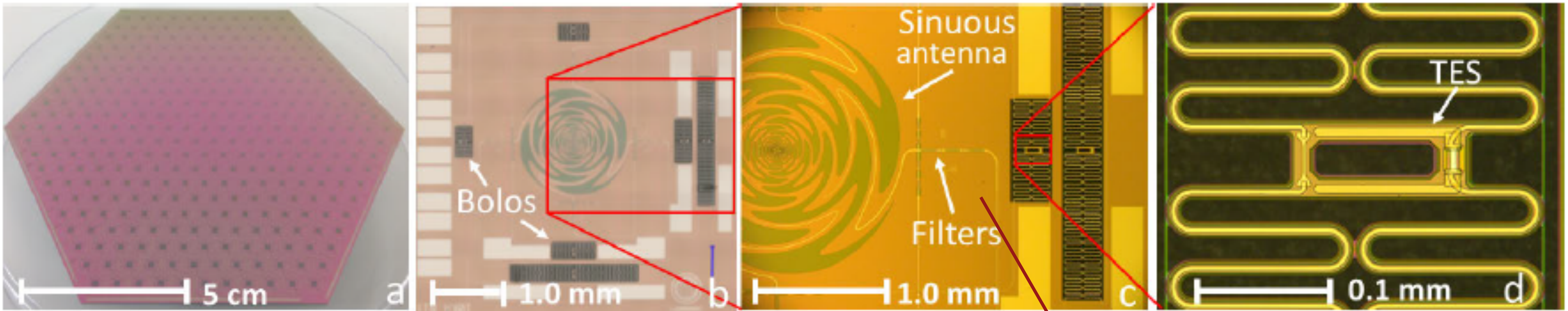


- **2316 High frequency pixels (220,280,360)**
- **1680 Low frequency pixels (150/180,250,320)**
- **All available Strehl area allocated to the High (42% in # of pixels)**
- **Total 20,562 TES-based bolometers**



