Stripping a Debris Disk by Close Stellar Encounters in an Open Cluster

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Introduction :

We have studied the depletion of planetesimals in a debris disk caused by stellar flybys in the environment of an open cluster when its star number density decreases from the highest initial value of the originating embedded cluster to as low as 0.1 pc^{-3} in the course of 100 Myr.

Such a stripping would impact dust production and therefore detectability debris disks.

The high star density cluster Trapezium in Orion : 30 000 stars/pc^3 at age 1-2 Myr

The open cluster Pleiades : a few stars/pc^3 at age 125 Myr

Estimation of the number of stellar encounters :

The kinetic theory complemented by gravitational focusing can estimate analytically the encounter time t_{enc} (Binney & Tremaine) :

$$\frac{1}{t_{enc}} = 1.910^{-8}\left(\frac{n}{1000\,pc^{-3}}\right)\left(\frac{\sigma}{1\,km/s}\right)\left(\frac{d_{enc}}{100\,AU}\right)^2 + 8.810^{-9}\left(\frac{m_c+m_p}{1M_{sol}}\right)\left(\frac{n}{1000\,pc^{-3}}\right)\left(\frac{d_{enc}}{100\,AU}\right)\left(\frac{1\,km/s}{\sigma}\right)$$

valid for 2 stars, the central star and passing star of our problem, of masses $\boldsymbol{m_c}$ and $\boldsymbol{m_p}$ moving in a field with uniform star number density $\boldsymbol{n_i}$ (*i* for each stellar spectral type) :

This star number density $\boldsymbol{n_i}$ is taken to be a ***linear function of time*** over the open cluster lifetime.

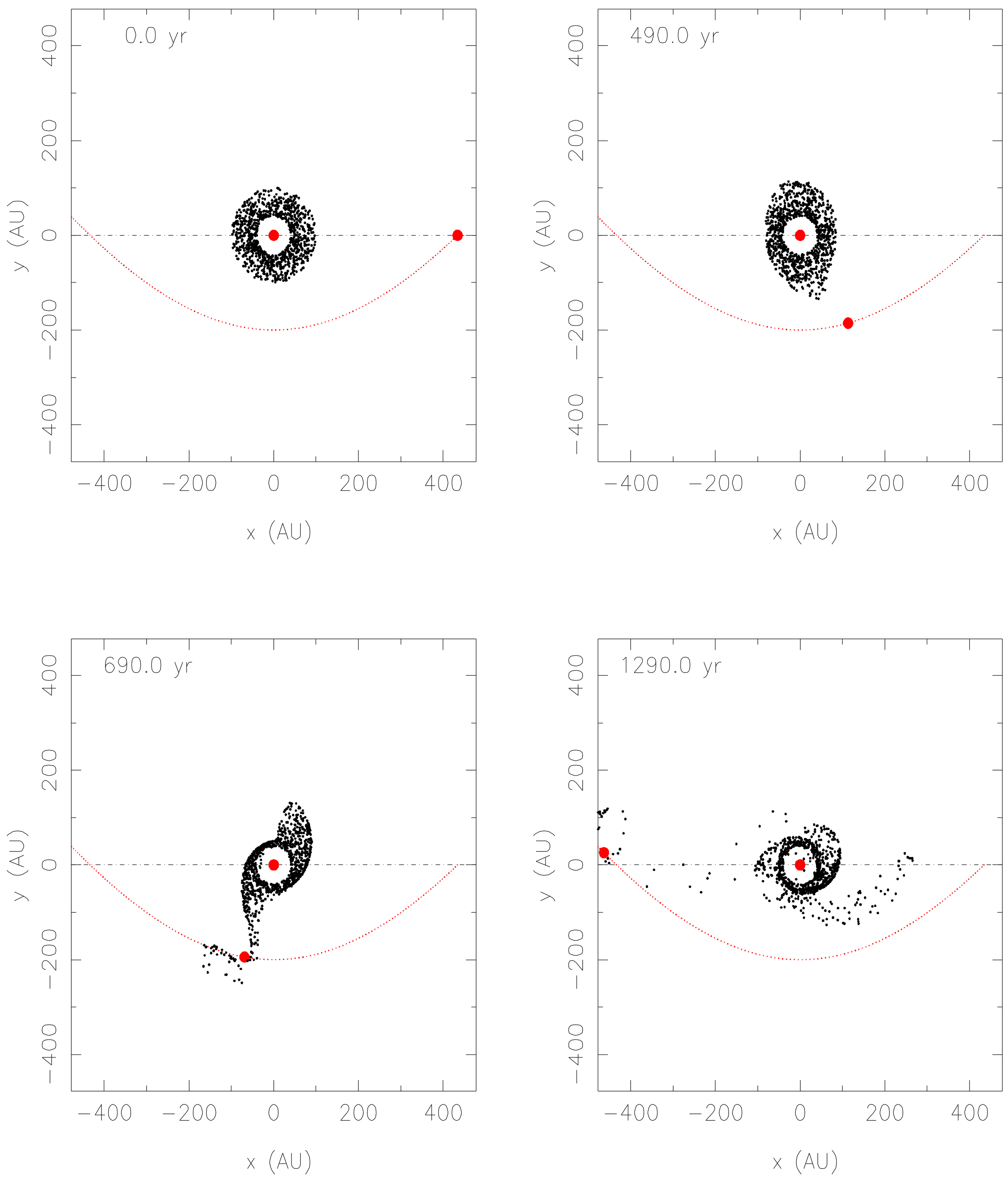
The number of stellar encounters of miss distances $\boldsymbol{d < d_{enc}}$ can be tracked by the phase in cycle:

$$\varphi(d < d_{enc}) = \int_0^{cluster-lifetime} \frac{1}{t_{enc}}\,dt$$

Table 1. Stellar mass distribution of passing stars

Spectral type m_p	Mass range ($M_\odot$)	Fraction f_p
M8-M5	0.10 - 0.21	43.0 %
M4-M0	0.21 - 0.47	31.5 %
K8-K0	0.47 - 0.80	12.4 %
G8-G0-F0	0.80 - 1.70	8.5 %
A8-A0	1.70 - 3.20	2.7 %
B8-B5	3.20 - 6.50	1.3 %

Simulation of stellar flybys:



The **debris disk** has inner and outer radii of 40 and 100 AU, and is non self-graviting. The **central star** is at the origin of the coordinate system. The trajectory of the **passing star** is parabolic, coplanar and prograde with respect to the disk (clock wise). The mass ratio between the two stars is unity. At the closest approach, the miss distance is 200 AU and the maximum velocity is 4.5 km/s. The fraction of planetesimals stripped off the disk is 35 % during this close stellar encounter.

Results:

Simulations (10 000 particles under sole gravitational forces of the central star and planet) have provided the fraction of stripped planetesimals as a function of the encounter miss distance and the ratio of the masses of the central and passing stars. Figure : solid lines for an initially non excited disk (circular initial orbits), dotted lines for an initially dynamically excited disk (excentric initial orbits). Table : stripped planetesimals by stellar flybys after 100 Myr.

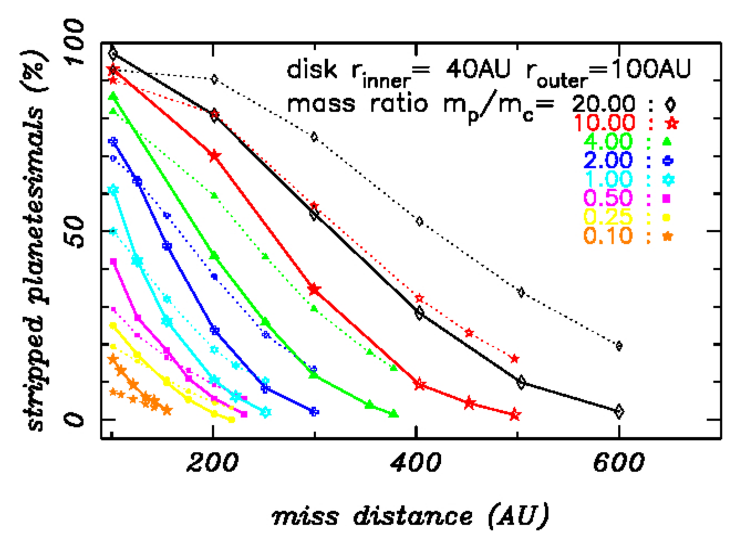


Table 1. Planetesimals left in a debris disk after 100 Myr in open clusters with initial star number densities n_0 comprised between 100 and 30 000 pc^{-3}.

Central star m_c ($M_\odot$)	Open cluster[(*)] n_0 (pc^{-3})	Fraction of planetesimals left after stellar encounters (%)
0.25	100	100
0.5	“	100
1.0	“	100
2.5	“	100
0.25	1000	< 85
0.5	“	100
1.0	“	100
2.5	“	100
0.25	3000	< 49
0.5	“	< 63
1.0	“	< 72
2.5	“	< 94
0.25	10 000	< 19
0.5	“	< 31
1.0	“	< 37
2.5	“	< 54
0.25	20 000	< 4
0.5	“	< 10
1.0	“	< 14
2.5	“	< 29
0.25	30 000	< 1
0.5	“	< 4
1.0	“	< 7
2.5	“	< 21

(*) : $\sigma = 5$ km/s, $\phi(d < d_{enc}) = 4$.

Conclusions:

We have found that :
1) **depletion is insignifiant** in disks around stars born in embedded clusters with **low star number densities** (< 1000 pc^{-3}).
2) **depletion is significant** in disks around stars born in **high star number density embedded clusters** such as the Orion Nebula Cluster with a core stellar density of 20 000 pc^{-3}. In these conditions, debris disks lose > 96 % of their planetesimals around M-dwarfs, > 86 % around solar-type stars and > 71 % around A stars in 100 Myr.

High depletion in high density clusters could affect 2/3 of the stars searched for debris disks in surveys since 2/3 of them are born in high stellar density embedded clusters according to the catalog of Lada and Lada (2003).

We have found also that this depletion depends significantly on the mass of the central star in our model, and, interestingly, this is consistent with the observations that have revealed that less debris disks are detected around low-mass stars.