Asteroids, Comets, Meteors 1991, pp. 601–604
Lunar and Planetary Institute, Houston, 1992

S140-90

N93-19253

The vicinity of Jupiter : a region to look for comets

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ABSTRACT

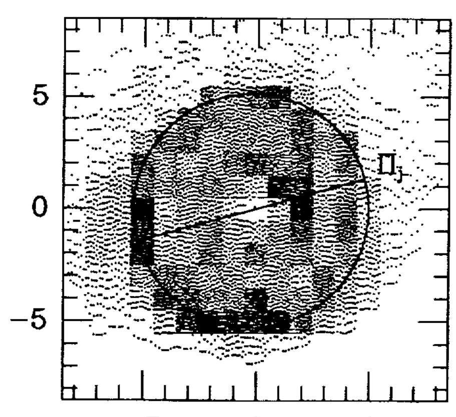
Low-relative velocity and long-lasting encounters can dramatically change the orbital elements of a comet; the object could be temporarily bound to Jupiter for a period of several years.

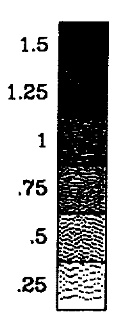
It is well stated that most of the discoveries of comets ocurred just after a close encounter with the planet and a decrease of the perihelion distance of the comet. So, why don't we look for comets during close encounters with Jupiter rather than wait to find them afterwards? To estimate the feasibility of this proposal we have made dynamical computations and observational analysis of the Jupiter family of comets. A criterion to distinguish comets during an encounter from other moving objects in the field is discussed.

THE SPACE DISTRIBUTION OF JUPITER-FAMILY COMETS

Kresák (1979) made a first attemp to look at the space distribution of asteroids and comets and found a few interesting patterns not observed in the usual orbital elements phase-space where we study these objects. We made numerical integrations of the whole sample of Jupiter family (hereafter JF) comets (143 short-period comets with P<20 yr) to have a new look into the problem and in particular to analyze the distribution of objects on different regions of the Solar System. We integrated each comet and the nine planets at a time, starting at J.D. 2448000.5 for 200 yr into the past (for more details about the integration method see Tancredi and Rickman 1991, hereafter TR). At every 500 days the heliocentric positions and velocities of the objects were stored.

We were interested in the positional distribution of comets at any time. As JF comets have low inclinations, we took the ecliptic plane as the reference plane and divided the plane into square boxes of 1 AU. Cubes of 1 AU centered on these boxes were considered to compute the mean number of comets inside each cube at any time. In Fig. 1 we present a grey-scale picture of the observed distribution, where the darkest point corresponds to a density of 1 obj/AU^3. The orbit of Jupiter with its perihelia and apsidal lines is superposed. We can see a "crater-like" structure, with a slight increase of the density of comets towards the orbit of Jupiter. This is naturally explained considering that JF comets tend to have their aphelia in the range 5 to 7 AU where they spend most of their time.





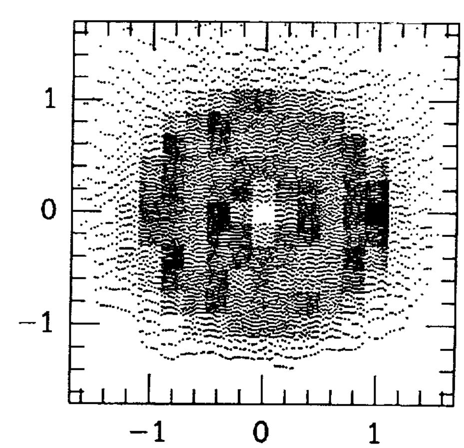


Fig. 1. *Grey-scale picture of the positional distribution of observed short-period comets at any time in ecliptic-fixed frame. The orbit of Jupiter with its perihelion and apsidal line is superposed.*

Fig. 2. *Grey-scale picture of the positional distribution of observed short-period comets at any time in a rotating-pulsating frame with Jupiter fixed (unit distance = distance Jupiter-Sun).*