Multi-chroic Pixels

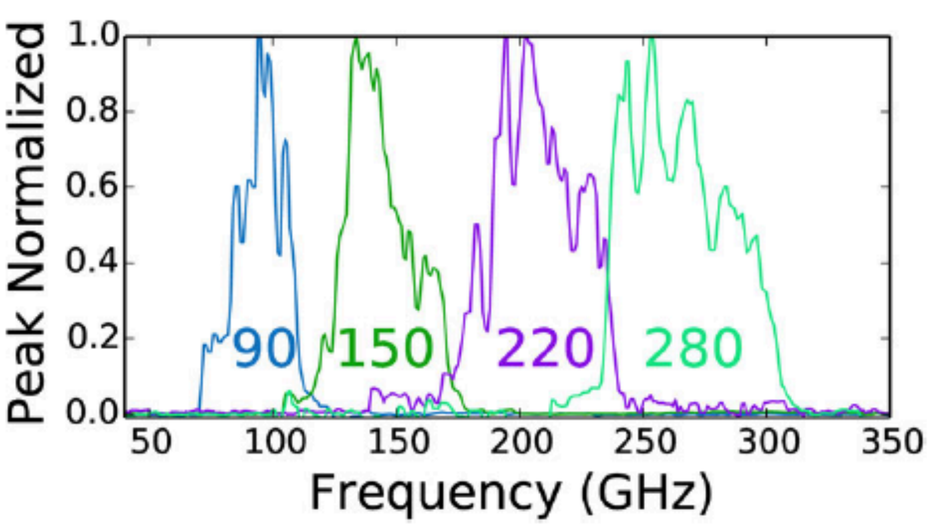
Lee, Suzuki, Westbrook - UCB

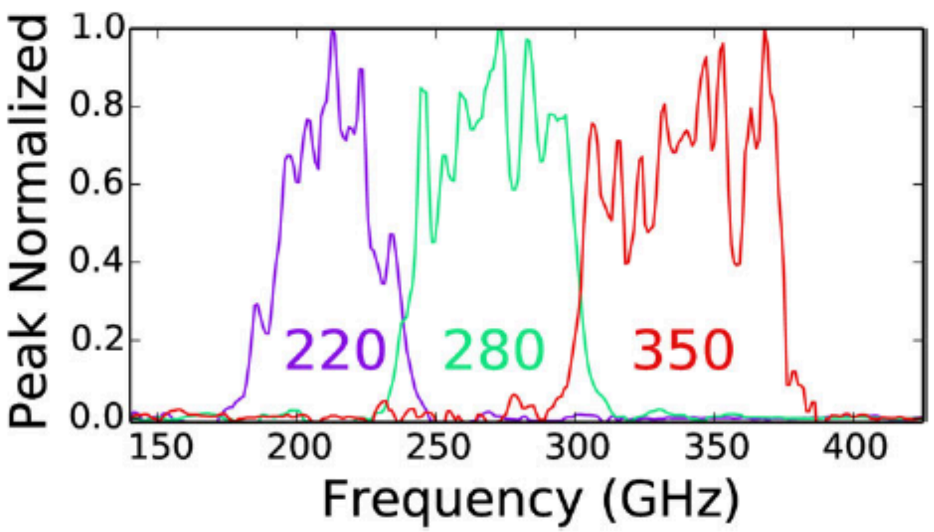


Sinuous Antenna and 6 bolometers

Filters + 2 bolometers

TES + Meander bolometer legs

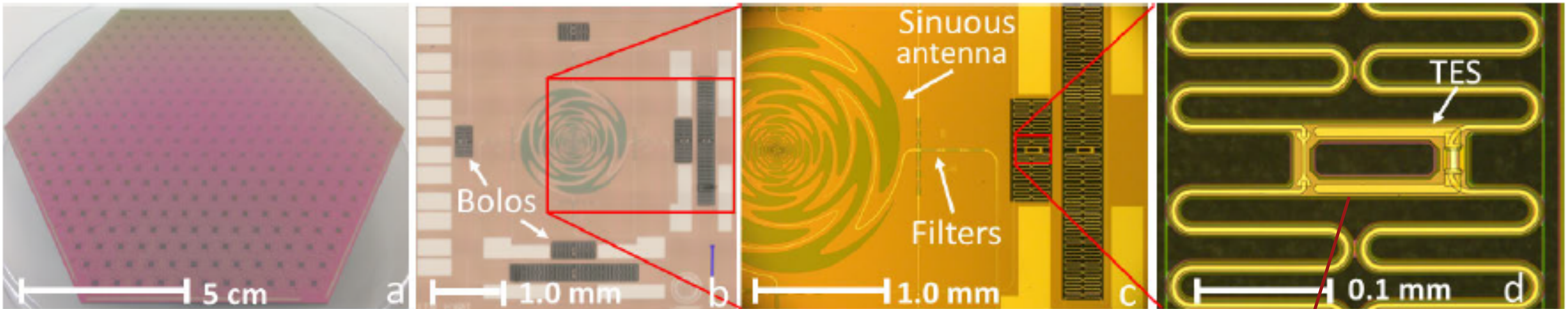




Filters demonstrated across entire frequency band

Multi-chroic Pixels

Lee, Suzuki, Westbrook - UCB

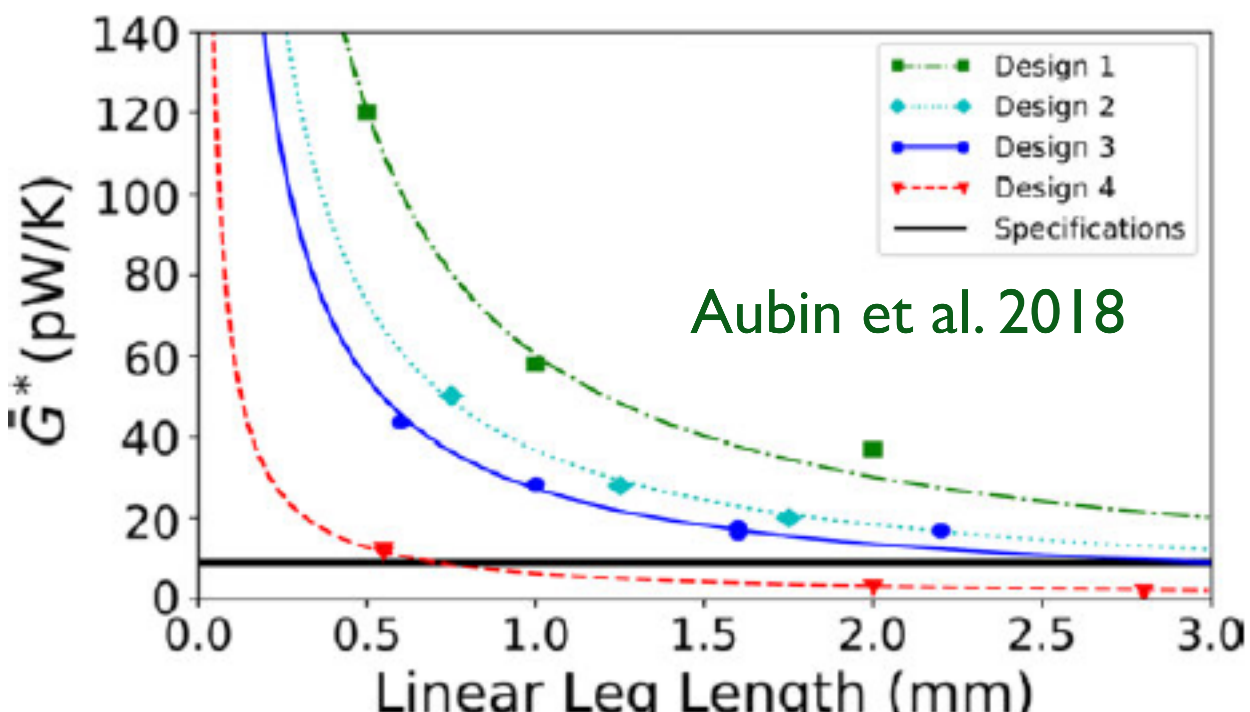


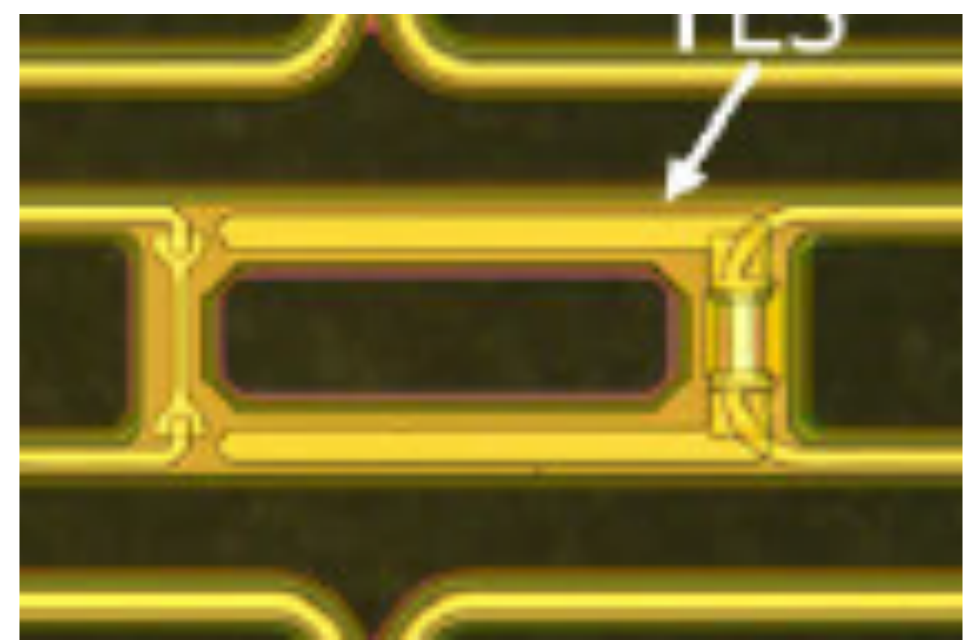
Sinuous Antenna and 6 bolometers

Filters + 2 bolometers

TES + Meander bolometer legs

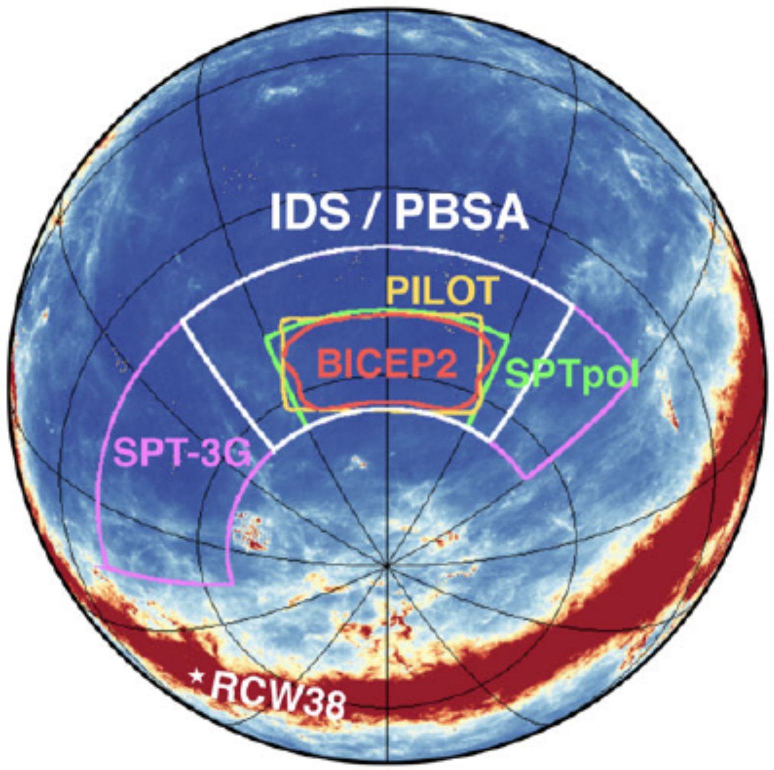
P= 0.6 pW, <G>=9*10^{-12} W/K demonstrated



