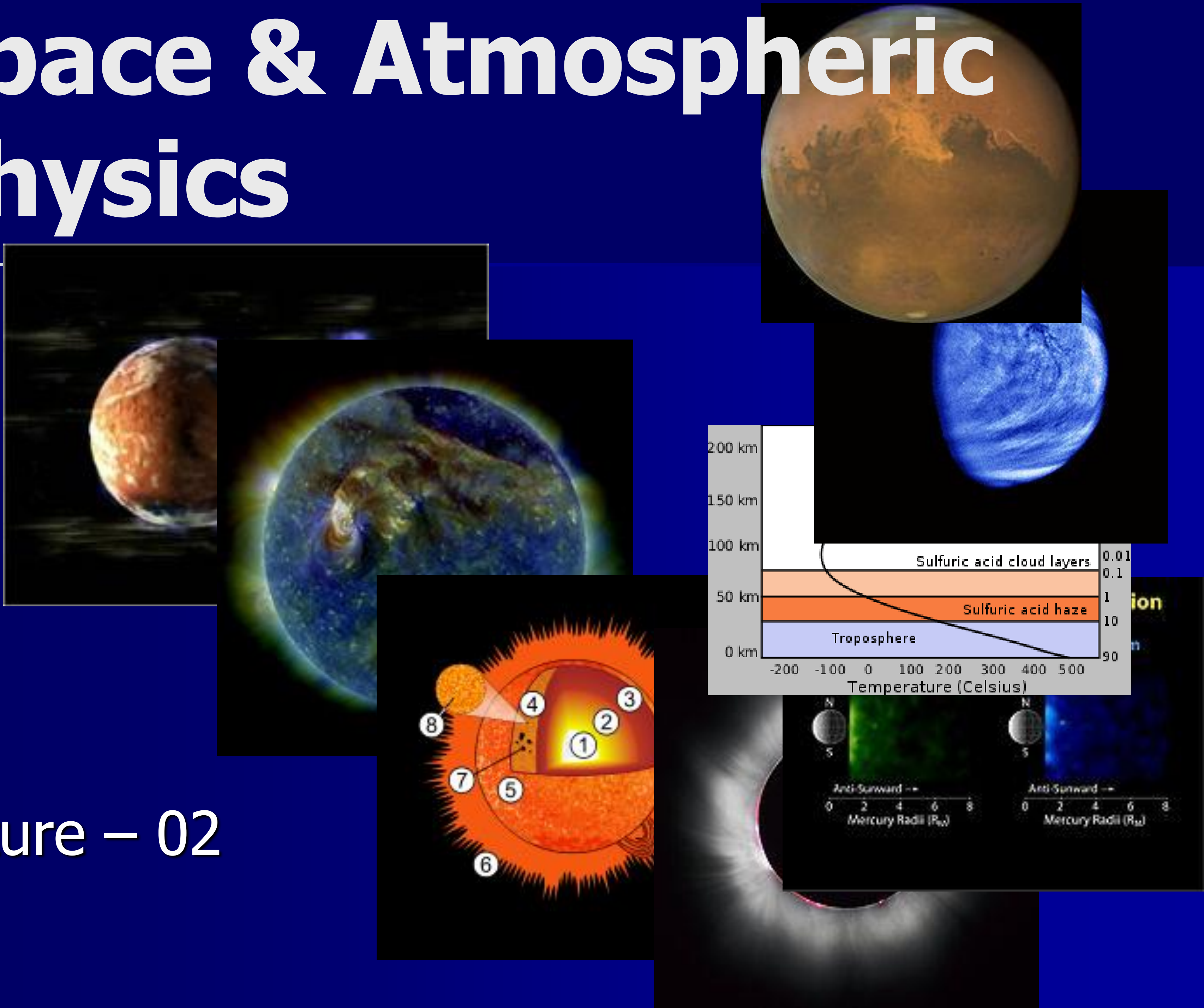
Space & Atmospheric Physics

Space & Atmospheric Physics



Lecture – 02

Planetary Atmospheres

Planetary Atmospheres

- Formation and Evolution of Planetary Atmospheres
- **The Structure of the Terrestrial Atmosphere**
- The Temperature of the Neutral Atmosphere
- The Escape of the Atmospheric Gases
- The Atmospheres of the Planets

The physical parameters of an average atmosphere.

TABLE 1.2-I

Altitude in km	Tempe-rature in °K	Density in gr/cm^{-3}	Mean Mol. Weight	Pressure in dyn/cm^2	Mean Free Path in m	Accel. Grav. in cm/s^2
0	288	1.23×10^{-3}	28.96	1.01×10^{6}	6.63×10^{-8}	981
2	275	1.01×10^{-3}	28.96	7.95×10^{5}	8.07×10^{-8}	980
4	262	8.19×10^{-4}	28.96	6.17×10^{5}	9.92×10^{-8}	979
6	249	6.60×10^{-4}	28.96	4.72×10^{5}	1.23×10^{-7}	979
8	236	5.26×10^{-4}	28.96	3.57×10^{5}	1.55×10^{-7}	978
10	223	4.14×10^{-4}	28.96	2.65×10^{5}	1.96×10^{-7}	978
20	217	8.89×10^{-5}	28.96	5.53×10^{4}	9.14×10^{-7}	975
40	250	4.00×10^{-6}	28.96	2.87×10^{3}	2.03×10^{-5}	968
60	256	3.06×10^{-7}	28.96	2.25×10^{2}	2.66×10^{-4}	962
80	181	2.00×10^{-8}	28.96	1.04×10	4.07×10^{-3}	956
100	210	4.97×10^{-10}	28.88	3.01×10^{-1}	1.63×10^{-1}	951
140	714	3.39×10^{-12}	27.20	7.41×10^{-3}	2.25×10	939
180	1156	5.86×10^{-13}	26.15	2.15×10^{-3}	1.25×10^{2}	927
220	1294	1.99×10^{-13}	24.98	8.58×10^{-4}	3.52×10^{2}	916
260	1374	8.04×10^{-14}	23.82	3.86×10^{-4}	8.31×10^{2}	905
300	1432	3.59×10^{-14}	22.66	1.88×10^{-4}	1.77×10^{3}	894
400	1487	6.50×10^{-15}	19.94	4.03×10^{-5}	8.61×10^{3}	868
500	1499	1.58×10^{-15}	17.94	1.10×10^{-5}	3.19×10^{4}	843
600	1506	4.64×10^{-16}	16.84	3.45×10^{-6}	1.02×10^{5}	819
700	1508	1.54×10^{-16}	16.17	1.19×10^{-6}	2.95×10^{5}	796

Altitude in km	Density in gr/cm^{-3}
0	1.23×10^{-3}
2	1.01×10^{-3}
4	8.19×10^{-4}
6	6.60×10^{-4}
8	5.26×10^{-4}
10	4.14×10^{-4}

The graph of h (in km) vs Density (in gr cm^(-3))

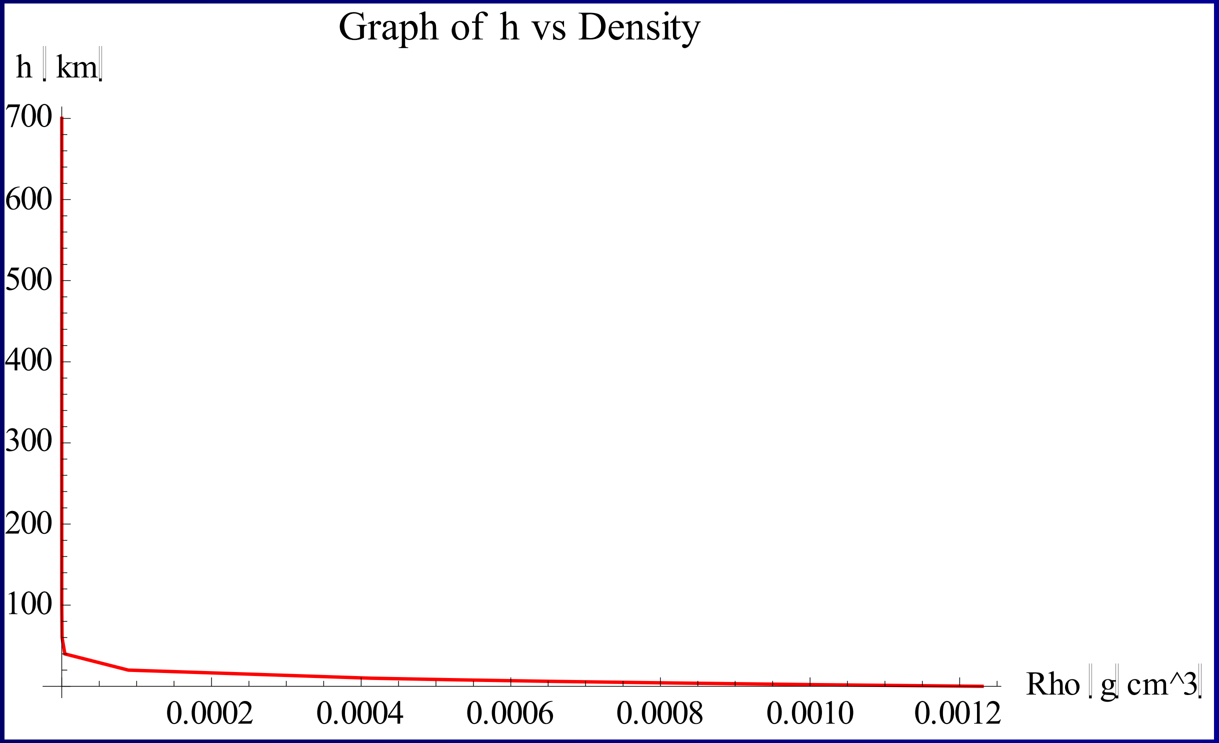
Enter the data as two 1D arrays....

```
(* This program is to plot the Earth's parameters w.r.t
 altitude from the Earth Surface *)

hgh = {0, 2, 4, 6, 8, 10, 20, 40, 60, 80, 100, 140, 180, 220,
   260, 300, 400, 500, 600, 700}; (* Altitude *)
rho = {1.23*10^(-3), 1.01*10^(-3), 8.19*10^(-4),
  6.60*10^(-4), 5.26*10^(-4), 4.14*10^(-4), 8.89*10^(-5),
  4.00*10^(-6), 3.06*10^(-7), 2.00*10^(-8), 4.97*10^(-10),
  3.39*10^(-12), 5.86*10^(-13), 1.99*10^(-13),
  8.04*10^(-14), 3.59*10^(-14), 6.50*10^(-15),
  1.58*10^(-15), 4.64*10^(-16), 1.54*10^(-16)};
(* Density *)
```

The graph of h (in km) vs Density (in gr cm^(-3))

```
d1 = Transpose[{rho, hgh}]; (* to get the h vs Rho data set *)
ListPlot[d1, PlotJoined → True,
 PlotStyle → {RGBColor[1, 0, 0], PointSize[0.02]},
 PlotLabel → "Graph of h vs Density",
 AxesLabel → {"Rho (g/cm^3)", "h (km)"}]
(* To Plot the h vs Rho graph *)
```

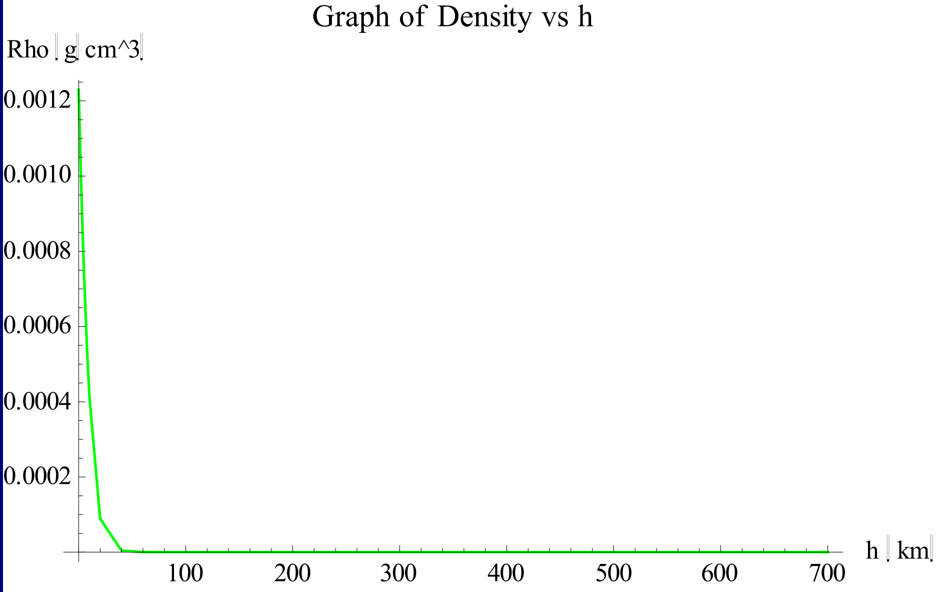
Plot the graph…..