As Jupiter is the main body responsible for shaping the distribution of JF comets, we plotted the distribution of objects in a more appropriate frame : a rotating-pulsating frame, with the instantaneous distance Jupiter-Sun as unit distance and the instantaneous Jupiter's angular velocity as the rotating velocity. In this frame the Sun is at the centre and Jupiter is always at $x = 1$, $y = 0$. Fig. 2 shows a grey-scale picture of the space distribution. The "crater rim" observed in Fig. 1 almost shrinks to a point, i.e. Jupiter's position; where the density reaches a value of 1.4 obj/AU^3.

The importance of this finding is that we do not only constrain the position where comets tend to concentrate but we also constrain their velocities, because, as we will show later, the relative velocities to Jupiter are generally low.

The previous density values give only a rough estimate of the number of comets close to Jupiter at any time, computed by making an average over the last 200 yr. Most comets have been discovered just after a close encounter with Jupiter (Karm and Rickman 1982, TR), when their perihelion distance decreased. In addition to this point, when we plot the distribution of number of encounters at distances < 0.5 AU from Jupiter during the past and future 1000 yr for the whole sample of observed JF comets (TR), we see a peak at the present time (Fig. 3).

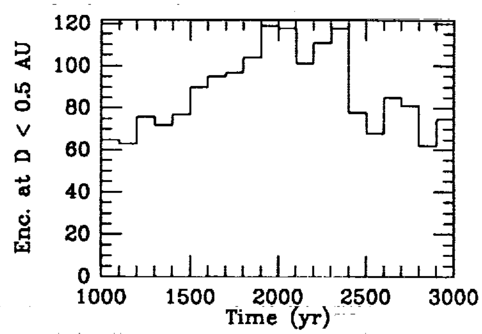


Fig. 3. *Distribution of the number of encounters with minimum distance D < 0.5 AU for 2000 years centered in the present epoch.*

It is obvious that the observed JF comets is a biased sample of the whole population in the sense that we have a preponderance of comets that have experienced a close encounter in the near past. Due to the chaotic behaviour of the majority of short-period comets orbits, if we integrate the observed population for a long enough period of time, the successive encounters with Jupiter will randomize the orbital distribution and we would obtain a closer representation of the whole sample. We will compare the figures obtained averaging over the last 1000 yr and the ones obtained for the last 40 yr (when the discovery rate of JF comets has had a dramatic increase, TR).

In Fig. 4 we plot the number of comets at any time within a certain distance D to Jupiter as a function of this distance (the full-line corresponds to the average over the last 40 yr, the dashed-line over the last 1000 yr). Although at greater minimum distances to the planet the number of encounters increases, the duration of these encounters does not have a steep increase. This fact is shown in Fig. 5, where we plot the time a comet spends within a certain distance D to Jupiter as a function of this distance (full and dashed-lines are the same as in Fig. 4).

These calculations, using the observed 143 JF comets, then shows that in the near past there was a density of 1.5 objects at any time at distances less than 0.5 AU from Jupiter (1 % of the observed population) and averaging over the last 1000 yr the density decreases to 0.6 objects (0.4 %) . These comets spend an average time of 1.1 and 0.7 yr within 0.5 AU from the planet in the last 40 and 1000 yr, respectively. These numbers agree quite well with similar calculations made by Carusi et al. (1985).

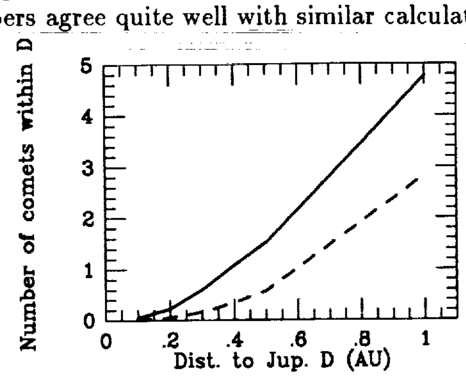


Fig. 4. *Number of comets at any time within a certain distance D to Jupiter as a function of this distance (full-line : average over the last 40 years, dashed-line : average over last 1000 years).*

