



Simulation of Small Satellite Photovoltaic Power Generation Systems

# Goal: Simulate Satellite Solar Power Generation

Questions we should ask:

What environment will be the satellite be in?

How do we simulate power generation?

How do we simulate power consumption?

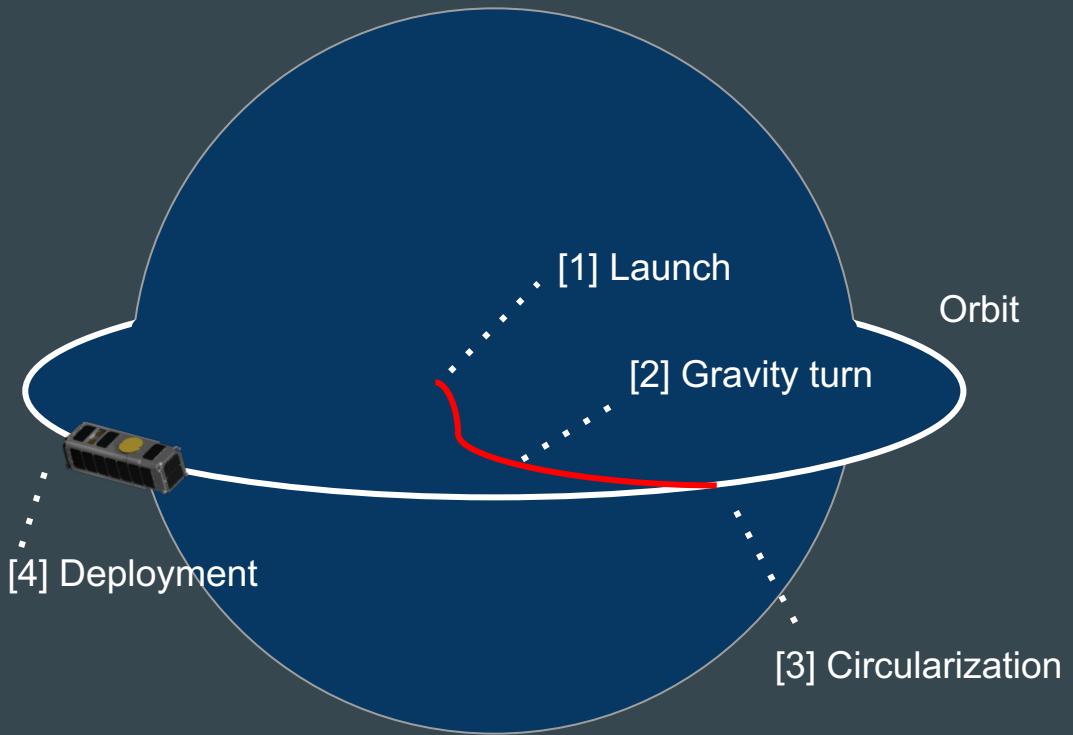
How would the onboard battery system respond to these inputs?

What we are simulating

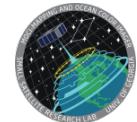
3U CubeSat in ISS orbit



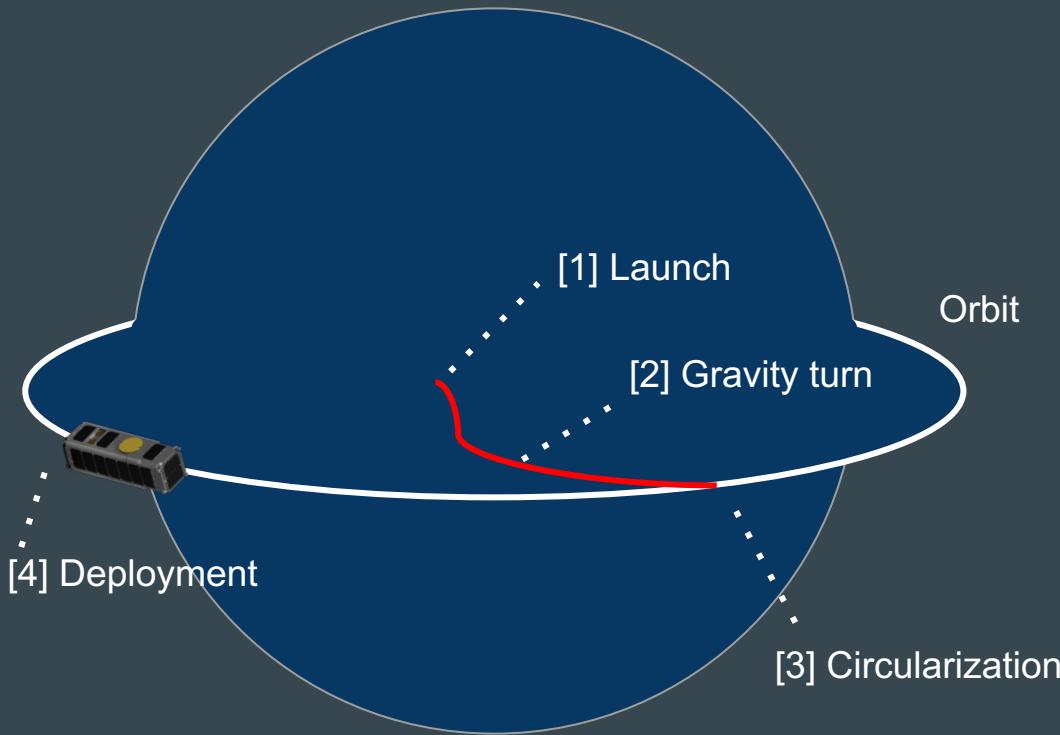
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[1] Launch



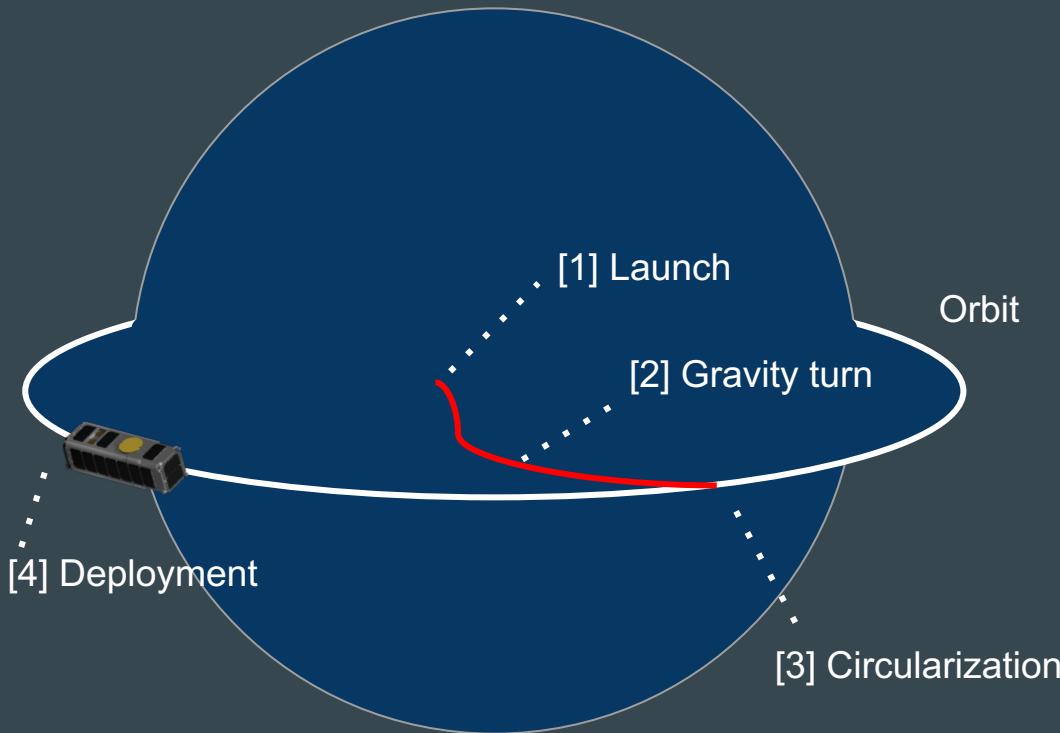
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[2] Gravity turn



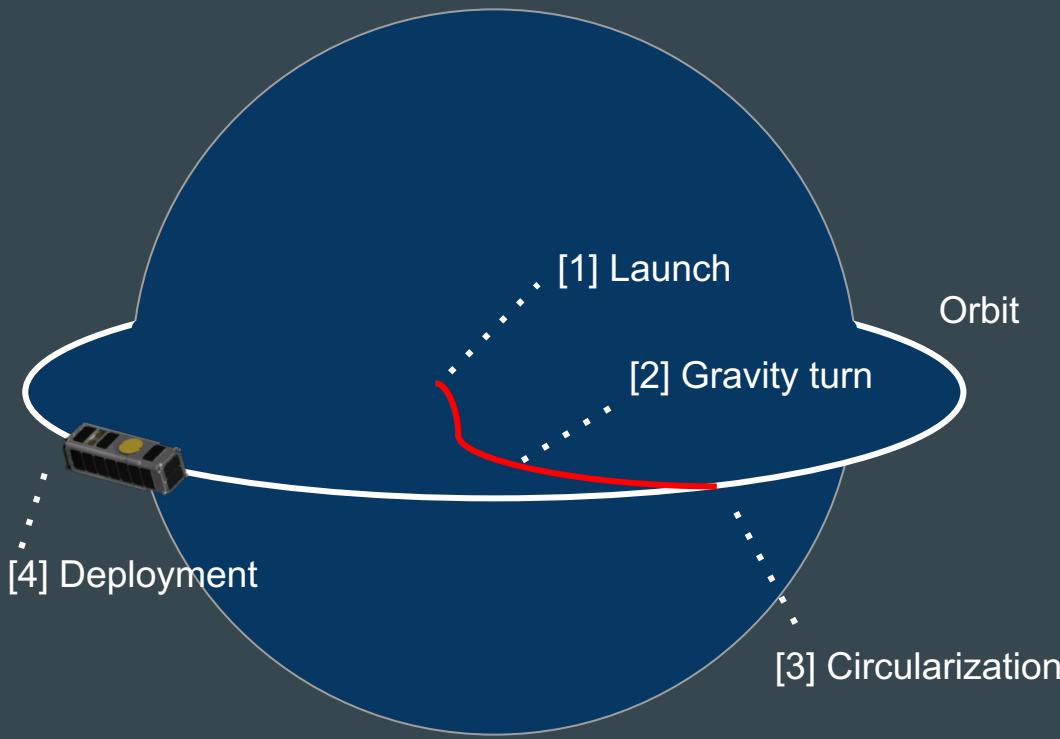
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[3] Circularization