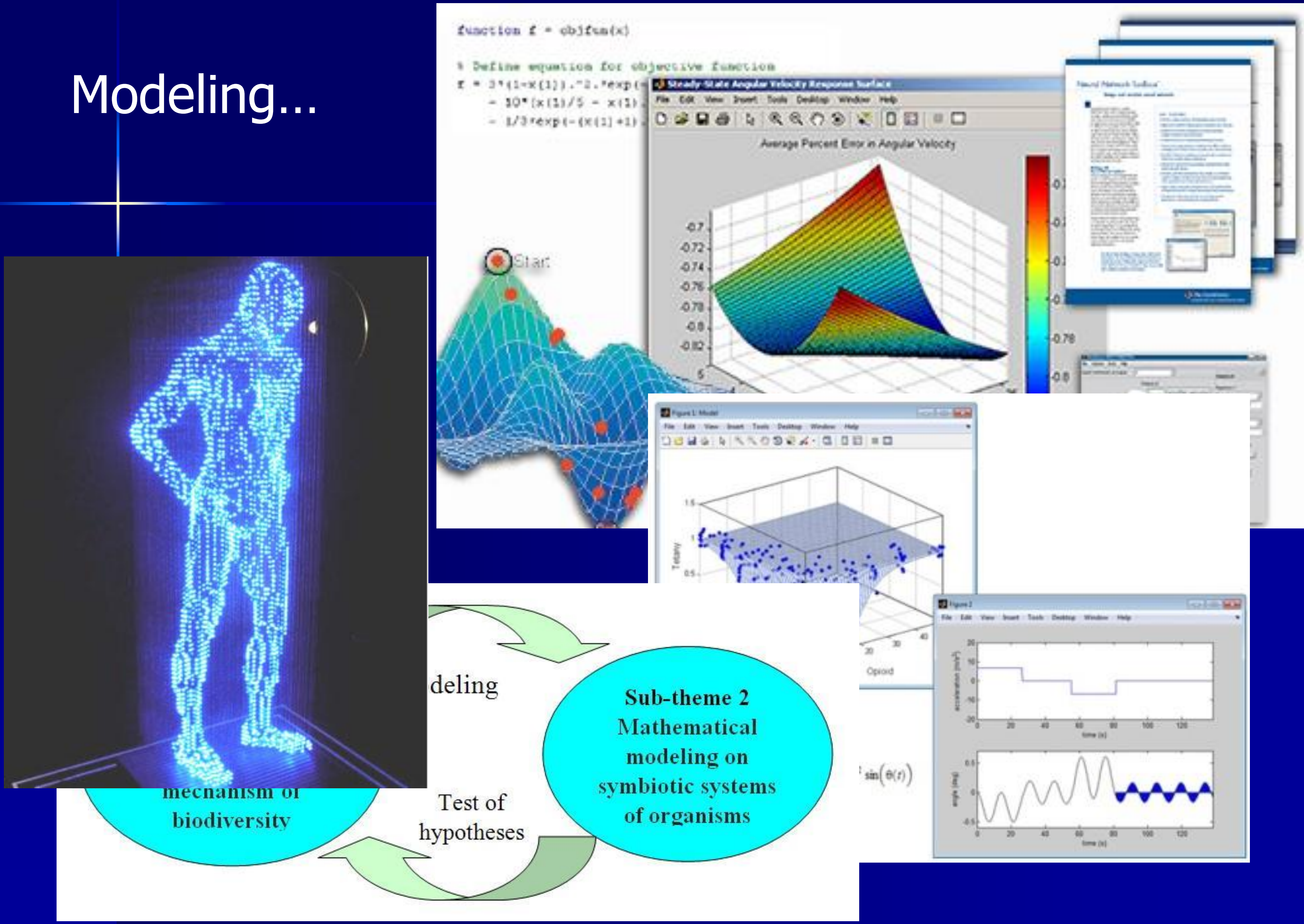
To model the data set …

```
(* To model the data set in Rho vs h format *)
data = Transpose[{hgh, rho}];
g1 = ListPlot[data, PlotJoined → True,
  PlotStyle → {RGBColor[0, 1, 0], PointSize[0.02]},
  PlotLabel → "Graph of Density vs h",
  AxesLabel → {"h (km)", "Rho (g/cm^3)"}]
(* To Plot the Rho vs h graph *)
```

To Model …..



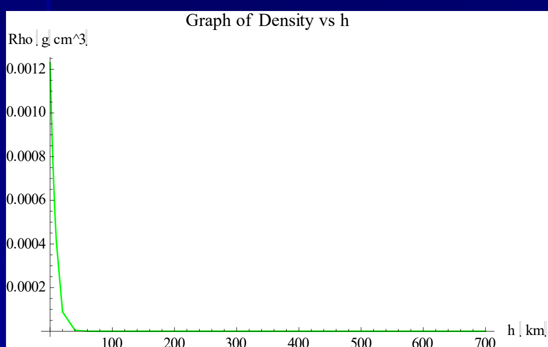
Modeling…

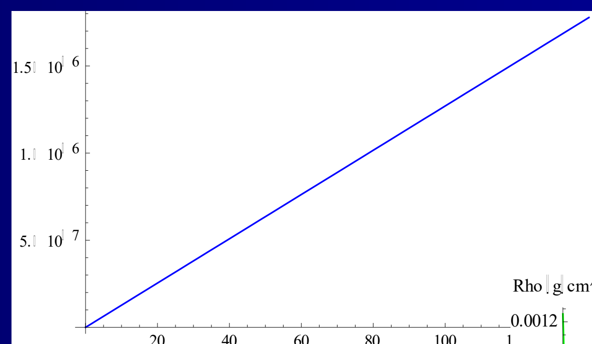

function f = objfun(x)
% Define equation for objective function
Steady-State Angular Velocity Response Surface
Average Percent Error in Angular Velocity
Start
deling
Sub-theme 2
Mathematical
modeling on
symbiotic systems
of organisms
mechanism of
biodiversity
Test of
hypotheses

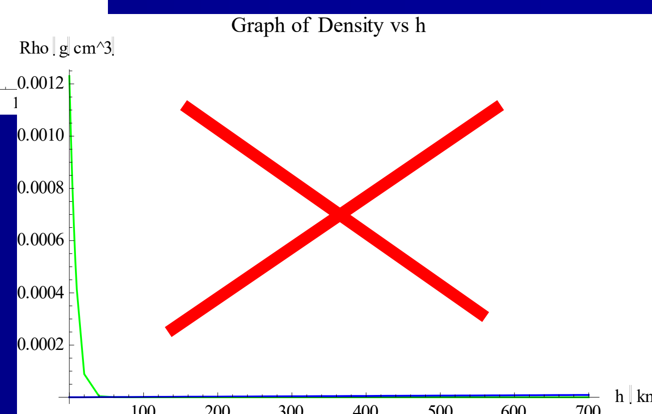
Modeling Part …

```
f = Fit[data, {h, 1}, h]
(* To find a suitable polynomial or relationship *)
g2 = Plot[f, {h, hgh[[1]], hgh[[Length[hgh]]]},
  PlotStyle → {RGBColor[0, 0, 1], PointSize[0.02]}]
(* To plot the predicted model *)
Show[{g1, g2}]
```

Modeling .....



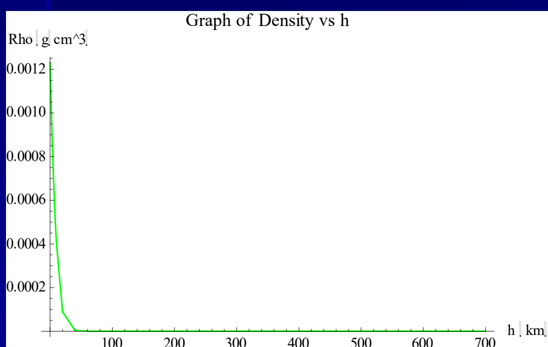


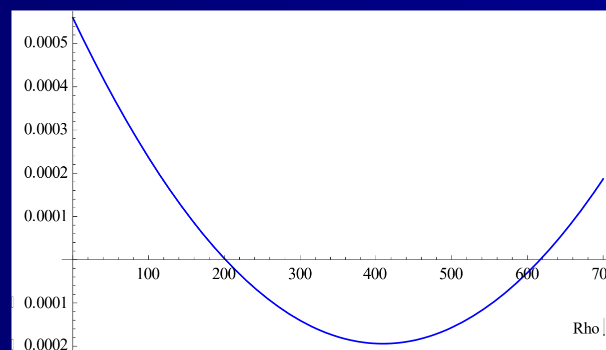


Modeling Part …

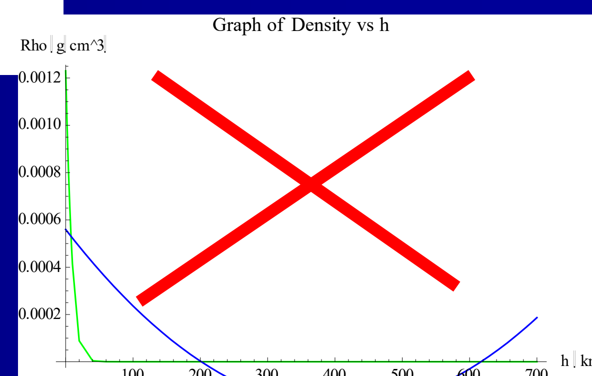
Modeling …..

```
f = Fit[data, {h, 1}, h]
(* To find a suitable polynomial or relationship *)
g2 = Plot[f, {h, hgh[[1]], hgh[[Length[hgh]]]},
  PlotStyle → {RGBColor[0, 0, 1], PointSize[0.02]}]
(* To plot the predicted model *)
Show[{g1, g2}]
```





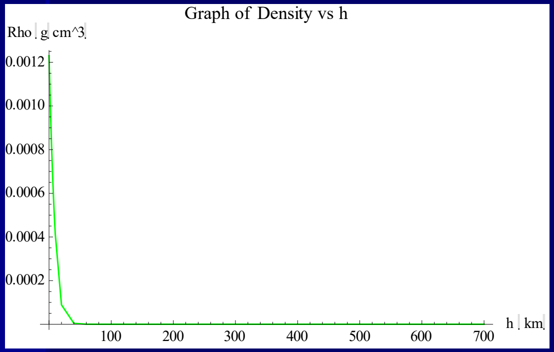
{h^2, h, 1}



Modeling Part …

```
f = Fit[data, {h, 1}, h]
(* To find a suitable polynomial or relationship *)
g2 = Plot[f, {h, hgh[[1]], hgh[[Length[hgh]]]},
  PlotStyle → {RGBColor[0, 0, 1], PointSize[0.02]}]
(* To plot the predicted model *)
Show[{g1, g2}]
```

Modeling …..



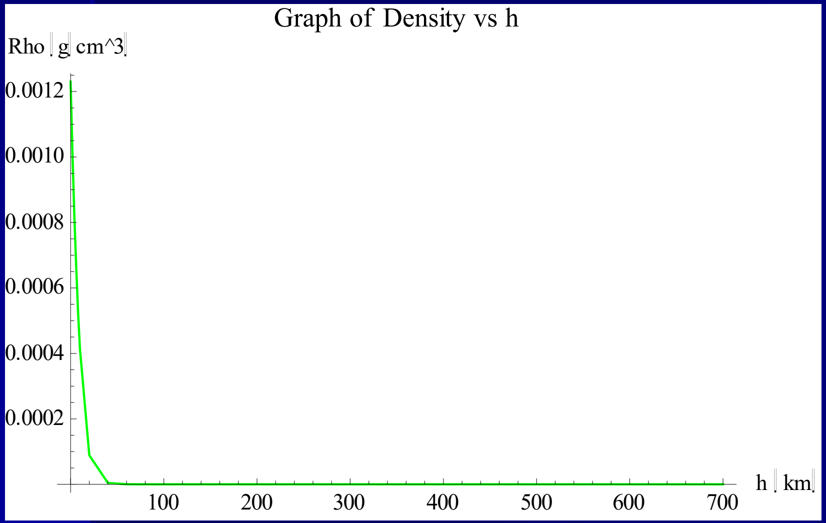
{h^2, h, 1}

Sin[x]	Cos[x]	Tan[x]
x^2	x^3	……..
1/x	1/x^2	1/x^3
Exp[x]	Exp[-x]	Exp[- a x]

Modeling Part …

```
f = Fit[data, {h, 1}, h]
(* To find a suitable polynomial or relationship *)
g2 = Plot[f, {h, hgh[[1]], hgh[[Length[hgh]]]},
  PlotStyle → {RGBColor[0, 0, 1], PointSize[0.02]}]
(* To plot the predicted model *)
Show[{g1, g2}]
```

Modeling …..



Exp[- a x]

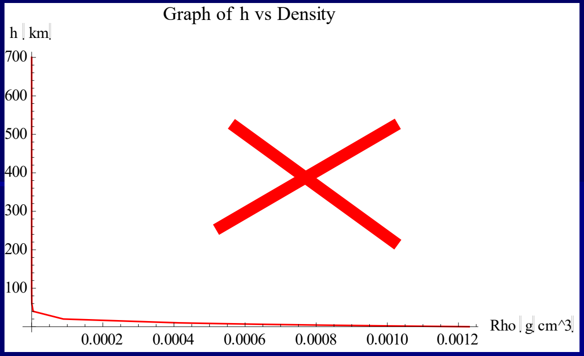
a = 1, 2, 3, …..

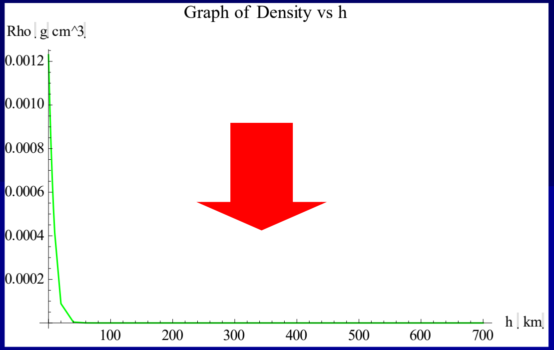
a = ½, 1/3, …

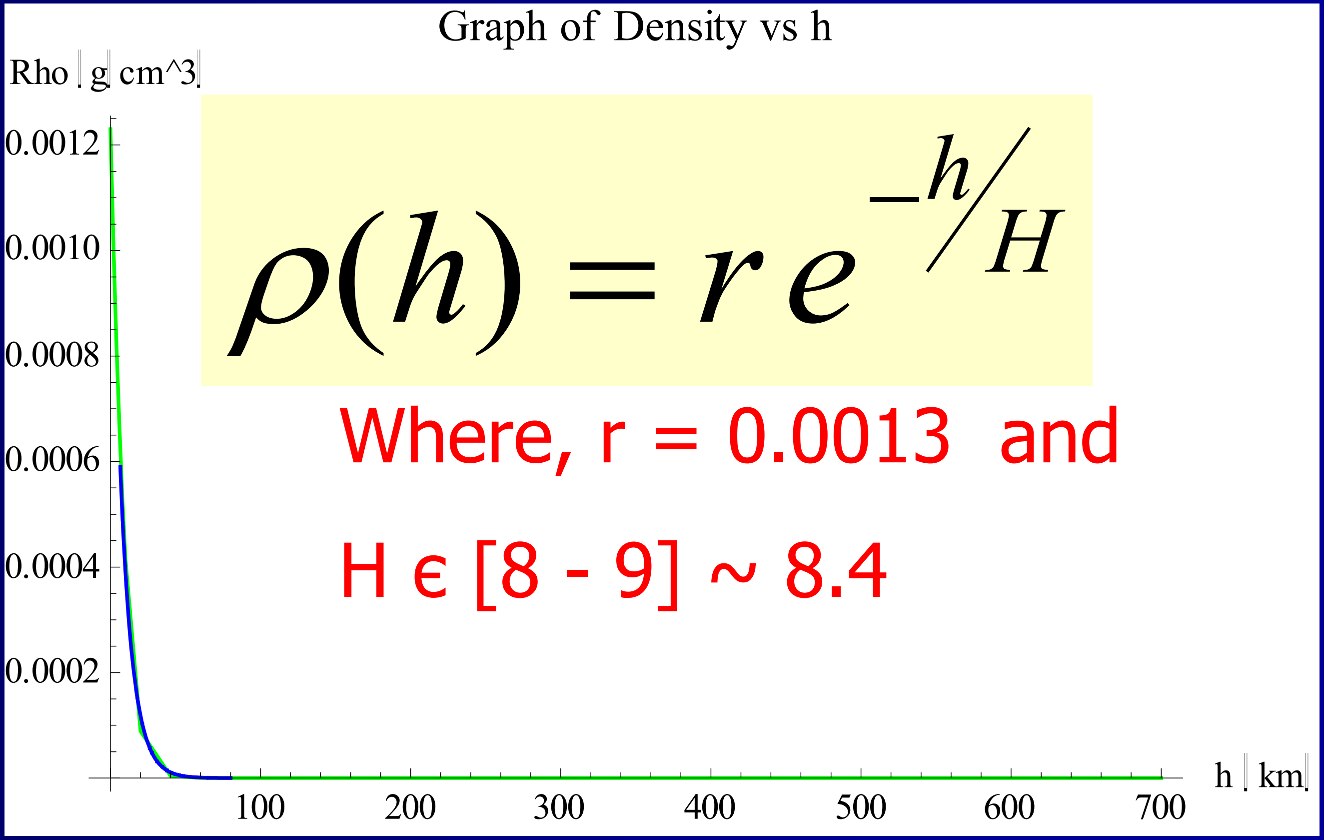
a = 1/8 - 1/9

The graph of h (in km) vs Density (in gr cm^(-3))

