Analysis of NASA Bolide Data

Mark Biegert

April 23, 2016

Abstract

Provide an analysis of NASA bolide data the shows how NASA generated their values for

- meteor velocity
- impact energy

I will augment the NASA data with estimates for the bolide mass and size using the same method that NASA has for other reports. With this data, I will then graph the data to identify any patterns.

Definitions

Bolide

A bolide is an extremely bright meteor, especially one that explodes in the atmosphere. In astronomy, it refers to a fireball approximately as bright as the full moon, and it is generally considered a synonym of a fireball.

Radiant Energy

The total luminous energy released by the fireball.

Impact Energy

The estimated total kinetic energy in the meteor. The meteor dissipates its energy in the form of light and by working against the air. NASA has established an empirical relationship between the radiant energy and the impact energy.

Data Analysis Setup

```
require(ggplot2)
require(devtools)
require(DT)
require(xtable)
require(ggthemes)
require(dplyr)
require(tidyr)
require(scales)
require(magrittr)
require(stringi)
require(knitr)
require(data.table)
require(plyr)
require(sqldf)
```

```
require(rvest)
meteor=read.csv("C:\\Users\\mbiegert\\Dropbox\\Blog\\RecentMeteorImpacts\\MeteorMinimal.csv")
colnames(meteor)=c("date","lt","lg","alt","vx","vy","vz","ER")
keeps=c("date","alt","vx","vy","vz","ER")
meteor=meteor[keeps]
head(meteor)
```

```
##        date  alt   vx    vy   vz       ER
## 1  1-Jul-08 36.1  2.8   1.7 -9.2 3.60e+10
## 2 26-Jun-14 28.5  7.0   2.9  8.3 6.10e+10
## 3 21-Oct-08 29.6  9.6   5.8  1.5 4.60e+10
## 4  9-Jan-08 31.5  4.3   5.7  9.1 4.10e+10
## 5 25-May-11 59.0 -3.4 -10.8  2.4 2.28e+12
## 6  3-Mar-16 31.8  4.8  -7.1  7.9 5.80e+10
```

Analysis Basics

Relationship Between Radiant Energy and Impact Energy

NASA has done a study relates the radiant energy to the impact energy through the following formula (link).

$$E = 8.2508 \cdot {E_R}^{0.885}$$

where E is the impact energy and E_R is the measured radiant energy of the meteor.

Augment the Meteor Data

Add Total Velocity

```
meteor$v_T = (meteor$vx^2+meteor$vy^2+meteor$vz^2)^0.5 #Euclidean Norm
```

Convert Radiant Energy in Kilotons

```
kt = 4.184*10^12 # definition of kiloton in joules
meteor$ERkt=meteor$ER/kt
```

Add Impact Energy in Kilotons

```
meteor$EIkt = 8.2508*(meteor$ERkt)^0.885 # NASA formula relating radiant to impact energy
```

Add Estimated Mass in Tonne

```
meteor$Mass = 8.368E6*10^-3*meteor$EIkt/meteor$v_T^2
```

Add Diameter of Spherical Object of Equivalent Mass

```
rho=3.6  #gm/cm3
meteor$Dia=(6*meteor$Mass/(rho*pi))^(1/3)
```

