Modeling Accretion Flows Around Black Holes with AMR(Adaptive Mesh Refinement)

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- G. R. effects are connected to fast flows in different astrophysical scenarios,
    - accreting compact objects
    - coalescing compact binaries
    - stellar collapse

- Our focus: Origin of time variying X-ray emissions from stellar black hole candidates

- Such problems have multiple spatial & time scales $\Rightarrow$ Adaptive Mesh Refinement (AMR)

GRH Equations

- Covariant form of GRH equations:

$$\nabla_\mu T^{\mu\nu} = 0, \qquad \nabla_\mu \mathbf{J}^\mu = \mathbf{0}.$$

- Conservative form of GRH:

$$\frac{\partial \vec{U}}{\partial t} + \frac{\partial \vec{F}^i}{\partial x^i} = \vec{\mathrm{S}},$$

- Perfect fluid stress energy tensor and equation of state are used.

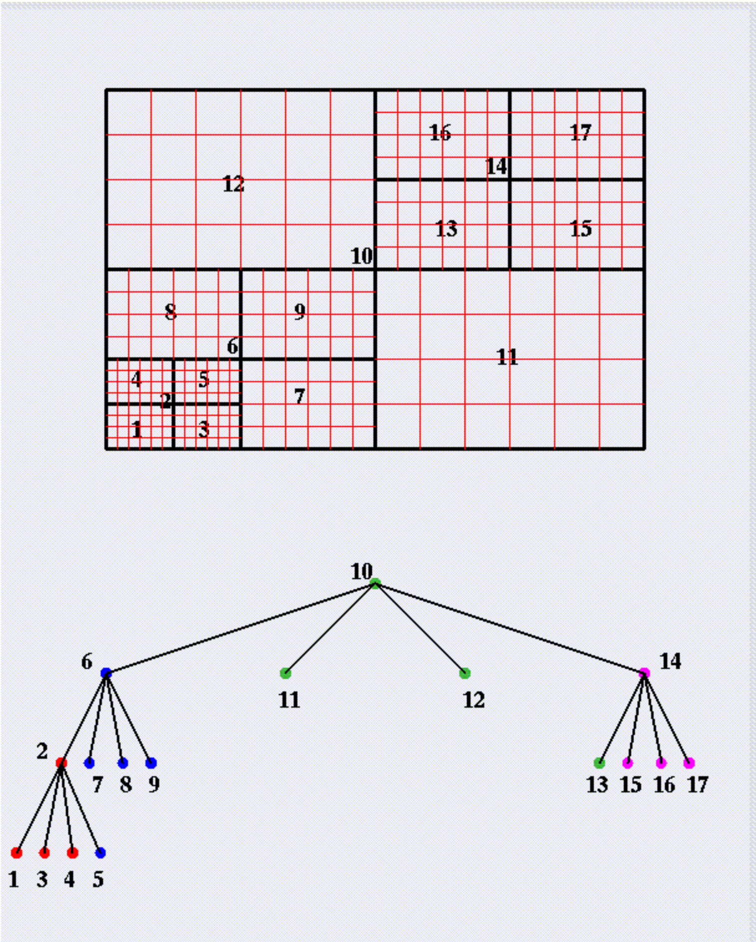
- Flux part is solved by Marquina method with MUSCL left and right states.

- Second order Runge-Kutta method is used in source part.

- The Strang Splitting is used to couple flux and source part of GRH equations.

