LEC

Laboratory Experiment of Cosmic Hydrodynamics

宇宙流体実験

Yoshiaki SOFUE

祖父江義明

1. Spiral Galaxies, Spiral Pattern, Galactic Shock

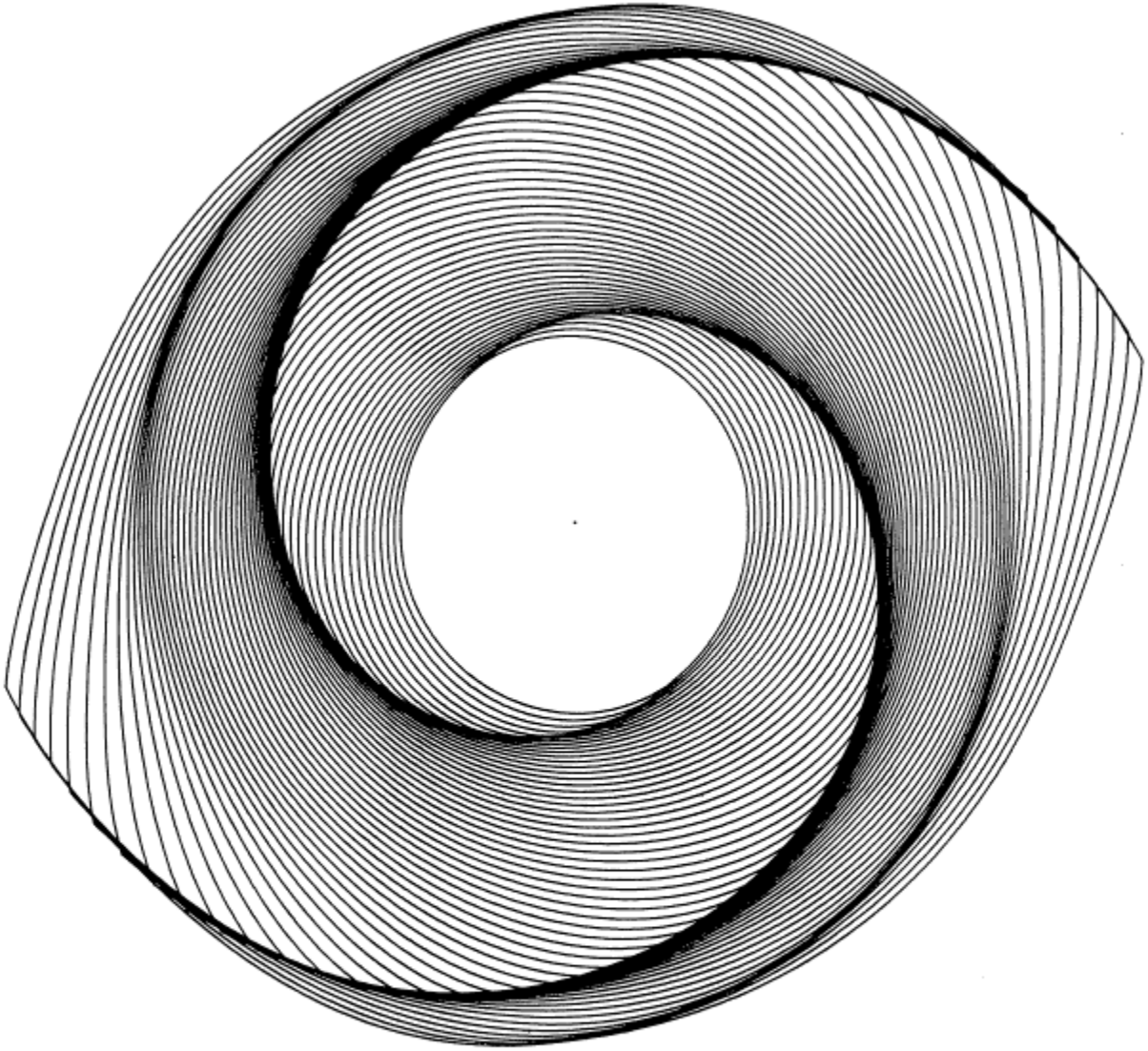
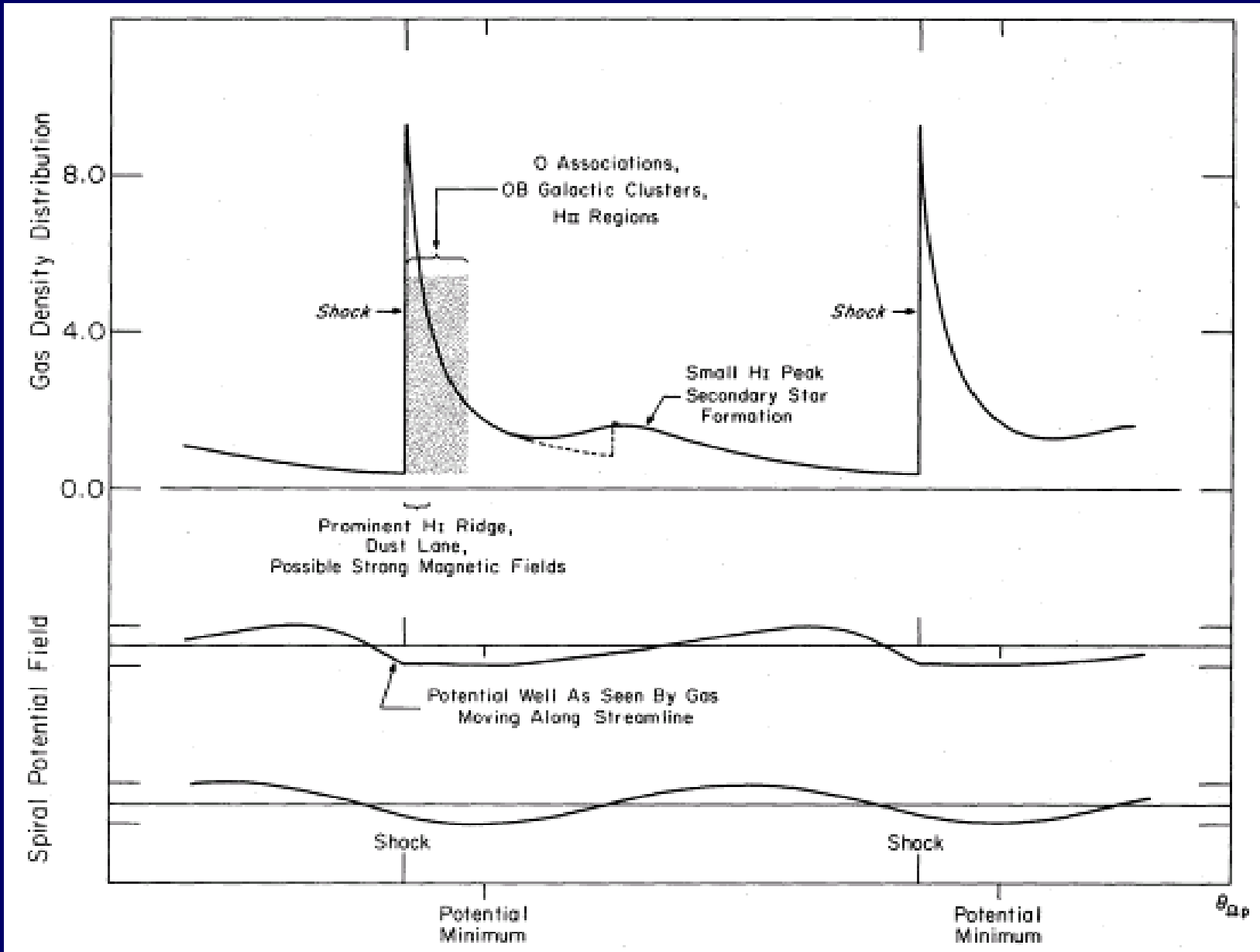


