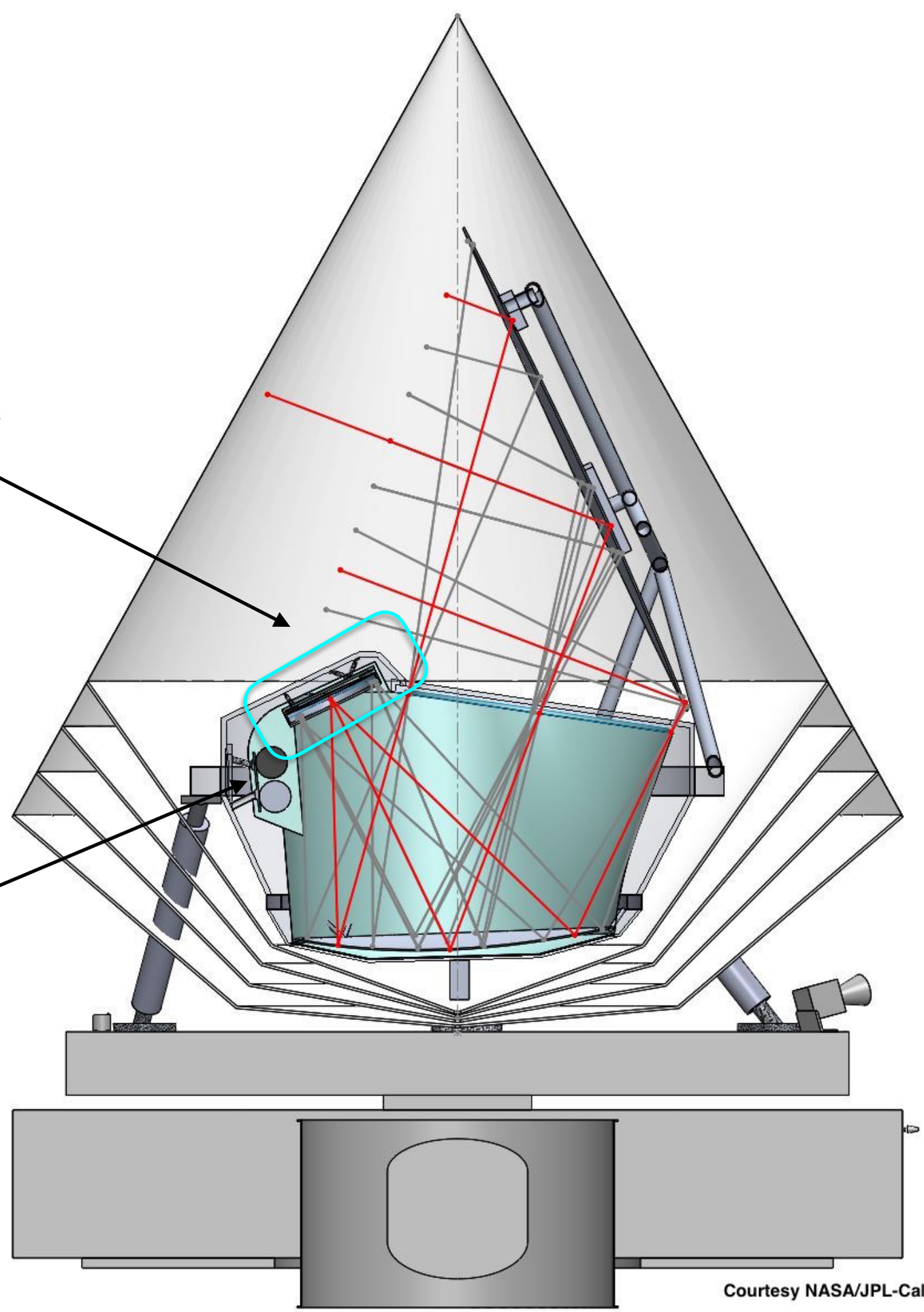
Progress of Mechanical Design of PICO Focal Plane

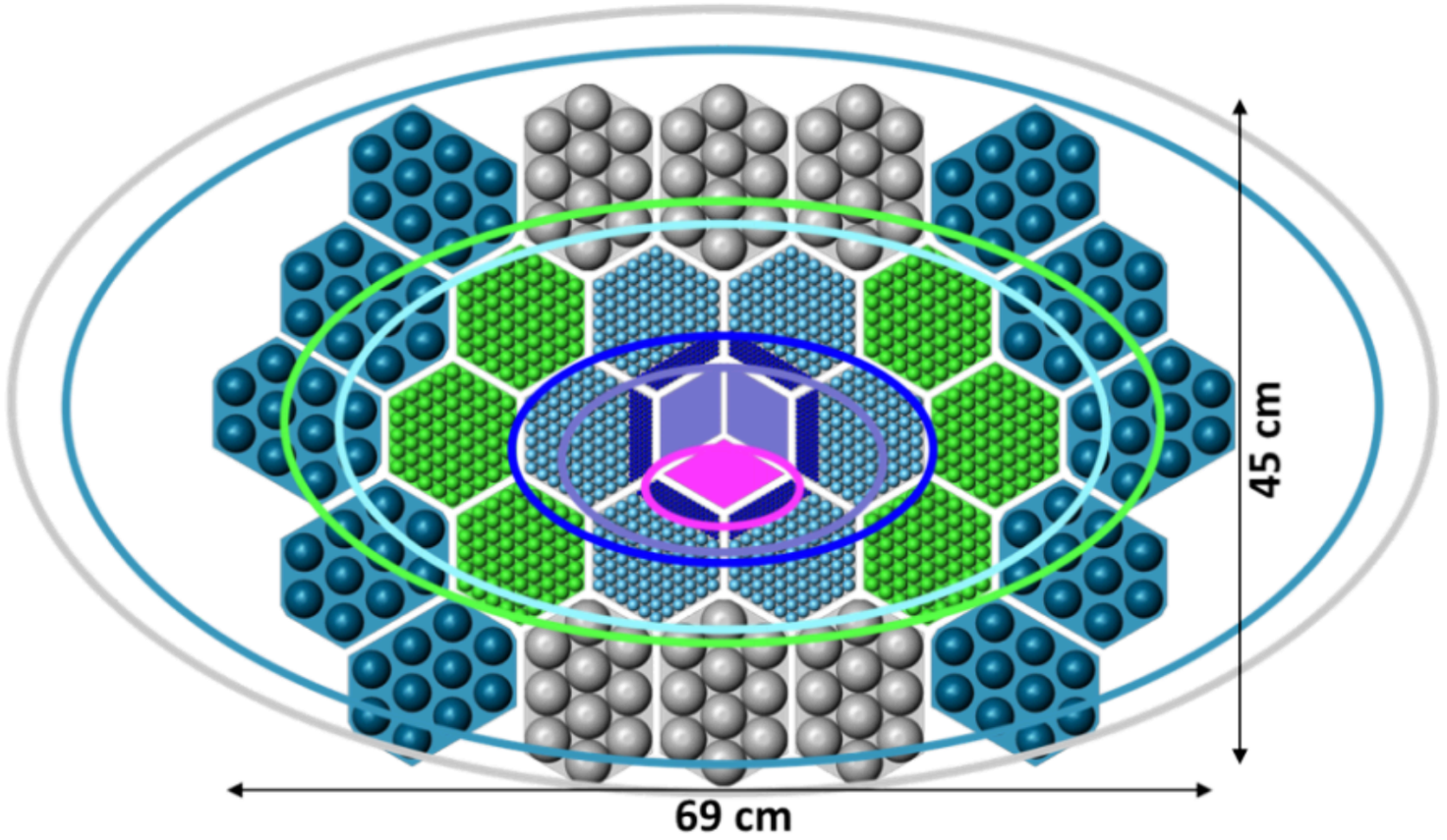
Qi Wen, Shaul Hanany, Joel Nielsen
July 25th, 2018