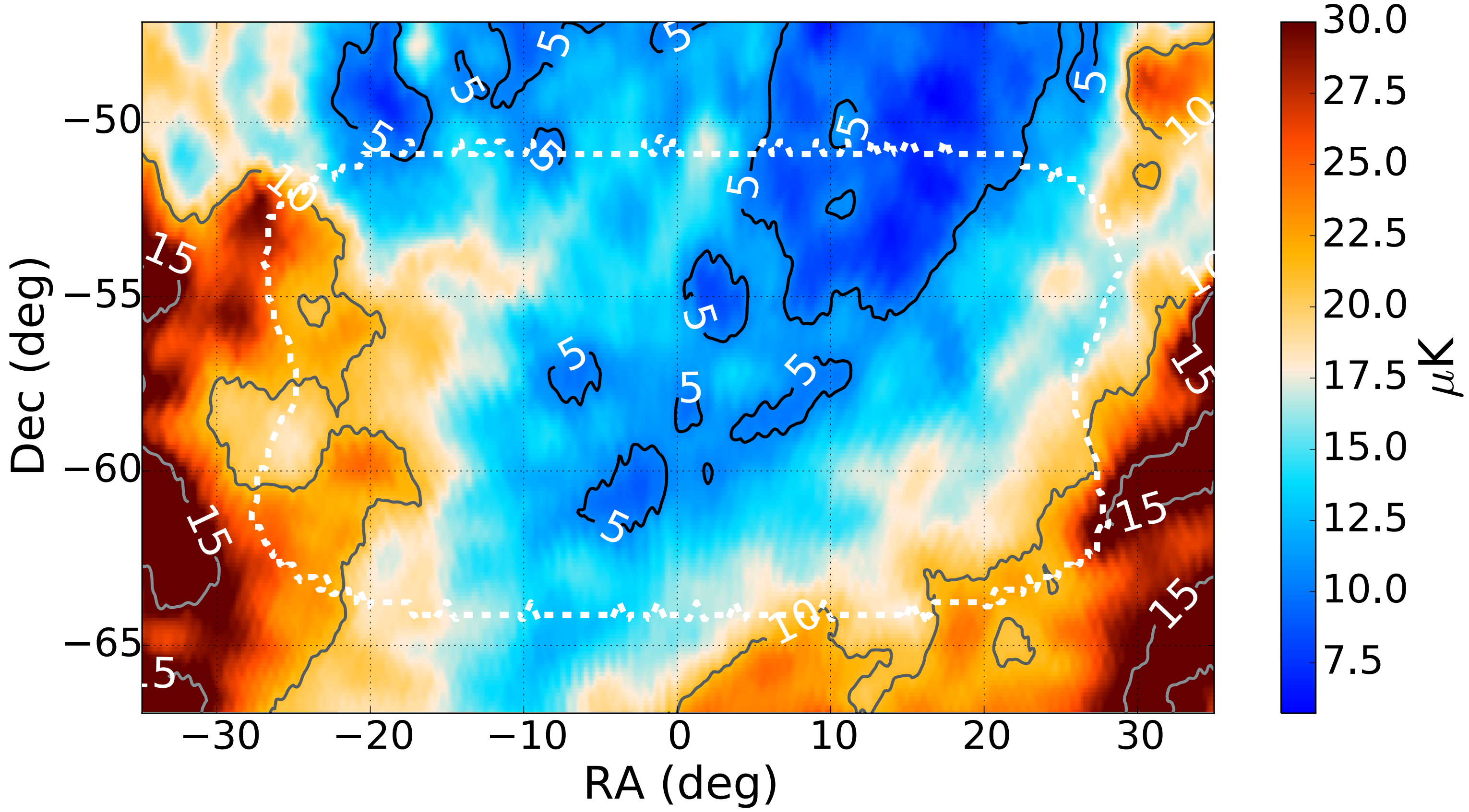


Survey Area

- **20 day Antarctic flight**
- **1500 sq*deg**
- **Overlap with Bicep/Keck + SA + SPT-3G (+SO? + S4?)**
- **Entire area available until ~Dec. 25**



- **S/N > 5 for Planck dust over majority of patch at 360 GHz with 14' pixels**



Keep it Simple

EBEX New (Balloon) Technologies

- **Arrays of TES**
  - **3 wafers in 2009**
  - **14 wafers in 2012/13**
- **Digital FDM**
  - **x8 in 2009**
  - **x16 in 2012/13**
- **Superconducting Magnetic Bearing**
  - **first 4 K operation**
  - **first implementation with HWP modulation**
- **Broadest band AHWP**
  - **characterization**
  - **5-layer ARC on sapphire**

