Coating Mirrors In Space

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11/2/16

A brief history …..

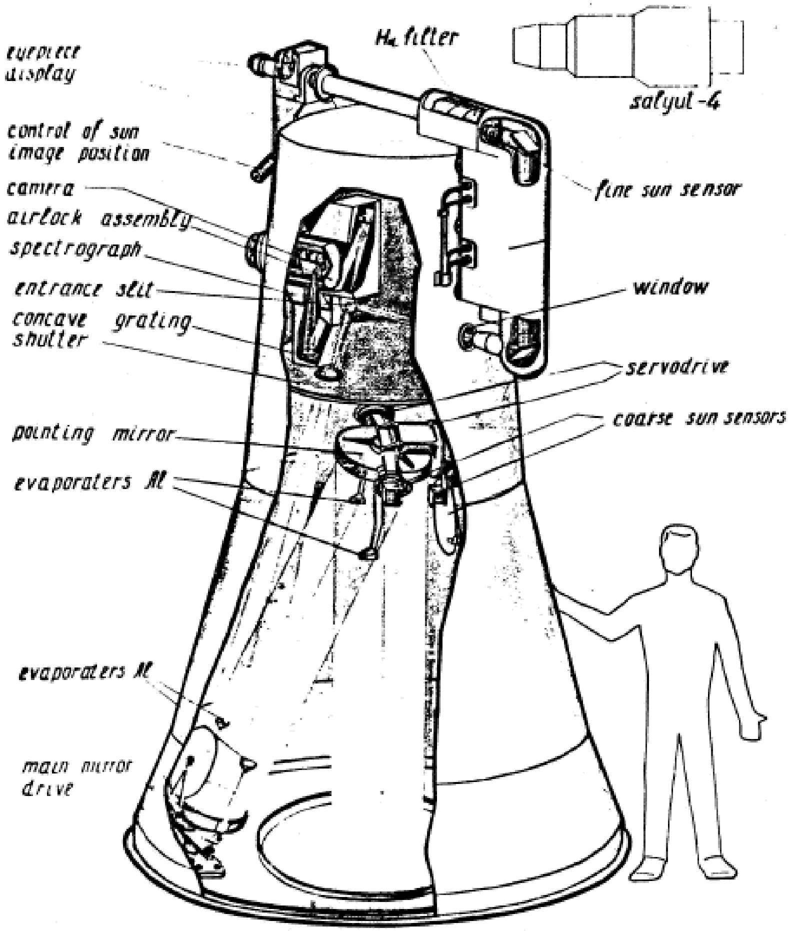
“…to utilize fully their high reflectance in satellite equipment, the aluminum film has to be deposited onto iridium-coated mirrors and gratings after the satellite has been placed in an orbit high enough so that no oxidation of the aluminum surface takes place…“ – *George Hass (1967)*

In 1975, Russia coated a telescope in space; Orbiting Solar Telescope (OST)

“the technology exists today to coat mirrors in space” – *Perkin Elmer report to NASA (1983)*

“…if the space-based coating technology was mastered the reward would be an increase in throughput for a 3-reflection optical system by an order of magnitude, i.e. a COS-like effective area for a 2.4 m class instrument in the FUV” – *NASA FUSE Lessons Learned, 2004.*

Russian Orbiting Solar Telescope (1975)



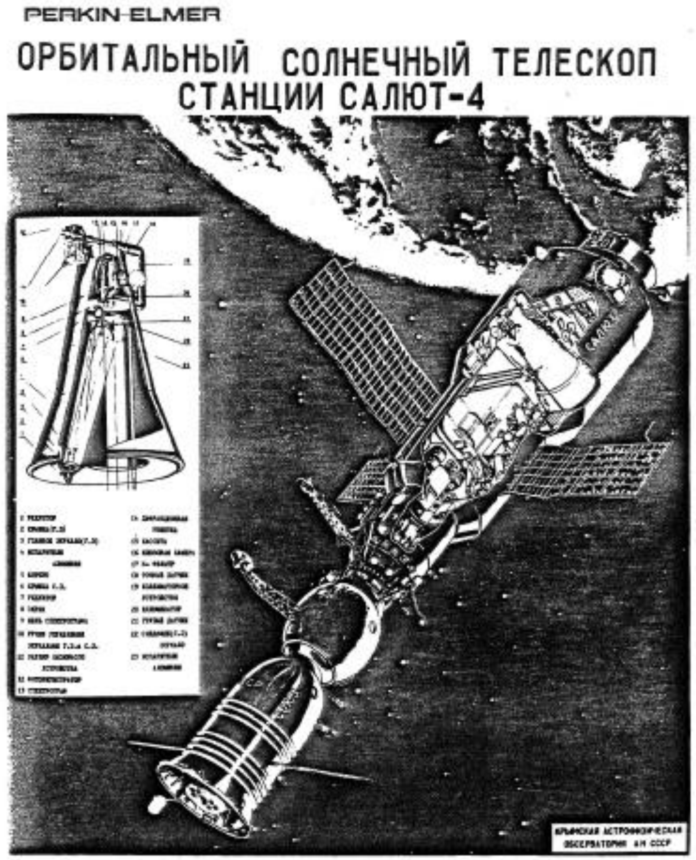


Figure 18. Orbiting Solar Telescope on the Space Station Salyut-4 (154).

