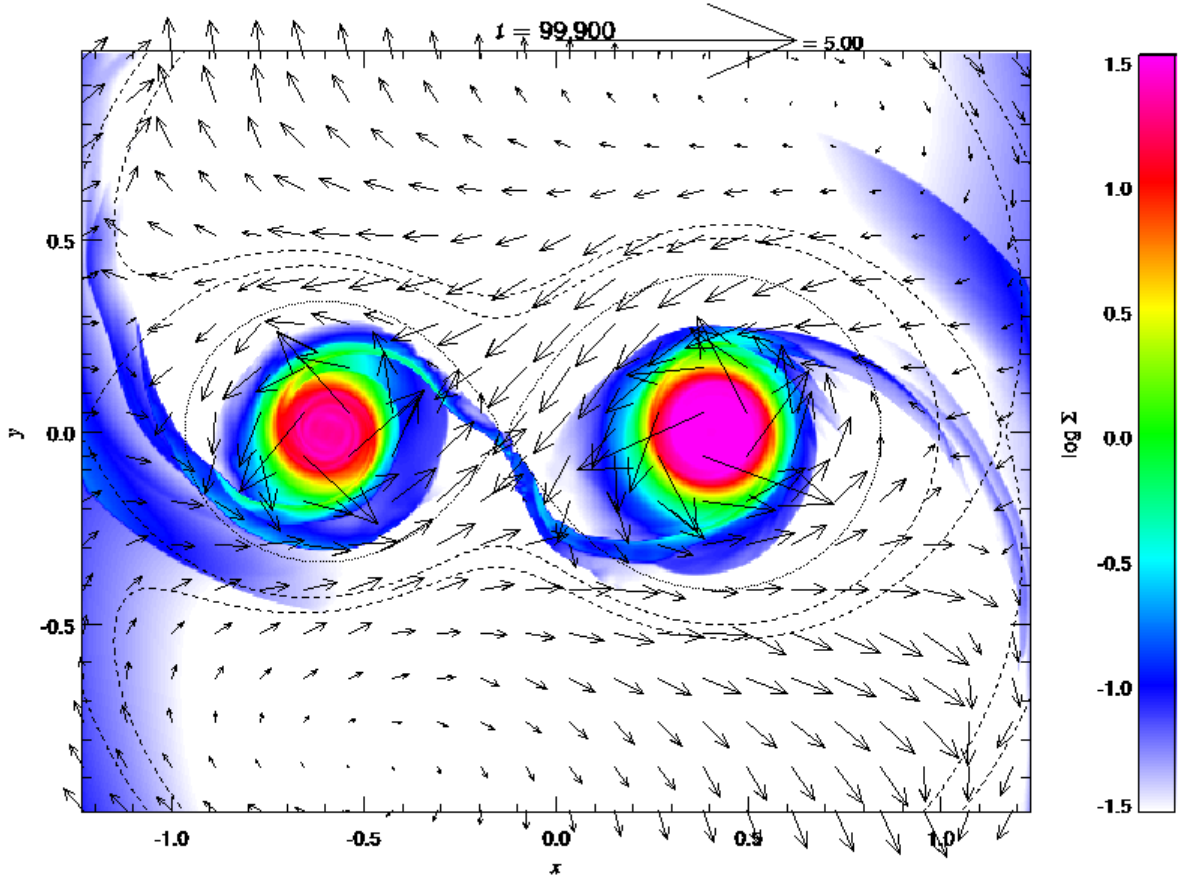
A New Scheme to Solve Gas Disks around Stars

