Instituto de astronomía
unam

# Dynamical Evolution of Planetary Disk Under the Effect of Stellar Encounters

Instituto de Astronomía, UNAM
**Santiago Torres**

ADeLA 2014
September 29 2014
Santiago de Chile, Chile

Mon. Not. R. Astron. Soc. **000**, ??–?? ()  Printed 23 September 2014  (MN LaTeX style file v2.2)

# Dynamical Evolution of Planetary Disks Under the Effect of Stellar Encounters

Santiago Torres [1,⋆] & Bárbara Pichardo [1]

[1] *Instituto de Astronomía, Universidad Nacional Autónoma de México, Apdo. postal 70-264 Ciudad Universitaria, D.F., México*

ADeLA 2014
September 29 2014
Santiago de Chile, Chile

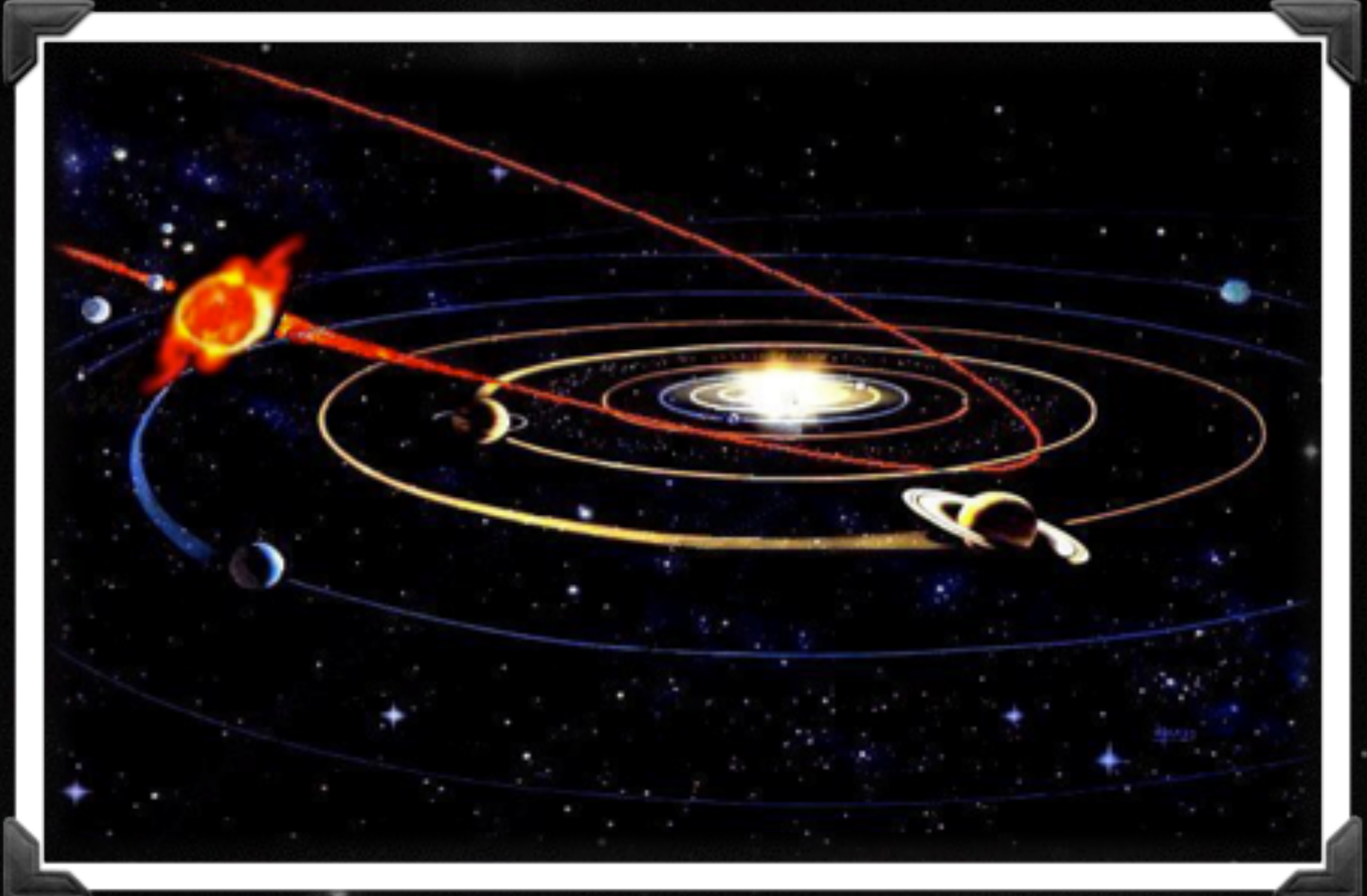
# Dynamical Evolution of Planetary Disk Under the Effect of Stellar Encounters

Instituto de Astronomía, UNAM
**Santiago Torres**

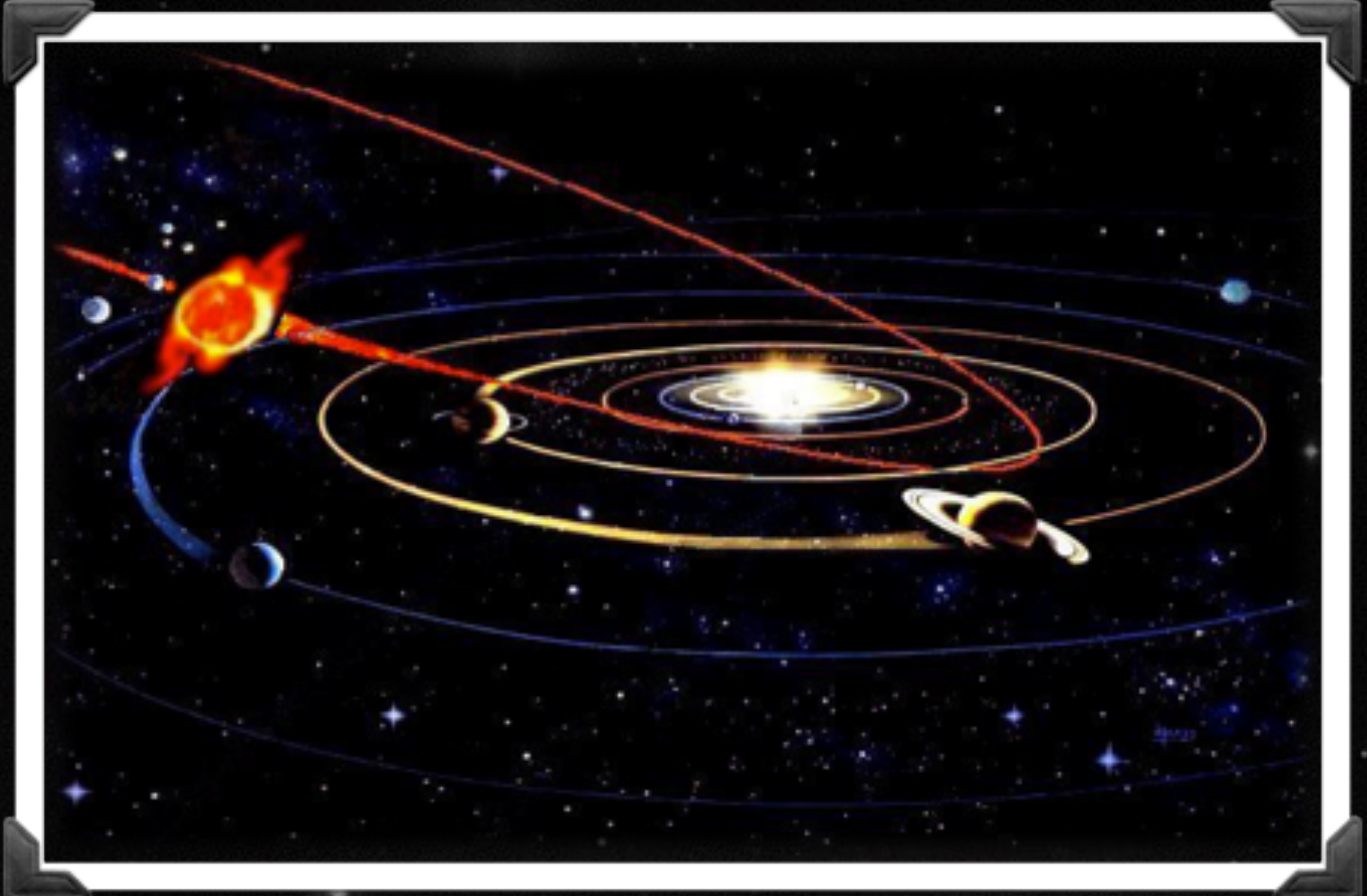
ADeLA 2014
September 29 2014
Santiago de Chile, Chile

# Goal

# Goal



# Goal



Analyze the orbital conditions of a planetary disk which interacts gravitationally with a passing star in a stellar cluster.

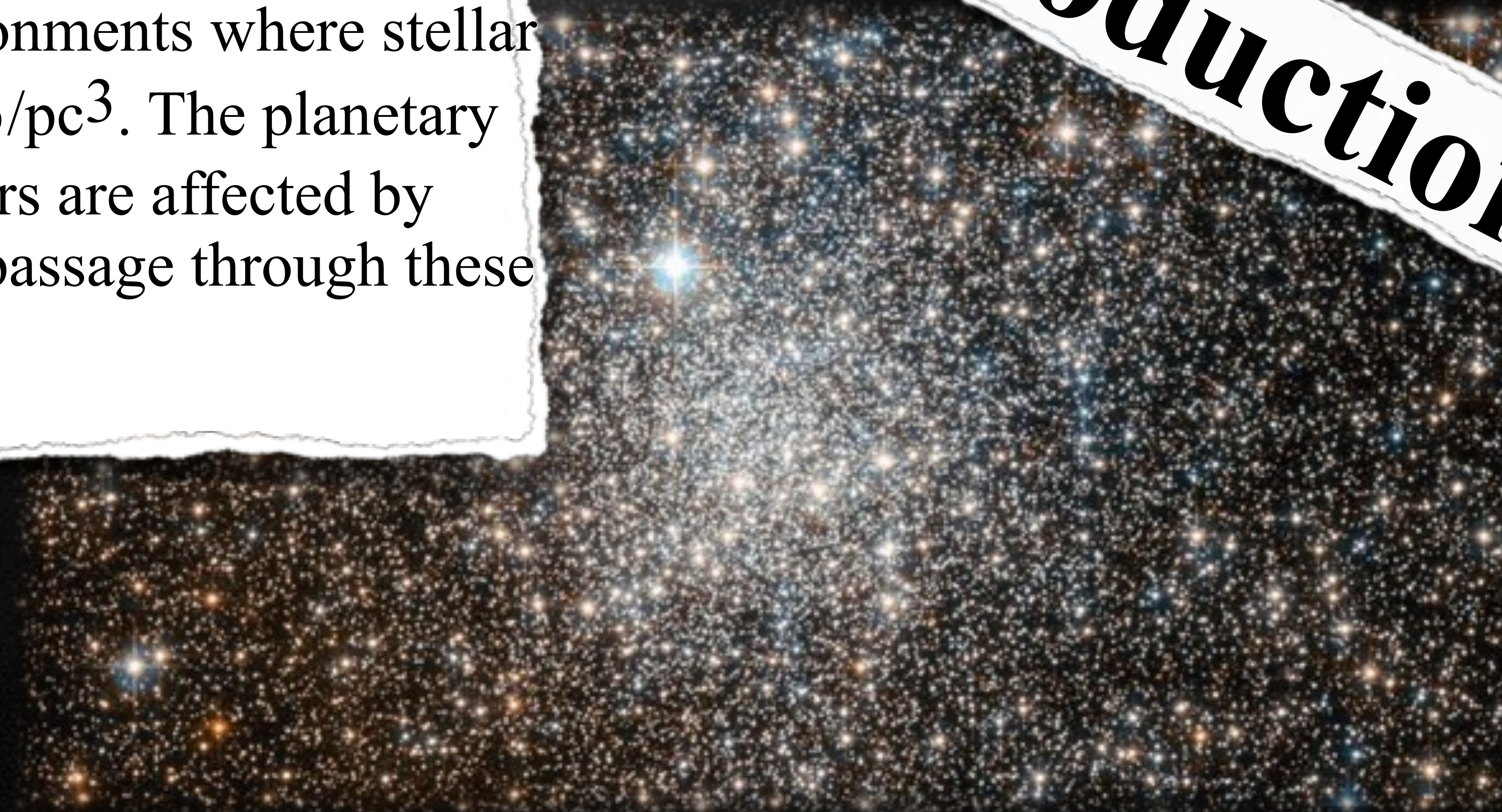
# Introduction

# Introduction

Most stars are formed in stellar clusters (Carpenter 2000; Lada & Lada 2003), which are environments where stellar density reaches $1 M_\odot/pc^3$ to $10^4 M_\odot/pc^3$. The planetary disks around stars in stellar clusters are affected by gravitational interactions along their passage through these stellar regions.

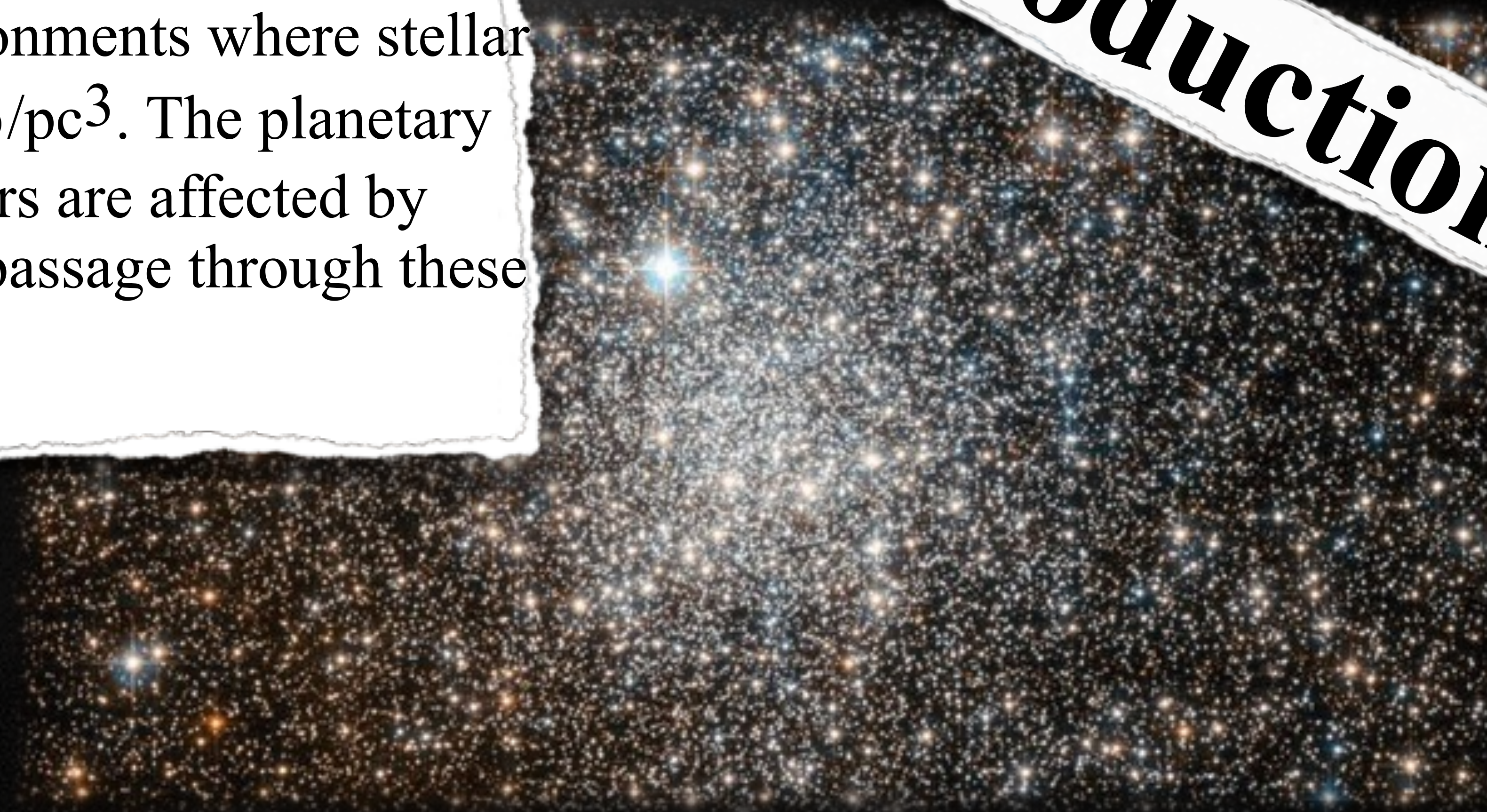
# Introduction

Most stars are formed in stellar clusters (Carpenter 2000; Lada & Lada 2003), which are environments where stellar density reaches $1 M_{\odot}/pc^3$ to $10^4 M_{\odot}/pc^3$. The planetary disks around stars in stellar clusters are affected by gravitational interactions along their passage through these stellar regions.