Adaptive Mesh Refinement Technique

Grid Hierarchy

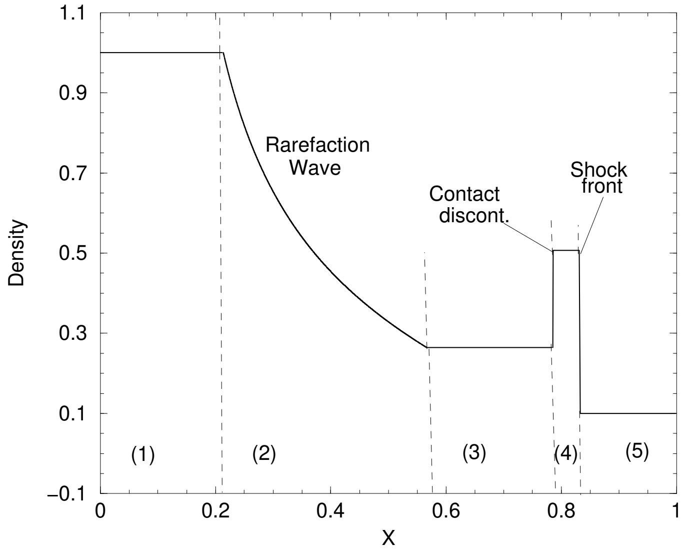


- "Block"-based AMR Algorithm (Quirk & DeZeeuw; Powell)
  - ○ Multiple levels of locally-uniform grid-blocks.
  - ○ Refinement: Bisect a block in each coordinate direction for refinements.
  - ○ Refinement criteria: specified by user
    Refine a block if $\tau \geq \tau_c$ and derefine if $\tau \leq \tau_d$ ($\tau_c, \tau_d \equiv$ a user-specified threshold).
  - ○ Used PARAMESH (MacNiece *et al*,NASA/GSFC).

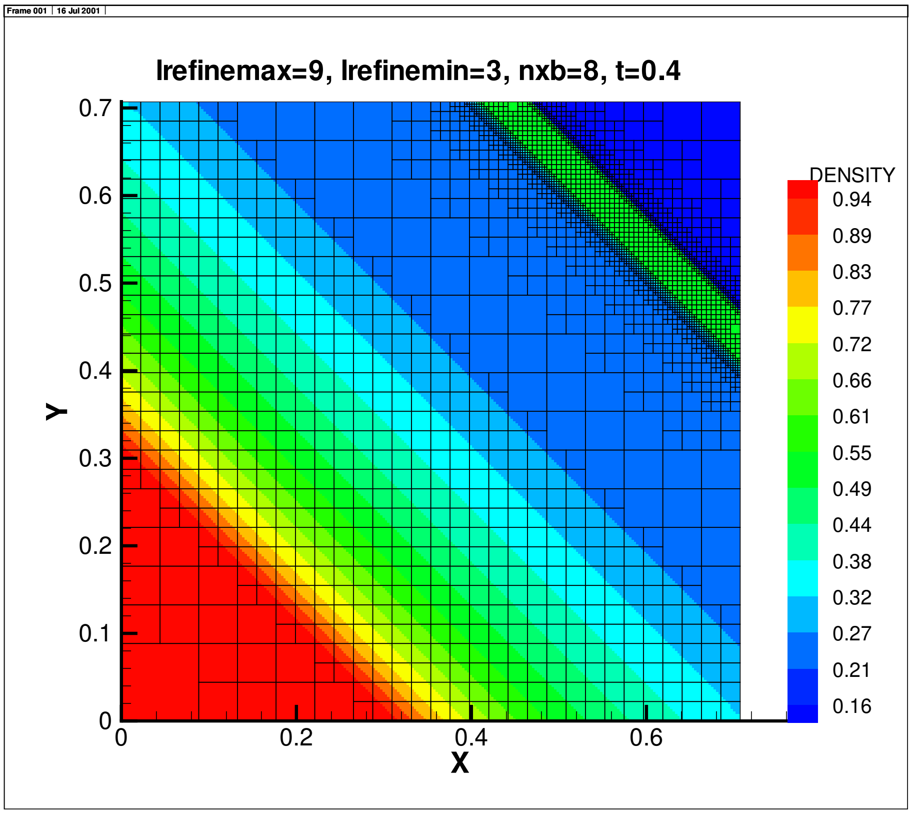
Test Case:

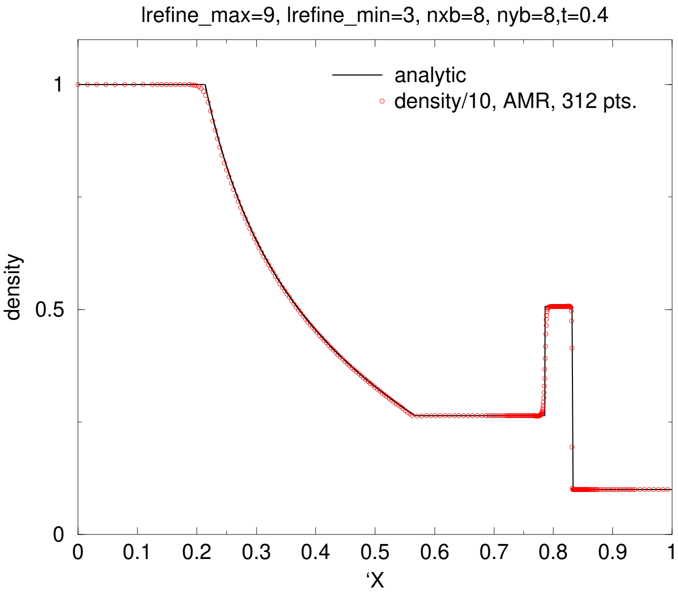
◦ Special Relativistic shock tube has a time dependent analytic solution
◦ we can test the ability of the code to evolve both smooth and discontinuous solution.

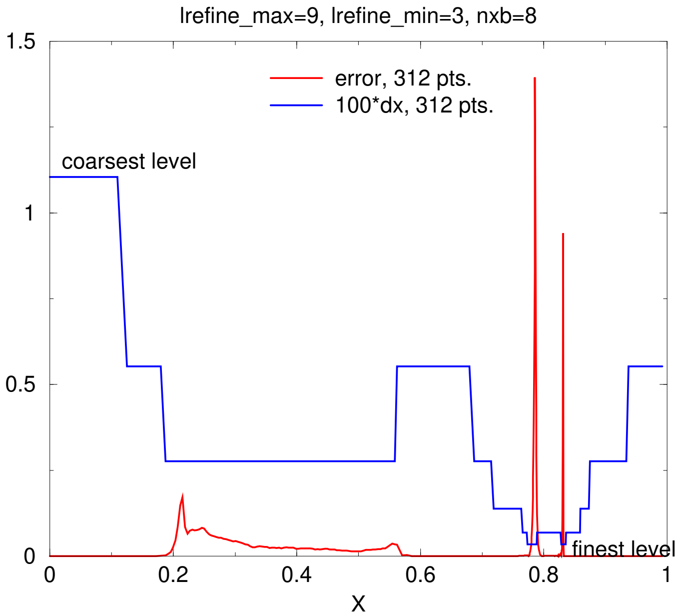
◦ Fluid is initially in two different thermodynamical states on either side of an interface, ρ_1, p_1, v_1, ρ_2, p_2, v_2
◦ Rarefaction wave moves to the left and shock and contact discontinuity travel to the right.



