DENSITY PROFILES OF MERGER REMNANTS OF INTERACTING GALAXIES

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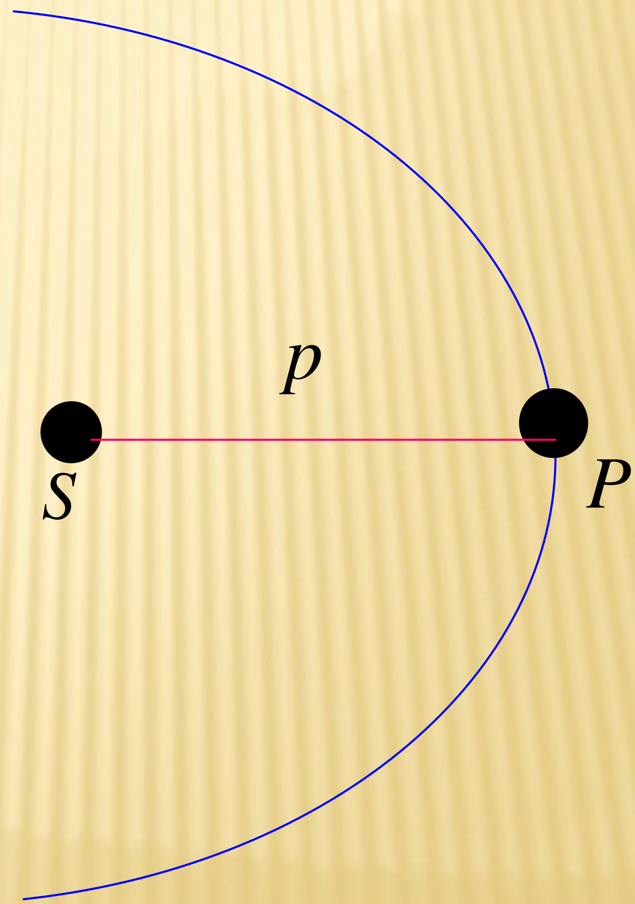
Important parameters in a galactic encounter:

(1)The impact parameter

(2)The velocity of collision

(3)The mass ratio of galaxies

Dynamically important parameter is the distance of closest approach (peri-galactic distance).



Geometry of collision

$p = 0 \rightarrow$ head-on collision

$p < R_1 + R_2 \rightarrow$ overlapping collision

$p = R_1 + R_2 \rightarrow$ gracing collision

$p > R_1 + R_2 \rightarrow$ distant collision

Other parameters are less significant

Computations are performed to see

- for what values of p merging takes place
- what is the density profile of the merger remnant

