**"Steps to use Multiplicity\_Analyzer.py"**

1) Import the functions known as load\_files,system\_initialization,Plots & Multi\_Plot

OPTIONAL: also import OrbitalPlot2D and smaxis\_tracker if you would like to look at the orbital plot or evolution of the semi major axis of ONE system. You can also ignore Multi\_Plot and just use plot = False parameter in the plots function and DIY a multiplot. You can also import Plots\_key to see the list of which\_plots for the Plots function.

2) For load\_files, provide a 'Filename List'. I would recommend creating a list of filenames and saving this in a variable called Filename\_List.

3) load\_files will return the files (filtered to remove brown dwarfs) in a list. I would recommend saving this as Files\_List.

4) Next, use system\_initialization by inputting the (unpickled) file that was the previous output, the name of the file and using read\_in\_result if you have the system pickle files.

5) This will return the systems for each snapshot. I would recommend naming this variable Systems\_List.

OPTIONAL: Now you can save each of the elements in the Files\_List and Systems\_List into variables called filename and filename\_systems. This will make it easier for you to call them later on.

6) Now, you can use the Plots function. Note that this function has a lot of keywords and sub-functions, but its main goal is to produce a plot for any of the previous plots that have looked at a distribution over systems or snapshots. This means that you don't have the orbital plane plot or the semi major axis tracking plots as they pertain to just one system.

7) If you are comparing more than one file, you can use Multi\_Plot. It has the same names for which\_plot as Plots and uses the same keywords, though it provides bins by default. It should be easy to understand after understanding how to use Plots and reading the documentation for Multi\_Plot.

**Plots Function:**

This function operates by recieving a string known as 'which\_plot'. I will detail the expected inputs here for each of the possible 'which\_plot's.

**Section I (Distribution Plots for one snapshot):**

**1) System Mass**

This is the system mass distribution. You can view both the system mass dist in isolation or you can compare it with the IMF.

**Inputs required:**

which\_plot = 'System Mass';

system: (This is the systems of the snapshot to look at. E.g M2e4\_C\_M\_2e7\_systems[-1] will be the systems in the last snapshot)

file: This is the file you want to look at. E.g M2e4\_C\_M\_2e7

**Inputs optional:**

snapshot: (e.g -1)

This is the snapshot you are looking at. It is required if you are comparing with the IMF but otherwise you don't need it since you can use it in the 'systems' parameter.

compare:(e.g True or False)

This is if you want to compare the distribution to the IMF. Note that you will have to provide the snapshot number if you do. False by default.

log: True or False

Sets the y axis to log systems. True by default.

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Inputs optional:**

snapshot: (e.g -1)

This is the snapshot you are looking at. It is required if you are comparing with the IMF but otherwise you don't need it since you can use it in the 'systems' parameter.

compare:(e.g True or False)

This is if you want to compare the distribution to the IMF. Note that you will have to provide the snapshot number if you do. False by default.

**Example:**

1. Plots(‘System Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7) [Basic Plot]
2. Plots(‘System Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with the filtered data]
3. Plots(‘System Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,compare = True,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with filtered data and IMF]
4. Plots(‘System Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,plot = False) [Return the basic plot values]

**2) Primary Mass**

This is the system mass distribution. You can view both the primary mass dist in isolation or you can compare it with the IMF.

**Inputs required:**

which\_plot = 'Primary Mass';

system: (This is the systems of the snapshot to look at. E.g M2e4\_C\_M\_2e7\_systems[-1] will be the systems in the last snapshot)

file: This is the file you want to look at. E.g M2e4\_C\_M\_2e7

**Inputs optional:**

snapshot: (e.g -1)

This is the snapshot you are looking at. It is required if you are comparing with the IMF but otherwise you don't need it since you can use it in the 'systems' parameter.

compare:(e.g True or False)

This is if you want to compare the distribution to the IMF. Note that you will have to provide the snapshot number if you do. False by default.

log: True or False

Sets the y axis to log systems. True by default.

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Example:**

1. Plots(‘Primary Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7) [Basic Plot]
2. Plots(‘Primary Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with the filtered data]
3. Plots(‘Primary Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,compare = True,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with filtered data and IMF]
4. Plots(‘Primary Mass’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,plot = False) [Return the basic plot values]

**3) Companion Mass Ratio Distribution**

This is the companion mass distribution (mass of the companion/mass of primary) for companions in the system. It can be used to only look at the most massive companion as well as compare to the IMF to see if the companions have been randomly sampled.

**Inputs required:**

which\_plot = 'Mass Ratio';

system: (This is the systems of the snapshot to look at. E.g M2e4\_C\_M\_2e7\_systems[-1] will be the systems in the last snapshot)

file: This is the file you want to look at. E.g M2e4\_C\_M\_2e7

upper\_limit: The maximum mass of the primaries you want to look at.

lower\_limit: The minimum mass of the primaries you want to look at.

**Inputs optional:**

all\_companions: Look at the mass ratio of all companions, not just the most massive. True by default.

compare: Compare the distribution to a normalized IMF (In the case of all\_companions) (and/or) the normalized IMF weighted by number of systems (in case of only secondary)

log: True or False

Sets the y axis to log systems. True by default.