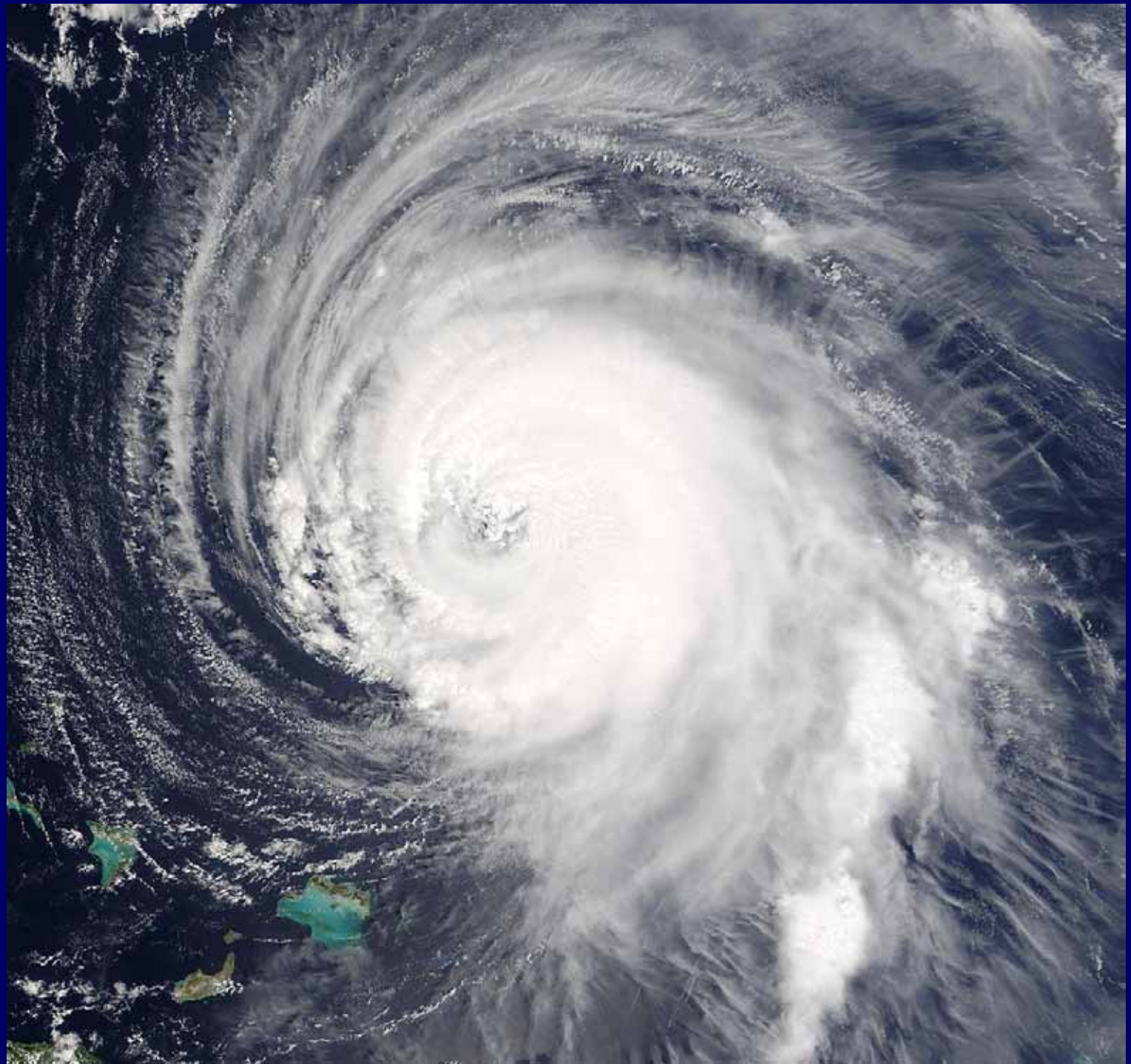
Fig. 2. Streamlines of the final model with an increment of 0.1 kpc in mean radial distance, seen face-on. Note that the r
streamlines crossing a unit area is a measure of the (unsmoothed) perturbed surface density of the gas. In the outer regions t
enhancement due to the growing importance of the second harmonic resonance can be seen. The line showing the length s
plane of the galaxy is in the major-axis direction

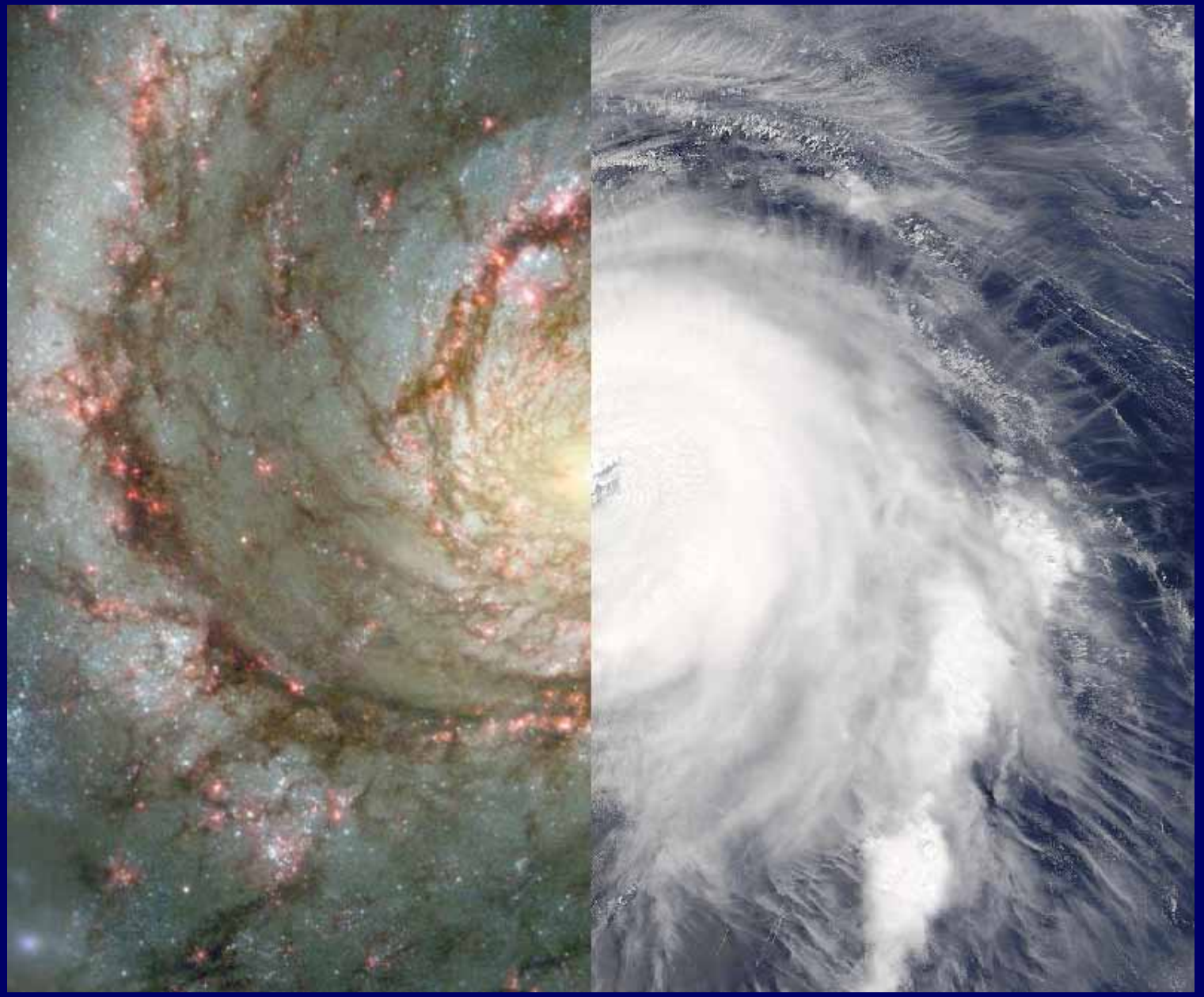
銀河衝撃波Galactic shock



Similarity to Typhoon/Haricane

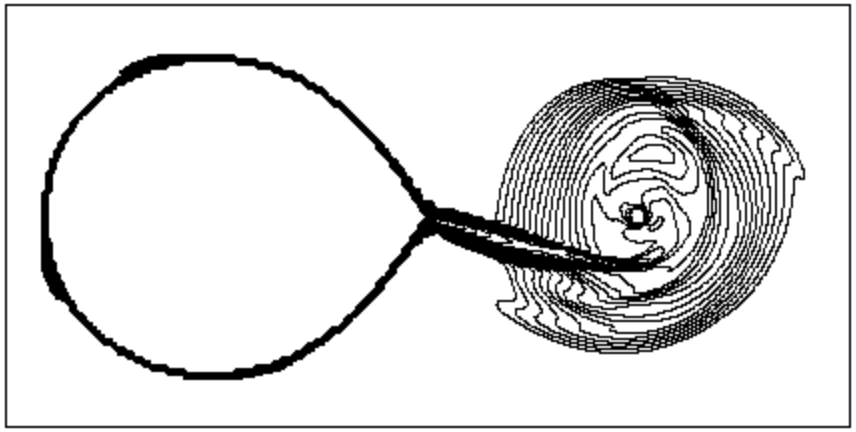
Spiral=Pattern Density wave

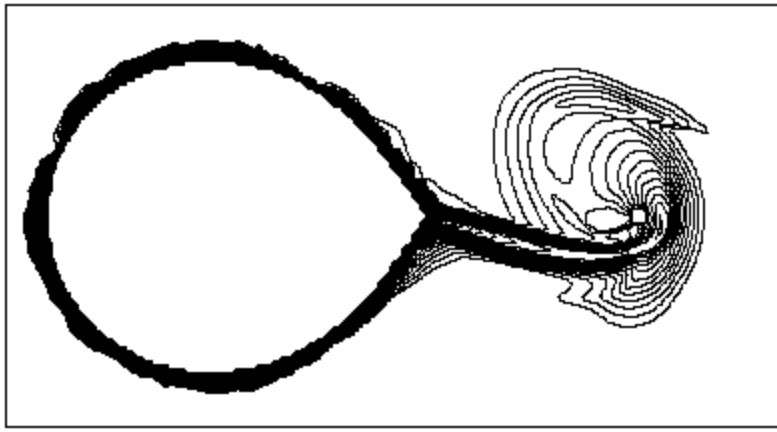


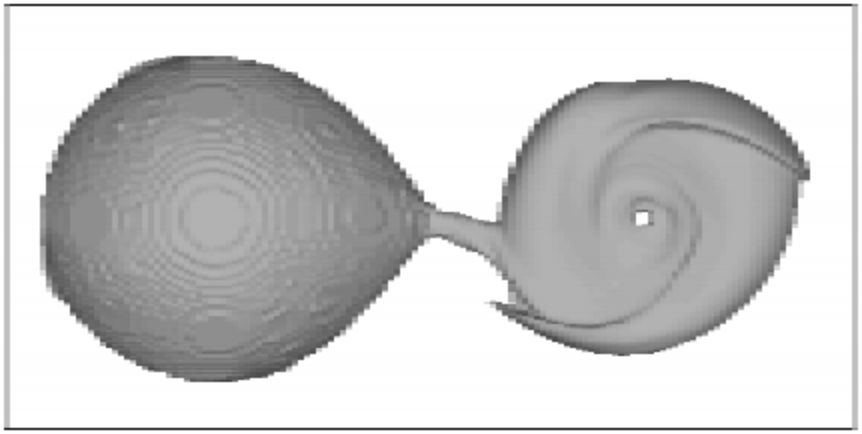


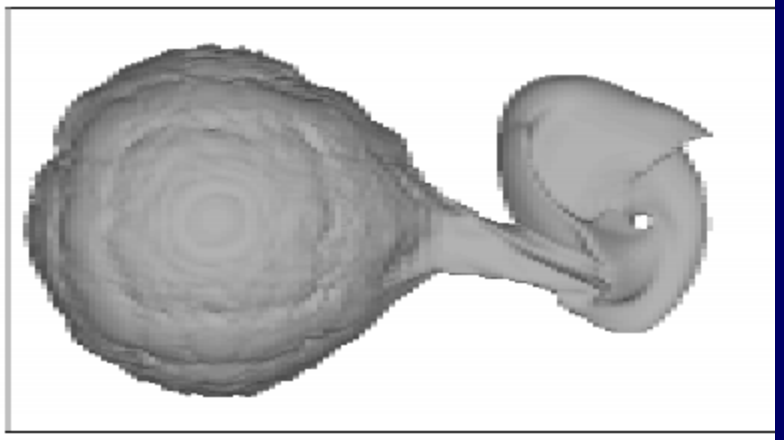
2. Spiral Shock in accretion disk: BH, Binary

