A SIMPLE MODEL FOR GALACTIC INTERACTION

Ilya A. Rezyapkin, Leonid P. Ossipkov

Department of Space Technologies and Applied Astrodynamics, Saint Petersburg State University, Russia

1 Introduction

Tidal interaction of galaxies is one of main factors governing their dynamical evolution. It was studied by a lot of authors after pioneering works by P.O. Lindblad (1960), J. Pfleiderer (1962), N. Tashpulatov (1969, 1970), T. Eneev *et al.* (1974). A deep analysis of the problem was fulfilled by A. & J. Toomre (1972).

The most of current studies of galaxy interaction and merging are based on N-body simulations (see e. g. a paper by Tutukov *et al.*, 2007 and a book by Orlov & Rubinov, 2008). Many expressing scenarios of galaxy evolution has appeared in course of discussing of obtained results. For instance, Byrd & Valtonen (1990) put forward a hypothesis that SO galaxies result from spirals after destroying their spiral structure under the external gravitation of passing by galaxies.

But we think that main features of galaxy interaction can be revealed in frames of the restricted three-body problem. Such model was used by Sotnikova (1980), Belov (1990) and recently by Tutukov & Fedorova (2006).

In this work we study an evolution of an ensemble of test points under action of two gravitating point masses for various initial conditions. We shall restrict ourselves with the plane problem.

2 The Equations of Motion

Let m_A, m_B be masses of gravitating points A, B, X_A, X_B be coordinates of the point B relatively the point A, and X, Y relative coordinates of the test point. The equations of motion will be as follows:

$$\ddot{X} + \frac{Gm_A}{R^3}X = Gm_B\left(\frac{X_B - X}{\Delta^3} - \frac{X}{R^3}\right),$$

$$\ddot{Y} + \frac{Gm_A}{R^3}Y = Gm_B\left(\frac{Y_B - Y}{\Delta^3} - \frac{Y}{R^3}\right).$$

Here

$$R = \sqrt{X^2 + Y^2}, \qquad \Delta = \sqrt{(X_B - X)^2 + (Y_B - Y)^2},$$

G is the gravitational constant, and $X_B = X_B(t)$ and $Y_B = Y_B(t)$ are considered as known functions.

Now it is necessary to transform to transform the equations into a dimensionless form. We shall choose m_A as the mass unit, the least distance between points A and B, r_0, as the distance unit,

$$t_0 = \left(\frac{r_0^3}{Gm_A}\right)^{1/2}$$

as the time unit.

Denote

$$\mu = \frac{m_B}{m_A}, \qquad x_B = \frac{X_B}{r_0},\ y_B = \frac{Y_B}{r_0}, \qquad x = \frac{X}{r_0},\ y = \frac{Y}{r_0}, \qquad \delta = \frac{\Delta}{r_0}, \qquad \tau = \frac{t}{t_0}.$$

Then

$$\frac{d^2x}{d\tau^2} + \frac{x}{r^3} = \mu\left(\frac{x_B - x}{\delta^3} - \frac{x}{r^3}\right),$$

$$\frac{d^2y}{d\tau^2} + \frac{y}{r^3} = \mu\left(\frac{y_B - y}{\delta^3} - \frac{y}{r^3}\right),$$

with $r^2 = x^2 + y^2$. These equations were integrated numerically by the Runge–Kutta method of the fourth order for $\tau \in [-5, 10]$ under condition that $x_B^2 + y_B^2 = 1$ for $\tau = 1$.

3 Some Results

We considered cases when the relative motion of the point B is parabolic, hyperbolic and elliptic. Below we shall restrict ourselves with discussion of results for the parabolic orbit of point P.

At first we considered the simplest model when initial orbits of test points were circular. When the motion is direct (Fig. 1, 3) a transient spiral structure is formed and disappeared. Nothing interesting one can see in the case of retrograde motions for $\mu = 0.1$) (Fig. 2), but a rin structure can be formed from retrograde particles for larger μ (see Fig. 4 for $\mu = 0.2$).