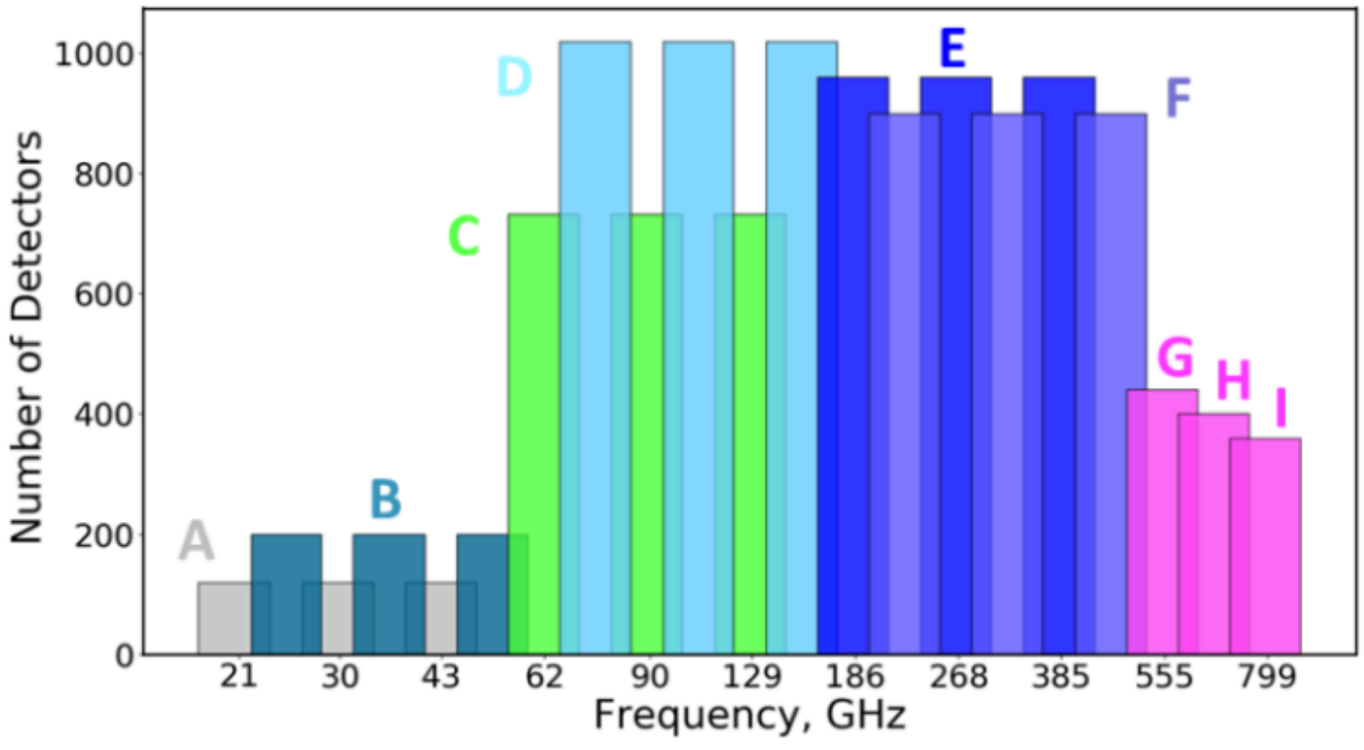
Focal Plane

ADR

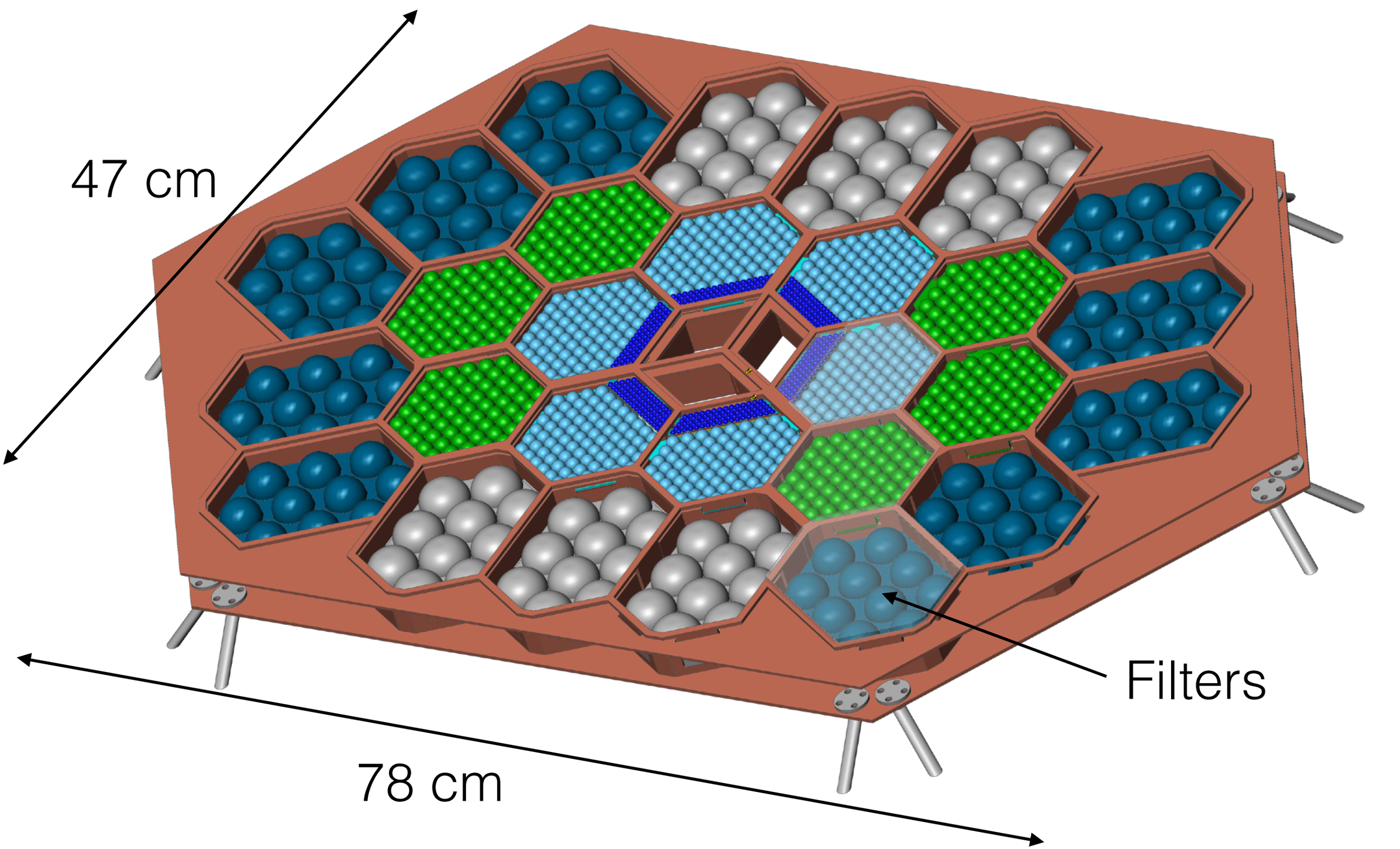


Courtesy NASA/JPL-Caltech


45 cm
69 cm


Number of Detectors
Frequency, GHz
0
200
400
600
800
1000
21
30
43
62
90
129
186
268
385
555
799
A
B
C
D
E
F
G
H
I

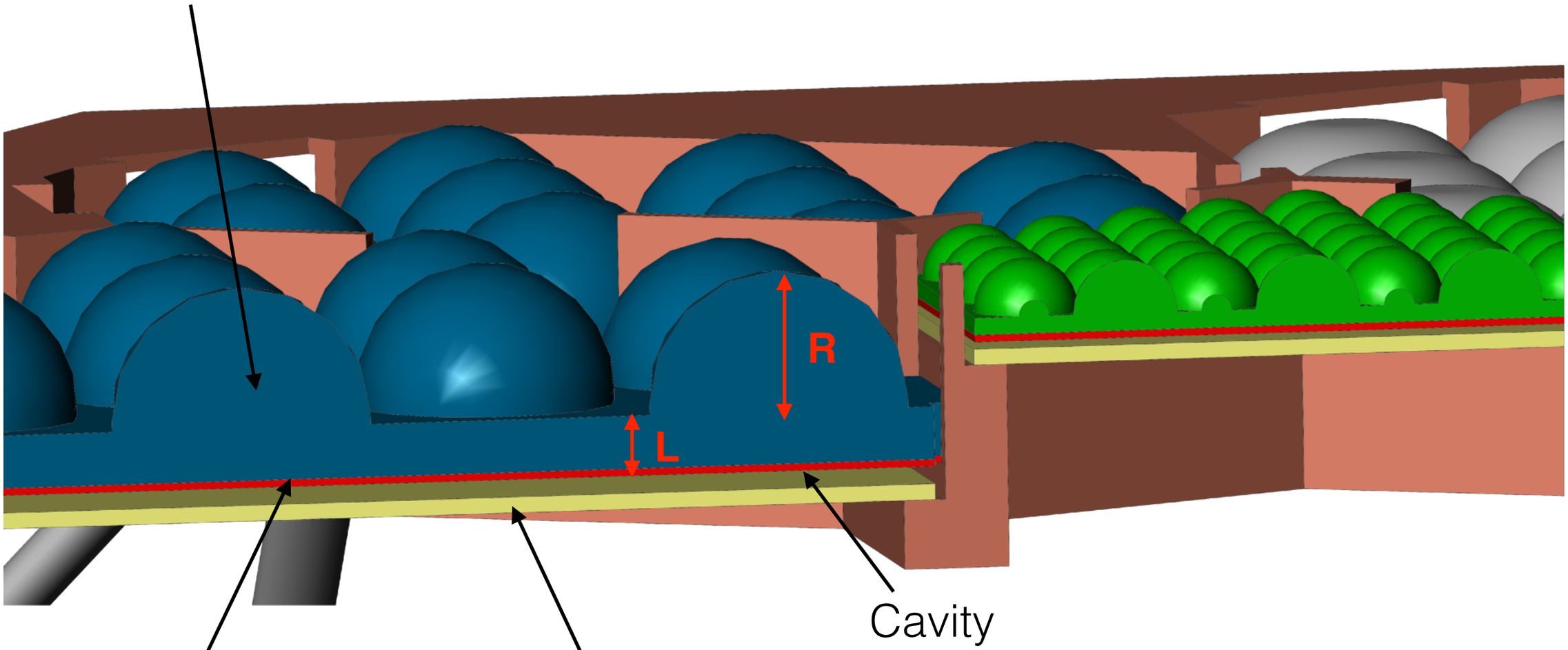
Mechanical Design



Things from last meeting

- Putting top of lenslets on same plane
- Cavity between detector wafers and backplane
- Thermal expansions: wafer-mount slots
- Heat sinking: Indium is superconductive at 100 mK