Altitude in km	Density in gr/cm^{-3}
0	1.23×10^{-3}
2	1.01×10^{-3}
4	8.19×10^{-4}
6	6.60×10^{-4}
8	5.26×10^{-4}
10	4.14×10^{-4}
20	8.89×10^{-5}
40	4.00×10^{-6}
60	3.06×10^{-7}
80	2.00×10^{-8}
100	4.97×10^{-10}
140	3.39×10^{-12}
180	5.86×10^{-13}
220	1.99×10^{-13}
260	8.04×10^{-14}
300	3.59×10^{-14}
400	6.50×10^{-15}
500	1.58×10^{-15}
600	4.64×10^{-16}
700	1.54×10^{-16}







$$\rho(h) = r\, e^{-h/H}$$

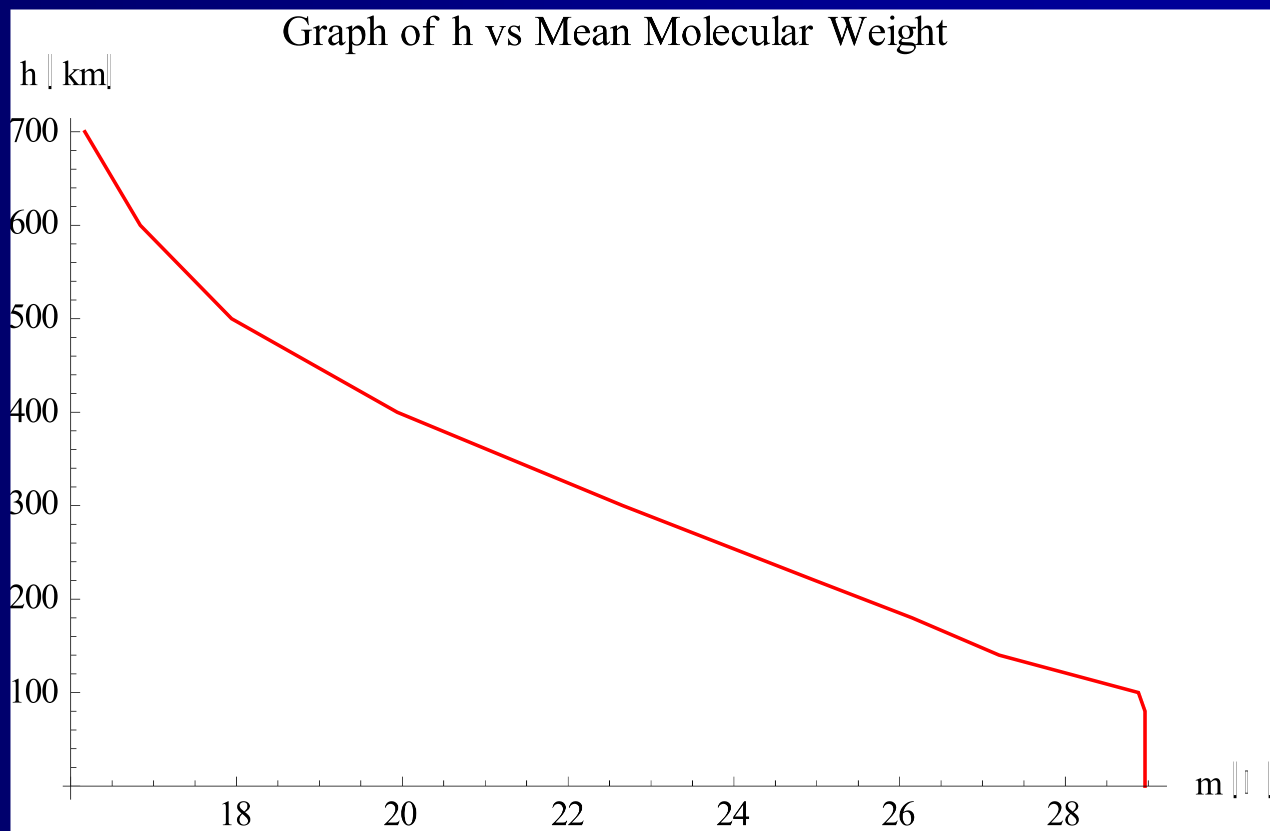
Where, r = 0.0013 and

H ϵ [8 - 9] ~ 8.4

The graph of h (in km) vs Mean Molecular Weight

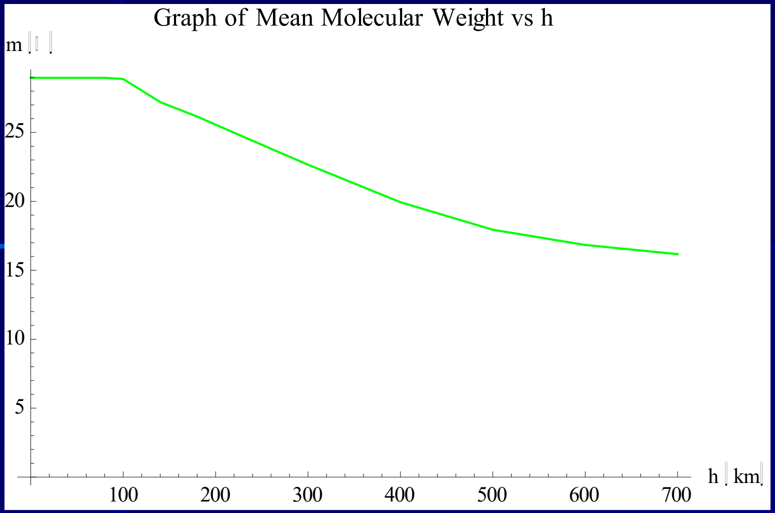
Altitude in km	Mean Mol. Weight
0	28.96
2	28.96
4	28.96
6	28.96
8	28.96
10	28.96
20	28.96
40	28.96
60	28.96
80	28.96
100	28.88
140	27.20
180	26.15
220	24.98
260	23.82
300	22.66
400	19.94
500	17.94
600	16.84
700	16.17

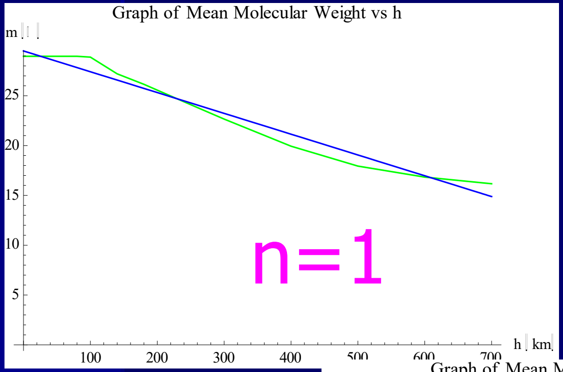
Enter the data as two 1D arrays….

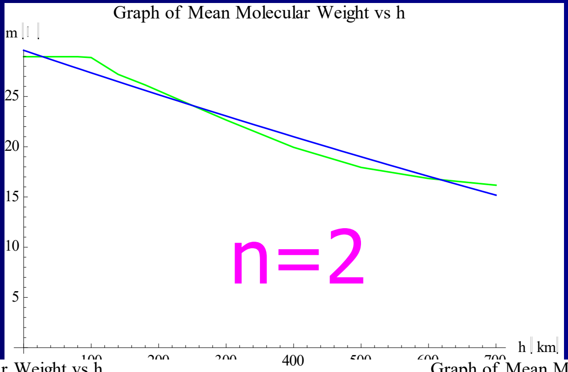


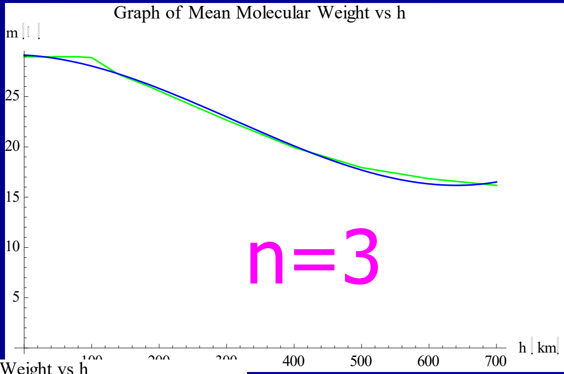
To model the data set …

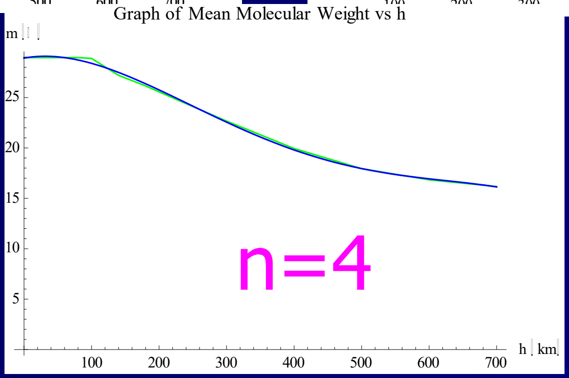
To Model …..

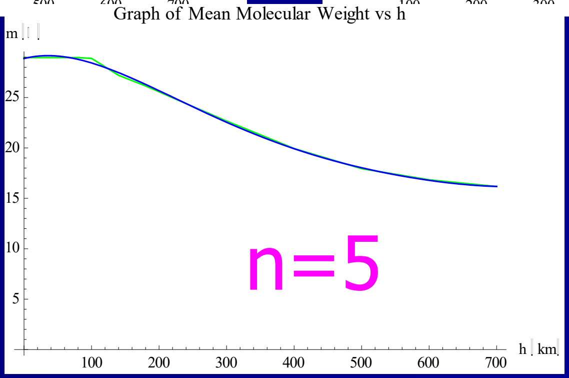






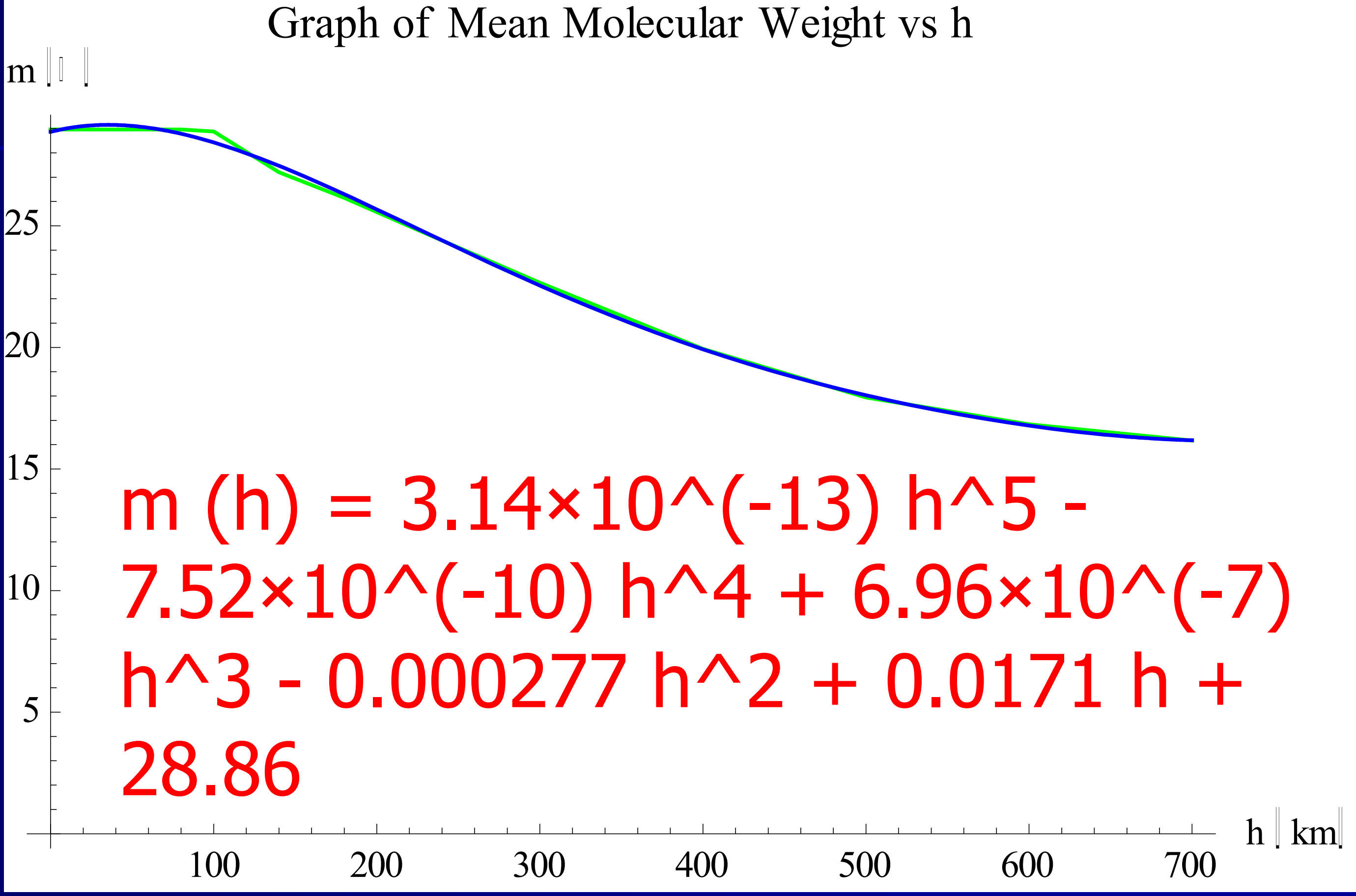






The graph of h (in km) vs m

Altitude in km	Mean Mol. Weight
0	28.96
2	28.96
4	28.96
6	28.96
8	28.96
10	28.96
20	28.96
40	28.96
60	28.96
80	28.96
100	28.88
140	27.20
180	26.15
220	24.98
260	23.82
300	22.66
400	19.94
500	17.94
600	16.84
700	16.17

