Replication: Orbital Eccentricity-Multiplicity Relation

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```
# install.packages("plyr")
# install.packages("Hmisc")
```

Introduction

TODO

```
library(plyr)
library(Hmisc)
```

```
## Warning: package 'Hmisc' was built under R version 3.1.1
```

```
## Loading required package: grid
## Loading required package: lattice
## Loading required package: survival
## Loading required package: splines
## Loading required package: Formula
```

```
## Warning: package 'Formula' was built under R version 3.1.1
```

```
##
## Attaching package: 'Hmisc'
##
## The following objects are masked from 'package:plyr':
##
##     is.discrete, summarize
##
## The following objects are masked from 'package:base':
##
##     format.pval, round.POSIXt, trunc.POSIXt, units
```

```
library(lattice)
library(ggplot2)
library(boot)
```

```
## Warning: package 'boot' was built under R version 3.1.1
```

```
##
## Attaching package: 'boot'
##
## The following object is masked from 'package:survival':
##
##     aml
##
## The following object is masked from 'package:lattice':
##
##     melanoma
```

The Dataset

```
planets.all <- read.csv("data/exoplanets.1392162267.csv")
```

A summary of the discovery methods in this dataset. (why so many rows with no discovery method?)

```
table(planets.all$PLANETDISCMETH)
```

```
##
##                   Imaging Microlensing           RV       Timing
##         3466            8           18          441           10
##      Transit
##          298
```

> "We chose to use RV data only for our analysis since the planets in that data set typically have known and relatively reliably measured eccentricities." ... "If the eccentricity of the planet was not listed or if it was given as zero, the exoplanet was excluded from our sample."

```
planets.selected <- subset(planets.all, PLANETDISCMETH == "RV" & ECC != 0.0)
cat("Planets in selected dataset: ", nrow(planets.selected))  # Expecting 403
```

```
## Planets in selected dataset:  403
```

Data for the Solar System (see *References* for sources):

```
mercury <- data.frame(STAR="Sun", ECC=0.20563593, A=0.38709927, NCOMP=8)
venus   <- data.frame(STAR="Sun", ECC=0.00677672, A=0.72333566, NCOMP=8)
earth   <- data.frame(STAR="Sun", ECC=0.01671123, A=1.0,        NCOMP=8)
mars    <- data.frame(STAR="Sun", ECC=0.0933941,  A=1.523662,   NCOMP=8)
jupiter <- data.frame(STAR="Sun", ECC=0.04838624, A=5.2028870,  NCOMP=8)
saturn  <- data.frame(STAR="Sun", ECC=0.05386179, A=9.53667594, NCOMP=8)
uranus  <- data.frame(STAR="Sun", ECC=0.04725744, A=19.189165,  NCOMP=8)
neptune <- data.frame(STAR="Sun", ECC=0.00859048, A=30.069923,  NCOMP=8)
```

Append Solar System to the selected data set:

```
planets.selected <- rbind.fill(planets.selected, mercury, venus, earth, mars, jupiter, saturn, uranus, n
```

> "The 5- and 6-planet systems, one of each, were combined into one bin so that there was sufficient data for a statical analysis." Apply the bins to the data as a new multiplicity factor column (called `mfactor`):

```
planets.selected$mfactor <- cut(planets.selected$NCOMP,
    breaks=c(0,1,2,3,4,6,7,8),
    labels=c("1 Planet", "2 Planets", "3 Planets", "4 Planets", "5 or 6 Planets", "7 Planets", "8 Planet
)

# For plots, it is useful to have 5.5 for "5-6 Planets". This will be `$numplanets`
planets.selected$numplanetsFactor <- cut(planets.selected$NCOMP,
```

