SOURCE MODELING and WAVEFORMS

Required Components

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Required Components

- Physically appropriate initial data
- Long term stable evolution
- Wave Extraction

PHYSICALLY APPROPRIATE INITIAL DATA

- Match to inspiraling postNewtonian orbits
- Data setting algorithms set conformal factor in metric, longitudinal components of extrinsic curvature (momentum of metric)
  - Mathematical (arbitrary choices- what do they mean?)
- Problem gets better if data set farther out,

Long term stable evolution

- Correct formalism ("classic ADM",hyperbolic, BSSN, etc)
- Correct Discretization
- Correct boundary condition (excision, outer)
- Appropriate gauge
- Constraints?

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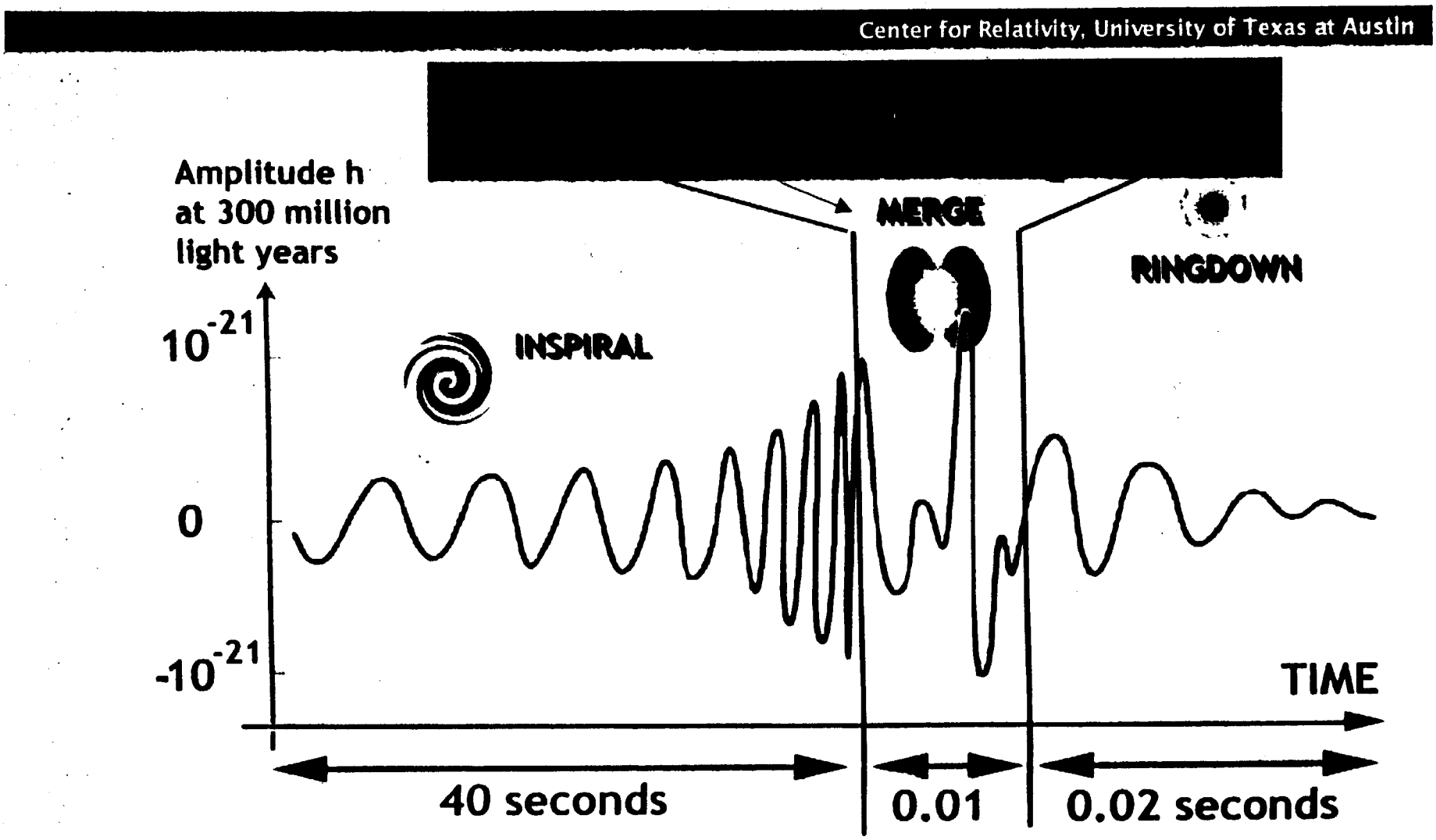
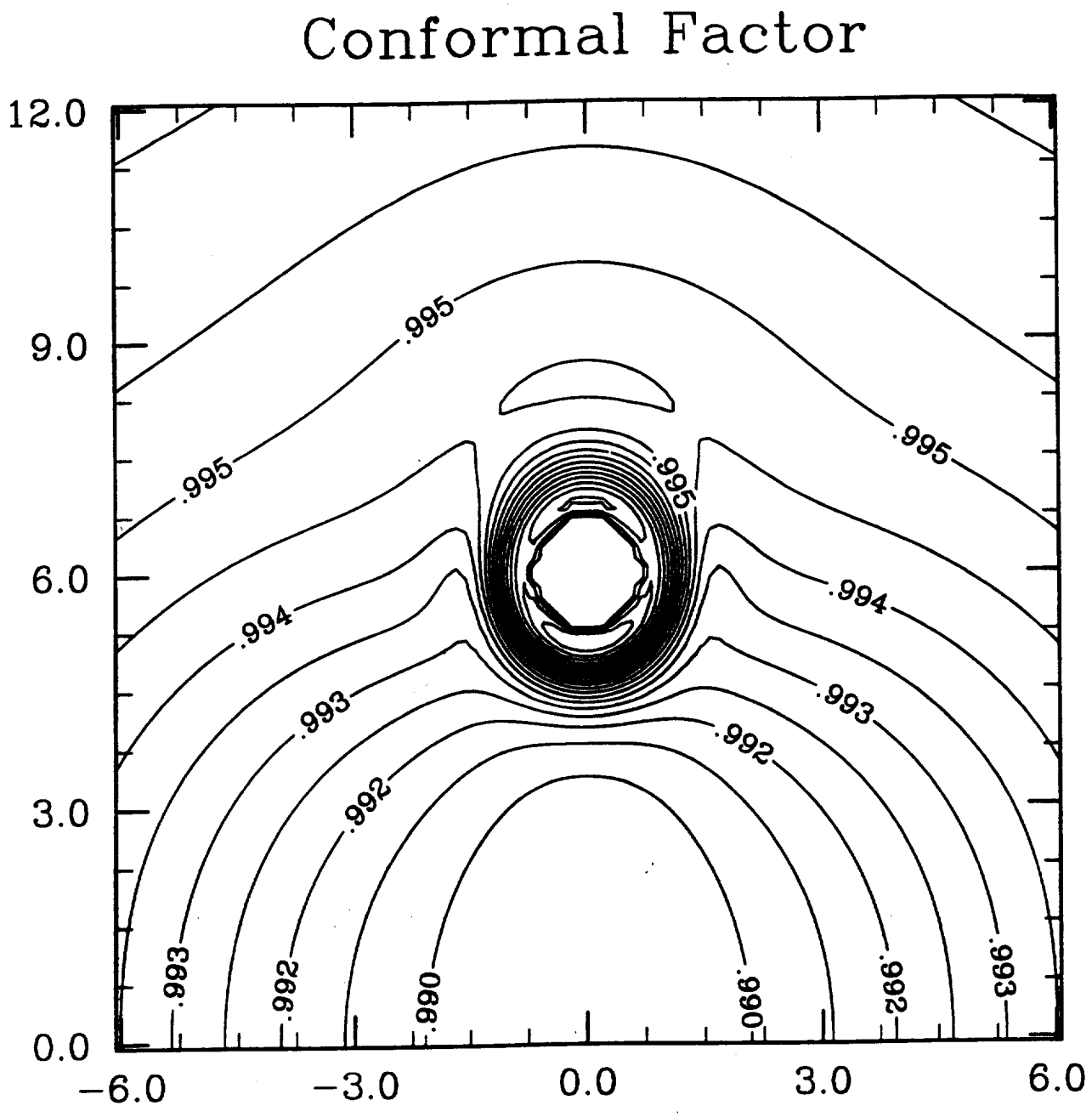
M. Anderson, E. Bonning, S. Caveny,
D. Neilsen, R. Matzner