2D Matsuda et al. 2000

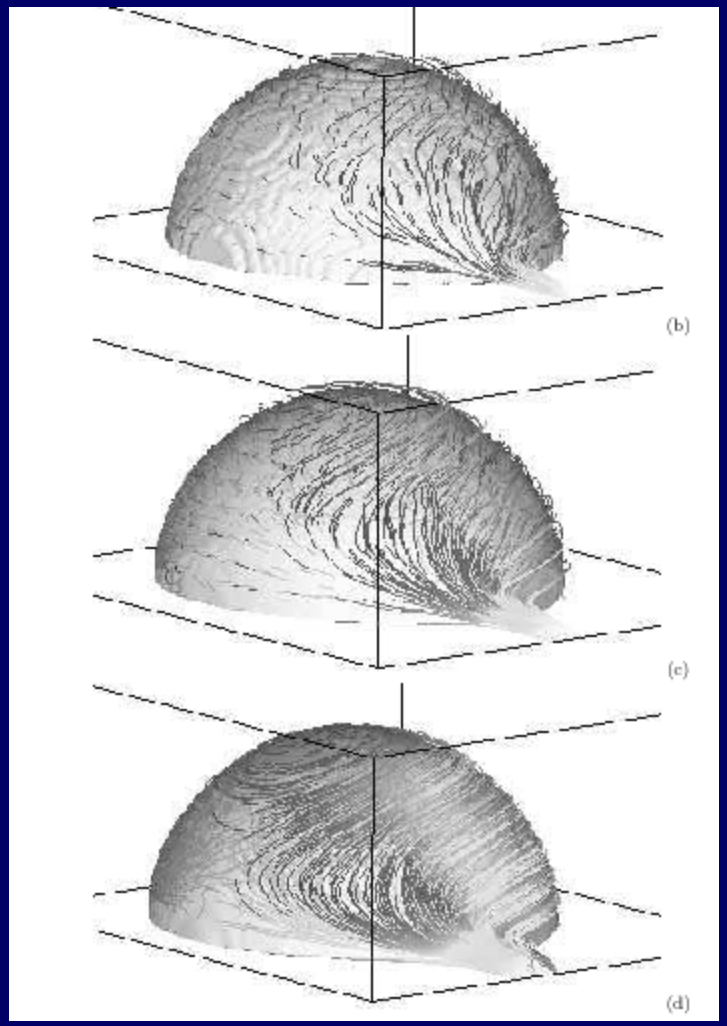








3D Oka et al. 2002



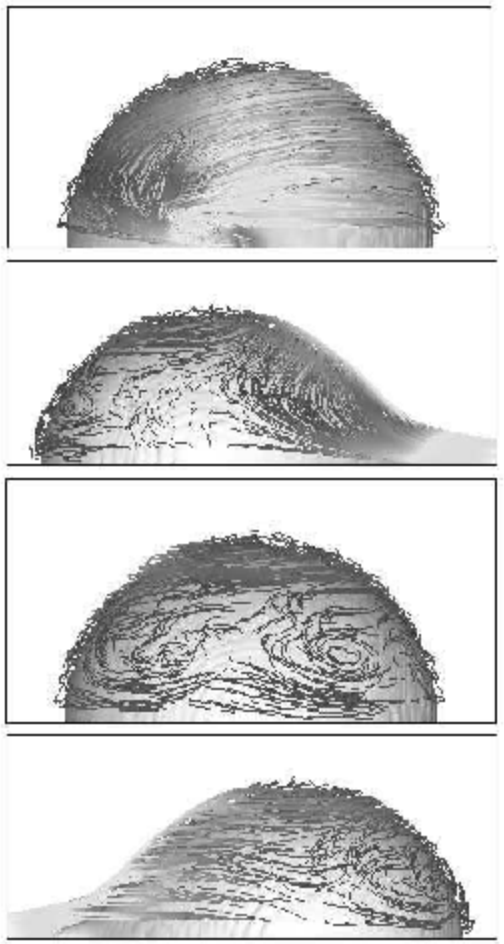


Fig. 2. Streamlines starting from the equi-density surface of $\log_{\_} \rho = -2.5$ and equi-density surfaces of $\log_{\_} \rho = -2$ seen from various view angles.

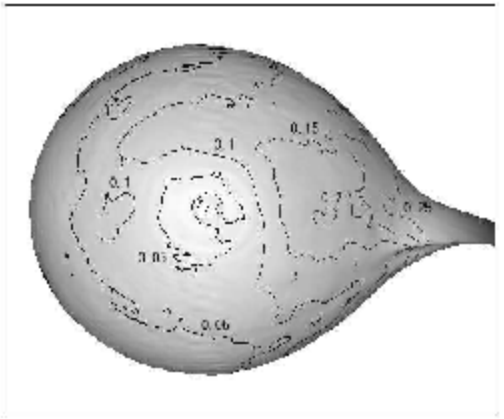


Fig. 3. Iso-velocity lines plotted on the equi-density surface of $\log_{\_} \rho = -2.5$ seen from the north pole. The gray color shows the combined effect of the magnitude of the velocity and the lighting effect.

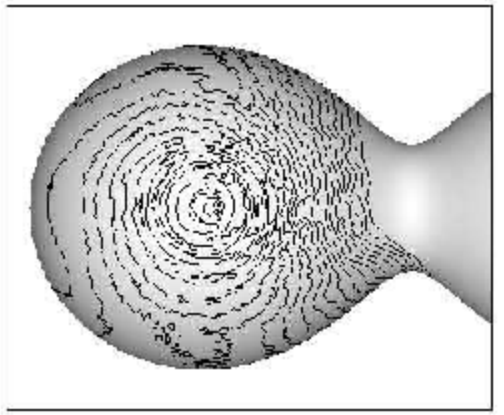
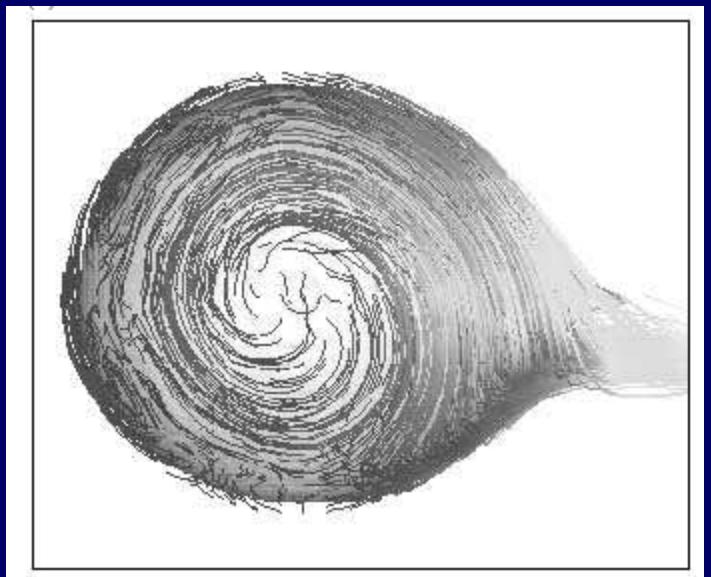
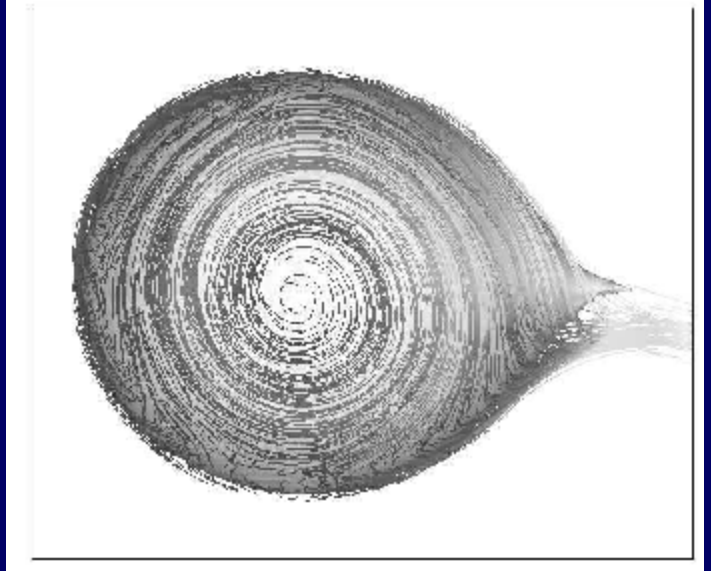
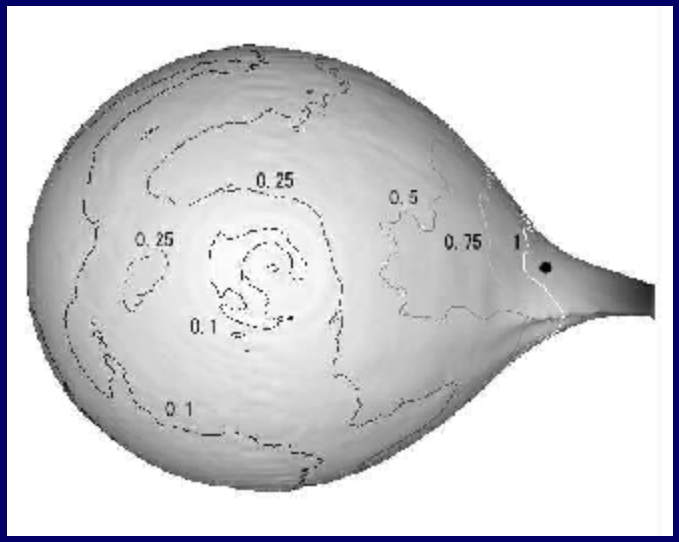


Fig. 4. Isobaric lines plotted on the equi-potential surface seen from the north pole.