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[4] Deployment



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Eclipse

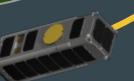
Sunlit

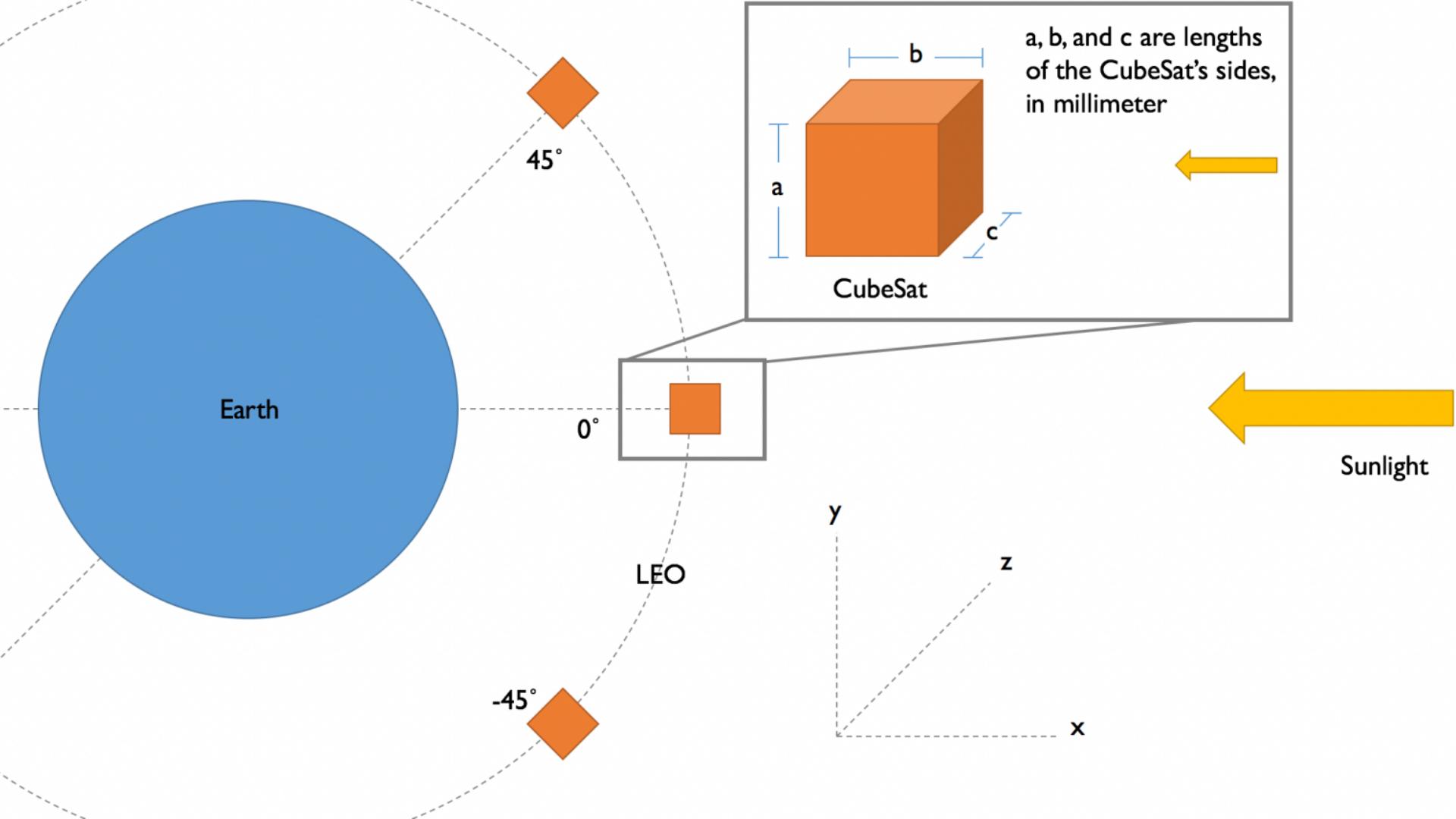
Sun

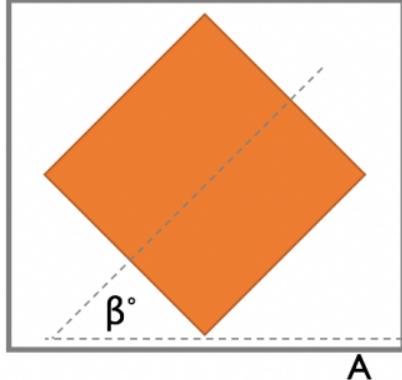
Earth

Umbra

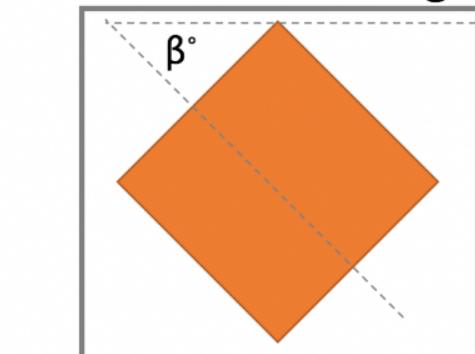
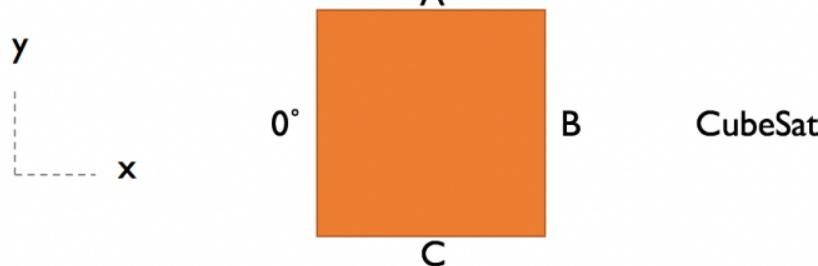
Penumbra



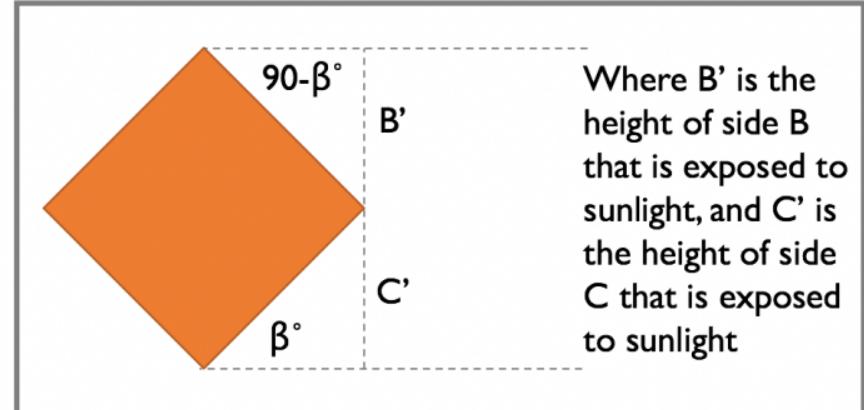




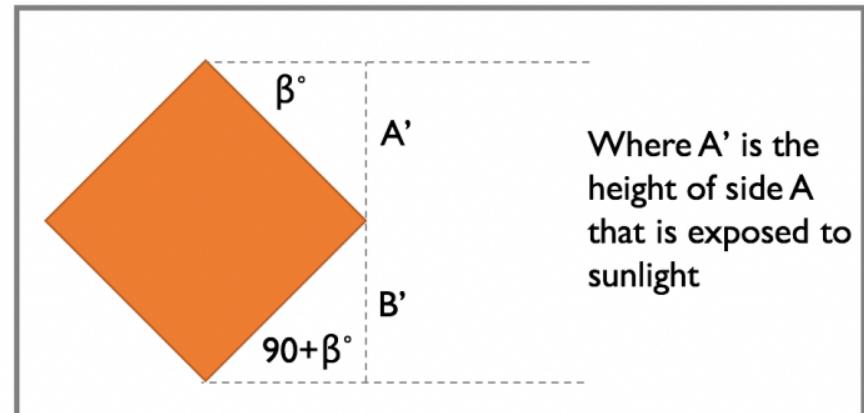
Where  $\beta^\circ$  is the angle that the CubeSat's body frame create with the positive x-axis



A, B, and C are arbitrary sides assigned as shown, given that far positive x is the sun