# Introduction

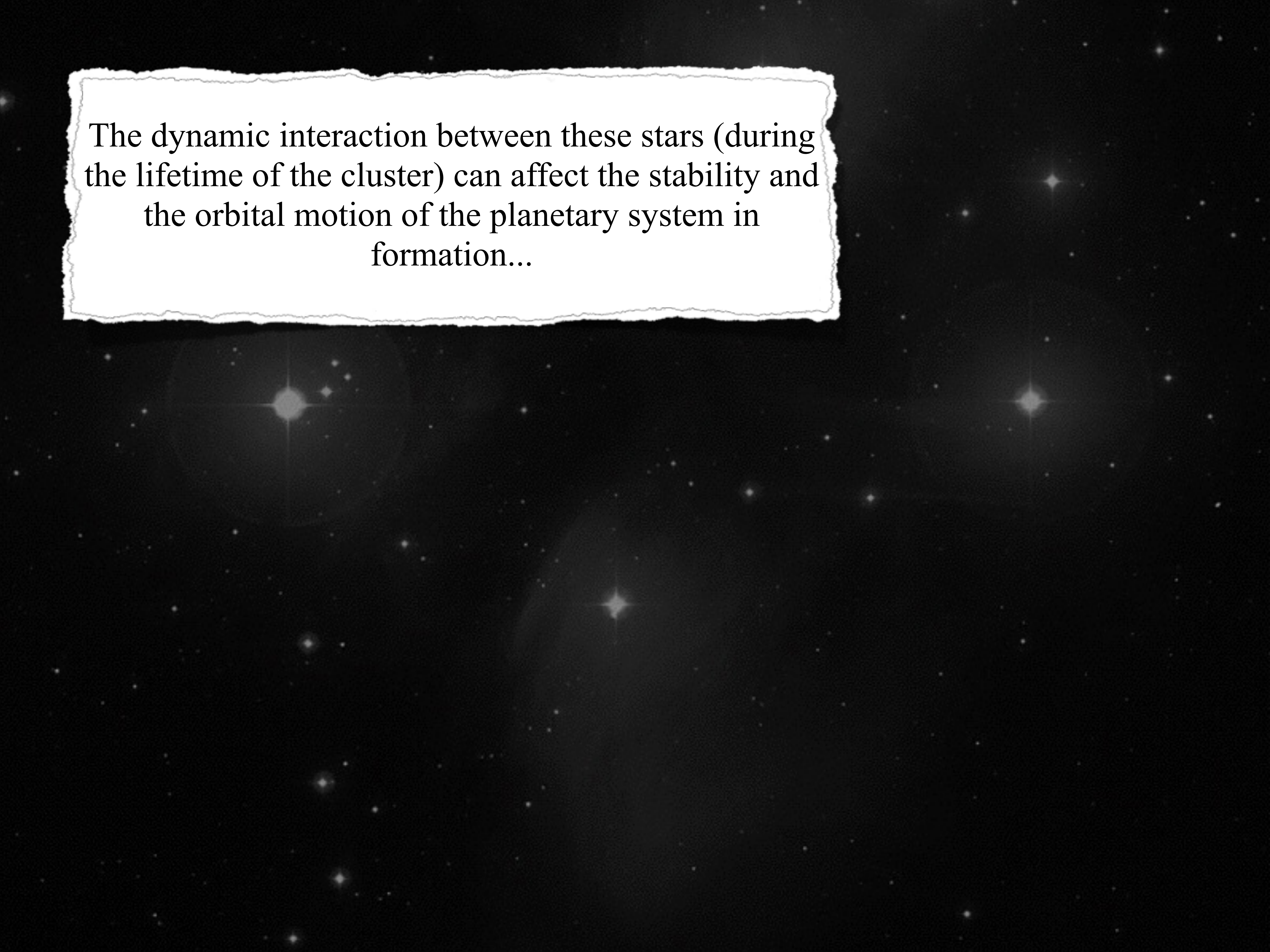
Most stars are formed in stellar clusters (Carpenter 2000; Lada & Lada 2003), which are environments where stellar density reaches $1 M_{\odot}/pc^3$ to $10^4 M_{\odot}/pc^3$. The planetary disks around stars in stellar clusters are affected by gravitational interactions along their passage through these stellar regions.



# Introduction

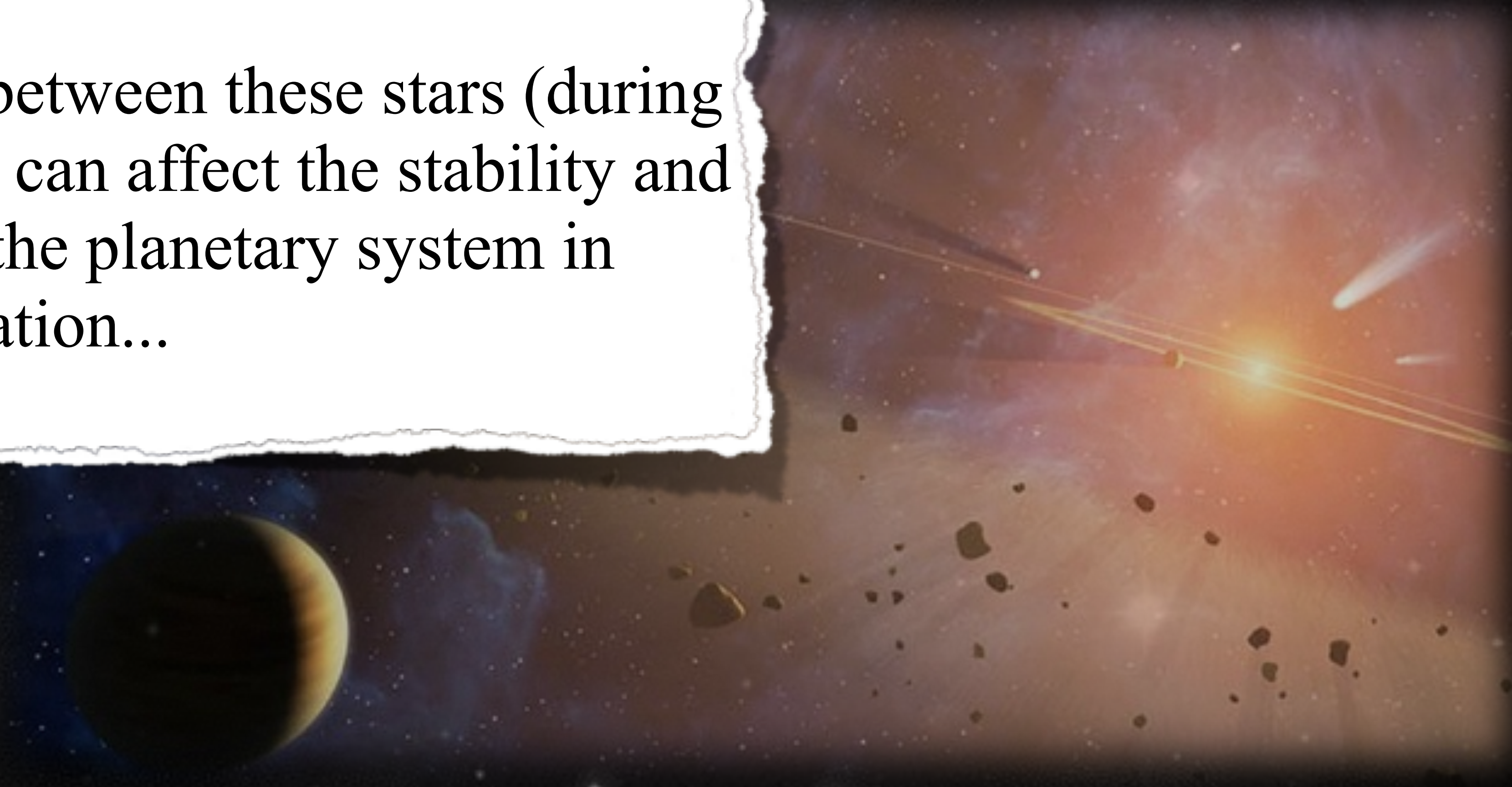
Most stars are formed in stellar clusters (Carpenter 2000; Lada & Lada 2003), which are environments where stellar density reaches $1M_{\odot}/pc^3$ to $10^4M_{\odot}/pc^3$. The planetary disks around stars in stellar clusters are affected by gravitational interactions along their passage through these stellar regions.

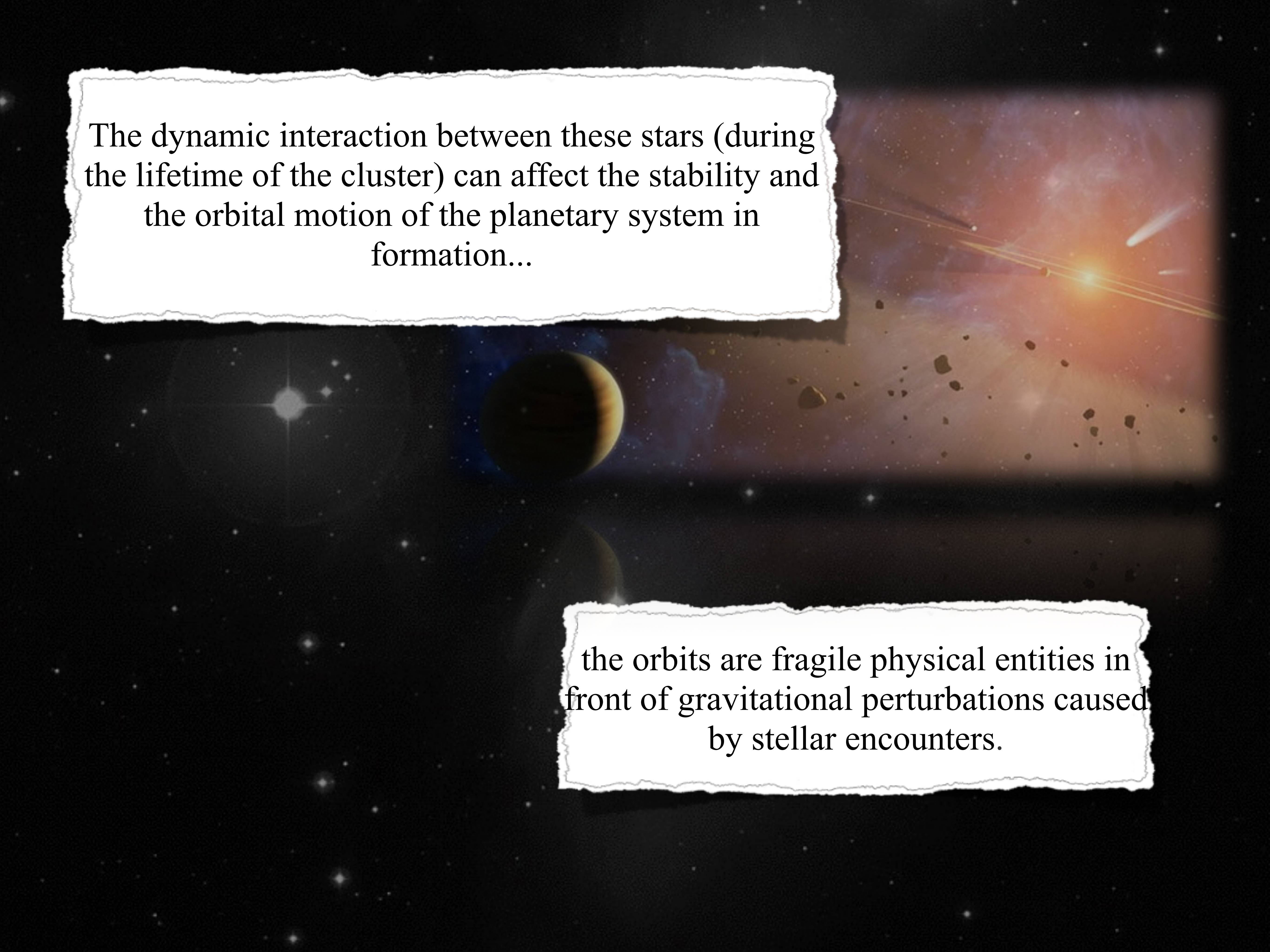
The mass distribution of the stars in these environments decrease with the radii => from the most massive star in the inner region to the very low mass stars in the outer region according with the IMF of the stellar clusters (Kroupa 2001, Sabbi et al. 2008, Silva-Villa et al. 2007, Oey 2011, Bonnell 2001, …)..



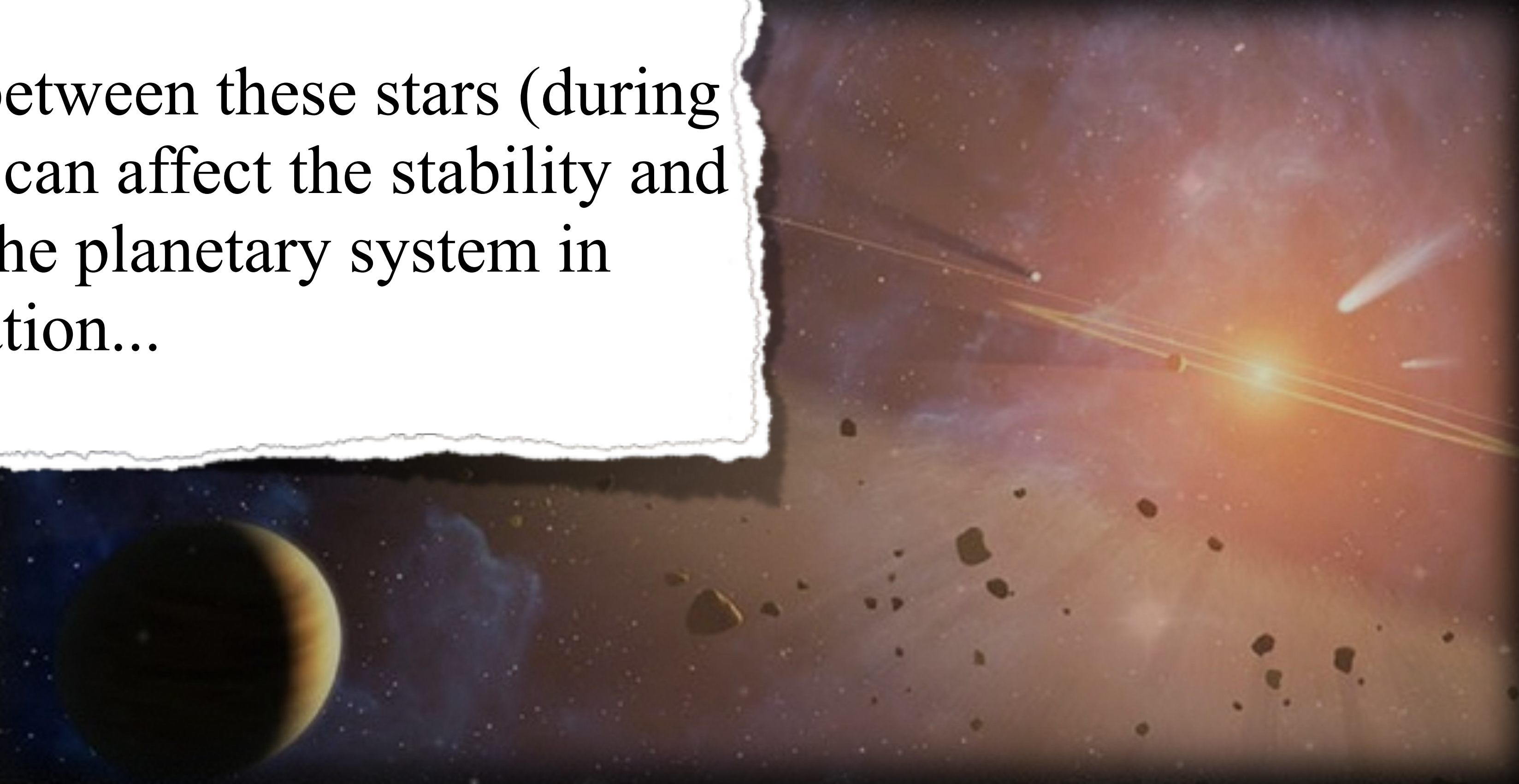
The dynamic interaction between these stars (during the lifetime of the cluster) can affect the stability and the orbital motion of the planetary system in formation...