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Why am I standing up here talking about this?

- Someone asked me how to make a broadband reflective coating that works down to 80-nm instead of only 90-nm, and I answered, “sorry, mother nature says no”.
- My experience with my moving source evaporation system led me to conclude that a single moving evaporation source would not produce the coating rates needed for coating large optics on earth with highly reflective aluminum for FUV applications – (instead, many sources are desirable)
- Someone else asked me if I had any ideas for how to coat an optic in space

This reflectance data illustrates one basic problem related to coating large mirrors with aluminum in a vacuum chamber

Evaporation rate	200-nm (reflectance %)	400-nm (reflectance %)
40 (A/sec)	82.7	91
65 (A/sec)	87.6	91.5
125 (A/sec)	90.2	91.8

* Aluminum deposited at a background pressure of ~1x10^-6 torr

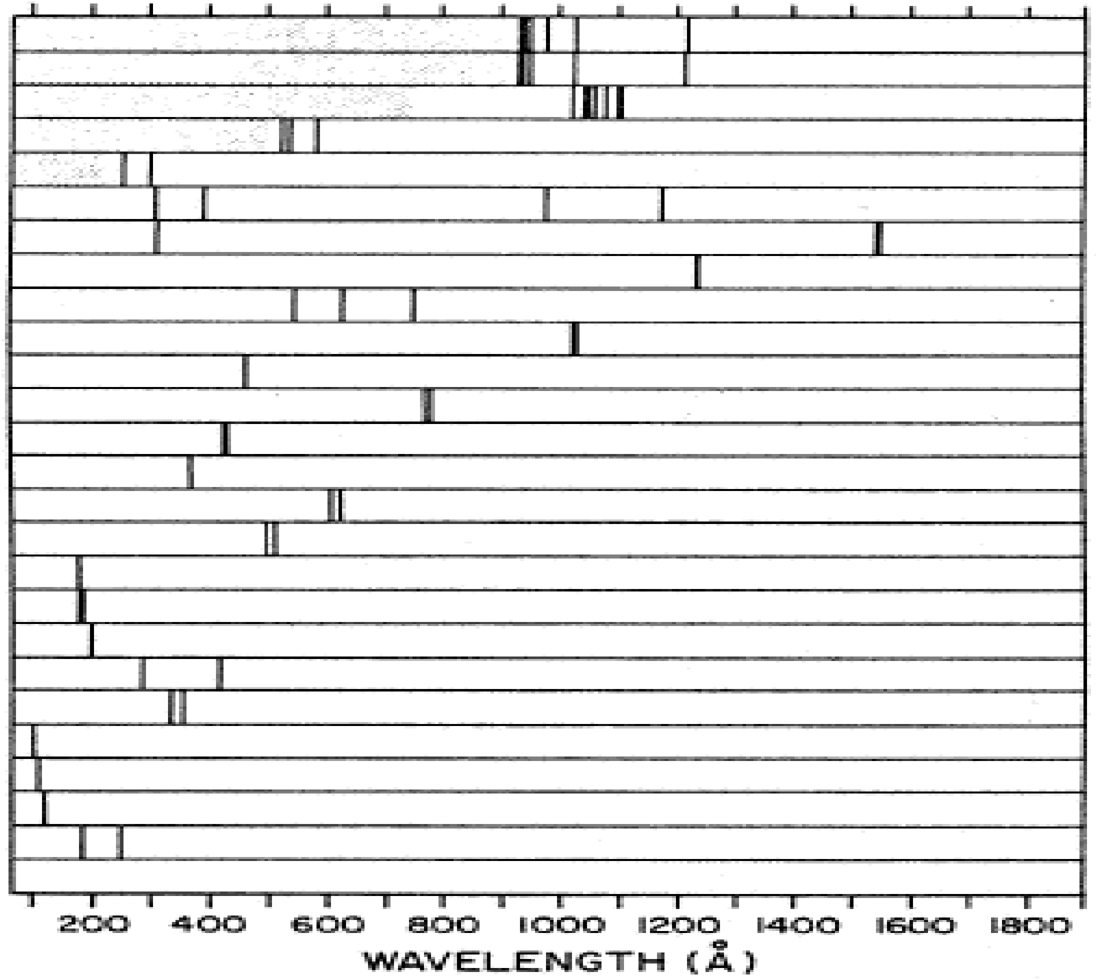
Why coat fresh aluminum in space?