EBEX Collaboration et al. x3
ApJS, in print,
1803.01018
1703.03847
1702.07020

This was challenging

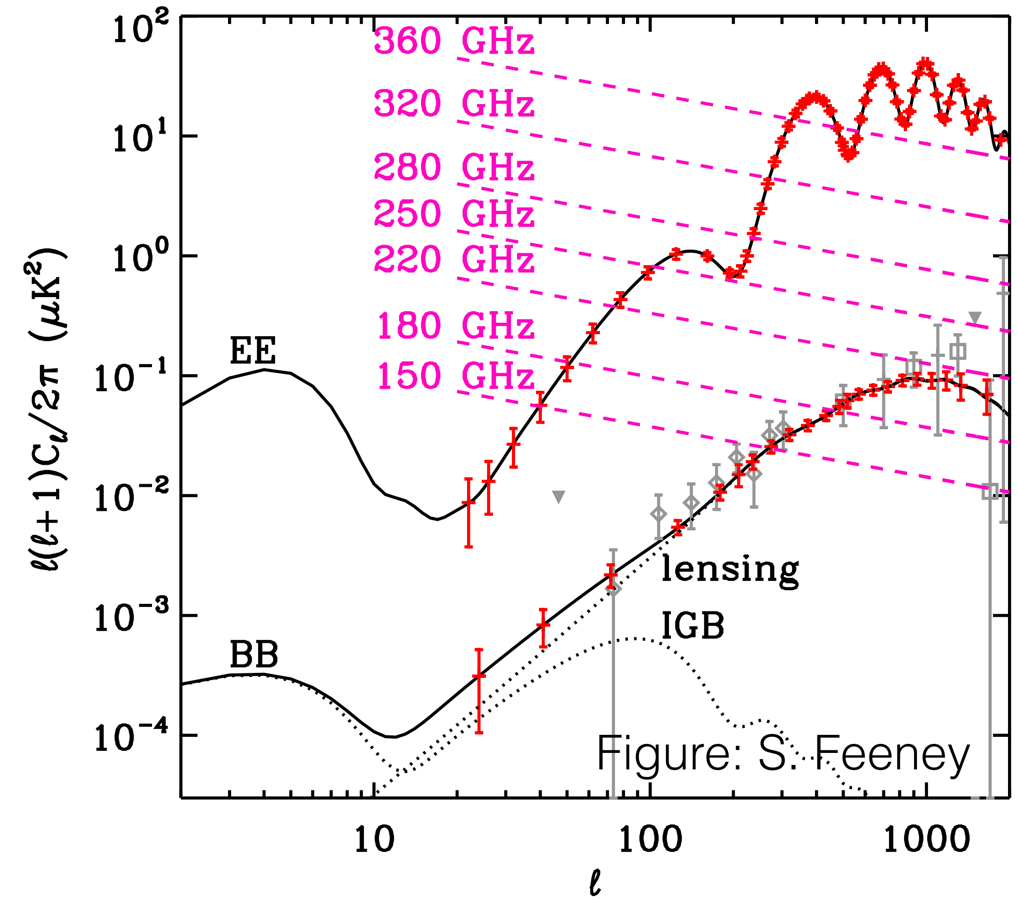
IDS - Keep it Simple

- **Standard Antarctic Flight**
  - **20-50 days flights (limited by cryogens, and launch date)**
  - **Suitable for ‘small, deep patch’**
  - **New Zealand limited to 4000 lb**
    - **more effort on low mass everything (EBEX was 6000 lb)**
    - **but more suitable for a larger sky coverage**
  - **Very high risk (most balloons to date leaked)**
    - **need to telemeter all data down - not been done before**
- **Using 300 mK baseplate**
  - **100 mK less forgiving with cryogenics**
- **Using standard FDM**
  - **Current μmux consumes x2-5 more power; new development required for lower power**
  - **TDM also possible (but more wires into the lower T stage)**
  - **KIDs possible but 4 K amplifiers dissipate significant amount of power**
- **Integration of receiver + gondola in the same place**
  - **more time for integrated end-to-end testing**

Forecasts

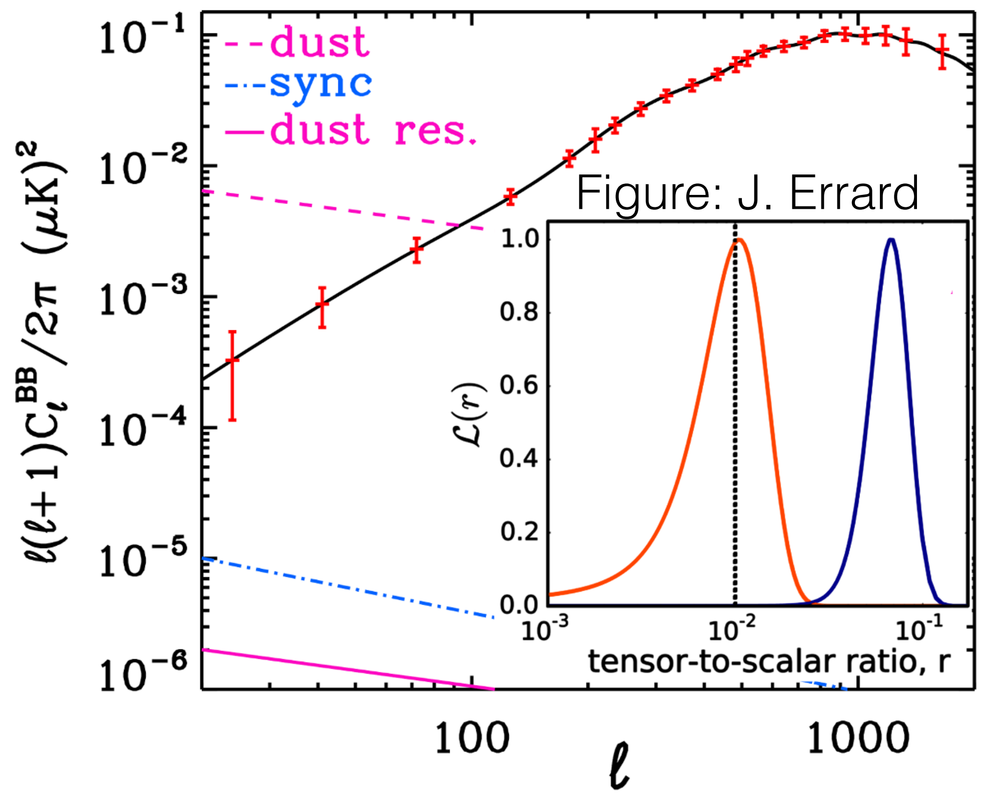
Forecasts

- 5.5, 9.5, 11, 16, 24, 41 μK*arcmin for (150/180, 220, 250, 280, 320, 360)
- 7.5 times deeper than Planck's 350 GHz
- IDS alone: r < 0.008 (95%)
- IDS + BK + SA: r < 0.003 (95%)