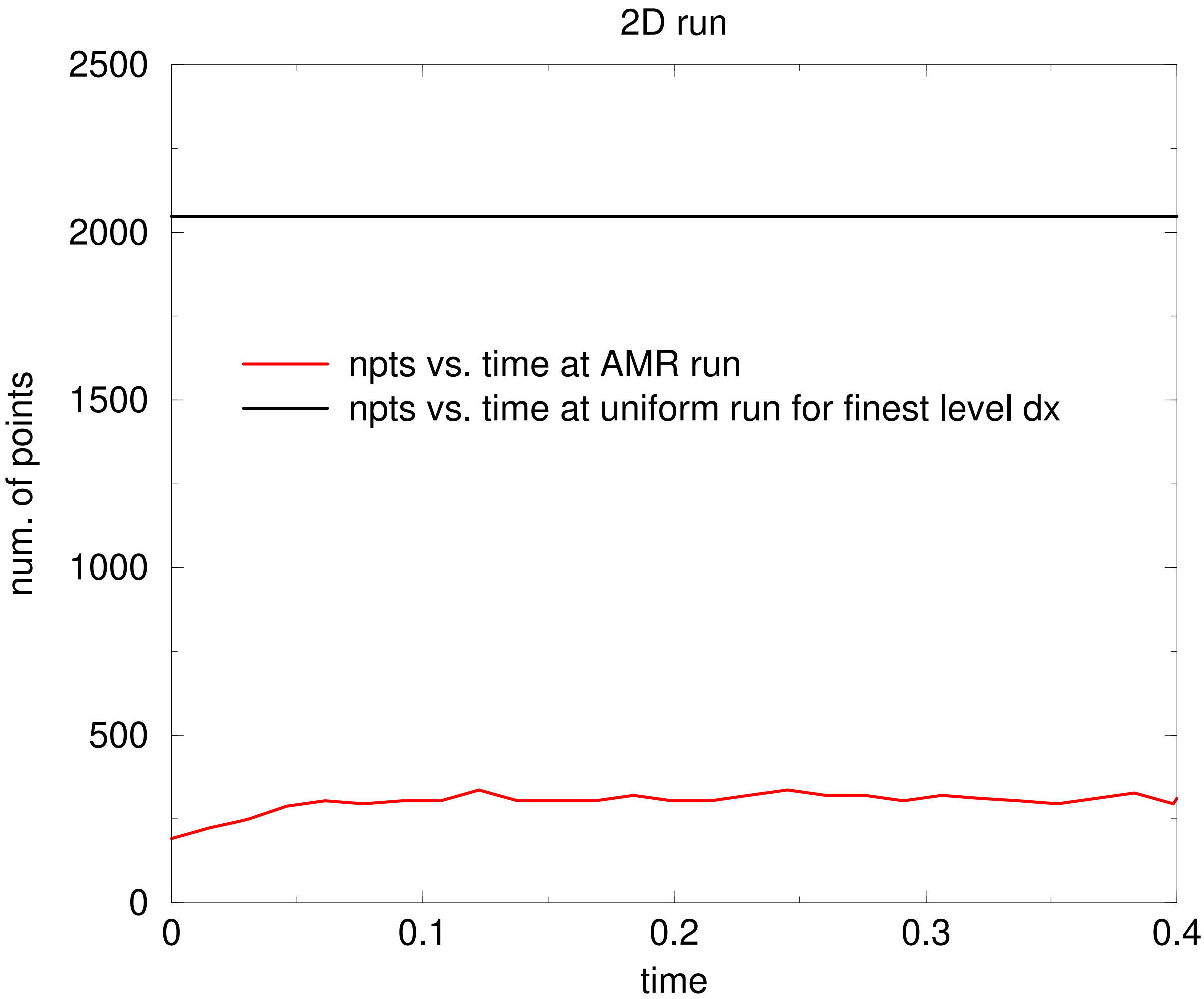
$\rho_1 = 10.0, p_1 = 13.3, v_1 = 0,$
$\rho_2 = 1.0, p_2 = 0.6610^{-6}, v_2 = 0$
We use the perfect fluid equation of state with $\Gamma = 5/3$.







$dx = 1/64$ for coarsest level, $dx = 1/2048$ for finest level



2D run
2500
2000
1500
1000
500
0
0
0.1
0.2
0.3
0.4
time
num. of points
npts vs. time at AMR run
npts vs. time at uniform run for finest level dx

Free Falling Gas on to Black Hole

- Using Schwarzschild coordinate for metric.

- Working at equatorial plane ($\theta = \pi/2$)