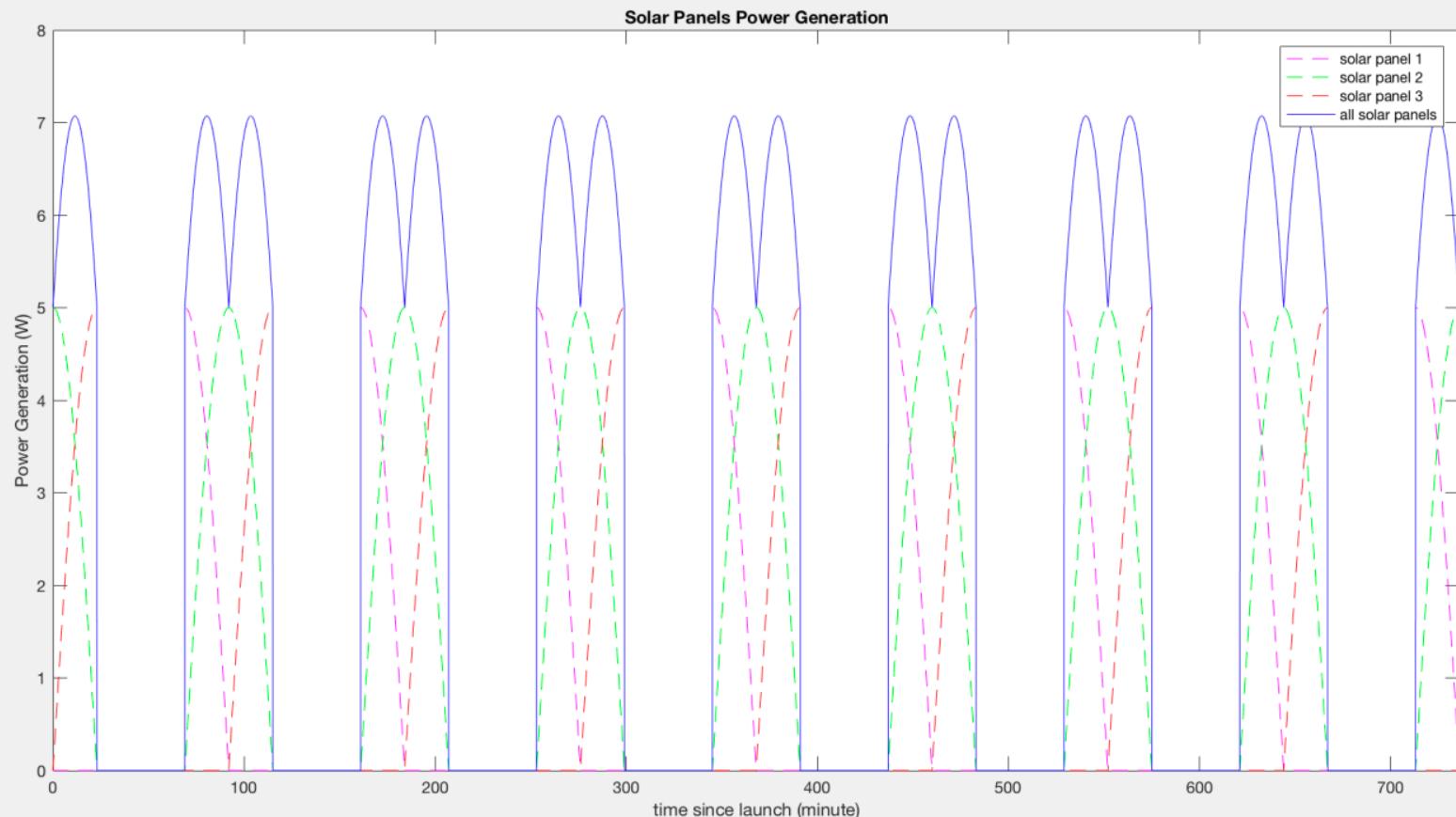
Where  $B'$  is the height of side B that is exposed to sunlight, and  $C'$  is the height of side C that is exposed to sunlight



Where  $A'$  is the height of side A that is exposed to sunlight

Figure 1

File Edit View Insert Tools Desktop Window Help



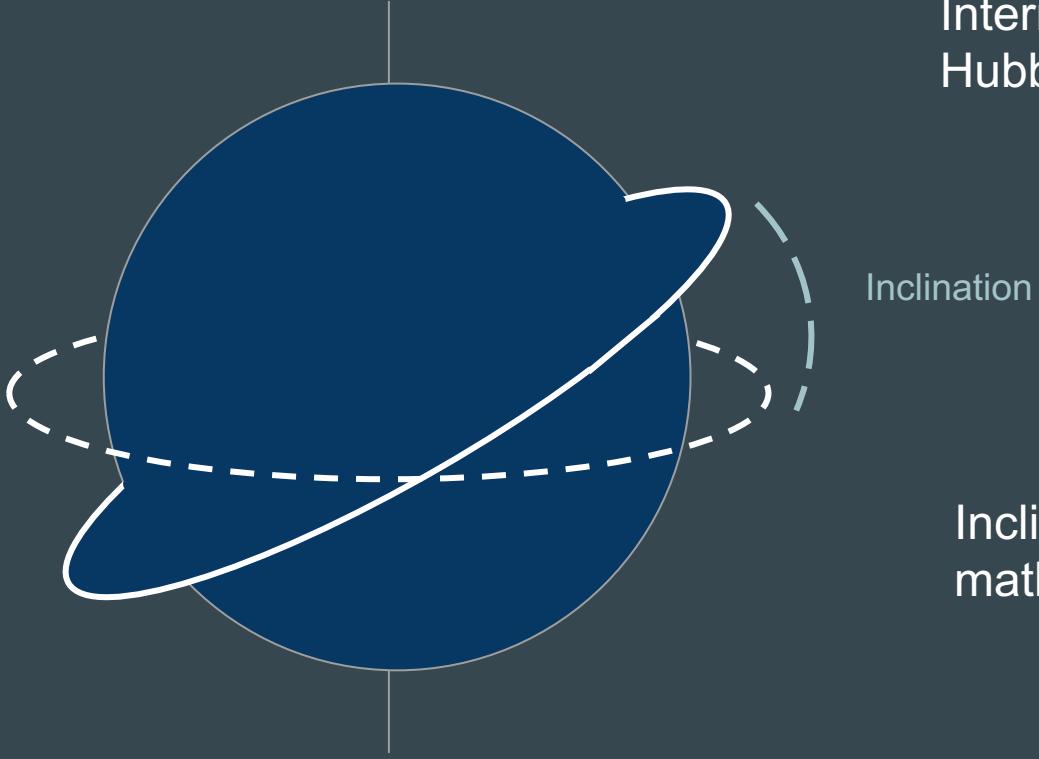
```
221 -     disp(avg_power)
222 -     disp('Average Power Generation (W)(30% margin)')
223 -     disp(avg_power_margin)
224 - %disp('Form factor ')
225 - %fprintf('    %dU\n',(CUBESAT_HEIGHT / CUBESAT_SIDE));
226 - %console outputs end#####
227 - end
```

### Command Window

Average Power Generation (W) (raw)  
3.18305615026072

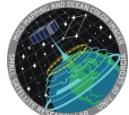
Average Power Generation (W)(30% margin)  
2.22813930518251

fx >>

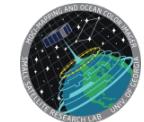
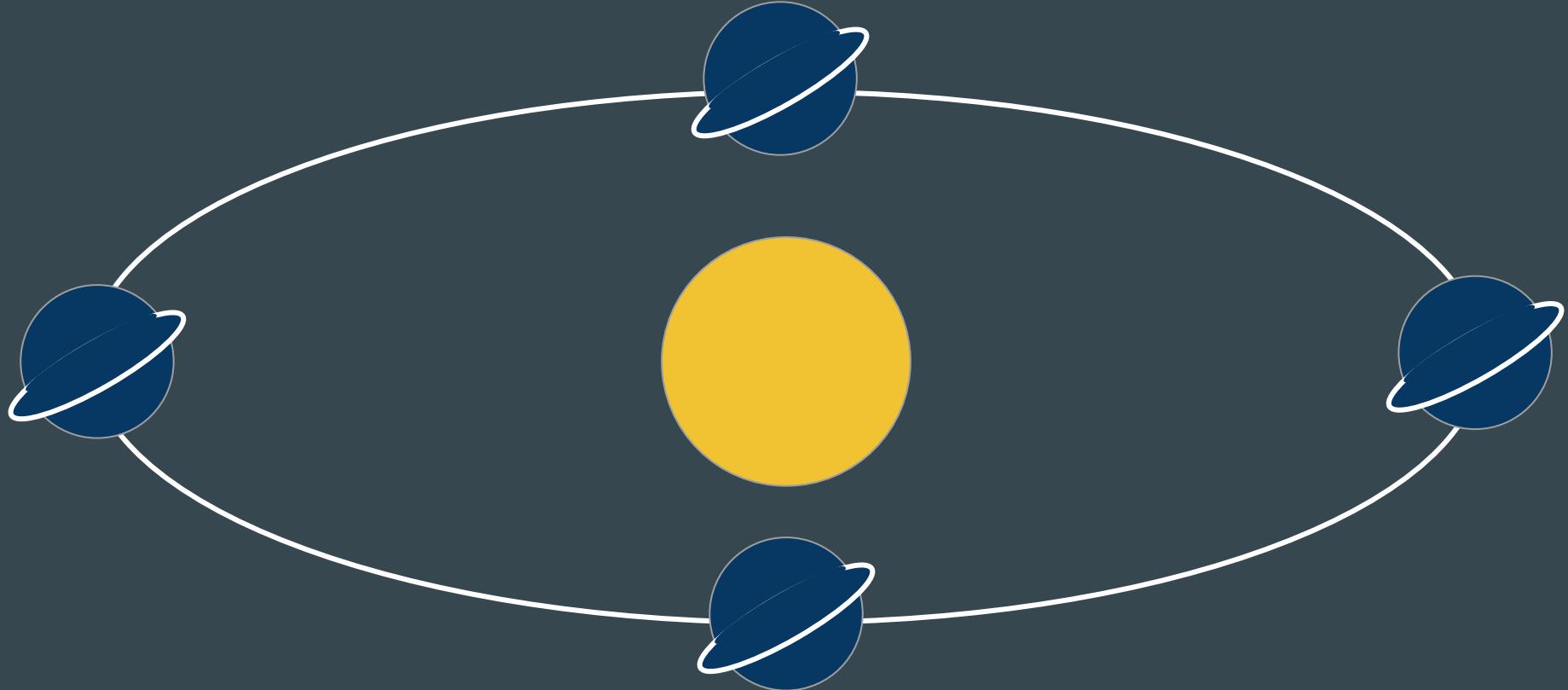