Foreground Separation (xForecast, Errard)

- Red error bars + magenta residuals: dust T assumed known, spectral indices uniform over 14 deg pixels
- Likelihoods: input r = 0.01; fit for T dust, assume spectral indices vary by 1% over 0.5 deg pixels
  - blue: ground data, no IDS
  - orange: + IDS data



Status and Summary

- **IDS is designed to complement BK, SA, SPT-3G (SO, S4) by giving high frequency, medium resolution (3’-6’) information on dust, on the same patch**

- **There is no experiment that matches IDS for this science goal**

- **Proposed, not yet approved**

Additional Slides

Keep it Simple

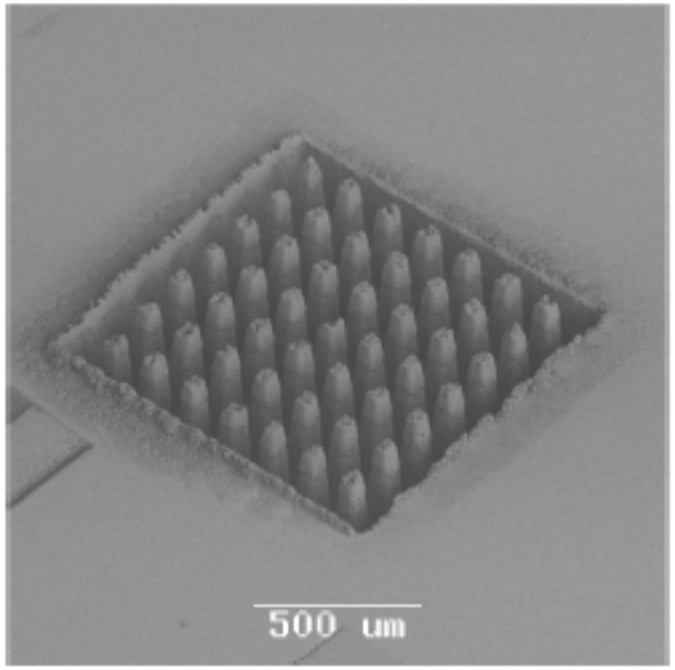
EBEX (2013, EBEX Collaboration et al. 2018)

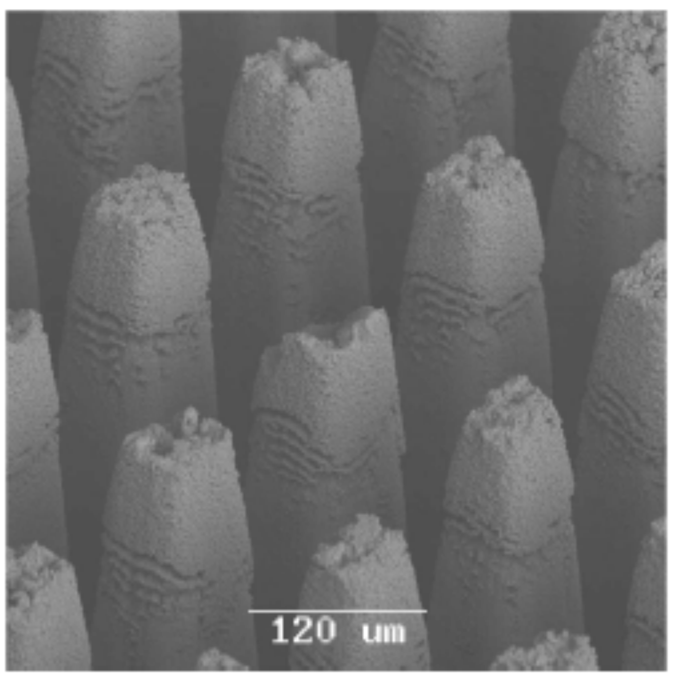
- **Two warm mirrors**
- **Large (thicker) window, thicker absorptive filter**
- **250 mK focal plane**
- **Calculated: 180 μK*s$^{-1/2}$ @ 150 GHz (N=504)**
- **Calculated (higher G, P): 220 μK*rt(sec) @ 150 GHz (N=504)**
- **Achieved (excess noise from readout + RF): 400 μK*s$^{-1/2}$ @ 150 GHz (N=504)**

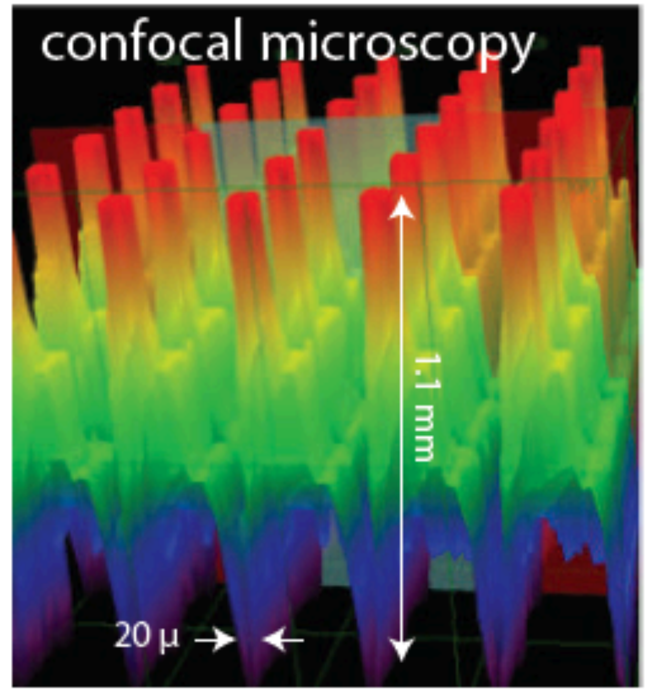
EBEX New Technologies

- **Arrays of TES**
  - **3 wafers in 2009**
  - **14 wafers in 2012/13**
- **Digital FDM**
  - **x8 in 2009**
  - **x16 in 2012/13**
- **Magnetic Bearing**
  - **first 4 K operation**
- **Broadest band AHWP**
  - **characterization**
  - **5-layer ARC on sapphire**