Model galaxy

Density n=4 polytrope;
appropriate for elliptical
& bulges of spirals

Mass $10^{11} M_{\Theta}$

Radius 45 kpc

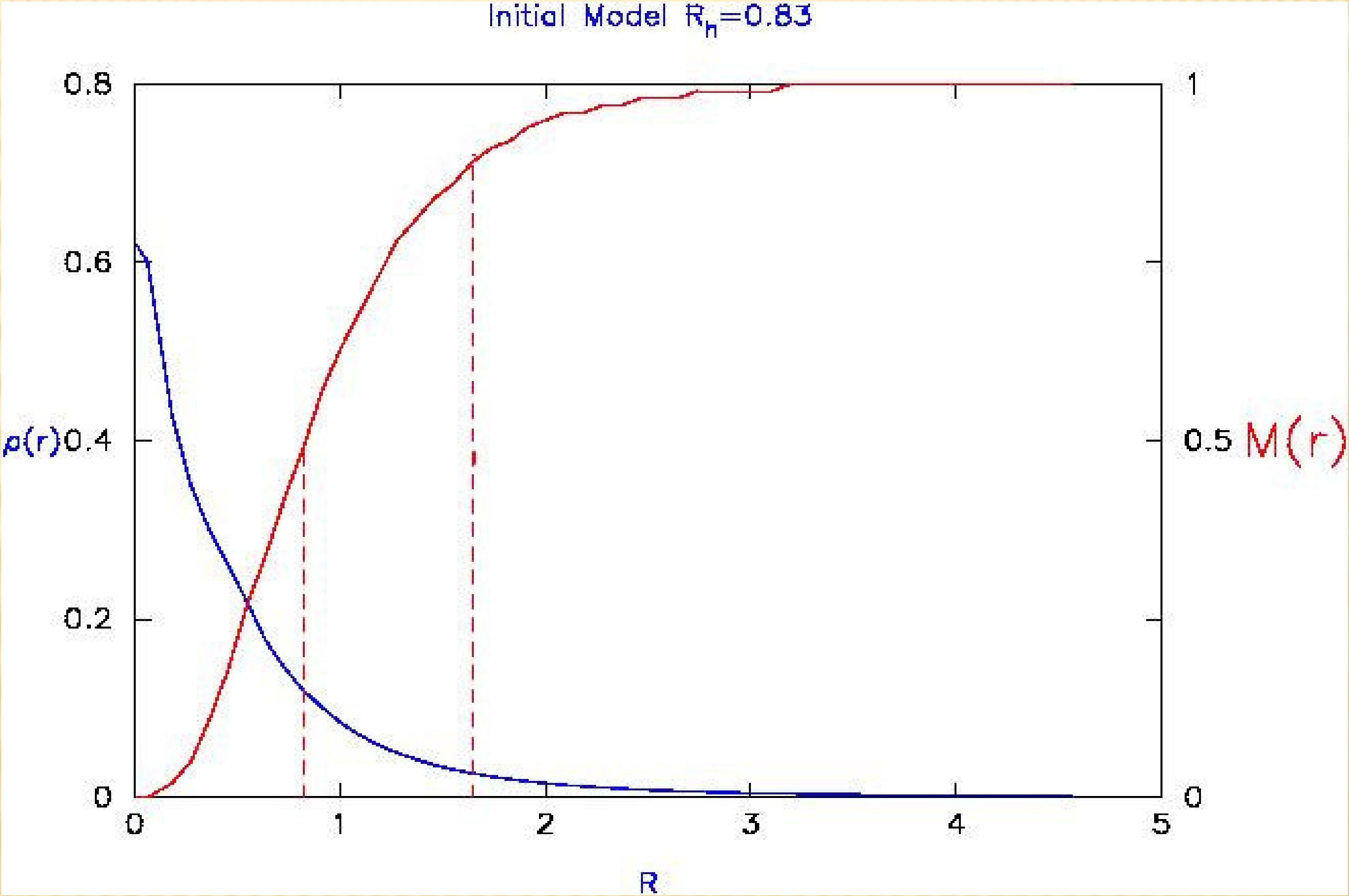
H-Radius R_h 8.3 kpc

10 % mass 3 kpc

90 % mass 2 R_h

Crossing time t_{cr} 2.8 unit

Model galaxy is close to virial eqlbm. with no net ang. mom.



Initial Model R_h=0.83
0.8
0.6
ρ(r)0.4
0.2
0
0
1
2
3
4
5
R
1
0.5 M(r)
0

UNITS

$G = 1$

$M = 10^{11} M_{\Theta}$

L = 10 kpc

t = 4.7 M yr

V = 210 km/s

- Bound orbit encounters merge rapidly.

- Collisions with high e produce negligible tidal effects.

- Encounters in which the galaxies move on parabolic orbit is expected to produce maximum tidal effects.

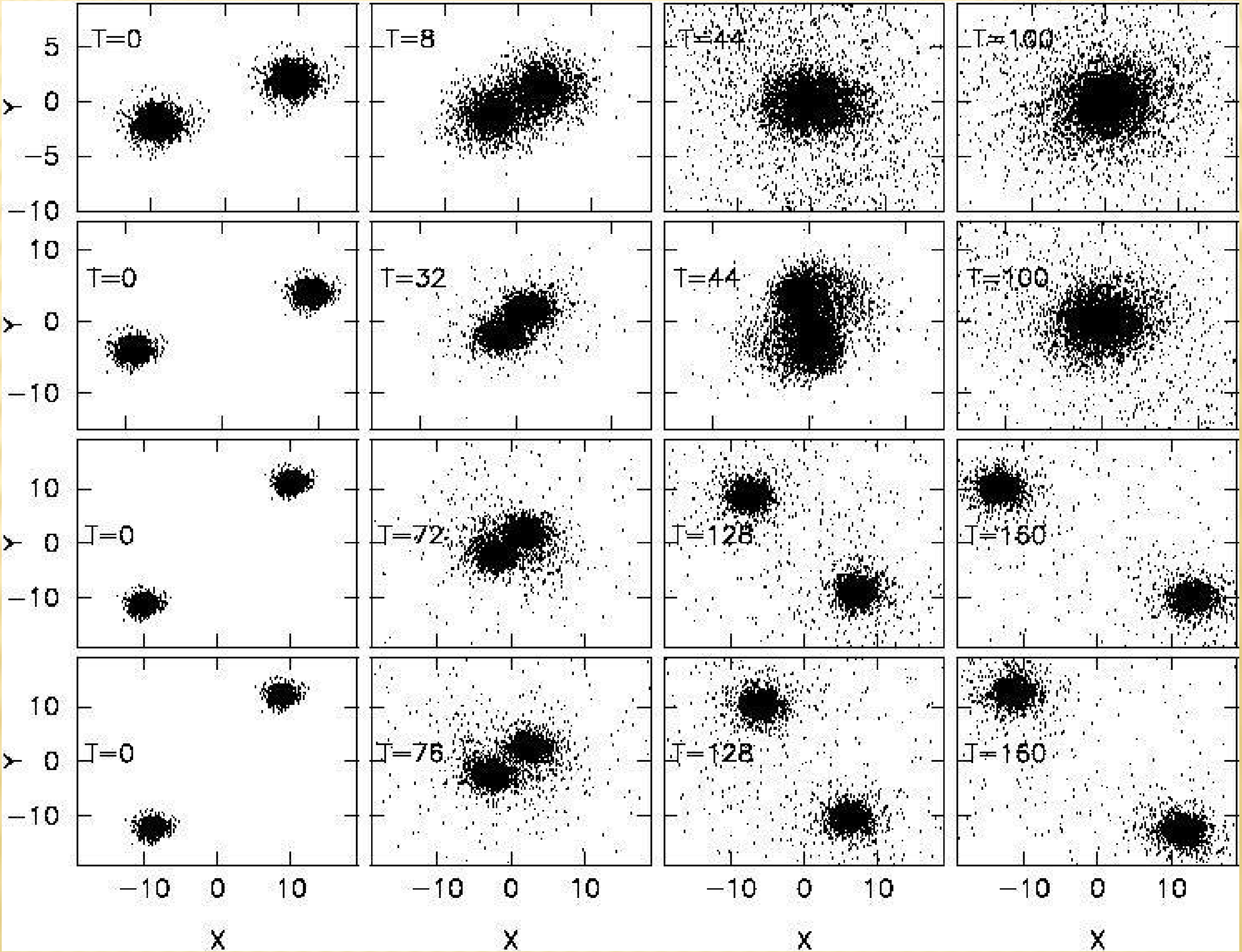
Two equal mass galaxies set to move on parabolic orbit