International Space Station: 51.6 degrees  
Hubble Space Telescope: 28.5 degrees

Inclination will invalidate our previous mathematical modeling assumptions

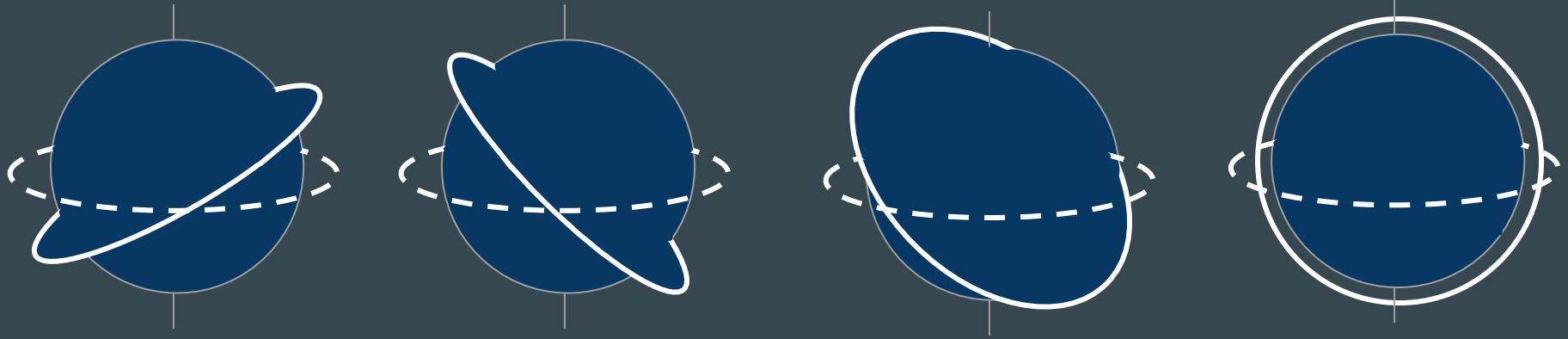


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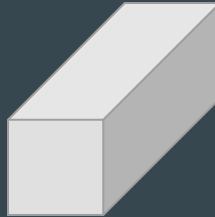
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Depends on the season, sun's view of the orbit and the satellite will change. This effect is the resultant of the satellite's Earth orbital inclination and the orbit of Earth around the Sun



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Flight configuration 1: 3U face toward velocity

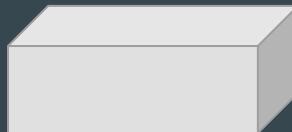


Orbital velocity vector

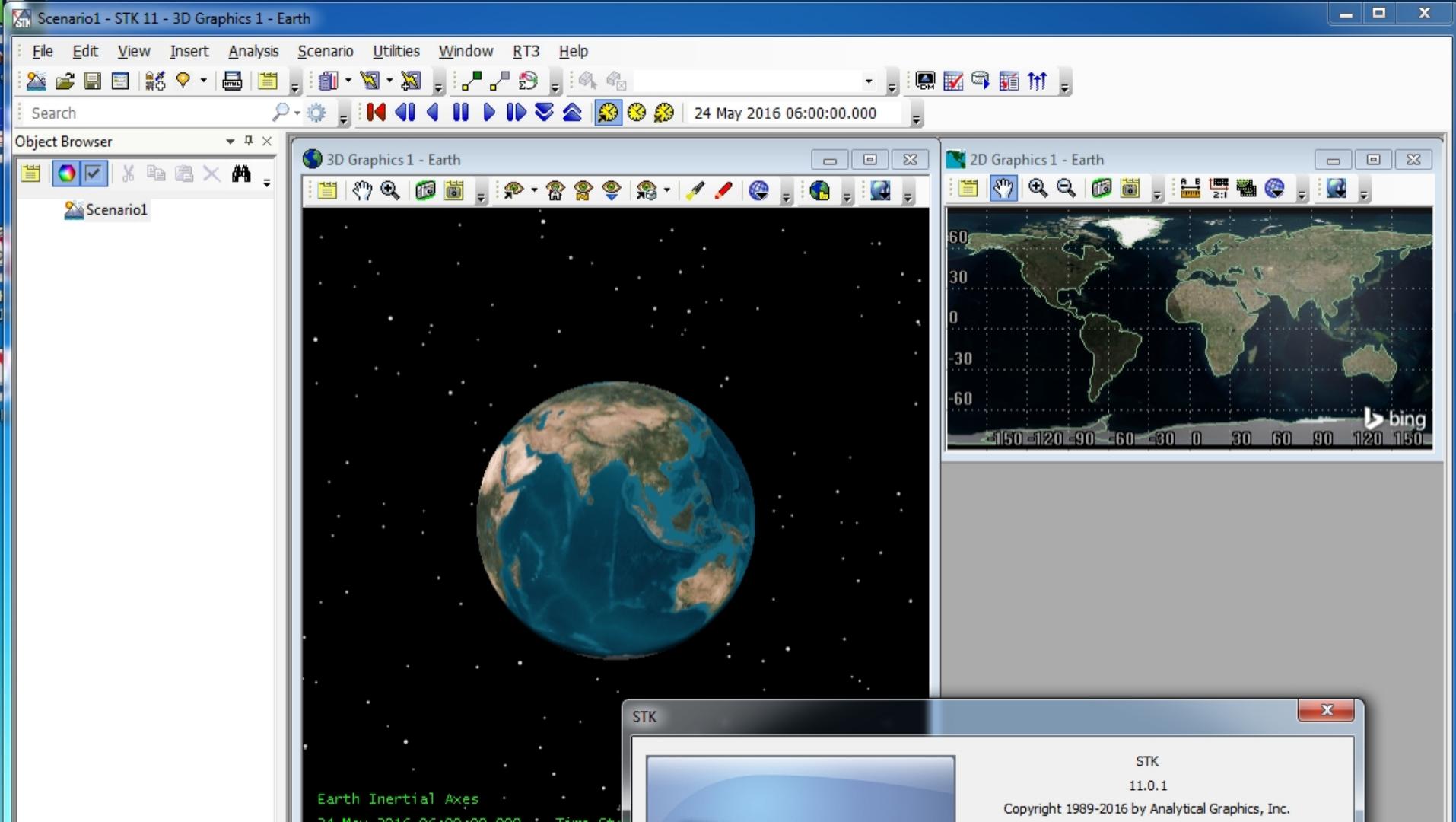


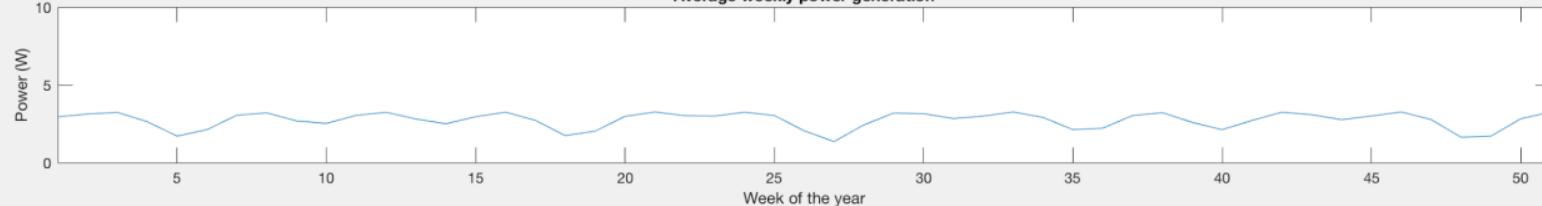
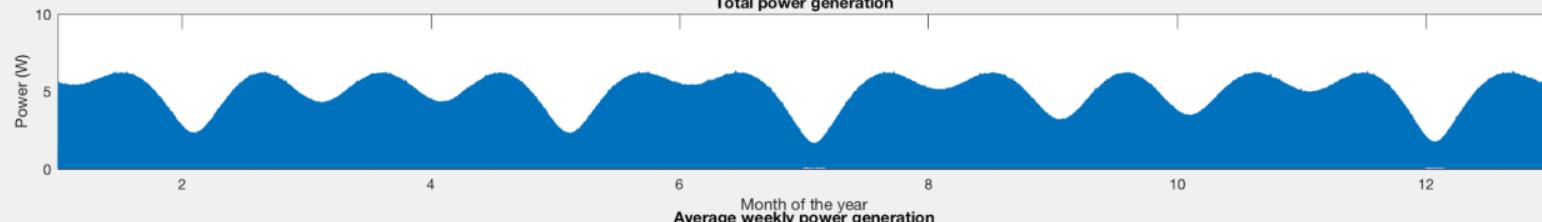
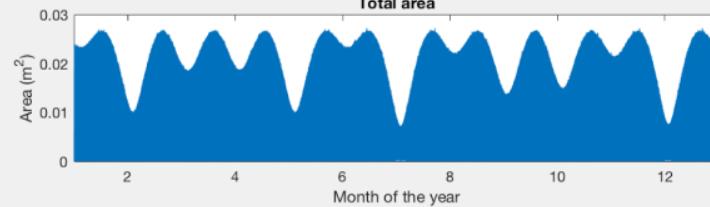
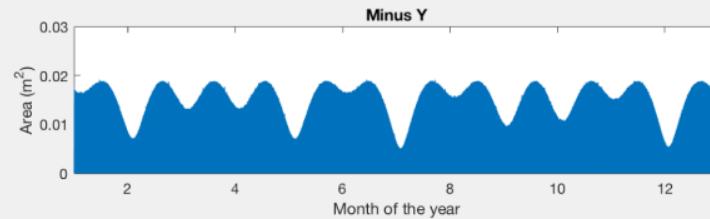
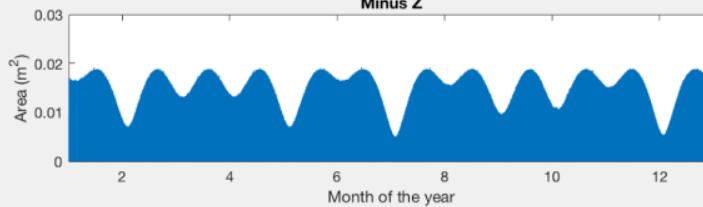
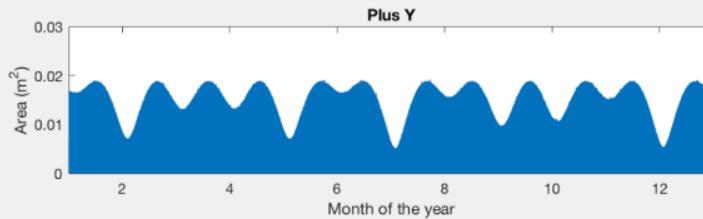
Estimated 8 months  
before deorbit