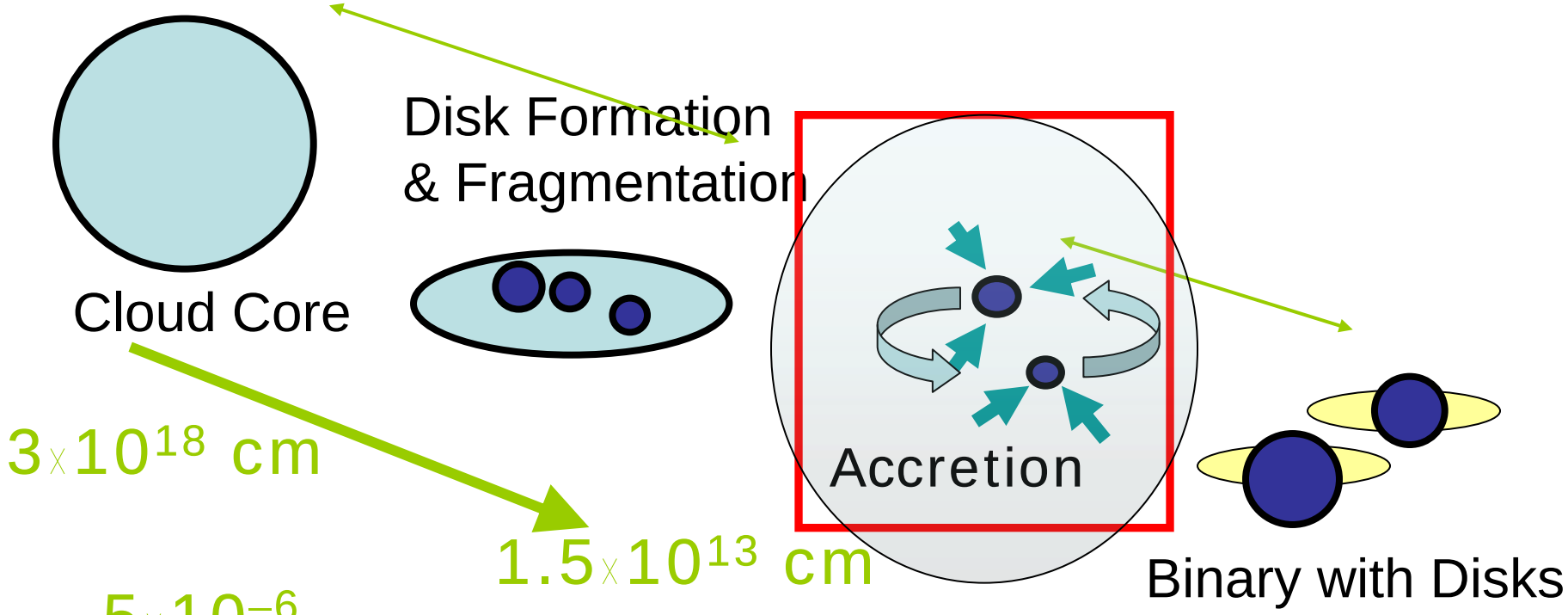
Application to Binary Stars



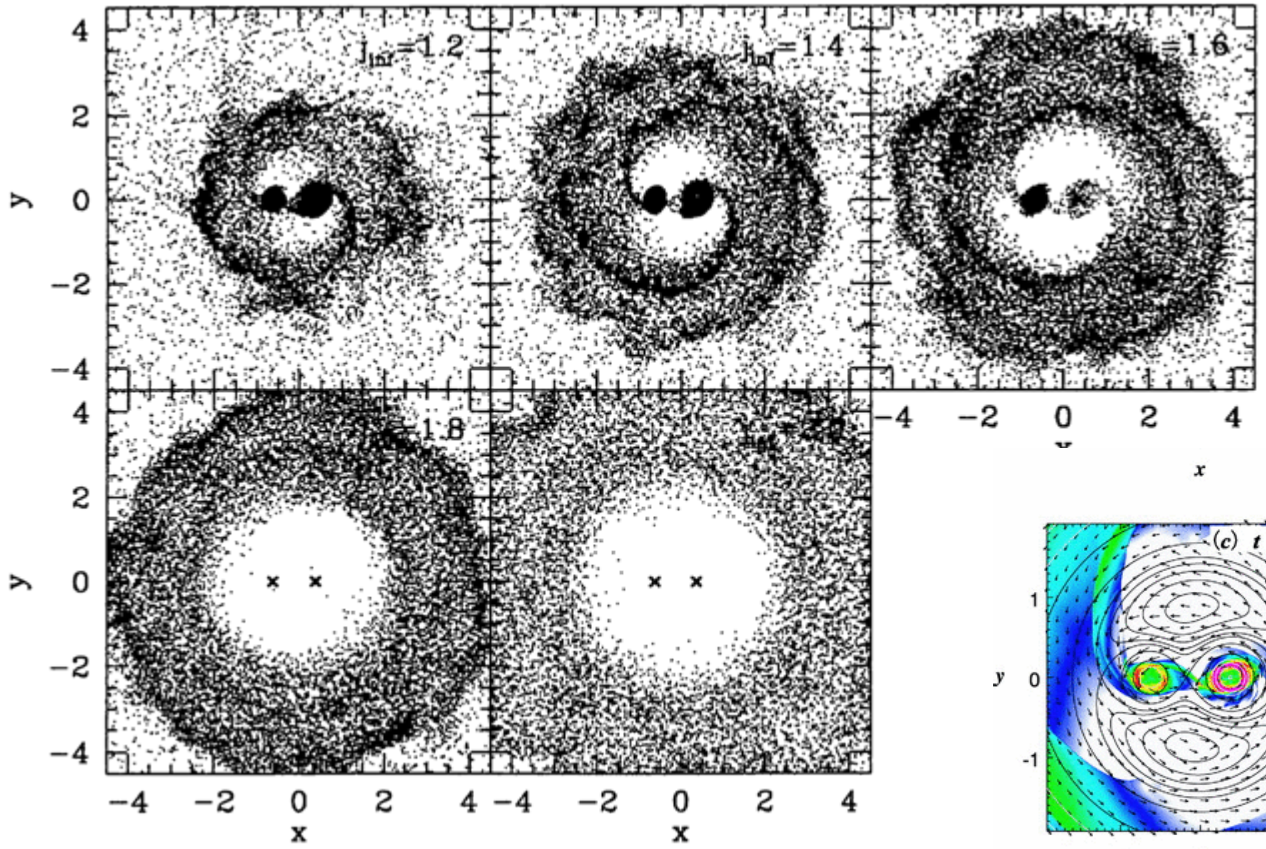
Tomoyuki Hanawa

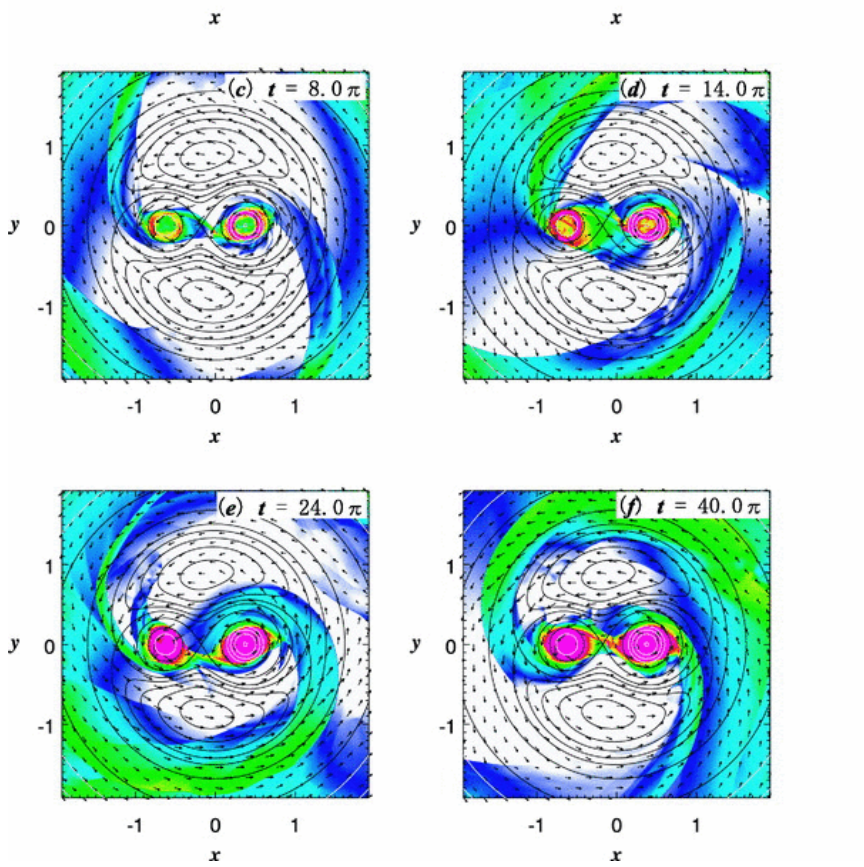
(Chiba Univ.)

Binary Formation Scenario



Still Difficult Problem





3D SPH Bate & Bonnell (1997)

Ochi, Sugimoto, & Hanawa (2005)

Numerical Difficulty in Handling Centrifugally Supported Disk

$$\frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v} \bullet \nabla)\mathbf{v} + \frac{\nabla P}{\rho} = \mathbf{g}$$

Dominant
but cancelled

Small but important

$$\Delta r << H_P \cong \frac{P}{g\rho} << r$$

Very high spatial resolution is reqquired.

Reference Velocity Method

$$\mathbf{u}(\mathbf{r}, t) = \mathbf{w}(\mathbf{r}) + \mathbf{v}(\mathbf{r}, t)$$

Real = Reference + Residual

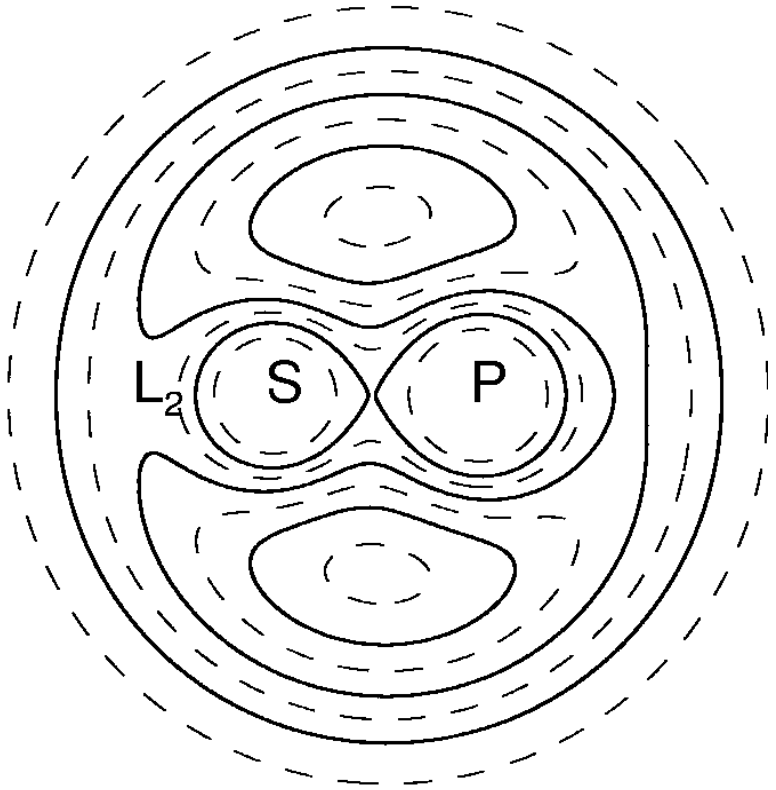
$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \bullet \nabla)\mathbf{u} + \frac{\nabla P}{\rho} = \mathbf{g} - 2\boldsymbol{\Omega} \times \mathbf{u}$$

$$\frac{\partial \mathbf{v}}{\partial t} + [(\mathbf{v} + \mathbf{w}) \bullet \nabla]\mathbf{v} + \frac{\nabla P}{\rho} = [\mathbf{g} - 2\boldsymbol{\Omega} \times \mathbf{w} - (\mathbf{w} \bullet \nabla)\mathbf{w}]$$

$$- [2\boldsymbol{\Omega} \times \mathbf{v} + (\mathbf{v} \bullet \nabla)\mathbf{w}] \qquad \equiv \mathbf{g}_{\text{eff}}$$

Simplification of the Problem

- No Self-Gravity
- Circular Orbit ($e = 0$)
- The Orbit and Disks are Coplanar (2D)
- Co-rotating Frame



