

FIREBIRD

Ian Lyon

Engineering and Physics
Carroll College

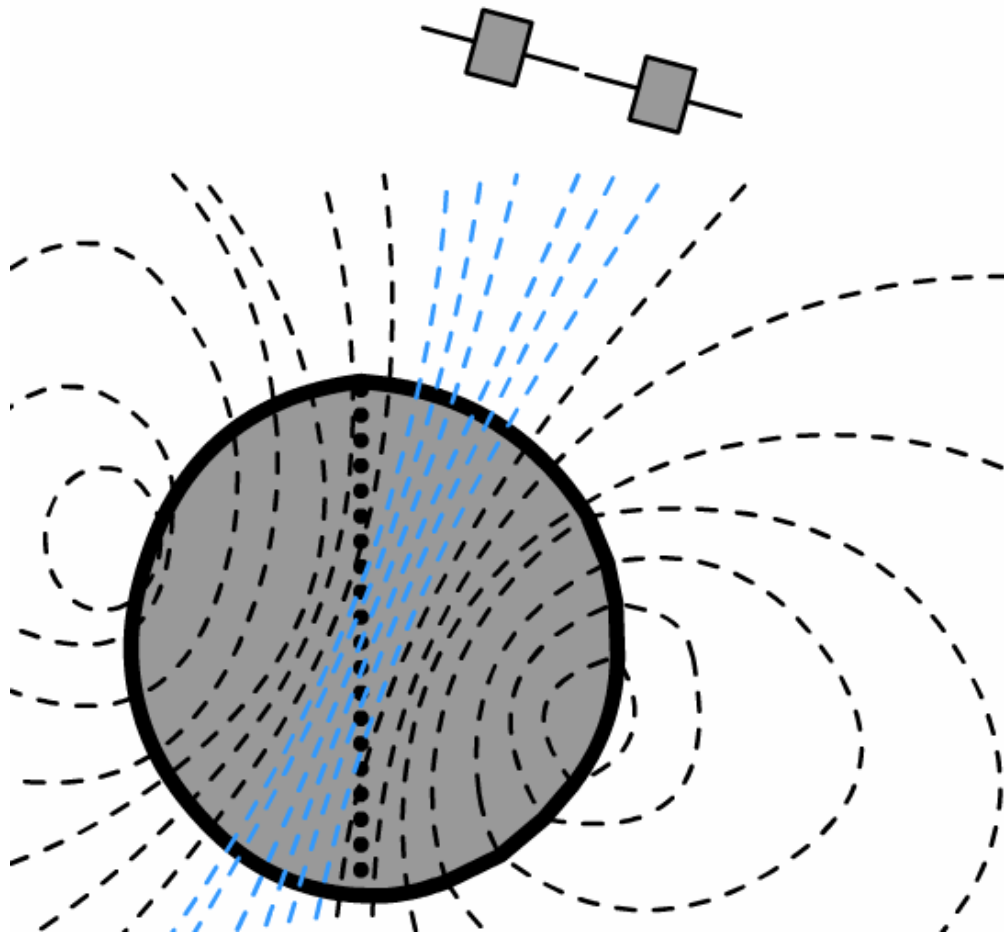


Simulation of the
Precise Separation of a
Two-Nanosatellite System
using Differential Drag



Looking For Electrons

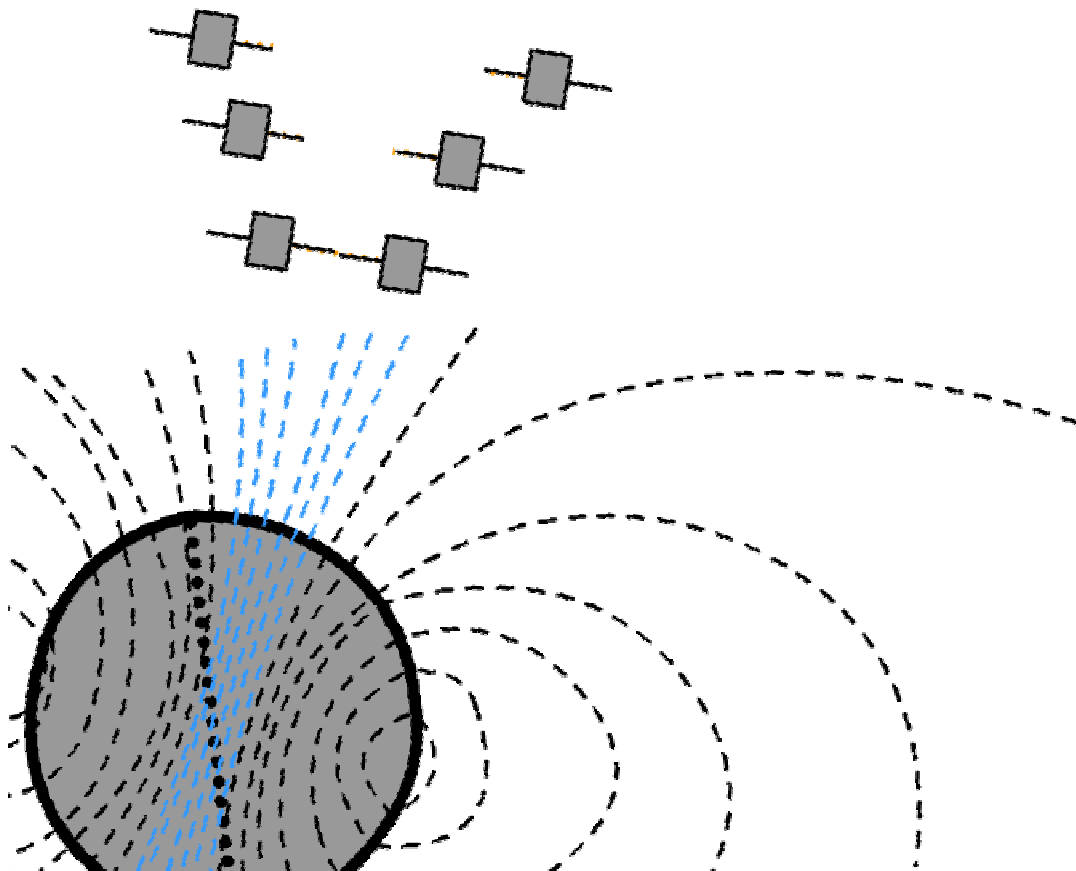
FIREBIRD: Focused Investigations of
Relativistic Electron Burst Intensity, Range, and Dynamics