When masses are equal ($\mu = 1$) the most of particles on direct orbits are captured by passing point B (Fig. 5). No spiral structure is formed but there are some evidences tails formed by thrown particles. The most of paricles on retrograde orbits leave the system and the rest form the ring structure (Fig. 6).

When the orbits of test particles are elliptical (see Fig. 7 for $\mu = 0.5$) the influence of the passing point is not so significant.

In the case of the circular restricted three-body problem the resonance phenomena, described by Lindblad (1960) are significant for small μ. The cloud of test particles is deformed and the spiral structure is developed. The larger μ, the more significant is the spiral structure that is transient and unstable in the case of direct orbits. The stable spiral structure develops in the case of retrograde orbits.

When the point B moves along a hyperbolic orbit, a relatively stable spiral structure results in the case of direct orbits of test particles.

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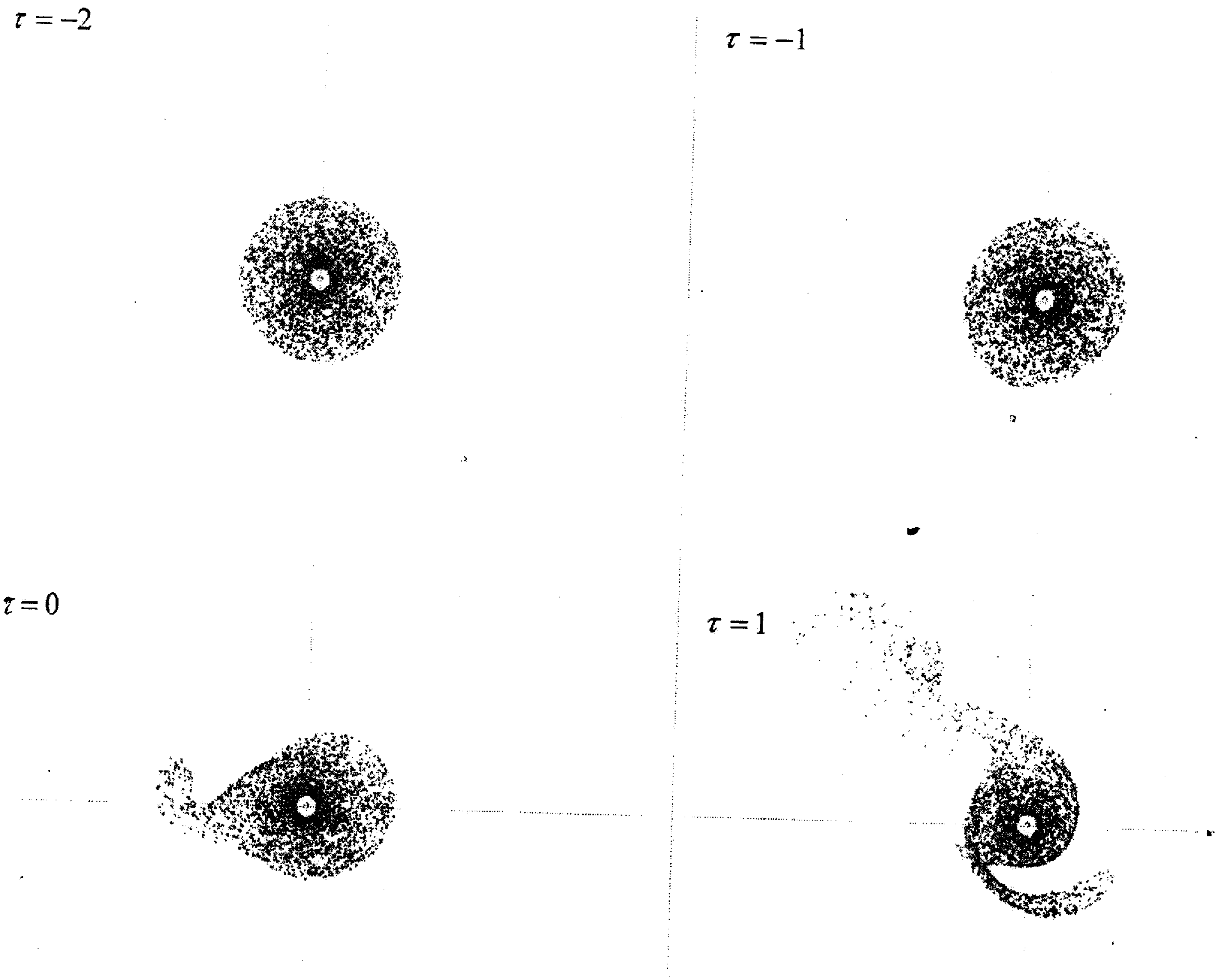