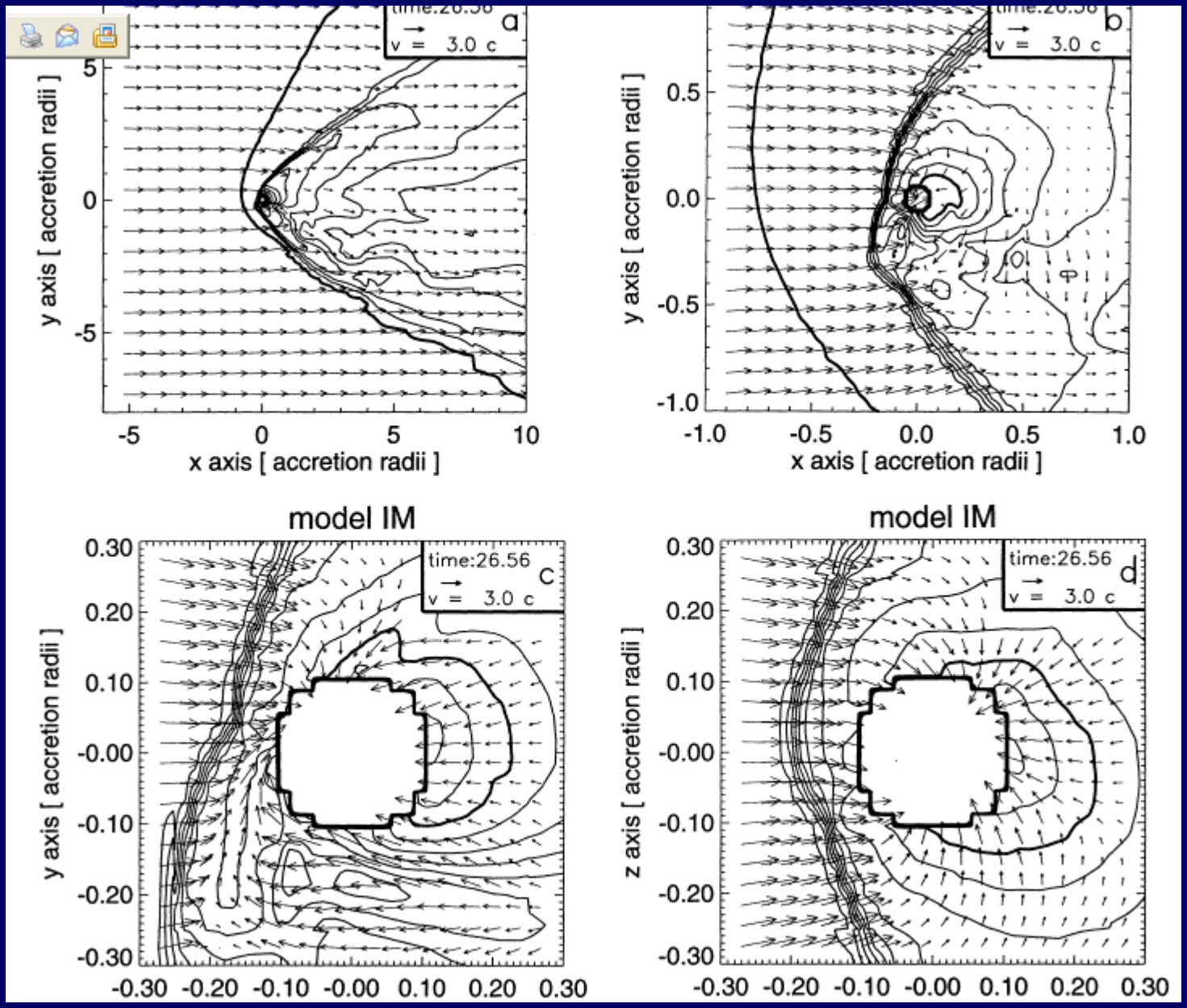
(b)