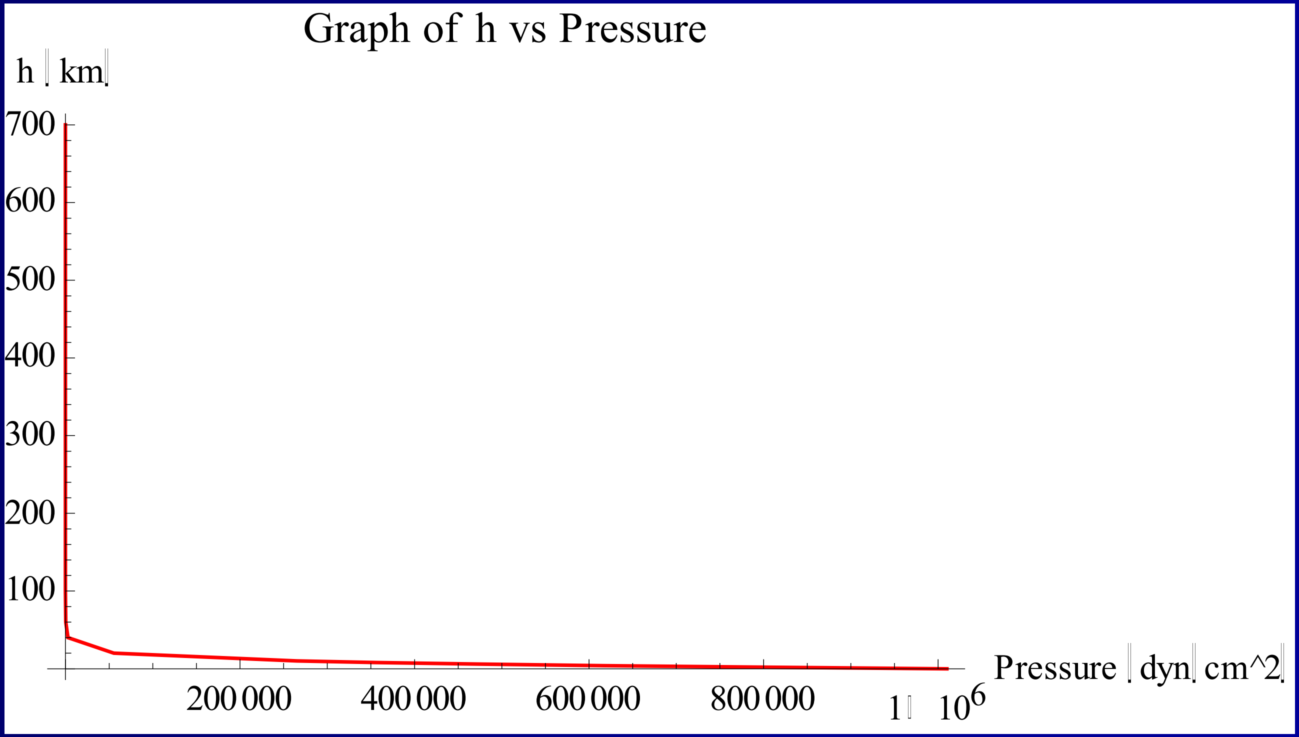


$$m(h) = 3.14\times10^{-13} h^5 - 7.52\times10^{-10} h^4 + 6.96\times10^{-7} h^3 - 0.000277 h^2 + 0.0171 h + 28.86$$

The graph of h (in km) vs Pressure (in dyn/cm^2)

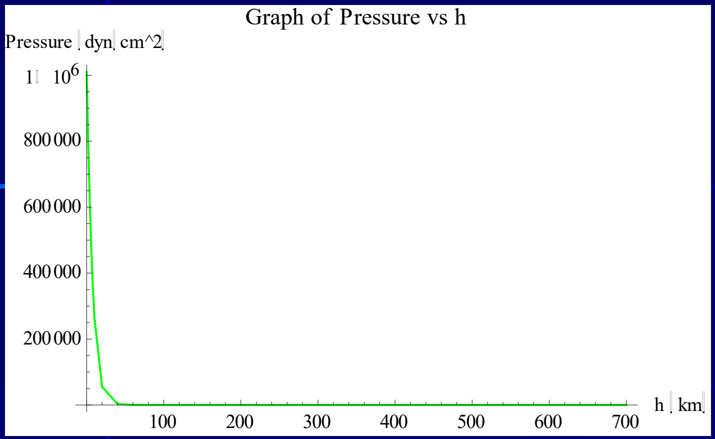
Altitude in km	Pressure in dyn/cm^2
0	1.01×10^6
2	7.95×10^5
4	6.17×10^5
6	4.72×10^5
8	3.57×10^5
10	2.65×10^5
20	5.53×10^4
40	2.87×10^3
60	2.25×10^2
80	1.04×10
100	3.01×10^{-1}
140	7.41×10^{-3}
180	2.15×10^{-3}
220	8.58×10^{-4}
260	3.86×10^{-4}
300	1.88×10^{-4}
400	4.03×10^{-5}
500	1.10×10^{-5}
600	3.45×10^{-6}
700	1.19×10^{-6}

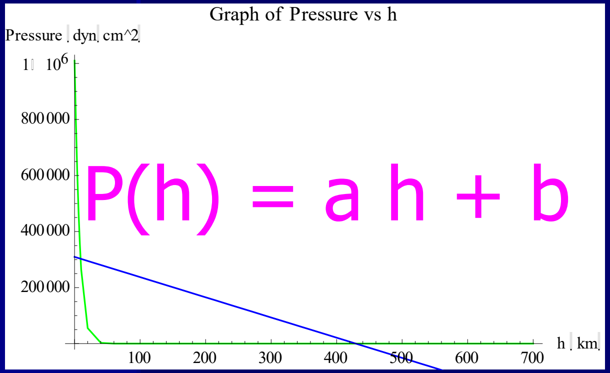
Enter the data as two 1D arrays….



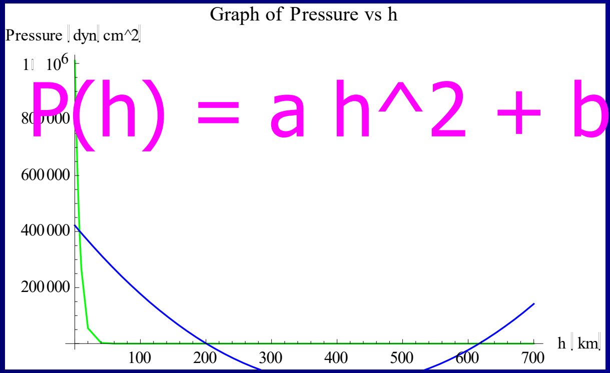
To model the data set …

To Model …..

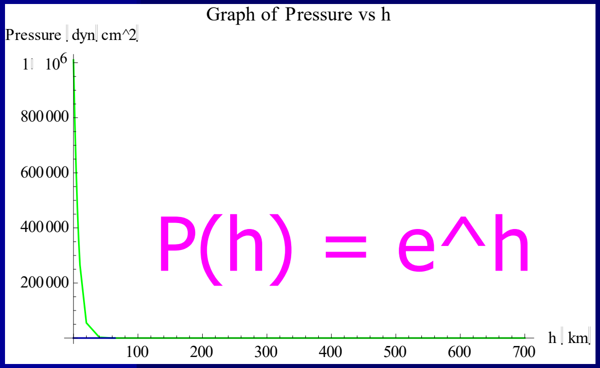




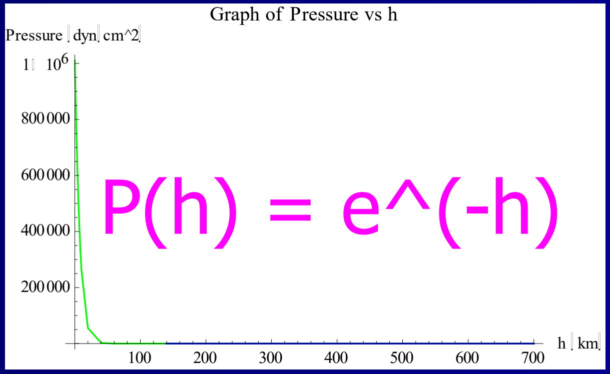
$P(h) = a\,h + b$



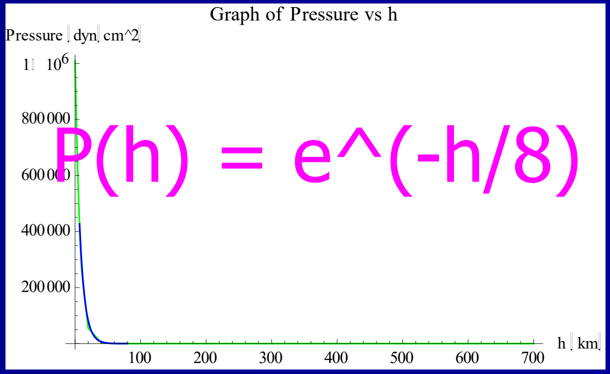
$P(h) = a\,h^2 + b\,h + c$



$P(h) = e^h$



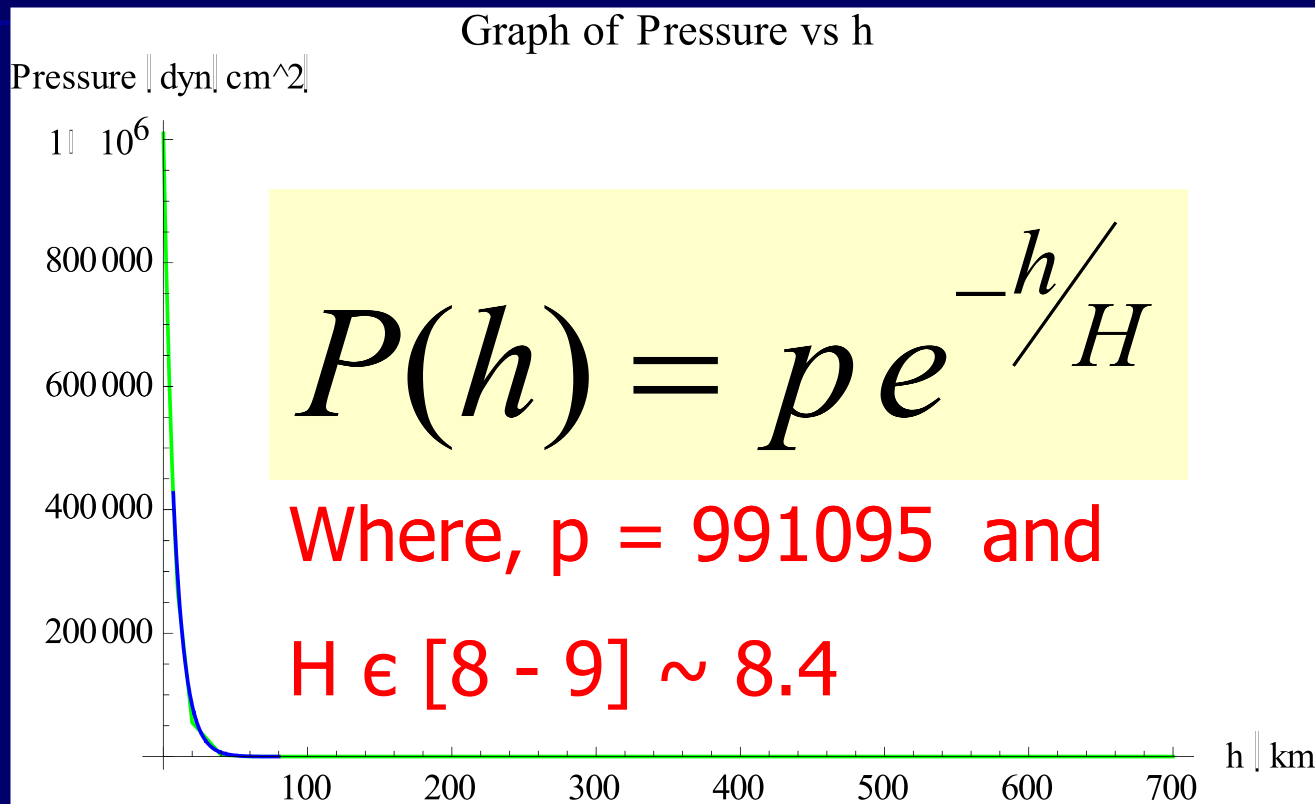
$P(h) = e^{-h}$



$P(h) = e^{-h/8}$

The graph of h (in km) vs Pressure (in dyn/cm^2)

Altitude in km	Pressure in dyn/cm²
0	1.01×10^{6}
2	7.95×10^{5}
4	6.17×10^{5}
6	4.72×10^{5}
8	3.57×10^{5}
10	2.65×10^{5}
20	5.53×10^{4}
40	2.87×10^{3}
60	2.25×10^{2}
80	1.04×10
100	3.01×10^{-1}
140	7.41×10^{-3}
180	2.15×10^{-3}
220	8.58×10^{-4}
260	3.86×10^{-4}
300	1.88×10^{-4}
400	4.03×10^{-5}
500	1.10×10^{-5}
600	3.45×10^{-6}
700	1.19×10^{-6}