- Aluminum forms a natural oxide when applied on earth, cutting off UV reflectance in the FUV around 160-nm.
- MgF_2, LiF, AlF may be applied to aluminum to prevent oxidation but these materials cut off reflectance at 90-nm and severely degrade reflectance below about 105-nm
- Aluminum deposited in space (high orbit such as L2) could extend observations into the EUV down to 50-nm

Wavelengths of important spectral lines in the far UV

IMPORTANT STRONG LINES

SPECIES	LOG N	LOG T
H I	12.00	4.0
D I	7.2	4.0
H_2	6. – 11.7	1.9
He I	11.00	4.3
He II	11.00	4.3
C III	8.57	4.9
C IV	8.57	5.1
N V	8.06	5.3
O V	8.83	5.5
O VI	8.83	5.5
Ne VII	7.45	5.8
Ne VIII	7.45	5.9
Mg VIII	7.54	6.1
Mg IX	7.54	6.1
Mg X	7.54	6.2
Si XII	7.55	6.5
Fe IX	7.40	<6.0
Fe X		6.2
Fe XII		6.4
Fe XV		6.6
Fe XVI		6.8
Fe XVIII		7.1
Fe XIX		7.2
Fe XXI		7.2
Fe XXIV		7.5

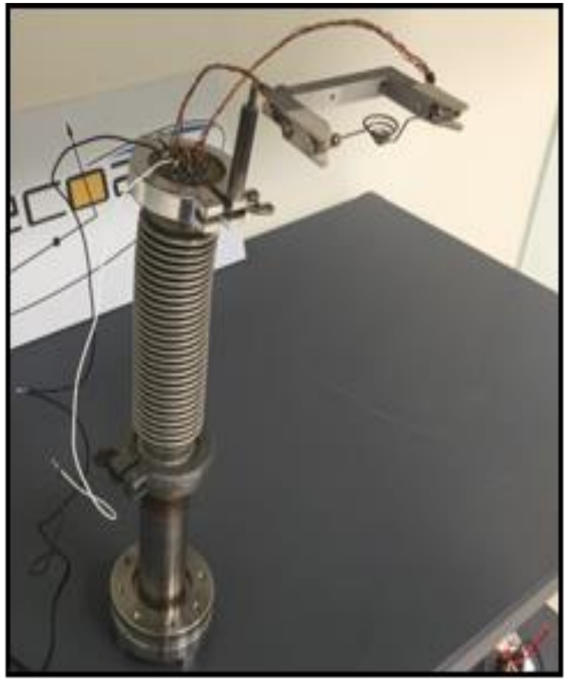


Battery-powered deposition

-Using batteries would allow many evaporation sources to be powered simultaneously (faster rates and more uniform coatings)

- Low voltage, high current (e.g, 7.4 volts and 100 amps, per source)
- Many sources means high evaporation rates, higher reflectance, better coating uniformity, and less scatter
- Putting the power supply in close proximity to the evaporation filament means no huge copper cables needed to carry the power to the filament

ZeCoat's battery-powered evaporation source in pressurized vessel inside coating chamber

a. 

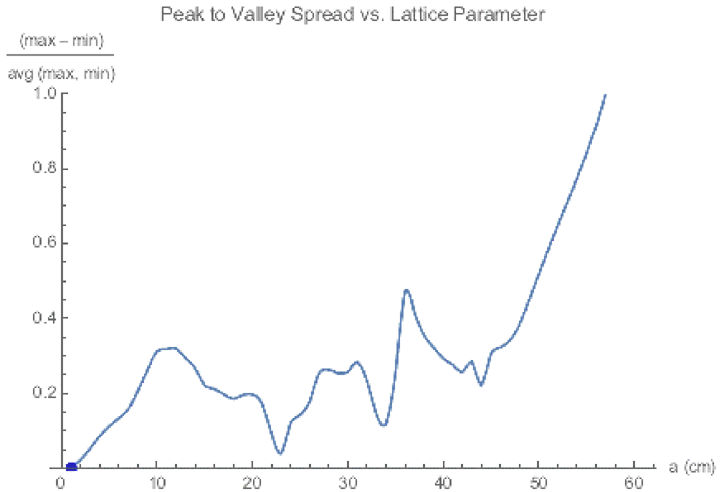
b. 

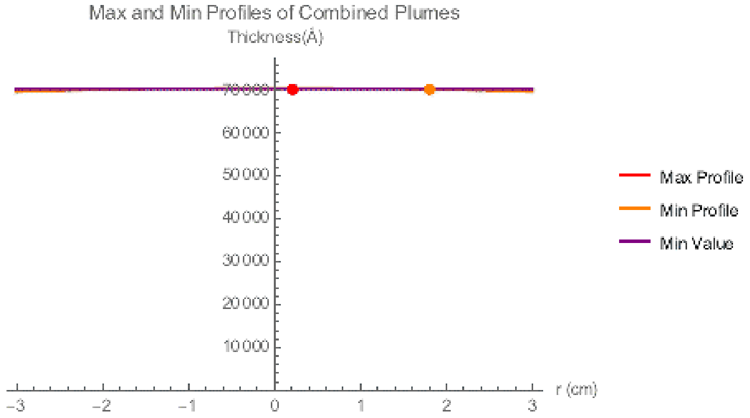
c. 

