DYNAMICAL MECHANISMS FOR TRANSFERRING COMETS IN AND OUT OF THE OORT CLOUD

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ABSTRACT

We study scenarios where comets are not original members of the Solar System but have been acquired from the surrounding medium through dynamical evolution. This leads to estimates of the present day number density of comets in the interstellar medium which are not in contradiction with observational upper limits. We also consider the dynamical transfer of Oort Cloud comets into short period comets. The process is very sensitive to the inclination of the comet orbit which leads to strong bias in favour of low inclinations in short comet orbits.

INTRODUCTION

Comets are in many ways odd members of the Solar System. The majority of the comets, forming the so called Oort Cloud, are very weakly bound to the Sun. Also their orbits are randomly inclined to the plane of the planetary system in contrast to the smaller number of strongly bound short period comets which follow mostly low inclination orbits. This poses a problem if one considers the short period comets as captured members of the Oort Cloud (Duncan, Quinn and Tremaine 1988). Also there are questions about the adequancy of the capture rate (Joss 1973). The structure and origin of the Oort Cloud, as well as its ability to survive through the age of the Solar System have been under discussion in recent years (Bailey et al. 1986, Stagg and Bailey 1989).

In this paper we summarize several dynamical studies which may shed light on the above cometary problems. We consider the origin of the Oort Cloud, its ability to survive

stellar perturbations and the capture of short period comets from the Oort Cloud.

CAPTURE OF OORT CLOUD COMETS

The extreme looseness of the clouds of comets which surrounds the Solar System gives a clue to the origin of the system. If the comets were born with the rest of the solar system we might expect a disk-like distribution of comets somewhere at the periphery of the planetary system (Kuiper 1951). This kind of disk would be a natural source of short period comets (Fernandez 1980) but it is unclear how the orbits of the Oort Cloud comets could evolve from a Kuiper disk. It may be attractive to consider the opposite trend where the comets become more strongly bound when time goes on. Initially comets are captured from the interstellar medium and form an Oort Cloud. Stellar perturbations then deviate some of orbits to the inner Solar System and a group of short period comets is formed.

The starting point of our scenario is a star cluster where the Sun is one of the newly formed stars. The cluster may have several tens of other stars of different masses, and in addition to that, a swarm of comets as a left over from star formation (McCrea 1975, Donn 1976). We then follow what happens to the comets during the dynamical evolution of the star cluster. In particular, we are interested in the number of comets which attach themselves to a typical star such as the Sun, and the number of comets which end up as free members of interstellar medium.

Our calculations, reported in more detail by Zheng,Valtonen and Valtaoja (1991) and Valtonen and Zheng (1991), show that typically an Oort Cloud of 10^{12} comets (Oort 1950, Weissman 1982) is attached to a single, escaping star if the cluster has about 10^{16} comets initially. Most of these comets are dispersed in the interstellar space. If the process is common and occurs in all star clusters, a comet mass density of about 10^{-3} solar mass per cubic parsec arises in the Galaxy. The upper limit derived from not having ever observed a clearly interstellar comet comes to about the same number(Sekanina 1976). Thus acquiring of the Oort Cloud by dynamical processes in a star cluster is at least possible. Such a large comet density would have important effects in the evolution of the Galaxy (Bailey 1988). The structure of the Oort Cloud formed by this process is not unlike the cloud deduced originally by Oort (1950), but does not include the unobservable extension of the cloud inward ("inner Oort Cloud") which is often discussed (Bailey 1986).

STABILITY OF THE OORT CLOUD OF COMETS

The survival of the Oort Cloud of comets has been studied by several authors, see e.g. Bailey (1983). Zheng (1989) cal-

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culates the cumulative effect of 23000 stellar perturbations
on comet orbits of different kinds. In the simulation the
perihelion distances of the passing stars are randomly dist-
ributed between 0 and 1 pc, the orbits are randomly oriented
and the masses of the perturbing stars are randomly distri-
buted between 0.8 and 1.2 solar mass. During the stellar en-
counter, the comet and the Sun suffer changes in velocity gi-
ven by

$$\Delta\vec{V}_c = (K/D) * (\vec{D}/D)$$

$$\Delta\vec{V}_o = (K/D_o) * (\vec{D}_o/D_o). \tag{1}$$

and the cometary velocity relative to the Sun gains an incre-
ment

$$\Delta\vec{V} = \Delta\vec{V}_c - \Delta\vec{V}_o . \tag{2}$$

where $K = 2GM/V$, (GM is gravitational mass of the passing
stars, $\vec{V}$ is encounter velocity), and $\vec{D}$ is the vector of the
closest distance between the comet and the star, $\vec{D}_o$ being
that between the Sun and the star.

It is found that only about 3-9% of the Oort Cloud sur-
vive through the age of the Solar System if the aphelion
distance of the comets is 40000 AU. At the aphelion distance
of 10000 AU it is found that 26 - 80% of the comets survive,
depending on the eccentricity of the orbit. Therefore we must
assume that the present day Oort Cloud is only a remnant of a
more populous initial Oort Cloud which had many times more
comets than the Oort Cloud of today.