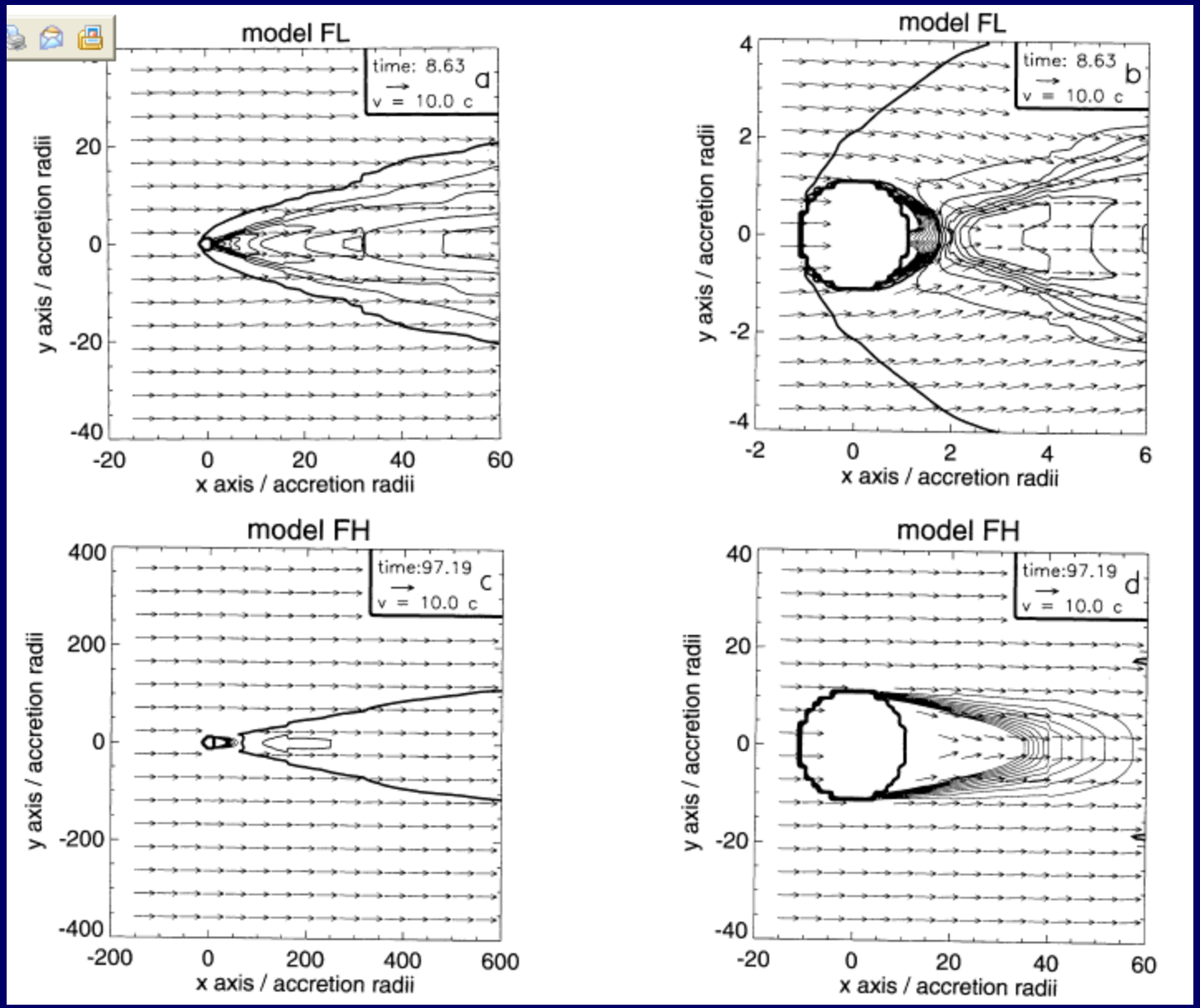


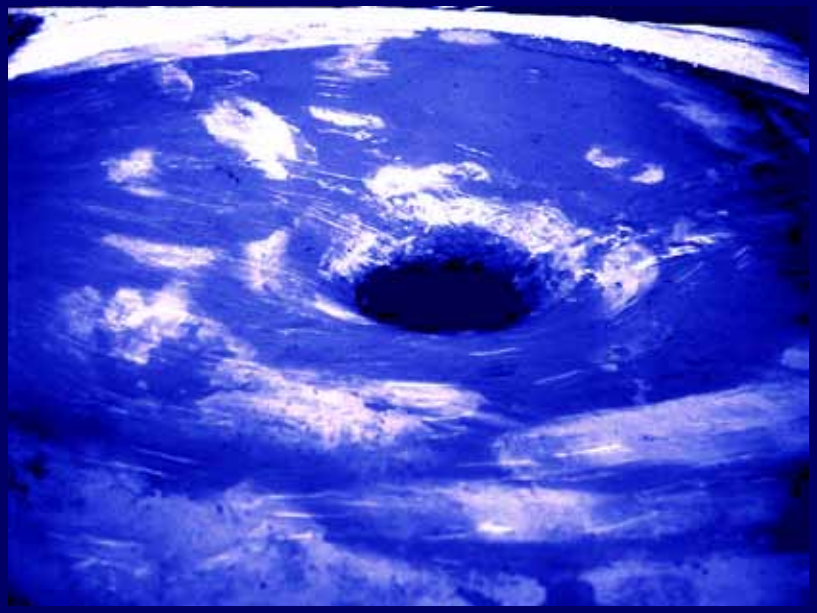


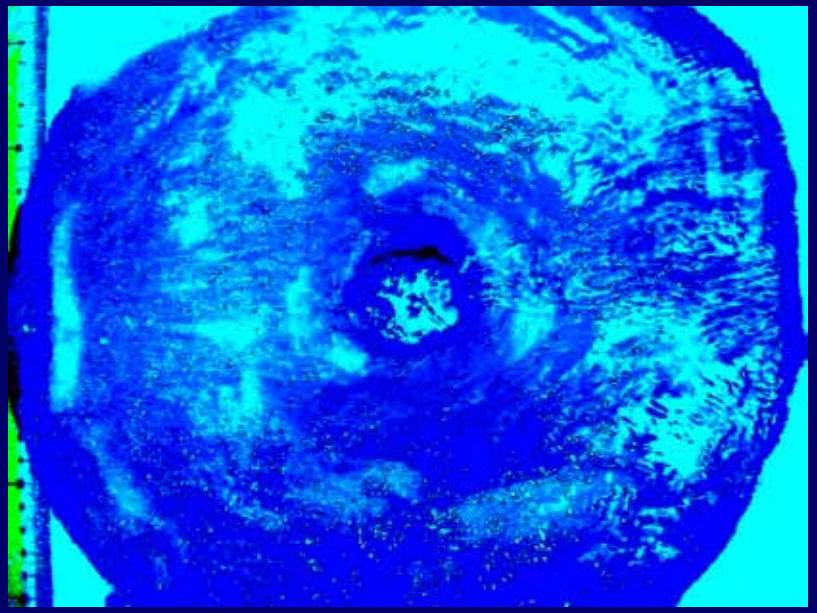
Bondi-Hoyle Accretion

Rufert, Anzer 1995



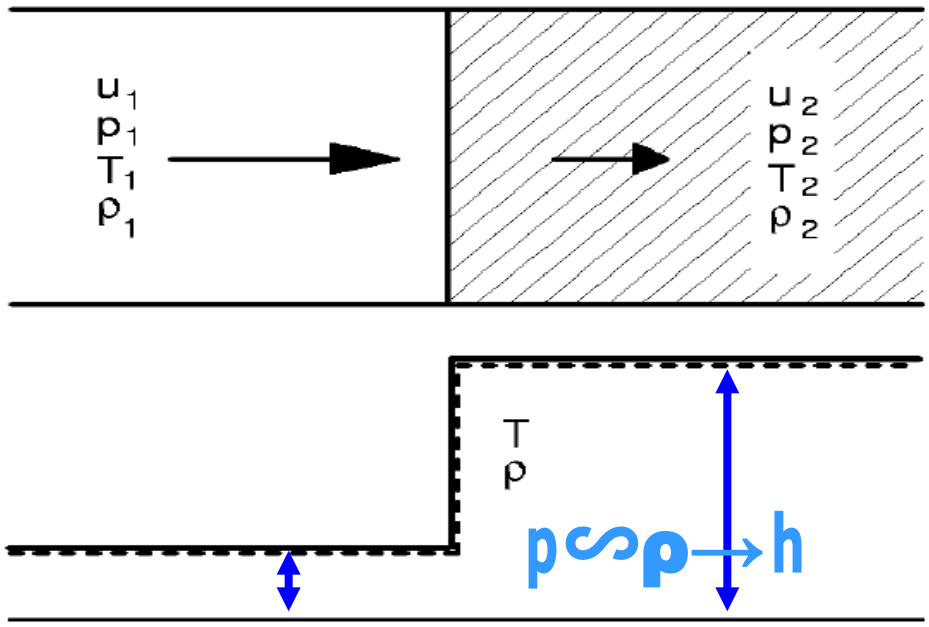

model FL
time: 8.63
v = 10.0 c
a
y axis / accretion radii
x axis / accretion radii
model FL
time: 8.63
v = 10.0 c
b
y axis / accretion radii
x axis / accretion radii
model FH
time:97.19
v = 10.0 c
c
y axis / accretion radii
x axis / accretion radii
model FH
time:97.19
v = 10.0 c
d
y axis / accretion radii
x axis / accretion radii

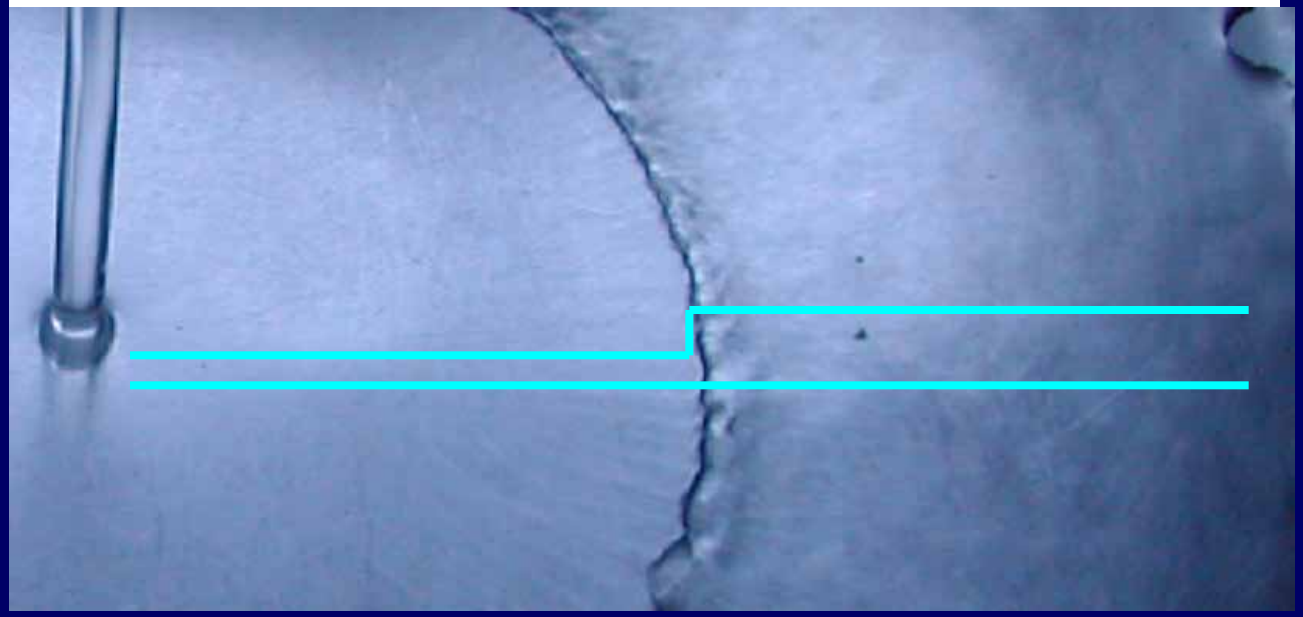




3. Shock-wave Simulation by Hydraulic Jump

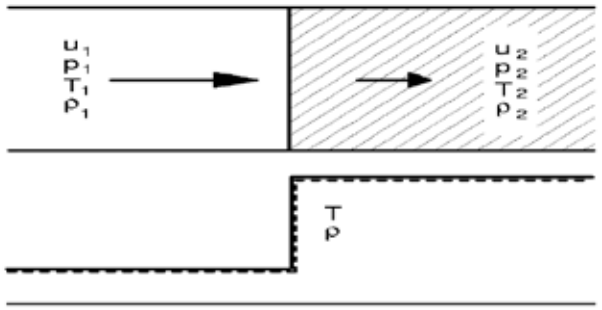
Hydraulic Jump
跳流、流体力学不連続


u1
p1
T1
ρ1
u2
p2
T2
ρ2
T
ρ
p≤ρ→h



鳴門の渦

衝撃波



$$T_1,\ u_1,\ \rho_1,\ p_1, U_1 = \frac{1}{\gamma-1}p_1$$

$$T_2,\ u_2,\ \rho_2,\ p_2, U_2 = \frac{2}{\gamma-1}p_2\ ,$$

$$\rho_1 u_1 = \rho_2 u_2,$$

$$p_1 + \rho_1 u_1 u_1 = p_2 + \rho_2 u_2 u_2,$$

$$u_1 p_1 + u_1(\frac{1}{2}\rho_1 u_1^2 + U_1) = u_2 p_2 + u_2(\frac{1}{2}\rho_2 u_2^2 + U_2),$$

$$u_1^2 + \frac{2\gamma}{\gamma-1}\frac{p_1}{\rho_1} = u_2^2 + \frac{2\gamma}{\gamma-1}\frac{p_2}{\rho_2}.$$