Figure 1. Direct motions, $\mu = 0.1$

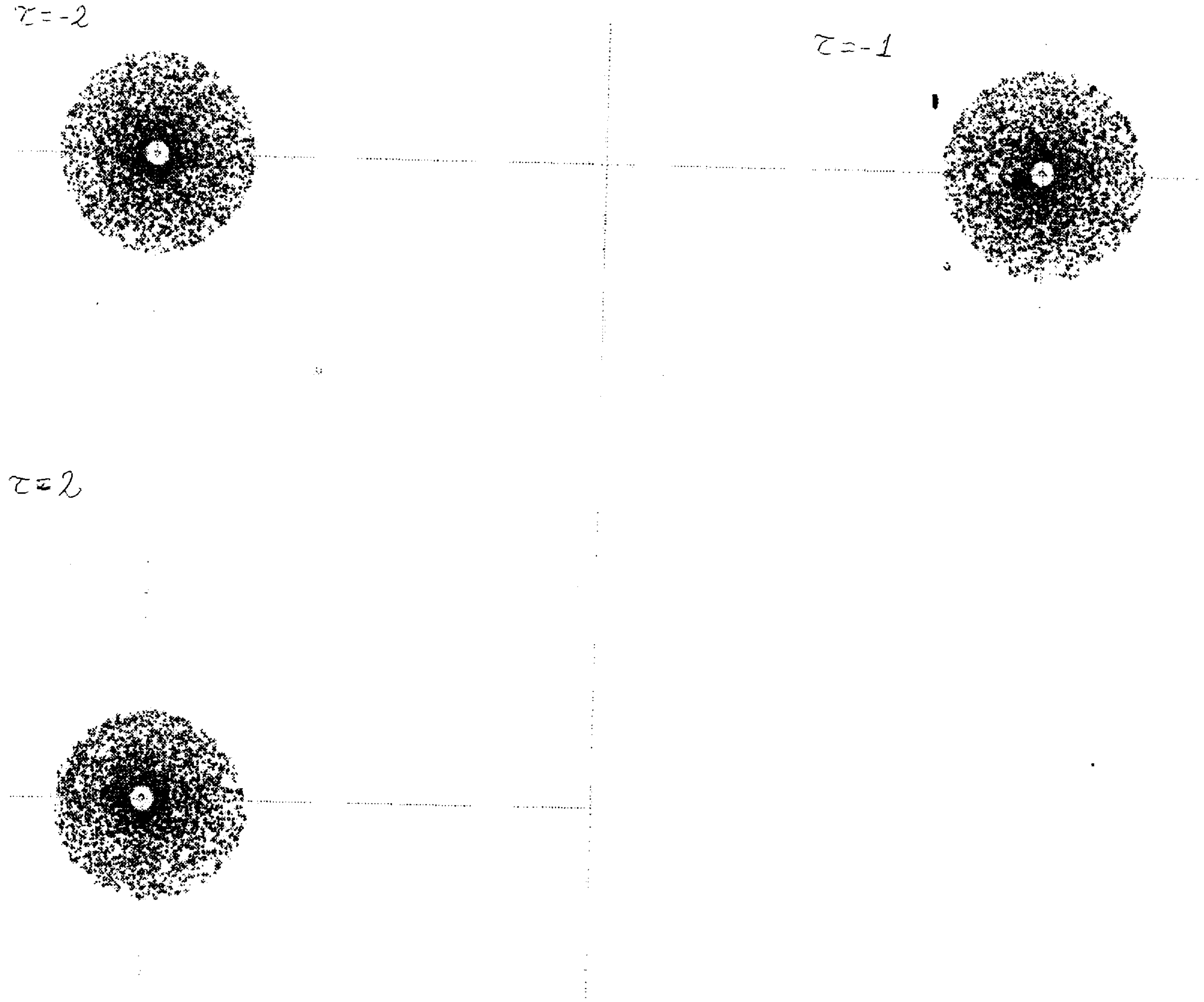

