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Summer Student Lecture Notes

DENSE STELLAR SYSTEMS AND EXTRAGALACTIC RADIO SOURCES

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Definition: Systems such that the existence and evolution of stars is affected by the proximity of their near neighbors, i.e. systems with up to 10^9 stars per pc^3.

Evidence for existence:

Galaxy - 10^7 stars/pc^3 in inner .1 pc.

M 31 - 2×10^5 stars/pc^3 in inner few pc.

M 32 - 3×10^6 stars/pc^3 in inner few pc.

Nuclei of Seyfert galaxies.

Nuclei of some elliptical galaxies.

a) Can a system evolve to 10^9 stars/pc^3?

b) What will happen if it does?

c) What is the relation to radio sources?

First, a brief review of some extragalactic radio source characteristics.

Two categories: 1) Compact 2) Extended

Both are associated with galaxies and QSO's. For galaxies, they are either located in the nucleus (Compact) or ejected from it (Extended).

1) Compact sources - about 1/2 of all observed at centimeter wavelengths.

Characteristics: variable, self-absorbed synchrotron radiation

Examples:

Source	D(Mpc)	R(pc)	L(erg s^{-1})	$\Delta\tau$(yr)
NGC 1052	14	< .07	2×10^{40}	1
3C 84	54	.27	1×10^{41}	2
3C 273	474	< .95	8×10^{42}	1
3C 345	1782	< 6.2	7×10^{43}	2
3C 446	4212	< 8.4	2×10^{44}	
2134+00	5790	<14.5	3×10^{45}	

Some outbursts can be fit by single explosion model and some cannot.

2) Extended sources - 80% are double.

Minimum total energy - 10^{60} ergs.
Lifetime - 10^6 - 10^9 years.
Sizes average around 200 kpc.

Cannot create an extended source from a compact one.

If their nature is known, one can extrapolate back to find conditions in the nucleus.

Dynamics of Dense Stellar Systems

Would like to see if it is possible to start with a "normal" galaxy and see if it evolves a dense core of stars which give rise to the radio sources described above.

Processes - low stellar density.

Binary encounters:

Relaxation time $T_R \sim \dfrac{8 \times 10^5 N^{1/2} R^{3/2} (pc)}{(M/M_\odot)^{1/2} (\log N - .3)}$ yr. if in virial equilibrium.

Evaporation of stars from:

Truncated Maxwellian distribution

Binary Encounters

Tidal forces

tends to produce a dense core over very long times. (See Figure 1.)

Processes which accelerate evolution:

Non identical masses

Non uniformity of gravitational potential

Violent relaxation (see figure)

High stellar density

Stellar collisions

Disruptive if K.E. > B.E. or

$$\frac{1}{2} m \overline{v}^2 > \frac{3}{2(5-n)} \frac{G m^2}{r}$$

Otherwise collisions are coalescing.