- Looking for high-energy electron bursts near the poles of Earth's magnetic field.
- Each satellite has sensors to record electron bursts.
- The satellites fly together and slowly separate over time to get data about the size of the bursts.

Benefits of Separating

Separation is Crucial to Mission Success



- To best observe patterns, FIREBIRD will obtain data for multiple spatial scales.
 - Observe the small, complex differences in patterns with a small separation distance.
 - Observe the larger patterns and see the grand scale with a larger separation distance.

Lifespan

- Best Separation Distance:
 - 0 - 100 kilometers apart
 - The *sweet spot* for data collection.
 - Within this range for as long as possible.
- Past separation tactics and methods involved a spring mechanism.
- While springs can provide that initial difference in speed, they are notoriously unpredictable and usually too powerful.



Atmospheric Drag

- Drag is inevitable.
 - Atmospheric particles exist almost everywhere around the Earth, even thousands of kilometers above the surface.
 - Particles constantly slam into a satellite in orbit, each one exerting a tiny force in the opposite direction of the satellite's velocity.
 - Over time, the satellite to loses some forward motion.

Increasing the Acceleration from Drag

$$a_{sat} = \frac{-\frac{1}{2}\rho v^2 C_d A \hat{v}}{m_{sat}}$$

- By slightly changing the physical characteristics of an object, it can be more susceptible or less susceptible to drag while in motion.
- One satellite of FIREBIRD could be slowed from drag more than the other, causing them to slowly separate over time without a spring.
- Making a satellite *lighter* would increase the drag effect. A less massive object is affected by drag more than a massive one, due to reduced inertia.