Figure 2. Retrograde motions, $\mu = 0.1$

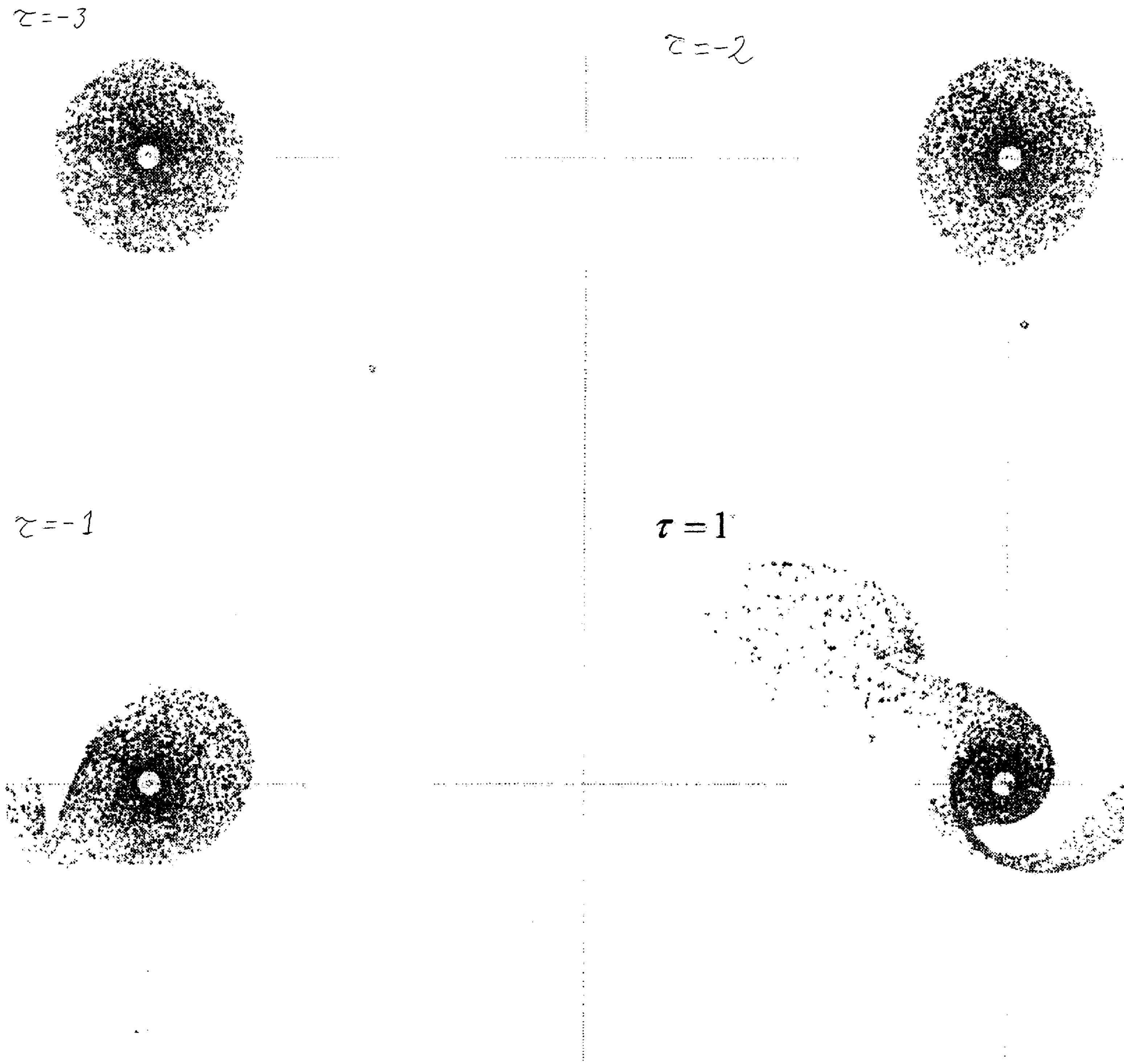