```
     breaks=c(0,1,2,3,4,6,7,8),
     labels=c(1,2,3,4,5.5,7,8)
)
planets.selected$numplanets <- as.numeric(as.character(planets.selected$numplanetsFactor))
```

Table 1: No. planets in dataset for given multiplicity

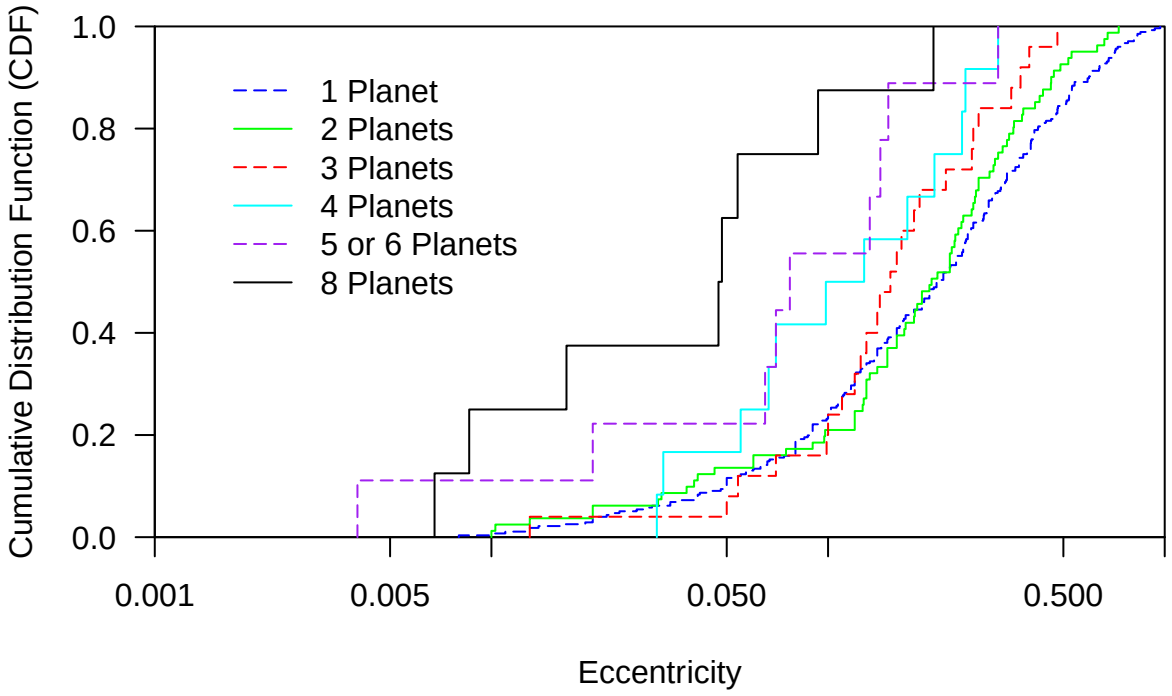
```
setNames(
  aggregate(STAR~mfactor,planets.selected,FUN="length"),
  c("Multiplicity", "Total number of planets")
)
```

```
##     Multiplicity Total number of planets
## 1       1 Planet                    276
## 2      2 Planets                     81
## 3      3 Planets                     25
## 4      4 Planets                     12
## 5 5 or 6 Planets                      9
## 6      8 Planets                      8
```

A Trend in Multiplicity versus Eccentricity

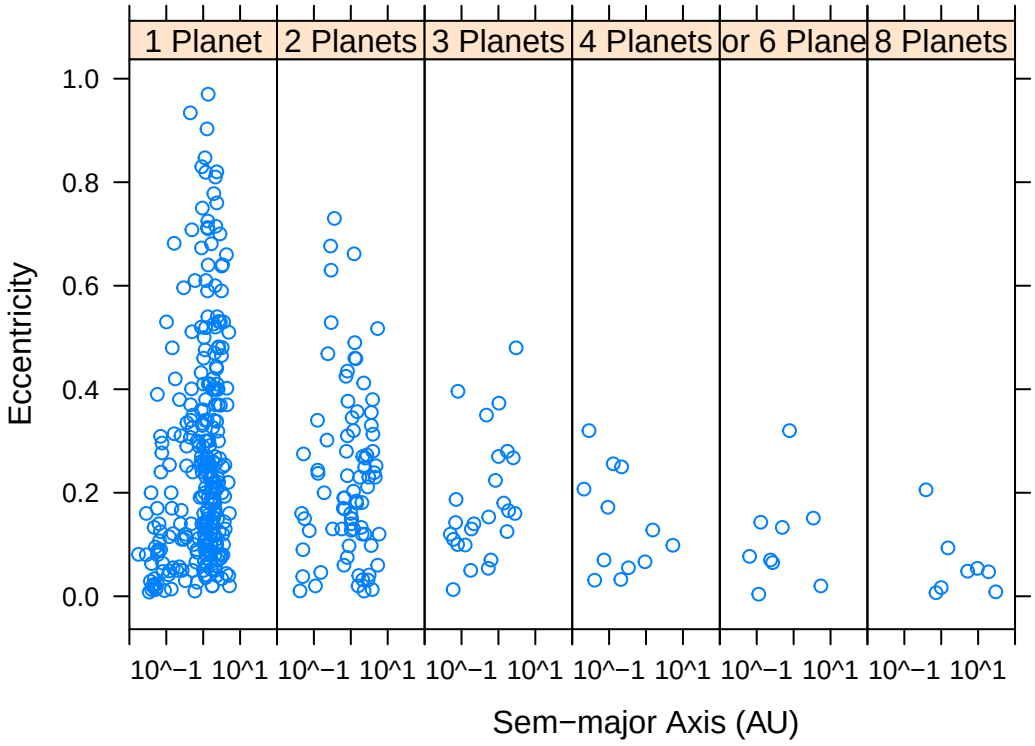
```
eccs <- planets.selected[, c("mfactor", "ECC")]

# See `?par` for a description formatting parameters such as `xaxs` and `las`
Ecdf(eccs$ECC, group=eccs$mfactor,
     log          = "x",
     xlim         = c(10^-3,1),
     ylim         = c(0,1),
     subtitle     = FALSE,
     label.curves = FALSE,
     xlab         = "Eccentricity",
     ylab         = "Cumulative Distribution Function (CDF)",
     xaxs = "i", yaxs = "i", las = "1",
     lty = c("longdash", "solid"),
     col = c("blue", "green", "red", "cyan", "purple", "black"))