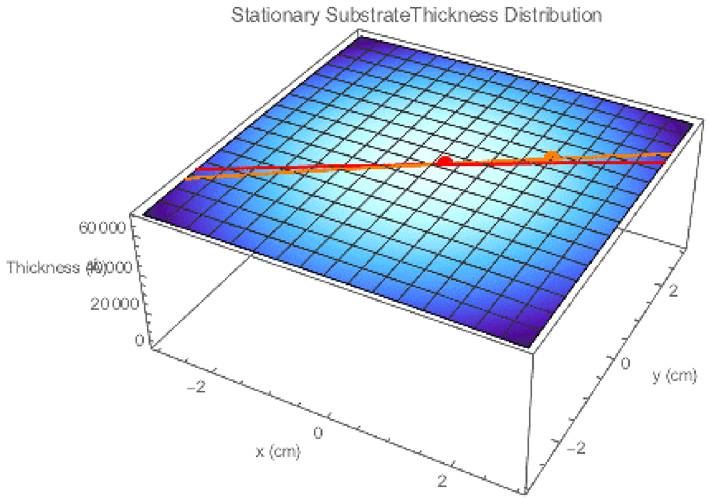
Experimental Procedure:

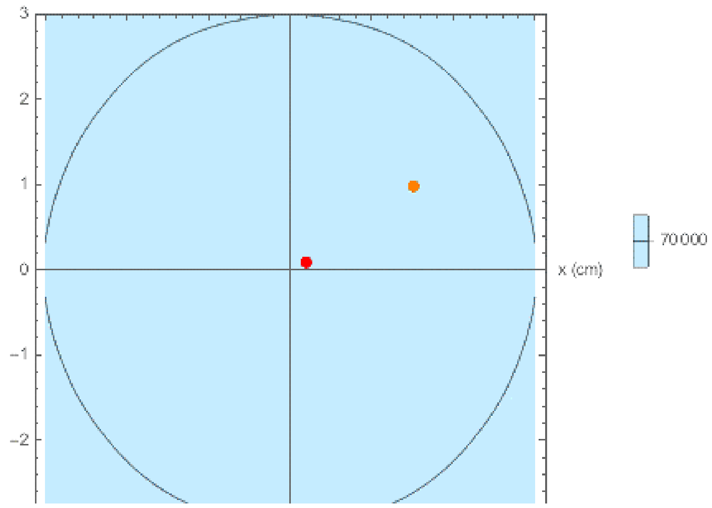
The coating thickness distribution for a single battery powered source was mapped using a stylus profilometer.

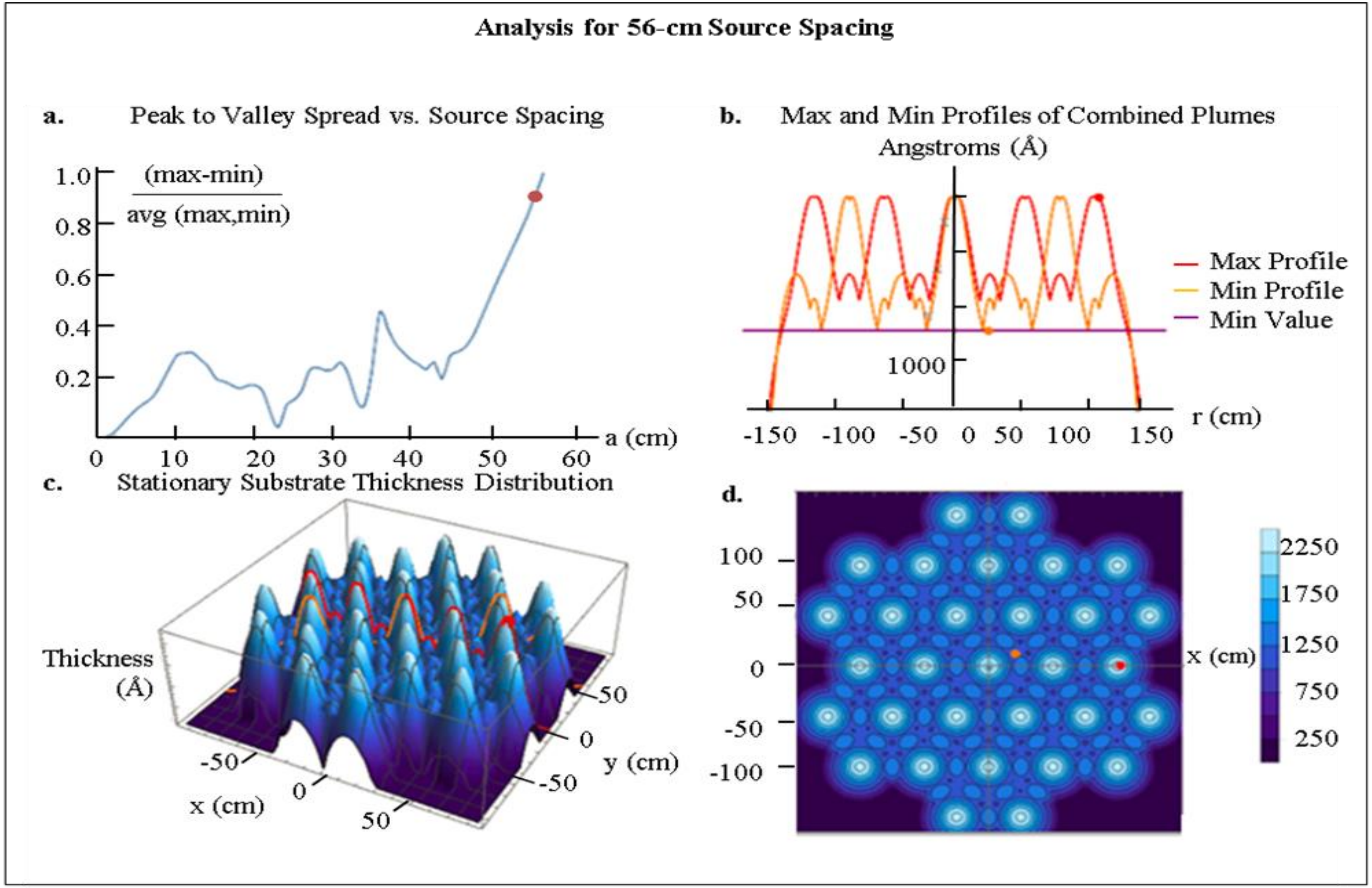
A computer simulation was developed to determine the optimum source spacing a hexagonal array of (31) sources