圧力 p_2/p_1 → h_2/h_1 水面高さ

$$\frac{p_2}{p_1} = \frac{2\gamma}{\gamma-1}M^2 - \frac{\gamma-1}{\gamma+1},$$

$$\frac{u_2}{u_1} = \frac{\rho_1}{\rho_2} = \frac{\gamma-1}{\gamma+1} + \frac{2}{\gamma+1}\frac{1}{M^2}.$$

$$M = \frac{u_1}{c_1} = \sqrt{\frac{\rho_1 u_1^2}{\gamma p_1}}$$

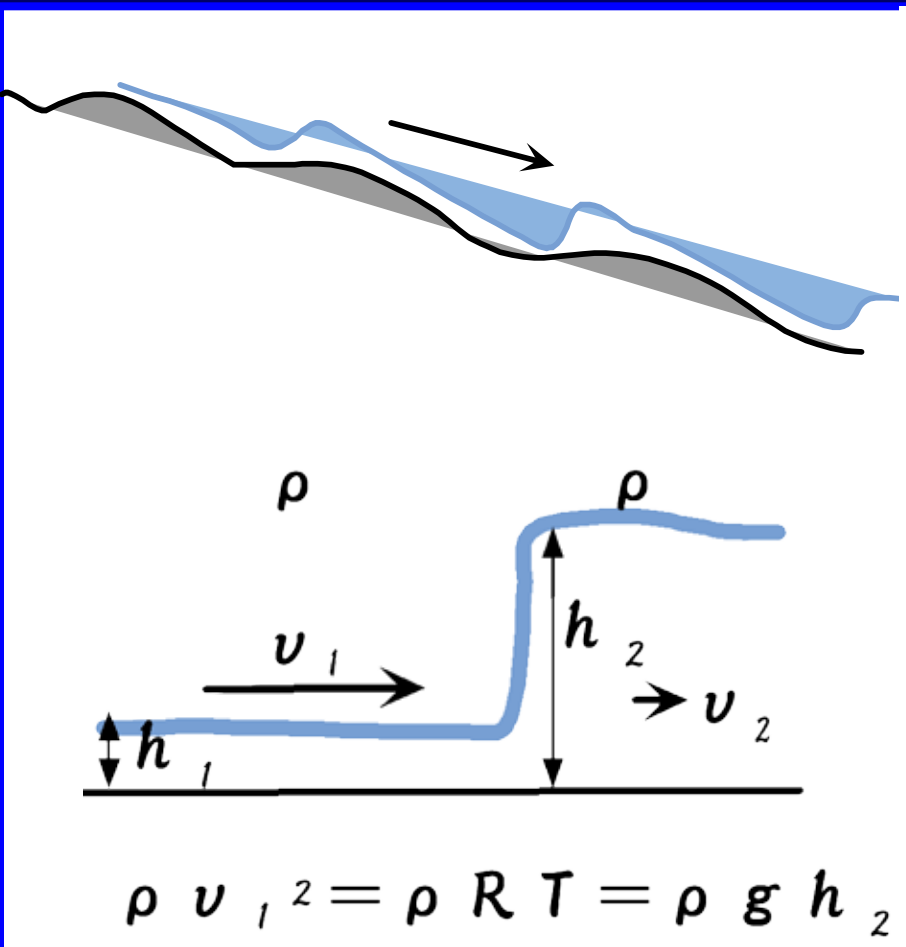
$u_1 \gg c_1 \quad (M \gg 1)$ $\qquad \frac{\rho_1}{\rho_2} \simeq \frac{\gamma-1}{\gamma+1} \simeq 4.$

$p \propto \rho;\ \gamma = 1$ $\qquad \frac{\rho_2}{\rho_1} = M^2.$

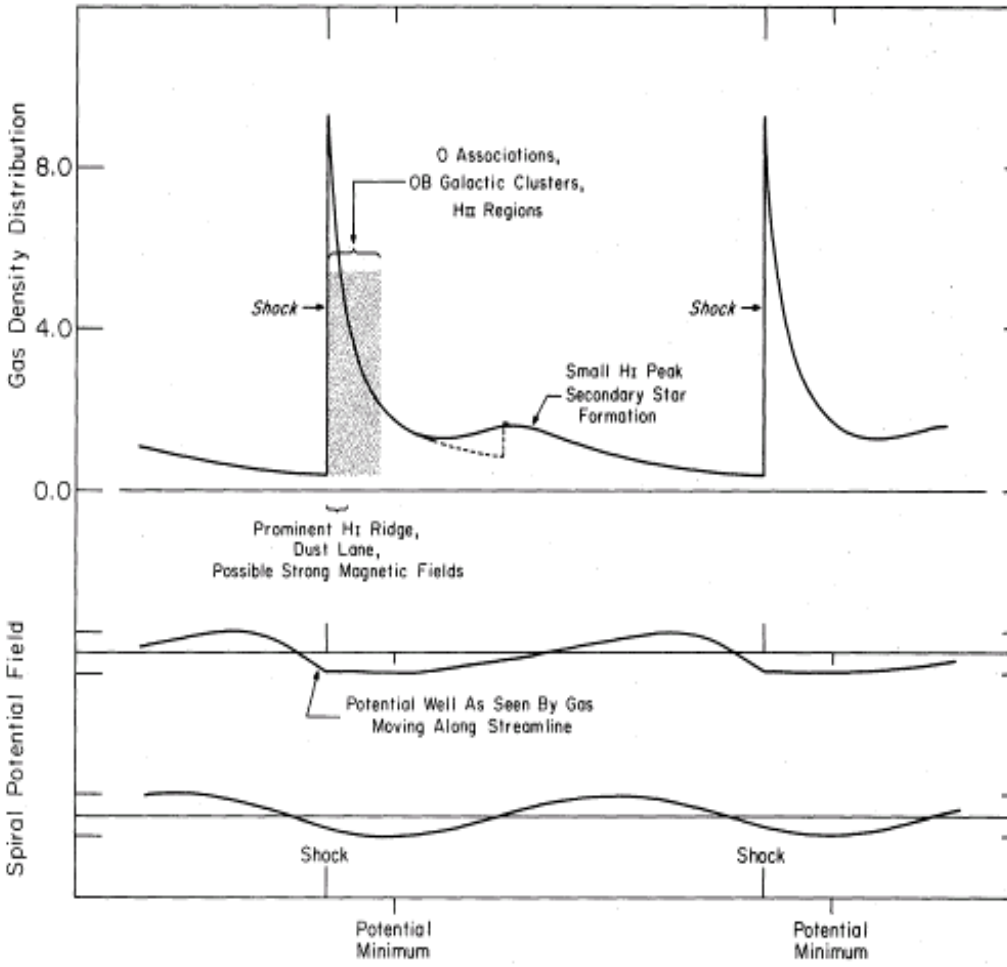
4. LEC

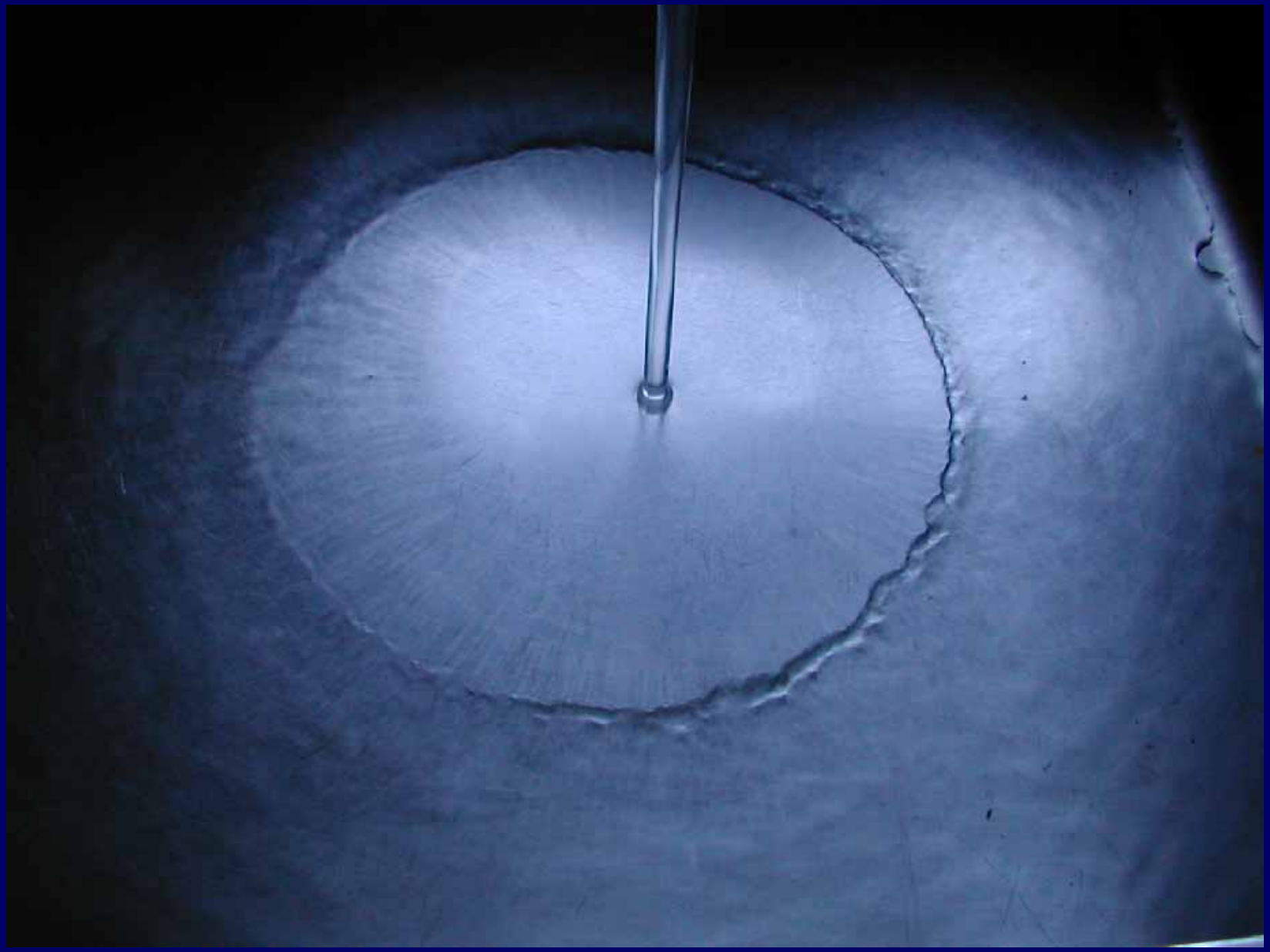
Laboratory Experiment of Cosmic Hydrodynamics