$$P(h) = p\,e^{-h/H}$$

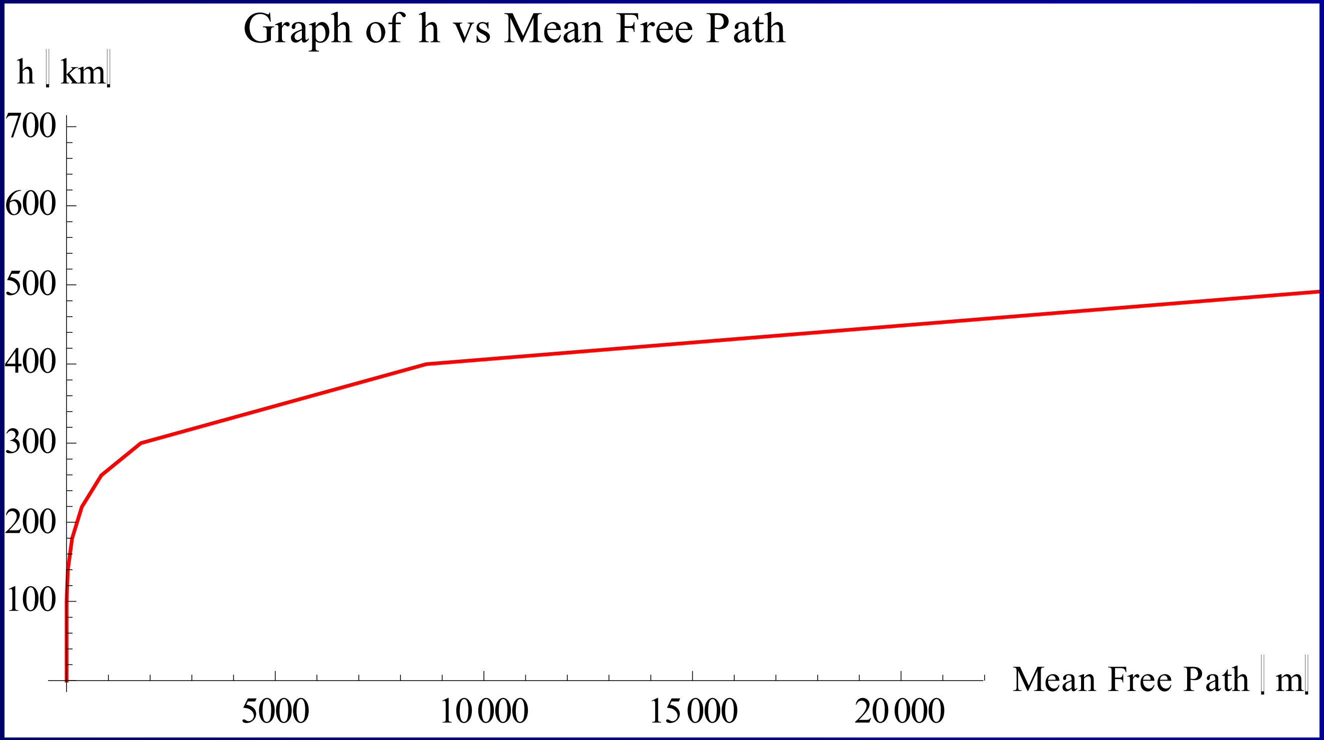
Where, p = 991095 and

H є [8 - 9] ~ 8.4

Altitude in km	Mean Free Path in m
0	6.63×10^{-8}
2	8.07×10^{-8}
4	9.92×10^{-8}
6	1.23×10^{-7}
8	1.55×10^{-7}
10	1.96×10^{-7}
20	9.14×10^{-7}
40	2.03×10^{-5}
60	2.66×10^{-4}
80	4.07×10^{-3}
100	1.63×10^{-1}
140	2.25×10
180	1.25×10^{2}
220	3.52×10^{2}
260	8.31×10^{2}
300	1.77×10^{3}
400	8.61×10^{3}
500	3.19×10^{4}
600	1.02×10^{5}
700	2.95×10^{5}

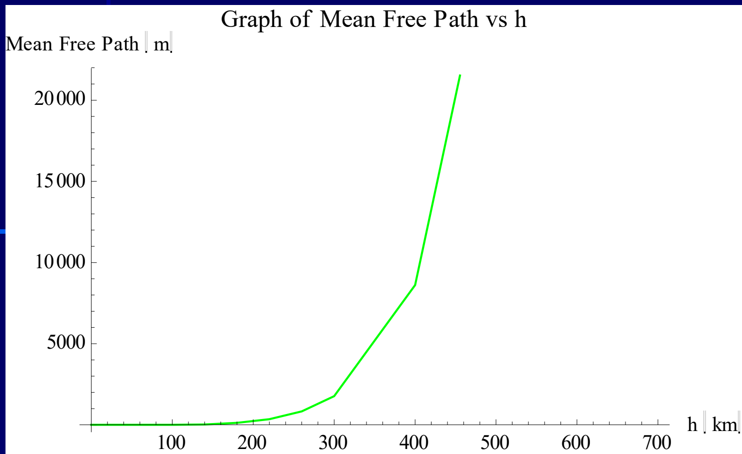
The graph of h (in km) vs Mean Free Path (in m)

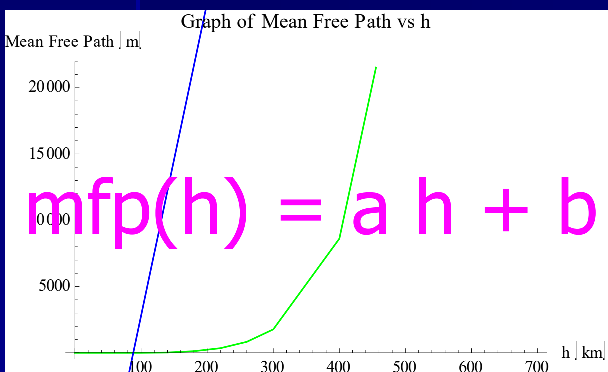
Enter the data as two 1D arrays….



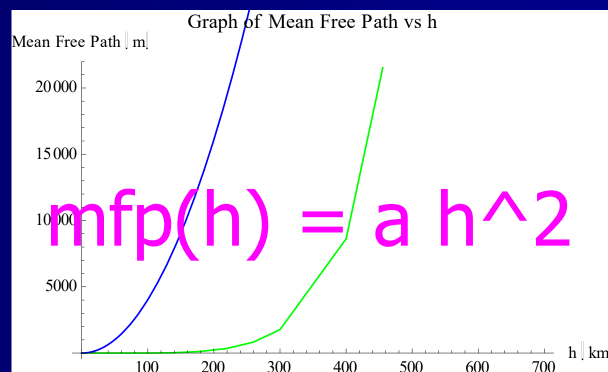
To model the data set …

To Model …..

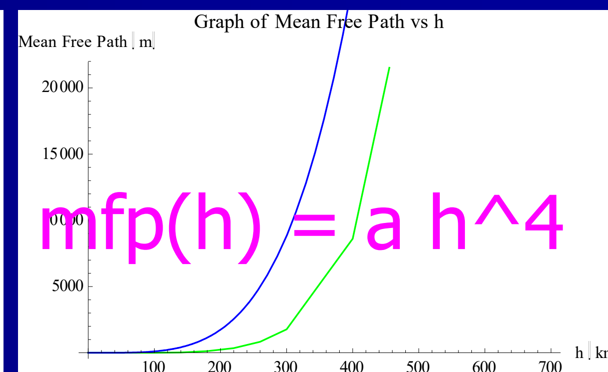




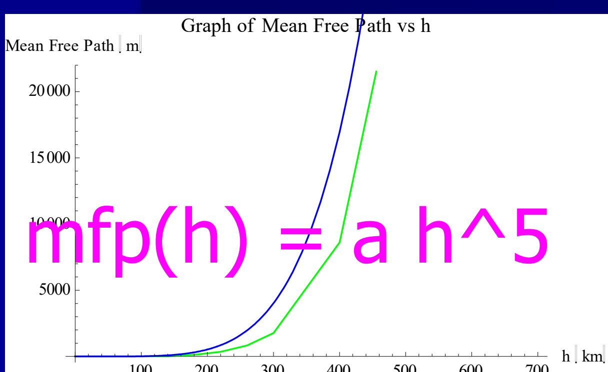
mfp(h) = a h + b



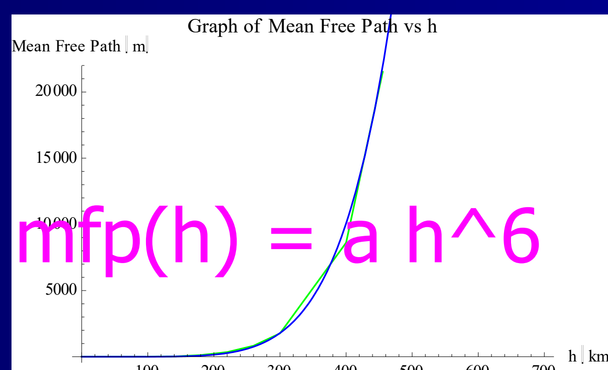
mfp(h) = a h^2



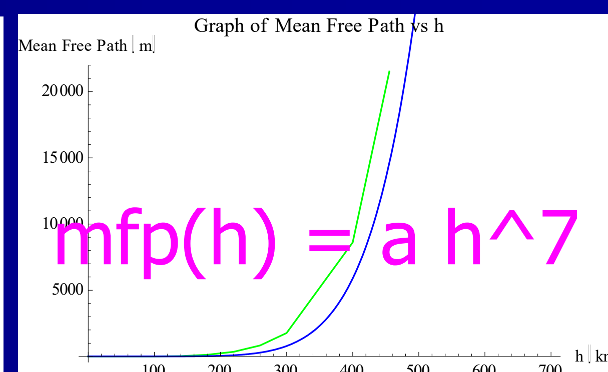
mfp(h) = a h^4



mfp(h) = a h^5



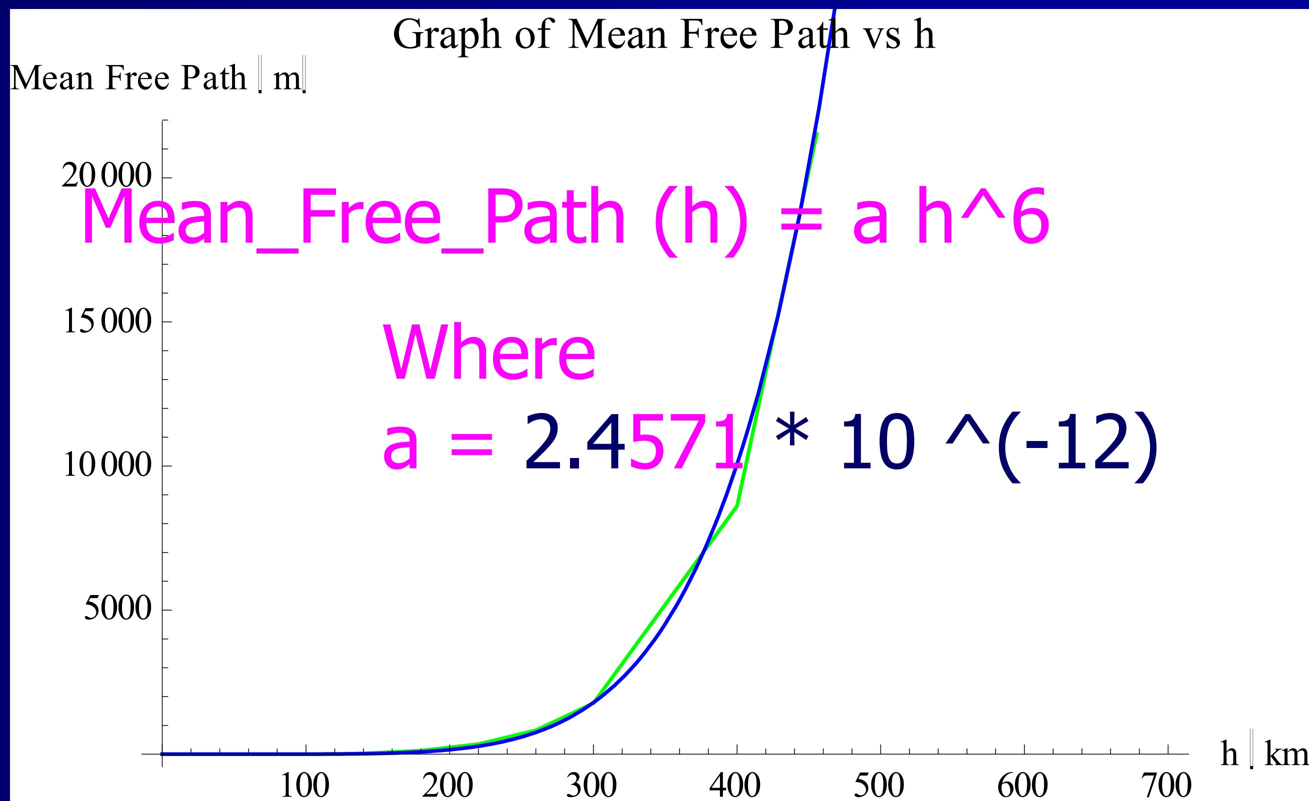
mfp(h) = a h^6



mfp(h) = a h^7

The graph of h (in km) vs Mean Free Path (in m)

Altitude in km	Mean Free Path in m
0	6.63×10^{-8}
2	8.07×10^{-8}
4	9.92×10^{-8}
6	1.23×10^{-7}
8	1.55×10^{-7}
10	1.96×10^{-7}
20	9.14×10^{-7}
40	2.03×10^{-5}
60	2.66×10^{-4}
80	4.07×10^{-3}
100	1.63×10^{-1}
140	2.25×10
180	1.25×10^{2}
220	3.52×10^{2}
260	8.31×10^{2}
300	1.77×10^{3}
400	8.61×10^{3}
500	3.19×10^{4}
600	1.02×10^{5}
700	2.95×10^{5}



Mean_Free_Path (h) = a h^6

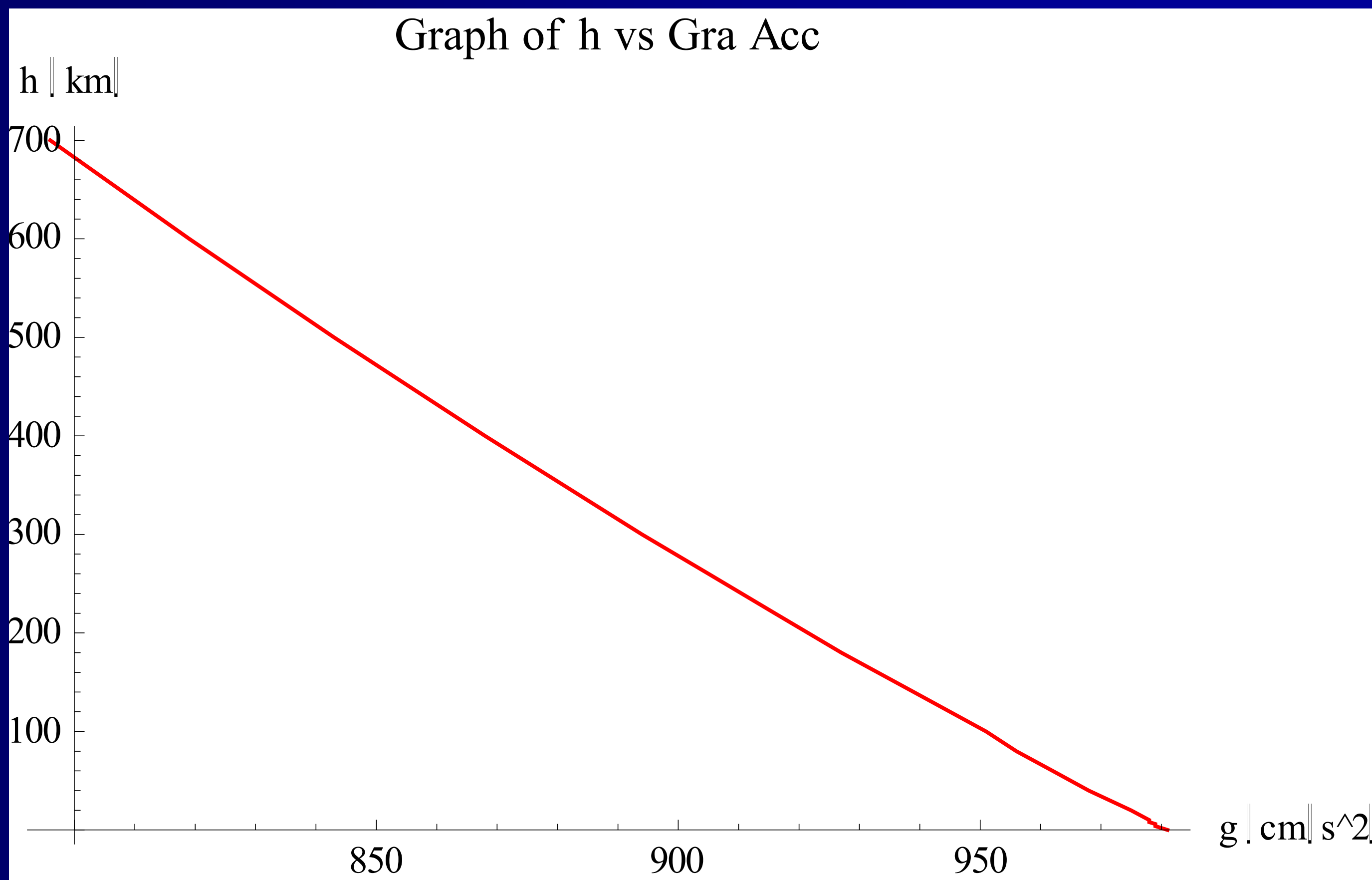
Where

a = 2.4571 * 10 ^(-12)