Remove Unneeded Data

```
meteor=select(meteor,select=-c(3,4,5,6))
```

Final Data Frame

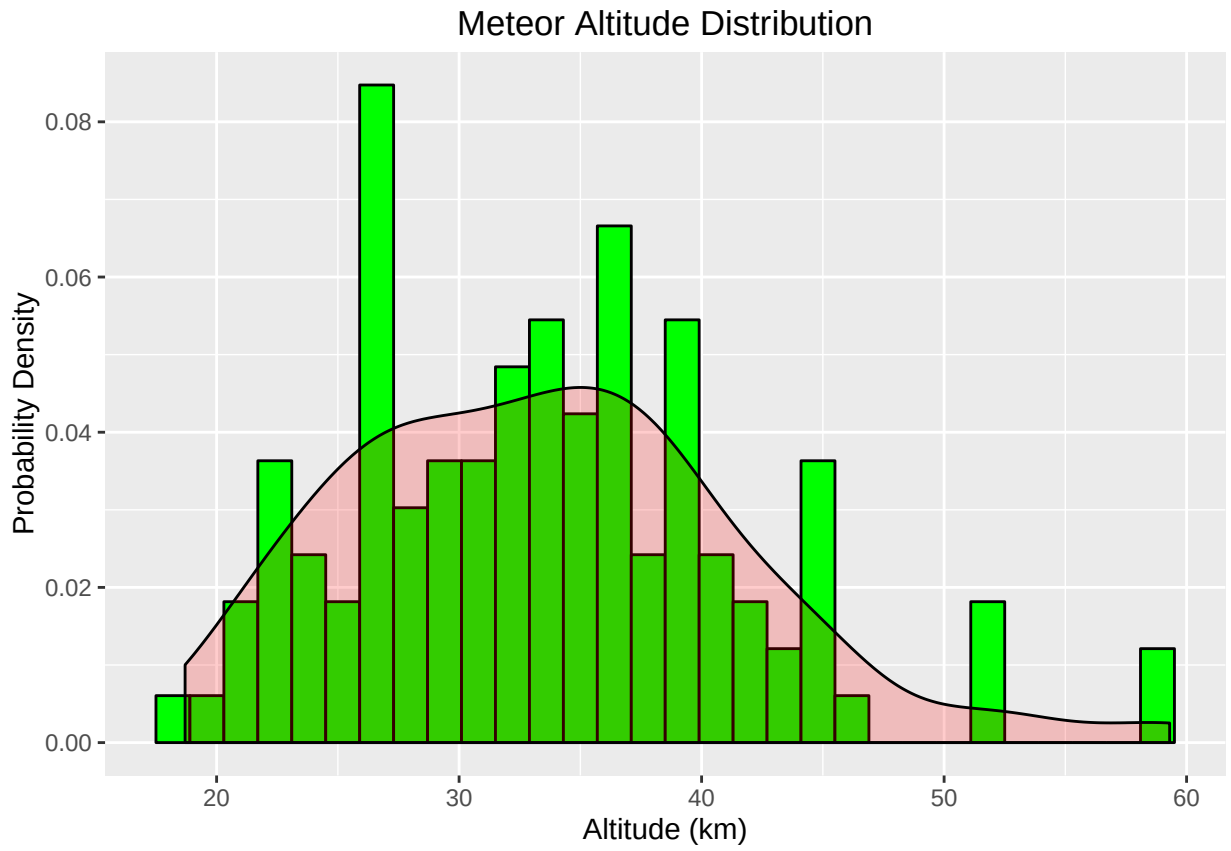
```
meteor=meteor%>%arrange(desc(Mass))
kable(head(meteor,25))
```

date	alt	v_T	ERkt	EIkt	Mass	Dia
15-Feb-13	23.3	18.61424	89.6271511	440.9659935	10649.66791	17.810590
25-Dec-10	26.0	18.54724	4.7801147	32.9457177	801.42374	7.519467
8-Oct-09	19.1	22.09072	4.7801147	32.9457177	564.93804	6.692164
30-Apr-13	21.2	12.08305	1.2213193	9.8478160	564.42825	6.690150
6-Jul-10	26.0	15.69873	1.8068834	13.9276940	472.90300	6.307012
9-Dec-06	26.5	15.86096	1.7710325	13.6828492	455.13409	6.227008
6-Feb-16	31.0	15.57370	1.6371893	12.7636117	440.36407	6.158906
25-May-11	59.0	11.57411	0.5449331	4.8212513	301.16625	5.426274
3-Sep-10	33.3	12.26947	0.4182600	3.8148380	212.05370	4.827418
23-Aug-14	22.2	17.60767	0.9130019	7.6122581	205.46197	4.776870
12-Oct-13	22.2	12.83783	0.3847992	3.5434665	179.91461	4.570059
21-Nov-09	38.0	32.04684	2.3900574	17.8396951	145.35790	4.256433
7-Feb-09	40.0	15.40714	0.3824092	3.5239814	124.22562	4.039274
2-Sep-06	44.1	14.15132	0.2939771	2.7922445	116.67583	3.955730
21-Apr-13	40.7	14.89966	0.2557361	2.4682666	93.03809	3.668202
28-Nov-14	26.1	13.37946	0.1673040	1.6955055	79.25808	3.477343
7-Sep-15	29.3	20.99238	0.4302103	3.9111421	74.26803	3.402778
10-Apr-16	35.2	15.14794	0.1565488	1.5986779	58.30095	3.139001
8-May-14	35.4	19.00579	0.2509560	2.4273922	56.23282	3.101437
15-Jan-10	25.0	14.00893	0.1175908	1.2410136	52.91619	3.039222
7-Oct-08	38.9	13.28307	0.0944073	1.0218234	48.46190	2.951434
16-Apr-10	22.2	18.84251	0.2017208	2.0007853	47.15686	2.924700
23-Aug-09	34.0	12.16347	0.0669216	0.7535677	42.62153	2.827761
28-Jan-06	37.0	18.70187	0.1768642	1.7809737	42.60975	2.827500
2-Oct-12	35.0	15.39643	0.1123327	1.1917743	42.07031	2.815517