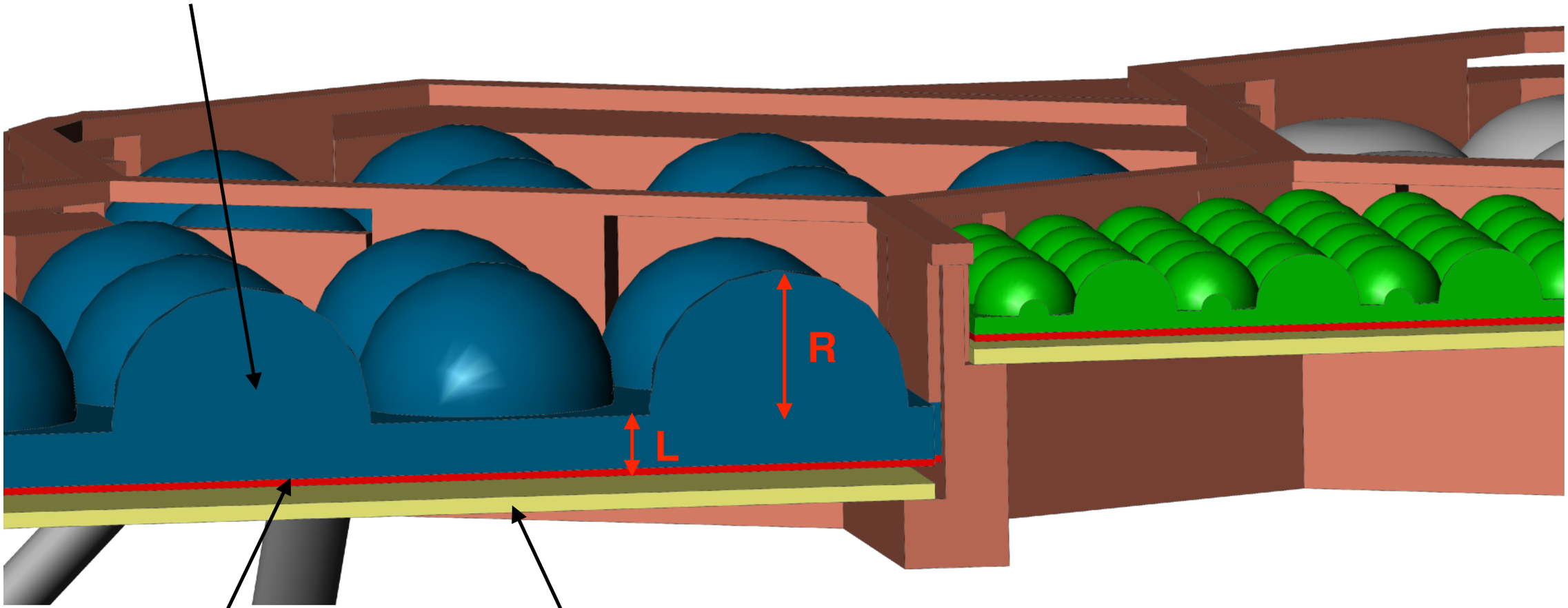
Bottom frame only



L / R = 0.46
Detector wafers (red) = 0.675 mm
Cavity = lambda_central / 5 (adjustable)
TDM silicon wafers (yellow) = 1.5 mm