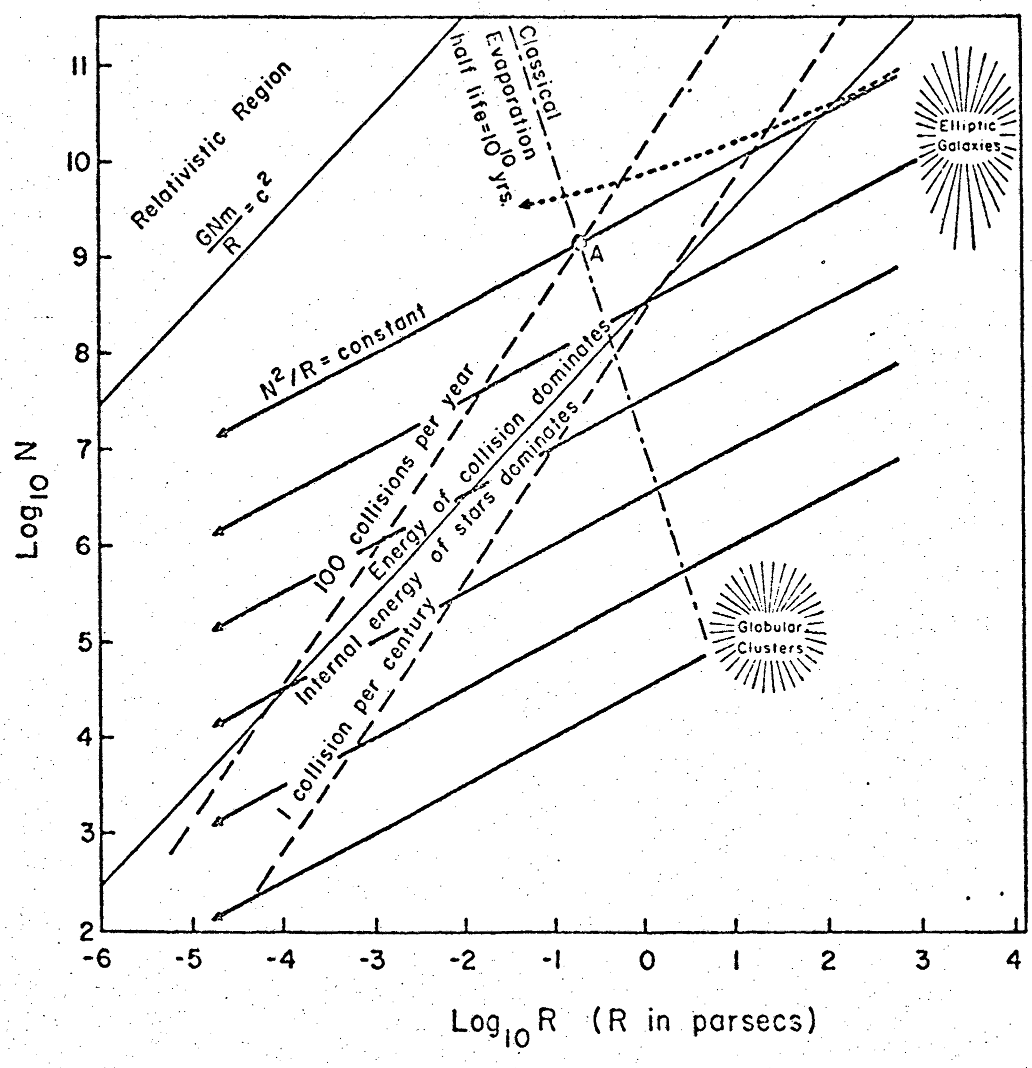