Rosche Potential

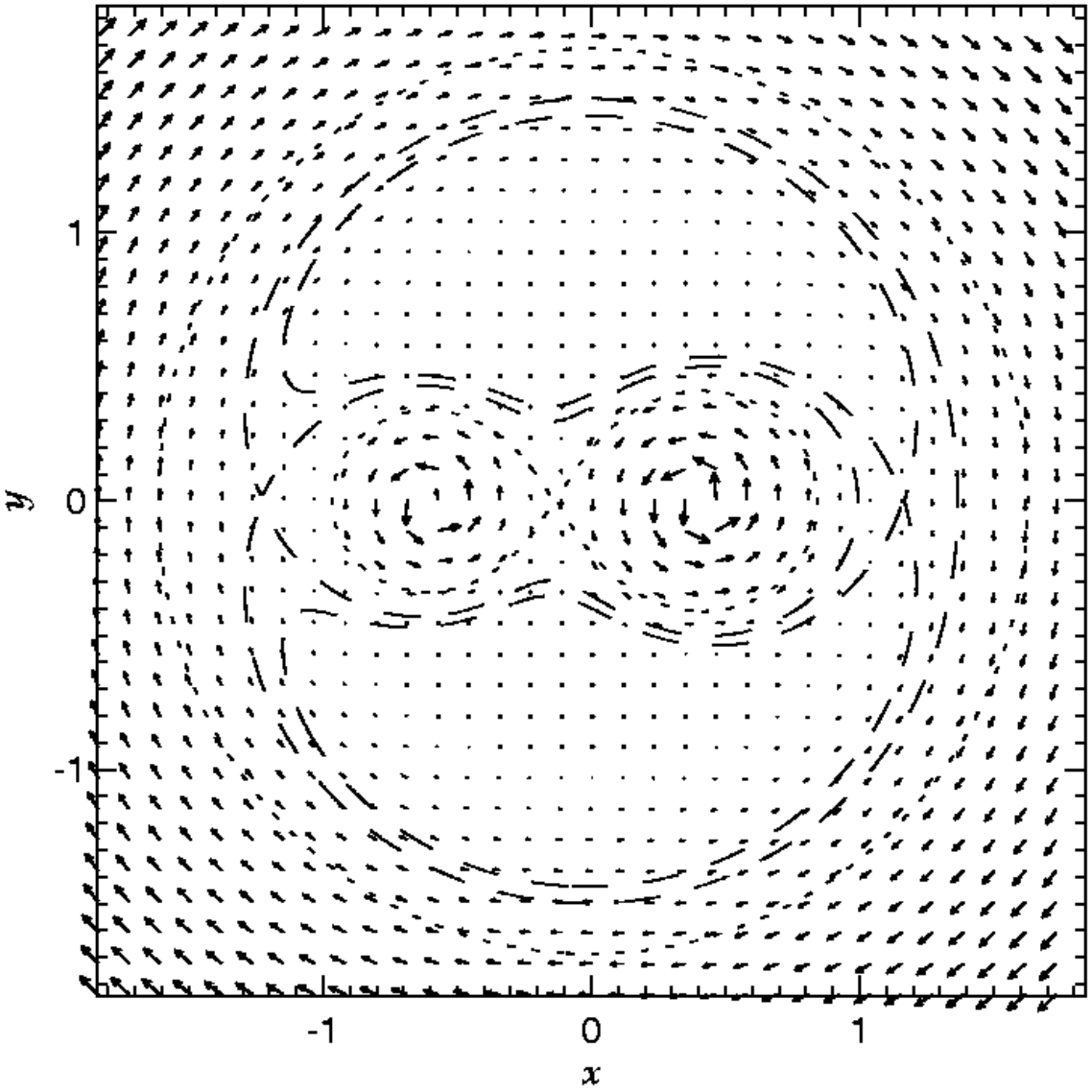
+ Coriolis force

Artymowicz & Lubow (1996)

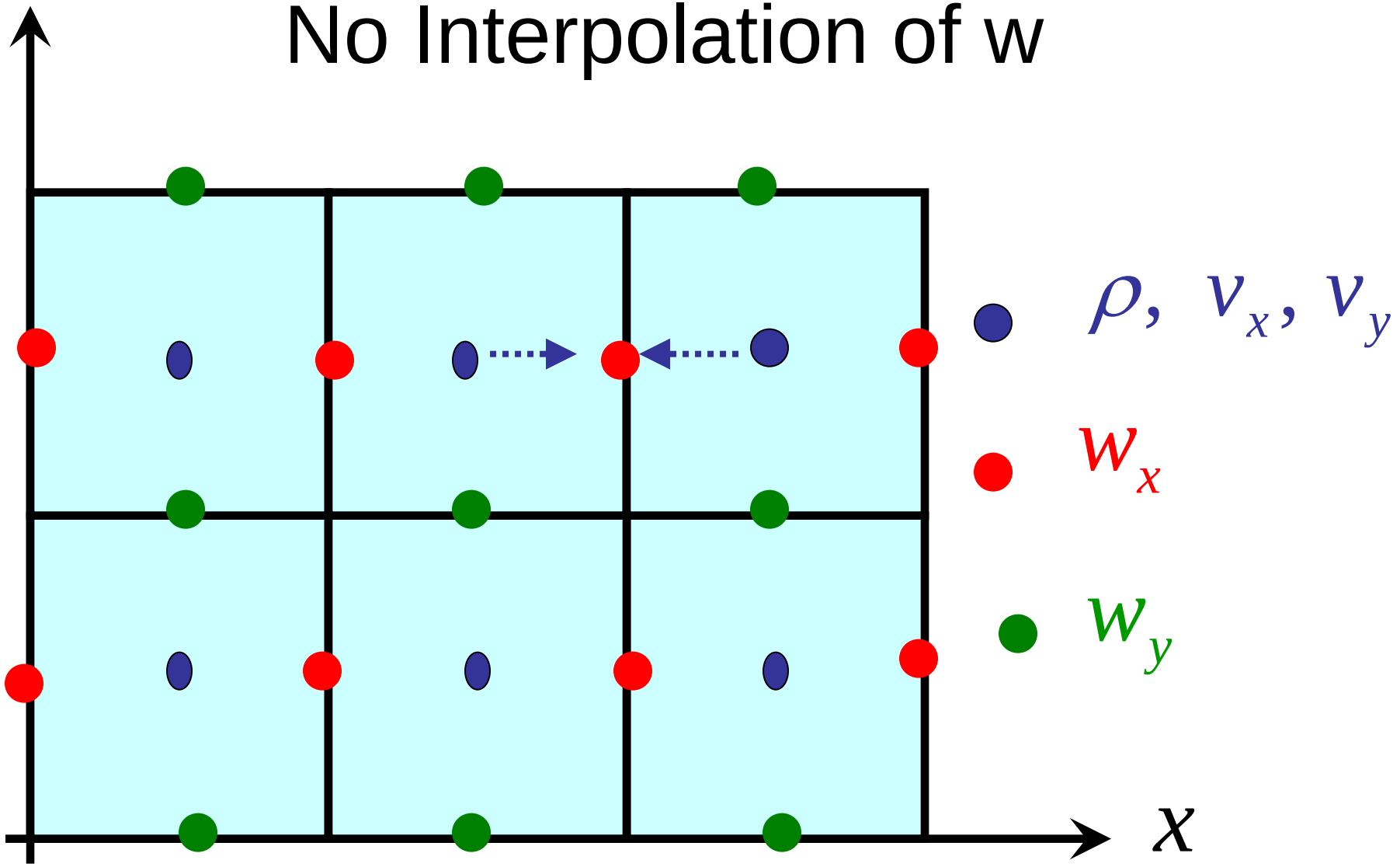
Bate & Bonnell (1997)

Ochi, Sugimoto, & Hanawa (2005)