Figure 3. Direct motions, $\mu = 0.2$

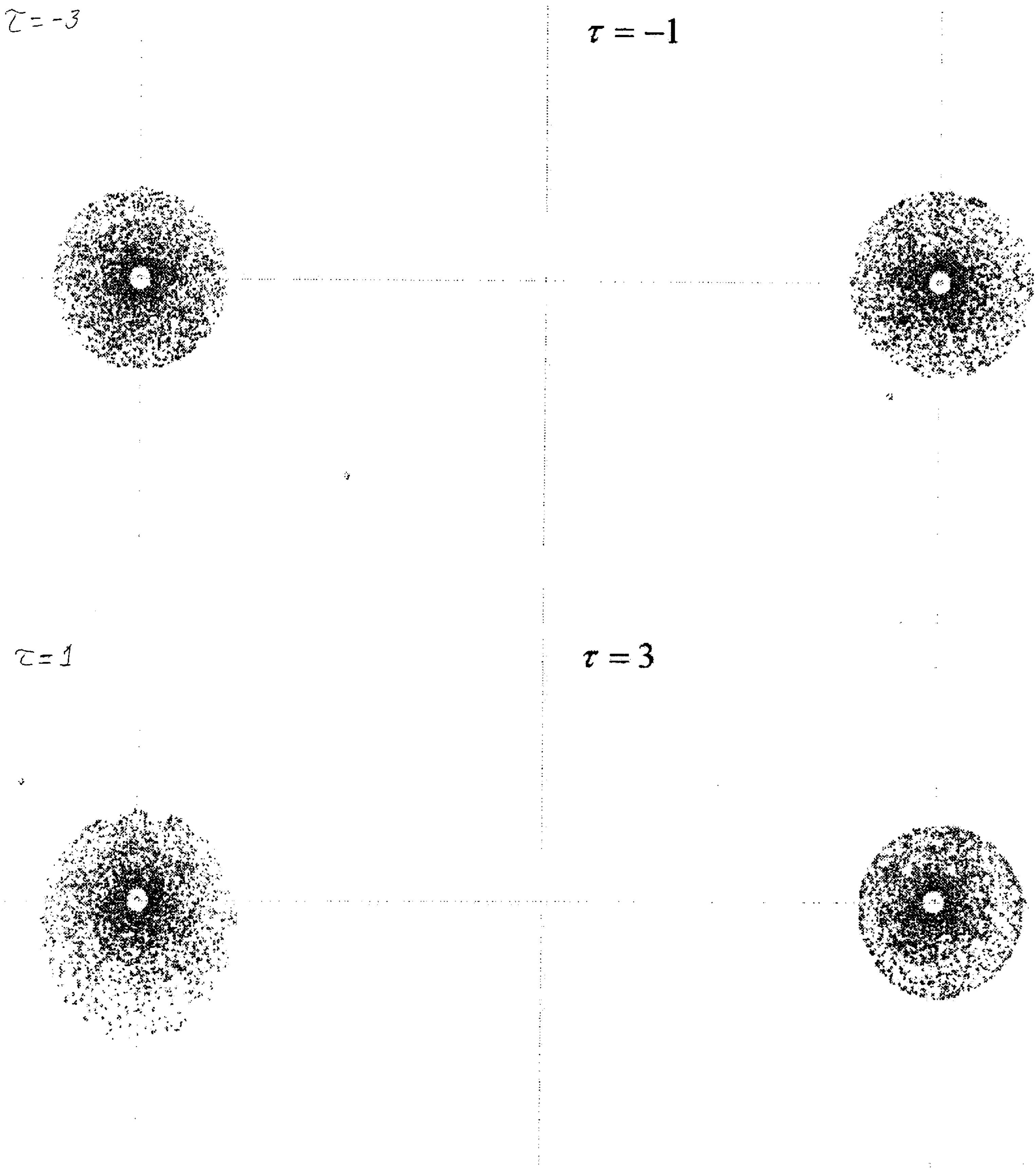

Figure 4. Retrograde