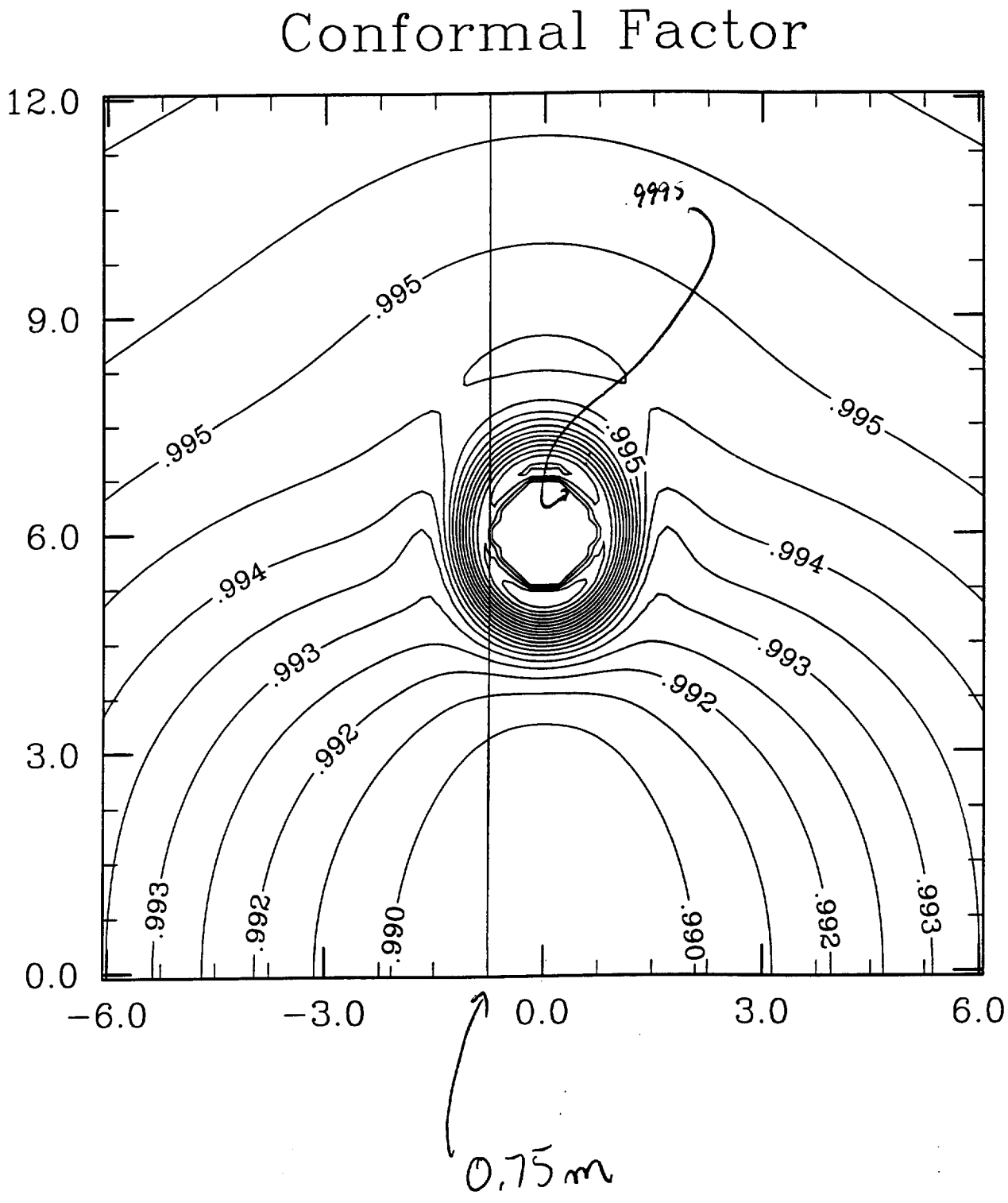
Collaboration: UBC, PSU, Pitt, UIUC

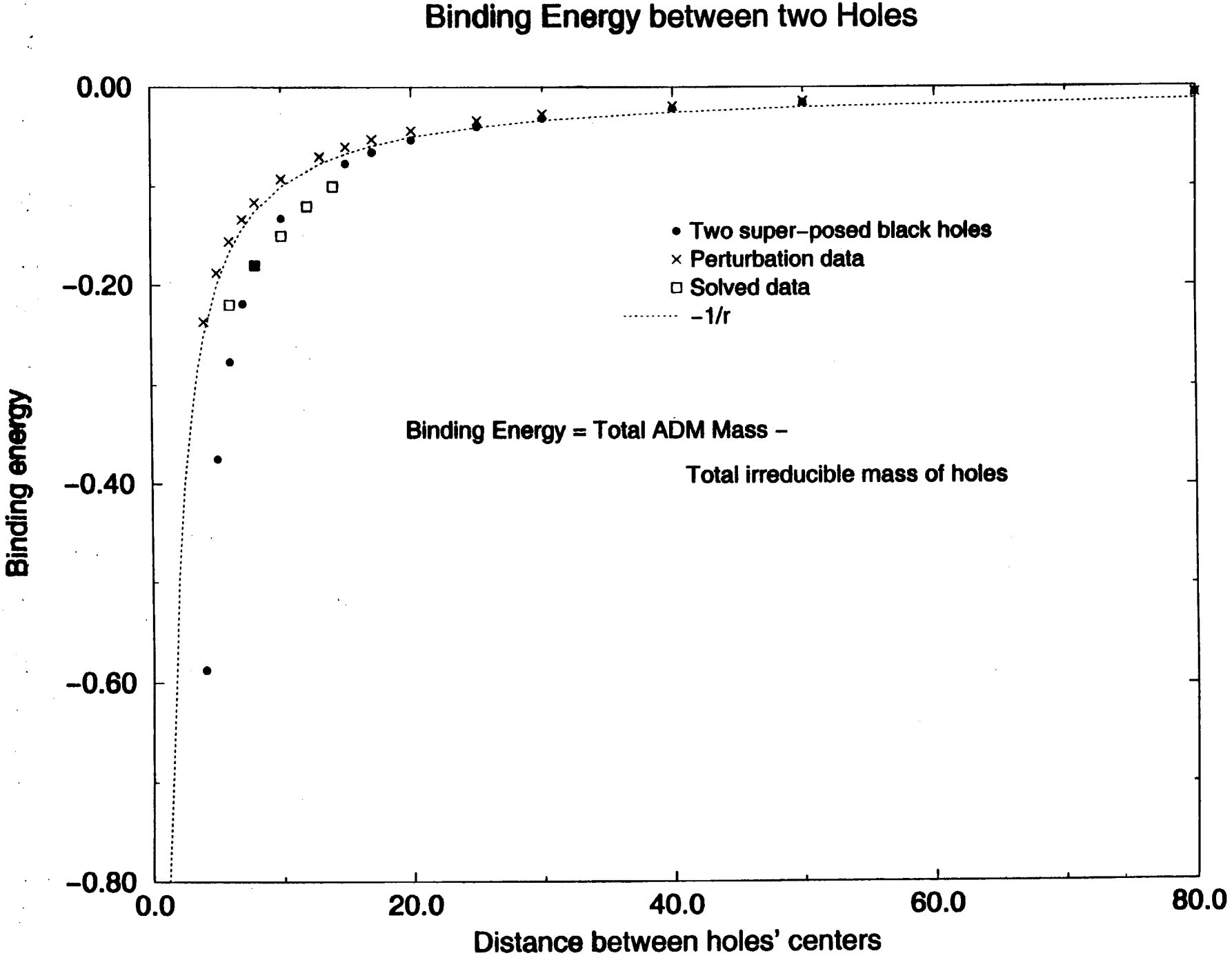
Expected wave signal

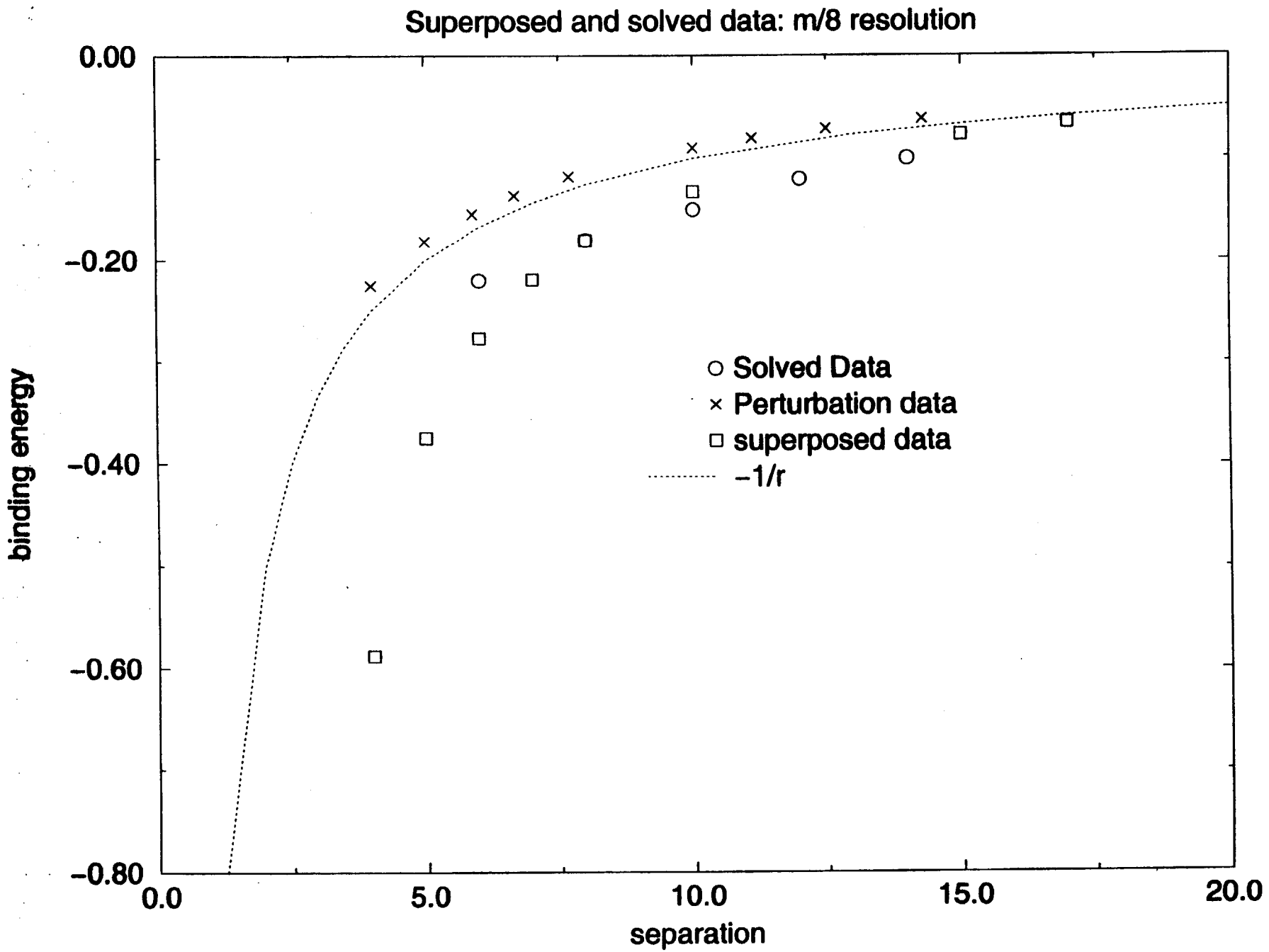