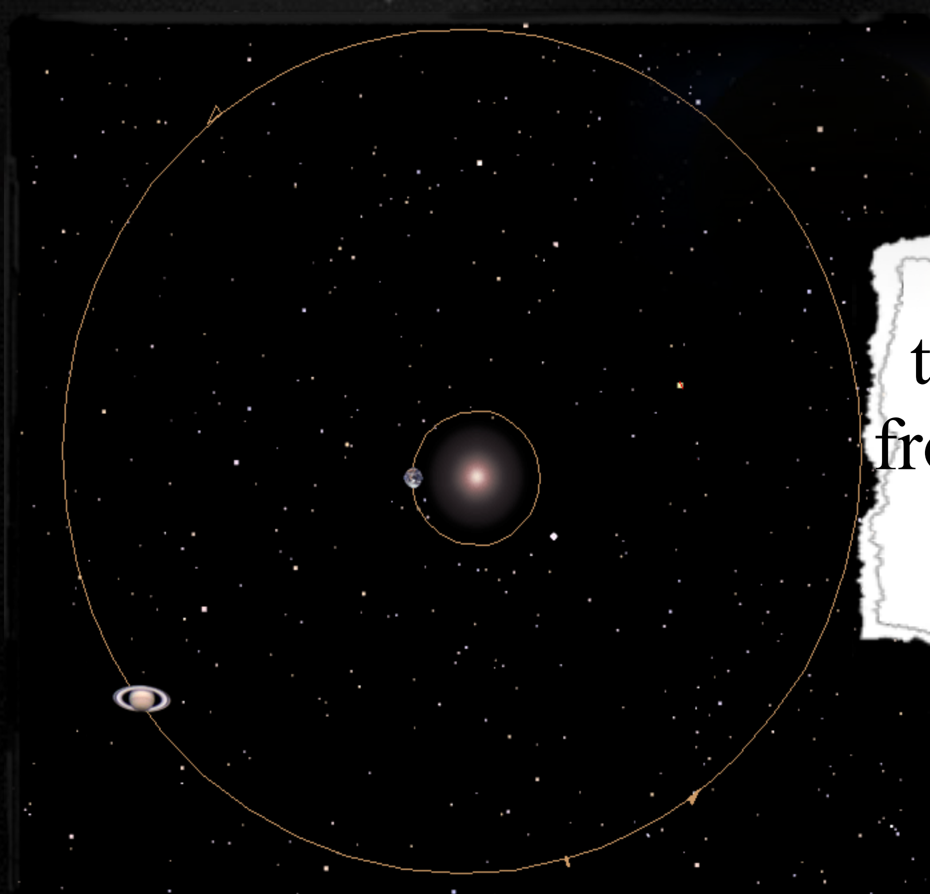
The dynamic interaction between these stars (during the lifetime of the cluster) can affect the stability and the orbital motion of the planetary system in formation...




The dynamic interaction between these stars (during the lifetime of the cluster) can affect the stability and the orbital motion of the planetary system in formation...
the orbits are fragile physical entities in front of gravitational perturbations caused by stellar encounters.

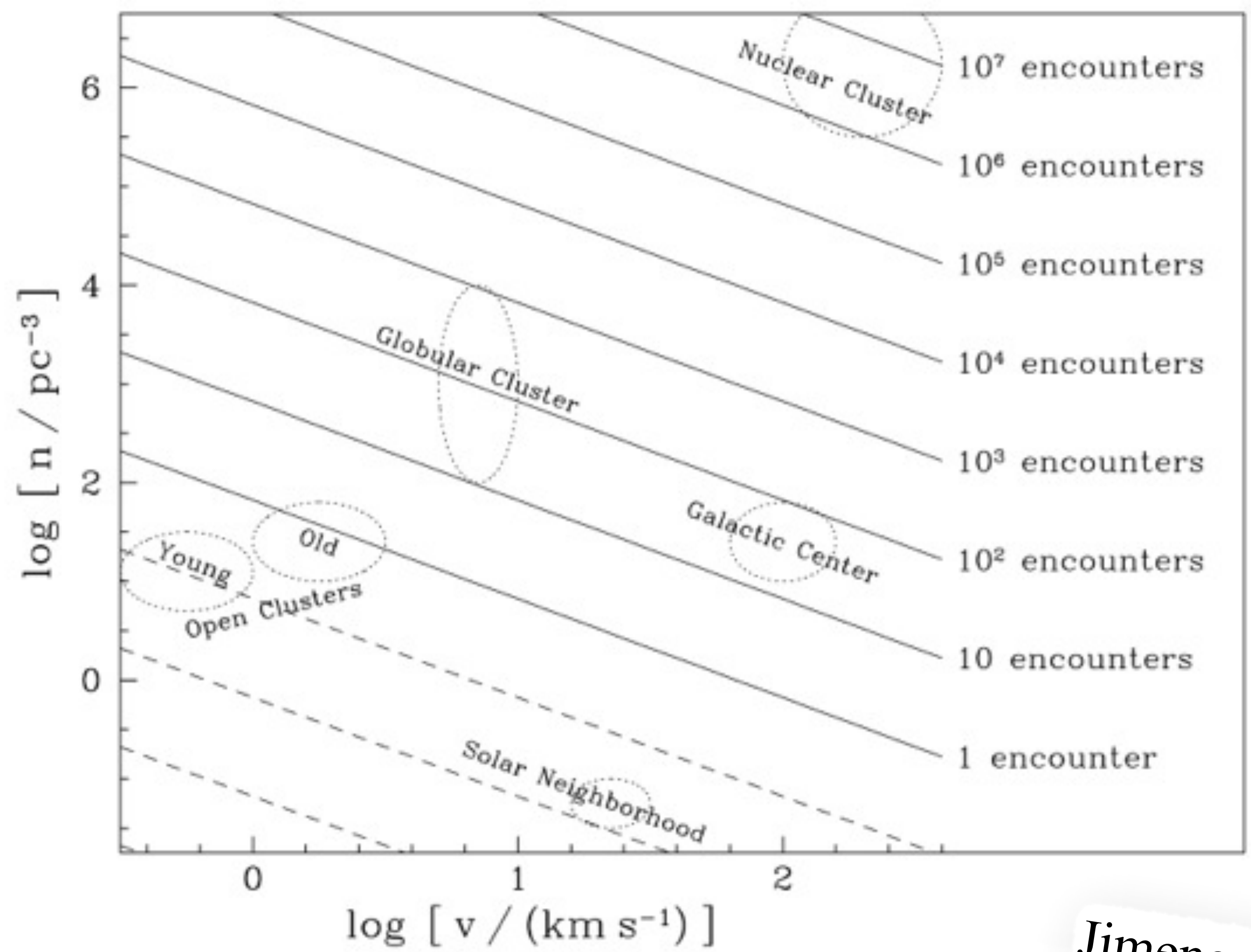
The dynamic interaction between these stars (during the lifetime of the cluster) can affect the stability and the orbital motion of the planetary system in formation...





the orbits are fragile physical entities in front of gravitational perturbations caused by stellar encounters.

# Encounter Rate




$$N_e = 4\pi n v T_e R^2$$

Jimenez-Torres et al. 2013

Log-log diagram of density vs. velocity dispersion in different Galactic environments, marked with an elliptical region that approximates typical values from literature. Straight lines represent the number of encounters, given a density and velocity dispersion for a total integration time Te of 5 Gyr (for all environments). All environments included have existed for the integration times we employed approximately (the most of them even more), except for young clusters (they live bounded about 10^8 years), however, this environment is so rarified that the number of encounters is almost the same in the total integration time Te employed.

# Method

# Method

This work was developed in a theoretical way by means of numerical simulations, that simulate a planetary or debris cold disk as test particle system dominated by host star.

# Method

This work was developed in a theoretical way by means of numerical simulations, that simulate a planetary or debris cold disk as test particle system dominated by host star.

```
      SUBROUTINE ODEINT2(ystart,nvar,x1,x2,eps,h1,hmin,nok,nbad,derivs2,
     * BSSTEP2)
      INTEGER nbad,nok,nvar,KMAXX,MAXSTP,NMAX
      DOUBLE PRECISION eps,h1,hmin,x1,x2,ystart(nvar),TINY
      EXTERNAL derivs2,BSSTEP2,condin,pot
      PARAMETER (NEQ=6,NEQext=7,maxorb=10001,maxhyp=10001)
      PARAMETER (MAXSTP=10000000,NMAX=50,KMAXX=200,TINY=1.d-30)
      INTEGER i,kmax,kount,nstp
      DOUBLE PRECISION dxsav,h,hdid,hnext,x,xsav,dydx(NMAX),xp(KMAXX),
     * y(NMAX),yp(NMAX,KMAXX),yscal(NMAX),Yiner(NEQ),
     * tsum,ERROR,ENERGY,hang
      DOUBLE PRECISION tTOT,tTOTuc,dTOTuc
      COMMON /path/ kmax,kount,dxsav,xp,yp
      x=x1
      h=sign(h1,x2-x1)
      nok=0
      nbad=0
      kount=0
      do 11 i=1,nvar
        y(i)=ystart(i)
      continue
      if (kmax.gt.0) xsav=x-2.d0*dxsav
      do 16 nstp=1,MAXSTP
        call derivs2(x,y,dydx)
        do 12 i=1,nvar
          yscal(i)=abs(y(i))+abs(h*dydx(i))+TINY
        continue
        if(kmax.gt.0)then
          if(abs(x-xsav).gt.abs(dxsav)) then
            if(kount.lt.kmax-1)then
              kount=kount+1
              xp(kount)=x
              do 13 i=1,nvar
                yp(i,kount)=y(i)
              continue
              xsav=x
            endif
          endif
        endif
        if((x+h-x2)*(x+h-x1).gt.0.d0) h=x2-x
        call BSSTEP2(y,dydx,nvar,x,h,eps,yscal,hdid,hnext,derivs2)
```

Pichardo & Torres 2012

# Method

This work was developed in a theoretical way by means of numerical simulations, that simulate a planetary or debris cold disk as test particle system dominated by host star.

```
      SUBROUTINE ODEINT2(ystart,nvar,x1,x2,eps,h1,hmin,nok,nbad,derivs2,
     * BSSTEP2)
      INTEGER nbad,nok,nvar,KMAXX,MAXSTP,NMAX
      DOUBLE PRECISION eps,h1,hmin,x1,x2,ystart(nvar),TINY
      EXTERNAL derivs2,BSSTEP2,condin,pot
      PARAMETER (NEQ=6,NEQext=7,maxorb=10001,maxhyp=10001)
      PARAMETER (MAXSTP=10000000,NMAX=50,KMAXX=200,TINY=1.d-30)
      INTEGER i,kmax,kount,nstp
      DOUBLE PRECISION dxsav,h,hdid,hnext,x,xsav,dydx(NMAX),xp(KMAXX),
     * y(NMAX),yp(NMAX,KMAXX),yscal(NMAX),Yiner(NEQ),
     * tsum,ERROR,ENERGY,hang
      DOUBLE PRECISION tTOT,tTOTuc,dTOTuc
      COMMON /path/ kmax,kount,dxsav,xp,yp
      x=x1
      h=sign(h1,x2-x1)
      nok=0
      nbad=0
      kount=0
      do 11 i=1,nvar
        y(i)=ystart(i)
      continue
      if (kmax.gt.0) xsav=x-2.d0*dxsav
      do 16 nstp=1,MAXSTP
        call derivs2(x,y,dydx)
        do 12 i=1,nvar
          yscal(i)=abs(y(i))+abs(h*dydx(i))+TINY
        continue
        if(kmax.gt.0)then
          if(abs(x-xsav).gt.abs(dxsav)) then
            if(kount.lt.kmax-1)then
              kount=kount+1
              xp(kount)=x
              do 13 i=1,nvar
                yp(i,kount)=y(i)
              continue
              xsav=x
            endif
          endif
        endif
        if((x+h-x2)*(x+h-x1).gt.0.d0) h=x2-x
        call BSSTEP2(y,dydx,nvar,x,h,eps,yscal,hdid,hnext,derivs2)
```