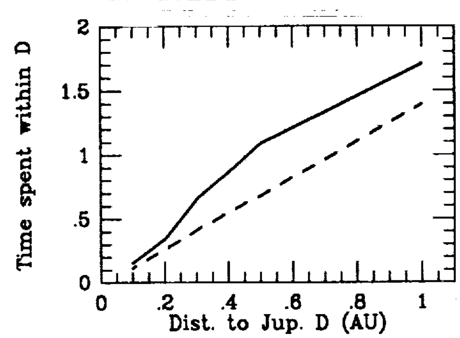


Fig. 5. *Time spent within a certain distance D to Jupiter as a function of this distance (full and dashed-line same as in Fig. 4).*

A SEARCH FOR COMETS AT CLOSE ENCOUNTERS

If comets are usually discovered after a close encounter with Jupiter and the actual density of observed JF comets around Jupiter is greater by a factor of 2 or 3 compared to any other place in the Solar System, we may ask why we do not look for comets around Jupiter. Below, we will identify the problems and define an observational strategy to do such a search.

a) The identification problem

At Jupiter's opposition, a distance of 0.5 AU from the planet corresponds to a projected angular distance in the sky plane of 7^o. A Schmidt telescope with a plate size on the order of $5^o \times 5^o$ is the most suitable instrument to cover such a big region of the sky.

If we take a plate of an ecliptic region we would find from 200 up to 400 asteroids down to 20 mag. in a $5^o \times 5^o$ field (van Houten et al. 1970). We may also find a few comets that are not undergoing a close encounter with Jupiter. How could we distinguish those objects from comets at close encounters? At Jupiter's distance to the Sun, we expect that comets would not show any trace of activity, making almost impossible any observational distinction from asteroids. Therefore, if we do not have clear physical differences we have to look for a dynamical criterion to separate these two samples.

The distribution of Tisserand parameters (T) for JF comets shows a concentration towards 3, and values generally greater than 2.5 (TR). Remembering that the encounter velocity with Jupiter (expressed in terms of the planet's orbital velocity) is given by $U^2 = 3 - T$, we concluded that JF comets tend to have low velocity encounters with Jupiter and their heliocentric orbital velocity is similar to that of Jupiter at the time of the encounter. If we make the observations close to Jupiter's opposition, the vast majority of the field asteroids will move with typical retrograde velocities of main belt objects, while the comets that are experiencing a close encounter will have a slower motion, similar to that of Jupiter.

Fig. 6 shows the hourly motion in α and δ of all numbered asteroids with angular separation from Jupiter less than 10^o (small dots) and the planet for the 1992 opposition (29/2/1992). We computed the mean relative velocities during the encounters for different JF comets that experienced encounters in the last 40 yr. For comets with a minimum distance to Jupiter < 0.5 AU, we found that the mean relative velocity had a median value of 6 km/s. As the previous value corresponds to a relative velocity in any direction, we calculated the projected median velocity on the sky plane averaging over all possible directions (a factor of $\frac{\pi}{4}$ times the velocity). In Fig. 6 we drew a full circle with radius corresponding to this projected median velocity (5"/hr in the sky plane) and dashed lines corresponding to the upper and lower quartiles. Tracking the telescope on Jupiter we would find that asteroids should show a trail on the order of 17" in one hour exposure (0.25 mm with a plate-scale of 67.5"/mm), while comets should be more like point-sources. The stars will appear as trails of 19".7 (0.29 mm with the same scale-plate) but in opposite direction compared to asteroids. Therefore, if we make the observations close to Jupiter's opposition and track the telescope on the planet, we would be able to pinpoint very easily comets at close encounters.