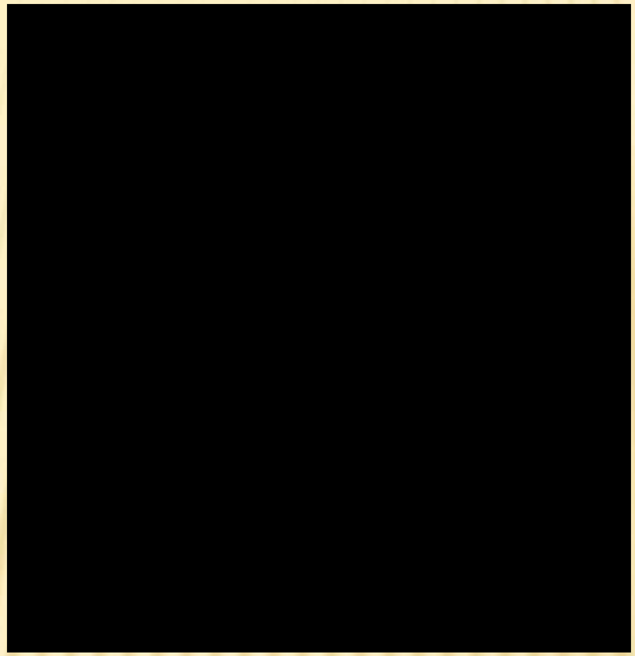
Orbital plane coincides with X-Y plane

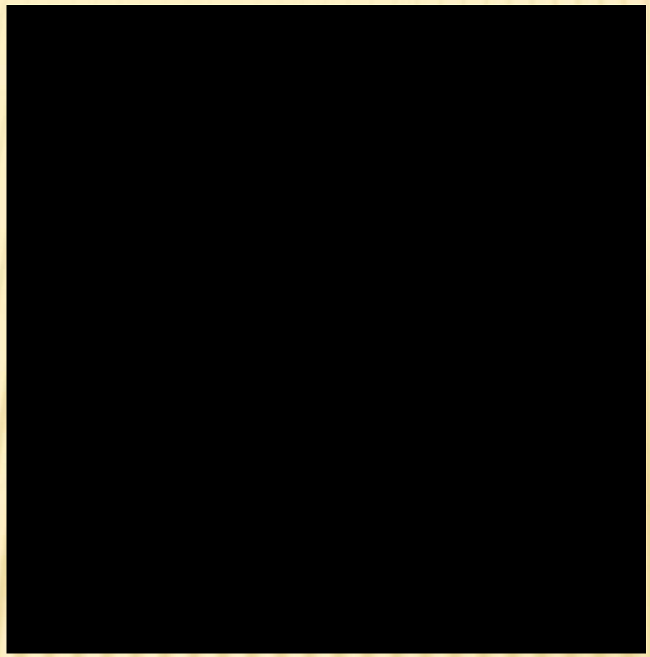
Distance of closest approach p/R_h takes on values in the range 0.5 – 10

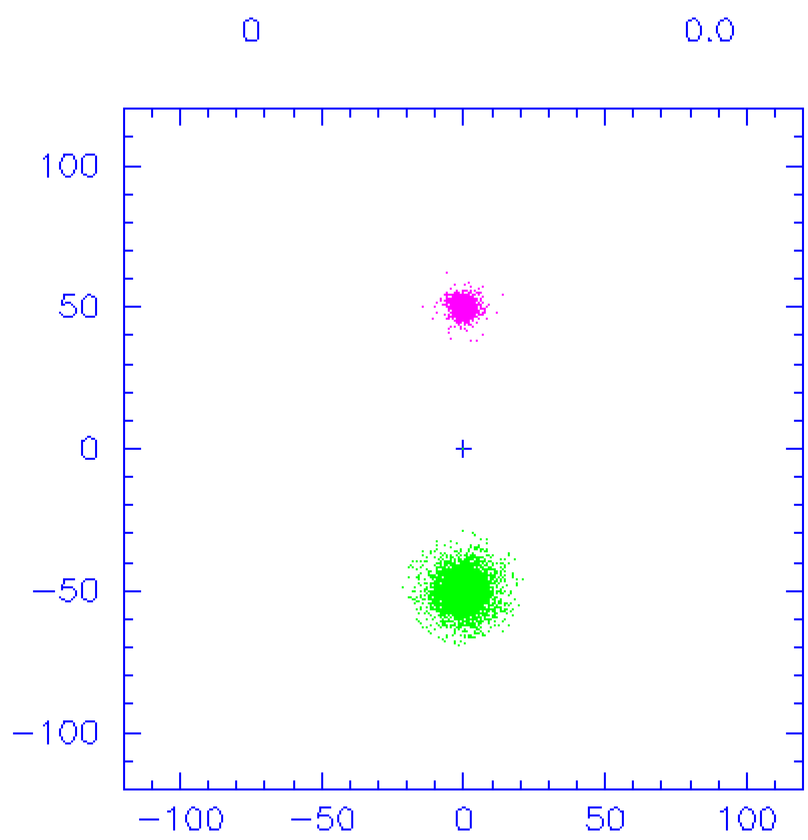
Evolution of the collision is followed by self-consistent N-body simulations

Model	**Init Vel**	**Sep.**	p/R_h	V_p/V_e
P1	0.633	10	0.5	0.483
P2	0.447	20	1.0	0.573
P3	0.447	20	2.5	1.023
P4	0.365	30	3.0	1.102
P5	0.365	30	4.0	1.214
P6	0.447	20	5.0	1.435
P7	0.365	30	6.0	1.518
P8	0.365	30	7.5	1.731
P9	0.447	20	10.0	2.032