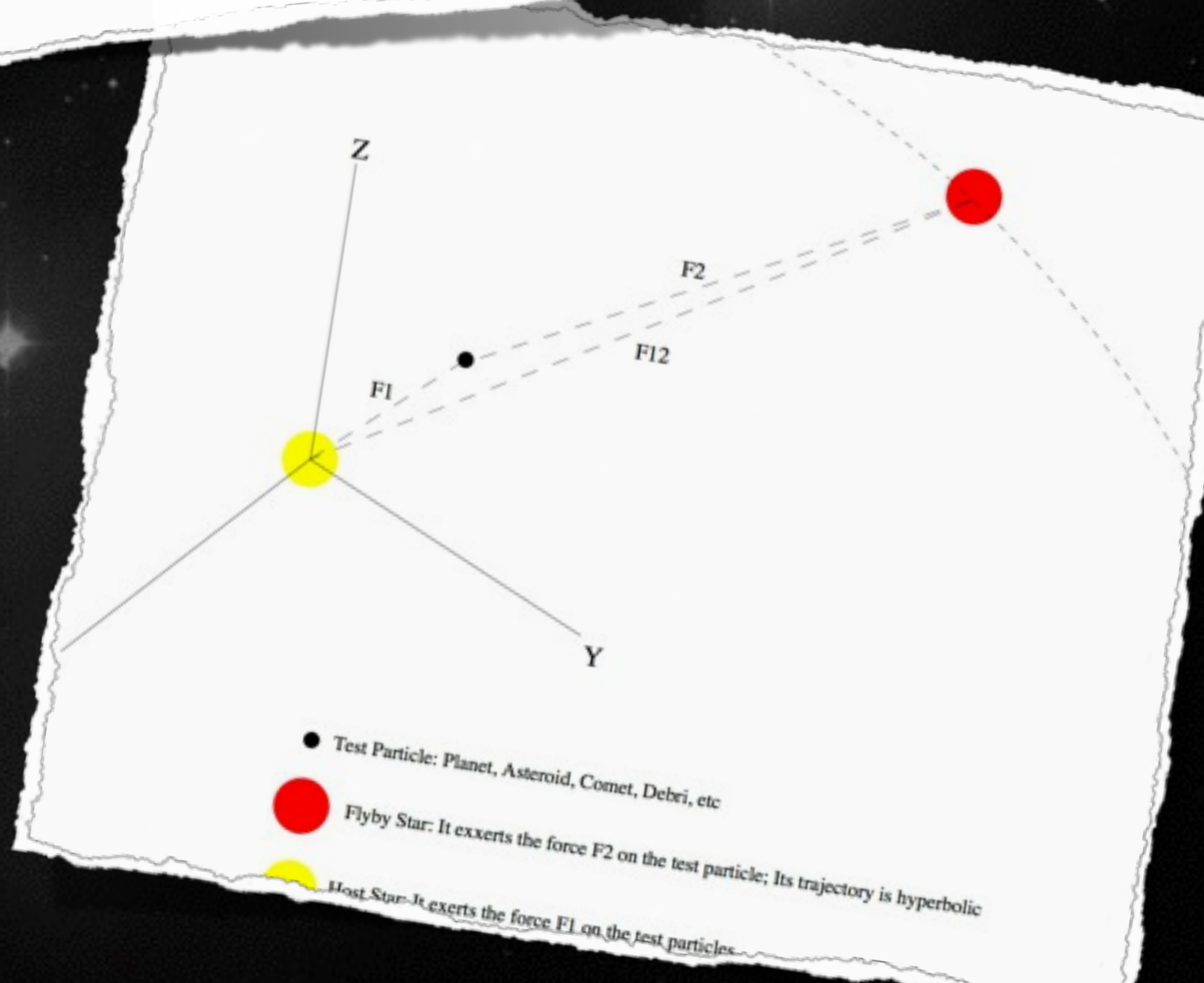
Pichardo & Torres 2012

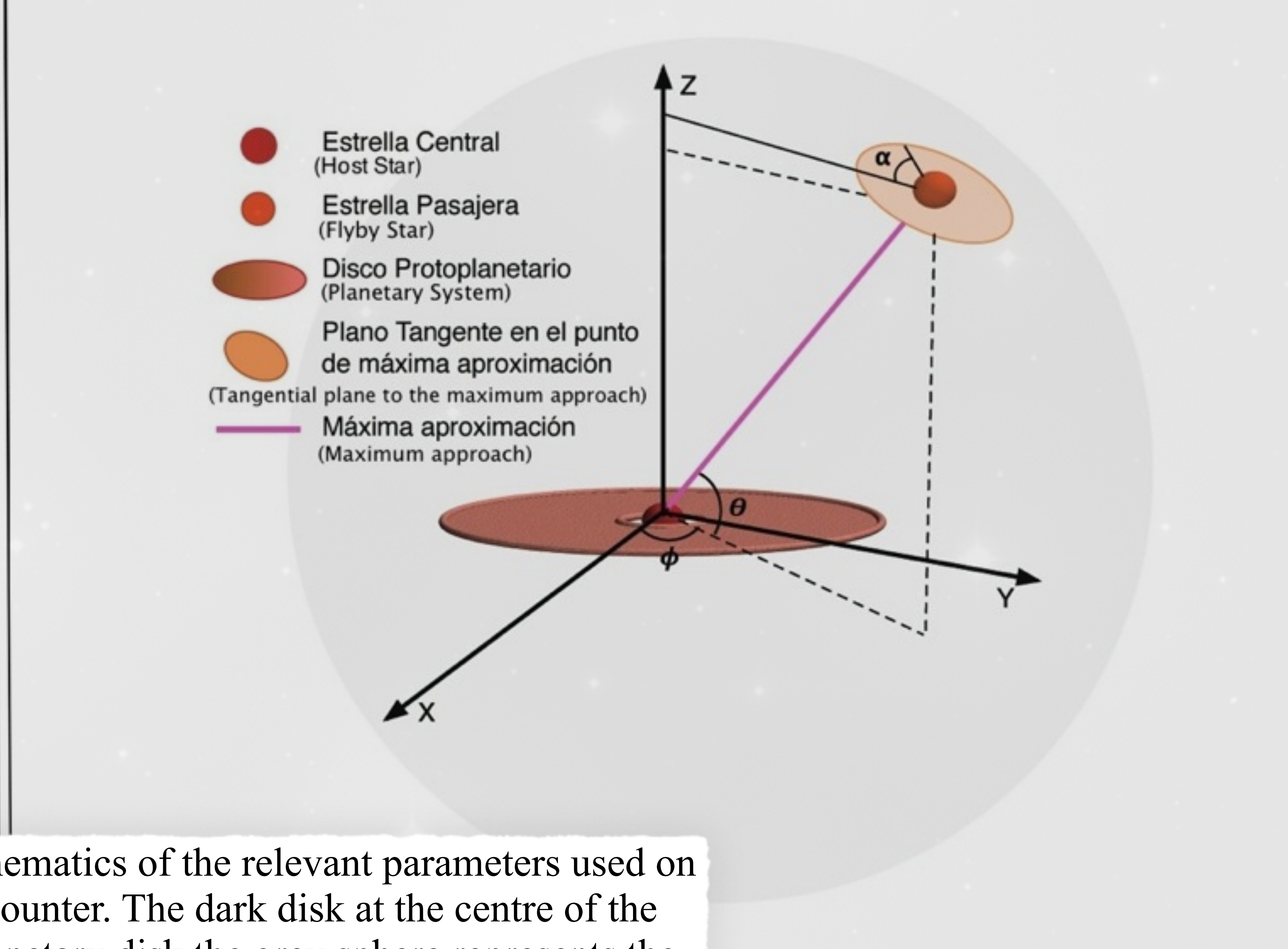
The code simulates the gravitational interaction between a planetary system characterized by a cold disk of test particles (representing planets, comets, etc… of the planetary system) in a Keplerian potential and a hyperbolic orbit of the flyby star.

This allows us to move from a three-body problem to a restricted three-body problem.

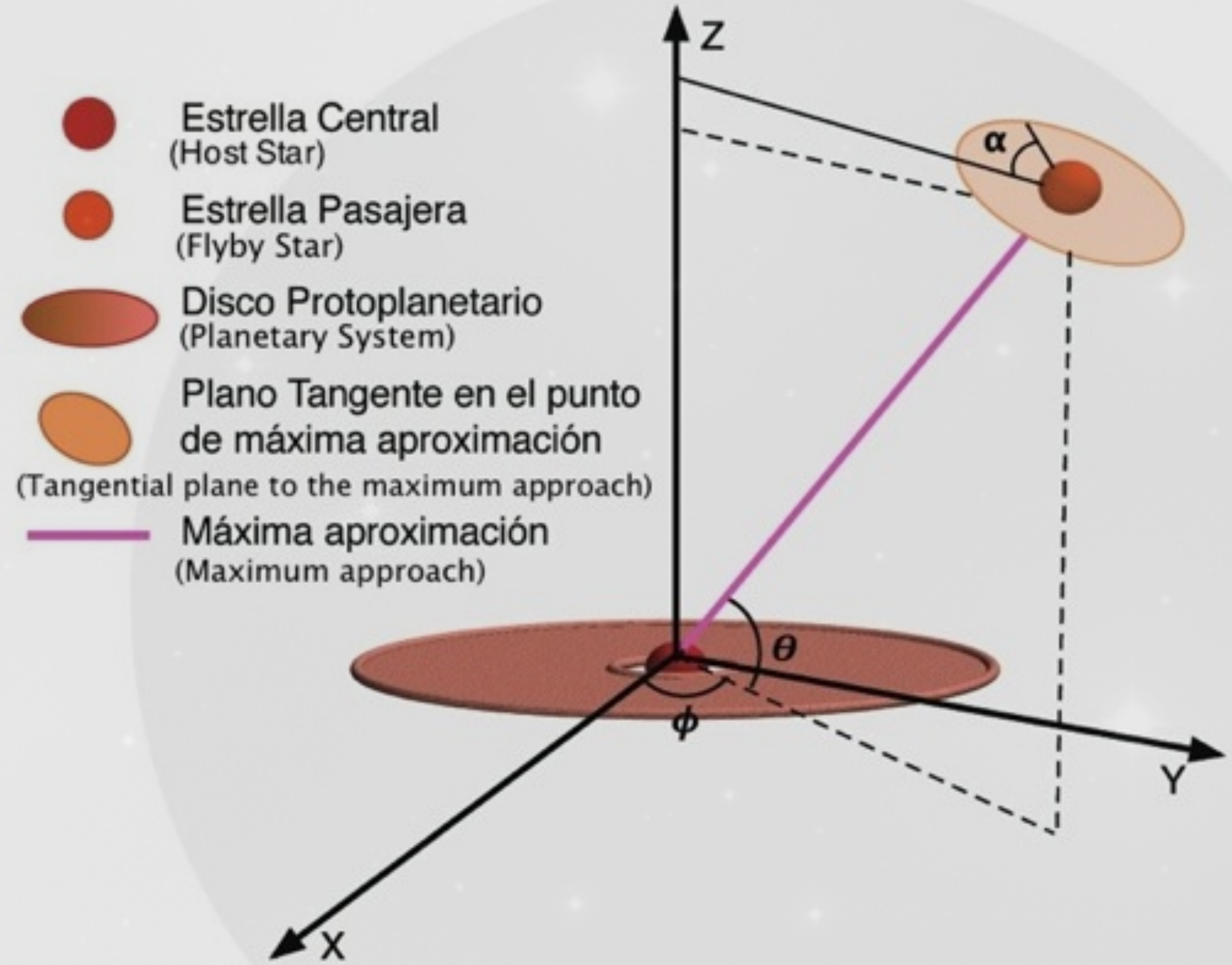
In general, the SEC solves the equations of motion in the non-inertial reference system of the central star, providing the required orbital parameters.

The code calculates the main orbital characteristics: eccentricity, major and minor semi-axes, perihelion, aphelion, and orbital inclinations of the test particle.






In Fig. 1, we show the schematics of the relevant parameters used on the code of a stellar encounter. The dark disk at the centre of the system represents the planetary disk the grey sphere represents the radius of the minimum distance of the flyby and the bright disk is tangent to the sphere at the point of minimum distance. The flyby attack angles are: φ, the azimuthal angle with respect to the disk, it goes from 0° to 360°; θ, the polar angle with respect to the disk, goes from −90° to 90°; and α, the angle between the flyby plane orbit and the symmetry axis of the planetary disc, it goes from 0° to 360°.




In Fig. 1, we show the schematics of the relevant parameters used on the code of a stellar encounter. The dark disk at the centre of the system represents the planetary disk the grey sphere represents the radius of the minimum distance of the flyby and the bright disk is tangent to the sphere at the point of minimum distance. The flyby attack angles are: φ, the azimuthal angle with respect to the disk, it goes from 0° to 360°; θ, the polar angle with respect to the disk, goes from −90° to 90°; and α, the angle between the flyby plane orbit and the symmetry axis of the planetary disc, it goes from 0° to 360°.

Fig.1 Geometry of encounter

# Code parameters

**Disk**
"Rmin (AU)=" 0.1d0(LMS), 0.5d0(VLMS) ,
"Rmax (AU)=" 100,150.0d0(LMS), 70.0d0(VLMS)

**Test particles**
"Norb="50
"Nph=" 50

**Interaction time**
"t1 (year)=" 0.d0
"t2 (year)=" 10000.d0

**Maximum approach**
"b or rp (0/1)=" 1
"b or rp value(AU)=" 100.1d0, 200.1d0, 300.1d0, 500.1d0, 1000.1d0

**Velocity dispersion (flyby).**
"v_inf (km/s)=" 8.0d0(GC), 3.0d0(OC)

**Interaction angle (Fig.1).**
"theta_rimp (deg)=" 45.d0
"alpha_rimp (deg)=" 45.0d0
"phi_rimp (deg)=" 0.d0

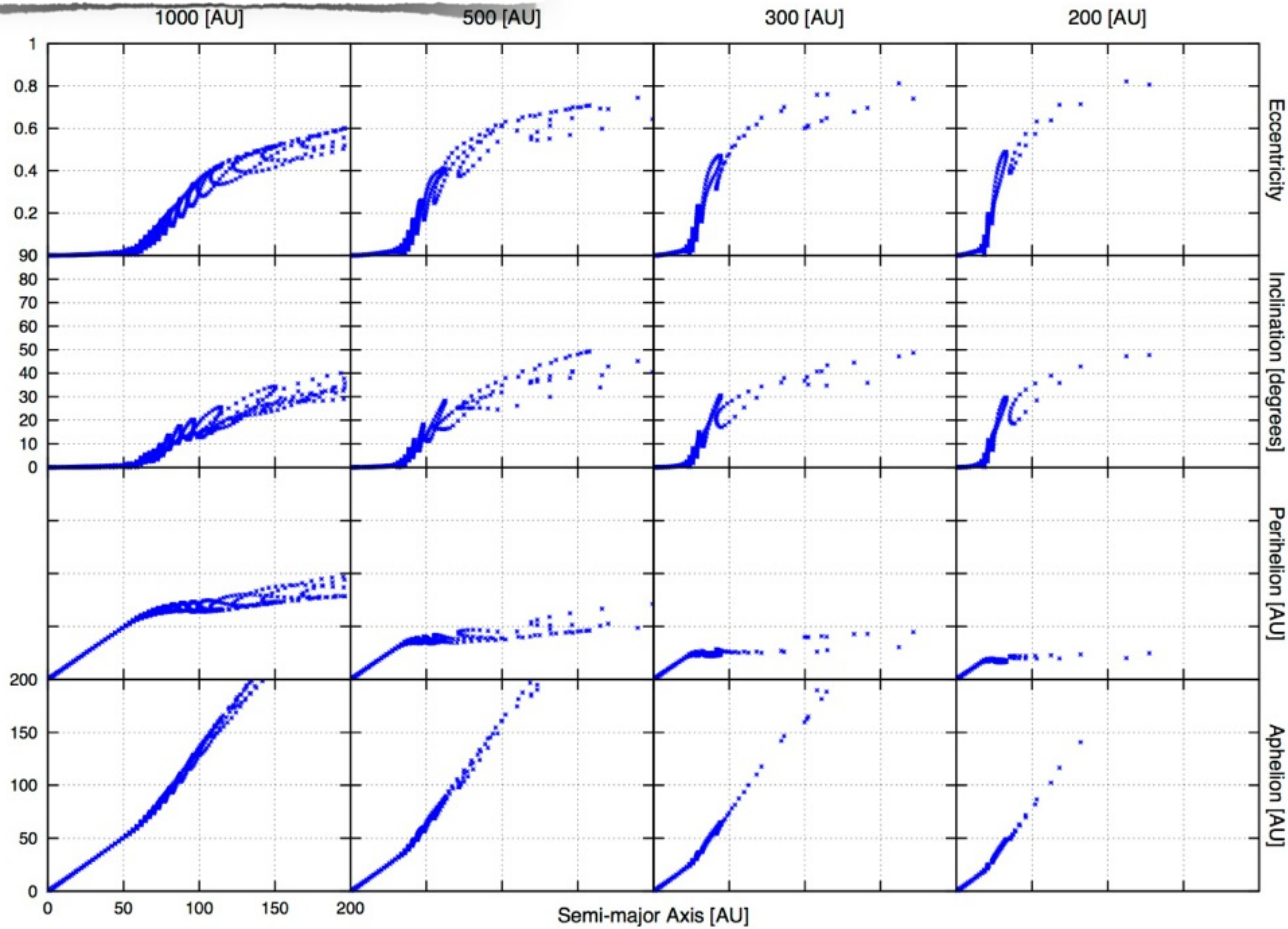
**Flyby star.**
"Mass of flyby star (Msun)=" 0.5d0(VLMS),2d0(LMS)