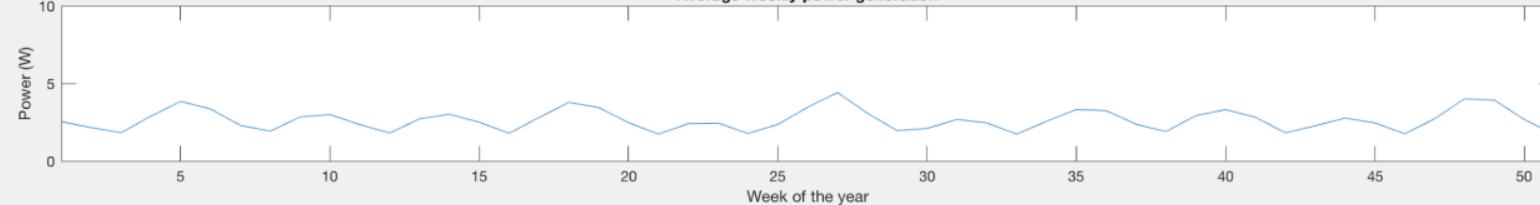
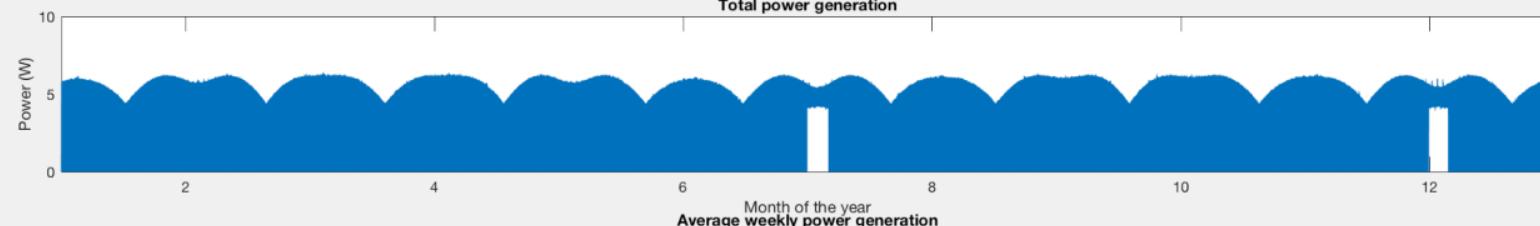
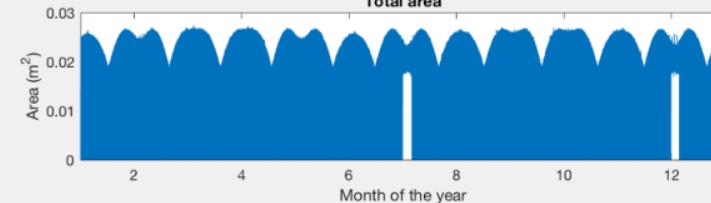
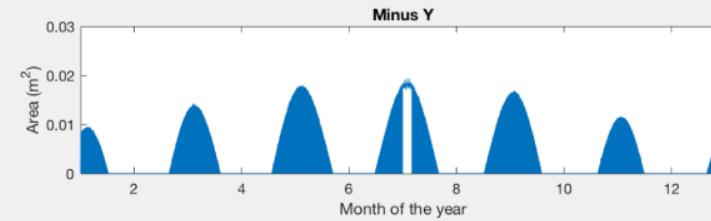
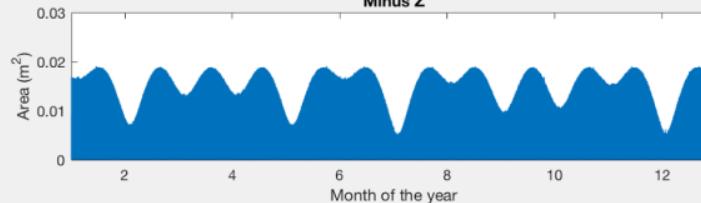
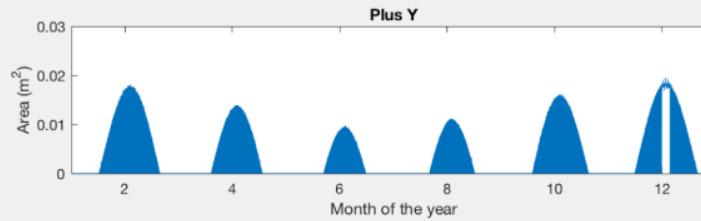
Flight configuration 2: 1U face toward velocity

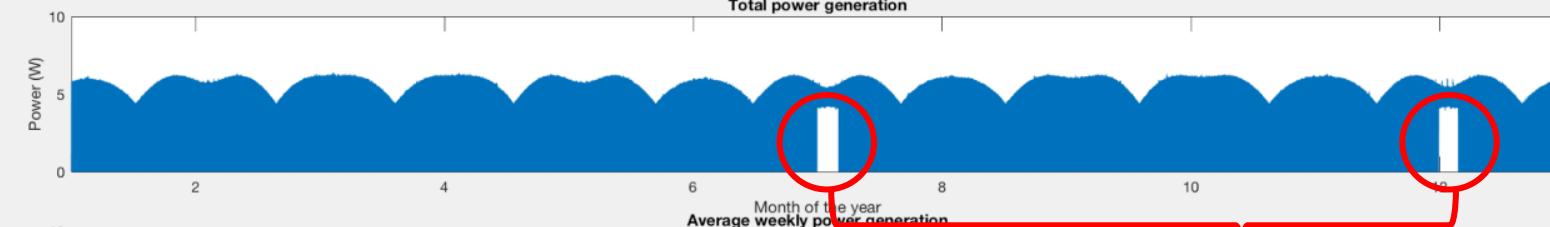
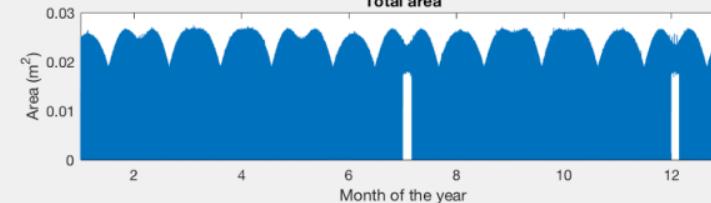
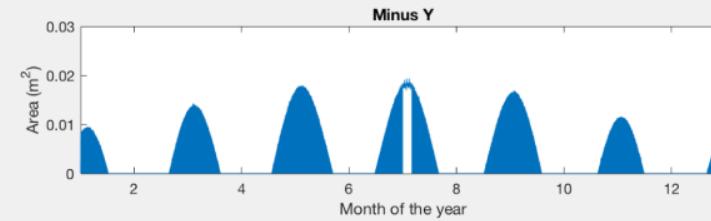
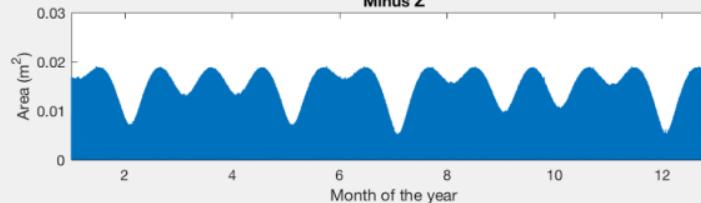
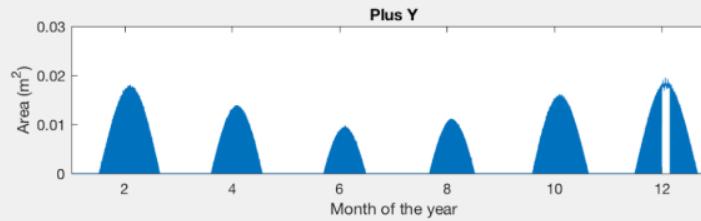


Estimated 18 months  
before deorbit



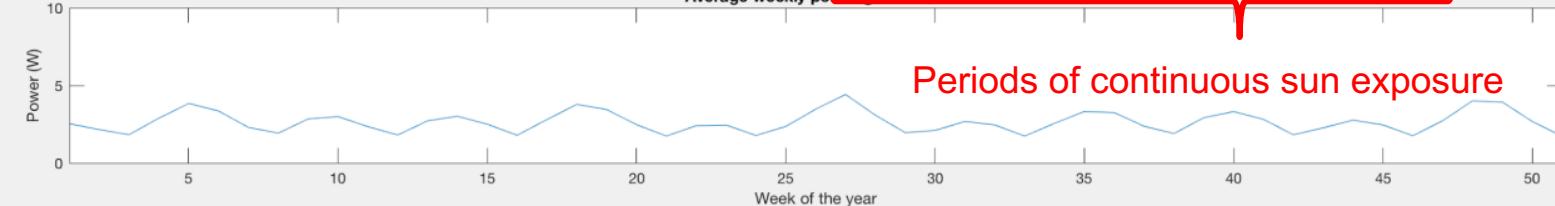
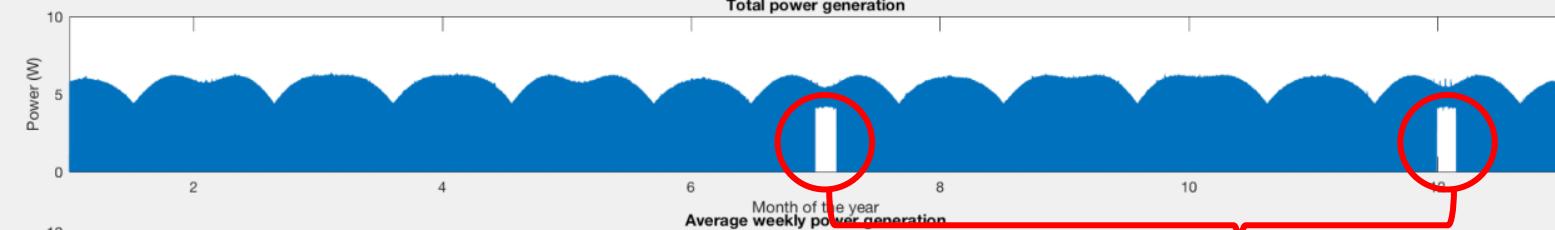
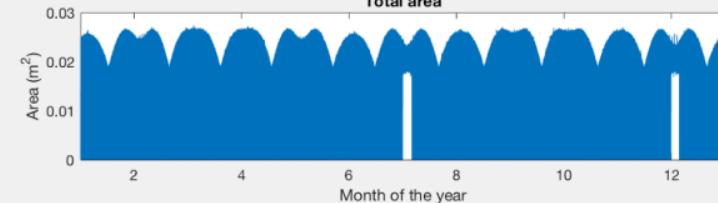
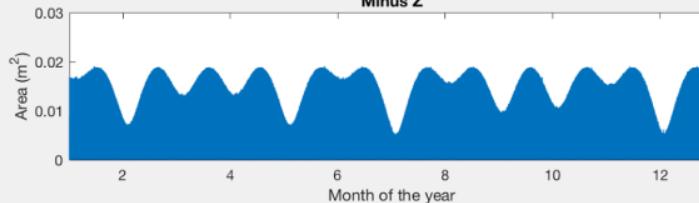
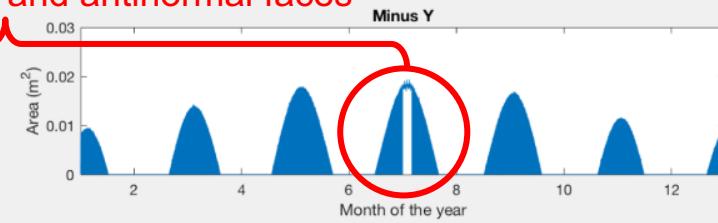
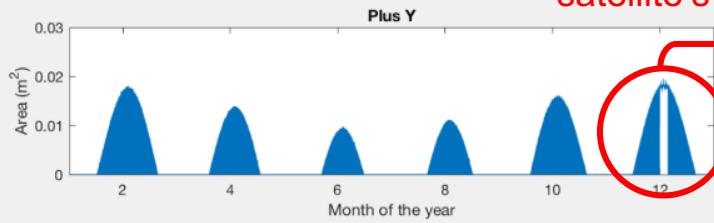