T=0
T=8
T=44
T=100
T=0
T=32
T=44
T=100
T=0
T=72
T=128
T=160
T=0
T=76
T=128
T=160
y
5
0
−5
−10
10
0
−10
10
0
−10
10
0
−10
−10
0
10
x





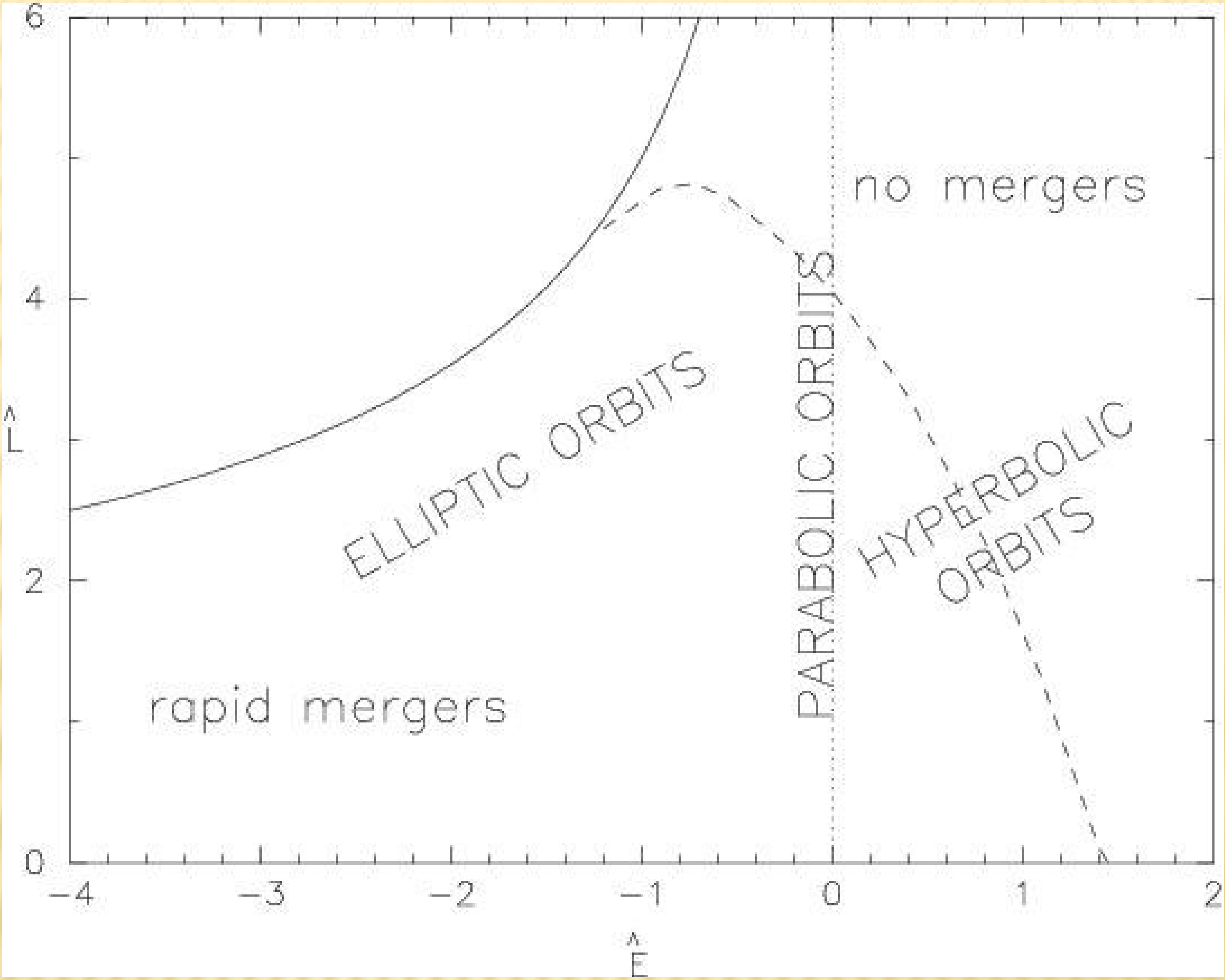

0
0.0
100
50
0
−50
−100
−100
−50
0
50
100

Models P1 – P4 merge in less than 40 t_{cr}

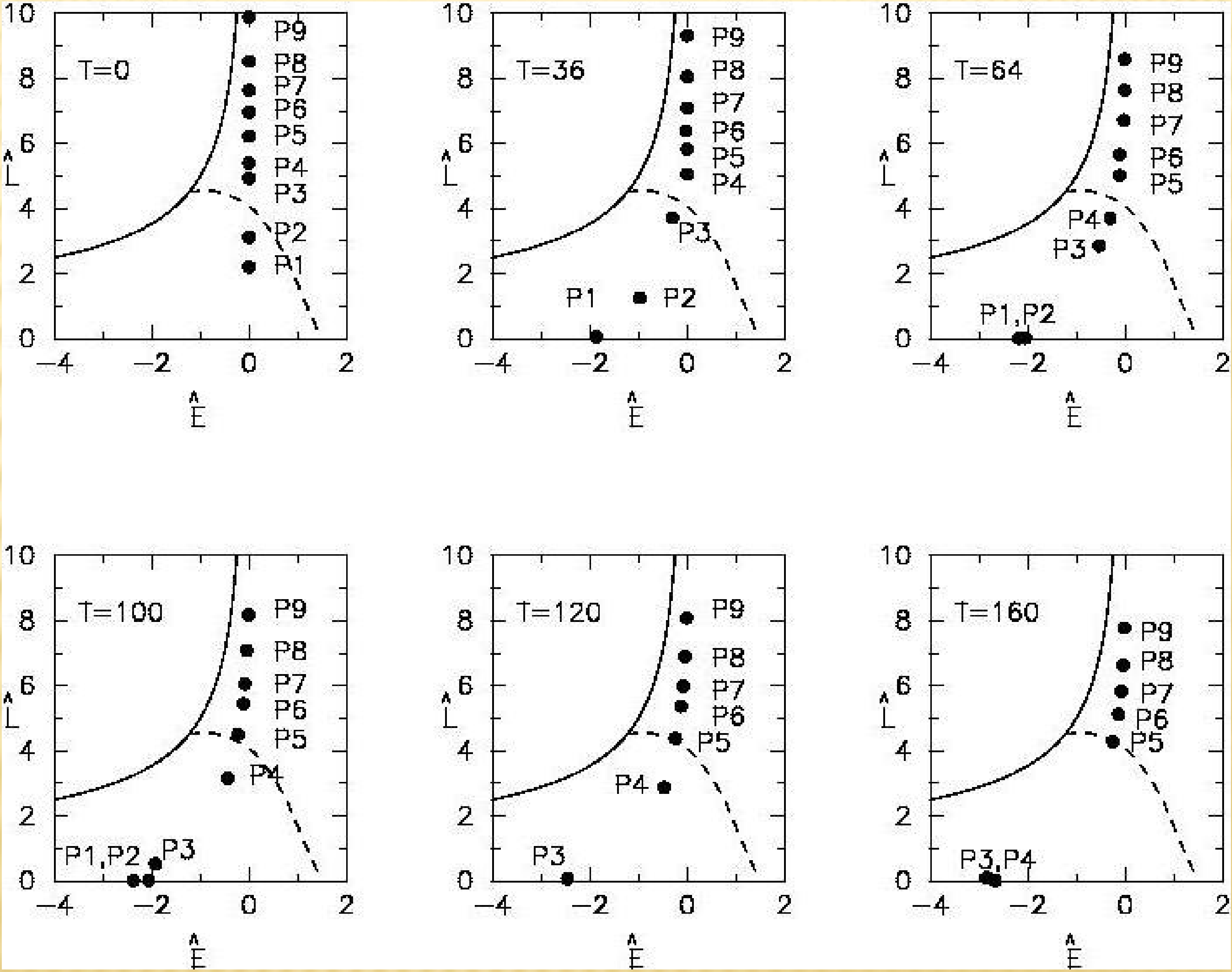
P5 – P9 do not merge even after 70 t_{cr}

$$\hat{E} = \frac{E_{orb}}{0.5 < v^2 >} \qquad \hat{L} = \frac{L_{orb}}{R_h < v^2 >^{0.5}}$$

These dimensionless quantities generally determines the out come of a galactic collision (Binney & Tremaine, 1987)



no mergers
ELLIPTIC ORBITS
PARABOLIC ORBITS
HYPERBOLIC ORBITS
rapid mergers
$\hat{L}$
$\hat{E}$
6
4
2
0
−4
−3
−2
−1