Graph The Data

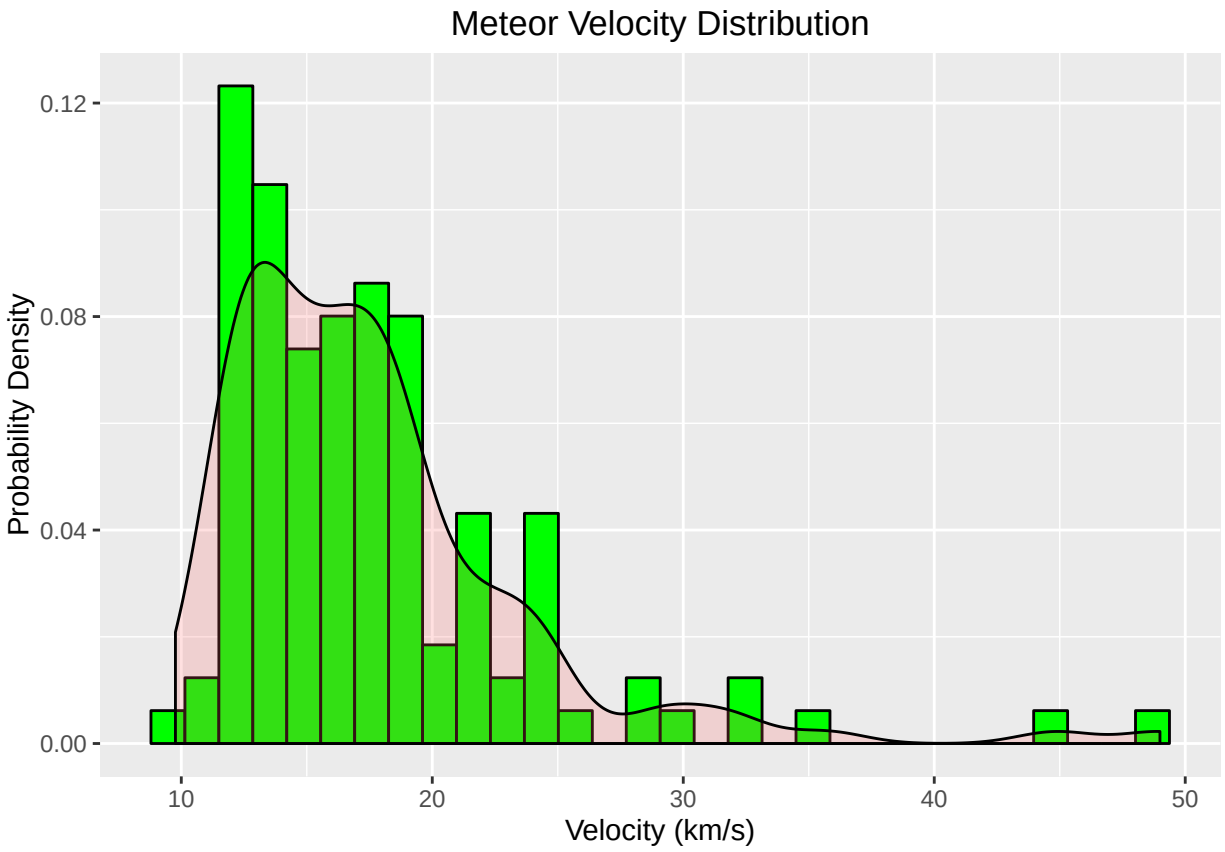
Altitude of Maximum Meteor Brightness

```
g1=ggplot(data=meteor,aes(x=alt)) + geom_histogram(aes(y=..density..), fill="green", colour="black")
g1=g1+geom_density(alpha=.2, fill="#FF0000")
g1=g1+ labs(title="Meteor Altitude Distribution",x="Altitude (km)", y = "Probability Density")
g1
```