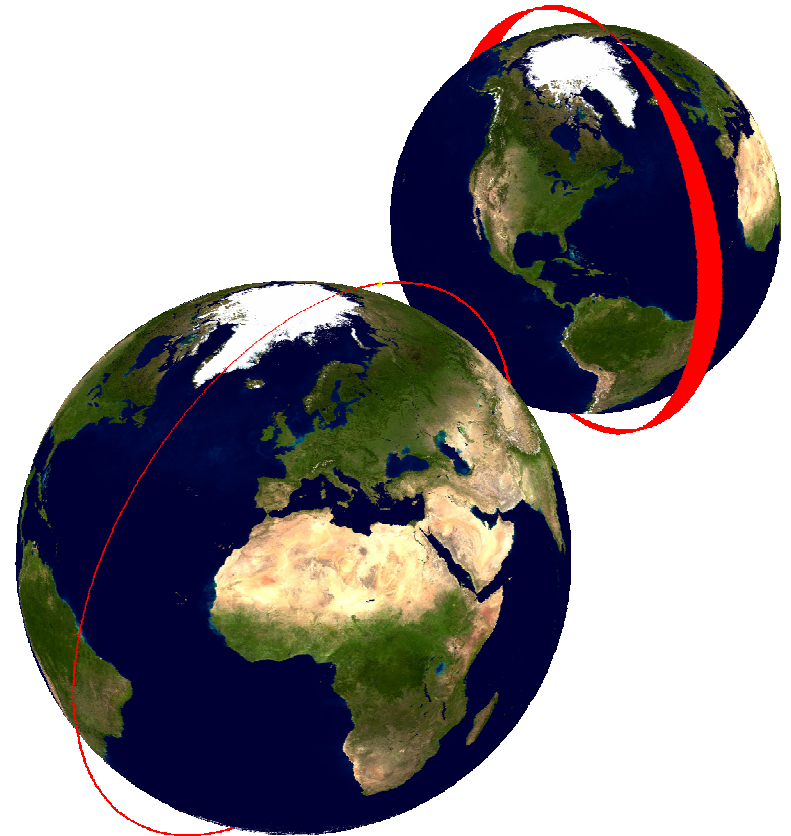
Simulating the Physics

```
14 strcmp(error_tol,'None') || strcmp(error_tol,'norm') || ...
15 strcmp(error_tol,'NORMAL') || strcmp(error_tol,'Normal') || ...
16 strcmp(error_tol,'normal')
17 error_tol='n';
18 elseif strcmp(error_tol,'M') || strcmp(error_tol,'MAX') || ...
19 strcmp(error_tol,'Max') || strcmp(error_tol,'max') || ...
20 strcmp(error_tol,'MAXIMUM') || strcmp(error_tol,'Maximum') || ...
21 strcmp(error_tol,'maximum')
22 error_tol='m';
23 else
24 error('INCORRECT ERROR TOLERANCE - CHOOSE NORMAL OR MAXIMUM')
25 end
26 if strcmp(error_tol,'n')
27 err=10;
28 elseif strcmp(error_tol,'m')
29 err=400;
30 end
31 elseif isnumeric(error_tol)
32 err=error_tol;
33 else
34 error('INCORRECT ERROR TOLERANCE - CHOOSE N, M, OR A NUMBER')
35 end
36
37 [Y1,M1,D1,H1,m1,s1]=datevec(tstart); % Time Start
38 [Y2,M2,D2,H2,m2,s2]=datevec(tend); % Time End
39
40 if strcmp(stats,'ON') || strcmp(stats,'YES') || strcmp(stats,'yes') || ...
41 strcmp(stats,'On') || strcmp(stats,'Yes')
42 stats = 'on' ;
43 elseif strcmp(stats,'OFF') || strcmp(stats,'NO') || strcmp(stats,'no') ...
44 || strcmp(stats,'No') || strcmp(stats,'Off') || strcmp(stats,'off')
45 stats = 'off' ;
46 else ~strcmp(stats,'on')
47 error('stats input Wrong')
48 end
49 if strcmp(sav,'ON') || strcmp(sav,'YES') || strcmp(sav,'yes') || ...
50 strcmp(sav,'On') || strcmp(sav,'Yes')
51 sav = 'on' ;
52 else ~strcmp(sav,'on')
53 error('sav input Wrong')
54 end
55 end
56
57 function a = fbird(t,y)
58 % CDE solver input function.
59
60 % Gravitaional Constants ( www.cdeagle.com/pdf
61 GMR = 3.986004415e14 ; % Earth Gravitational Co
62 CIO = -484165.05e9 ; % Normalized Conal 2
63 CIO = 597.12e9 ; % Normalized Conal 3
64 Eqp = 6378136.3 ; % Earth Semi-major Axial
65
66 SD = 86164.09054 ; % Sidereal Day - Earth Rotat
67
68 csa = 0.0185247 ; % Cross-sectional Area in V_
69 od = 4 ; % Drag Coefficient
70
71 X = y(1) ; % x position / ps
72 Y = y(2) ; % y position / ps
73 Z = y(3) ; % z position / ps
74 VX = y(4) ; % x velocity / vx
75 VY = y(5) ; % y velocity / vx
76 VZ = y(6) ; % z velocity / vx
77
78 dnm = y(7) ; % Density (1=Min, 2=Average, 3=Ma
79 dm = y(8) ; % Mass of Satellite (kg)
80
81 % PRECALCULATION FOR PERFORMANCE
82 hcan=2*pi*(1/SD) ; % Hour angle - Earth Rotatio
83
84 ECEF=ecdf2ecef([X;Y;Z],hcan); % Converting ECI
85 Xp=ECEF(1,:) ; ECEF X coordinate
86 Yp=ECEF(2,:) ; ECEF Y coordinate
87 Zp=ECEF(3,:) ; ECEF Z coordinate
88
89 [lat, lon, alt] = cart2geod([Xp;Yp;Zp]) ; % Conve
90
91 den = atnden(alt,dnm); % Inserting Atmospheric
92
93 rad2 = X^2+Y^2+Z^2 ; % ps^2*pp^2*pp^2
94 rad = sqrt(rad2) ; % ps*pp^2*pp^2
95 v=sqrt(VX^2+VY^2+VZ^2);
96 % [vTETA,vPHI,vZ] = cart2sph(v,vT,vZ) ;
97
98 g=1-GMR/rad^3 ;
99 a=-g*rad ;
100 a=[a; VX; VY; VZ; X; Y; Z];
101 end
```