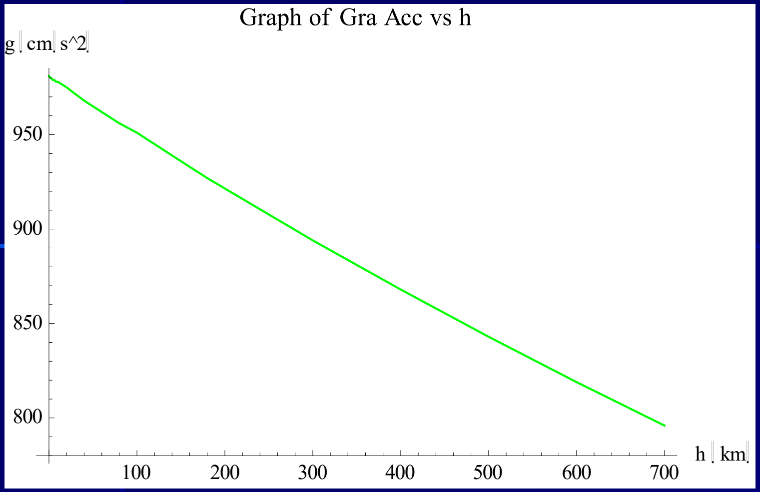
The graph of h (in km) vs Gravitational Acceleration (in cm/s^2)

Altitude in km	Accel. Grav. in cm/s^2
0	981
2	980
4	979
6	979
8	978
10	978
20	975
40	968
60	962
80	956
100	951
140	939
180	927
220	916
260	905
300	894
400	868
500	843
600	819
700	796

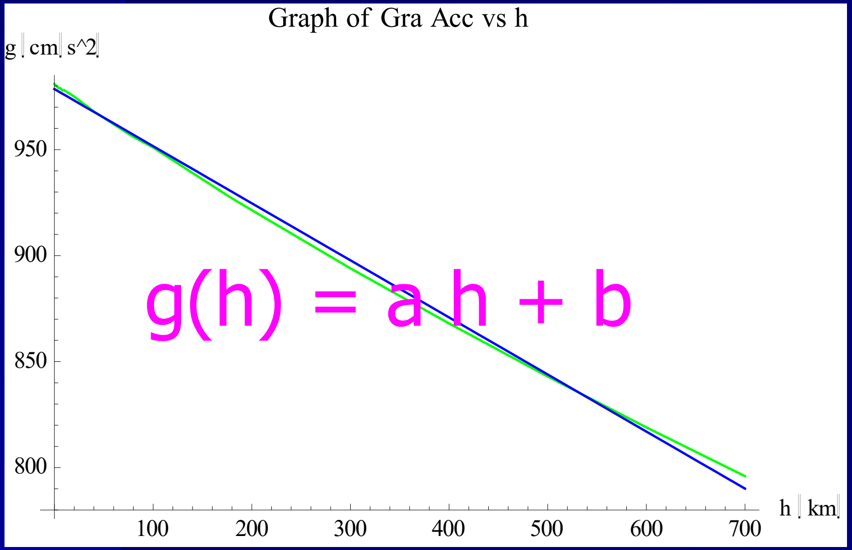
Enter the data as two 1D arrays….

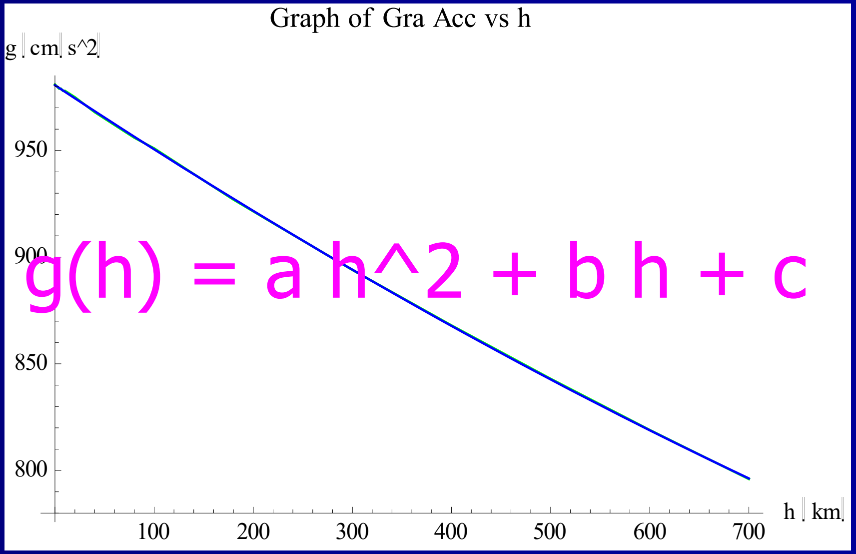


To model the data set …



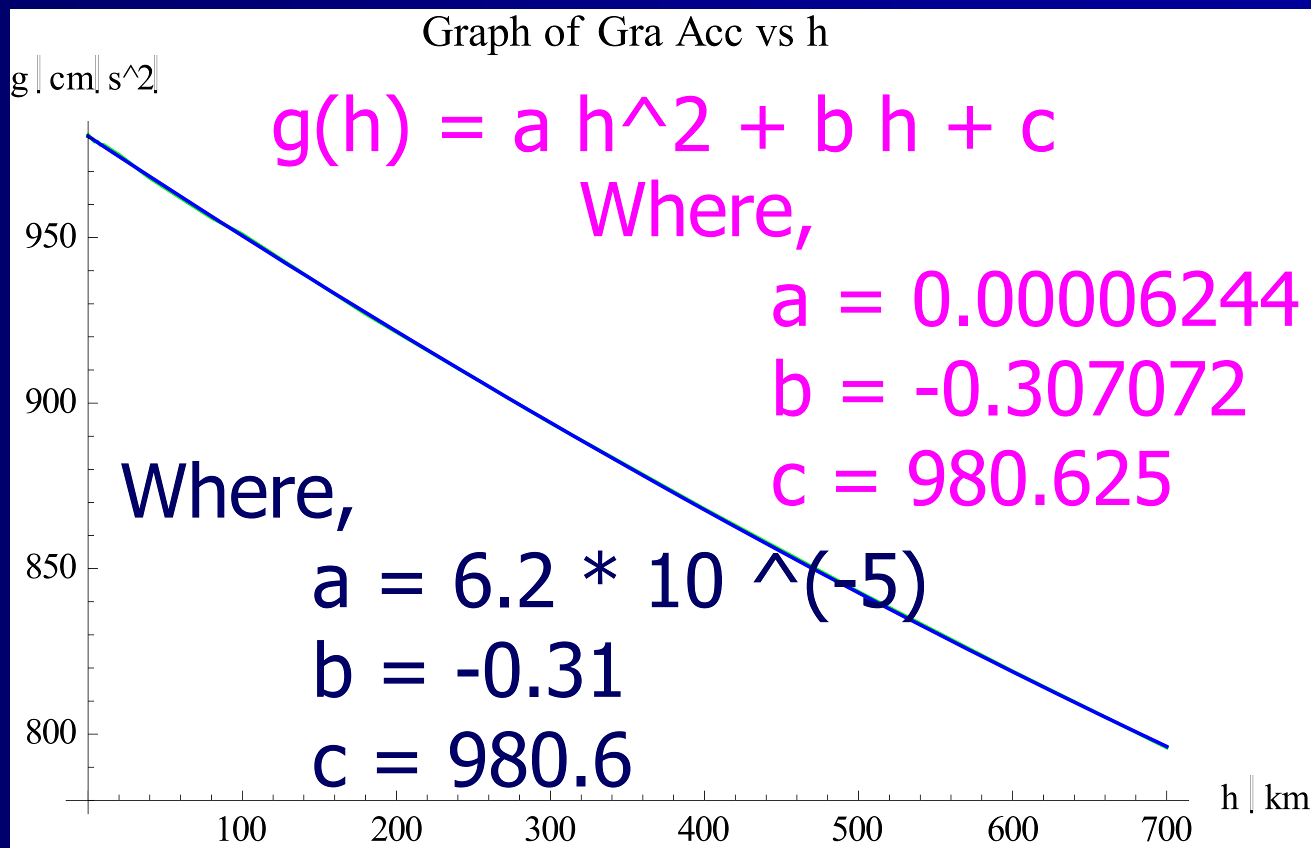
To Model …..



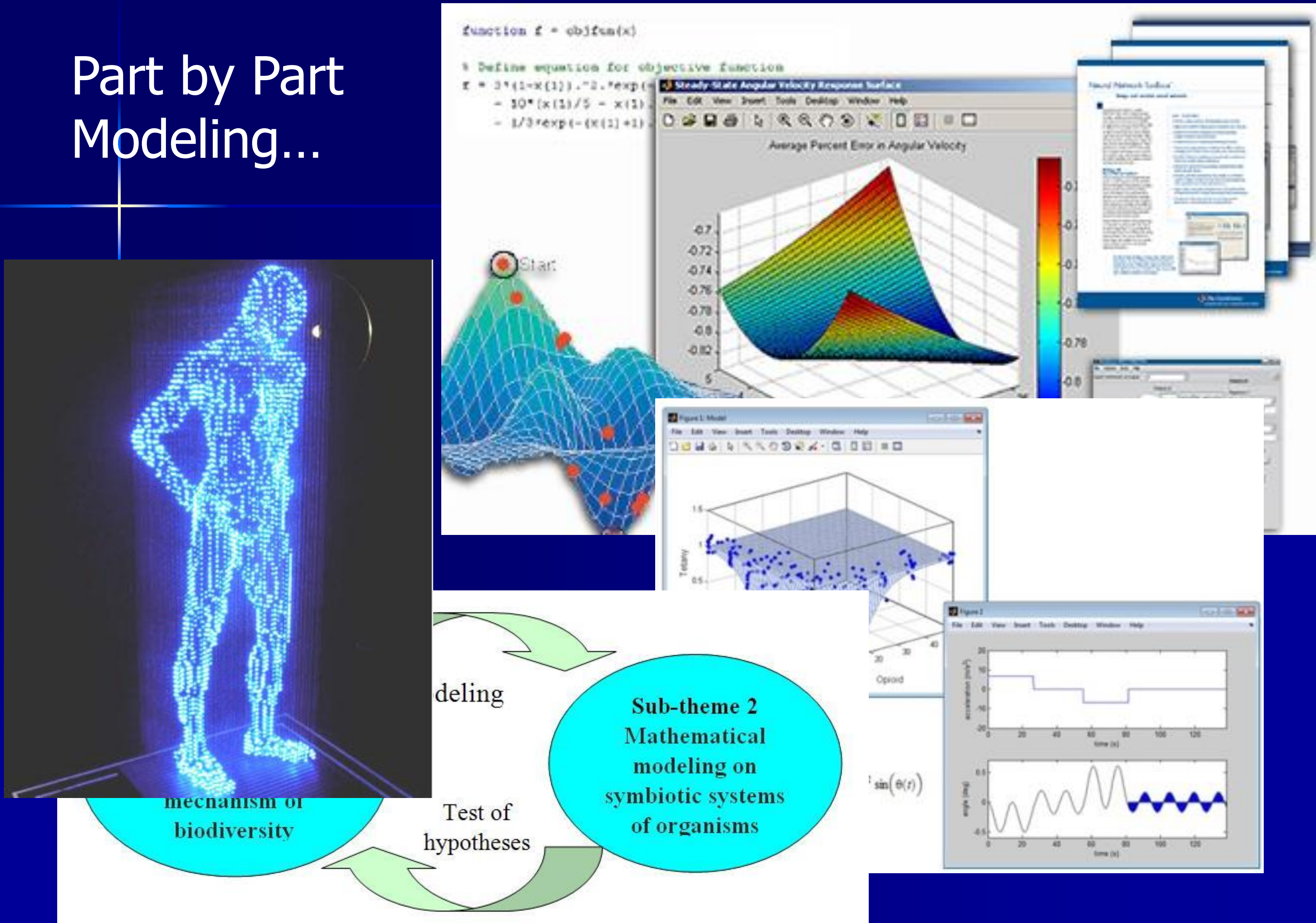


The graph of h (in km) vs Gravitational Acceleration (in cm/s^2)

Altitude in km	Accel. Grav. in cm/s^2
0	981
2	980
4	979
6	979
8	978
10	978
20	975
40	968
60	962
80	956
100	951
140	939
180	927
220	916
260	905
300	894
400	868
500	843
600	819
700	796