Bottom frame + top frame

Silicon Lenslet wafer

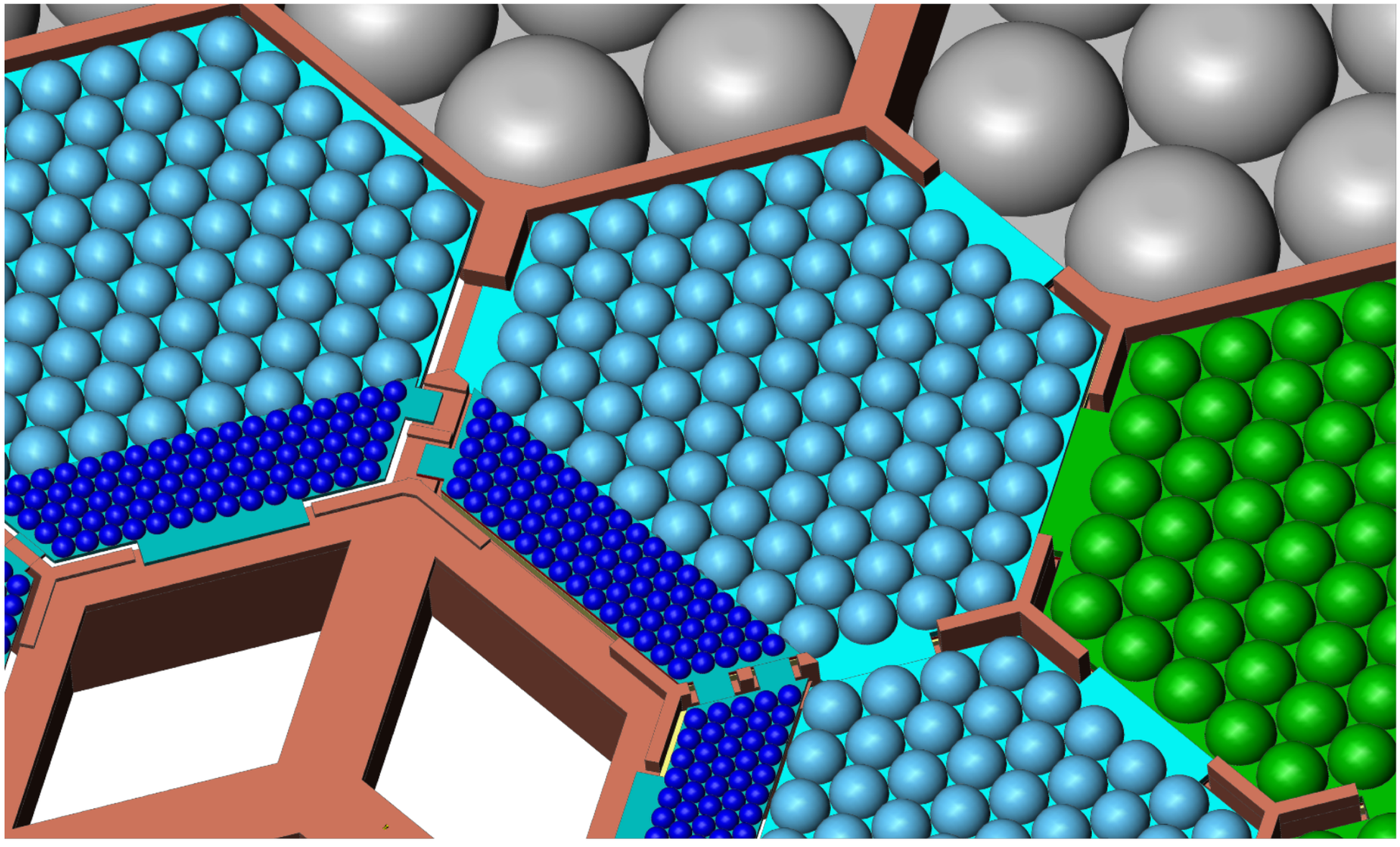


TDM silicon wafers

Silicon detector wafer

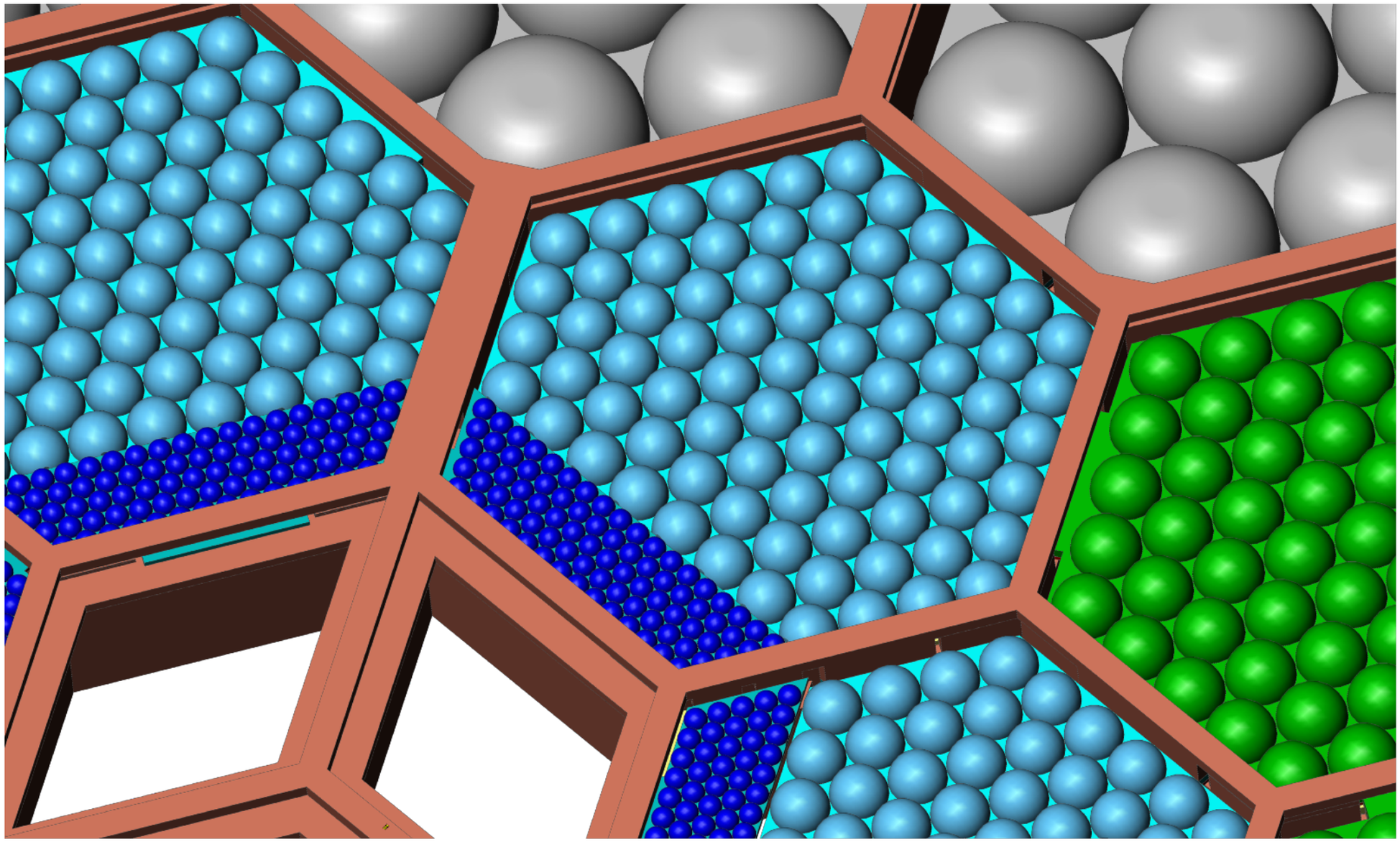
L / R = 0.46
Detector wafers (red) = 0.675 mm
Cavity = lambda_central / 5 (adjustable)