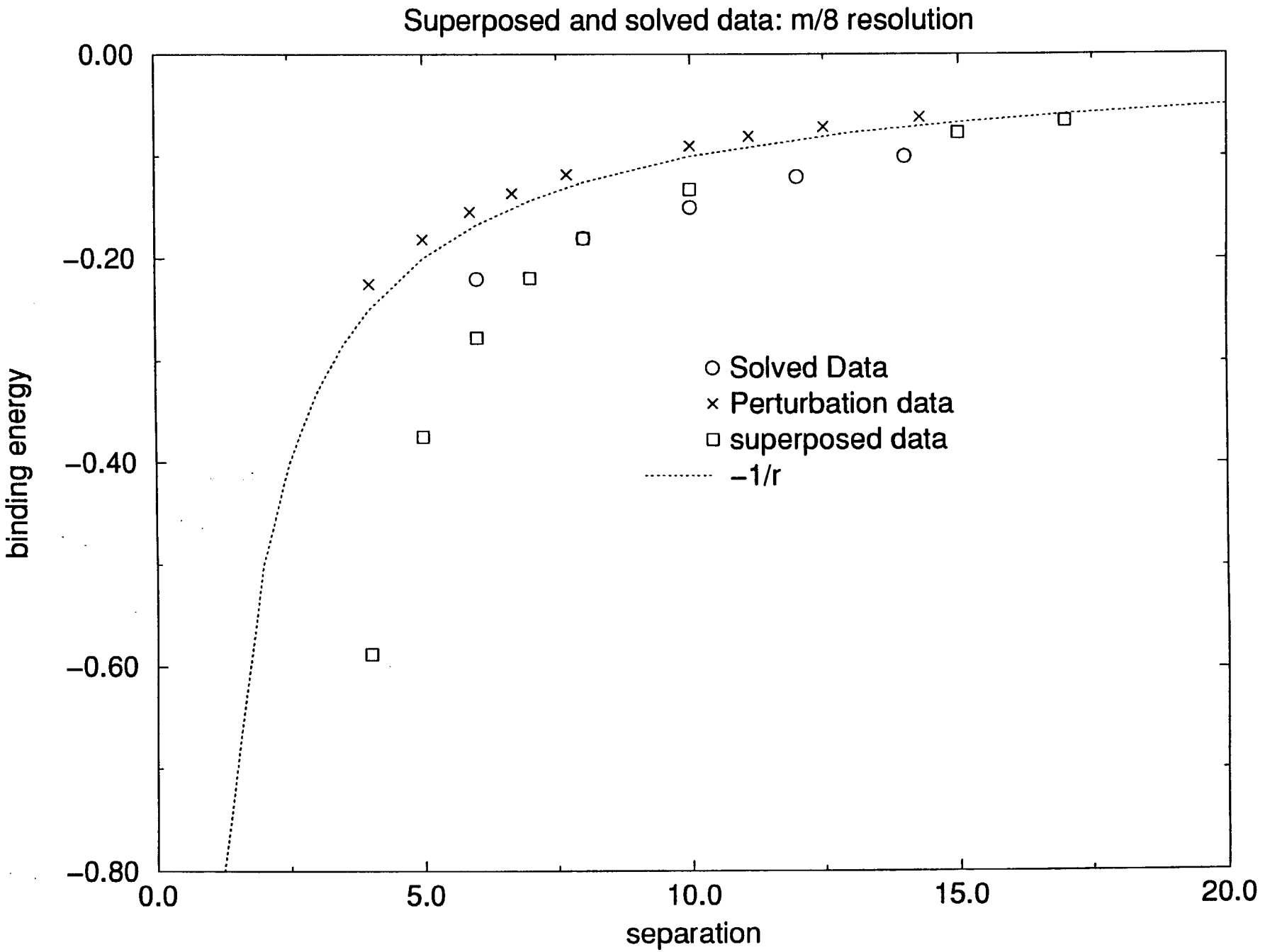

Conformal Factor
12.0
9.0
6.0
3.0
0.0
−6.0
−3.0
0.0
3.0
6.0
.995
.995
.995
.995
.994
.994
.993
.993
.992
.992
.990
.990
.992
.993
.993