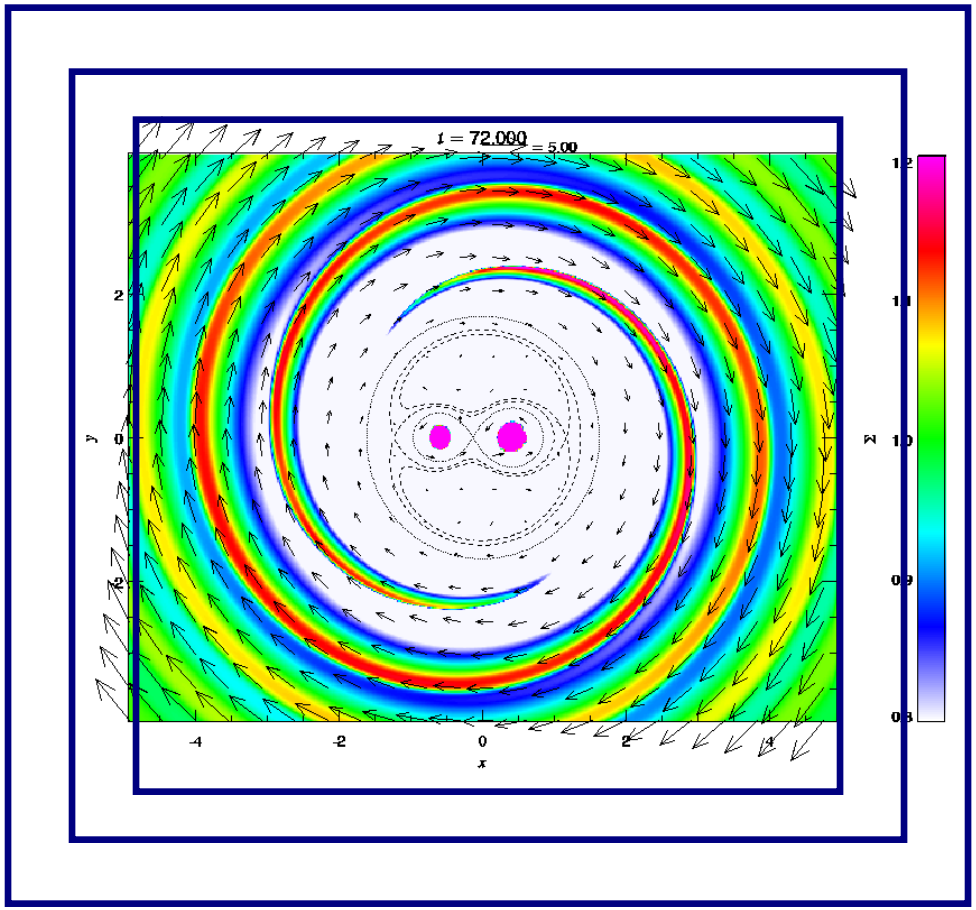
The Reference Velocity



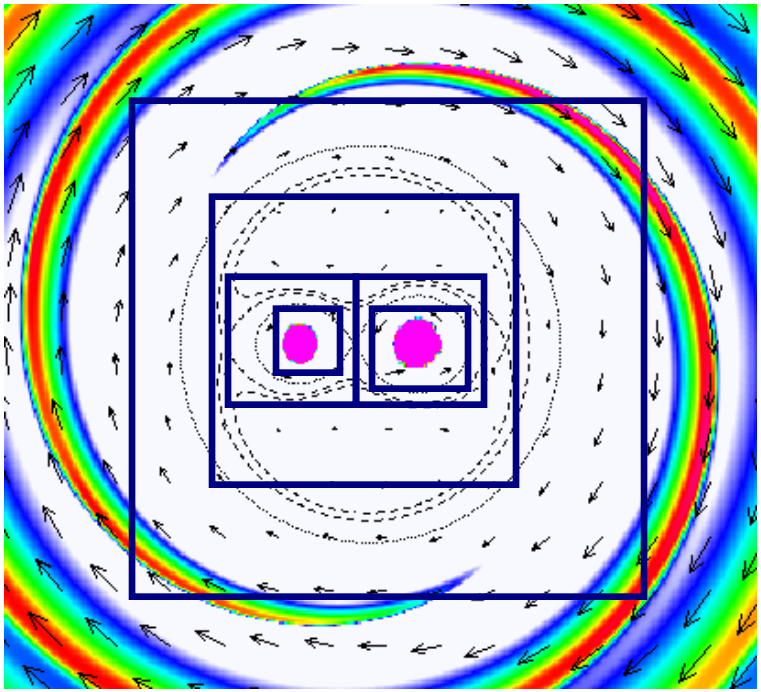
Numerical Flux:
No Interpolation of w



l = 6-10 Nested Grid $512^2 \times 10$



Wide Coverage +
High Resolution



l = 10, R_{out} = 39.3

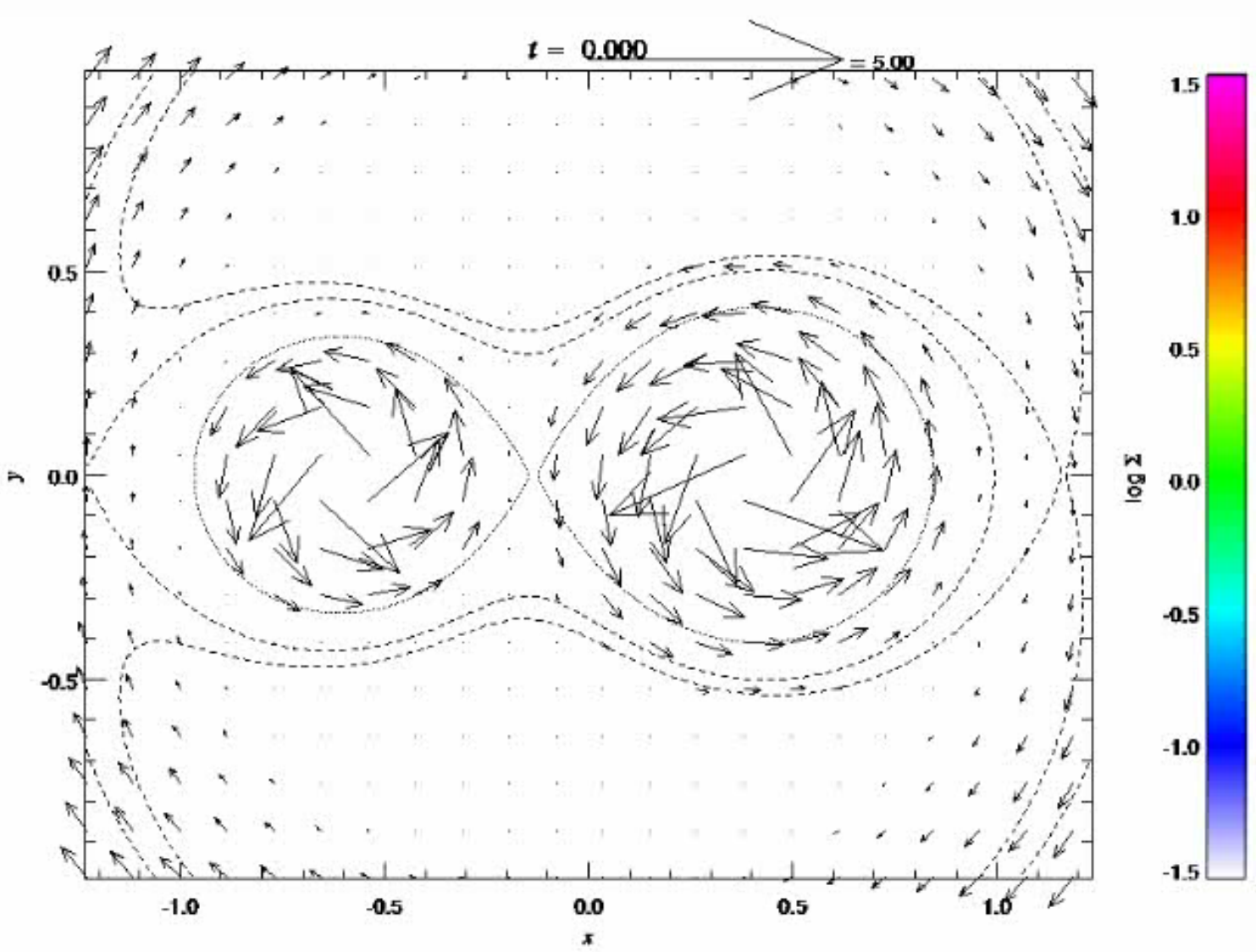
l = 1-5

The Finest Grids: 0.614^2 with $\Delta x = 1.2 \times 10^{-3}$

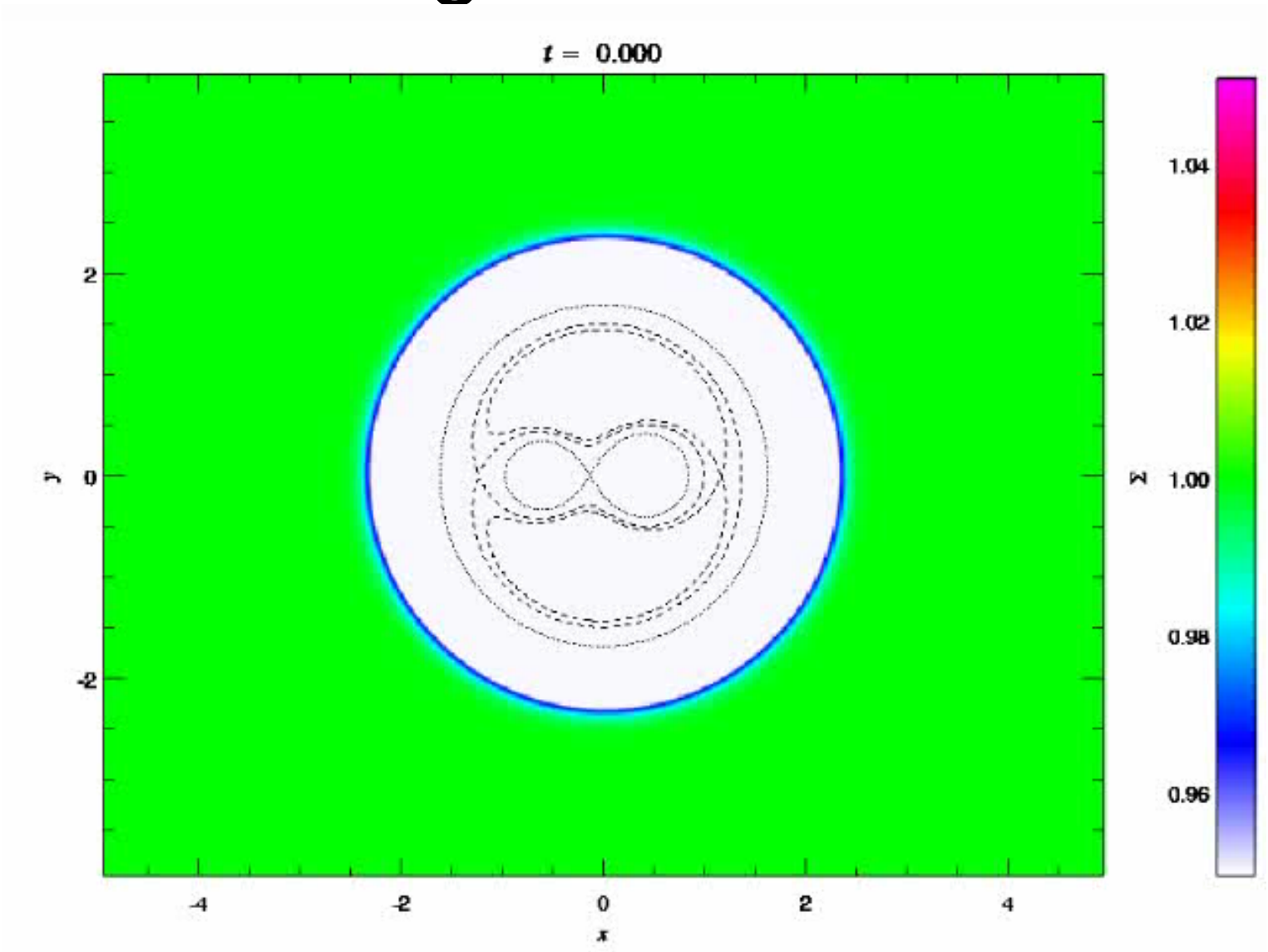
Model Parameters

- Sound Speed: Cs = 0.22
- Mass Ratio q = 0.95/1.4 = 0.68
- Softening of Gravity
  - $r_1 < 0.07$ & $r_2 < 0.07$
- Reference Velocity
  - Primary $r_1 < 0.4$ (Kepler) $r_1 < 0.58$ (Slow)
  - Secondary $r_2 < 0.27$ (Kepler) $r_2 < 0.41$ (Slow)