0
1
2


T=0
T=36
T=64
T=100
T=120
T=160
P1
P2
P3
P4
P5
P6
P7
P8
P9
P1,P2
P3,P4
L̂
Ê

Model	$\Delta U / \lvert U \rvert$	$\Delta M / M$	$(\Delta M / M)_E$	t_m / t_{cr}
P1	1.033	0.173	0.186	7.1
P2	1.011	0.166	0.193	10.6
P3	1.016	0.161	0.218	26.5
P4	1.030	0.182	0.226	35.3
P5	0.457	0.077		
P6	0.435	0.043		
P7	0.436	0.055		
P8	0.427	0.047		
P9	0.431	0.048		

Merging Models

The relative change in energy $\Delta U / |U|$ gives the strength of interaction.

$\Delta U / |U| > 1 \Rightarrow$ less massive galaxy suffers disruption

Models P1 – P4 undergo considerable disruption before merging.

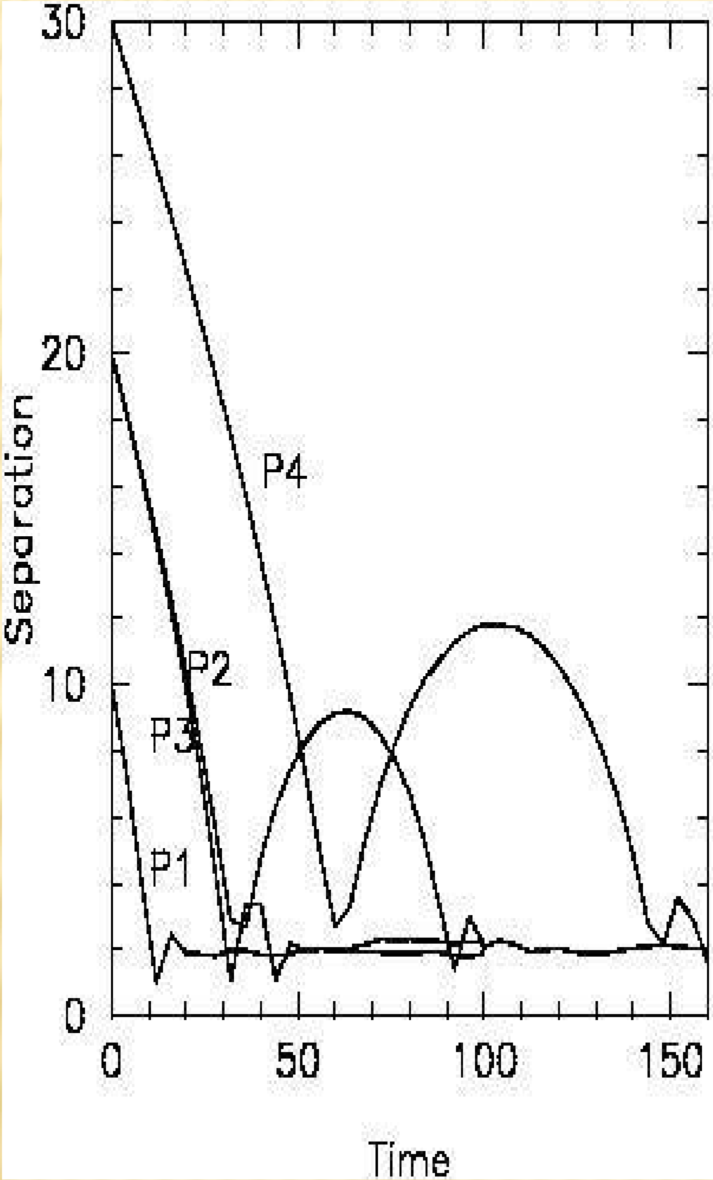
$\Delta M / M$ - the mass loss – less than 18%