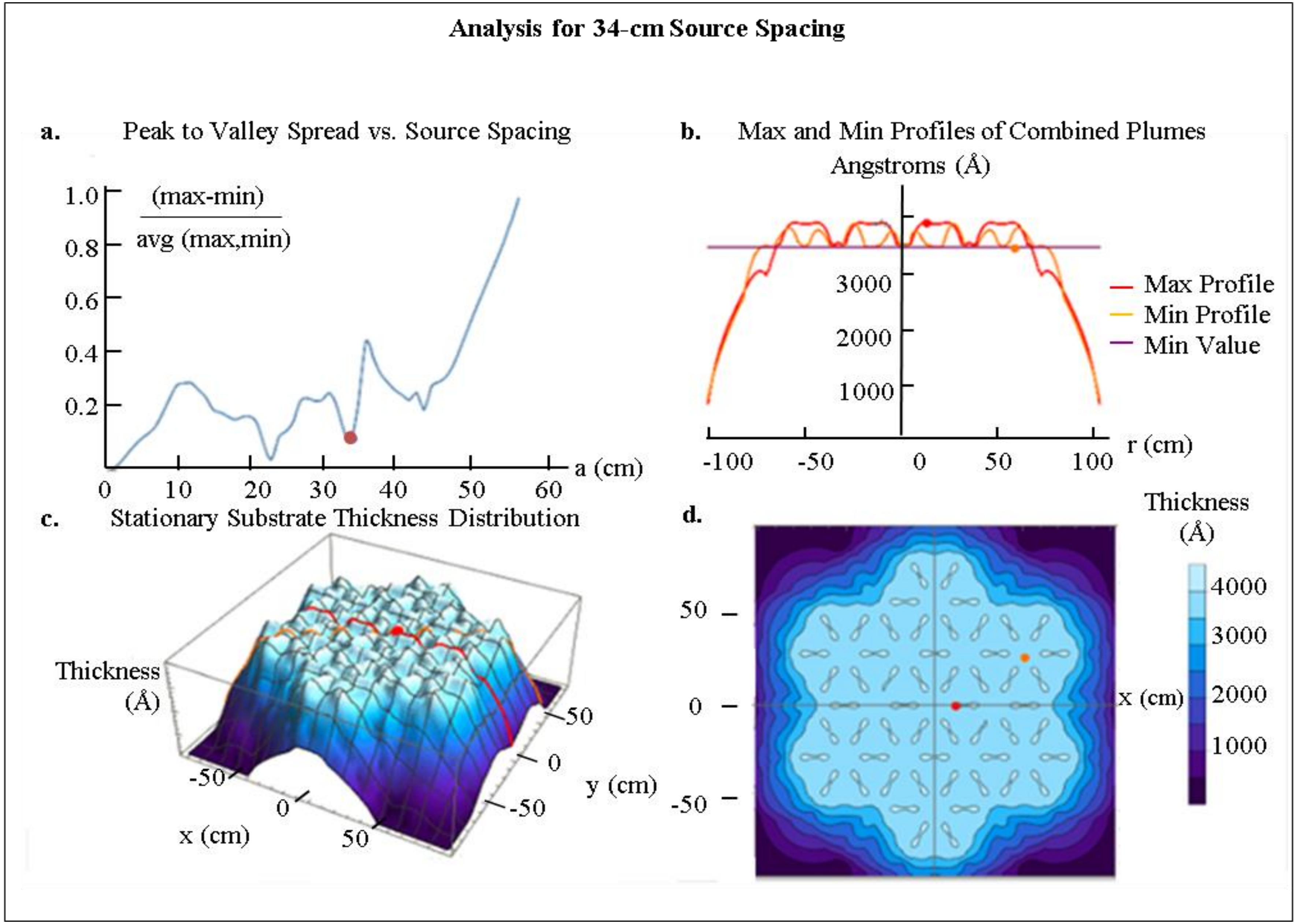

Peak to Valley Spread vs. Lattice Parameter
(max – min) / avg (max, min)
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
a (cm)