While many of the Oort Cloud comets leave the Solar Sys-
tem, others enter the planetary region. Figure 1 shows the
fraction of comets which escape, enter the planetary region
or survive at the aphelion distance of Q = 40000 AU, when the
perihelion distance is varied from q = 40AU to q = 40000 AU.

CAPTURE OF SHORT PERIOD COMETS

It has been generally assumed that short period comets
are captured members of the Oort cloud comets. However, in
recent years there has been a debate whether a random distri-
bution of inclinations such as is found in the Oort Cloud
could develop into the low inclination distribution of the
short period comets (Stagg and Bailey 1989). In our numerical
studies of the capture probability as a function of inclina-
tion we have found about 2:1 excess of zero inclination cap-
tures over the retrograde orbit captures (Valtonen and Inna-
nen 1982). This may be compared with the observed distribu-
tion of inclinations of short period comets which show about
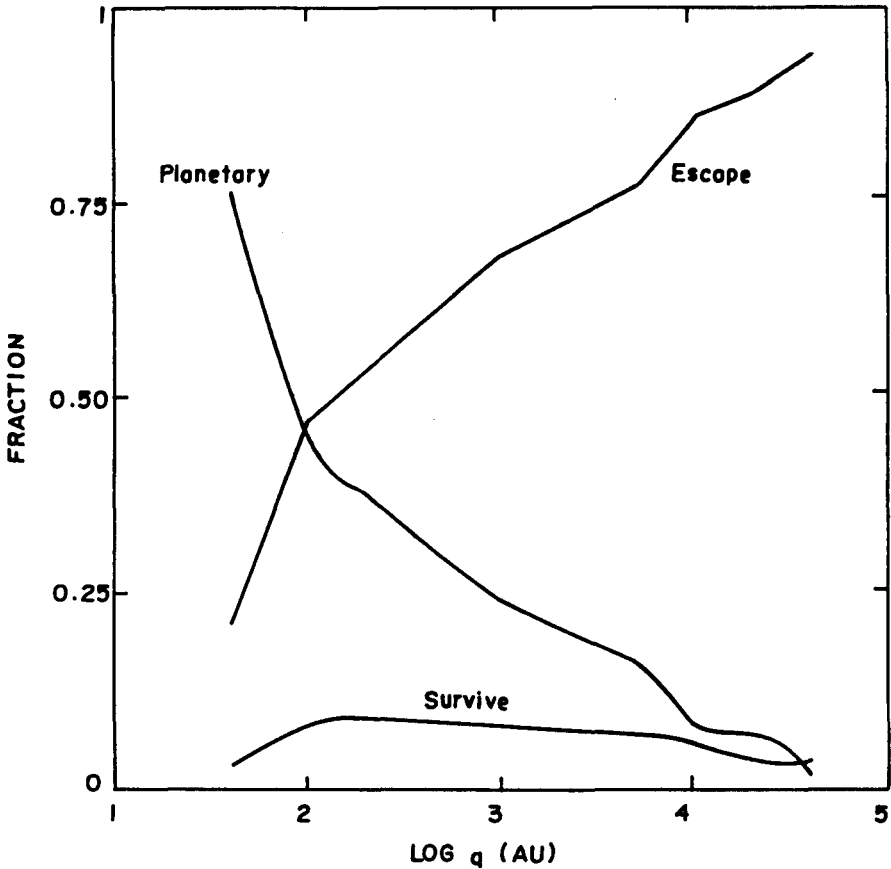7:1 excess of direct (cosi > 0.8) orbits over retrograde

Figure 1: The final states of the Oort Cloud at aphelion dis-
tance Q = 40000 AU at different perihelion distances
q.

orbits (comets with aphelia > 10 AU; Stagg and Bailey 1989).
If the comet capture proceeds only through the assistance of
a single planet, then indeed the observed inclination distri-
bution is definitely too strongly biased towards low inclina-
tions. However, if the comet is passed from the influence of
one planet to the one lower to it and so on, then the above
probabilities should be raised to power N of the number of
planets involved. For example, N = 3 leads us to expect an
8:1 bias in favour of direct orbits.

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CONCLUSIONS

       We have outlined a picture of the origin of both short
period and long period comets starting from an interstellar
population of comets in a star cluster in which the Sun was
born. First the Sun accumulates a cloud of loosely bound co-
mets, many of which are subsequently lost to the interstellar
space due to stellar perturbations. Some comets are diverted
to the inner Solar System and are captured via planetary in-
fluences. These form a cloud of short period comets with pri-
marily low inclination orbits.

       The primary test of this picture is to find a true inter-
stellar comet, a member of the Galactic population which must
necessarily arise during the process of break-up of a cluster
of stars and comets. Other tests include more detailed stud-
ies of capture of short period comets from the Oort Cloud,
including the influence of several outer planets.

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