Effective mass loss is less than 23 %.

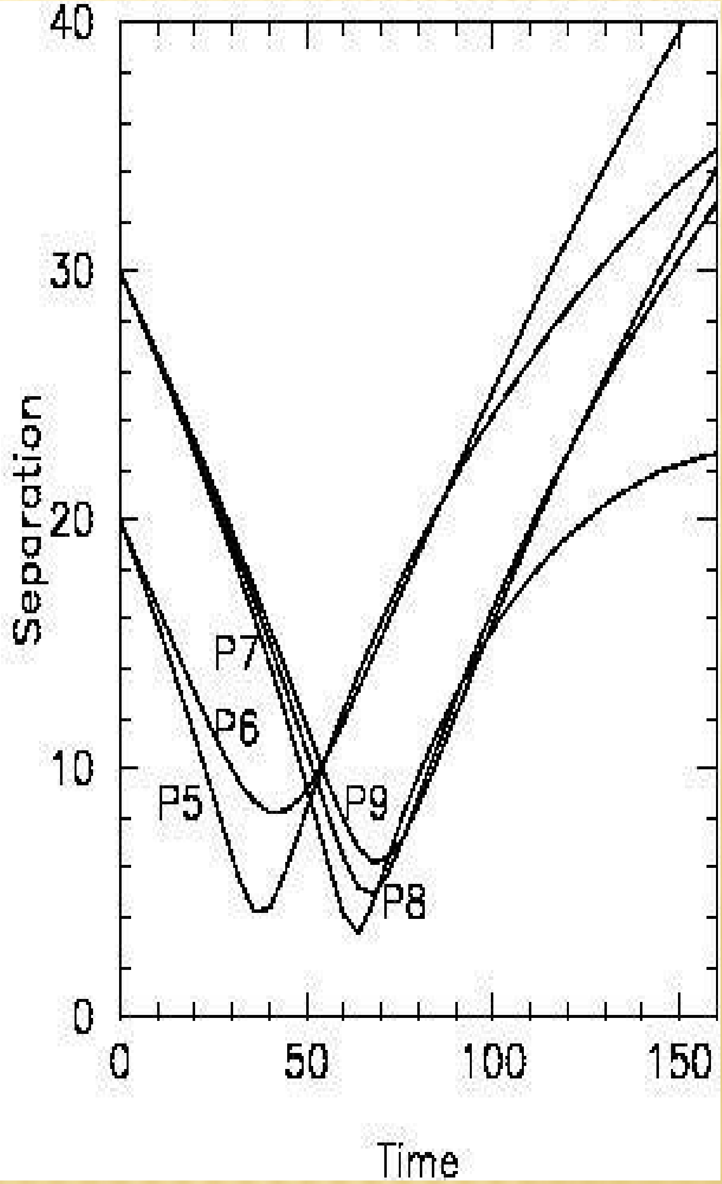
Non-merging Models

$\Delta U / |U| < 1$ $\Delta M / M < 8\%$

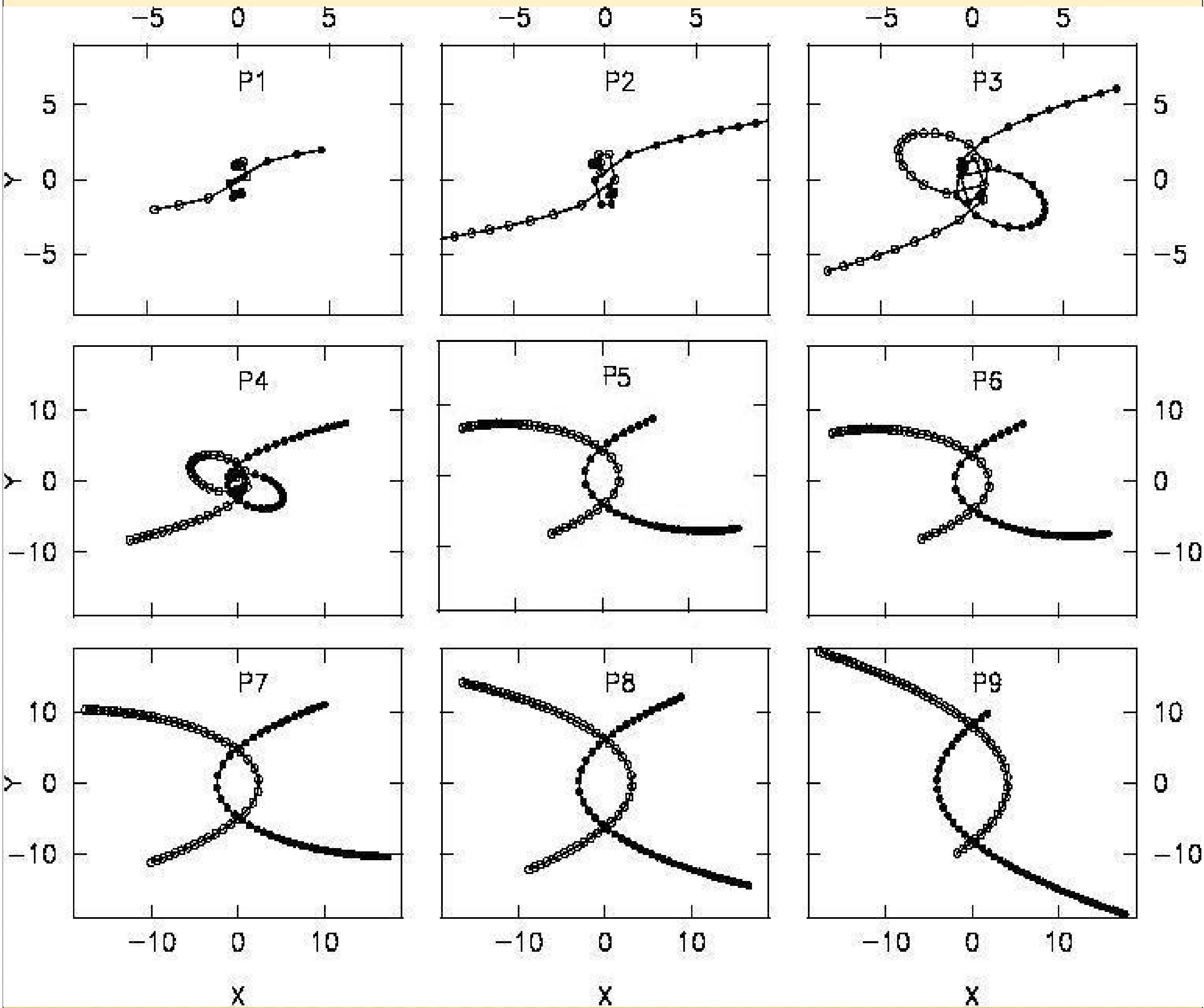