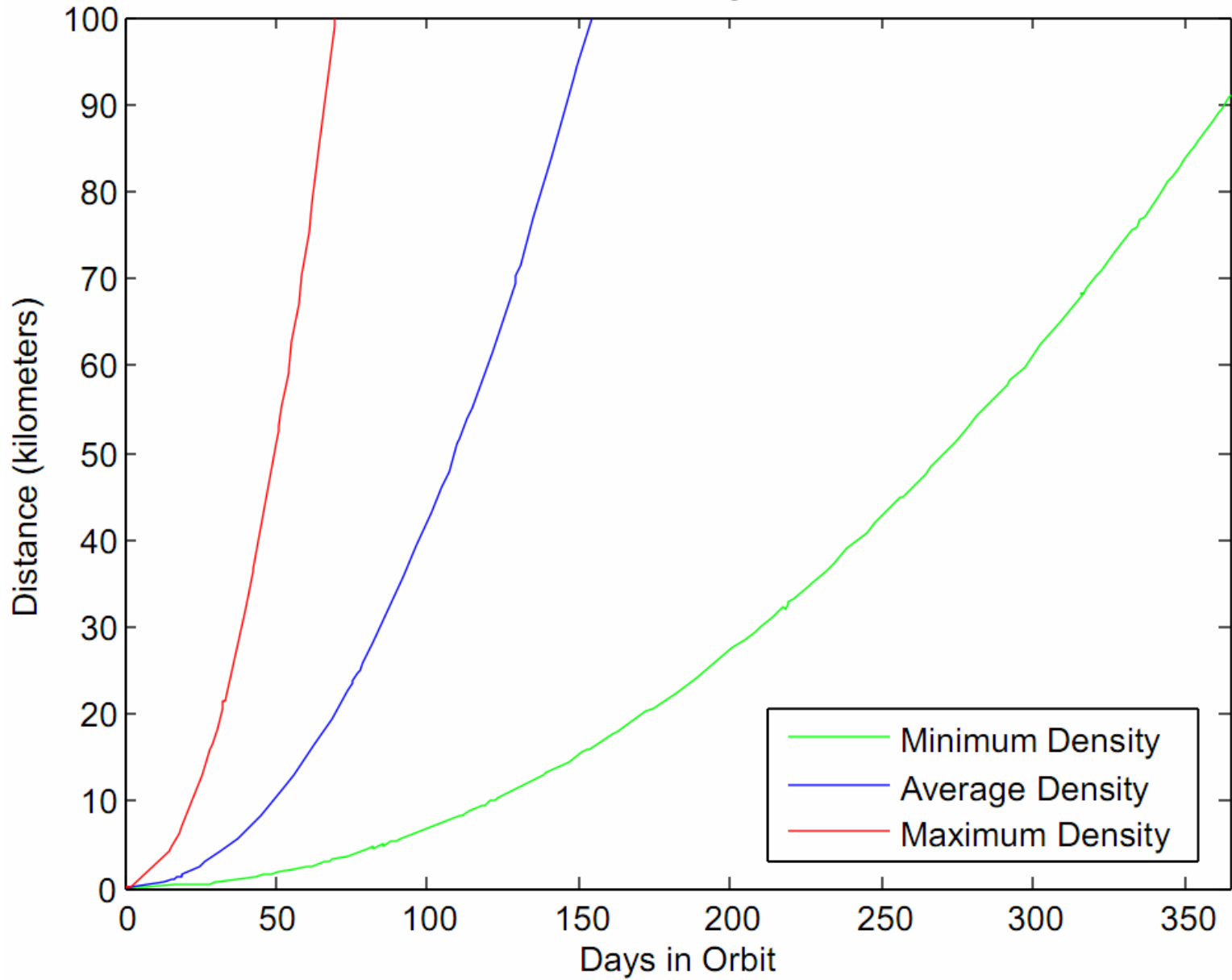
- System of six differential equations solved with MATLAB:
 - 3 dimensions, 2nd order
 - Gravity from oblate object - *J3 Spherical Harmonics*
 - Atmospheric Drag - *Density model with SMAD data*
 - Three models (minimum, average, and maximum density)
 - Cross-sectional area – *Average value over all possible attitudes*
- MATLAB program provides a simple interface for implementing orbital and separation simulations.