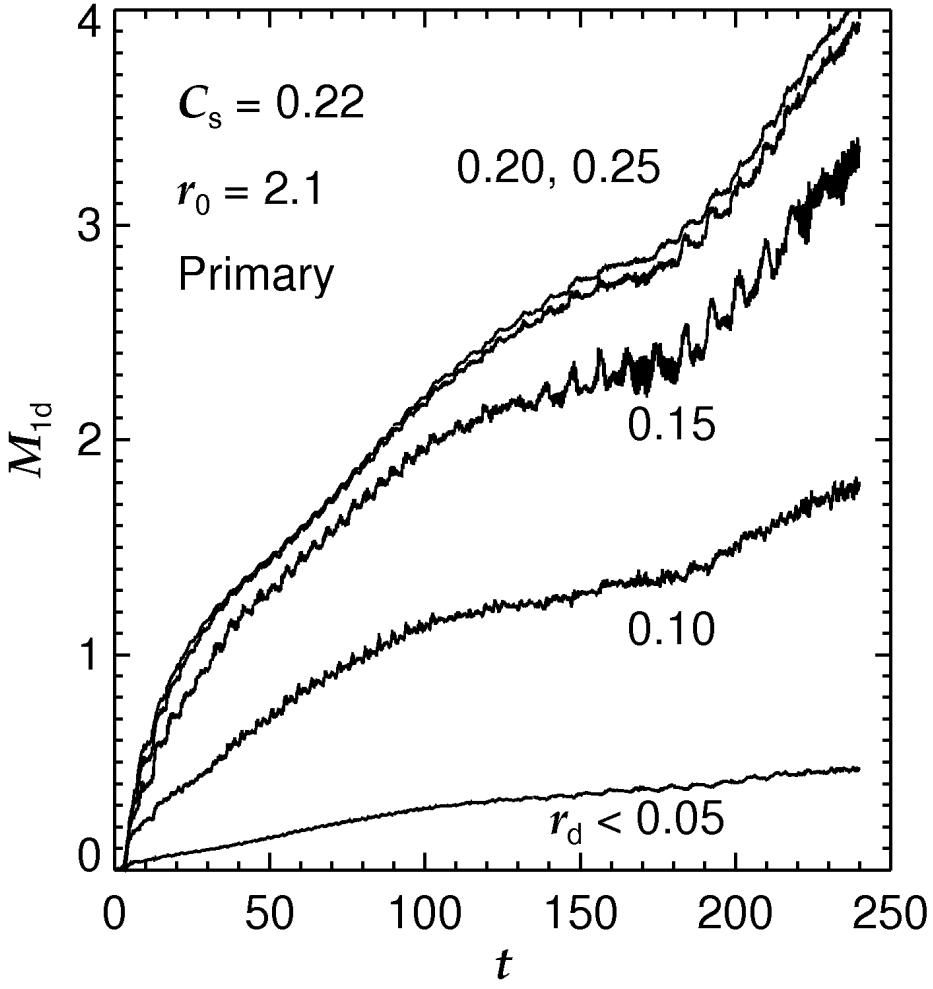
Close Up View

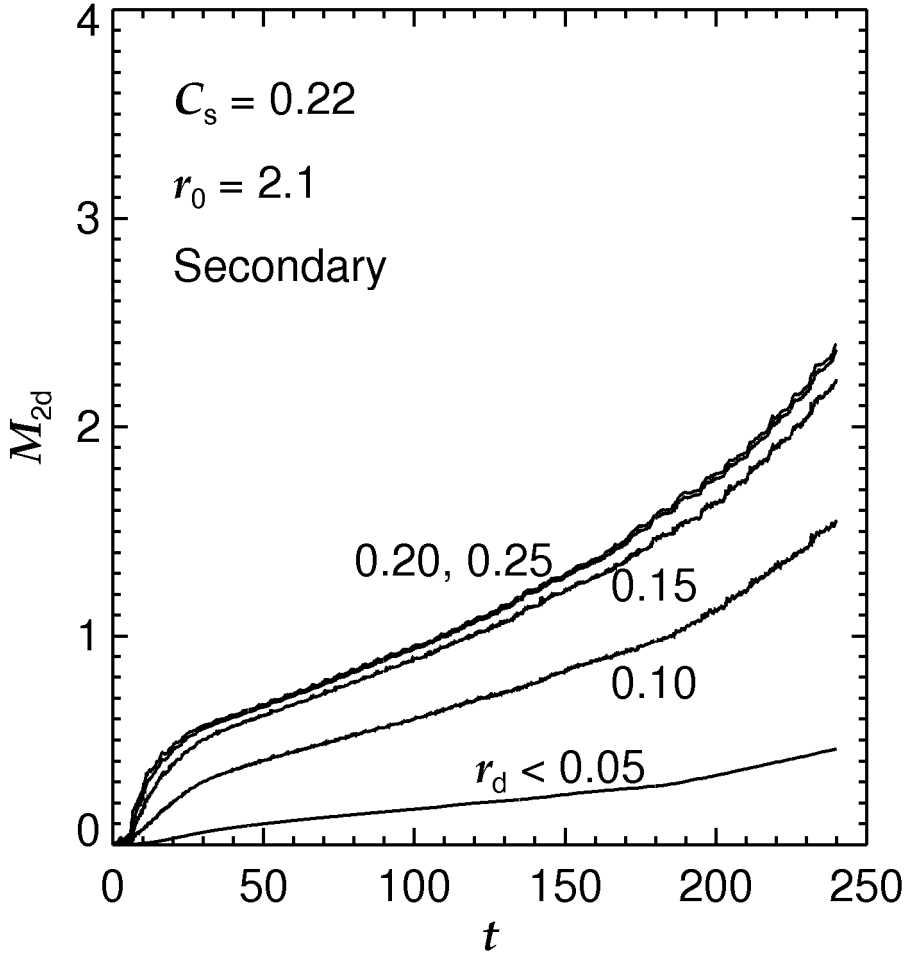


Large Scale View

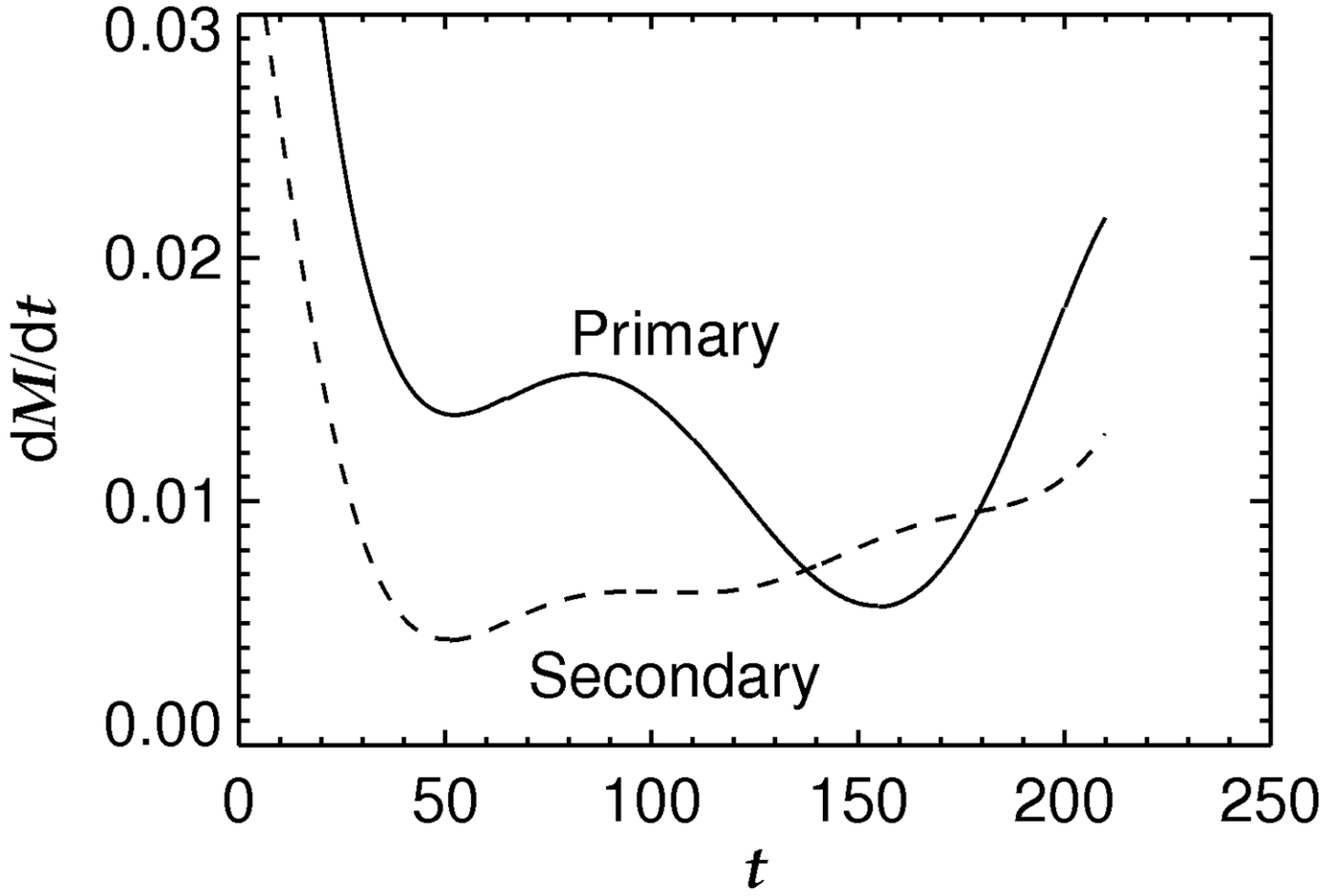


Growth in Disk Mass

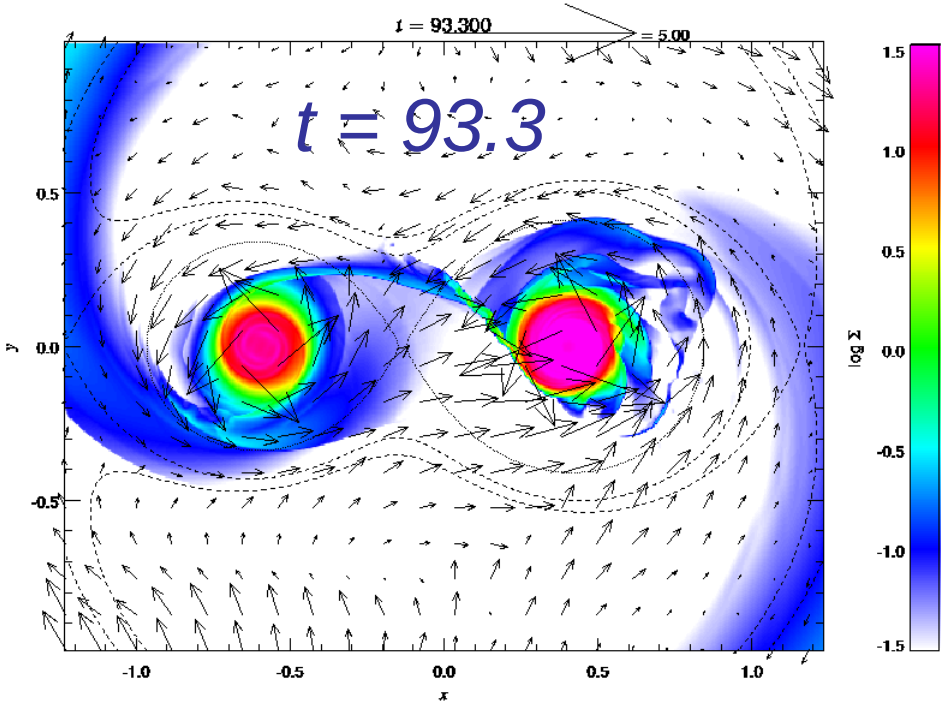