Retains initial structure.



30
20
10
0
Separation
P4
P2
P3
P1
0
50
100
150
Time



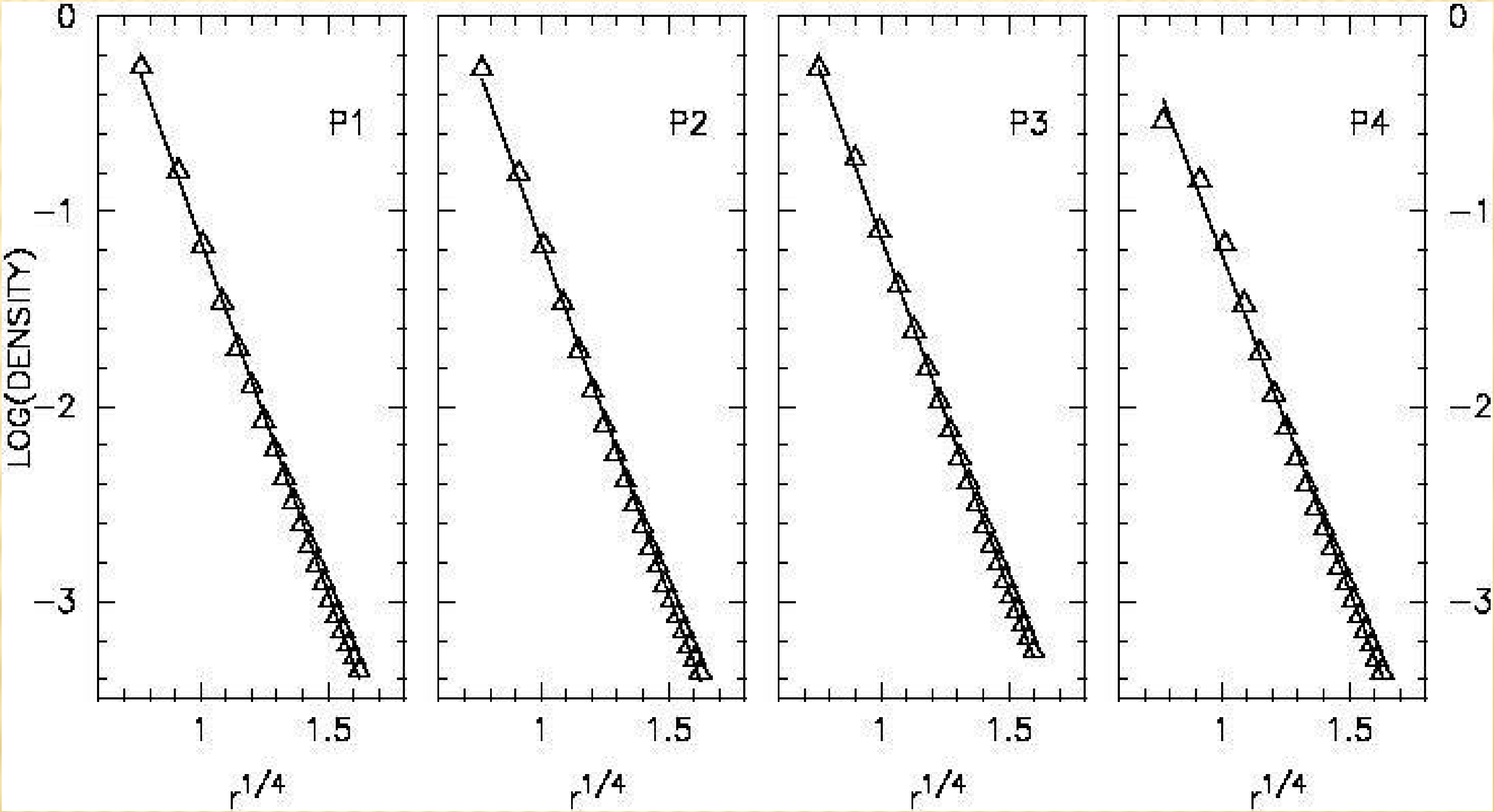
40
30
20
10
0
Separation
P7
P6
P5
P9
P8
0
50
100
150
Time