Those exposure events will occur at the satellite's normal and antinormal faces



ulation\_r2.m  
CX  
132.csv

```
6  
7 %definitions  
8 - sample_length = 104831; %the length of the data (steps)  
9 - sample_period_days = 7; %take average power of 7 days for seasonal  
10 %analysis
```

### Command Window

Year-long 3U-velocity 3U-nadir average power generation (W)  
2.73812872782543

3U-velocity 3U-nadir Minimum weekly-average power generation (W)  
1.34647083333333

3U-velocity 3U-nadir Maximum weekly-average power generation (W)  
3.25437453703704

Year-long 1U-velocity 3U-nadir average power generation (W)  
2.62282919937804

1U-velocity 3U-nadir Minimum weekly-average power generation (W)  
1.72094699074075

1U-velocity 3U-nadir Maximum weekly-average power generation (W)  
4.40866666666666

fx >>

stk\_spoc\_power\_r1

ulation\_r2.m  
cx  
132.csv

```
6  
7 %definitions  
8 - sample_length = 104831; %the length of the data (steps)  
9 - sample_period_days = 7; %take average power of 7 days for seasonal  
10 %analysis
```

### Command Window

Year-long 3U-velocity 3U-nadir average power generation (W)

2.73812872782543

Average power generation

3U-velocity 3U-nadir Minimum weekly-average power generation (W)

1.34647083333333

3U-velocity 3U-nadir Maximum weekly-average power generation (W)

3.25437453703704

Year-long 1U-velocity 3U-nadir average power generation (W)

2.62282919937804

1U-velocity 3U-nadir Minimum weekly-average power generation (W)

1.72094699074075

1U-velocity 3U-nadir Maximum weekly-average power generation (W)

4.408666666666666

fx >>

stk\_spoc\_power\_r1

ulation\_r2.m  
cx  
132.csv

```
6  
7 %definitions  
8 - sample_length = 104831; %the length of the data (steps)  
9 - sample_period_days = 7; %take average power of 7 days for seasonal  
10 %analysis
```

Command Window

Year-long 3U-velocity 3U-nadir average power generation (W)  
2.73812872782543

3U-velocity 3U-nadir Minimum weekly-average power generation (W)  
**1.346470833333333**

3U-velocity 3U-nadir Maximum weekly-average power generation (W)  
3.25437453703704

Year-long 1U-velocity 3U-nadir average power generation (W)  
2.62282919937804

1U-velocity 3U-nadir Minimum weekly-average power generation (W)  
**1.72094699074075**

1U-velocity 3U-nadir Maximum weekly-average power generation (W)  
4.408666666666666

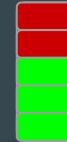
ion\_r2.m (Func... ^

fx >>

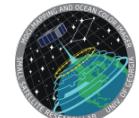
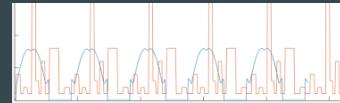
stk\_spoc\_power\_r1



2.62 W



2.55 W

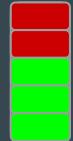


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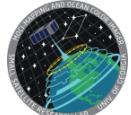
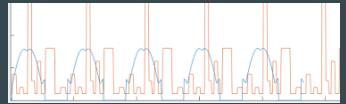
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2.62 W



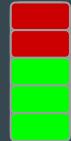
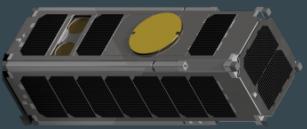
2.55 W



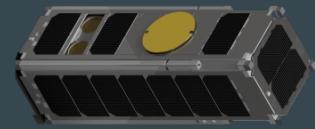
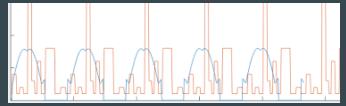
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2.62 W



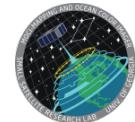
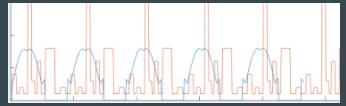
2.55 W



2.62 W

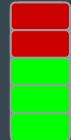
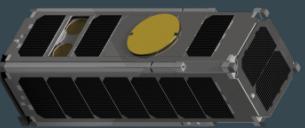


2.85 W

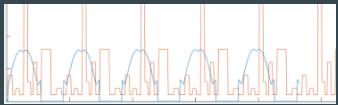
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2.62 W



2.55 W



2.62 W



2.85 W

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Screenshot of Microsoft Excel showing a schedule for 'operation\_schedule'.

The table has columns labeled A through I. The first row contains labels: Orbit 1, Orbit 2, Orbit 3, Orbit 4, and Orbit 5. Subsequent rows show consumption values over time for each orbit.

	A	B	C	D	E	F	G	H	I
1	Orbit 1	Orbit 2	Orbit 3	Orbit 4	Orbit 5				
2	Time	Consumption (W)	Time	Consumption (W)	Time	Consumption (W)	Time	Consumption (W)	Time
3	0	1	0	1	0	1	0	1	1
4	1	1	1	1	1	1	1	1	1
5	2	4	2	4	2	4	2	4	4
6	3	4	3	4	3	4	3	4	4
7	4	4	4	4	4	4	4	4	4
8	5	4	5	4	5	4	5	4	4
9	6	4	6	4	6	4	6	4	4
10	7	4	7	4	7	4	7	4	4
11	8	4	8	4	8	4	8.5	4	4
12	9	1	9	1	9	1	9	1	1
13	10	1	10	1	10	1	10	1	1
14	11	1	11	1	11	1	11	1	1
15	12	1	12	1	12	1	12	1	1
16	13	1	13	1	13	1	13	1	1
17	14	2	14	2	14	2	14	2	2
18	15	2	15	2	15	2	15	2	2
19	16	2	16	2	16	2	16	2	2
20	17	2	17	2	17	2	17	2	2
21	18	2	18	2	18	2	18	2	2

Below the table, there are three tabs: Power Schedule, User Inputs, and IMPORTANT.

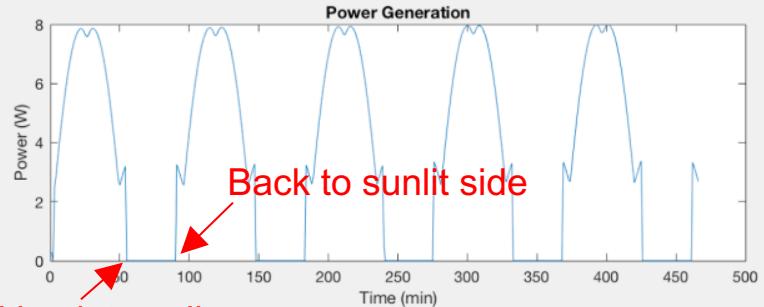
# Mission Planning (User Input)