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Example:**

1. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,upper\_limit = 1.3,lower\_limit = 0.7) [Basic Plot for solar type systems]
2. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,all\_companions = False, upper\_limit = 10000,lower\_limit = 0) [Basic Plot but only for the most massive companions in all systems]
3. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with the filtered data]
4. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True, Master\_File = M2e4\_C\_M\_2e7\_systems, snapshot = -1,compare = True) [Compare with IMF to check if companions are randomly drawn]
5. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,compare = True,all\_companions = False,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with IMF and weighted IMF to check if the most massive companions are randomly drawn]
6. Plots(‘Mass Ratio’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,plot = False) [Return the basic plot values]

**4) Semi Major Axis Distribution**

This is the semi major axis dist. You can look at the semi major axis between the primary and secondary subsystems. You can also check the semi major axis between all subsystems with the all\_companions keyword. If you use the limits of the Moe DiStefano Paper for solar mass primaries (0.8-1.2), the observations will also be plotted.

**Inputs required:**

which\_plot = 'Semi Major Axis';

system: (This is the systems of the snapshot to look at. E.g M2e4\_C\_M\_2e7\_systems[-1] will be the systems in the last snapshot)

file: This is the file you want to look at. E.g M2e4\_C\_M\_2e7

upper\_limit: The maximum mass of the primaries you want to look at.

lower\_limit: The minimum mass of the primaries you want to look at.

**Inputs optional:**

all\_companions: Look at the semi major axis of all subsystems, not just the primary and secondary. True by default.

log: True or False

Sets the y axis to log systems. True by default.

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Example:**

1. Plots(‘Semi Major Axis’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,upper\_limit = 1.3,lower\_limit = 0.7) [Basic Plot for solar type systems]
2. Plots(‘Semi Major Axis’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,all\_companions = False, upper\_limit = 10000,lower\_limit = 0) [Basic Plot but only for the semi major axis between primary and secondary for all systems]
3. Plots(‘Semi Major Axis’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Compare with the filtered data]
4. Plots(‘Semi Major Axis’,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,plot = False) [Return the basic plot values]

**Section II (Multiplicity Mass Dist. Plots):**

which\_plot = 'Multiplicity'

**5) Multiplicity Properties**

This is the comparison of stars that are primary, non-primary and unbound stars. Primary Stars are the most massive stars in multiple star systems, non-primary stars are stars in multiple star systems that are not primaries and unbound stars are stars in single star systems. This is plotted over a distribution of masses in log space.

**Inputs required:**

multiplicity = 'Properties'

bins: 'observer' or 'continous':

Observer bins are the Duchene Krauss bins. Continous bins are continous in log space.

**Example:**

1. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Properties ,bins = ‘observer’) [Basic Plot with observer bins]
2. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Properties’, bins = ‘continous, filtered = True, snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Basic Plot with continous bins and the filtered data also plotted]

**6) Multiplicity Fraction**

The multiplicity fraction at different log primary masses. It can be defined as no of primaries/no of primaries+single stars.

**Inputs required:**

multiplicity = 'Fraction'

bins: 'observer' or 'continous':

Observer bins are the Duchene Krauss bins. Continous bins are continous in log space.

**Inputs Optional:**

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Example:**

1. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Fraction’,bins = ‘observer’) [Basic Plot with observer bins]
2. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Fraction’,bins = ‘continous,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Basic Plot with continous bins and the filtered data also plotted]

**6) Multiplicity Frequency**

The multiplicity Frequency at different log primary masses. It can be defined as no of non-primaries/no of primaries+unbound stars.

**Inputs required:**

multiplicity = 'Frequency'

bins: 'observer' or 'continous':

Observer bins are the Duchene Krauss bins. Continous bins are continous in log space.

**Inputs Optional:**

filtered: True or False

Compares the results with a filter that discards companions less than 0.1 solar masses and averages over the last 10 snapshots.

**Example:**

1. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Frequency’, bins = ‘observer’) [Basic Plot with observer bins]
2. Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Frequency’, bins = ‘continous,filtered = True,snapshot = -1,Master\_File = M2e4\_C\_M\_2e7\_systems) [Basic Plot with continous bins and the filtered data also plotted]

**BONUS PLOTS:**

1. **Density/Mass Density Plots**

This function gives you the density or mass density at formation of primaries and solo stars within the same bins as the multiplicity. It also includes the error

e.g

1) Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Density, bins = ‘observer’)

2) Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Mass Density, bins = ‘observer’)

**2)Density Separate/Mass Separate Plots**

This function gives you the density or mass density at formation separated by solo, primary or companion stars within the multiplicity bins. It also includes the error for each.

e.g

1) Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Density Separate, bins = ‘observer’)

2) Plots(‘Multiplicity,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Mass Density Separate, bins = ‘observer’)