Hydraulic Jump vs Galactic shock

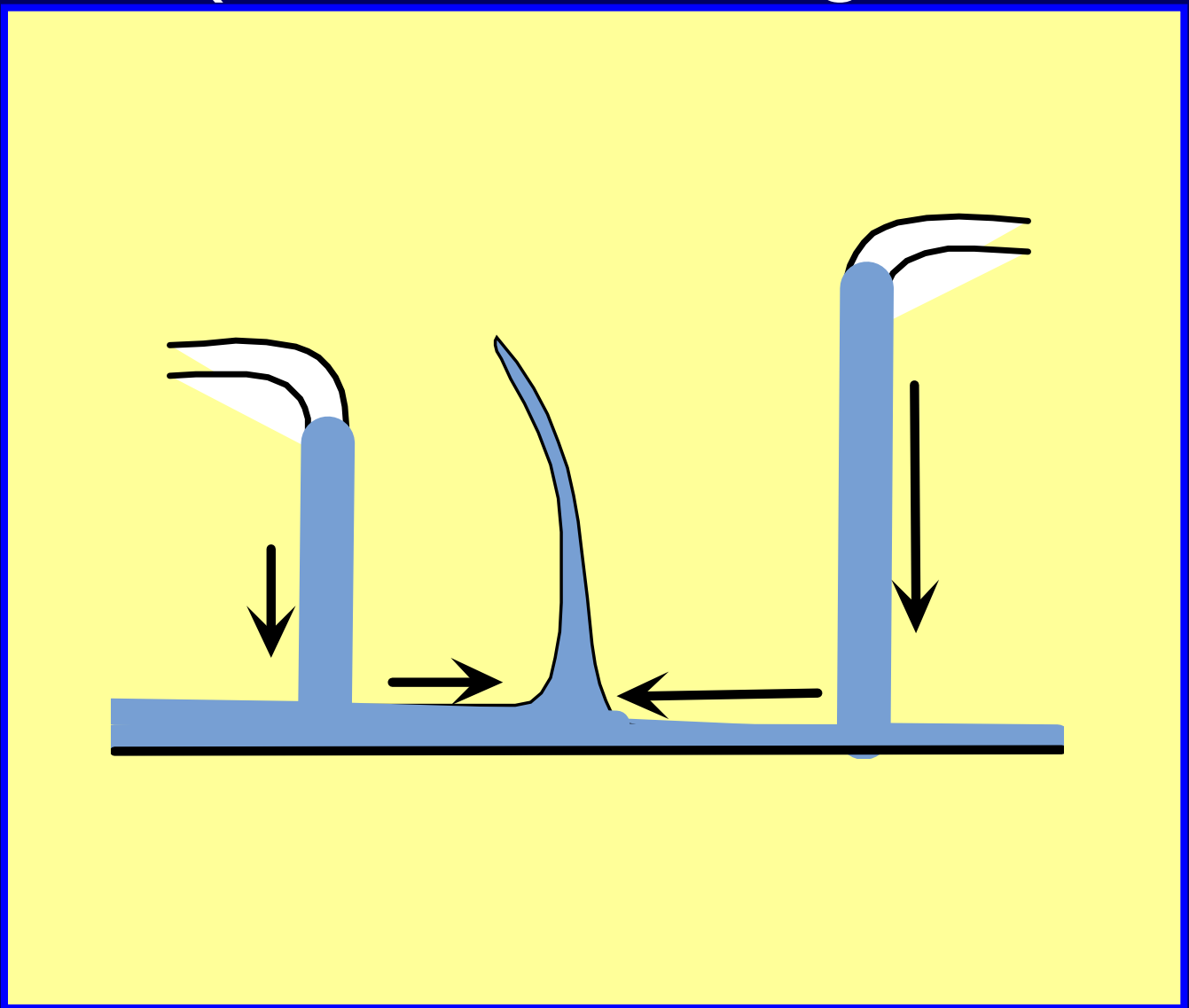


$$\rho v_1^2 = \rho R T = \rho g h_2$$

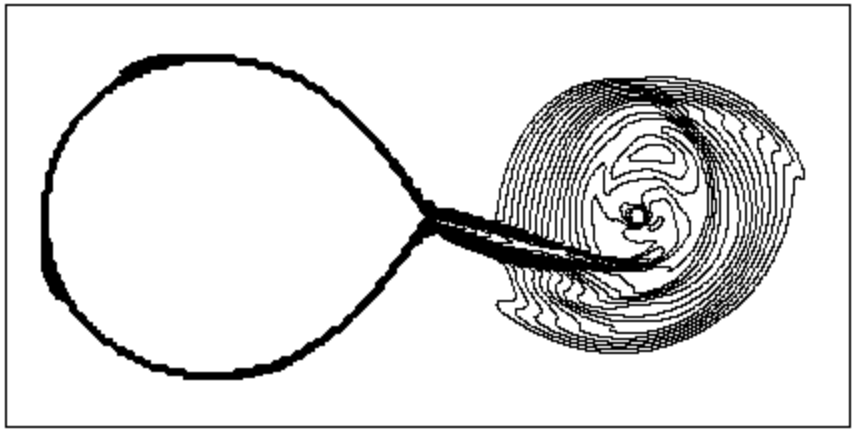


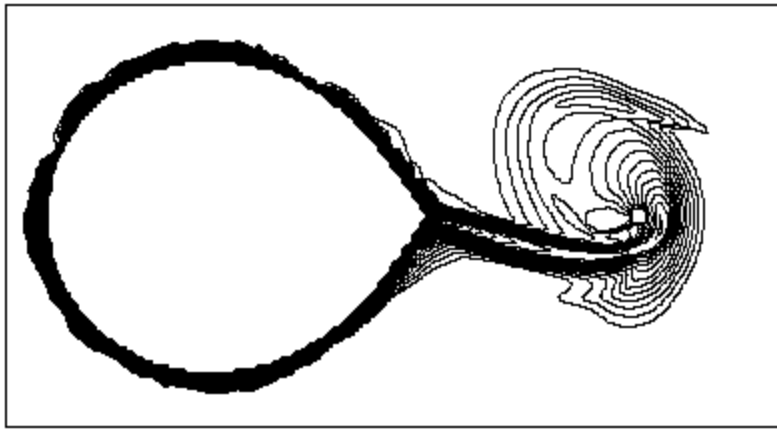


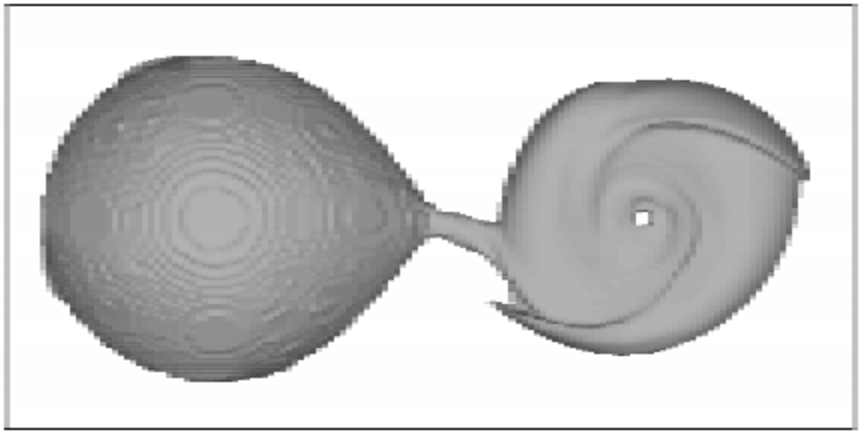
Collision of two supersonic flows (clusters of galaxies)