TDM silicon wafers (yellow) = 1.5 mm

Bottom frame only



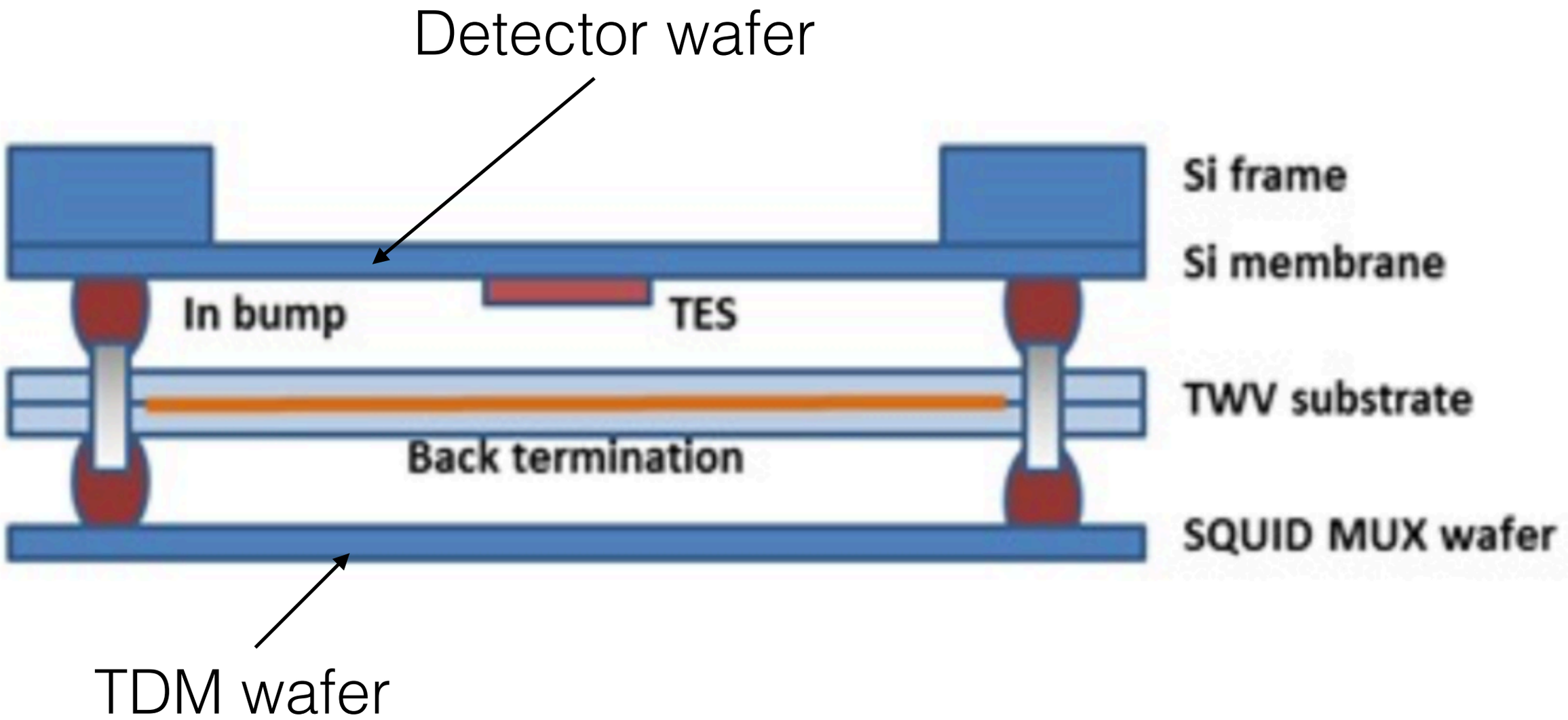
Minimum gap between neighboring wafers = 4 mm
Extension of wafers = 4 mm
Each wafer has at least 3 extensions
Wall thickness = gap - 2 mm (bot), gap (top)