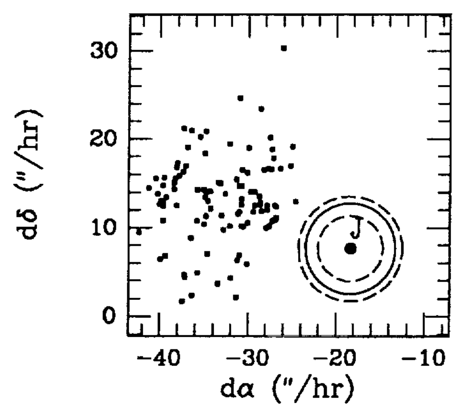


Fig. 6. *Hourly motion in α and δ of all numbered asteroids (small dots) and Jupiter for 28/2/1992. Circles centered in Jupiter with radius corresponding to different projected relative velocities are superposed (see text).*

b) The magnitude problem

The heliocentric distance of Jupiter ranges between 4.9 and 5.5 AU. The correction that we have to introduce to the absolute magnitude to obtain the apparent magnitude depends on the particular circumstances of the opposition. We make our calculations for the 1992 opposition, when Jupiter will have an heliocentric distance $r_j = 5.4$ AU and geocentric distance $\rho_j = 4.4$ AU. Assuming that at Jupiter's distance from the Sun, the comet would look like a bare nucleus, we express the difference between apparent and absolute nuclear magnitude $\Delta m = 5\ log(r\rho)$. For comets at close encounters we obtain a mean value of

$\Delta m = 7$. If the telescope has a limiting magnitude of 21 - 23 in a 1-2 hours exposure, we could detect comets brighter than absolute nuclear $H_n(1,0) \approx 14 - 16$.

Based on nucelar photographic magnitude determinations made by Roemer during 1960's and cratering rates on Galilean satellites, Shoemaker and Wolfe (1982) developed an expression for the power law distribution of number of comets (N) with brightness (H_n)

$$\frac{N(H_n + \Delta H_n)}{N(H_n)} = 10^{0.4\Delta H_n} \quad (1).$$

The size of the JF population is unknown and in fact, a search like the one proposed here could give a better estimation of the number of JF comets. Previous estimations of the population size range from one thousand (Shoemaker and Wolfe 1982) to a few (3-4) thousand objects (Fernández et al. 1991) down to nuclear magnitude $H_n(1,0) = 17.5$ and perihelion distance $q < 5.5$. Using eq. (1), the total number of comets in the range of detectable nuclear magnitudes (14-16) could then range from 60 to 170 for $H_n(1,0) < 14$ and 360 to 1000 for $H_n(1,0) < 16$.

If we take plates covering a region out to a distance of 0.7 AU from Jupiter (a field of $20° \times 20°$ centered on Jupiter) and consider the values of the density of comets around Jupiter found before, we would expect to find a comet with a probability of 60 % in the worst case (e.g. density of 0.6 comets at distances less than 0.5 AU, smallest population and observed limiting magnitude 21) up to 20 comets in the best alternative (e.g density of 1.5, largest population and mag. 23).

The values of the number of comets at close encounters obtained before are only a lower limit to the values that we would obtain during the observations because we are neglecting two other sources of encountering objects. When we consider the observed population, we are taking into account very few cases of comets moving between Jupiter and Saturn. This population of objects could contribute a lot to the number of encounters, and we would expect a large number of objects belonging to this sample if a gradual transfer of comets from the outer to the inner regions of the Solar System is assumed. Furthermore, there is another population of objects that could increase the number of objects at close encounters: dormant comets. As the magnitude distribution and the estimates of the population size were based on the observed active short-period comets, dormant comets are not included in our estimations, and at Jupiter's distance to the Sun, active and dormant comets would have a similar appearance.

Finally, we argue that a survey of comets during their close encounters with Jupiter could have important consequences in several aspects dealing with the evolution of small bodies of the Solar System; e.g.:

* the size of the Jupiter-family population of comets
* the origin of comets and the effects of encounters with Jupiter in the transfer of comets from the outer to the inner region of the Solar System
* the capture-hypothesis for the origin of the outer satellites of the outer planets.

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