**Host star.**
"Mass of host star (Msun)=" 0.5(VLMS), 1d0(LMS)

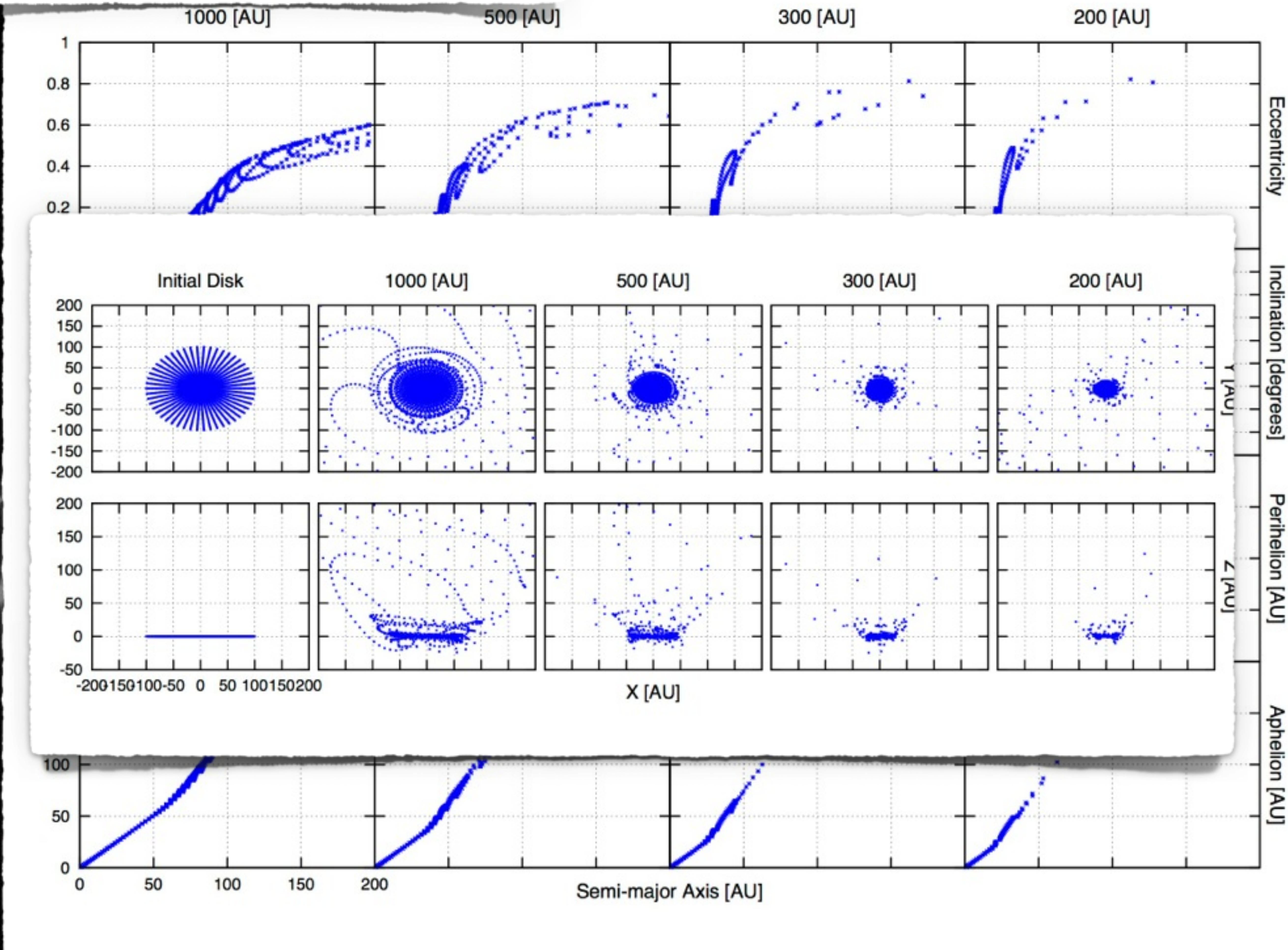
Code parameters

# Results & Applications

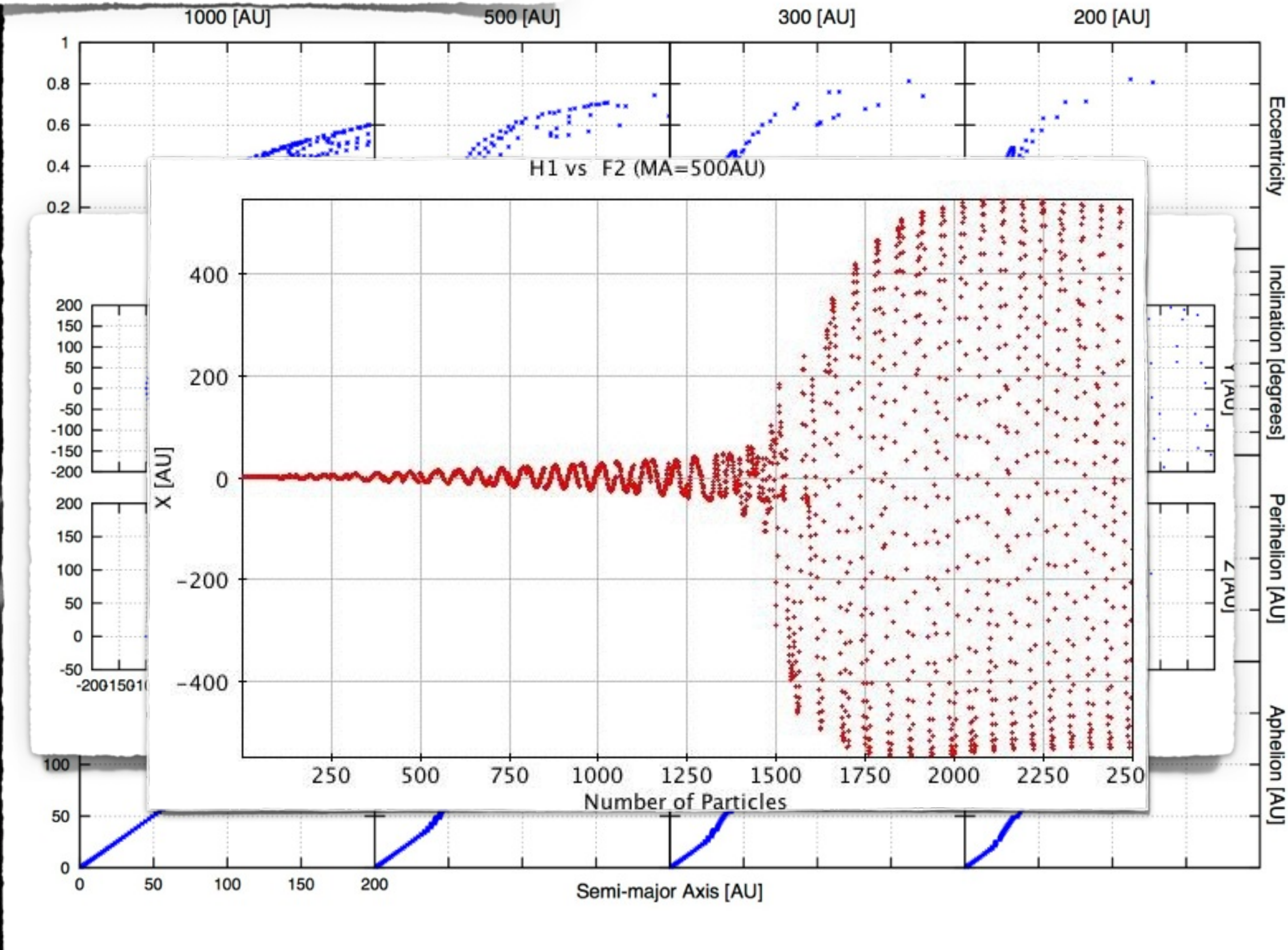
Low mas stars H1M⊙ vs F2M⊙



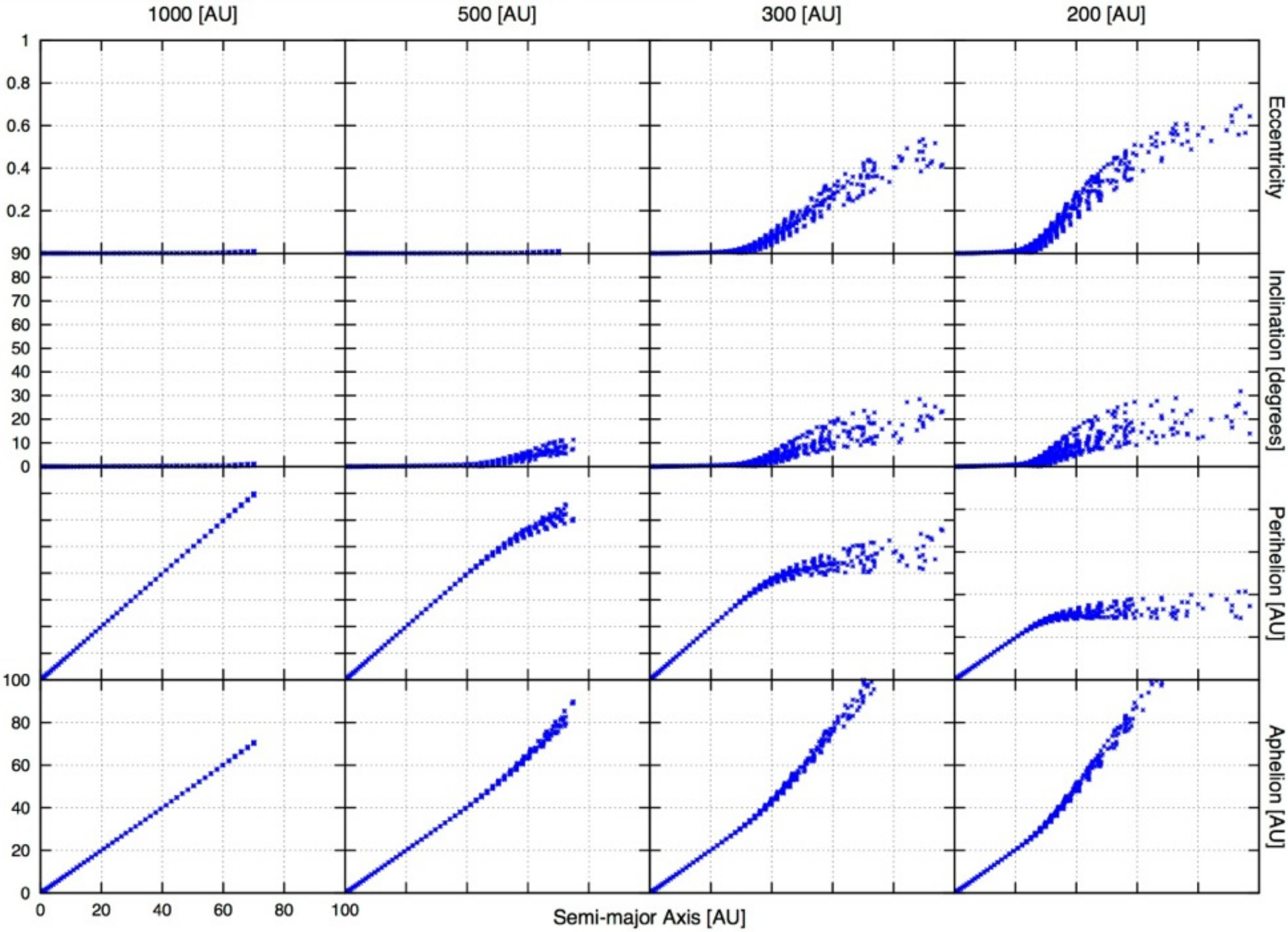
Low mas stars H1M⊙ vs F2M⊙



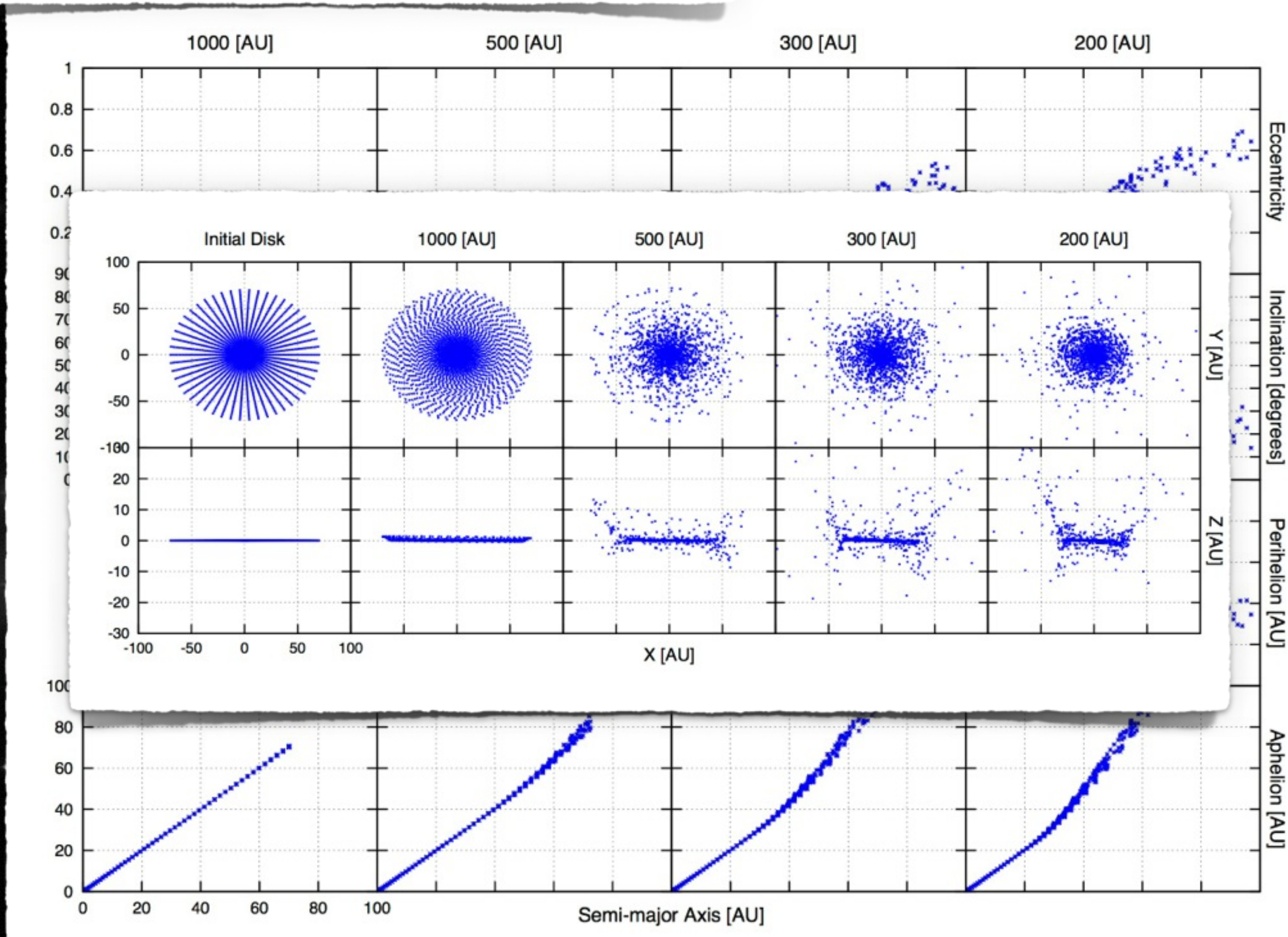
# Low mas stars H1M⊙ vs F2M⊙



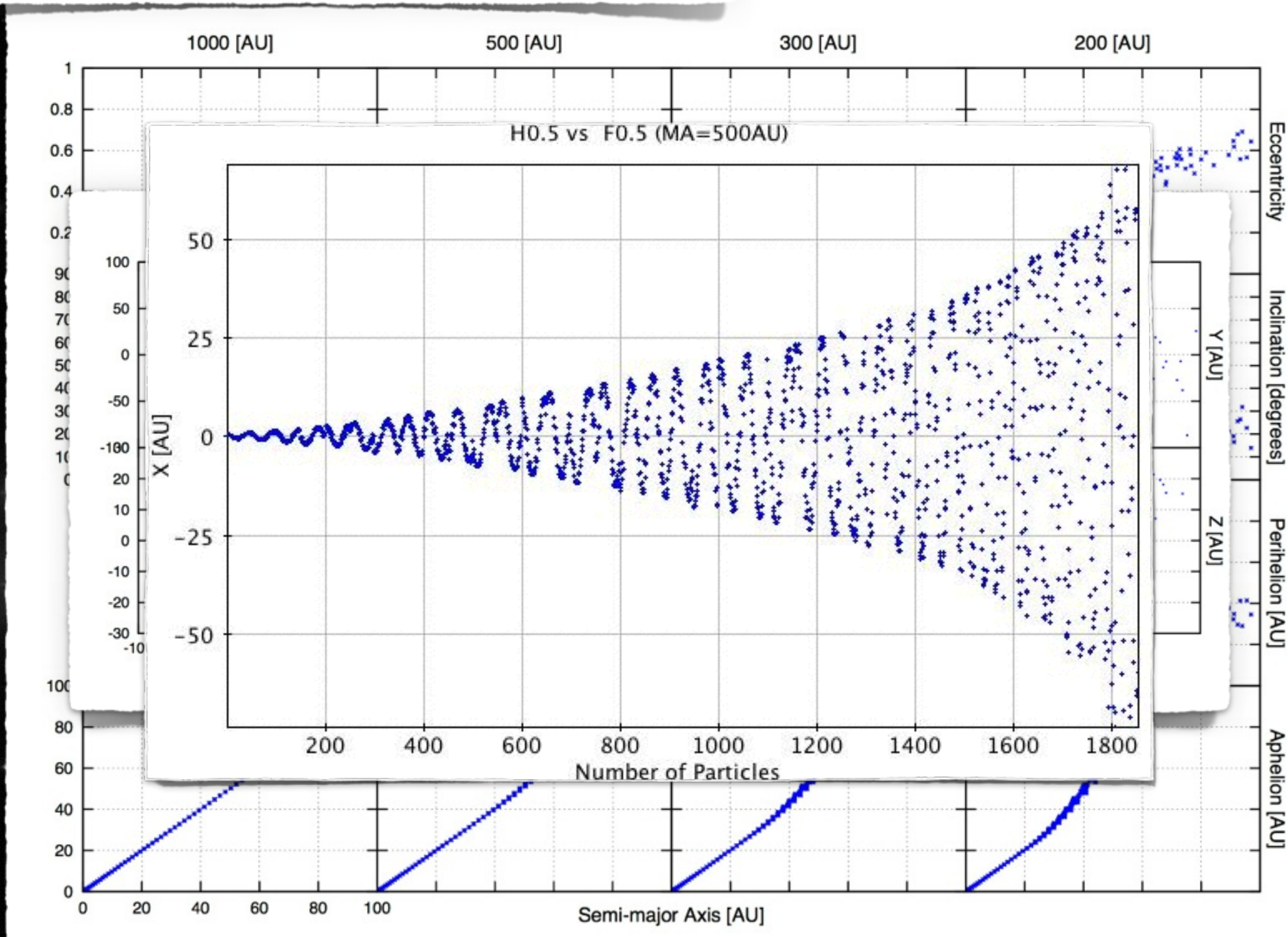
Very low mass stars H0.5M⊙ vs F0.5M⊙



# Very low mass stars H0.5M⊙ vs F0.5M⊙

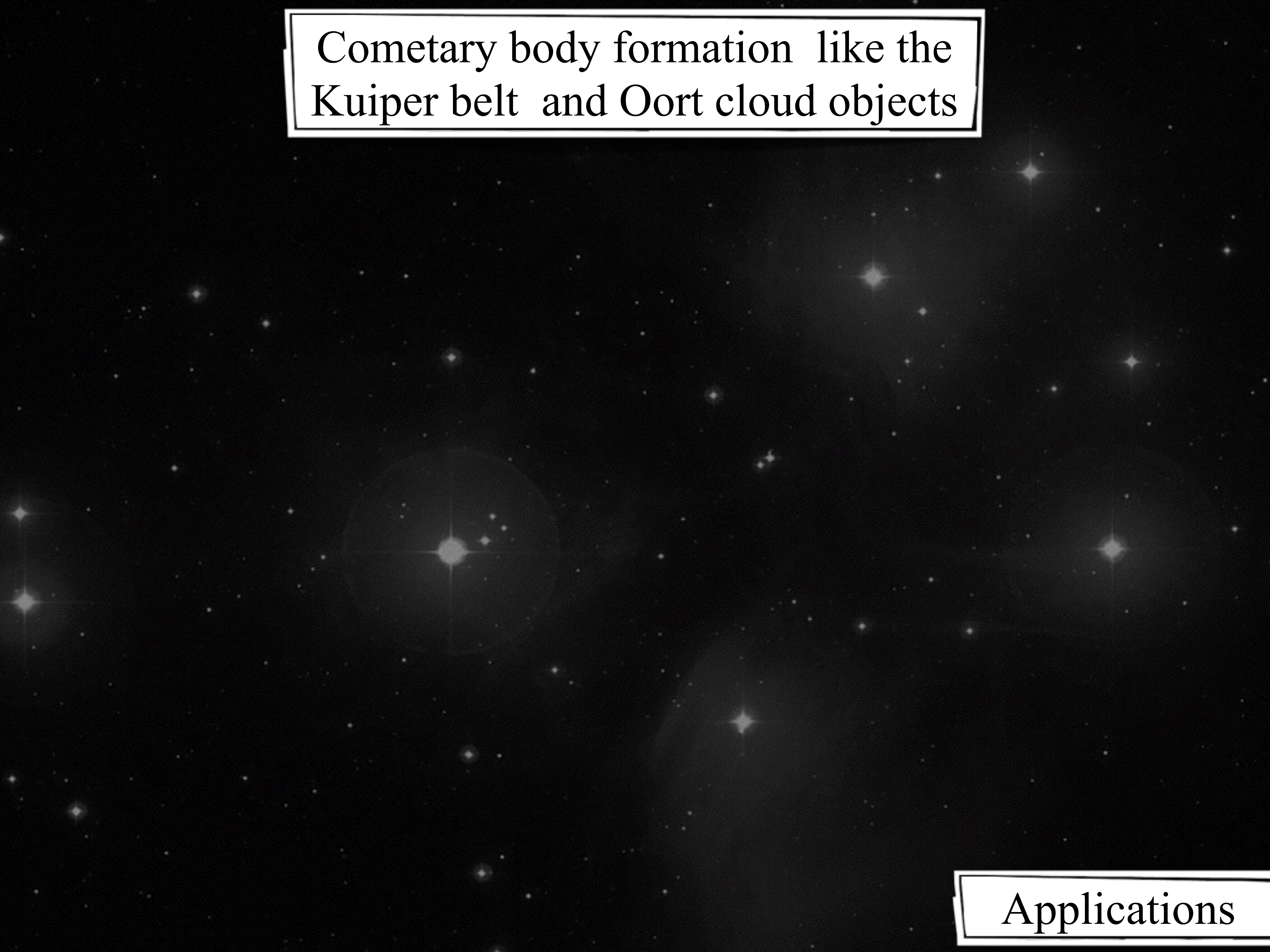


Very low mass stars H0.5M⊙ vs F0.5M⊙