motions, $\mu = 0.2$

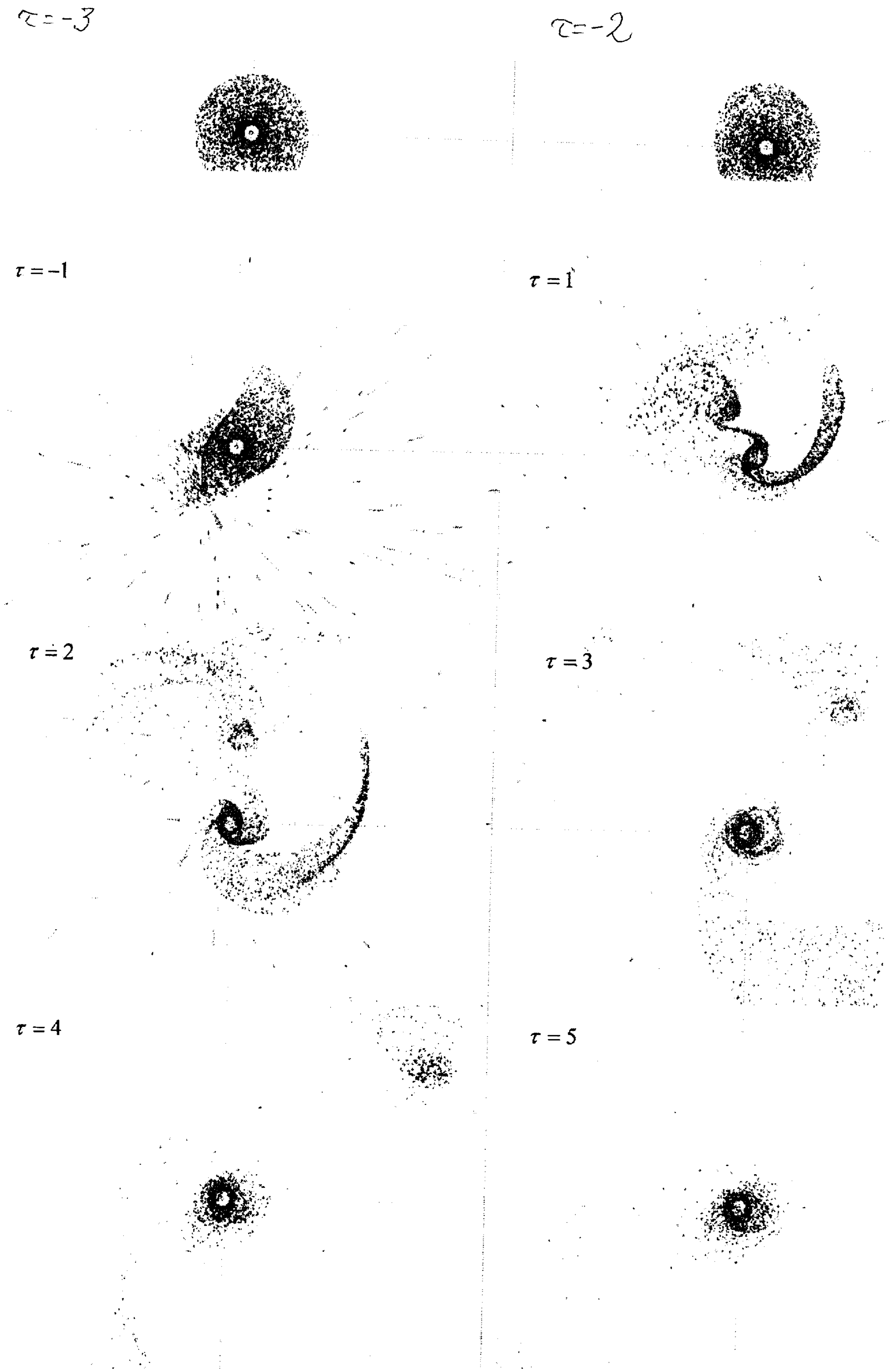

Figure 5. Direct