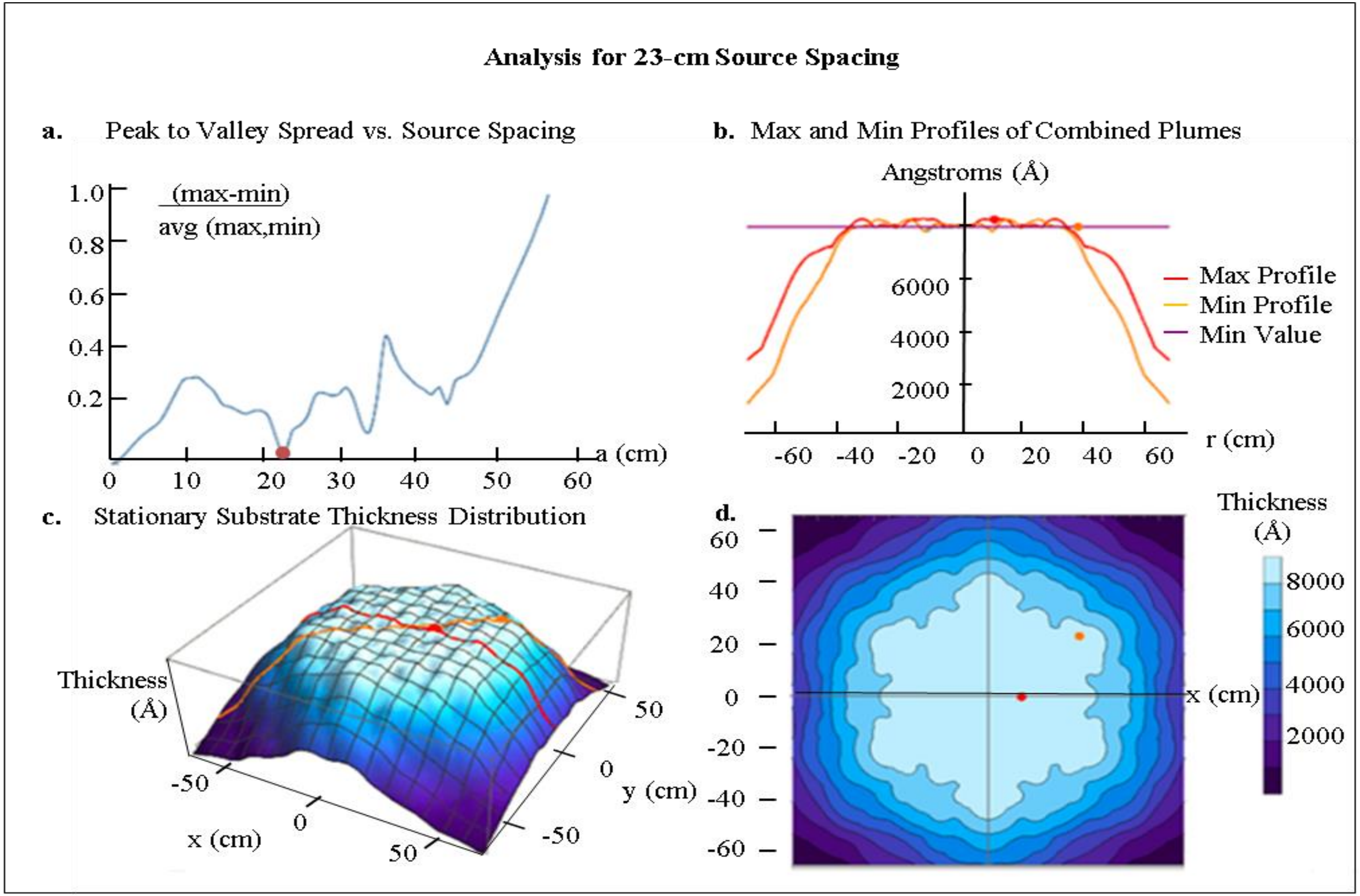

Max and Min Profiles of Combined Plumes
Thickness(Å)
70000
60000
50000
40000
30000
20000
10000
−3
−2
−1
0
1
2
3
r (cm)
Max Profile
Min Profile
Min Value


Stationary SubstrateThickness Distribution
60000
Thickness (Å)
20000
0
−2
0
2
x (cm)
2
0
−2
y (cm)


3
2
1
0
−1
−2
x (cm)
70000


Analysis for 56-cm Source Spacing
a. Peak to Valley Spread vs. Source Spacing
(max-min) / avg (max,min)
1.0
0.8
0.6
0.4
0.2
0 10 20 30 40 50 60
a (cm)
b. Max and Min Profiles of Combined Plumes
Angstroms (Å)
1000
-150 -100 -50 0 50 100 150
r (cm)
Max Profile
Min Profile
Min Value
c. Stationary Substrate Thickness Distribution
Thickness (Å)
-50 0 50
x (cm)
50 0 -50
y (cm)
d.
100
50
0
-50
-100
x (cm)
2250
1750
1250
750
250