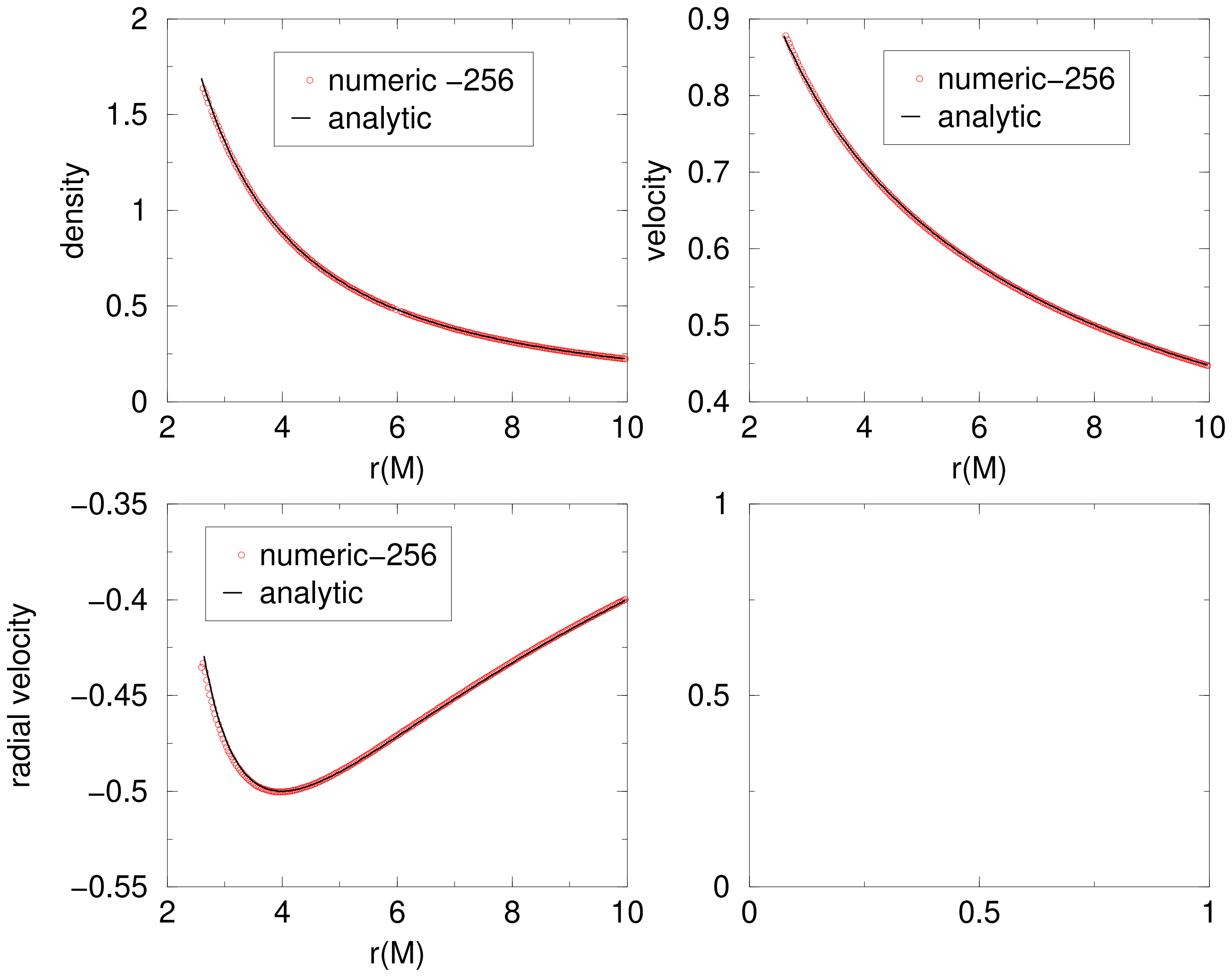
- Set inner boundary, $r > 2M$, with outflow boundary condition.

- Analytic solutions are injected at outher edge of the computational domain.

$$D = \frac{d}{(1 - \frac{2M}{r})(\frac{2M}{r})^{\frac{1}{2}}}, \qquad \rho = \frac{D}{\sqrt{\gamma} W}$$

$$v^r = [(\frac{2M}{r})(1 - \frac{2M}{r})]^{\frac{1}{2}}, \qquad P = 0.$$

- Run the code until solution reaches to steady state



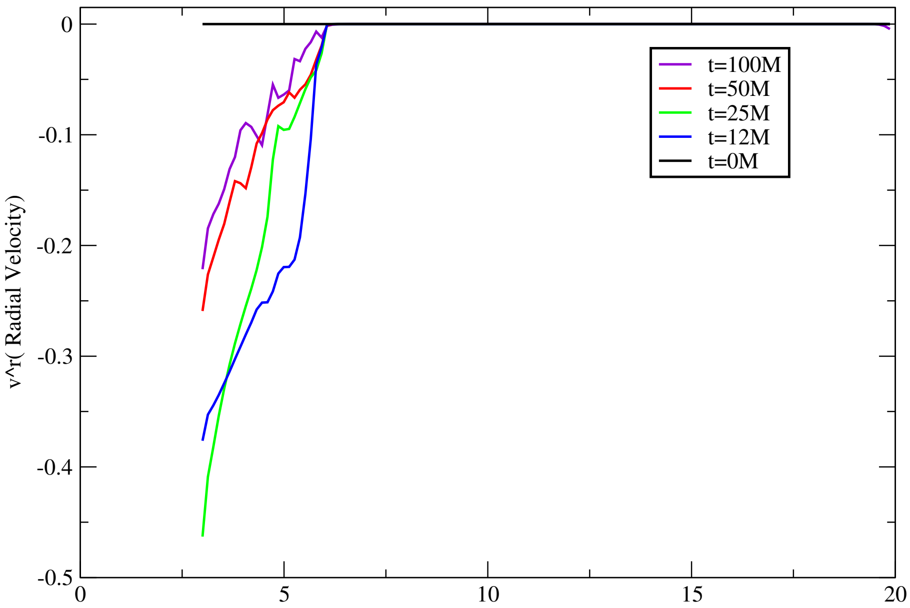
numeric -256
analytic
density
r(M)
numeric-256
analytic
velocity
r(M)
numeric-256
analytic
radial velocity
r(M)