Simulation Conditions

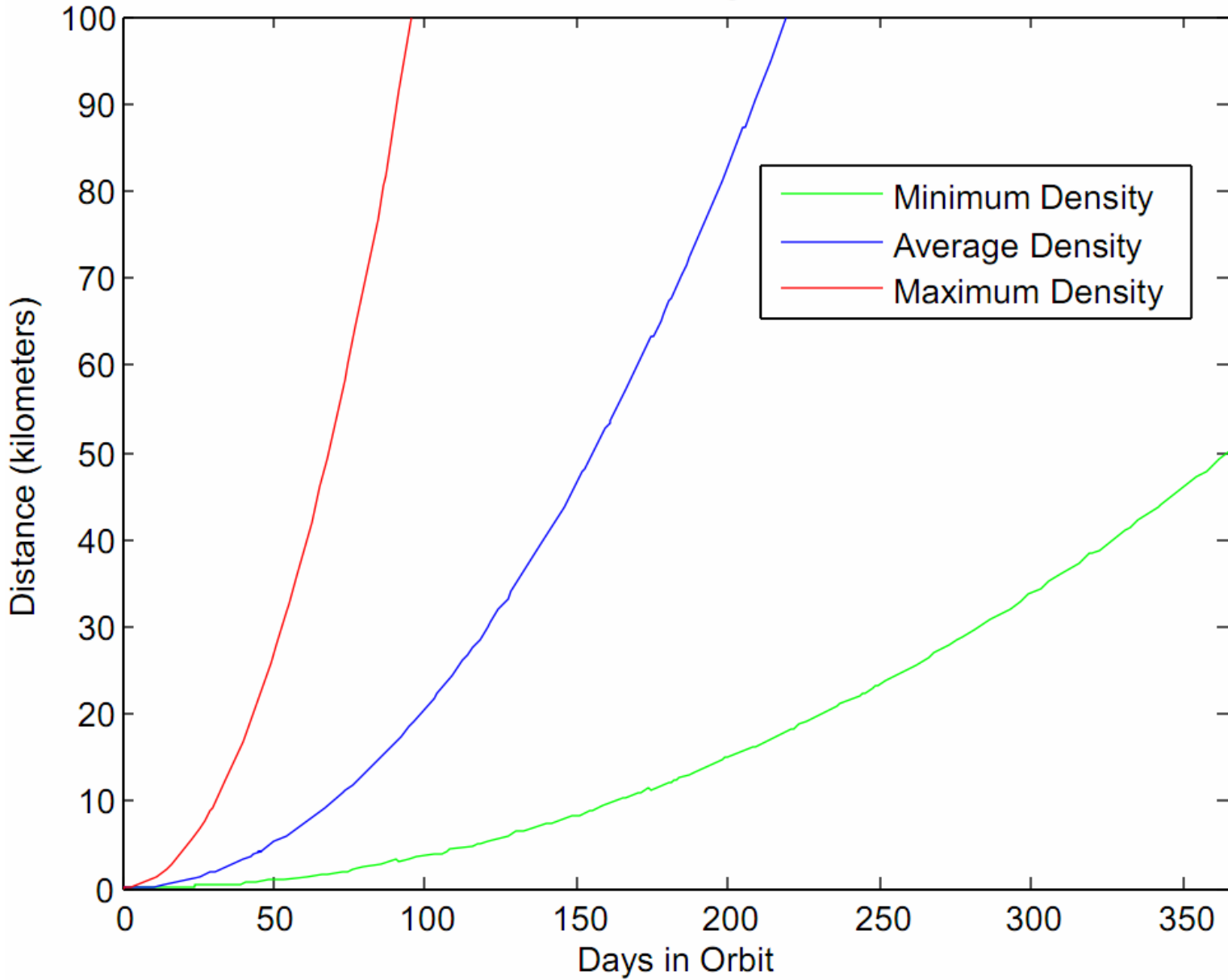
- Sun-synchronous orbit
 - Altitude between 600 and 800 kilometers
 - Mass of a FIREBIRD satellite is around 1.65 kilograms
- Experimenting with:
 - Various Altitudes
 - 600,650,700,750,800 kilometers
 - Various mass differences
 - 5 and 10 grams