motions, $\mu = 1$

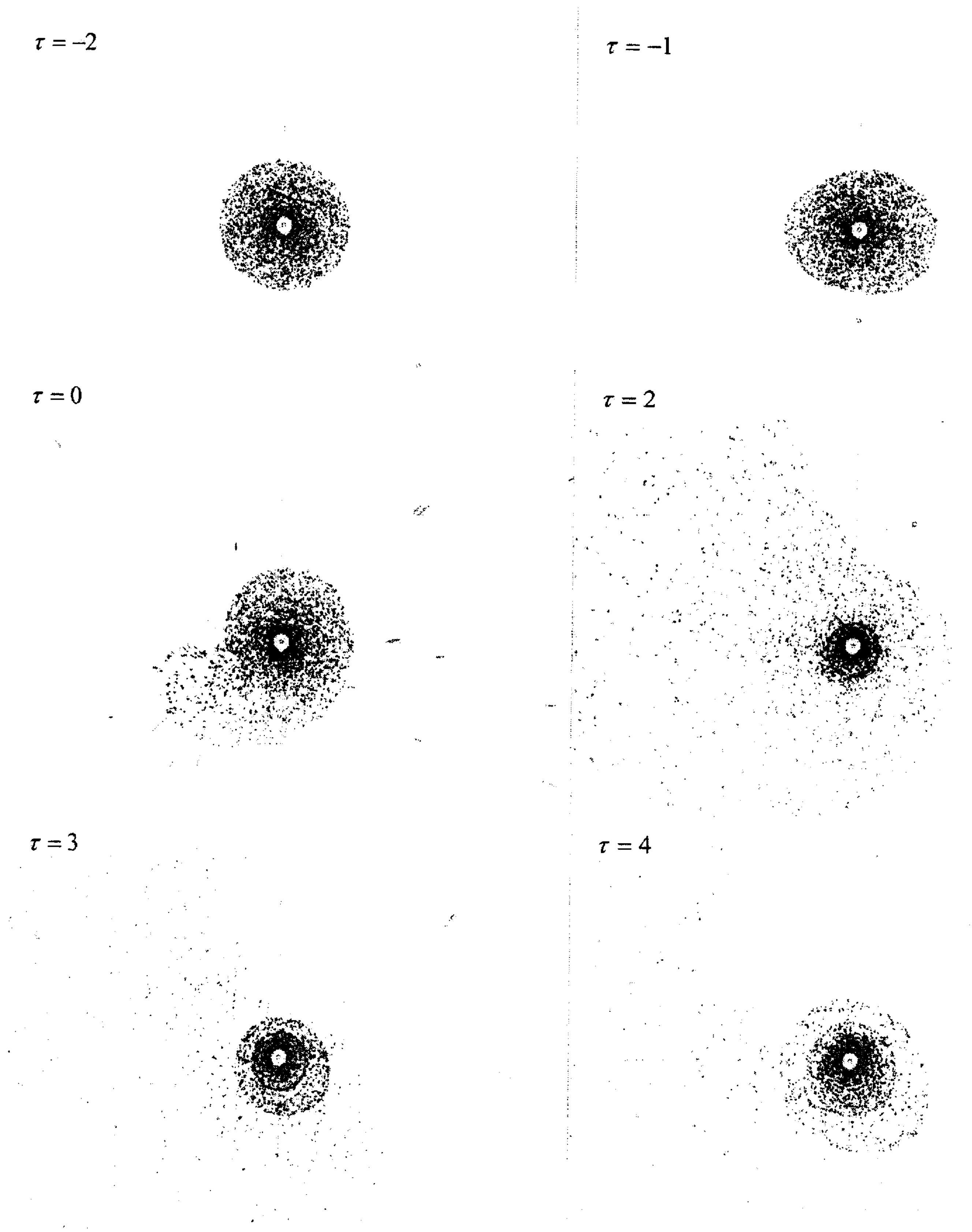

Figure 6. Retrograde motions, $\mu = 0.5$