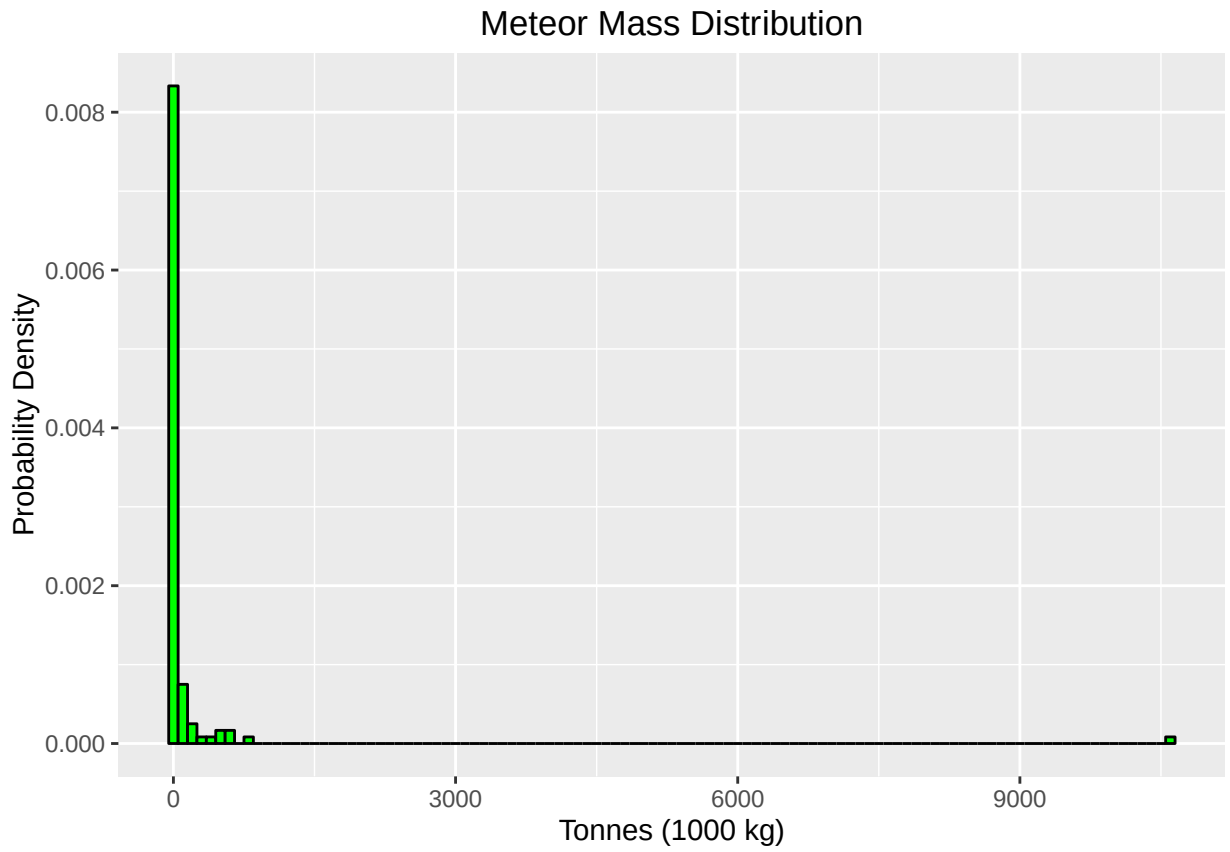
Histogram of Meteor Velocities

```
g1=ggplot(data=meteor,aes(x=v_T)) + geom_histogram(aes(y=..density..), fill="green", colour="black")
g1=g1+geom_density(alpha=.2, fill="#FF6666")
g1=g1+ labs(title="Meteor Velocity Distribution",x="Velocity (km/s)", y = "Probability Density")
g1
```