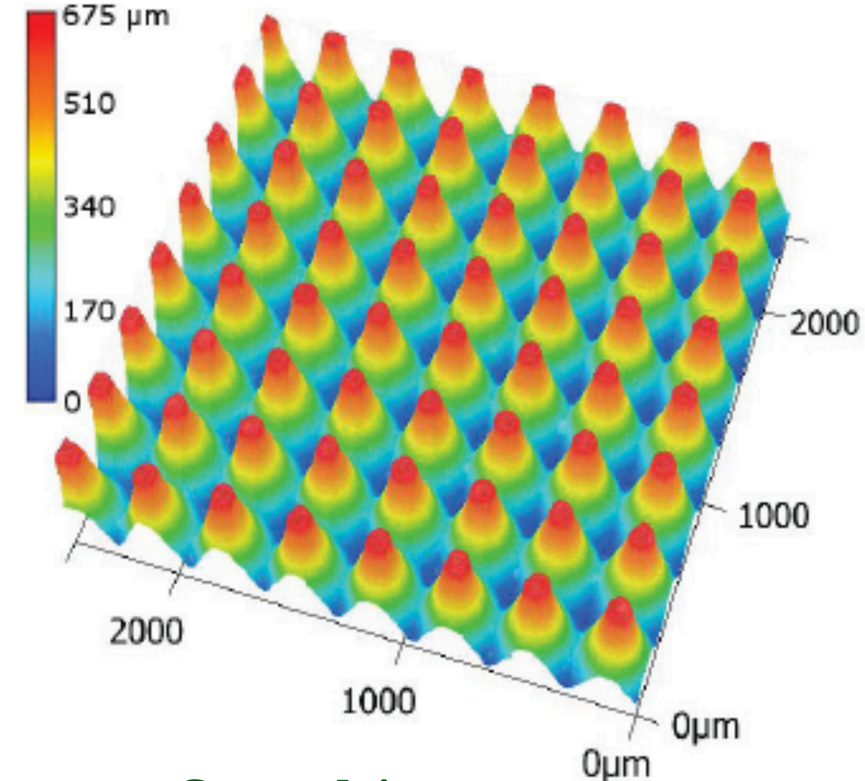
AR Coat



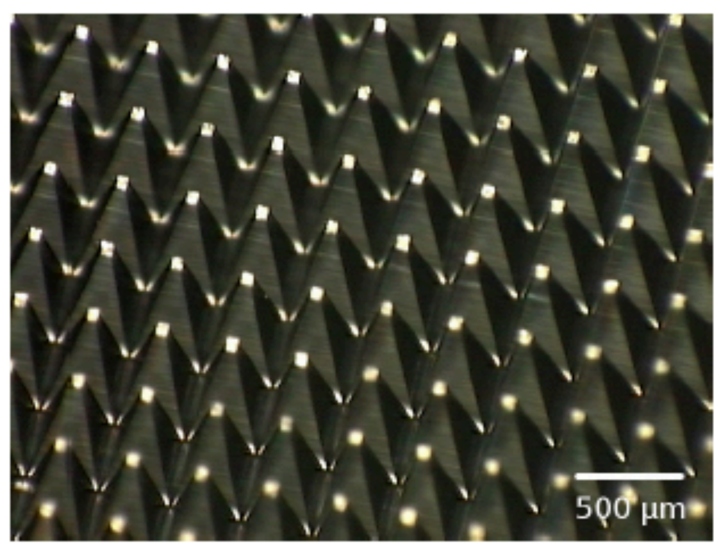


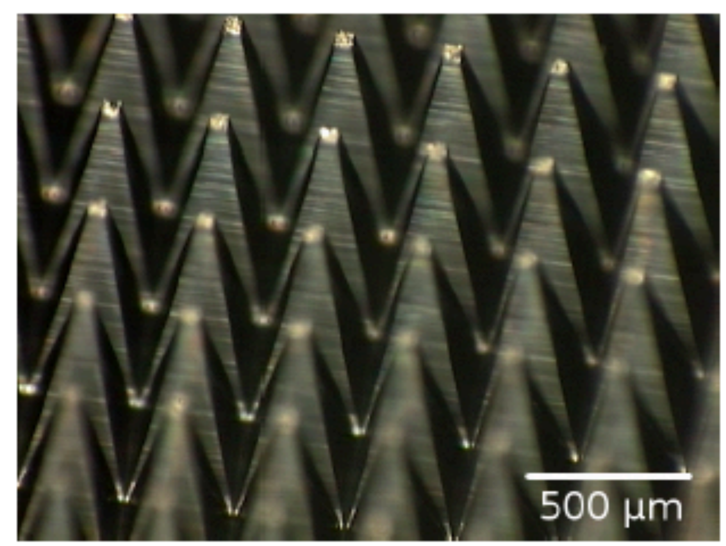


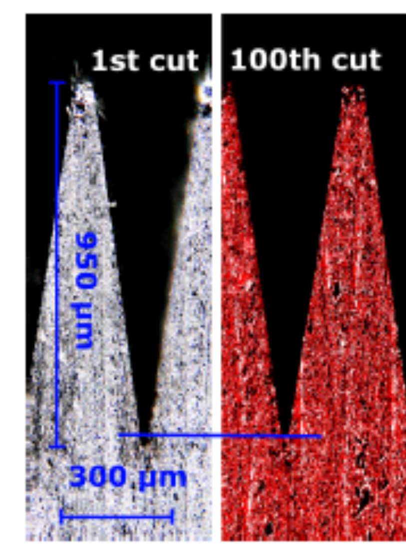
Silicon



Sapphire







Inflation and Dust Surveyor - IDS

- **Design Paradigm:**
  Complement S3 and S4 searches for GW in frequency bands, angular resolution, sky coverage