P1
P2
P3
P4
P5
P6
P7
P8
P9
Y
X

The surface density profiles fitted with de Vaucouleur's $r^{1/4}$ law

$$\log\left[\frac{I(r)}{I(0)}\right] = -3.33\left[\left(\frac{r}{r_e}\right)^{1/4} - 1\right]$$

r_e is the radius containing half the total light



LOG(DENSITY)
0
−1
−2
−3
P1
P2
P3
P4
1
1.5
$r^{1/4}$

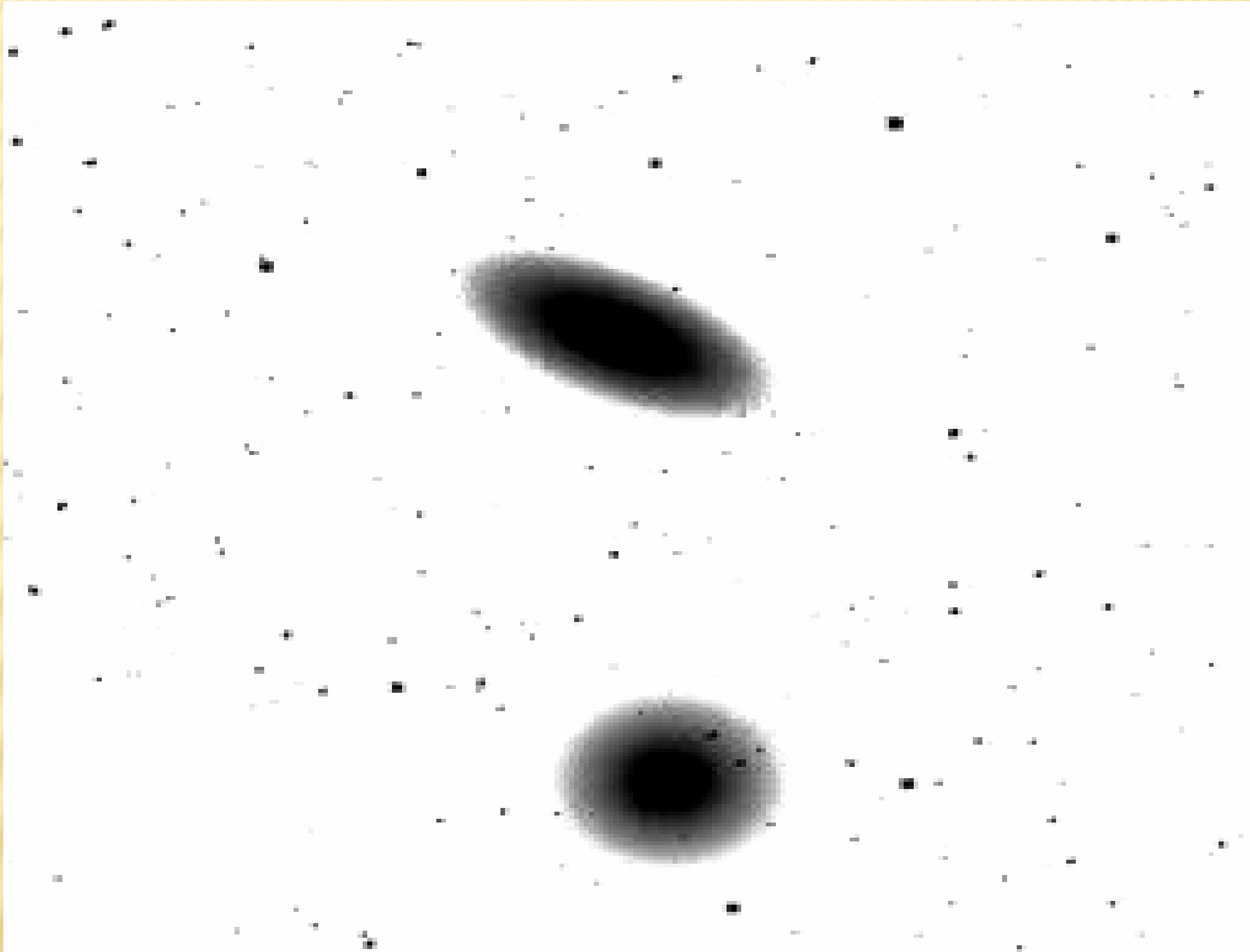
The fit is remarkably good in the inner region up to R = 4 R_h

Beyond this point the density shows tendency to develop tidal distension (Kormendy 1977).

CONCLUSIONS

For equal mass galaxies moving on parabolic orbits

- merging occurs when $p < 4R_h$
- merging occurs not in the first close collision but only during subsequent close contacts.
- the surface density profiles of the merger remnants follows $r^{1/4}$ law up to $R \approx 4R_h$ and shows tendency to develop tidal distension in the outer regions



The rate of tidal disruption and merger for a pair of galaxies is given by

$$\frac{t_d}{t_m} \approx \frac{6}{(5 - n)} \frac{a}{R} \frac{M}{M_1}$$

t_d, t_m	Disruption & Merging times
a	Orbital radius
R	Radius of M
M, M_1	Masses of the galaxies
n	Polytropic index of M