# The call to `factor` avoids plotting factors that do not occur in the data set. I.e, "7 planets"
legend("topleft", legend=levels(factor(eccs$mfactor)),
    inset = 0.05, bty = "n",
    lty   = c("longdash", "solid"),
    col   = c("blue", "green", "red", "cyan", "purple", "black"))
title("Fig. 1: Cumulative eccentricity distributions, by multiplicity")
```

Fig. 1: Cumulative eccentricity distributions, by multiplicity



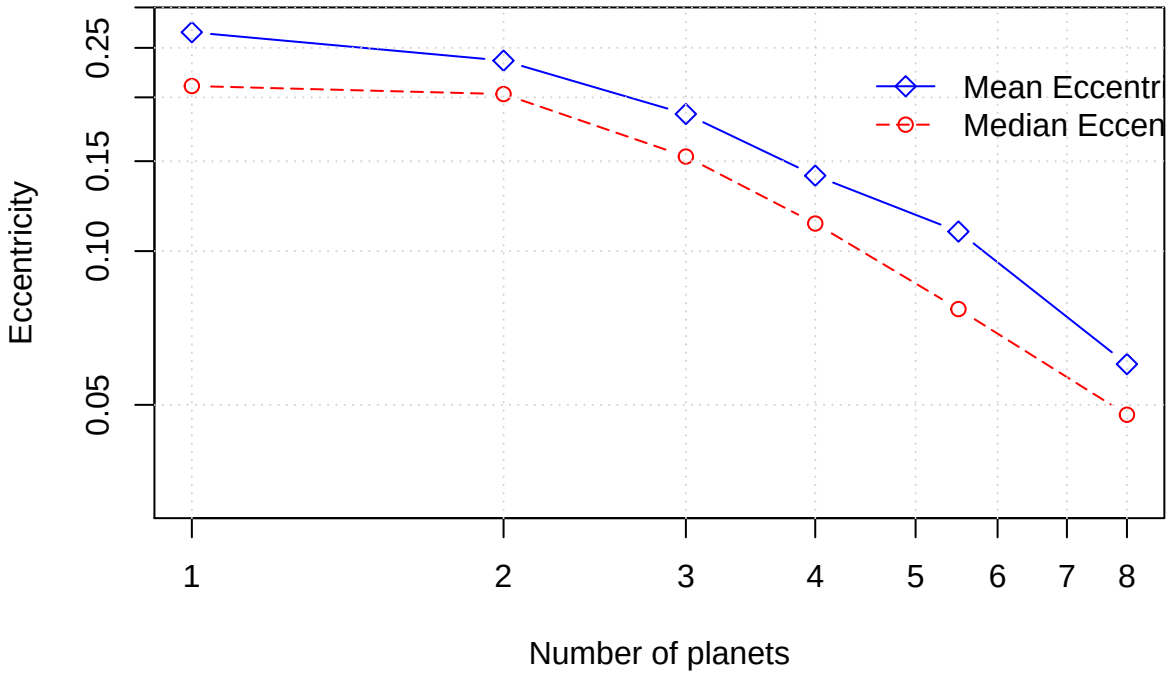

```
xyplot(ECC ~ A | mfactor, planets.selected,
  xlim   = c(10^-2,10^2),
  scales = list(x=list(alternating=FALSE,log=TRUE)),
  ylab   = "Eccentricity",
  xlab   = "Sem-major Axis (AU)",
  layout = c(7,1),
  drop.unused.levels = TRUE,
  main   = "Fig. 2: 'Eccentricity verses semi-major axis going from low- (left) to high-multiplicity (r
)
```

entricity verses semi−major axis going from low− (left) to high−multipli




```
summaryStats <- ddply(
  planets.selected, c("numplanets"),
  summarise,
  N    = length(ECC),
  mean = mean(ECC),
  median = median(ECC)
)


# boot(planets.selected, statistic=function(d,i){mean(d$ECC[i])},R=1000)
# foo <- subset(eccs, mfactor %in% c("8 Planets"))

plot(summaryStats$numplanets, summaryStats$mean, log="xy", xlab="Number of planets", ylab="Eccentricity
points(summaryStats$numplanets, summaryStats$median, type="b", col="red", lty="longdash")
grid()
legend(x=4.5, y=0.25,
  legend=c("Mean Eccentricity","Median Eccentricity"),
  lty=c("solid","longdash"),
  col=c("blue","red"),
  pch=c(5,1),
  box.col=NA
)
title("Fig. 3: Mean and median RV eccentricity by multiplicity (number of planets)")
```

Fig. 3: Mean and median RV eccentricity by multiplicity (number of plar



References

- Mercury, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Venus, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Earth, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Mars, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Jupiter, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Saturn, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Uranus, SSE Facts & Figures, NASA, accessed: 2014-10-21.
- Neptune, SSE Facts & Figures, NASA, accessed: 2014-10-21.