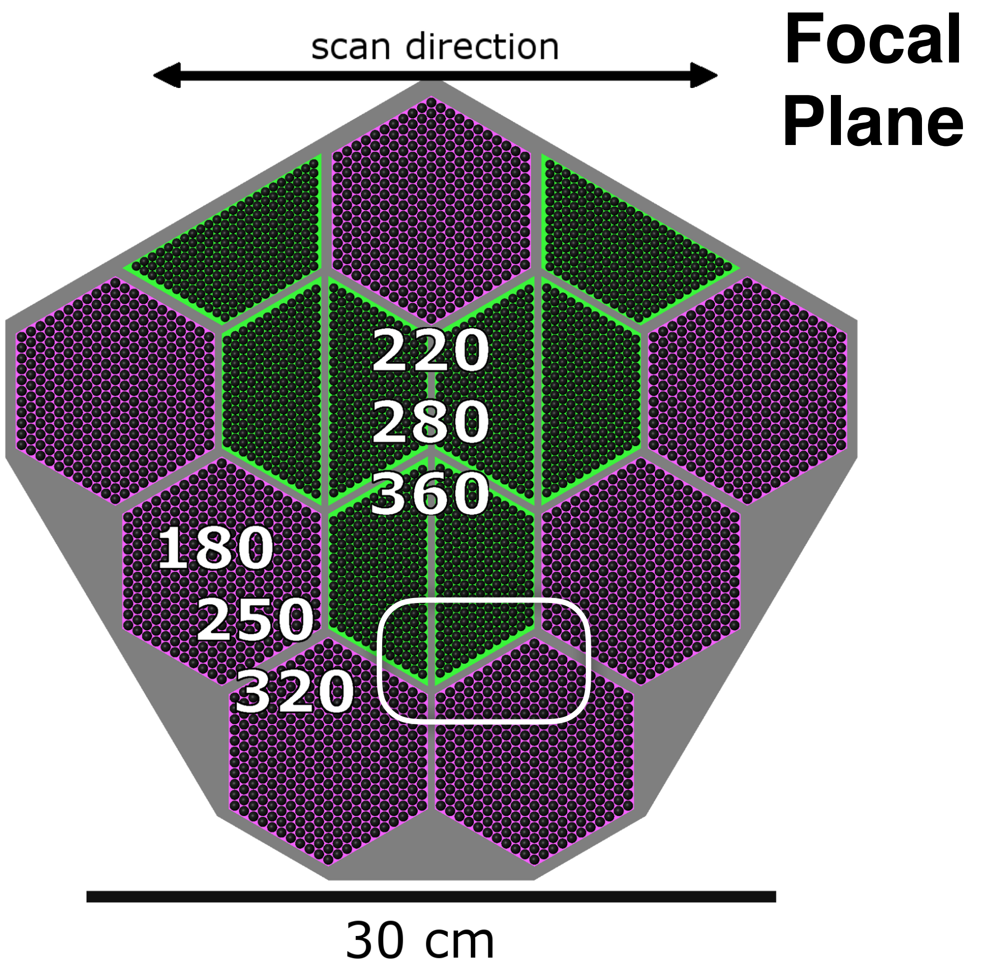
- 7 frequency bands: 150, 180, 220, 250, 280, 320, 360 GHz

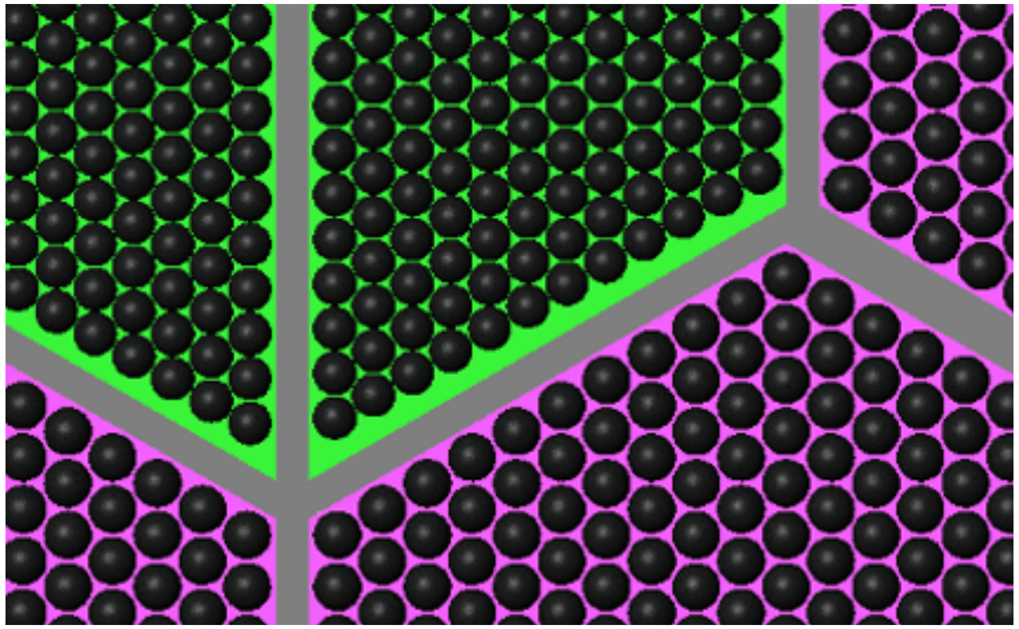
- Give crucial added information above 250 GHz (recall, r currently limited by foregrounds0