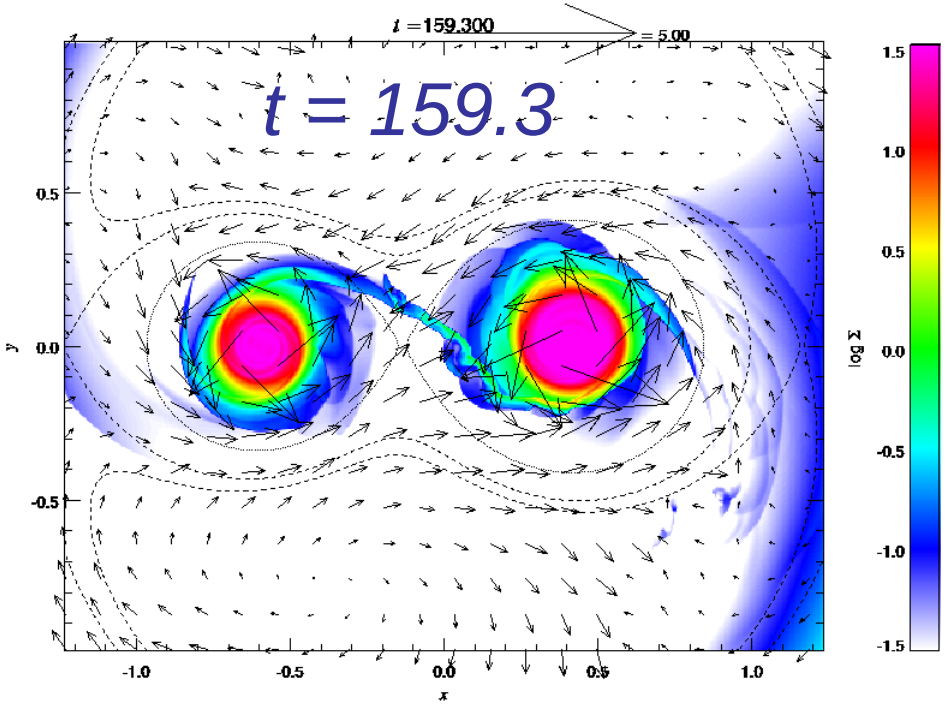
Average dM/dt



When Primary accretes more



When secondary accretes more



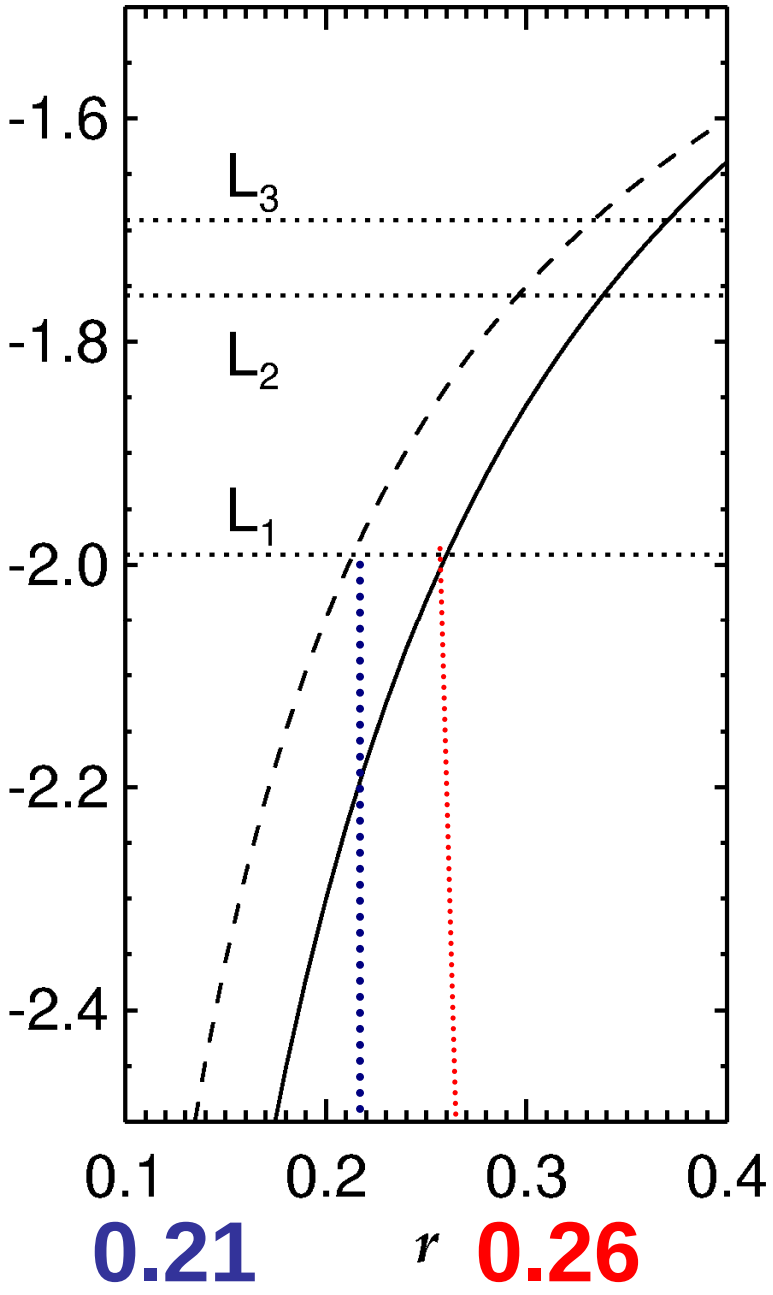
Primary Disk is always perturbed.