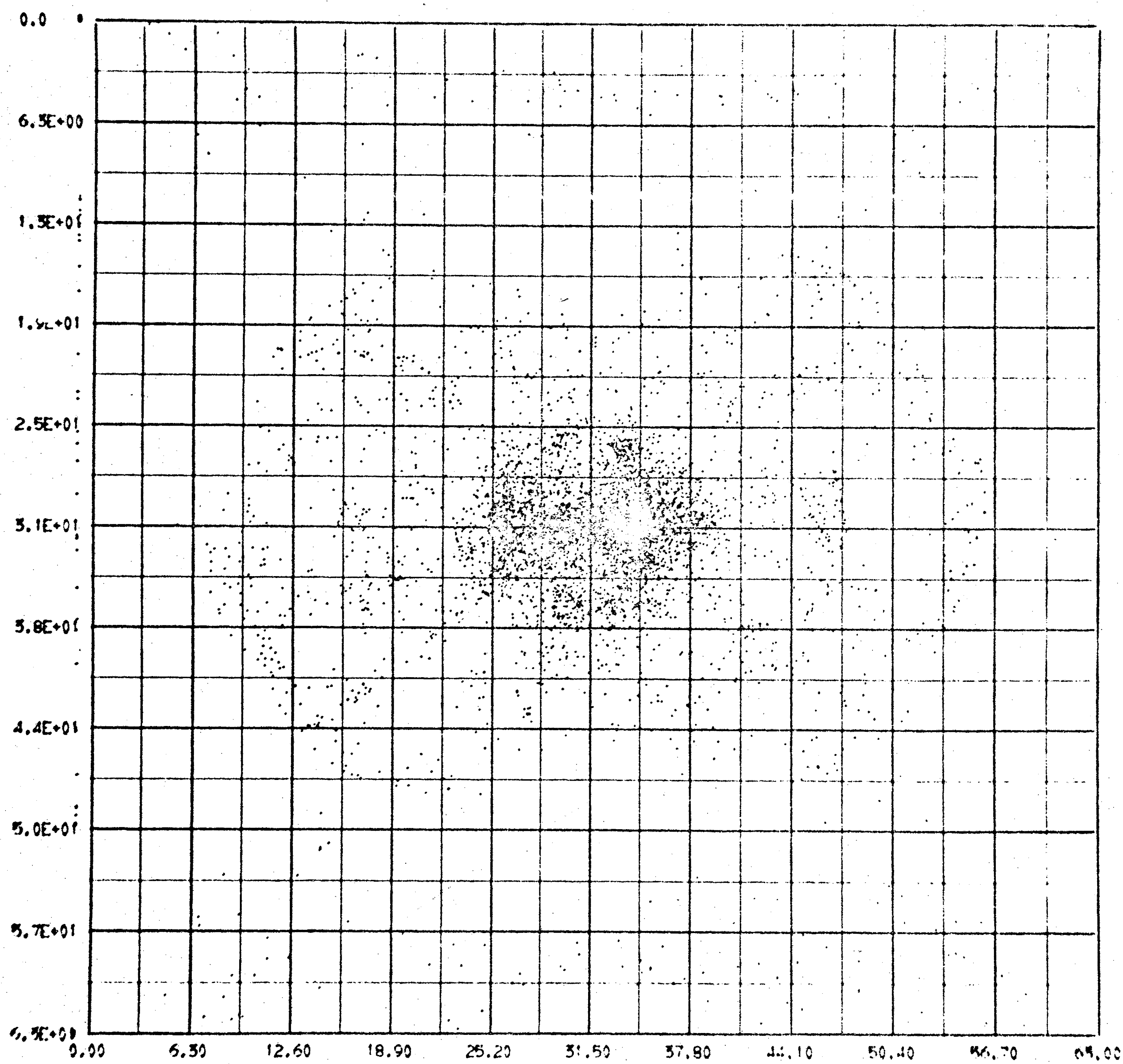