Part by Part Modeling…



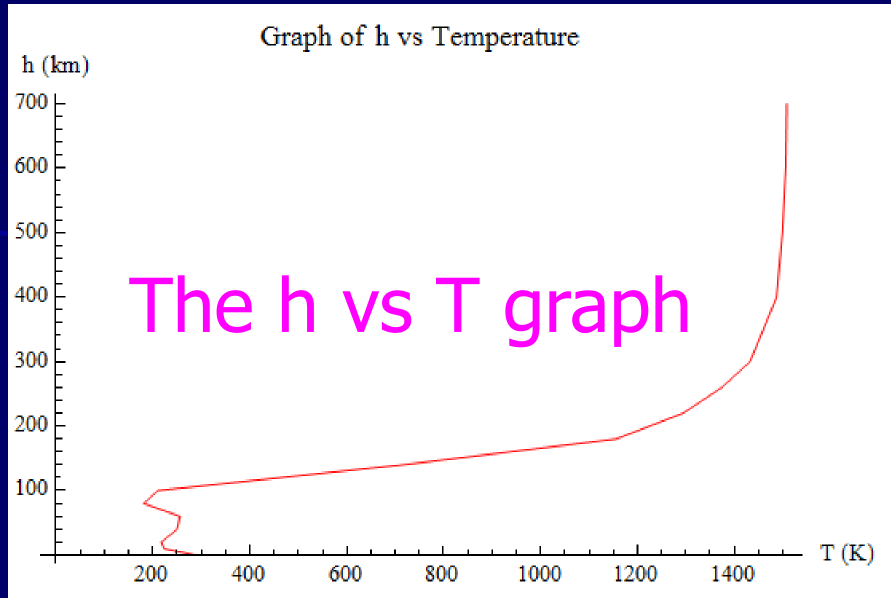
The graph of h (in km) vs T (in K)

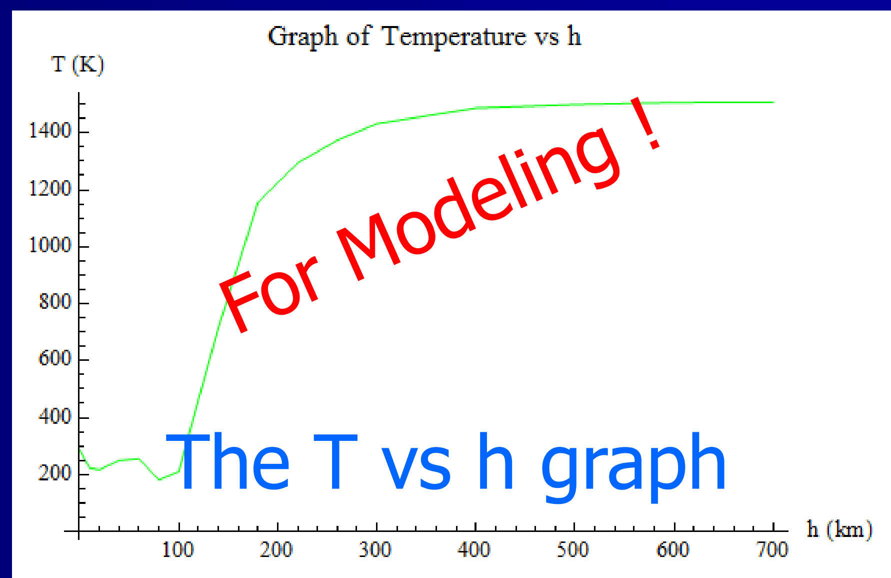
Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508

```
(* This program is to plot the Earth's parameters w.r.t altitude from the Earth Surface *)

hgh = {0, 2, 4, 6, 8, 10, 20, 40, 60, 80, 100, 140, 180, 220, 260, 300, 400, 500, 600, 700} ; (* Altitude *)
tem = {288, 275, 262, 249, 236, 223, 217, 250, 256, 181, 210, 715, 1156, 1294, 1374, 1432, 1487, 1499, 1506, 1508} ;(* Temperature *)
d1 = Transpose[{tem, hgh}]; (* to get the h vs T data set *)
ListPlot[d1, PlotJoined → True, PlotStyle → {RGBColor[1, 0, 0], PointSize[0.02]}, PlotLabel → "Graph of h vs Temperature", AxesLabel → {"T (K)", "h (km)"}] ;
(* To Plot the h vs T graph *)

(* To model the data set in T vs h format *)
data = Transpose[{hgh, tem}];
g1 = ListPlot[data, PlotStyle → {RGBColor[0, 1, 0], PointSize[0.02]}, PlotLabel → "Graph of Temperature vs h", AxesLabel → {"h (km)", "T (K)"}] ;
nnn = 11; (* Division point of the height *)
tt1 = Take[data, nnn];
tt2 = Take[data, - (nnn - 1)];
gtt1 = ListPlot[tt1, PlotStyle → {RGBColor[0, 1, 0], PointSize[0.02]}, PlotLabel → "Graph of Temperature vs h", AxesLabel → {"h (km)", "T (K)"}]
gtt2 = ListPlot[tt2, PlotStyle → {RGBColor[0, 1, 1], PointSize[0.02]}, PlotLabel → "Graph of Temperature vs h", AxesLabel → {"h (km)", "T (K)"}]
s1 = Show[{gtt1, gtt2}];
(* g1=ListPlot[data,PlotJoined→True,PlotStyle→ {RGBColor[0,1,0], PointSize[0.02]}, PlotLabel→ "Graph of Temperature vs h",AxesLabel→ {"h (km)","T (K)"}] *)
(* To Plot the T vs h graph *)

n1 = 5; (* Order of the polynomai *)
ph1 = Table[h^i, {i, 0, n1}] ; (* to create coifficient of polynomial *)
Print["Suitable First Polynomail Function is : "]
f1 = Fit[tt1, ph1, h] (* To find a suitable polynomial or relationship *)
gf1 = Plot[f1, {h, hgh[[1]], hgh[[nnn]]}, PlotStyle → {RGBColor[0, 0, 1], PointSize[0.02]}, PlotRange → Full] ; (* To plot the predicted model *)
s1 = Show[{gtt1, gf1}]

n2 = 5; (* Order of the polynomai *)
ph2 = Table[h^i, {i, 0, n2}] ; (* to create coifficient of polynomial *)
Print["Suitable Second Polynomail Function is : "]
f2 = Fit[tt2, ph2, h] (* To find a suitable polynomial or relationship *)
gf2 = Plot[f2, {h, hgh[[nnn]], hgh[[Length[hgh]]]}, PlotStyle → {RGBColor[1, 0, 1], PointSize[0.02]}, PlotRange → Full] ; (* To plot the predicted model *)
s2 = Show[{gtt2, gf2}]
mm1 = f1 /. h -> Take[hgh, nnn - 1];
mm2 = f1 /. h -> Take[hgh, - (nnn - 1)];
tempm = Join[mm1, mm2];
datam = Transpose[{hgh, tempm}];
gtm = ListPlot[datam, PlotStyle → {RGBColor[0, 1, 1], PointSize[0.02]}, PlotLabel → "Graph of Temperature vs h", AxesLabel → {"h (km)", "T (K)"}] ;
Show[{g1, gtm}]
```

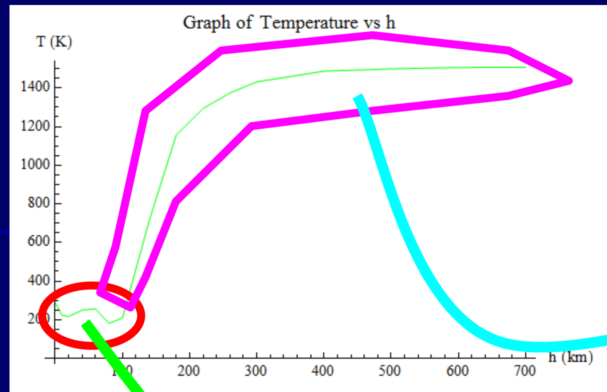
The graph of h (in km) vs T (in K)

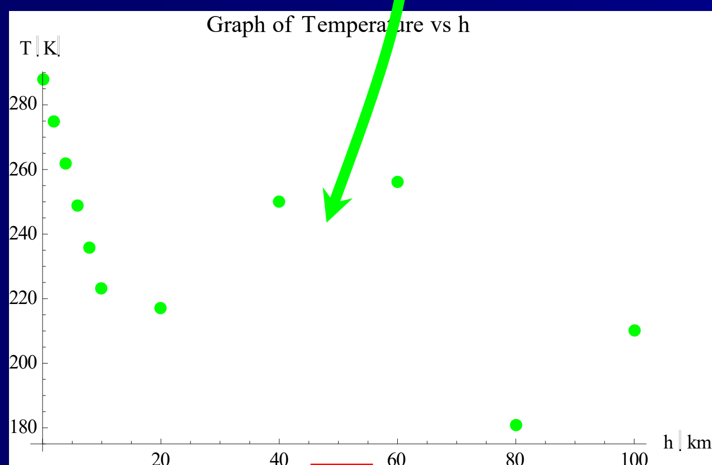
Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508

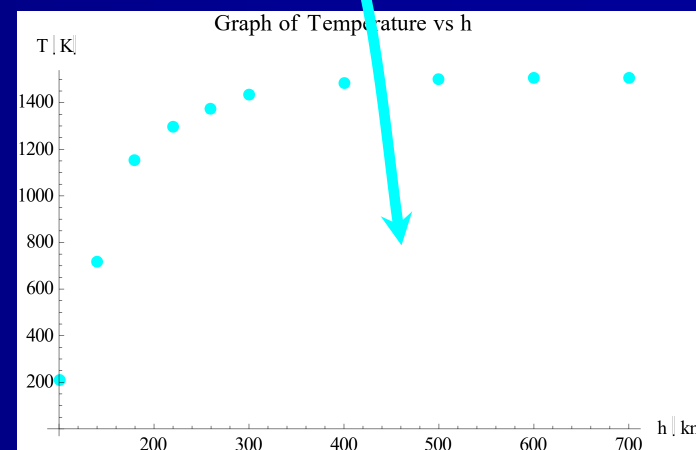




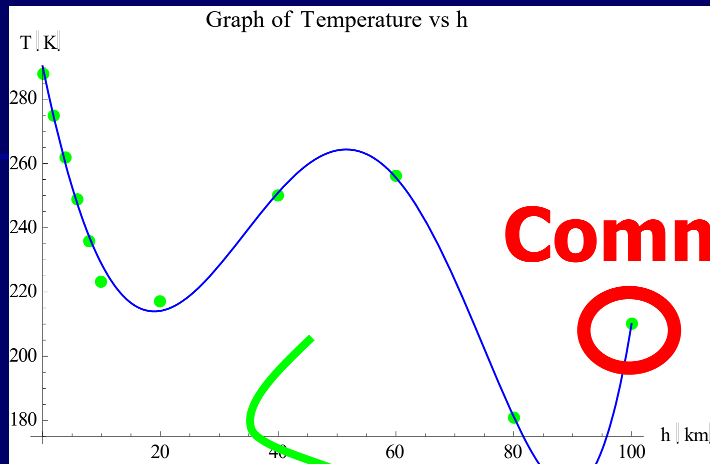
Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508

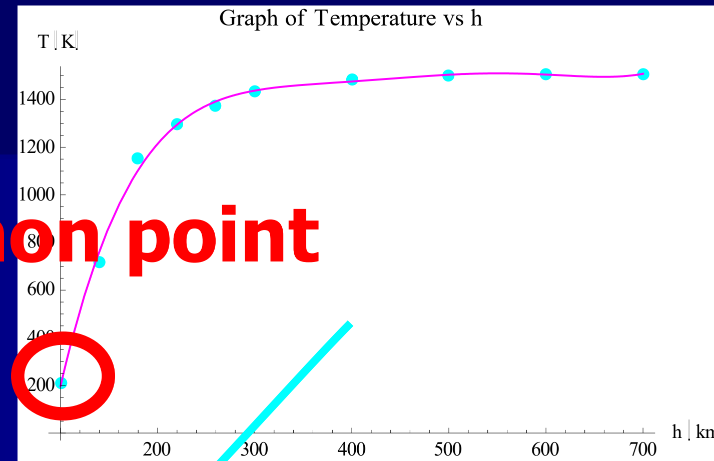






Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508



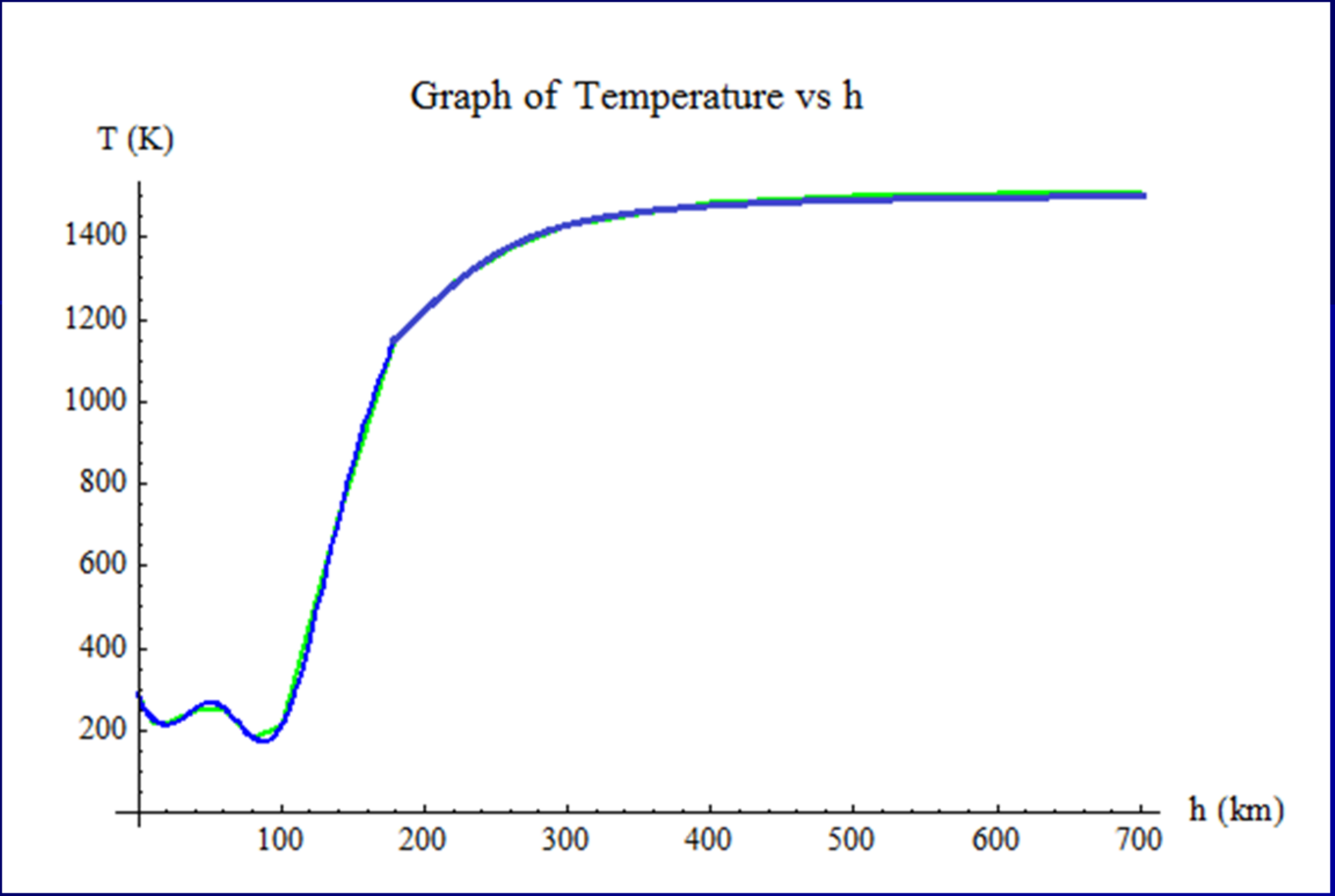


Common point

T1(h) = 3.40×10^(-7) h^5 - 0.000042 h^4 - 0.0013 h^3 + 0.299 h^2 - 8.98185 h + 290.294