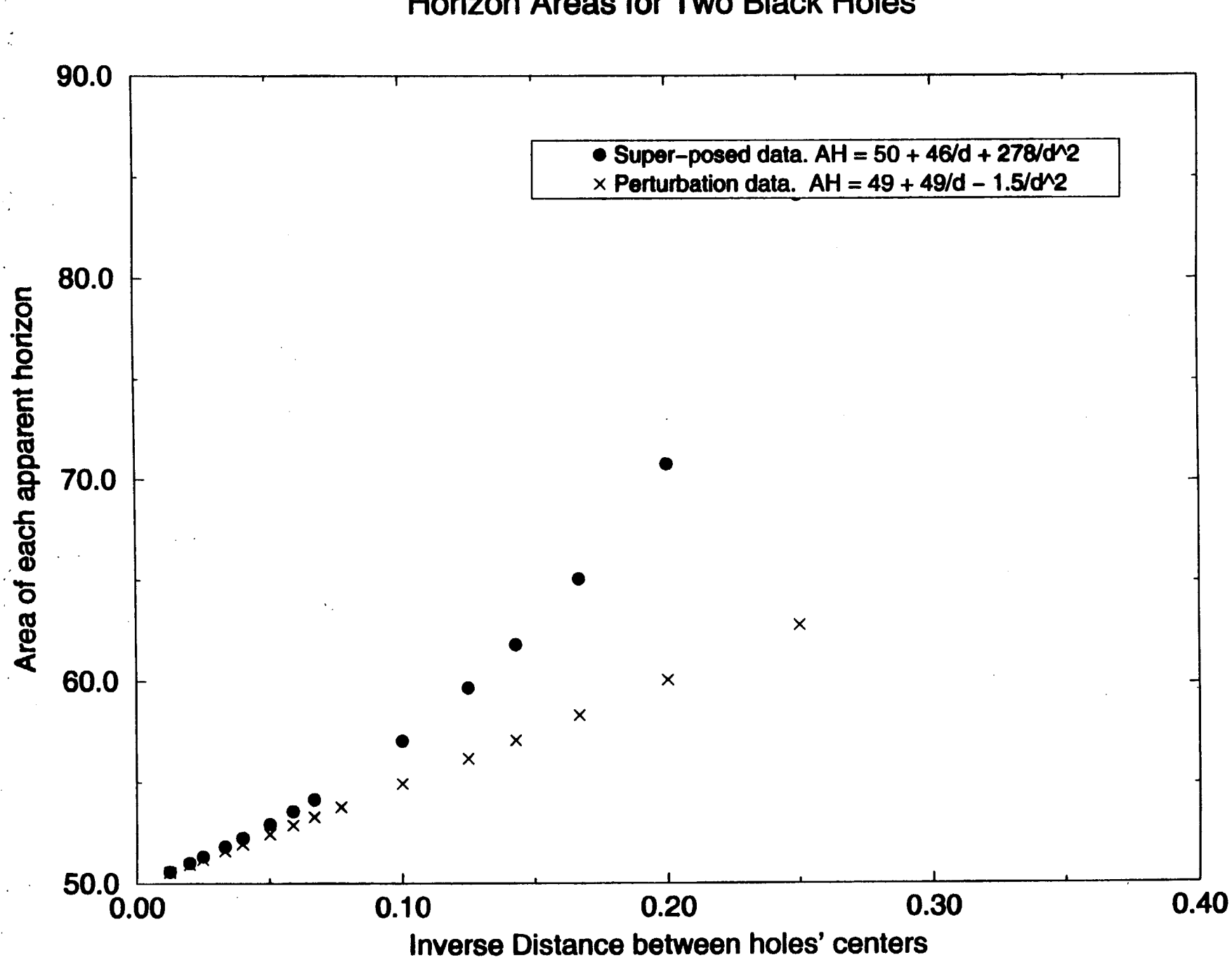
CONNING


Conformal Factor
12.0
9.0
6.0
3.0
0.0
−6.0
−3.0
0.0
3.0
6.0
.995
.995
.995
.995
.994
.994
.993
.993
.992
.992
.990
.990
.992
.993
0.75 m


Binding Energy between two Holes
0.00
−0.20
−0.40
−0.60
−0.80
Binding energy
0.0
20.0
40.0
60.0
80.0
Distance between holes' centers
• Two super−posed black holes
× Perturbation data
□ Solved data
−1/r
Binding Energy = Total ADM Mass −
Total irreducible mass of holes


Superposed and solved data: m/8 resolution
0.00
-0.20
-0.40
-0.60
-0.80
binding energy
0.0
5.0
10.0
15.0
20.0
separation
Solved Data
Perturbation data
superposed data
-1/r


Superposed and solved data: m/8 resolution
0.00
−0.20
−0.40
−0.60
−0.80
binding energy
0.0
5.0
10.0
15.0
20.0
separation
Solved Data
Perturbation data
superposed data
−1/r


Horizon Areas for Two Black Holes