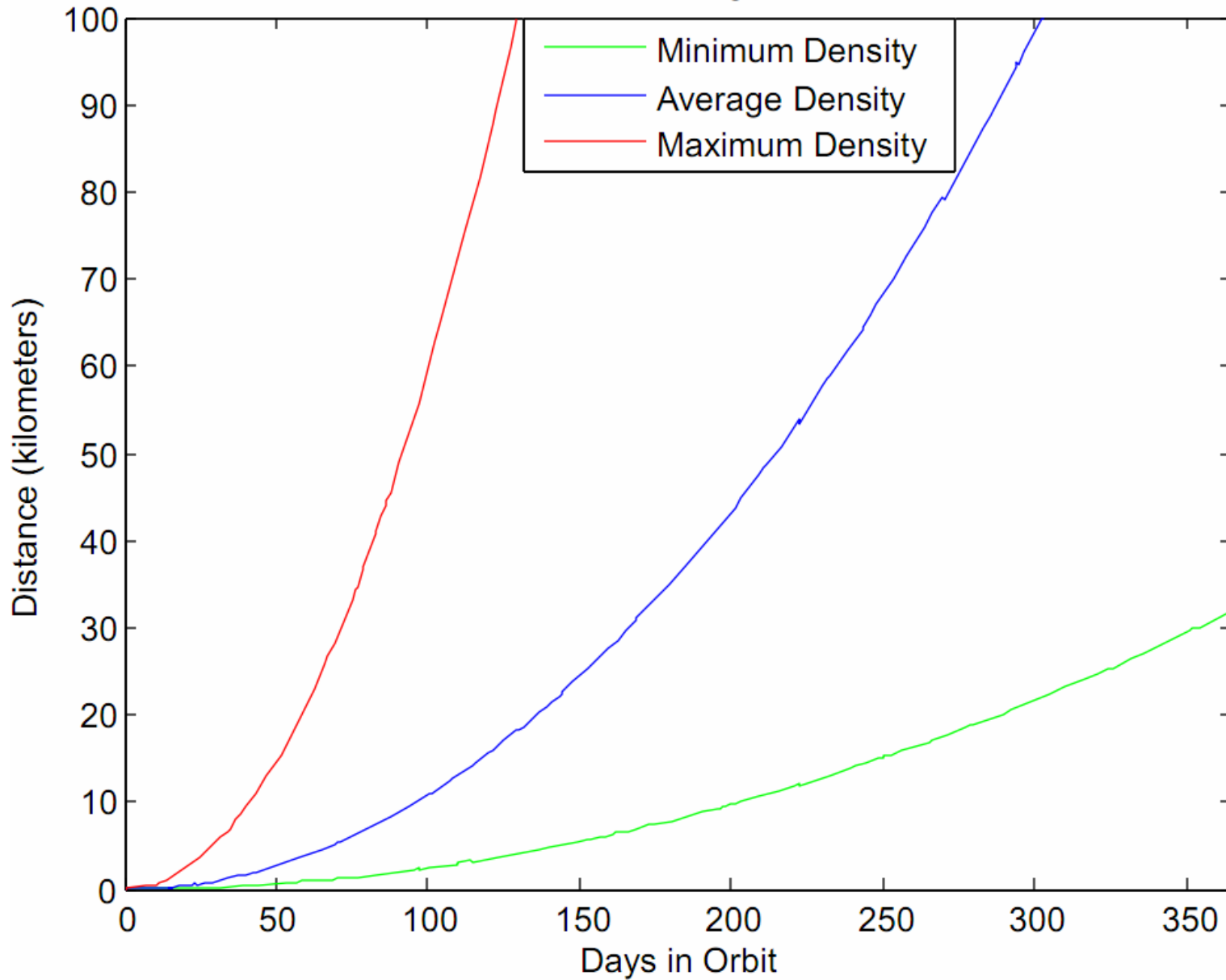
600 kilometer altitude and 5 gram mass difference



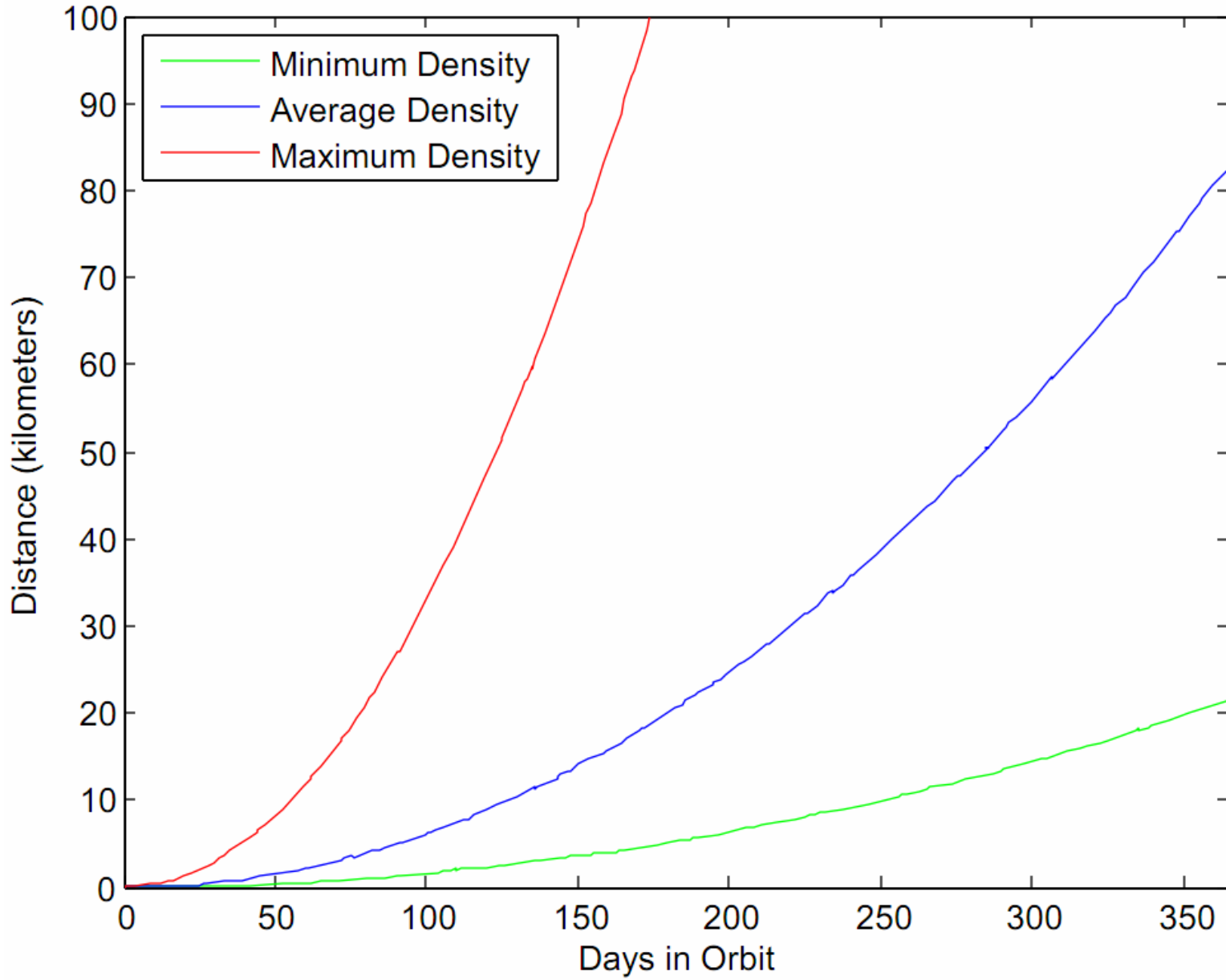
650 kilometer altitude and 5 gram mass difference