# Applications

# Cometary body formation like the Kuiper belt and Oort cloud objects



Applications

# Cometary body formation like the Kuiper belt and Oort cloud objects

The creation and evolution of the Kuiper Belt and Oort Cloud remains a mystery today, but models indicate that stellar encounters in the early stages of the evolution of the planetary disk, interaction of the planetesimals with the giant planets and the galactic tide were an important keys in his development.

Applications

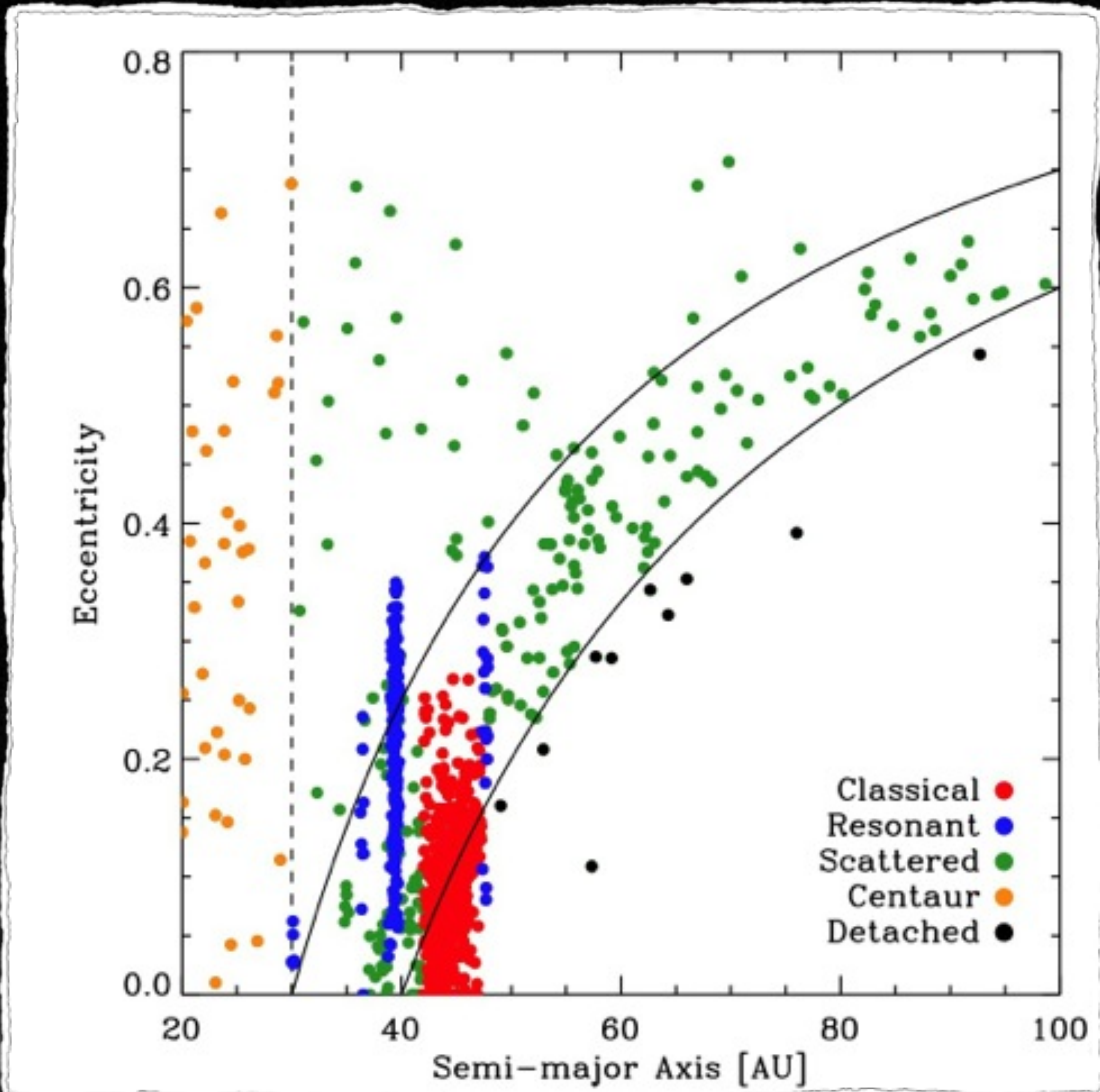
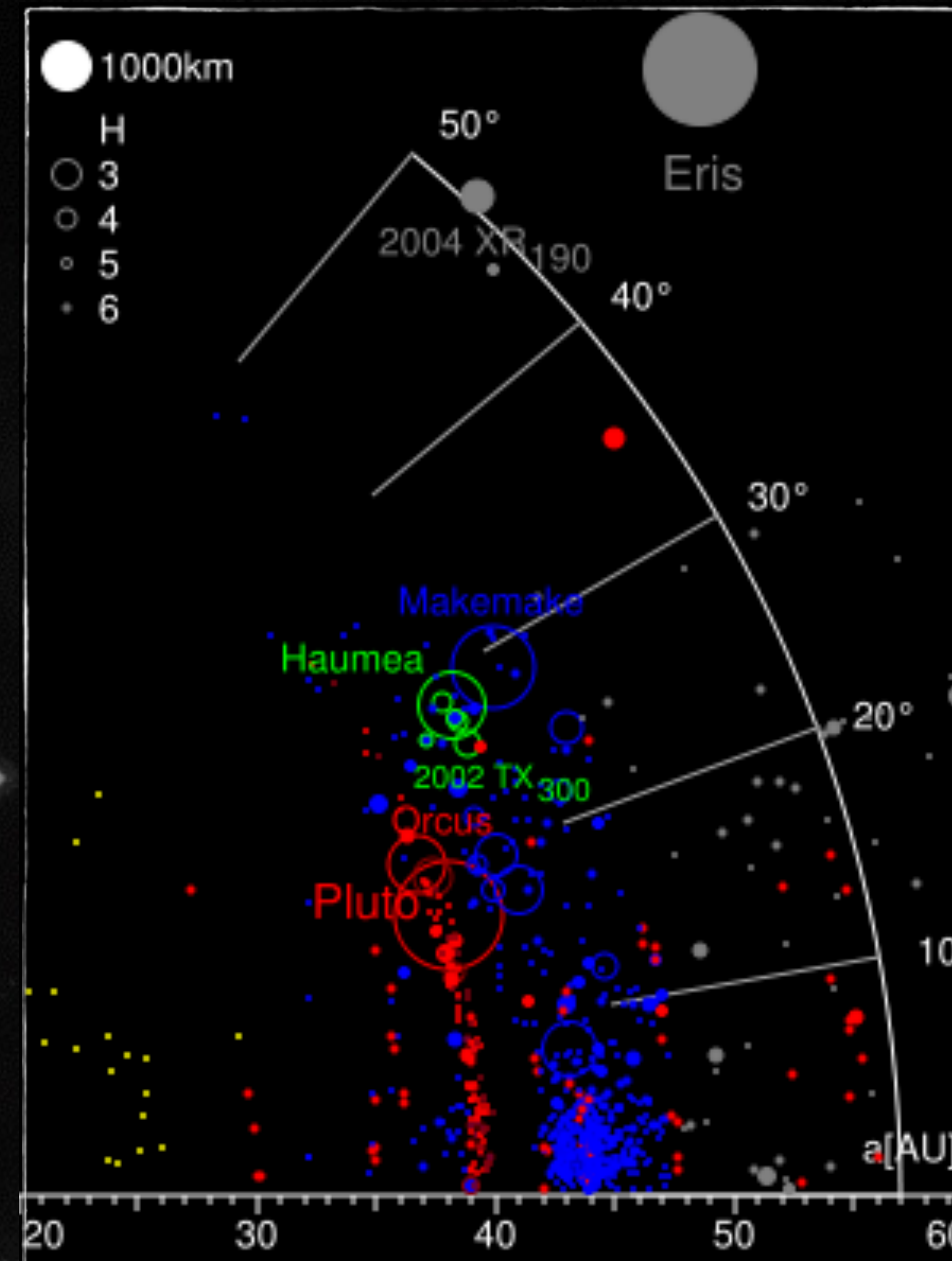
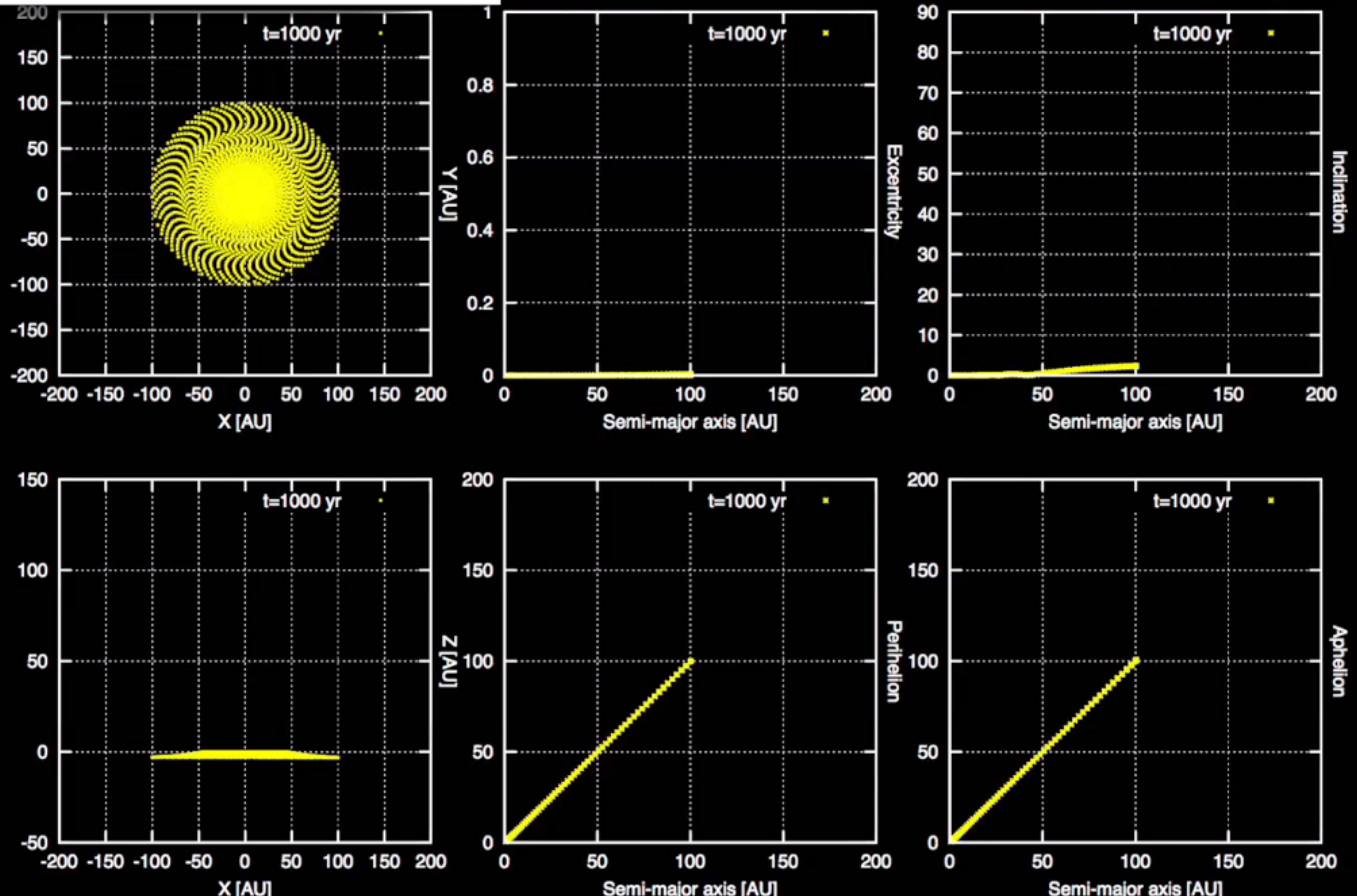