● Super-posed data. AH = 50 + 46/d + 278/d^2
× Perturbation data. AH = 49 + 49/d – 1.5/d^2
Area of each apparent horizon
90.0
80.0
70.0
60.0
50.0
0.00
0.10
0.20
0.30
0.40
Inverse Distance between holes' centers

Generalized Frittelli-Reula formulation

- Symmetric hyperbolic formulation

  Novelty $\neq$ success!

- Densitized lapse and given shift
- Add terms to the equations proportional to the constraints (η, Γ, Θ, Ξ).

Reduces to the Einstein-Christoffel equations (Anderson & York, 1999) when $\Xi = \eta = 1, \Gamma = \Theta = 0$.

References: Frittelli & Reula (1996), Stewart (1998), Hern (1999).

Black hole tests

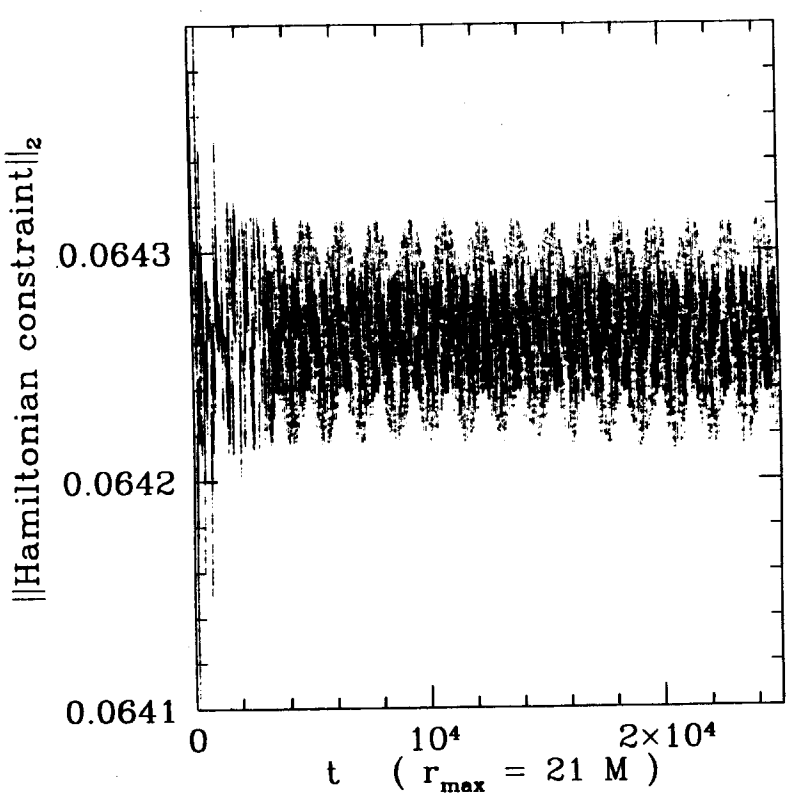
- Generalized Frittelli-Reula
- Physical characteristic speeds

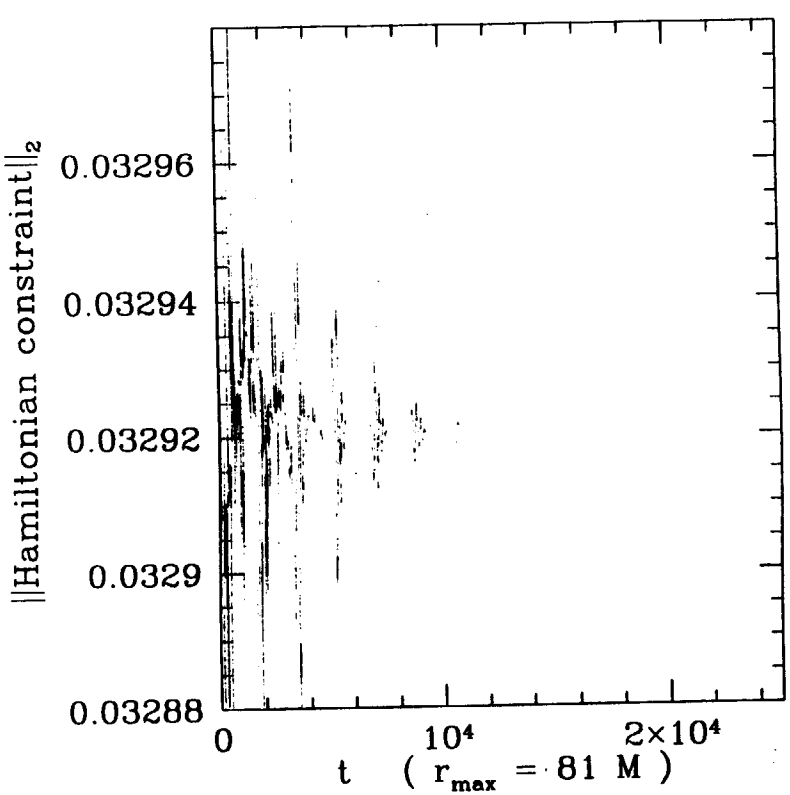
$$\eta = \frac{1}{2\Gamma - 1}, \Xi = \frac{\Gamma - 1}{2\Gamma - 1}$$