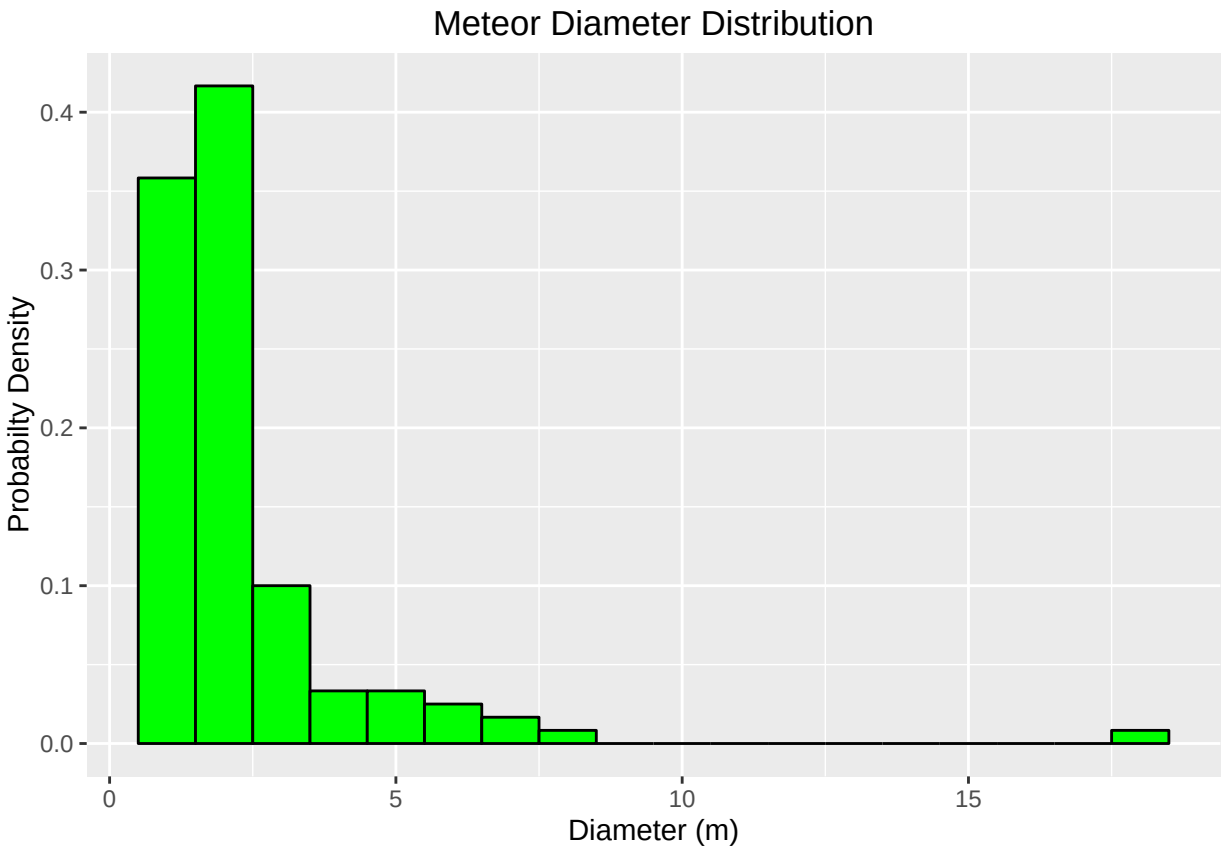
Histogram of Meteor Masses

```
g1=ggplot(data=meteor,aes(x=Mass))
g1=g1+geom_histogram(aes(y=..density..), fill="green", colour="black",binwidth=100)
g1=g1+ labs(title="Meteor Mass Distribution",x="Tonnes (1000 kg)", y = "Probability Density")
g1
```



Histogram of Meteor Diameters

```
g1=ggplot(data=meteor,aes(x=Dia))
g1=g1+geom_histogram(aes(y=..density..), fill="green", colour="black",binwidth=1)
g1=g1+ labs(title="Meteor Diameter Distribution",x="Diameter (m)", y = "Probabilty Density")
g1
```


Meteor Diameter Distribution
Probabilty Density
0.4
0.3
0.2
0.1
0.0
0
5
10
15
Diameter (m)