Diagram showing the distribution of objects in the outer Solar system in the semi-major axis vs. eccentricity plane. The orbit of Neptune is marked by a vertical dotted line. Objects in blue are resonant with Neptune. The most densely populated cluster of blues shows the 3:2 resonant objects which include Pluto. David Jewitt 2010

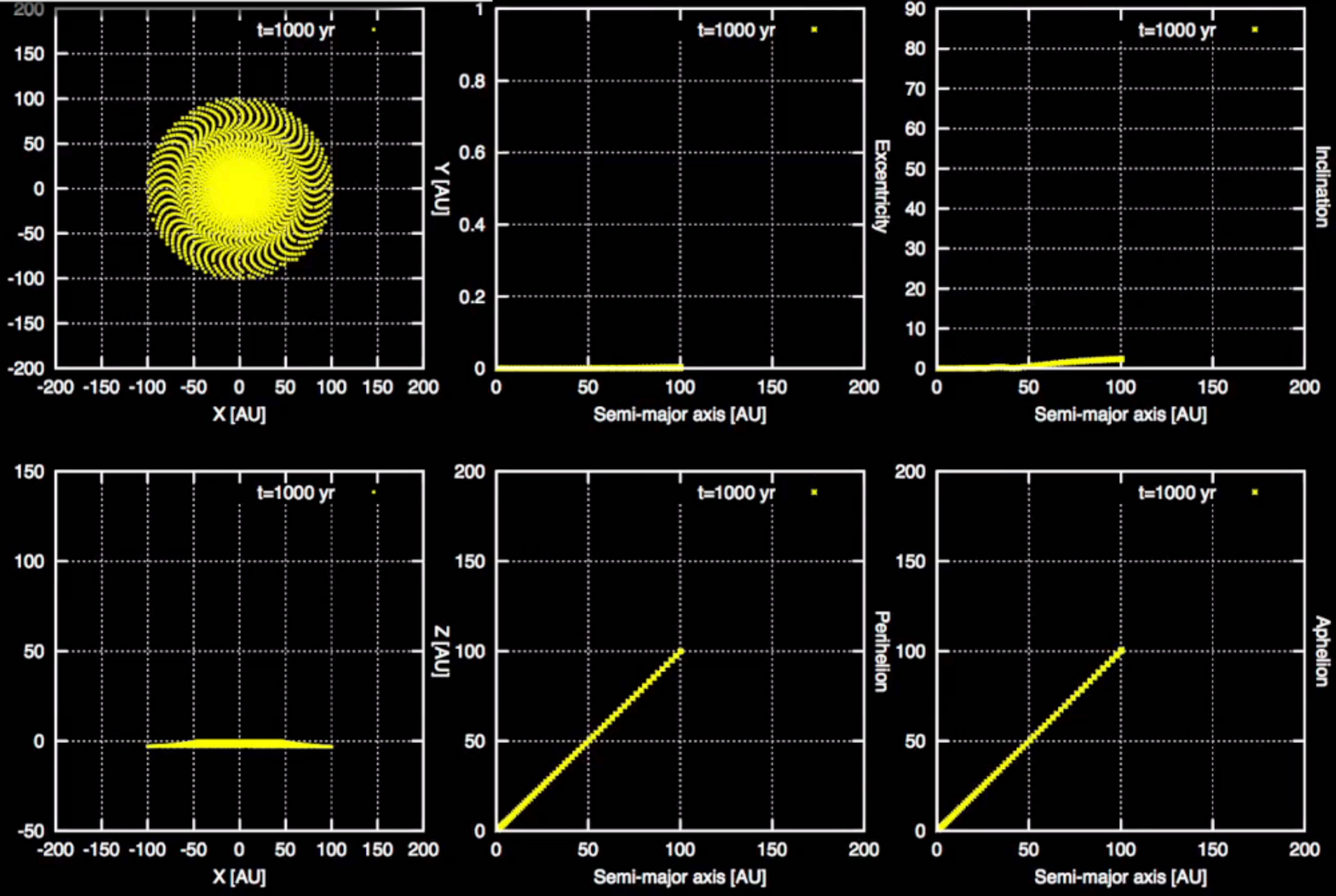



The collisional family of Haumea (in green), other classical KBO (blue), Plutinos and other resonant objects (red) and SDO (grey). Radius is semi-major axis, angle orbital inclination.

# H1M⊙ vs F2M⊙


t=1000 yr
X [AU]
Y [AU]
Semi-major axis [AU]
Excentricity
Inclination
Z [AU]
Perihelion
Aphelion

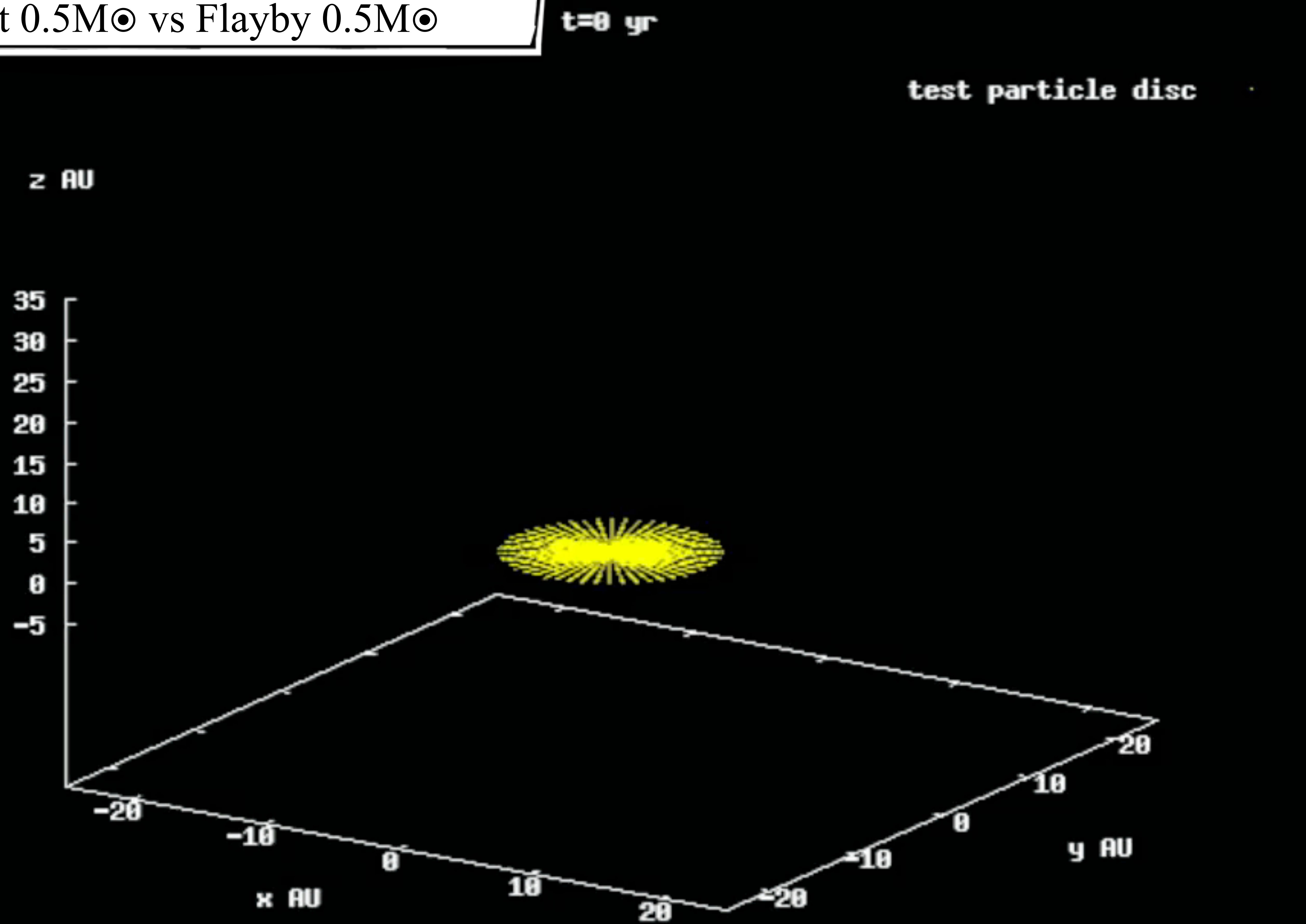
# H1M⊙ vs F2M⊙



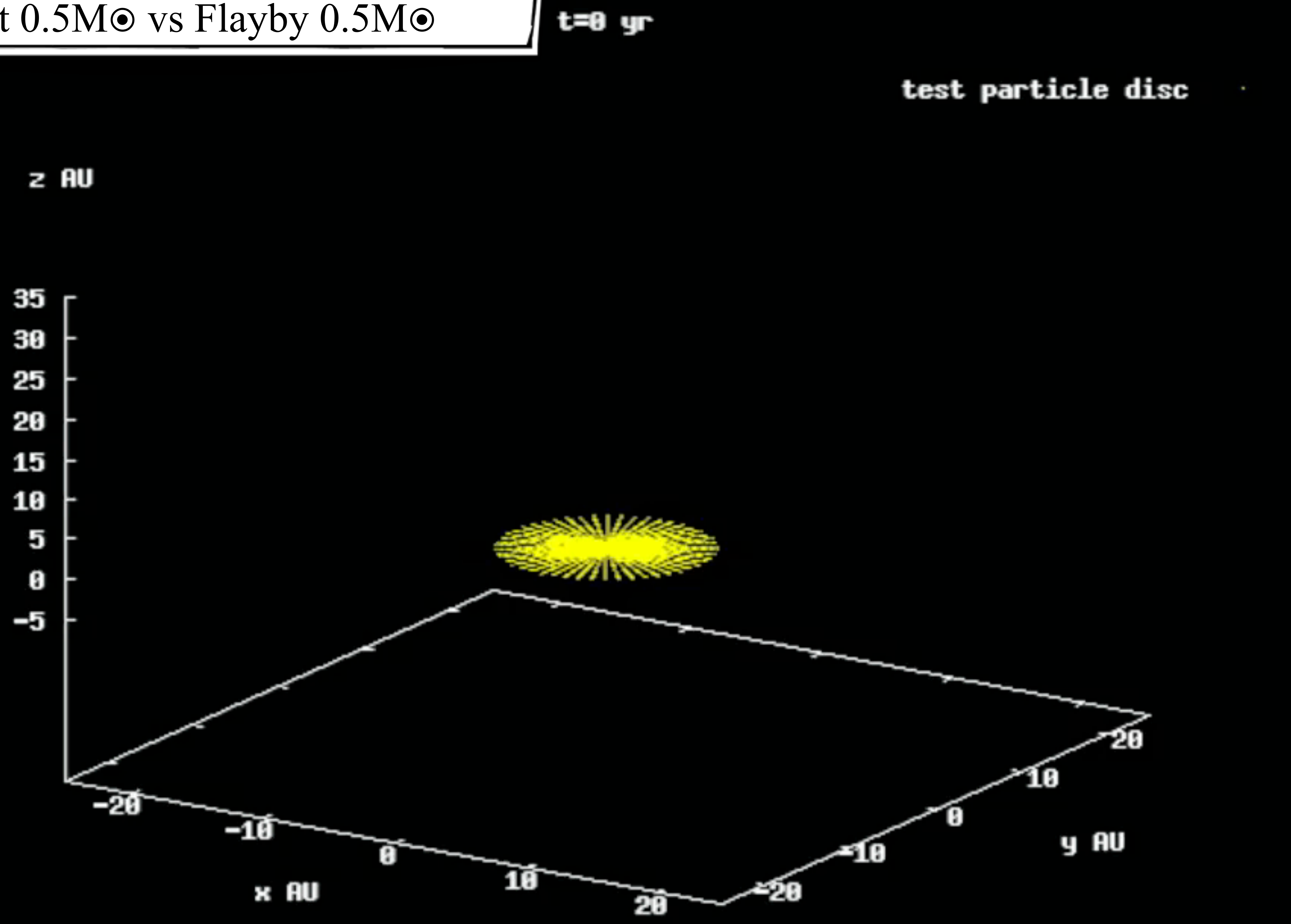
t=1000 yr
X [AU]
Y [AU]
Semi-major axis [AU]
Excentricity
Inclination
Z [AU]
Perihelion
Aphelion