- Excised Schwarzschild hole in iEF coordinates.
- Boundaries
  - Dirichlet outer boundaries (no blending)
  - "Out-going shock" inner boundary condition (Zero-order extrapolation into 2 ghost zones)
- Grid Resolution: 10 points/M ($\triangle r = 0.1$ M)

Results in spherical symmetry

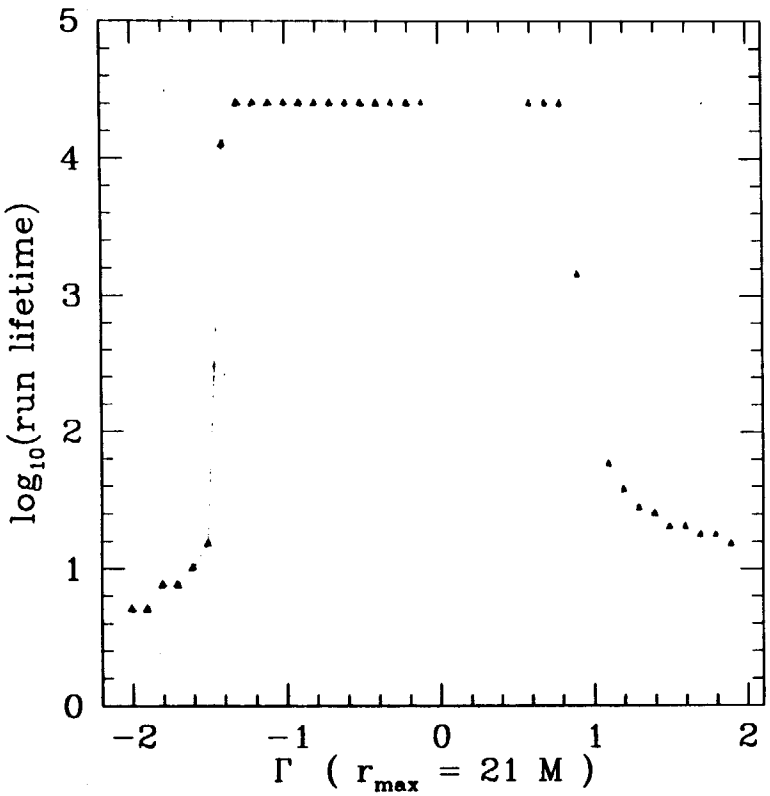
Hamiltonian Constraint, $\Gamma = -0.8$

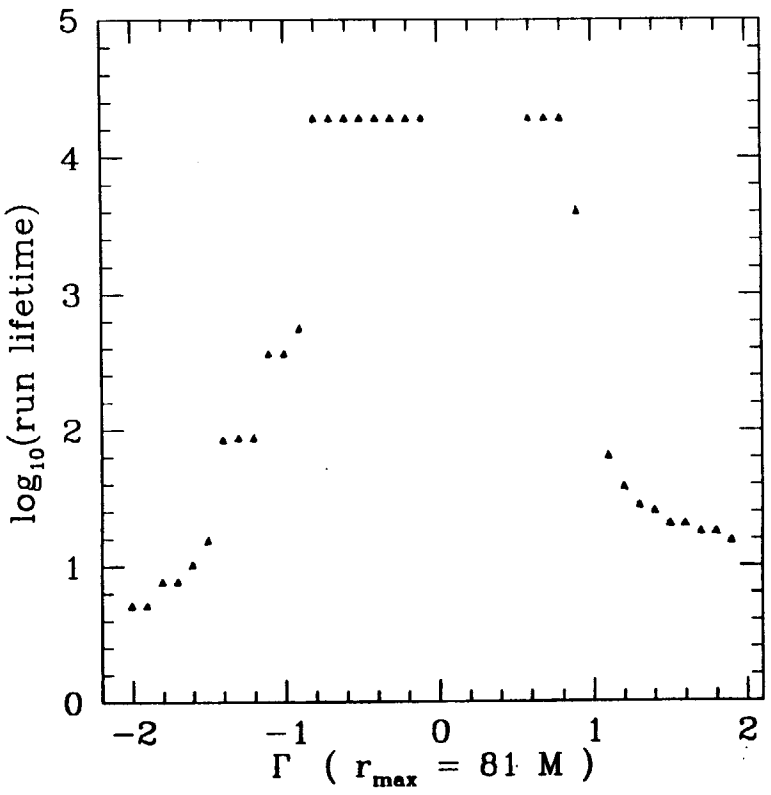




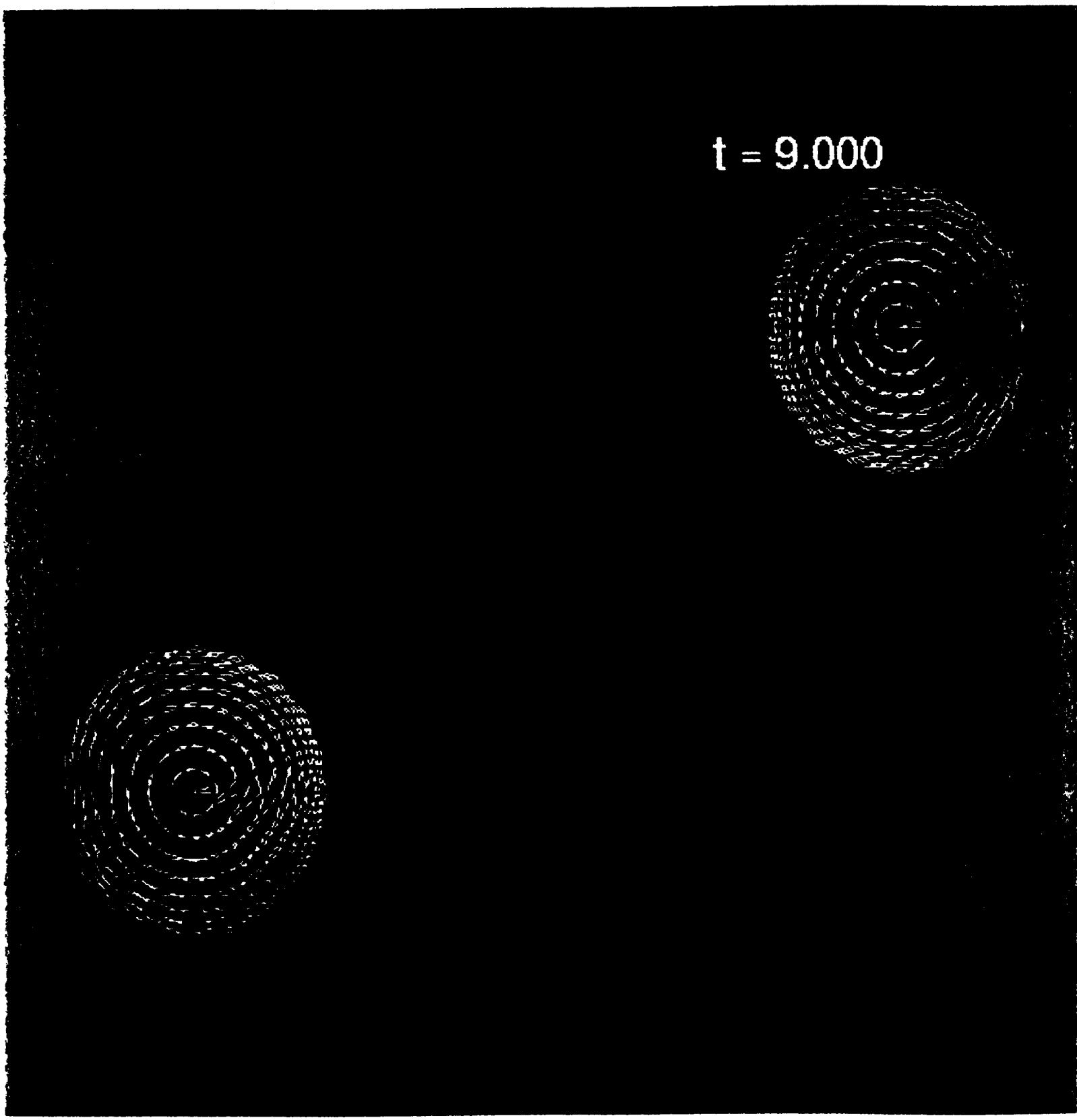
Results in spherical symmetry