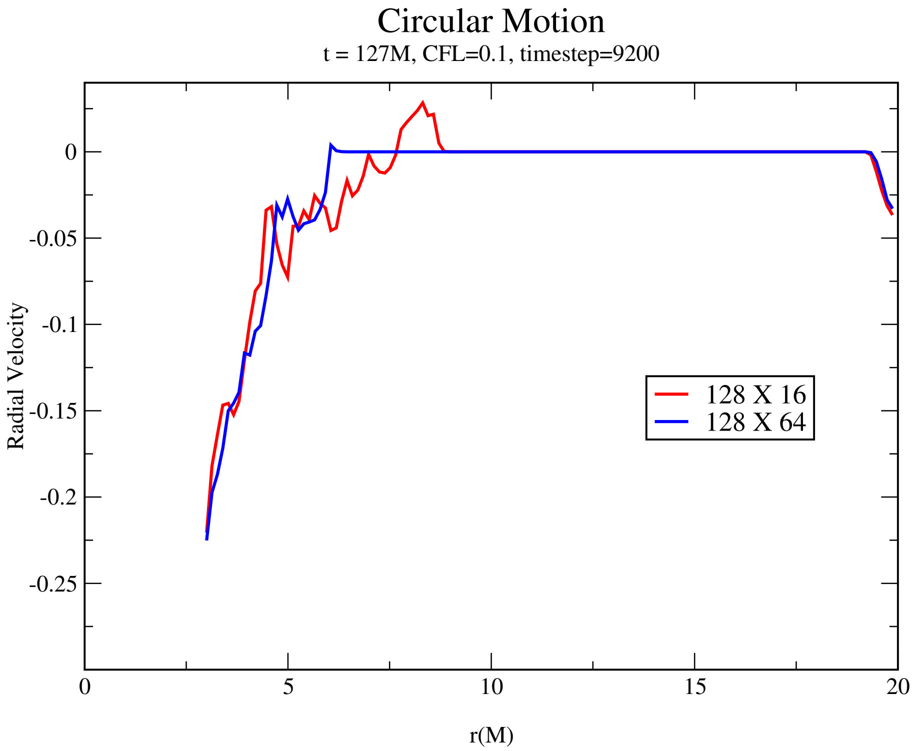
Circular Motion of Gas around the Black Hole

- Computational domain is filled with constant density and negliglible pressure.

- Velocities at r and ϕ directions are

$$v^r = 0.0, \qquad v^\phi = \frac{1}{(1 - \frac{2M}{r})^{\frac{1}{2}}} (\frac{M}{r^3})^{\frac{1}{2}}$$


v^r(Radial Velocity)
t=100M
t=50M
t=25M
t=12M
t=0M
0
-0.1
-0.2
-0.3
-0.4
-0.5
0
5
10
15
20


Circular Motion
t = 127M, CFL=0.1, timestep=9200
Radial Velocity
128 X 16
128 X 64
0
-0.05
-0.1
-0.15
-0.2
-0.25
0
5
10
15
20
r(M)

Future Work

- We need to finish code testting.
  - Epicylic frequencies
  - Accreting of gas with pressure.
  - AMR test
- Shock waves in accretion disk
- Possibile origin of time-varying X-ray emissions from diffrenet phenomena in fluid flow