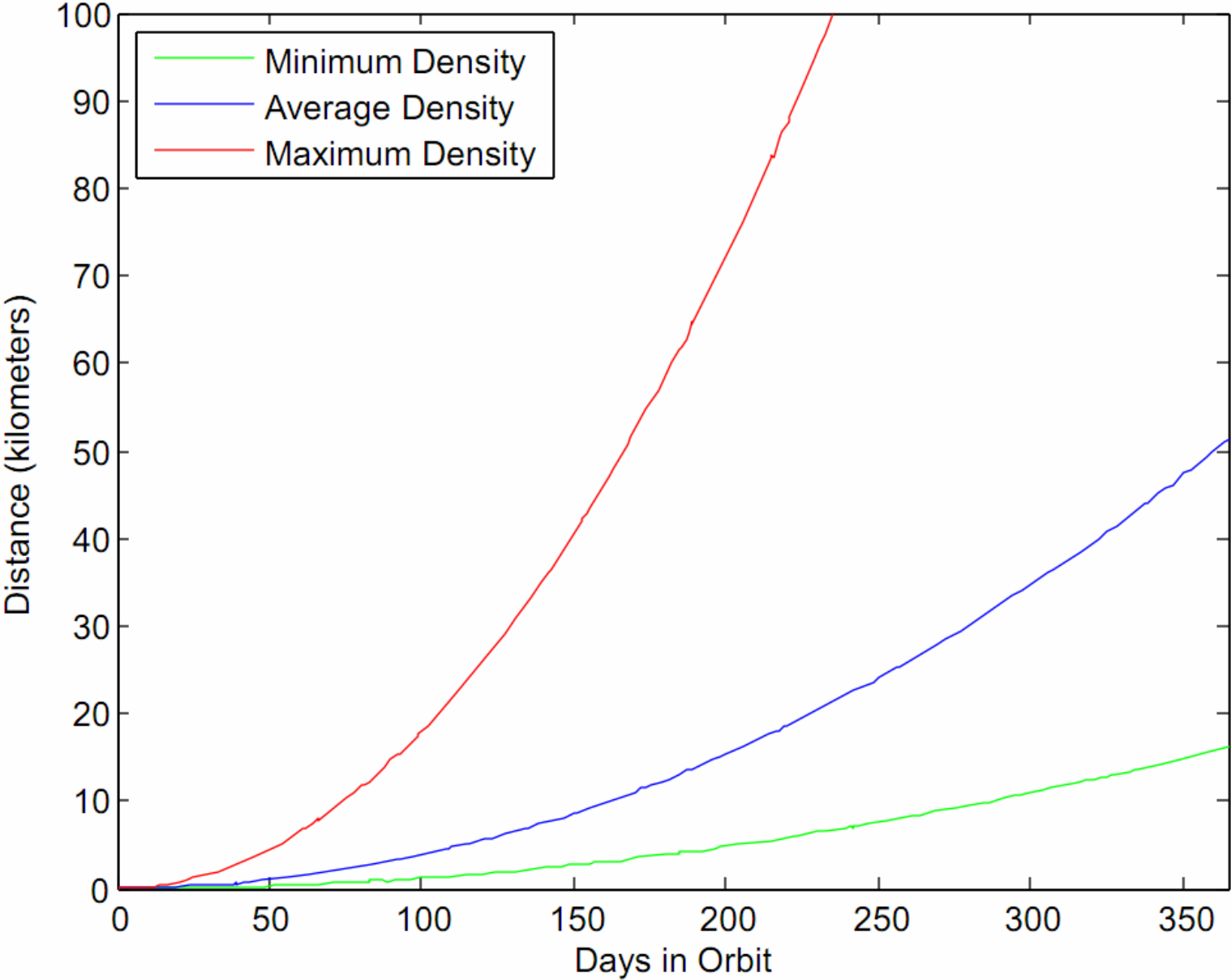
700 kilometer altitude and 5 gram mass difference