Bottom frame + top frame



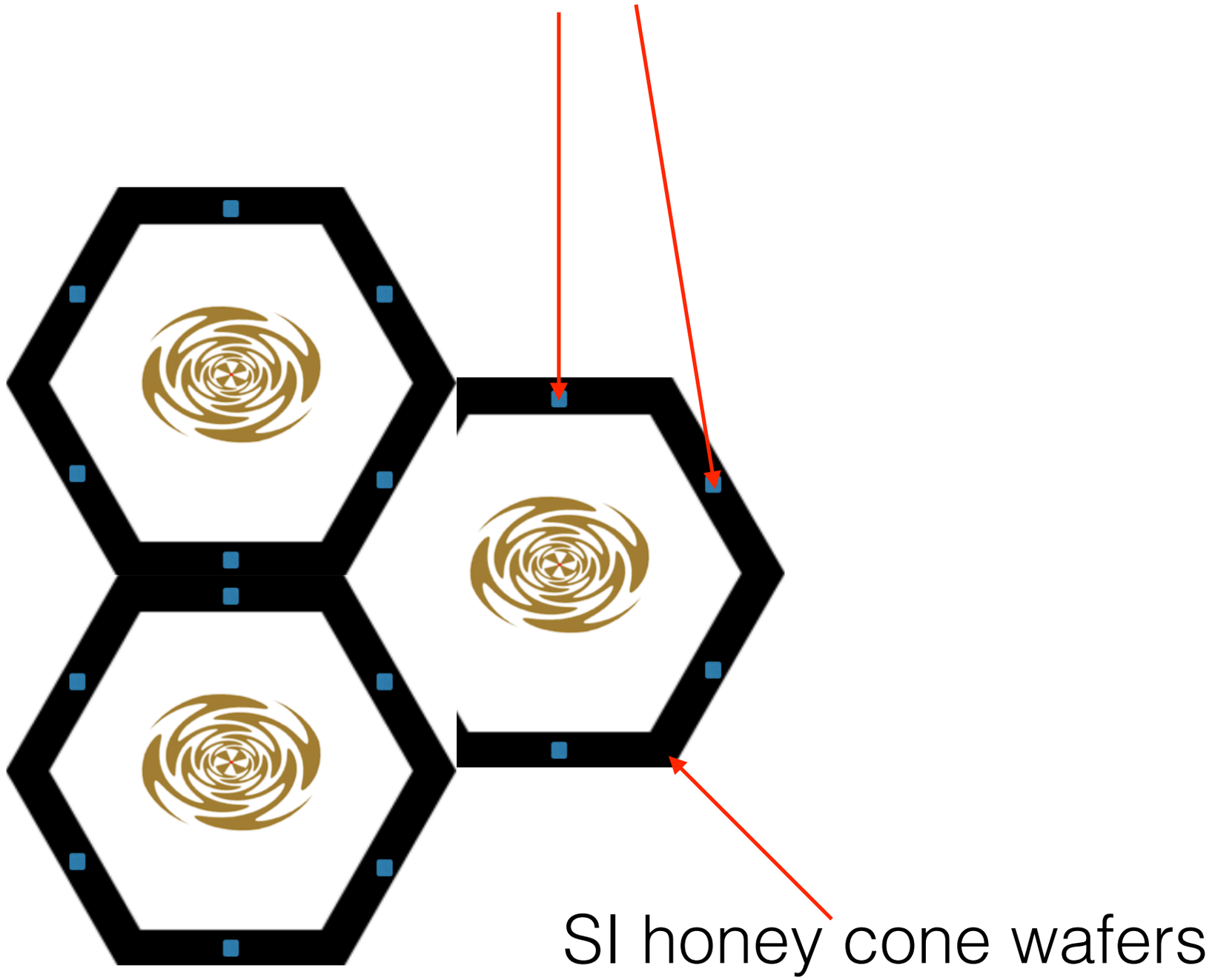
Minimum gap between neighboring wafers = 4 mm
Extension of wafers = 4 mm
Each wafer has at least 3 extensions
Wall thickness = gap - 2 mm (bot), gap (top)

Through wafer vias + Indium-bump bondings



Staguhn et al, Development of a robust, efficient process to produce scalable, superconducting kilopixel far-IR detector arrays, SPIE(2018)

Through wafer vias + Indium-bump bondings



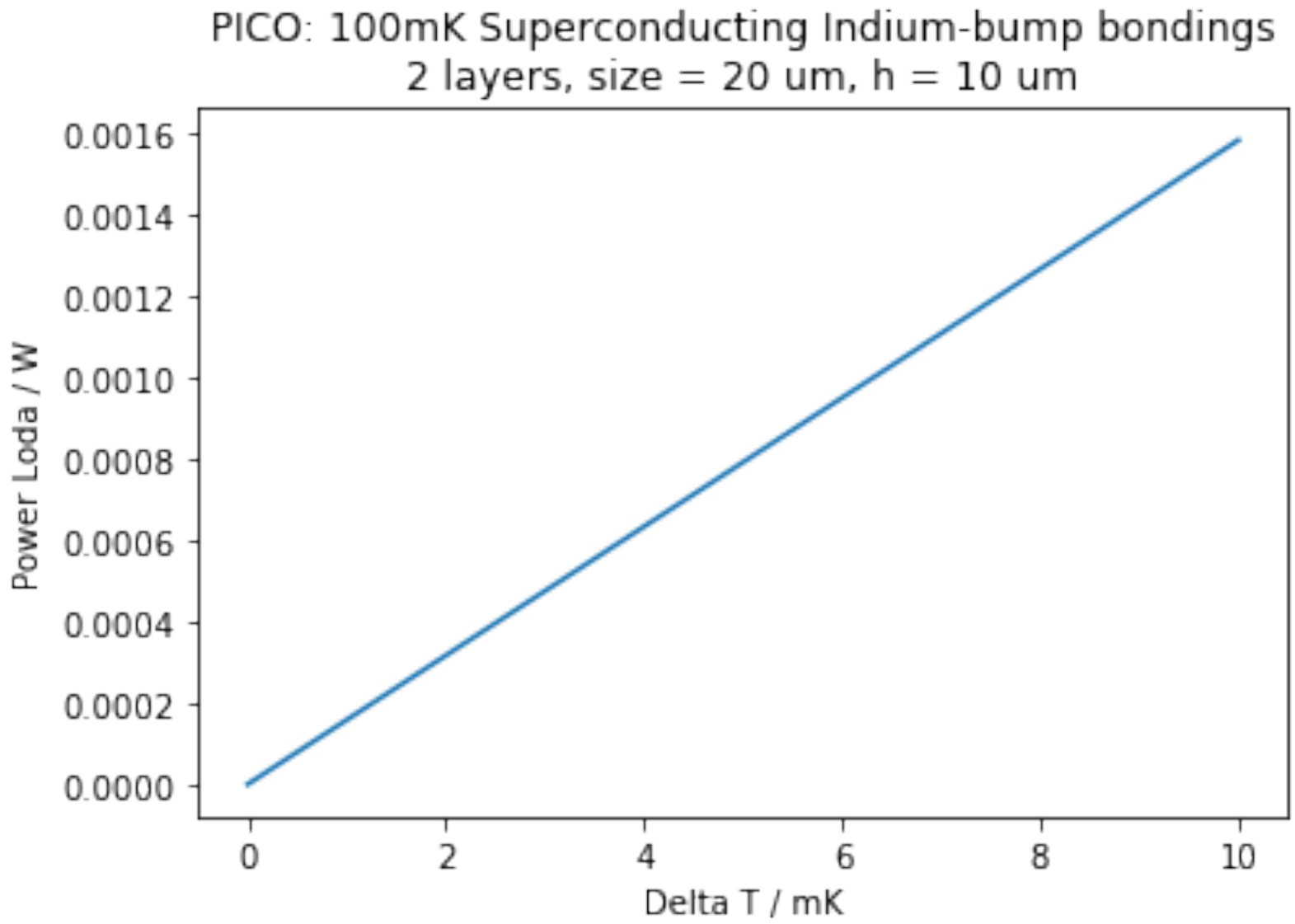
Heat sinking through Indium-bump bondings