Relativistic Region
GNm/R = c²
Classical
Evaporation
half life=10¹⁰ yrs.
Elliptic Galaxies
A
N²/R = constant
100 collisions per year
Energy of collision dominates
Internal energy of stars dominates
1 collision per century
Globular Clusters
Log₁₀ N
Log₁₀ R (R in parsecs)

FIG. 1

IT = 360 T = .350

T = .36



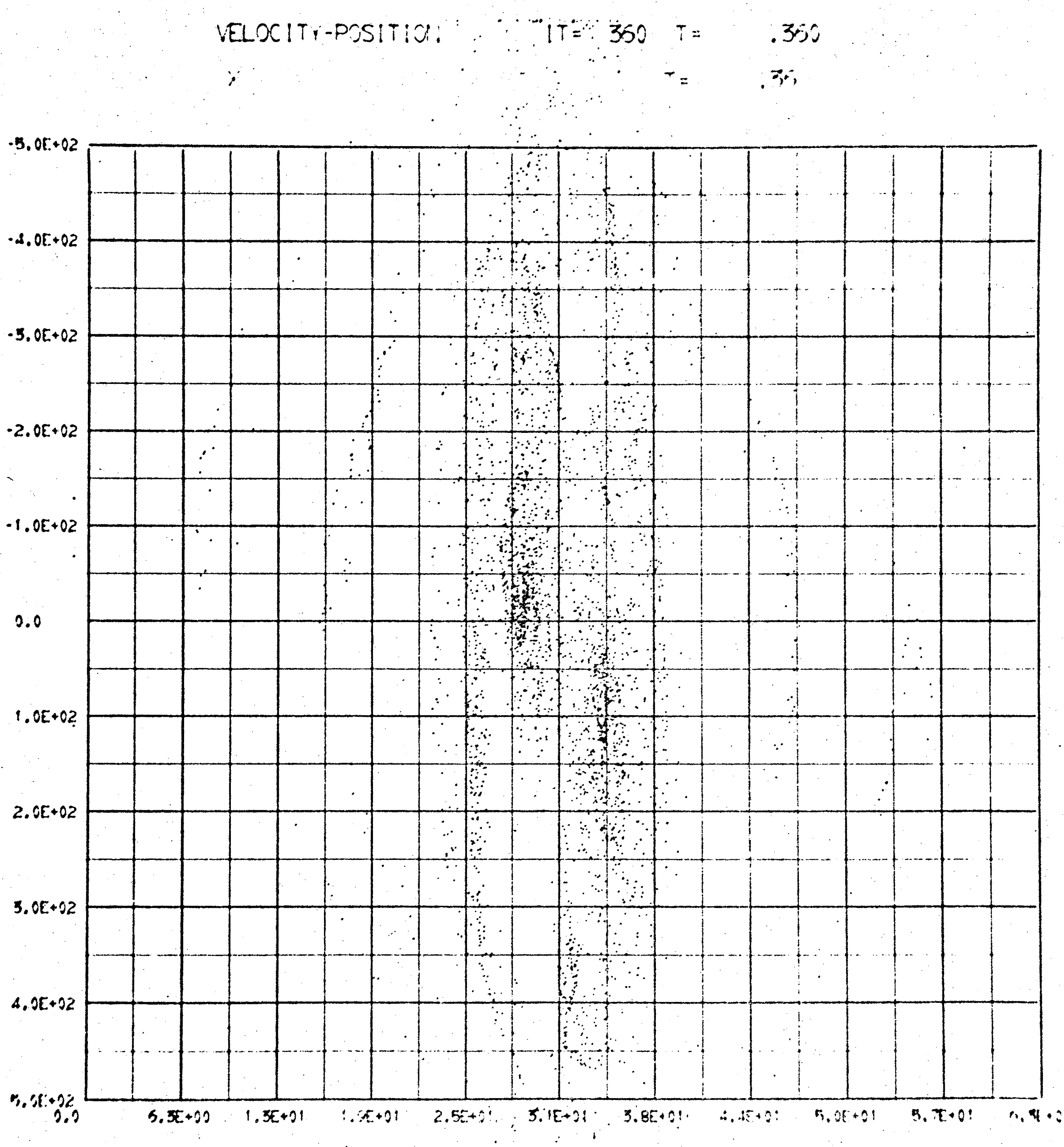

VELOCITY-POSITION IT= 360 T= .360
-5.0E+02
-4.0E+02
-3.0E+02
-2.0E+02
-1.0E+02
0.0
1.0E+02
2.0E+02
3.0E+02
4.0E+02
5.0E+02
0.0
6.3E+00
1.3E+01
2.5E+01
3.1E+01
3.8E+01
5.0E+01
5.7E+01

TABLE I*

PROPERTIES OF COMPACT, SPHERICAL STAR SYSTEMS

No. of Stars	Radius, R' (pc)	0.1	1	10	100
$N = 10^6$	Stellar velocity, v_s (km/sec)	147	47	14.7	4.7
	Relaxation time, T_R (years)	4.6×10^6	1.46×10^8	4.6×10^9	1.46×10^{11}
	Collision time, t_c (years)	3.2×10^8	1.09×10^{11}	3.5×10^{13}	1.09×10^{16}
$N = 10^8$	Stellar velocity, v_s	1470	470	147	47
	Relaxation time, T_R	3.4×10^7	1.08×10^9	3.4×10^{10}	1.08×10^{12}
	Collision time, t_c	2.8×10^6	5.2×10^9	3.1×10^{12}	1.09×10^{15}
$N = 10^{10}$	Stellar velocity, v_s	14700	4700	1470	470
	Relaxation time, T_R	2.7×10^8	8.6×10^9	2.7×10^{11}	8.6×10^{12}
	Collision time, t_c	3.1×10^5	9.7×10^6	2.8×10^{10}	8.5×10^{13}

Coalescing collisions can build stars of higher mass to 50 $M_\odot$ (see figure).