**Section III (Multiplicity Evolution Plot):**

**7) Multiplicity Time Evolution**

This is the multiplicity fraction/frequency at any time in the simulation. It is plotted in two ways, the multiplicity at any time and the multiplicity only for stars that have stopped accreting mass at that time.

which\_plot: 'Multiplicity Time Evolution'

**Inputs required:**

file: The file you want to look at. E.g M2e4\_C\_M\_2e7

Master\_File: The file with system assignment performed at every snapshot. E.g M24\_C\_M\_2e7\_systems

**Inputs Optional:**

multiplicity: Either 'fraction' or 'frequency'.

steps: The number of snapshots to look at it in a single step. This would usually be 1 if you want to look at every snapshot

start: First Snapshot to look at

read\_in\_result: Whether to read in result from the Master File(read\_in\_result = True) or perform system assignment.

upper\_limit: The maximum mass of the primaries you want to look at.

lower\_limit: The minimum mass of the primaries you want to look at.

**Example:**

1. Plots(‘Multiplicity Time Evolution’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Fraction’, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,upper\_limit = 1.3,lower\_limit = 0.7,target\_mass = 1) [Multiplicity Fraction Evolution]
2. Plots(‘Multiplicity Time Evolution’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Frequency’, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,upper\_limit = 1.3,lower\_limit = 0.7,target\_mass = 1) [Multiplicity Frequency Evolution]

**7) Multiplicity Lifetime Evolution**

This is the multiplicity fraction/frequency of stars of the selected mass and born in a selected timeframe. Then, it follows the evolution of the stars till the end of the simulation.

which\_plot: 'Multiplicity Lifetime Evolution'

**Inputs required:**

file: The file you want to look at. E.g M2e4\_C\_M\_2e7

Master\_File: The file with system assignment performed at every snapshot. E.g M24\_C\_M\_2e7\_systems

T: The list of times that the systems are born in the simulation. It is calculated with 0 being the end of the simulation. E.g [2] is 2 Myr from the end of simulation.

dt: The list of tolerances that the times have.

**Inputs Optional:**

multiplicity: Either 'fraction' or 'frequency'.

steps: The number of snapshots to look at it in a single step. This would usually be 1 if you want to look at every snapshot.

start: First Snapshot to look at.

read\_in\_result: Whether to read in result from the Master File(read\_in\_result = True) or perform system assignment.

upper\_limit: The maximum mass of the primaries you want to look at.

lower\_limit: The minimum mass of the primaries you want to look at.

zero: Whether to start from the time the star is formed ('formation') or stops accreting mass ('consistent mass').

**Example:**

1. Plots(‘Multiplicity Lifetime Evolution’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Fraction’, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,upper\_limit = 1.3,lower\_limit = 0.7,target\_mass = 1,T = [1,2],dt = [1,1]) [Multiplicity Fraction Evolution]
2. Plots(‘Multiplicity Lifetime Evolution’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7,multiplicity = ‘Frequency’, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,upper\_limit = 1.3,lower\_limit = 0.7,target\_mass = 1,T = [1,2],dt = [1,1]) [Multiplicity Frequency Evolution]

**8) YSO Multiplicity**

This is the multiplicity fraction of all systems younger than a certain age (and older than some age). A system is a YSO system if a majority of its objects are under the minimum age. The function also plots the number of YSO systems at different times and the average mass of them.

which\_plot: 'YSO Multiplicity'

**Inputs required:**

file: The file you want to look at. E.g M2e4\_C\_M\_2e7

Master\_File: The file with system assignment performed at every snapshot. E.g M24\_C\_M\_2e7\_systems

ProtoStellarAge: The protostellar age of the original file. This is one of the outputs of the load\_files function, so just provide that output.

target\_age: The age which all the objects are under.

min\_age: The minumum age of the objects. By default, it is 0.

**Inputs Optional:**

steps: The number of snapshots to look at it in a single step. This would usually be 1 if you want to look at every snapshot.

start: First Snapshot to look at.

**Example:**

1. Plots(‘YSO Multiplicity’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,target\_age = 1) [YSO as defined as objects lesser than 1 Myrs of age]
2. Plots(‘YSO Multiplicity’ ,M2e4\_C\_M\_2e7\_systems[-1], M2e4\_C\_M\_2e7, Master\_File = M2e4\_C\_M\_2e7\_systems,filename = ‘M2e4\_C\_M\_2e7’,target\_age = 1,min\_age = 0.5) [YSO as defined as objects lesser than 1 Myrs of age but older than 0.5 Myrs]

**Section IV (Scatter Plots):**

**9) Mass Ratio vs Semi Major Axis**

A scatterplot of mass ratio vs semi major axes. This is only plotted for the most massive companion.

**Inputs required:**

file: The file you want to look at. E.g M2e4\_C\_M\_2e7

systems: The systems you want to look at. E.g M2e4\_C\_M\_2e7\_systems[-1]

upper\_limit: The maximum mass of the primaries you want to look at.

lower\_limit: The minimum mass of the primaries you want to look at.

**Notes:**

1. If you provide the filename as ‘filename = filename’, it will label the file on the plot.