# MATLAB data processing

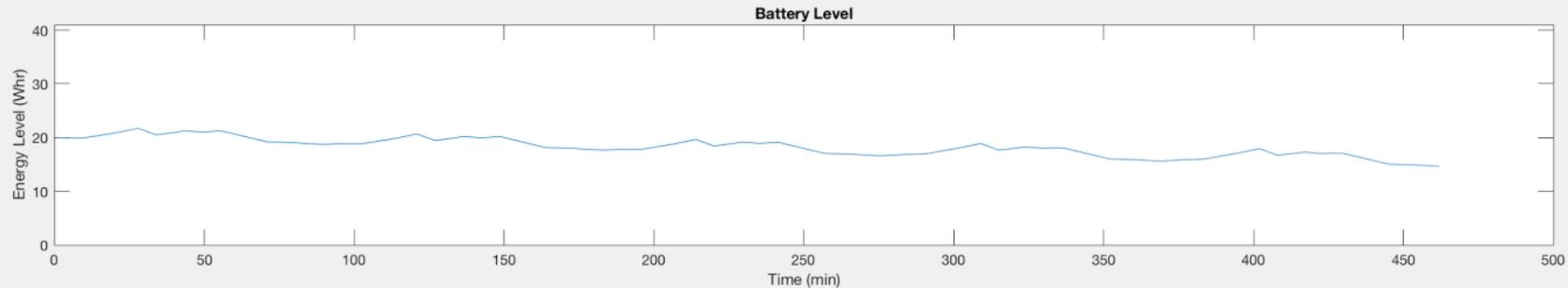
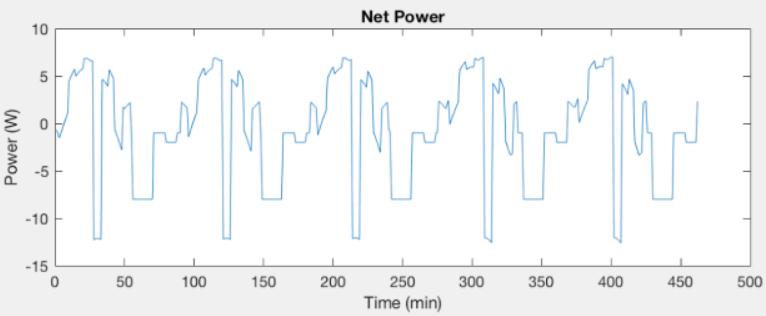
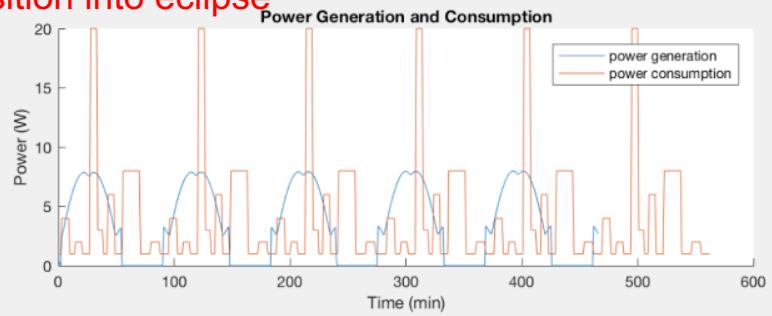
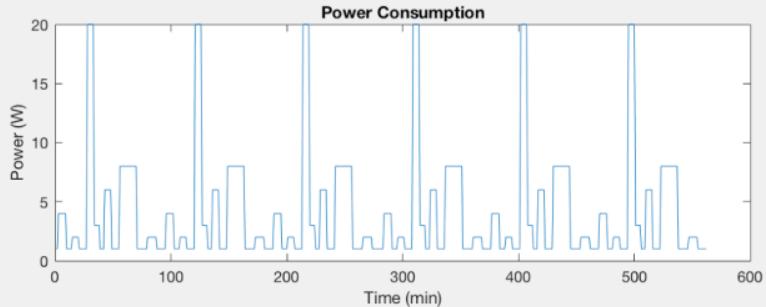
The screenshot shows the MATLAB R2016b interface. The top menu bar includes HOME, PLOTS, APPS, EDITOR, PUBLISH, and VIEW. A search bar at the top right says 'Search Documentation'. The current folder browser shows files like 'operation\_schedule.xlsx', 'augPanel\_Power.csv', and 'power\_simulation\_2.m'. The script editor window displays the code for 'spot\_power\_r2.m' and 'power\_simulation\_r2.m'. The command window at the bottom has the text 'A => |'.

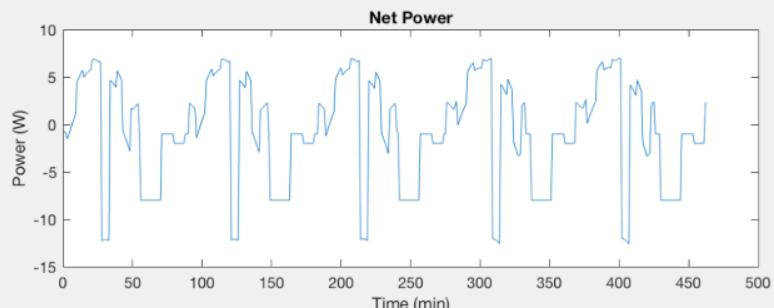
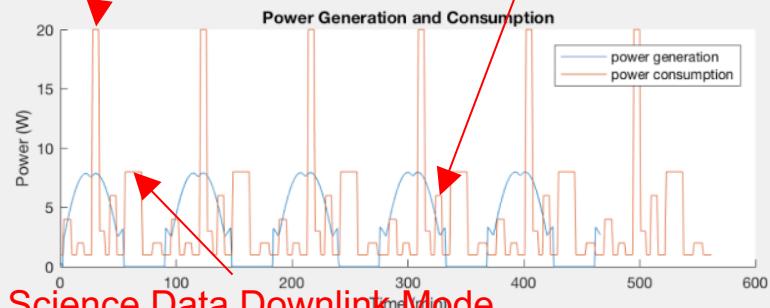
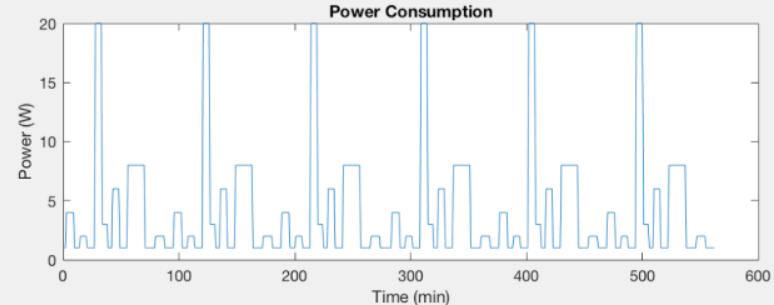
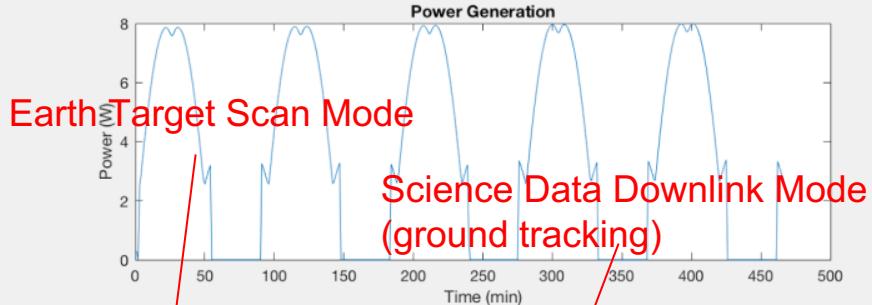
# STK solar projection data

Next slide

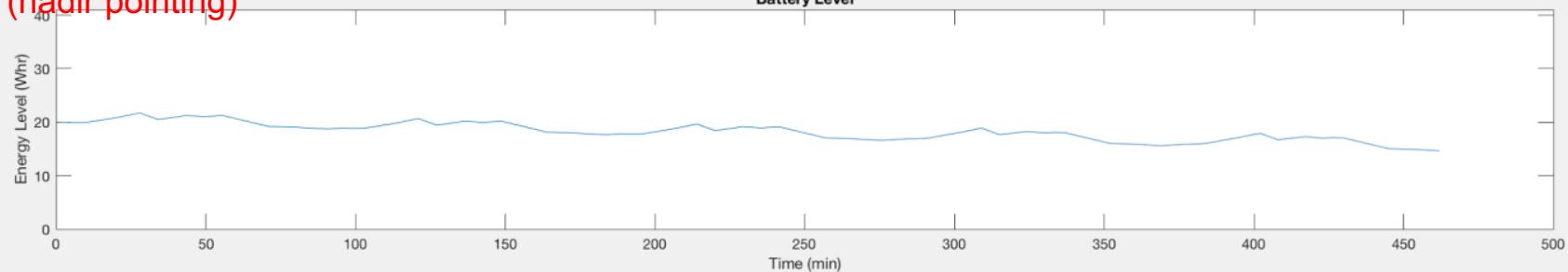


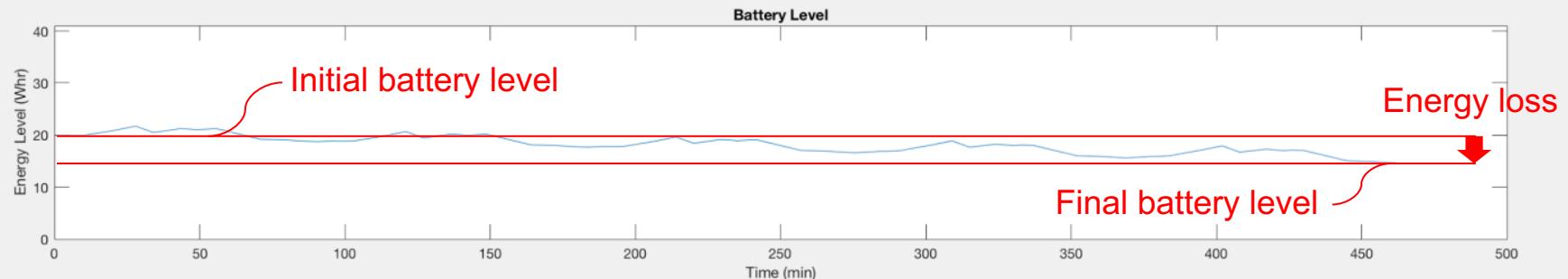
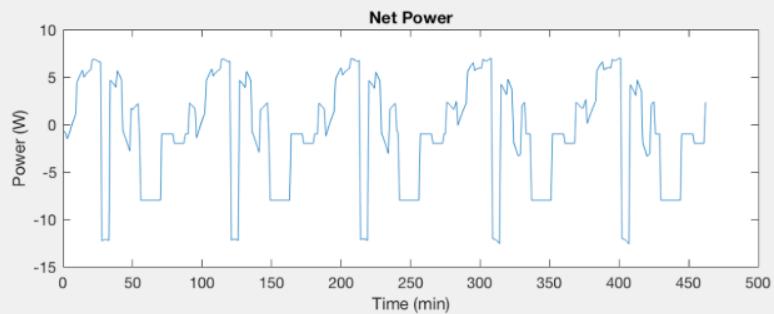
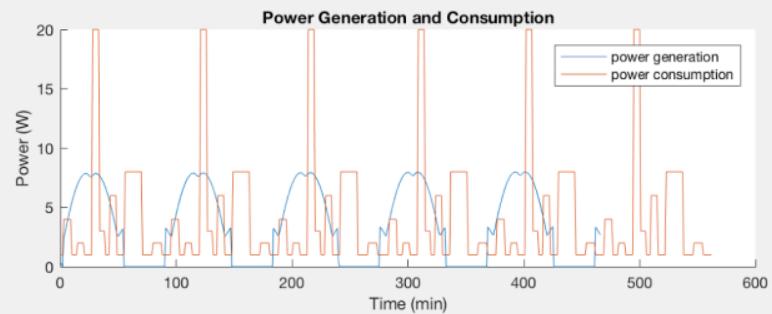
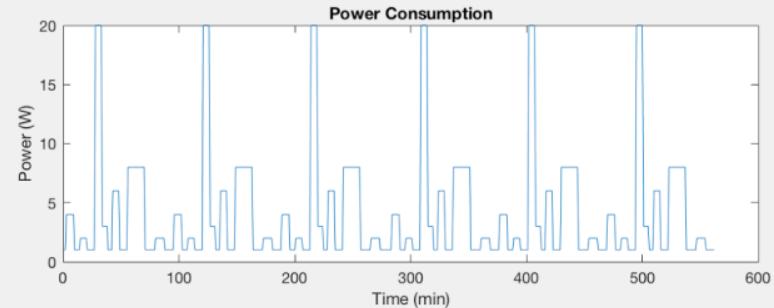
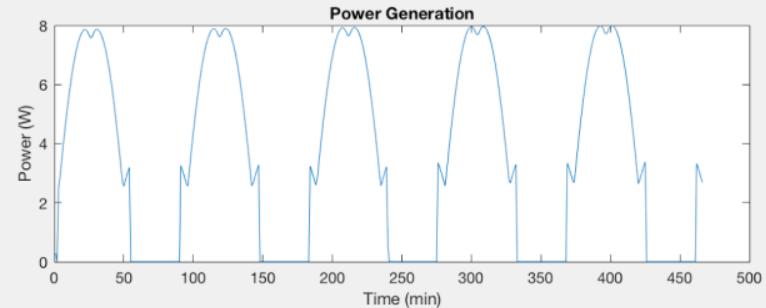
Transition into eclipse