Host 0.5M⊙ vs Flayby 0.5M⊙

Host 0.5M⊙ vs Flayby 0.5M⊙

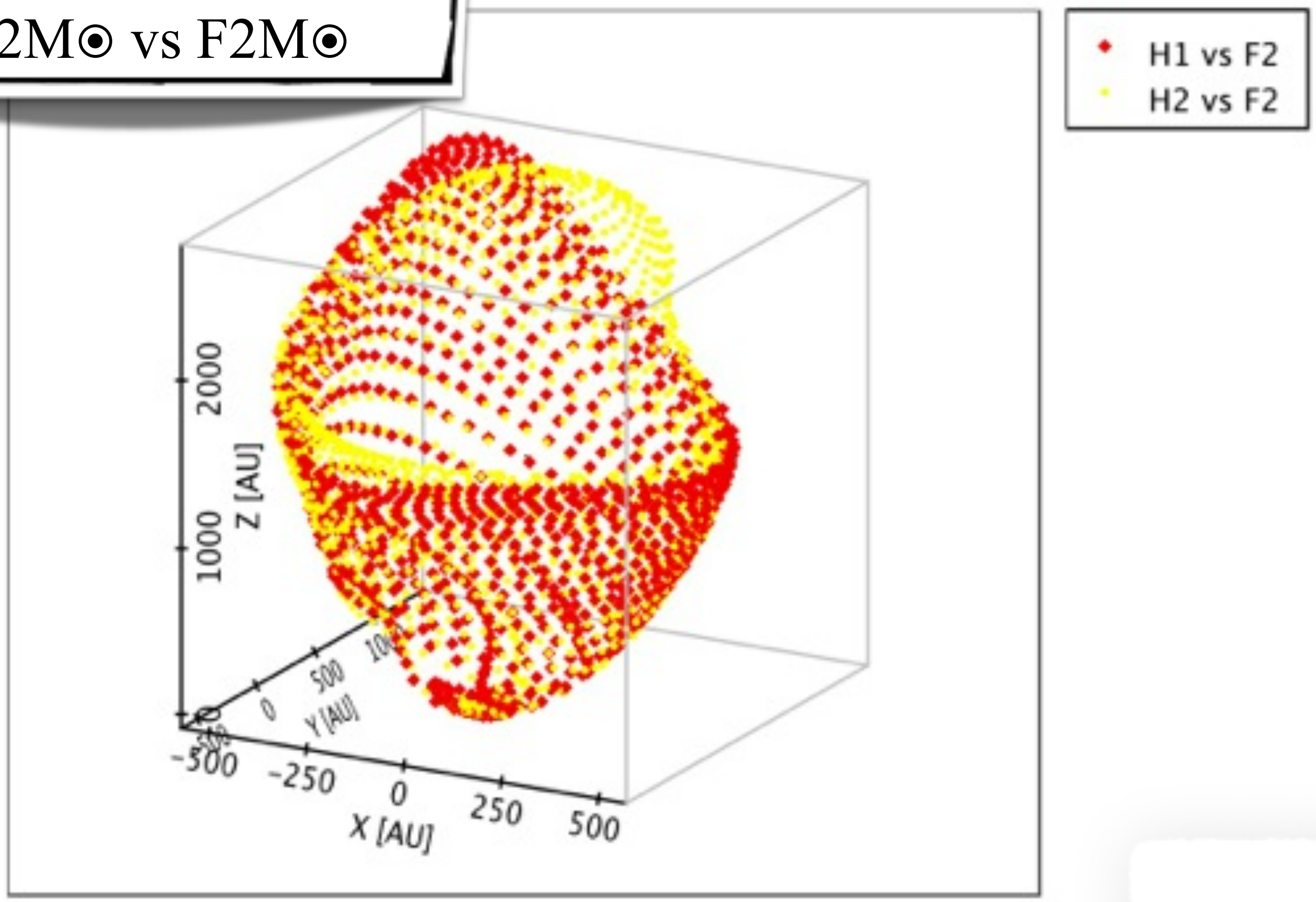


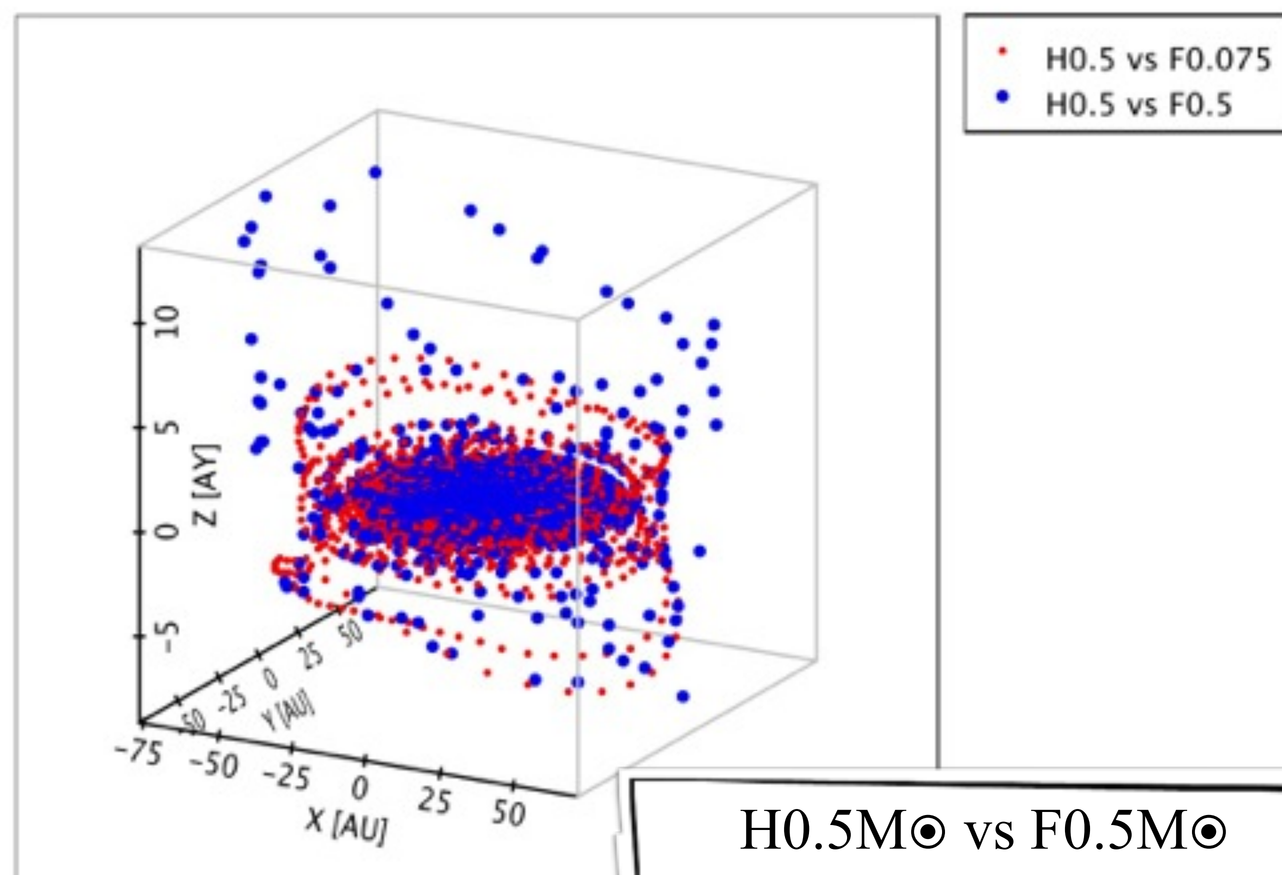
Host 0.5M⊙ vs Flayby 0.5M⊙



# Comparison of disk structure for different stellar encounters

H1M⊙ vs F2M⊙
H2M⊙ vs F2M⊙

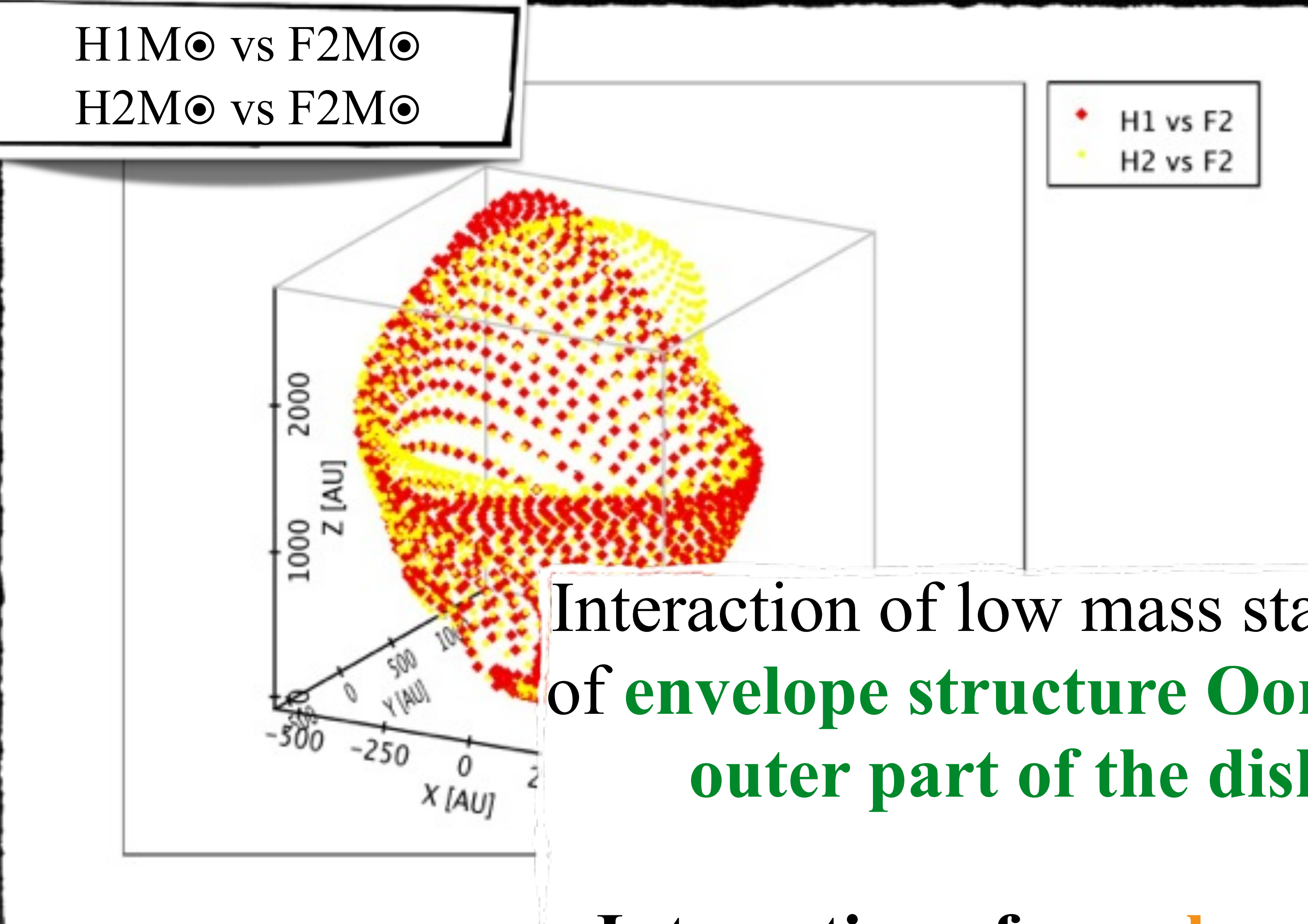



H0.5M⊙ vs F0.5M⊙
H0.075M⊙ vs F0.5M⊙

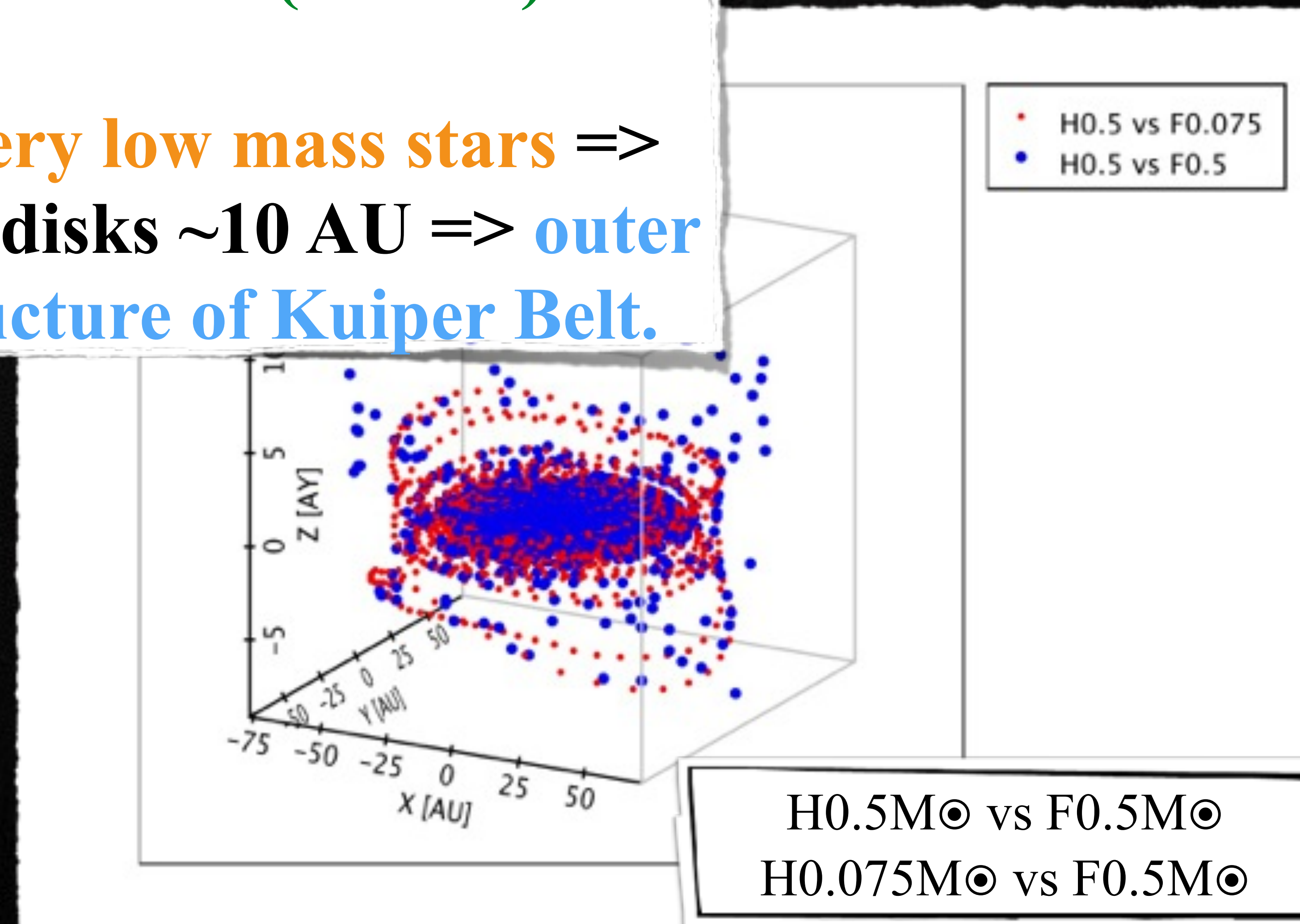
## Comparison of disk structure for different stellar encounters

H1M⊙ vs F2M⊙
H2M⊙ vs F2M⊙




Interaction of low mass stars => formation of **envelope structure Oort cloud, for the outer part of the disk (<30AU).**

**Interaction of very low mass stars => truncation of the disks ~10 AU => outer disk similar structure of Kuiper Belt.**




H0.5M⊙ vs F0.5M⊙
H0.075M⊙ vs F0.5M⊙

# Discussion & conclusions

- Particles in the inner disk (<10AU) doesn’t change in their orbital parameters => **Planets in this region can survive to a dramatic encounter with a passing star.**

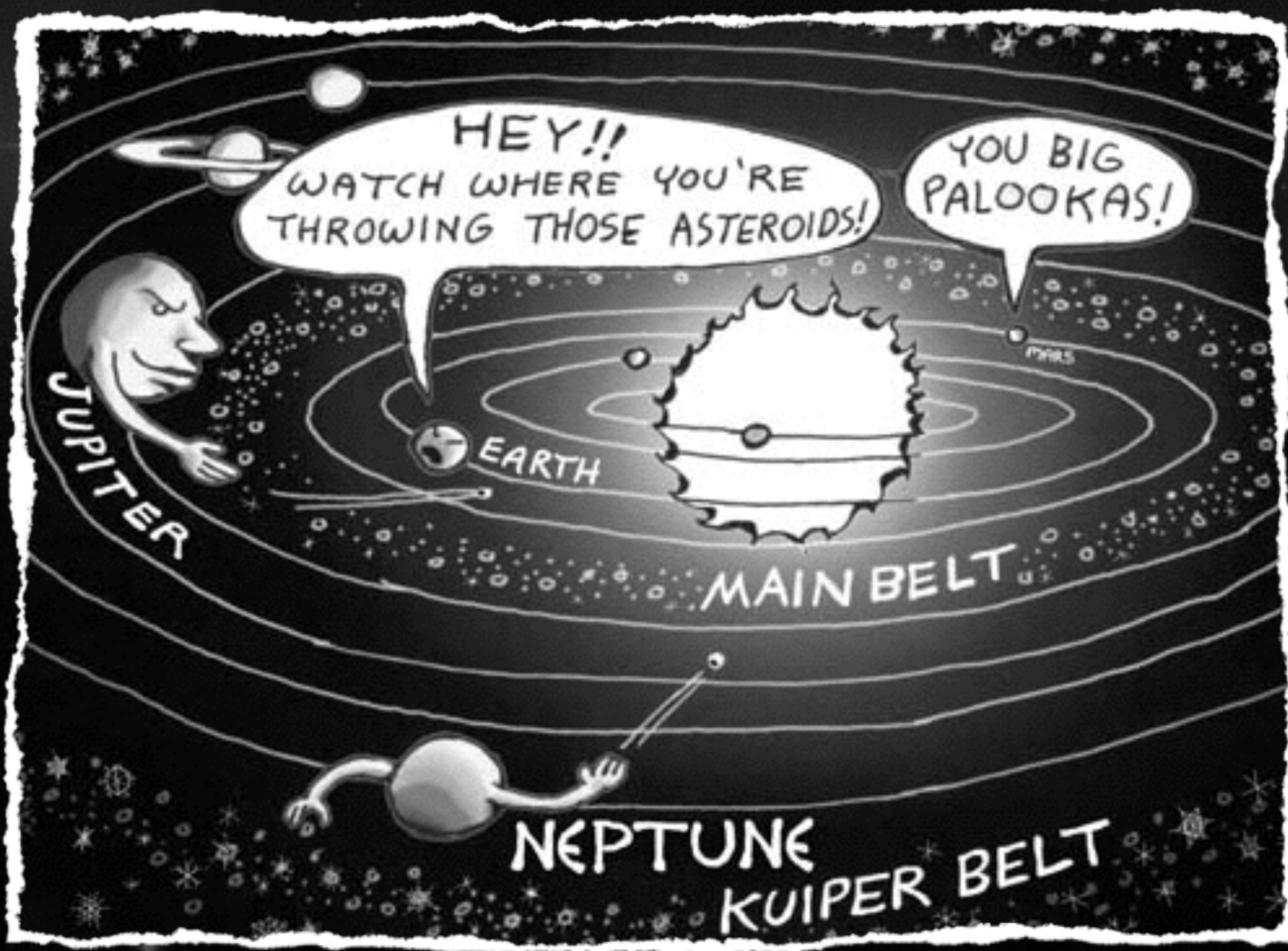
- A close encounter => eject particles in the periphery of the disk => **posible effect to reproduce the orbital parameters of the free floating planets.**

- Interaction of low mass stars => formation of **envelope structure Oort cloud, for the outer part of the disk (<30AU). Interaction of very low mass stars => truncation of the disks ~10 AU => outer disk (fluffy) similar structure of Kuiper Belt.**

- The effect of the stellar encounters in environments like open and globular clusters can reproduce the orbital parameters of the Kuiper Belt and Oort cloud objects => **The formation of the similar structures in different planetary systems.**

# Thanks!!!

# Thanks!!!



HEY!!
WATCH WHERE YOU'RE
THROWING THOSE ASTEROIDS!
YOU BIG
PALOOKAS!
JUPITER
EARTH
MARS
MAIN BELT
NEPTUNE
KUIPER BELT