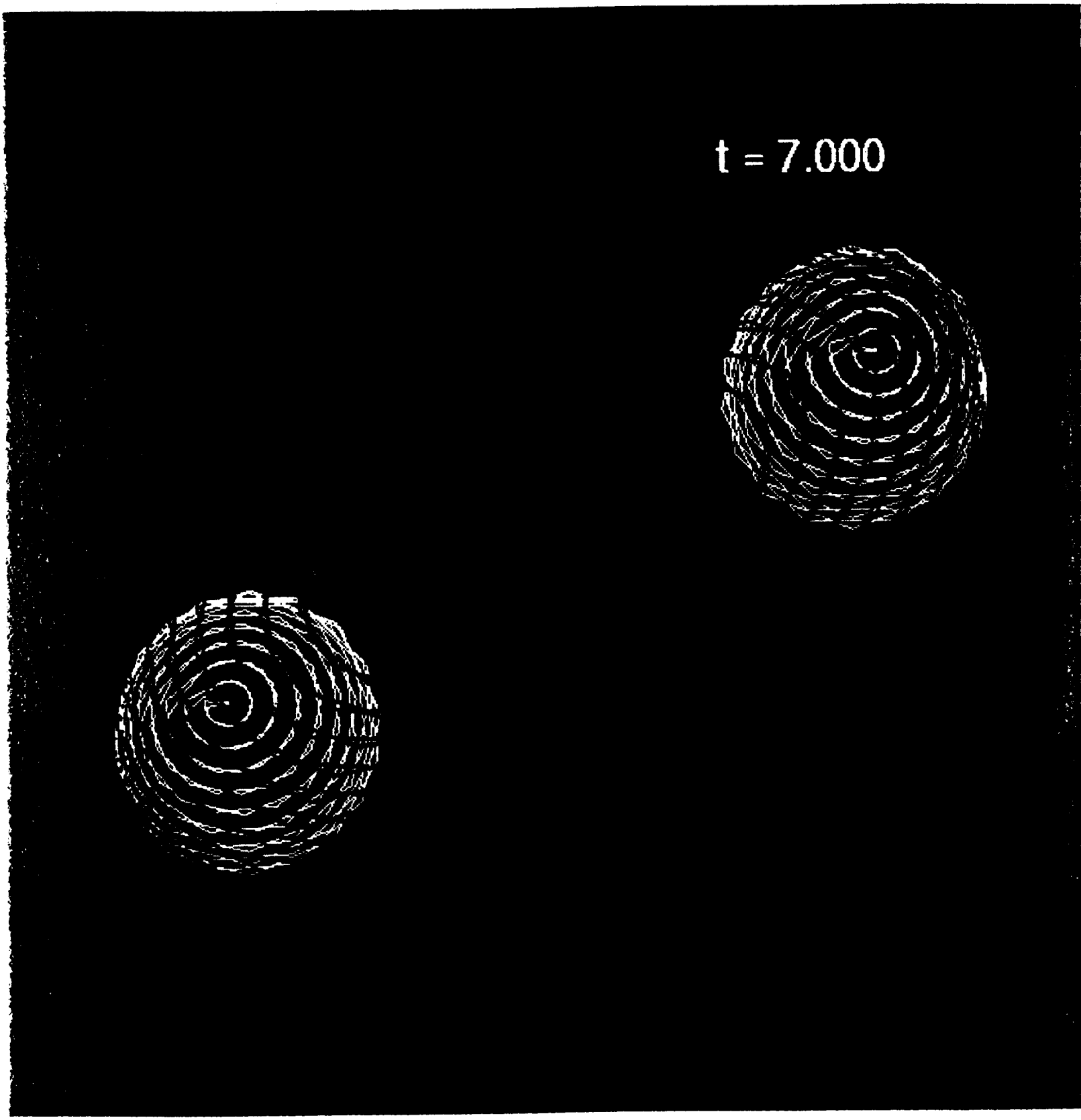
Run lifetime as a function of Γ

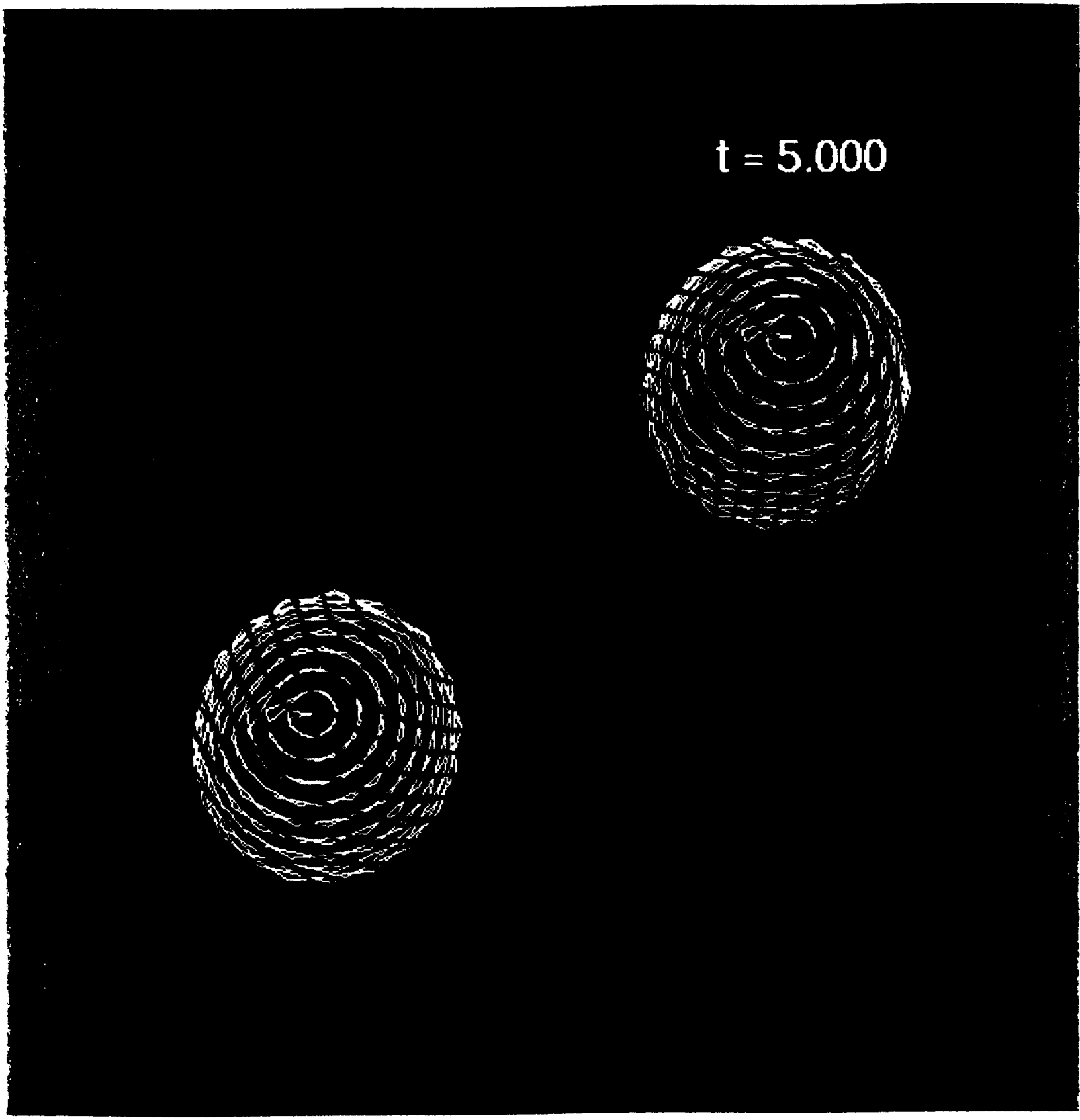


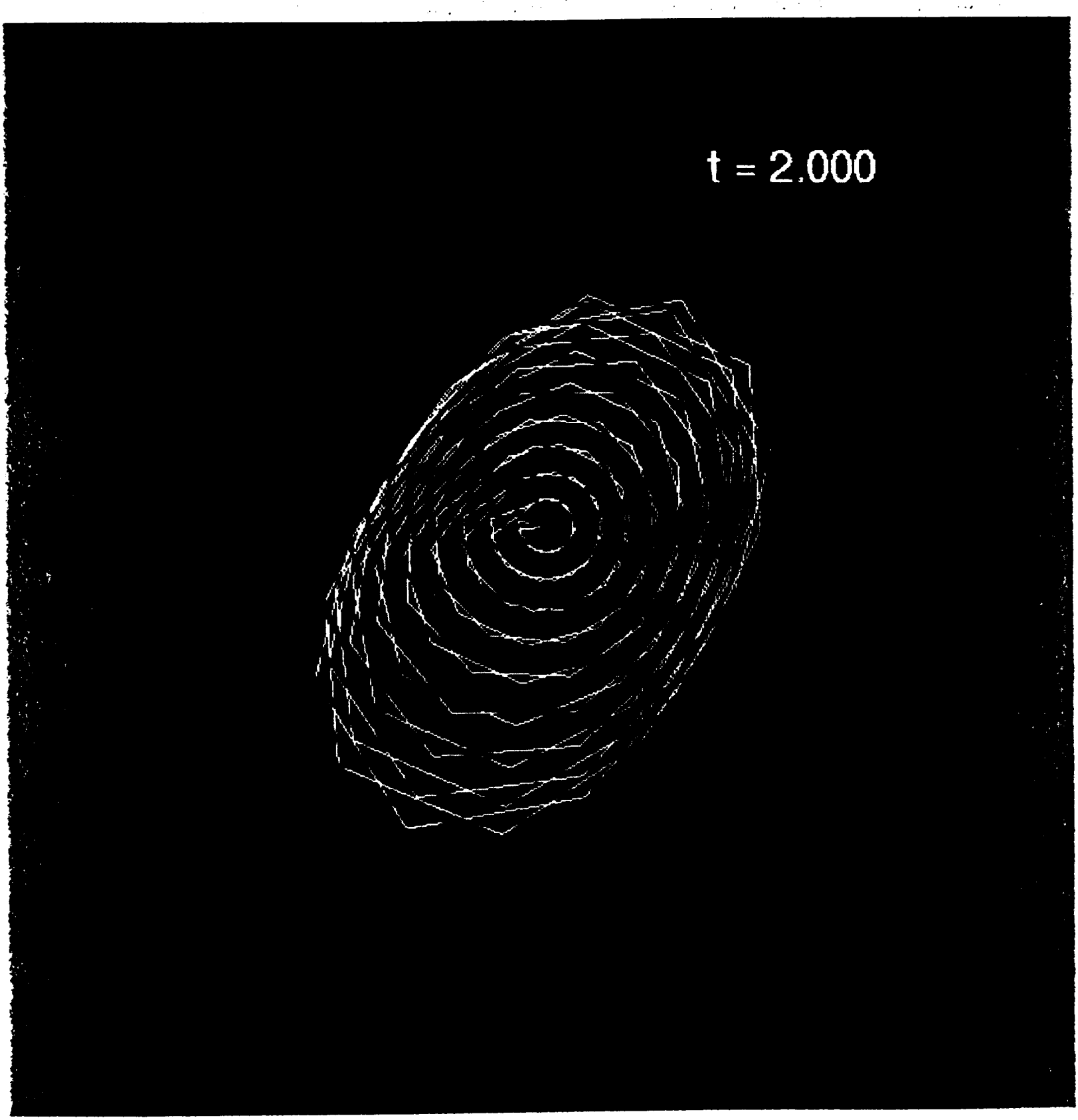


(All jobs halted after $t = 25,000$ M.)


t = 9.000


t = 7.000


t = 5.000


t = 2.000