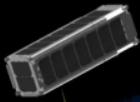
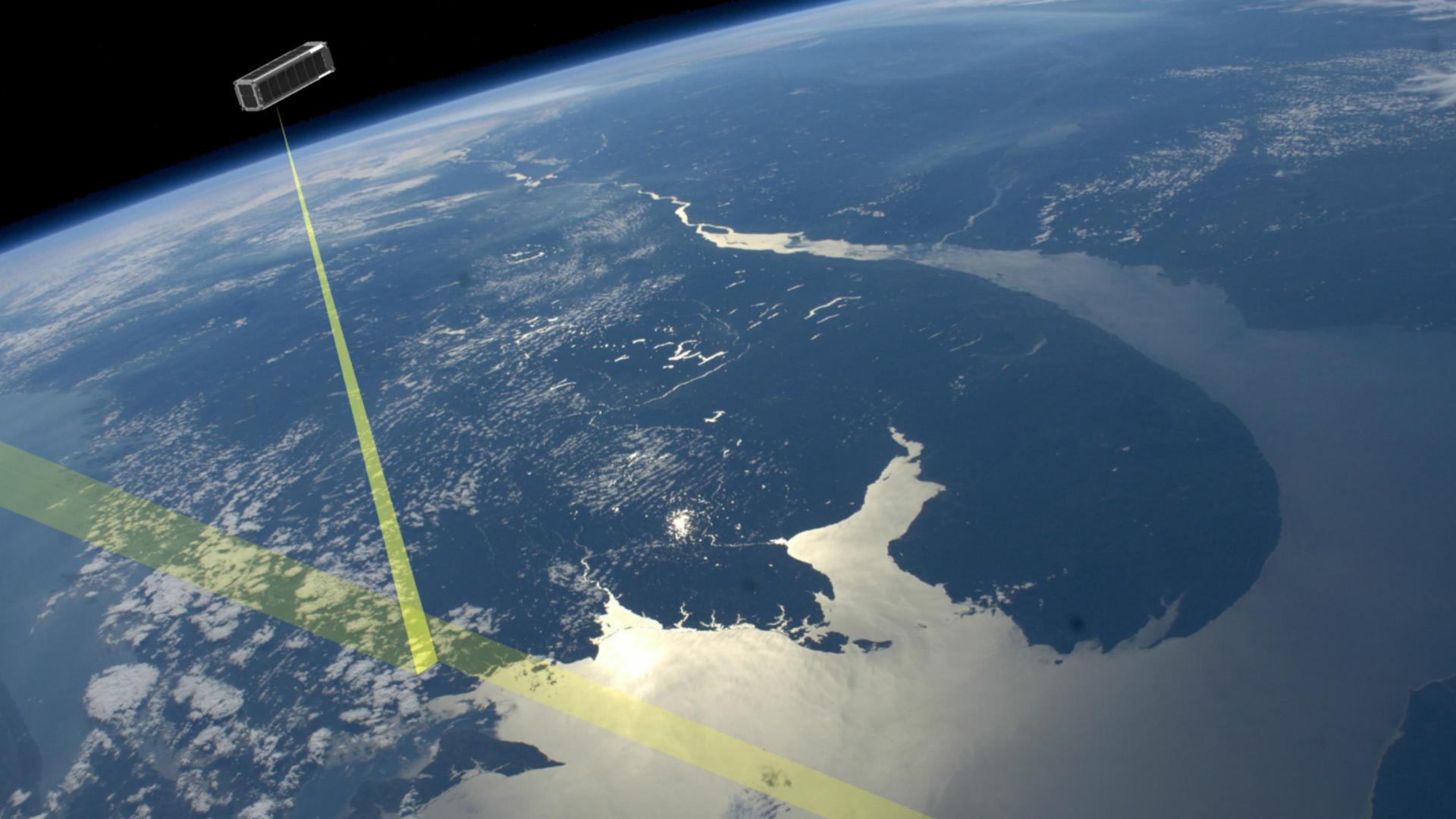


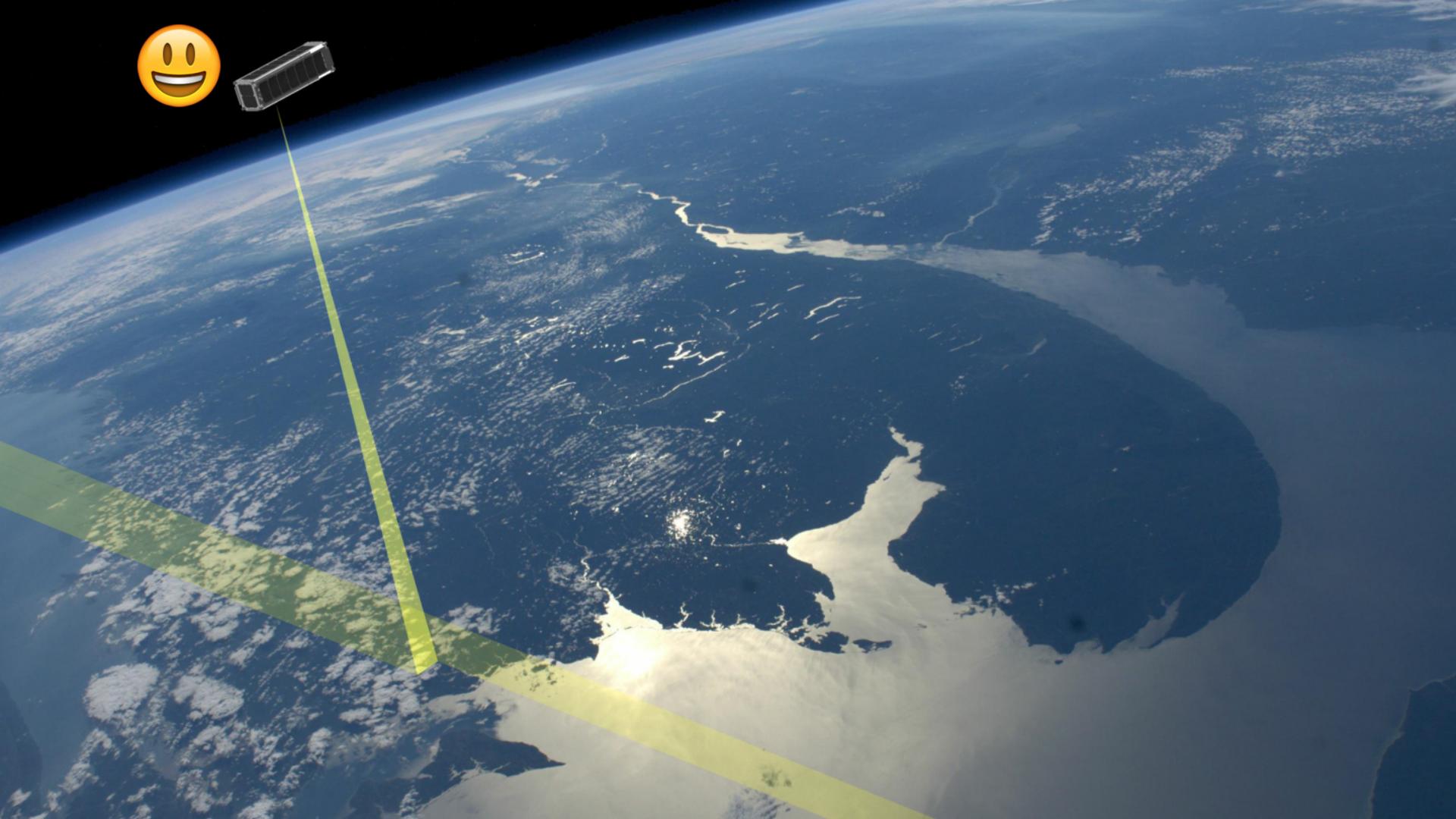
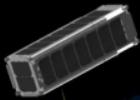


**Science Data Downlink Mode  
(nadir pointing)**









# Questions?