- 1.5 m aperture => 7' at 150 GHz; 3.2' at 360 GHz

- **Sinuous Antenna Multicolor Pixels (SAMP)**
  - **3 colors per pixel**

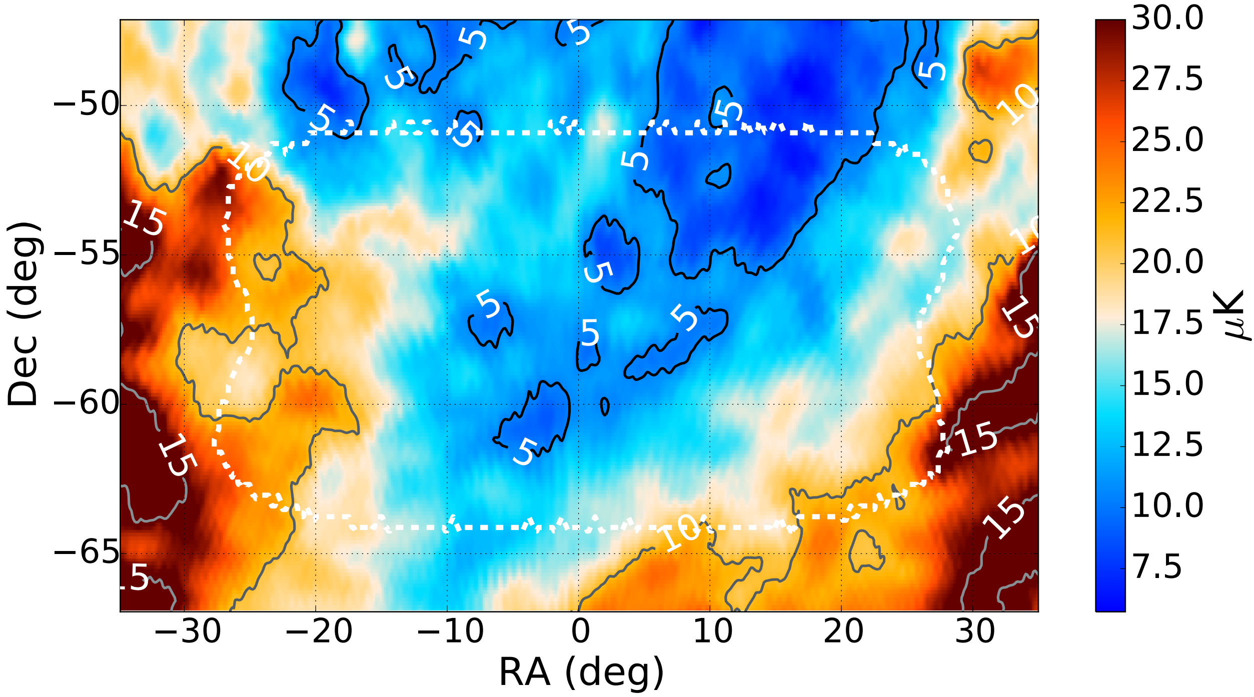
- **20,562 detectors**

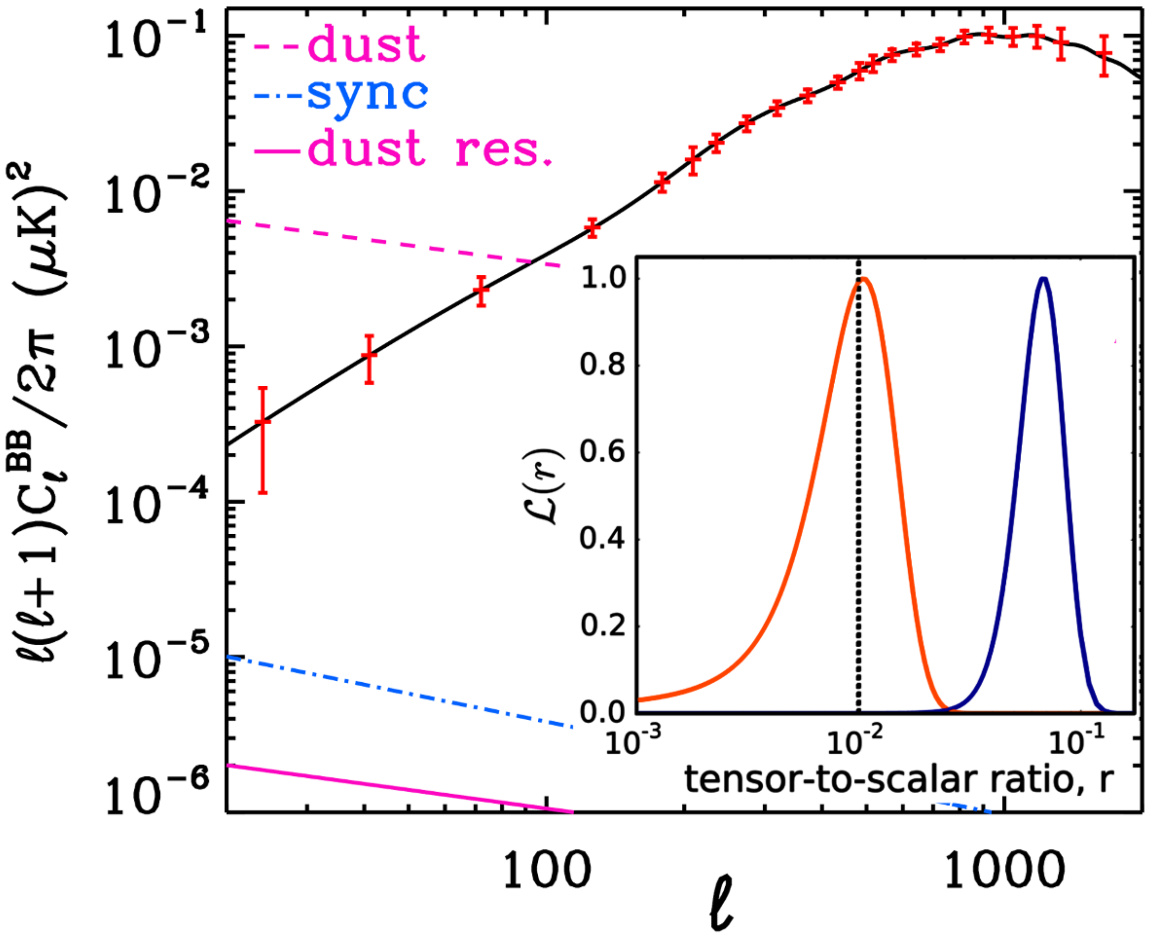




Inflation and Dust Surveyor - IDS

- **Design Paradigm: Complement S3 and S4 searches for GW in frequency bands, angular resolution, sky coverage**
- 7 frequency bands: 150, 180, 220, 250, 280, 320, 360 GHz
- Give crucial added information above 250 GHz (recall, r currently limited by foregrounds0
- 1.5 m aperture => 7' at 150 GHz; 3.2' at 360 GHz
- Sinuous Antenna Multicolor Pixels (SAMP)
  - 3 colors per pixel
- 20,562 detectors
- **1500 sq. deg. overlapping with BICEP/Keck; SPT3G; Simons Array; SO; S4**
- **r<0.003 (95%, 20 day flight + BK, SA)**





Comment About Noise + Depth

MAXIMA-1 (1998, Hanany et al. 2000)

- One warm mirror
- Small (thin) window, thin absorptive filter
- 100 mK focal plane
- 87 μK*rt(sec); @ 150 GHz (N=3)

Boomerang (1998, Crill et al. 2003)

- One warm mirrors
- Small (thin) window, thin absorptive filter
- 250 mK focal plane
- 140 μK*rt(sec) @ 150 GHz (N=6)

EBEX (2013, EBEX Collaboration et al. 2018)

- Two warm mirrors
- Large (thicker) window, thicker absorptive filter
- 250 mK focal plane
- Calculated: 180 μK*rt(sec) @ 150 GHz
- Calculated (higher G, P): 220 μK*rt(sec) @ 150 GHz (N=504)
- Achieved (excess noise, readout, RF): 400 μK*rt(sec) @ 150 GHz (N=504)

SPIDER (2015, Jones S4 talk)

- 0 warm mirrors
- 250 mK focal plane
- 154 μK*rt(sec) @ 150 GHz (N=504)

BICEP (Ade et al. PRL 2014): 250 mK; 300 μK*rt(sec) (N=512)