Shock Energy Dissipa
is Important.

Jacobi constant

$$\Phi = \frac{\mathbf{u}^2}{2} - \frac{GM_1}{|\mathbf{r}-\mathbf{r}_1|} - \frac{GM_2}{|\mathbf{r}-\mathbf{r}_2|} - \frac{|\Omega \times \mathbf{r}|^2}{2}$$

$C_s^2 = 0.0484$



V4046 Sgr

CTT+CTT

P=2.4d

2 Narrow Compnents

$v = 54\ \mathrm{km\ s^{-1}},\ -57\ \mathrm{km\ s^{-1}}$

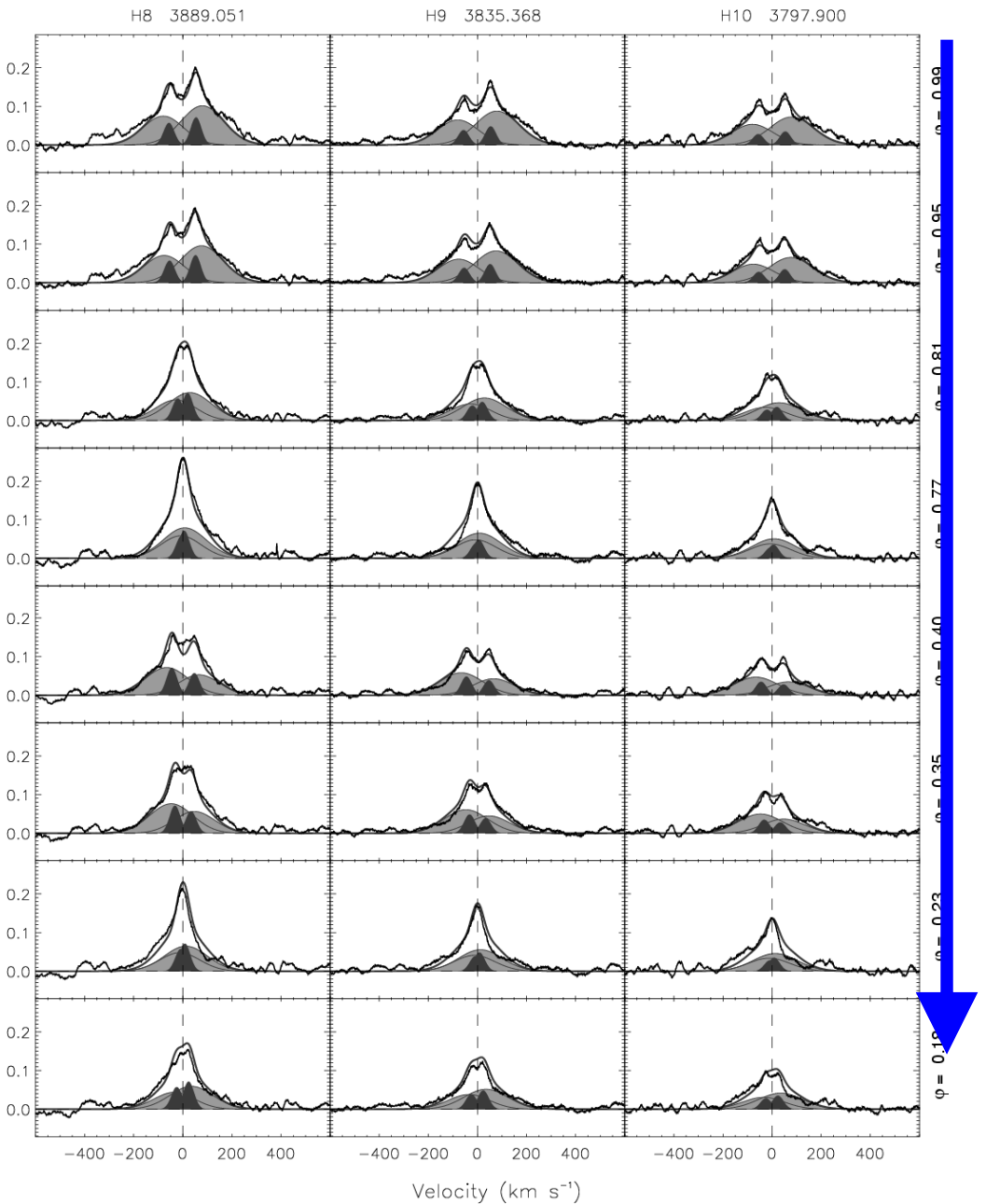
Emitted from Stars

2 Broad Components

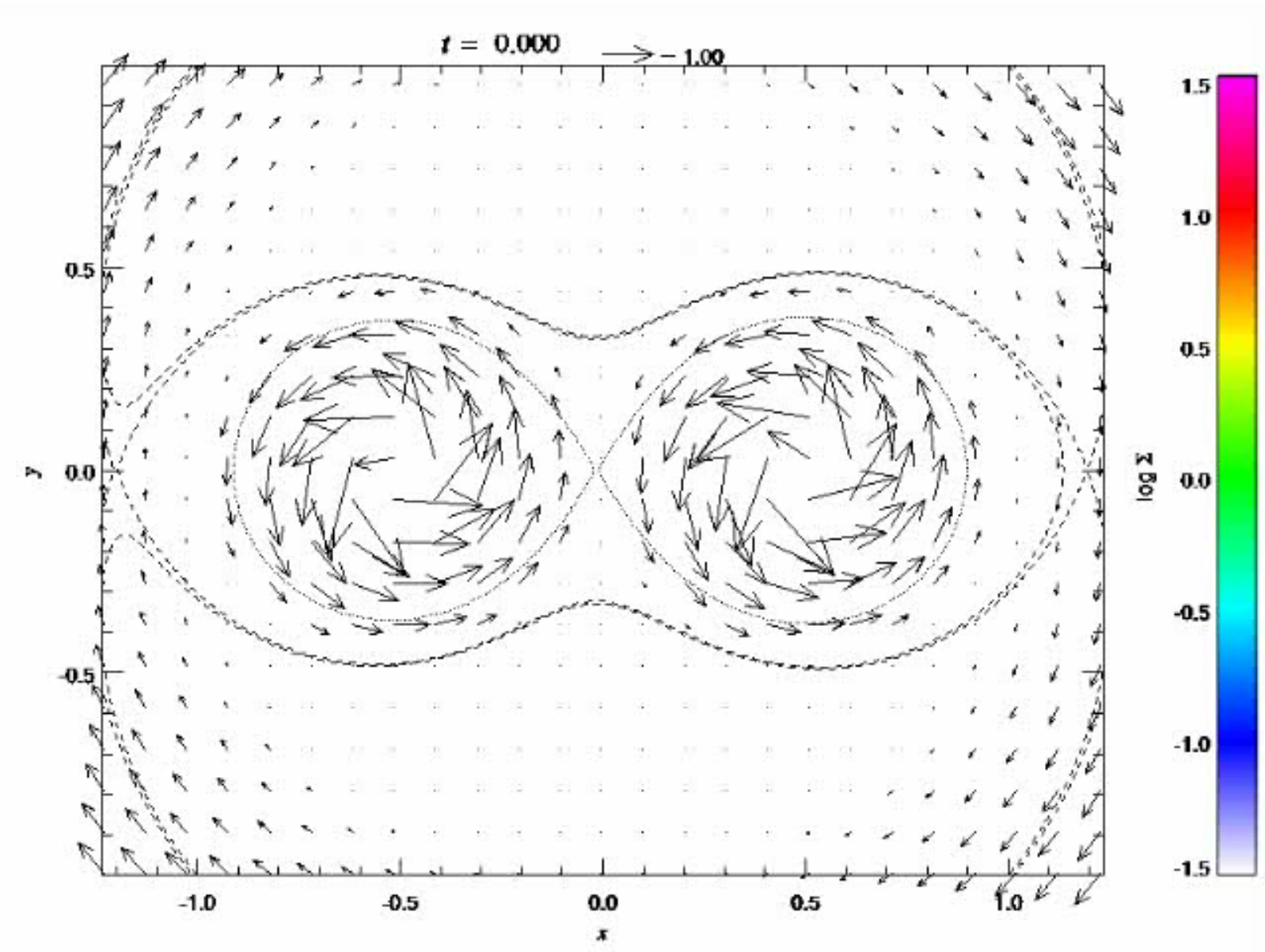
$v = \pm 80\ \mathrm{km\ s^{-1}}$

Stempels & Gahm 04

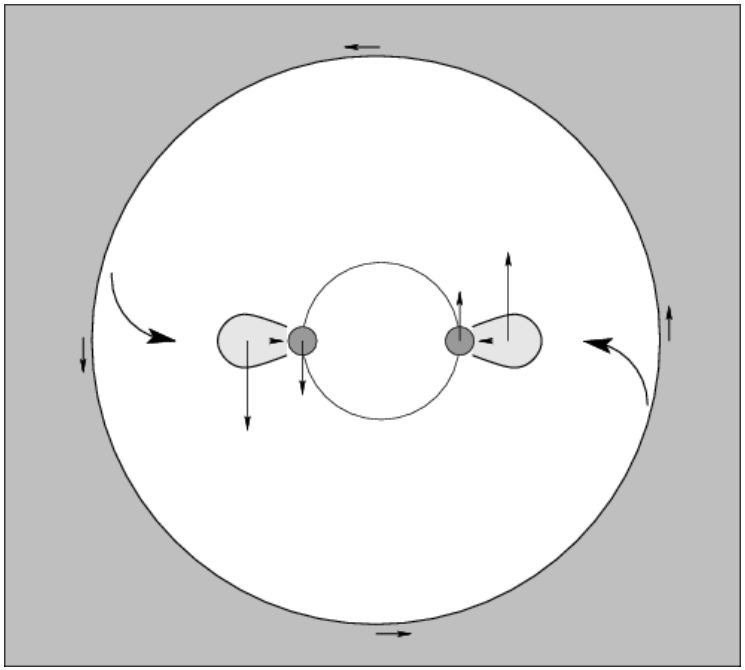
Balmer H8, H9, & H10

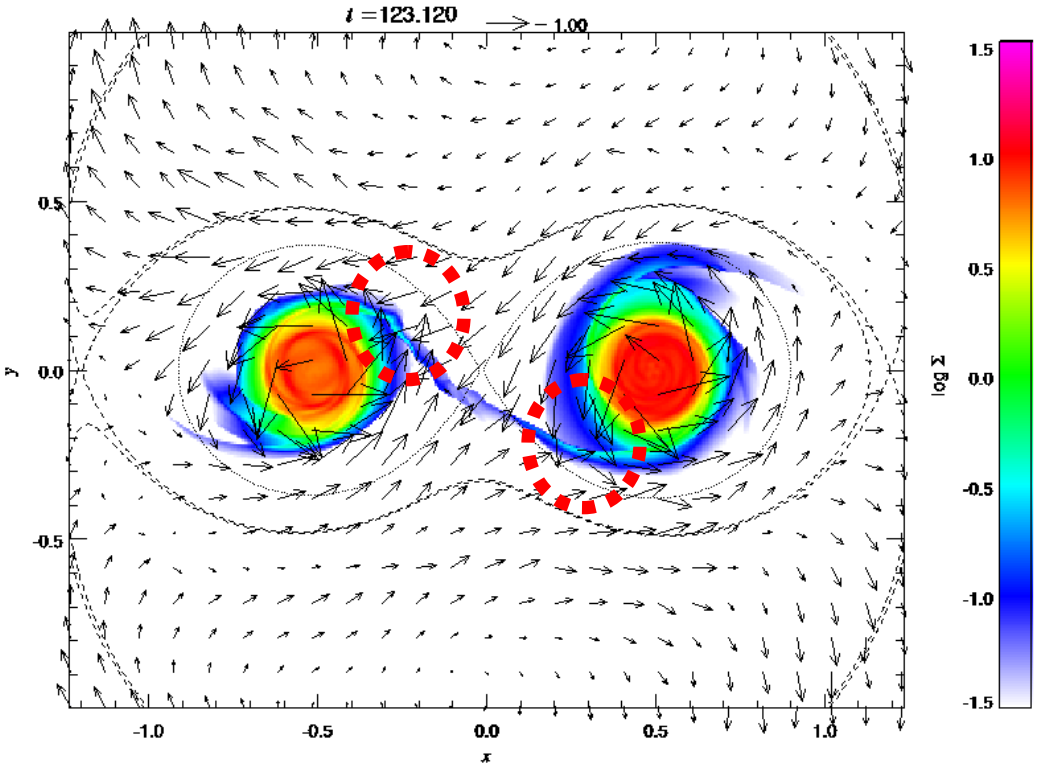