T2(h) = 2.0×10^(-10) h^5 - 4.81×10^(-7) h^4 + 0.00045 h^3 - 0.2089 h^2 + 47.7 h - 2895.7

Altitude in km	Temperature in °K
0	288
2	275
4	262
6	249
8	236
10	223
20	217
40	250
60	256
80	181
100	210
140	714
180	1156
220	1294
260	1374
300	1432
400	1487
500	1499
600	1506
700	1508



$$T(h)=\begin{cases} 3.4\times10^{-7}h^5-4.2\times10^{-5}h^4-1.3\times10^{-3}h^3 \\ +2.9\times10^{-1}h^2-8.98h+290.3 & 0km\le h\le 100km \\ 2.0\times10^{-10}h^5-4.8\times10^{-7}h^4+4.5\times10^{-4}h^3 \\ -2.1\times10^{-1}h^2+47.7h-2895.7 & 100km< h\le 700km \end{cases}$$

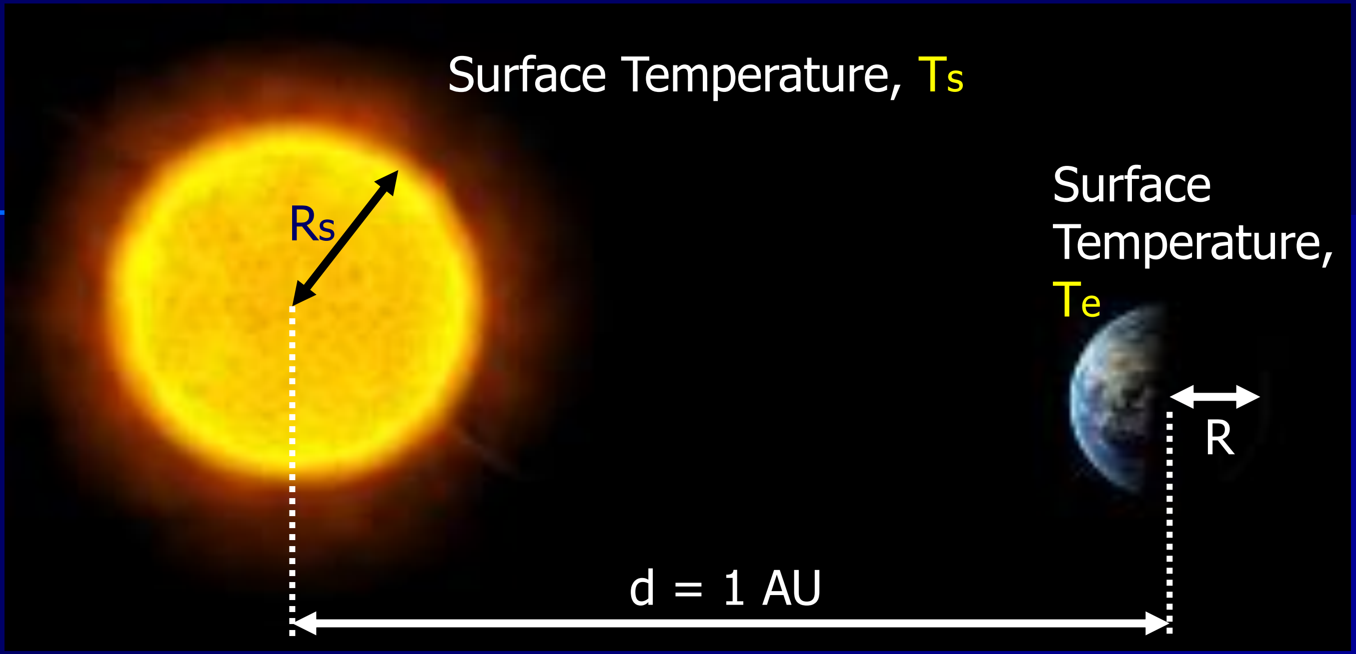
Thank You !

Planetary Atmospheres

Planetary Atmospheres

- Formation and Evolution of Planetary Atmospheres
- The Structure of the Terrestrial Atmosphere
- **The Temperature of the Neutral Atmosphere**
- The Escape of the Atmospheric Gases
- The Atmospheres of the Planets

The Temperature of the Neutral Atmosphere



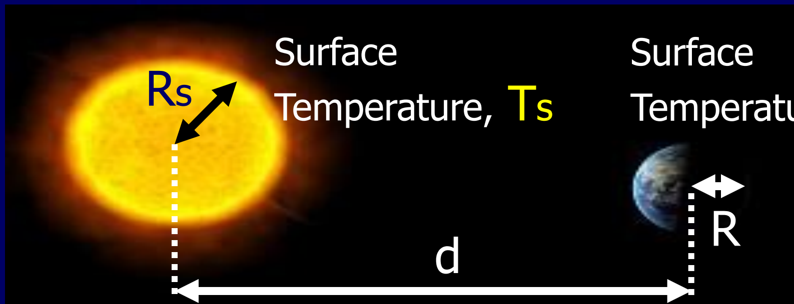
AL Method

$$\sigma = 5.67 \times 10^{-8}\ Js^{-1}m^{-2}K^{-4}$$

$$T_S = 5778\,K \ \ (\sim 6000\,K)$$

$$R_S = 695500\ km\ \ (\sim 7 \times 10^5\ km)$$

$$d = 149\,598\,000\ km\ \ (1\,AU)$$



Using Stephan's Law;

The **Energy** emitted per unit area, per second by the Sun =

$$E = \sigma T_S^{\ 4}$$

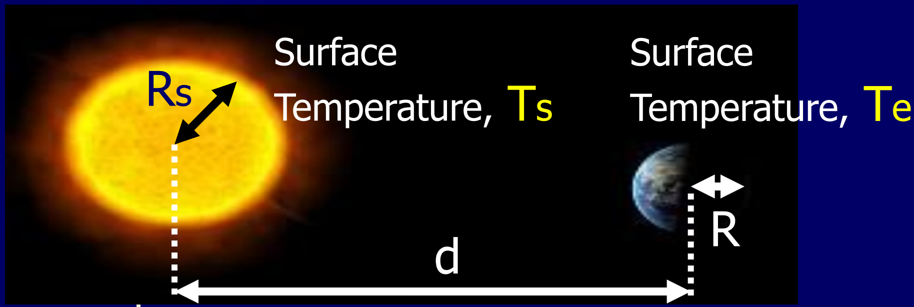
The **Total Energy** emitted per second by the Sun =

$$\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}$$

The Energy Density per second (Energy per unit area) at our orbit =

$$\frac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2}$$

Where this ***d*** is distance from the Sun to the Earth's Orbit (1.0 AU)

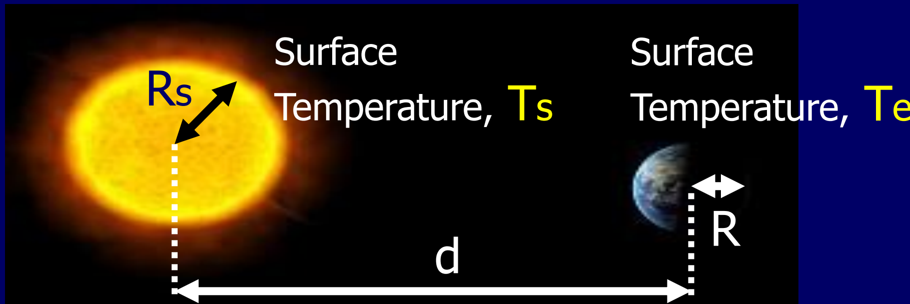


Using Stephan's Law

The Total Energy to the Earth = $\dfrac{\sigma T_S^{\ 4} \times 4\pi R_S^{\ 2}}{4\pi d^2} \times \pi R^2$ $\longrightarrow$ 1

The Energy absorbed by the Earth = $e\sigma T_e^{\ 4} \times 2\pi R^2$ $\longrightarrow$ 2

Where this ***e*** is emissivity of the Earth (Factor per BB, for BB ; e=1)



Connect equation 1 & 2 ;

$$\frac{\sigma T_S{}^4 \times 4\pi R_S{}^2}{4\pi d^2} \times \pi R^2 = e\,\sigma T_e{}^4 \times 2\pi R^2$$

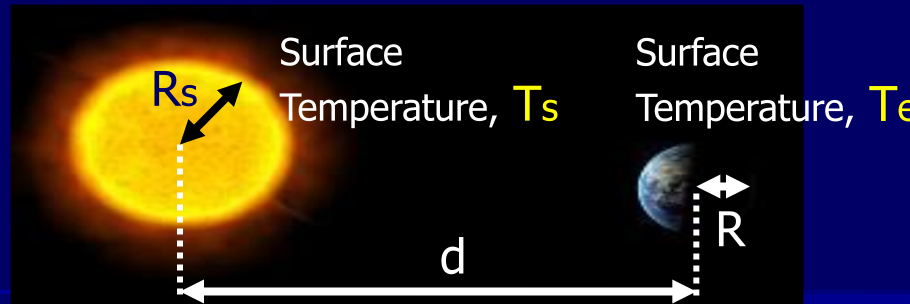
Where *e* should be [0 – 1]

$$T_e{}^4 = \frac{\sigma T_S{}^4 \times 4\pi R_S{}^2 \times \pi R^2}{4\pi d^2 \times e\,\sigma \times 2\pi R^2}$$

$$T_e = \left(\frac{T_S{}^4 \times R_S{}^2}{e\, d^2 \times 2}\right)^{1/4}$$

$$T_e = \{1047.62, 589.123, 393.97, 340.13, 332.121, 331.288\}\ C$$

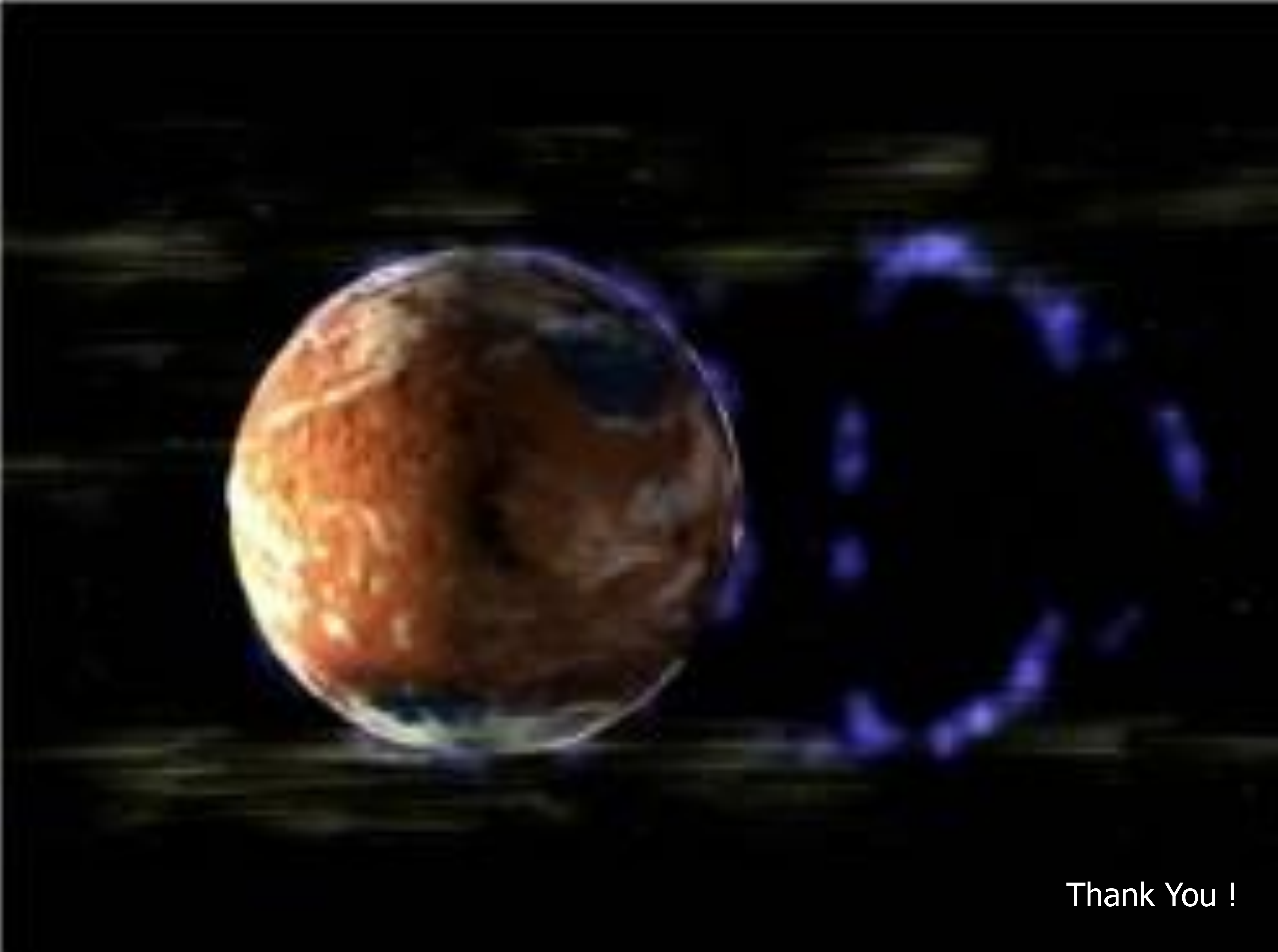
???



Space Physics 01.nb * - Wolfram Mathematica 10.0

File Edit Insert Format Cell Graphics Evaluation Palettes Window Help

```
In[61]:= sig = 5.67 * (10 ^ (-8)) ; (* in J/s m^2 K^4 *)
         ts = 5778; (* in K *)
         rs = 695500 * 1000; (* in m *)
         re = 6400 * 1000; (* in m *)
         d = 149598000 * 1000; (* in m *)
         e = {0.01, 0.1, 0.5, 0.9, 0.99, 1.0} ; (* e in between 0 and 1 *)

         te = (   ( (ts ^ 4) * (rs ^ 2) ) / ( e * (d ^ 2) * 2 )   ) ^ (1 / 4);
         Print["Temperature on the Earth is : ", te - 273, " C"]

         Temperature on the Earth is : {774.625, 316.123, 120.97, 67.1301, 59.1214, 58.288} C
```


Thank You !