Indium*	
Tc	3.374 K
Thermal conductivity k at 100 mK (superconducting state)	6.75 e-5 W/cm K

Geometry	
# of bolos	13 k
# of Indium bumps	26 k
Diameter of bumps	20 um
Height of bumps	10 um
# of bump layers	2
Total length L	20 um
Total area A	4.68 cm^2

*Sladek, R.J.: Thermal conductivity of Indium-Thallium alloys at low temperatures. Phys. Rev. 97(4), 902 (1955)

Heat sinking through Indium-bump bondings



$$P = A/L * k * \text{delta}(T)$$

Weight Estimation

Components	Mass [kg]
Copper (Invar) Frames	8.67 (7.89)
Silicon Lenslet wafers + detector wafers	4.59
Silicon TDM chips (if 2mm thick)	0.97
Total	14.23 (13.45)

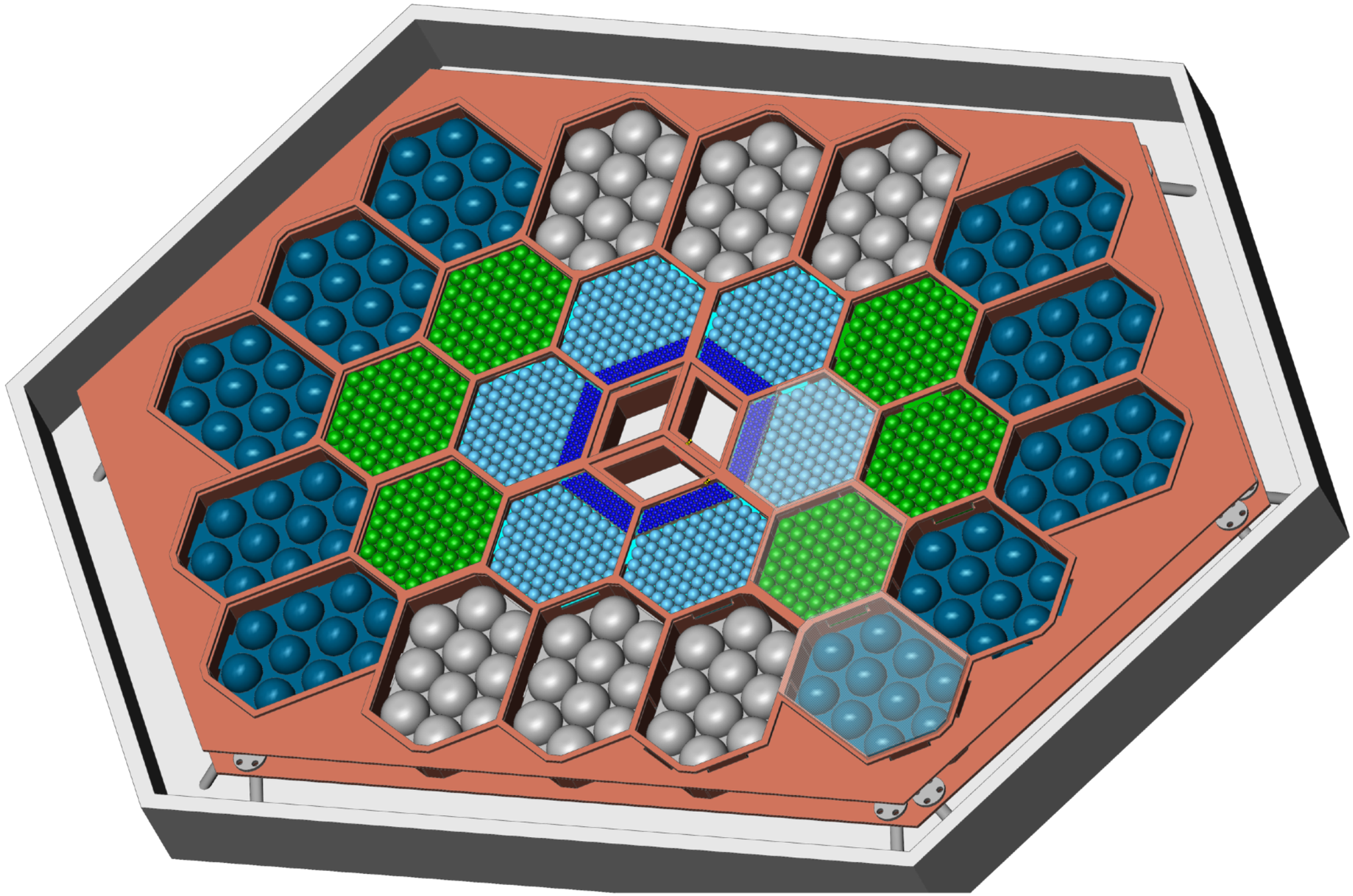
Things to do

- Back plane under wafers

- Determine the thermal load (optical + electrical) on focal plane
  - 20 K PR, 4K box

- Sizes of of central horn fed pixels G, H, I
  - plan to scale EBEX feed horns to desired frequencies

BACK-UP SLIDES



Normal states

Table 9.1 Very low temperature data of thermal conductivity (W/cm K) of metals and alloys