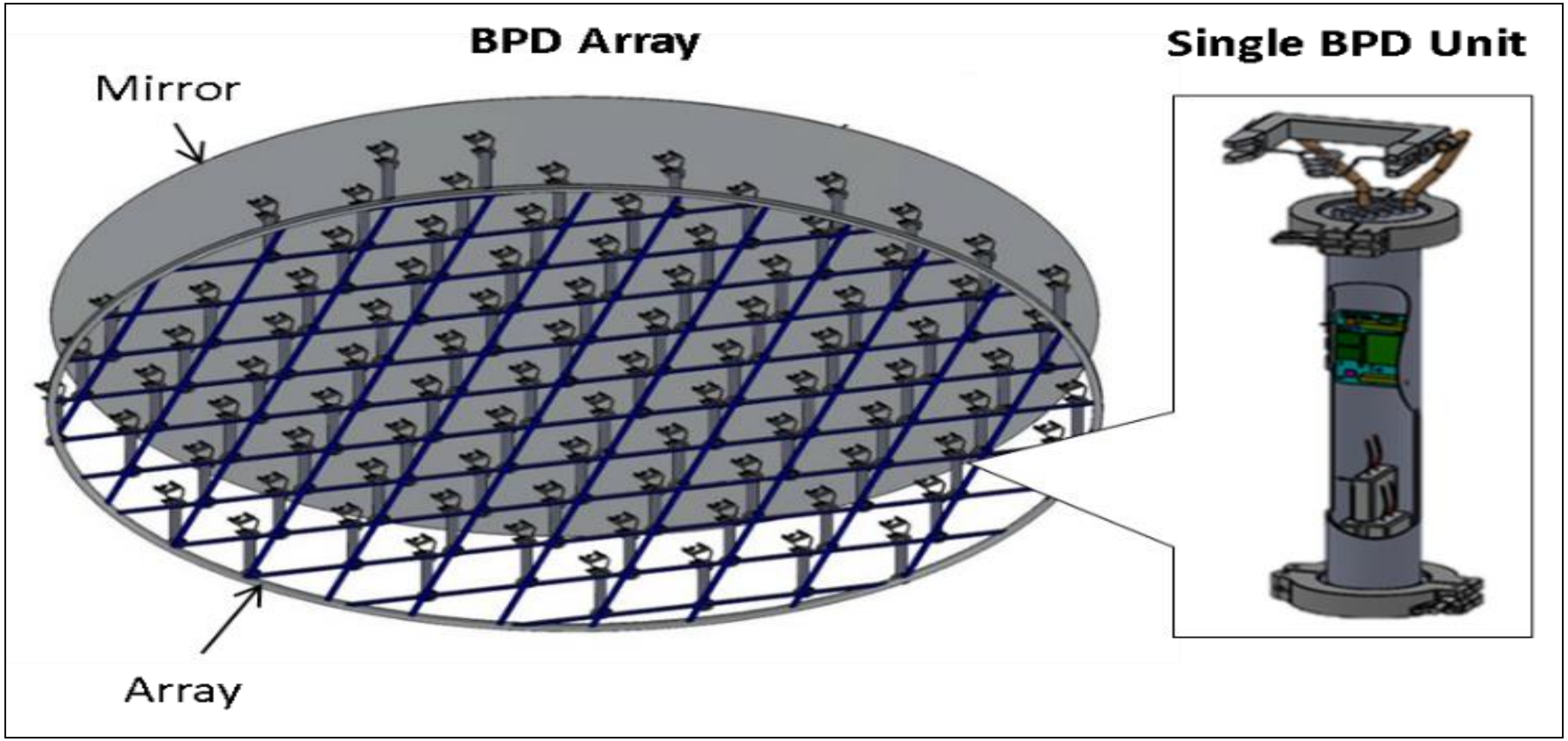

Analysis for 34-cm Source Spacing
a. Peak to Valley Spread vs. Source Spacing
(max-min)
avg (max,min)
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
a (cm)
b. Max and Min Profiles of Combined Plumes
Angstroms (Å)
3000
2000
1000
-100
-50
0
50
100
r (cm)
Max Profile
Min Profile
Min Value
c. Stationary Substrate Thickness Distribution
Thickness
(Å)
-50
0
50
x (cm)
50
0
-50
y (cm)
d.
Thickness
(Å)
50
0
-50
x (cm)
4000
3000
2000
1000


Analysis for 23-cm Source Spacing
a. Peak to Valley Spread vs. Source Spacing
(max-min)
avg (max,min)
1.0
0.8
0.6
0.4
0.2
0
10
20
30
40
50
60
a (cm)
b. Max and Min Profiles of Combined Plumes
Angstroms (Å)
6000
4000
2000
-60
-40
-20
0
20
40
60
r (cm)
Max Profile
Min Profile
Min Value
c. Stationary Substrate Thickness Distribution
Thickness
(Å)
-50
0
50
x (cm)
50
0
-50
y (cm)
d.
60
40
20
0
-20
-40
-60
x (cm)
Thickness
(Å)
8000
6000
4000
2000