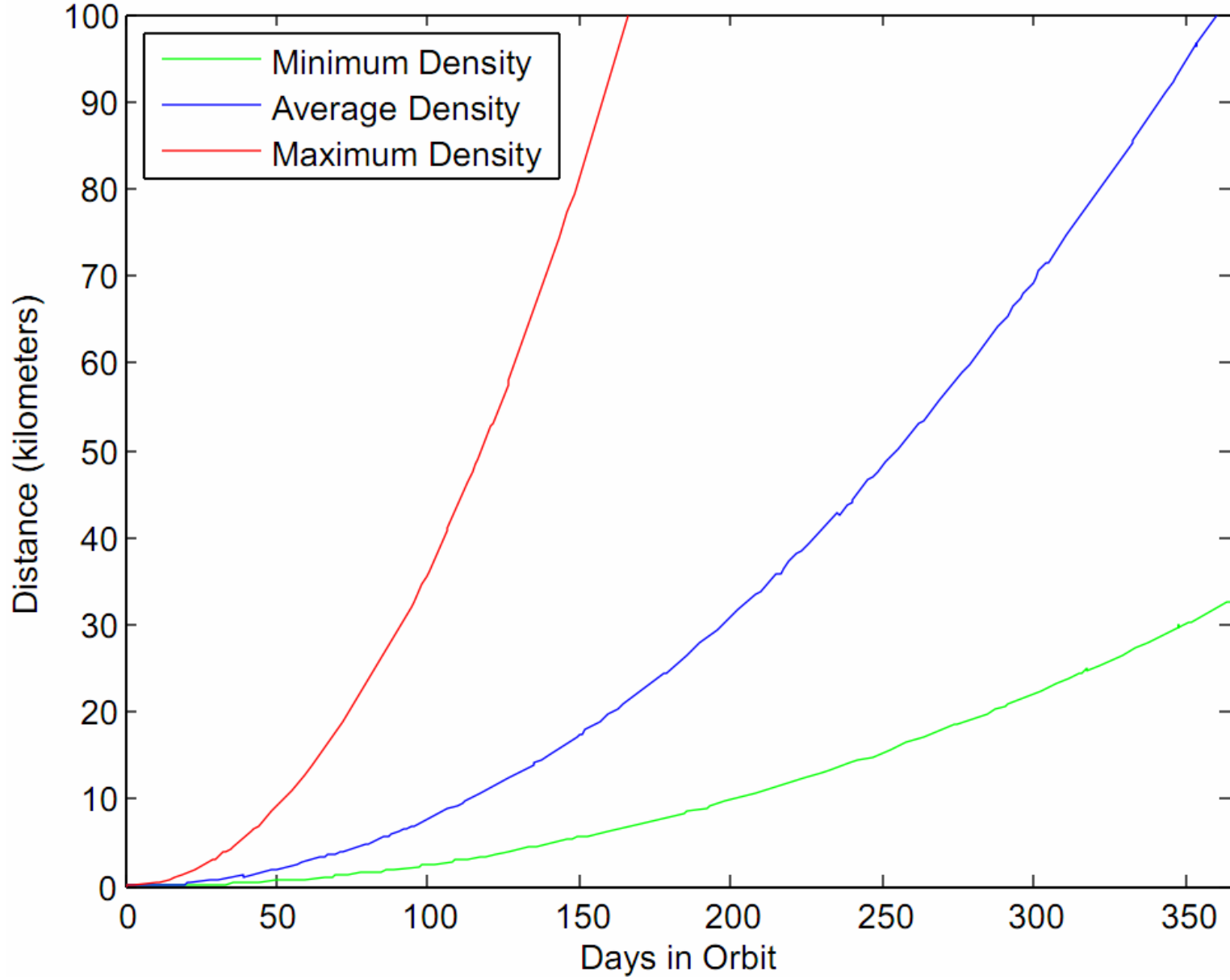
750 kilometer altitude and 5 gram mass difference



800 kilometer altitude and 5 gram mass difference



800 kilometer altitude and 10 gram mass difference



Conclusions

- From these preliminary simulations, I can demonstrate a possible and valid method of FIREBIRD separation using differential drag.
- Best to use a high altitude and a small mass difference for maximum time within 100 km.
- Losing springs makes it easier to stay within the mass budget; no longer must we precisely calibrate a spring mechanism.