Metal or alloy	Chemical composition	References	100 mK	250 mK	500 mK	750 mK	1 K	2 K
Alluminium	Al 99.999 %	[1]	–	–	3.1	4.3	–	–
Copper	Cu high purity	[2]	–	3.2	6.2	–	–	–
	Cu low purity	[2]	–	4×10^{-1}	8×10^{-1}	–	–	–
	Cu 99.999 %	[3]	–	–	–	–	3	–
Gold	Au 99.999 %	[1]	–	–	6.8×10^{-1}	1.0	–	–
	Au 99.999 %	[3]	–	–	–		–	
Indium	In	[4]	5×10^{-2}	2×10^{-1}	3×10^{-1}	5×10^{-1}	7×10^{-1}	1.3
Manganin[§]	$Cu_{8.4}Mn_{1.2}Ni_{0.4}$	[5]	5.2×10^{-5}	1.4×10^{-4}	3.0×10^{-4}	4.9×10^{-4}	$6\ 10^{-4}$	$2\ 10^{-3}$
Nickel	Ni 99.995 %	[1]	–	–	1.2×10^{-1}	1.9×10^{-1}	–	–
Palladium	Pd 99.999 %	[1]	–	–	1.8×10^{-1}	–	–	–
Palladium-Alluminium-Rhenium	$Pd_7Al_2Re_1$	[6]	–	–	1.6×10^{-5}	4.0×10^{-5}	8×10^{-5}	3×10^{-4}
Platinum	Pt 99.999 %	[1]	–	–	1.4×10^{-1}	2.4×10^{-1}	–	–
Rhenium	Re 99.994 %	[1]	–	–	4×10^{-1}	7.4×10^{-1}	–	–
Silver	Ag 99.999 %	[1]	–	–	6.7×10^{-1}	9.7×10^{-1}	–	–
	Ag > 99.99 %	[3]	–	–	–		4	
Tantalum	Ta 99.994 %	[1]	–	–	7×10^{-2}	1×10^{-1}	1.4×10^{-1}	–
Titanium Alluminium	Ti_6Al	[5]	–	1.6×10^{-5}	1×10^{-4}	2.5×10^{-4}	4×10^{-4}	1.1×10^{-3}
Tungsten	W	[1]	–	–	7×10^{-2}	1.1×10^{-1}	1.4×10^{-1}	–

The symbol [§] refers to weight percentage while other composition are molar

G. Ventura and M. Perfetti, Thermal Properties of Solids at Room and Cryogenic Temperatures, Springer, p 961. (2014)

Ratio between superconducting and normal states as a function of T/Tc

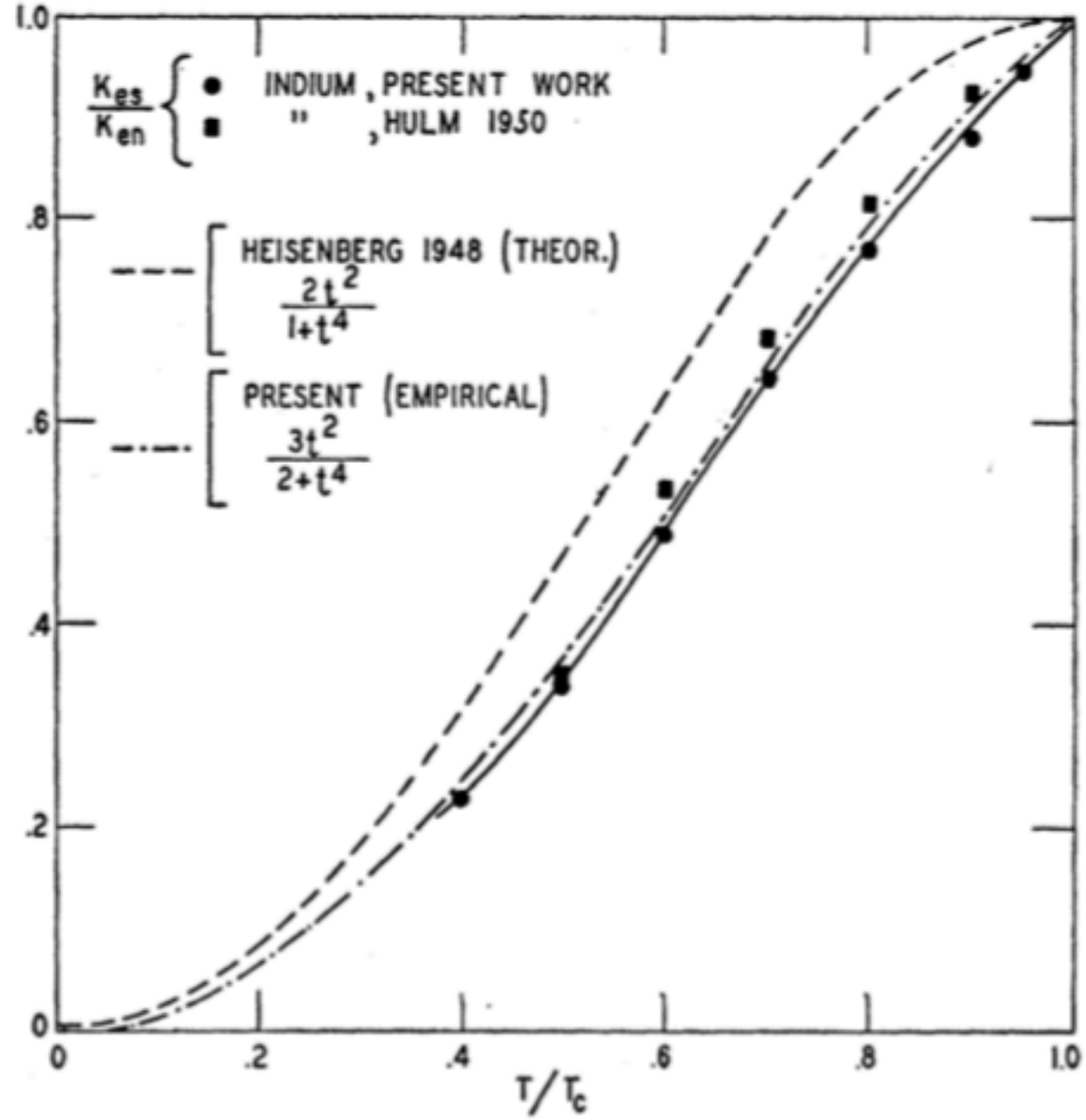


FIG. 9. K_{es}/K_{en} for indium *versus* reduced temperature compared with Heisenberg's function $2t^2/(1+t^4)$ and the empirical function $3t^2/(1+t^4)$.

Tc=3.374 K
At 100 mK, Kn = 5e-2 W / (cm*K).
So, according to empiricaI fit, Ks = 6.75 e-5 W/cm K

13K bolos, 26K indium bumps
20 um in diameter, 10 um in height
total area = 4.68 cm^2, total heigh = 20 um (two layers)
A/l = 4.7 / (0.002) = 2.34 e+3 cm