Disruptive collisions may liberate up to 10^{49} ergs in relativistic electrons.

Final Evolution

Liberation of gas due to collisions and ablation (see figure).

Subsequent collapse of gas and formation of stars, supermassive objects, rotating disks.

Maximum mass of object without gravitational collapse may be $\sim 10^6$ $M_\odot$.

Radio Source Models

Compact - outbursts due to supernova of 50 $M_\odot$ stars or to violent stellar collisions. Continuous activity due to less energetic collisions and smaller stellar eruptions.

Extended - formation of massive objects (10^6 $M_\odot$) from liberated gas. These can then form black holes, rotating magnetoids, or be ejected by 3 body encounters. Exact mechanism is conjectural.

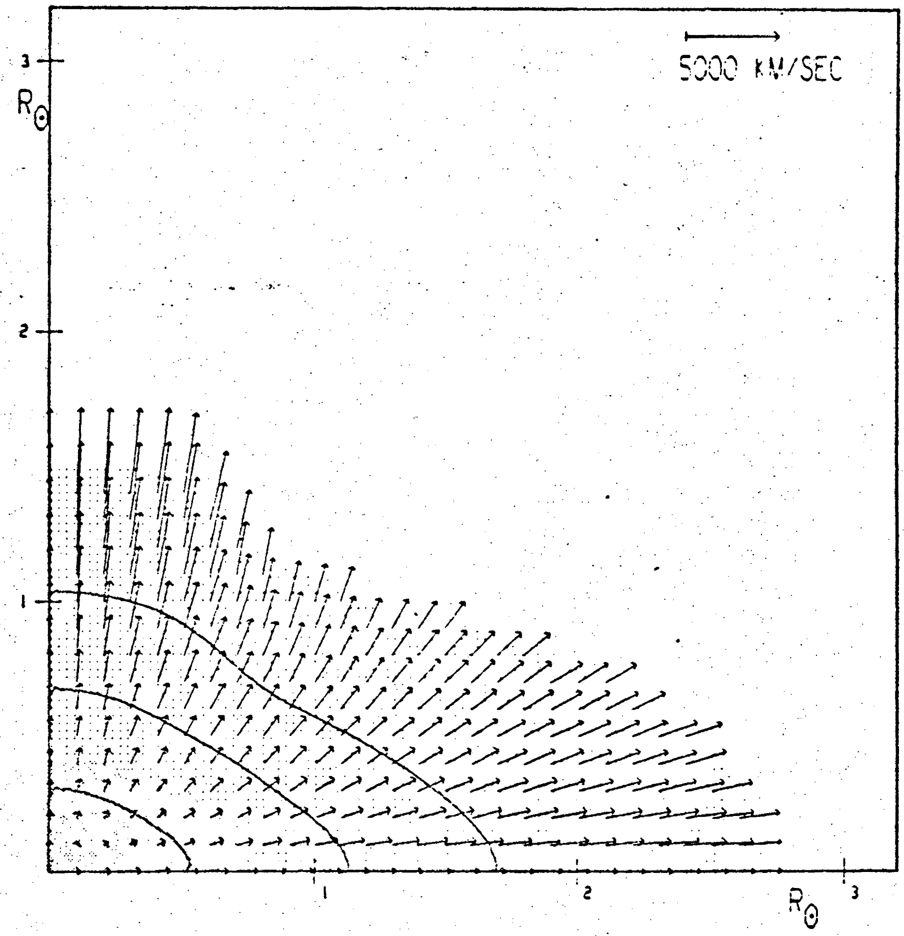
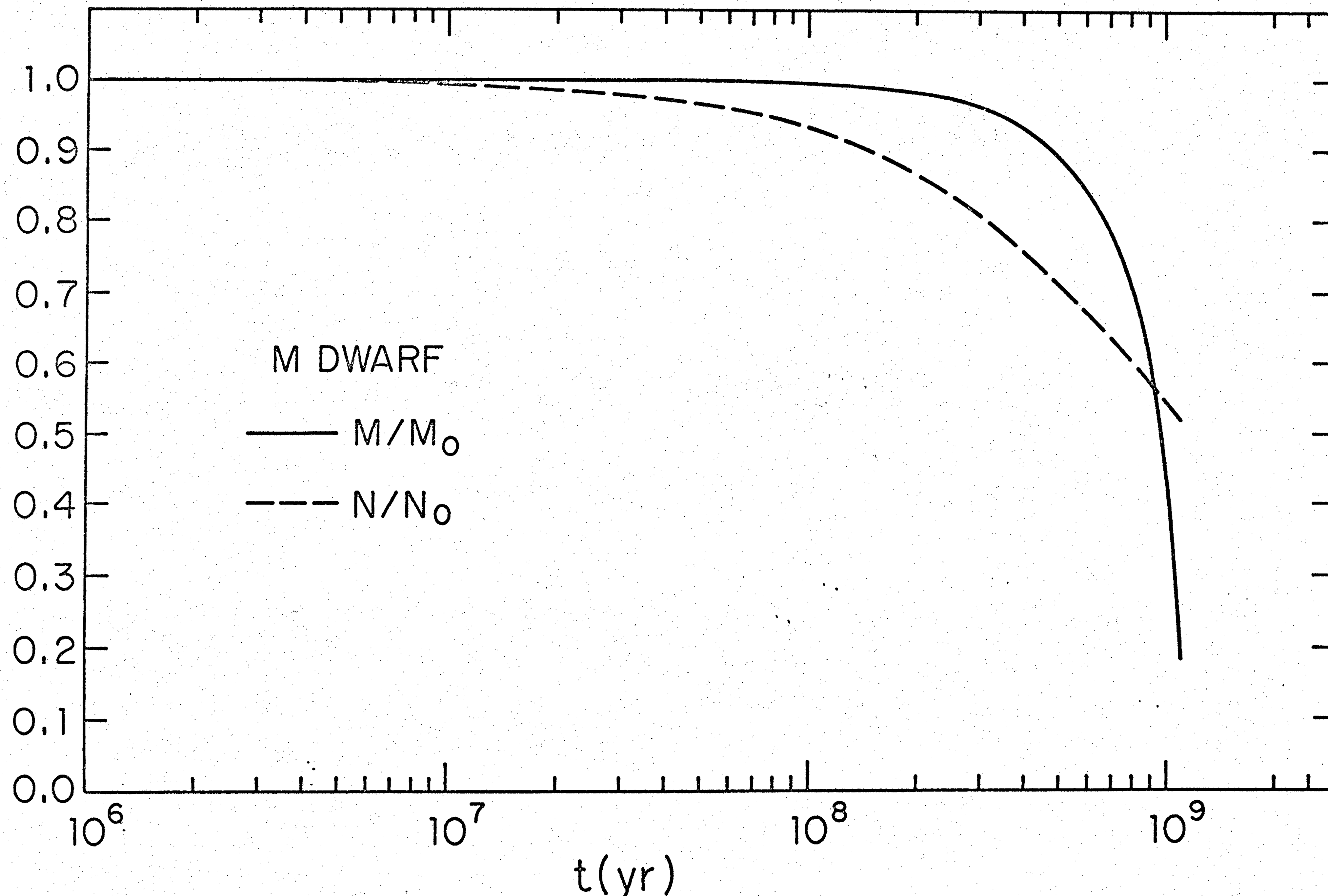


Fig. 8c. The 2000-km s^{-1} collision 1075 s after machine-zero (40 steps per $R_{\odot}$). Proceeding from the center out, the density contours are $\varrho/\varrho_c = 0.1$, 0.01, and 0.001. Outward streaming velocities near the collision axis are as high as 4600 km s^{-1}.


1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
M DWARF
M/Mo
N/No
10^6
10^7
10^8
10^9
t(yr)