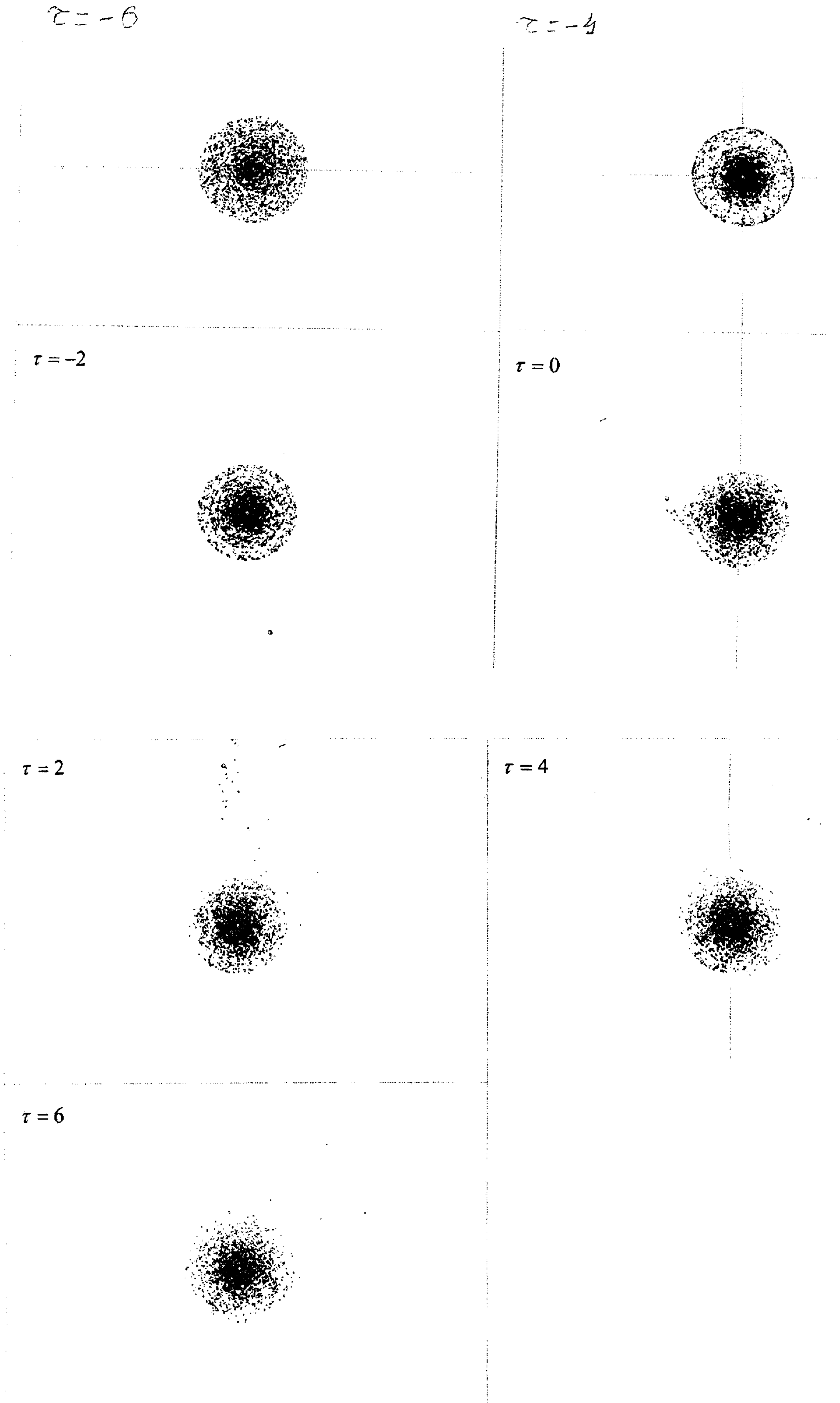

Figure 7. Direct motions, $\mu = 0.5$