V4046 Sgr



Origin of Broad Lines





"Clouds"

Stempels & Gahm 04

Hot Spots

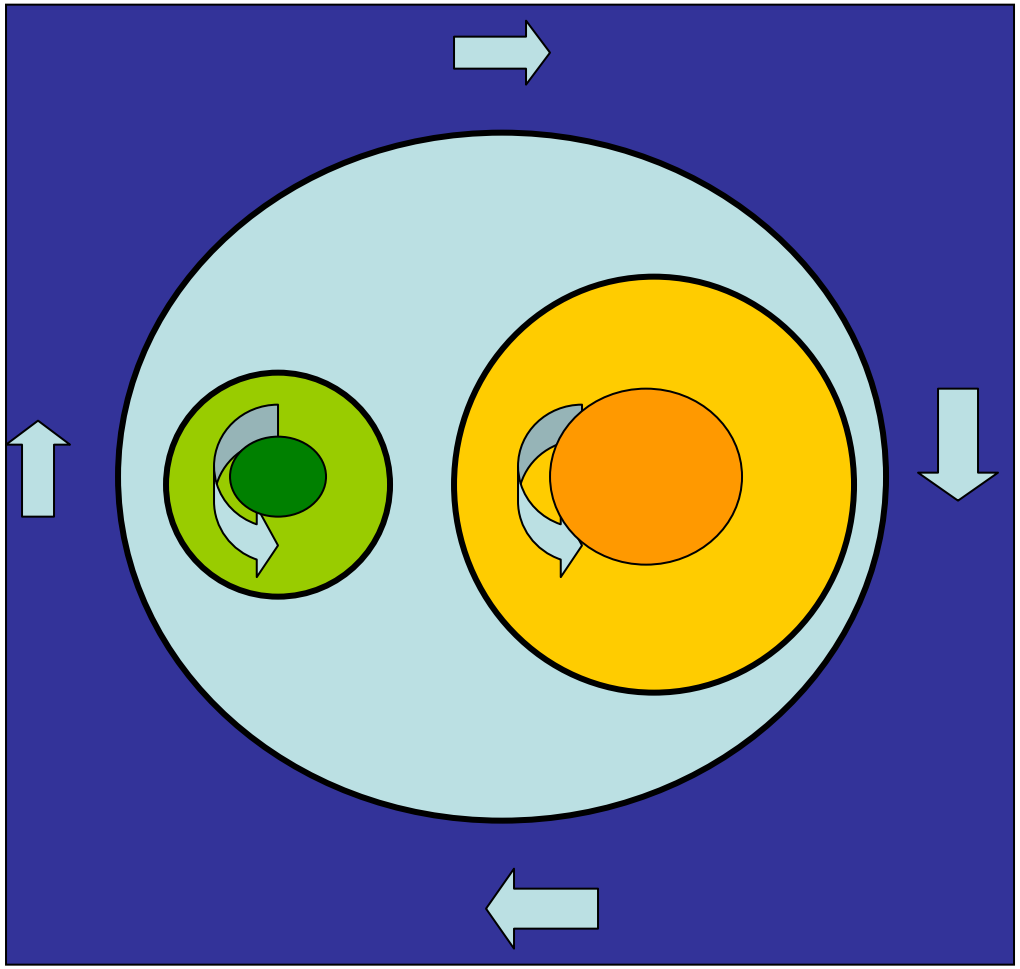
L2 ⇒ Primary

L3⇒ Secondary

Summary

- The effective gravity is greatly reduced by introduction of the reference velocity.
- The primary disk is always perturbed by the gas inflow through L2. (contradiction with SPH simulations)
- Spiral shock waves oscillate with variable amplitude.
- The hot spots appear on the L1 sides of primary and secondary disks.

Reference Velocity



P (Kepler Rot.)

P (Slow Rot.)

S (Kepler Rot.)

S (Slow Rot.)

Circumbinary (Kepler Rot.)

No Reference (w = 0)