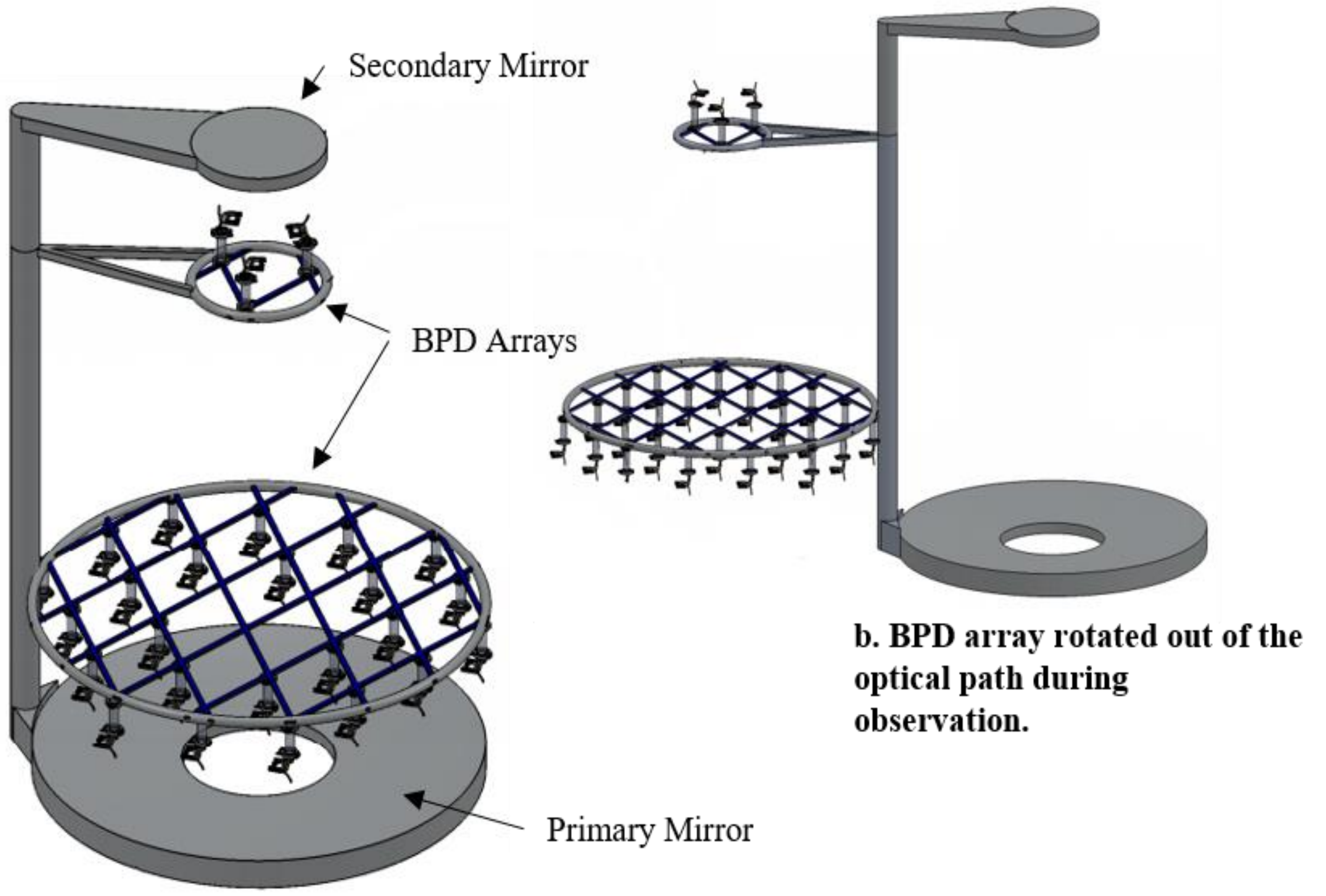
Modeling results summary

Source spacing (cm)	Coating rate (Å/sec)	PTV error	Flat radius (cm)	Flat area (m^2)	No. of sources /m^2
56	25	>160%	N/A	N/A	4
34	58	12.0%	65	1.3	23
23	133	6.4%	35	0.4	81

Battery-powered filament evaporator, or “battery-powered deposition (BPD)”



Telescope designed for coating in space



b. BPD array rotated out of the optical path during observation.

a. BPD array in front of the primary and secondary mirrors during coating

What are we doing next?

- Developing a more powerful unit with better batteries
- Adding a mechanical shutter to start and stop the deposition process
- Adding circuitry to control the evaporation rate
- Provisional patent was filed in January 2016 so patent application due in January 2017

Other applications for battery-powered filament evaporation BPFE “made on earth”

- Coat large UVOIR mirrors with FUV-quality aluminum for space telescopes - > 90-nm
- Coat large telescope mirrors with aluminum for higher UV reflectance @320-nm (8+ meter, ground-based telescopes)
- Coat large protected UV silver mirrors (>320-nm) (8+ meter, ground-based telescopes); (alternative to sputtered Gemini coating with improved UV)

Challenges and Issues

There are, of course, many engineering problems to solve.

- What kind of battery chemistry works best in space? Effects of zero gravity and cryo temperatures on batteries, etc?
- Questions regarding effects of zero gravity on coating quality..
- Deployment, heat transfer, contamination control, etc., etc.

So what? These are relatively simple, typical, engineering tasks.

Questions?