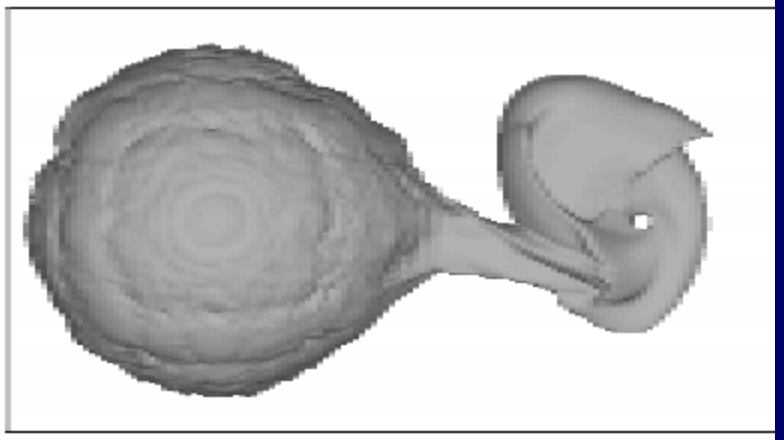


2D Matsuda et al. 2000



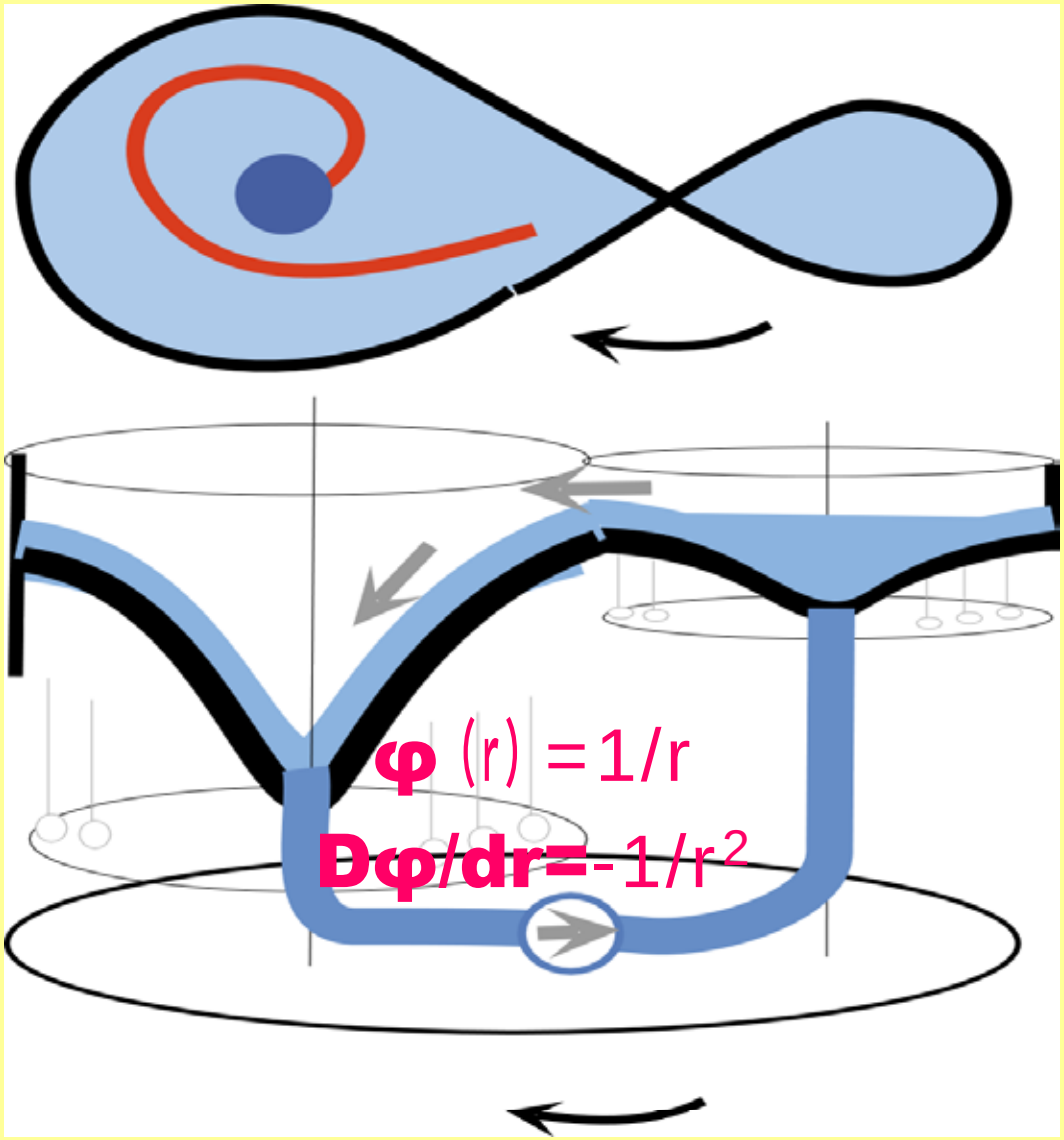






Binary accretion onto BH

$\varphi(r) = 1/r$



Accretion onto BH $\varphi(r) = 1/r$

gravity $= d\varphi(r)/dr = -GM/r^2$

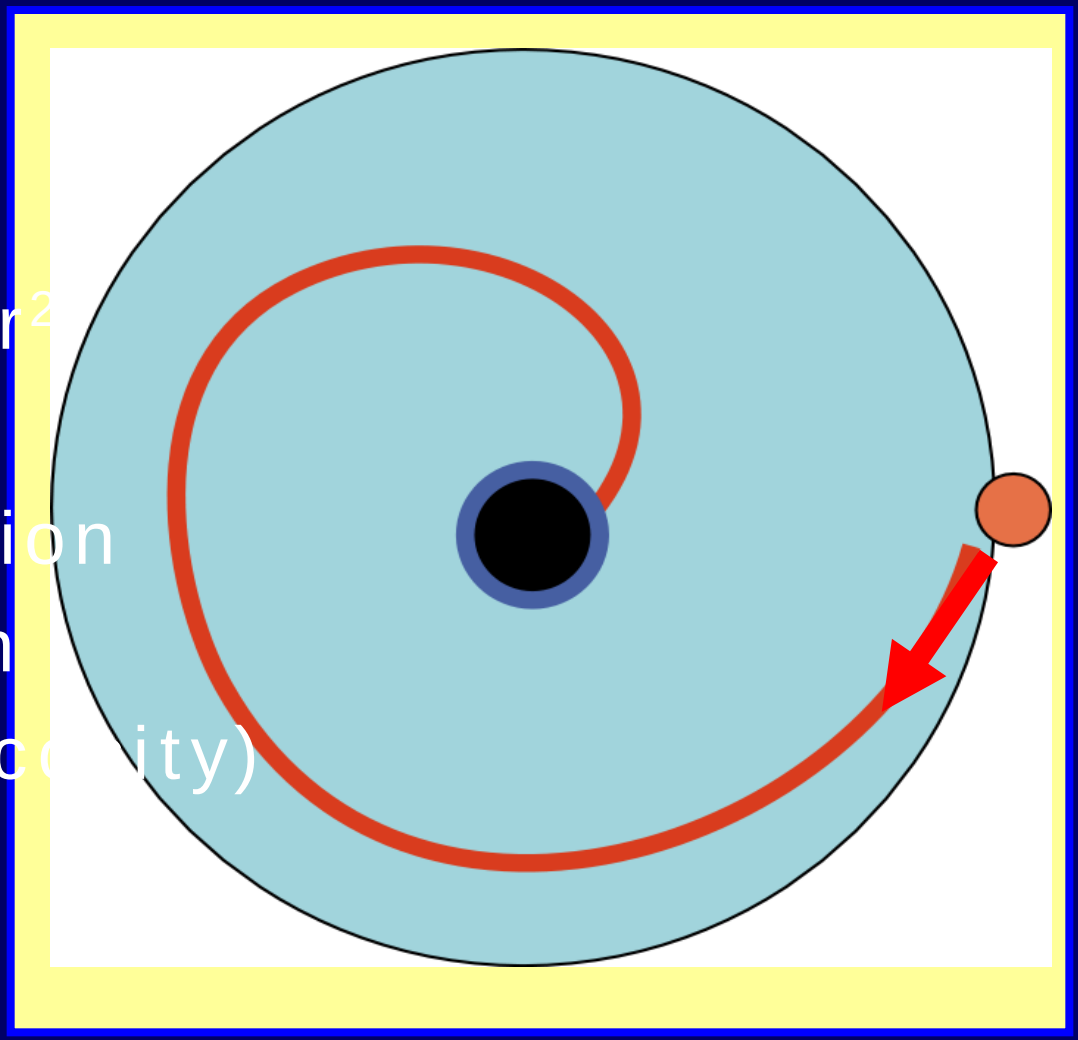
$\varphi(r) = GM/r$

$d\varphi/dr = -GM/r^2$

Kepler motion

+ Accretion

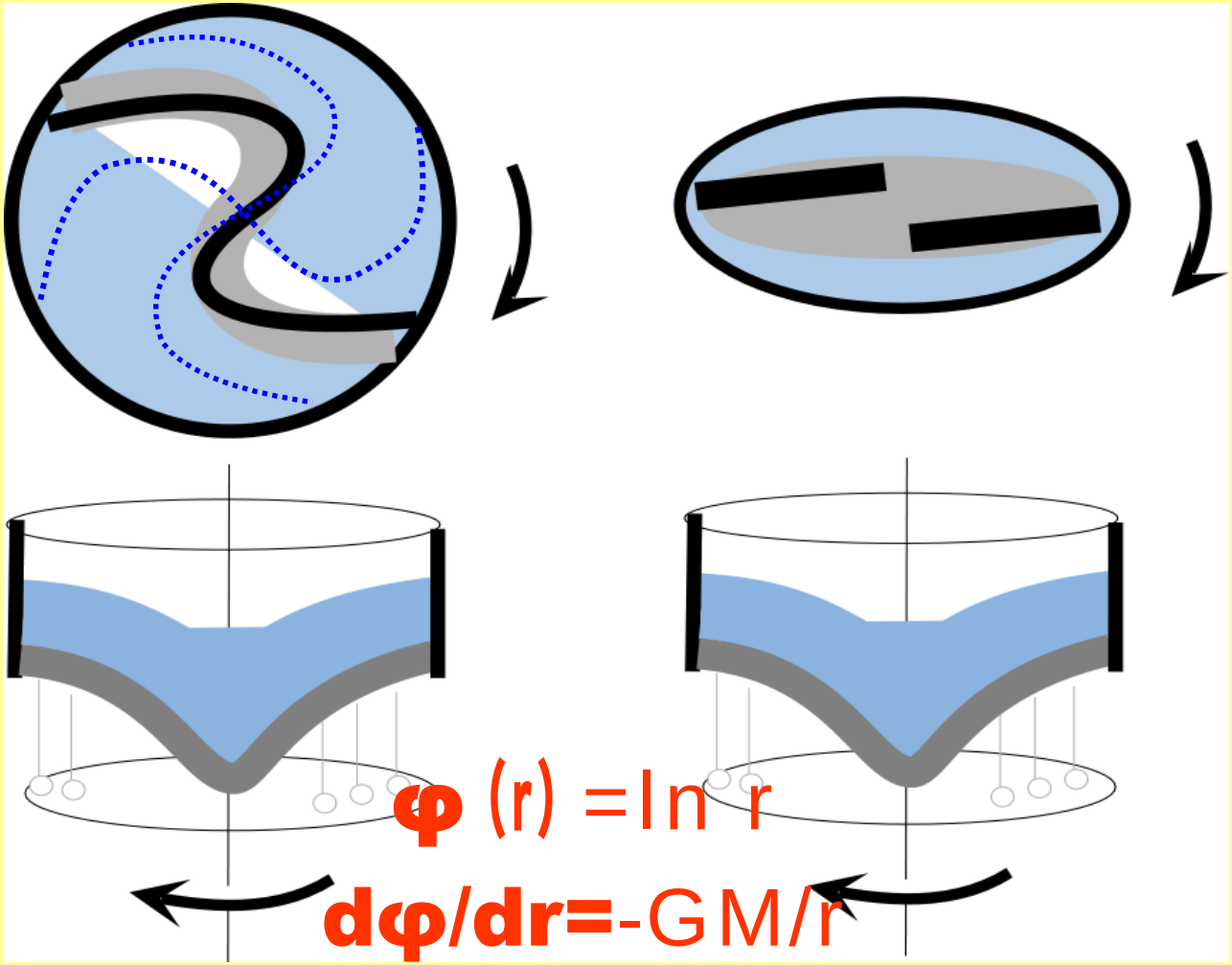
(shock, viscosity)



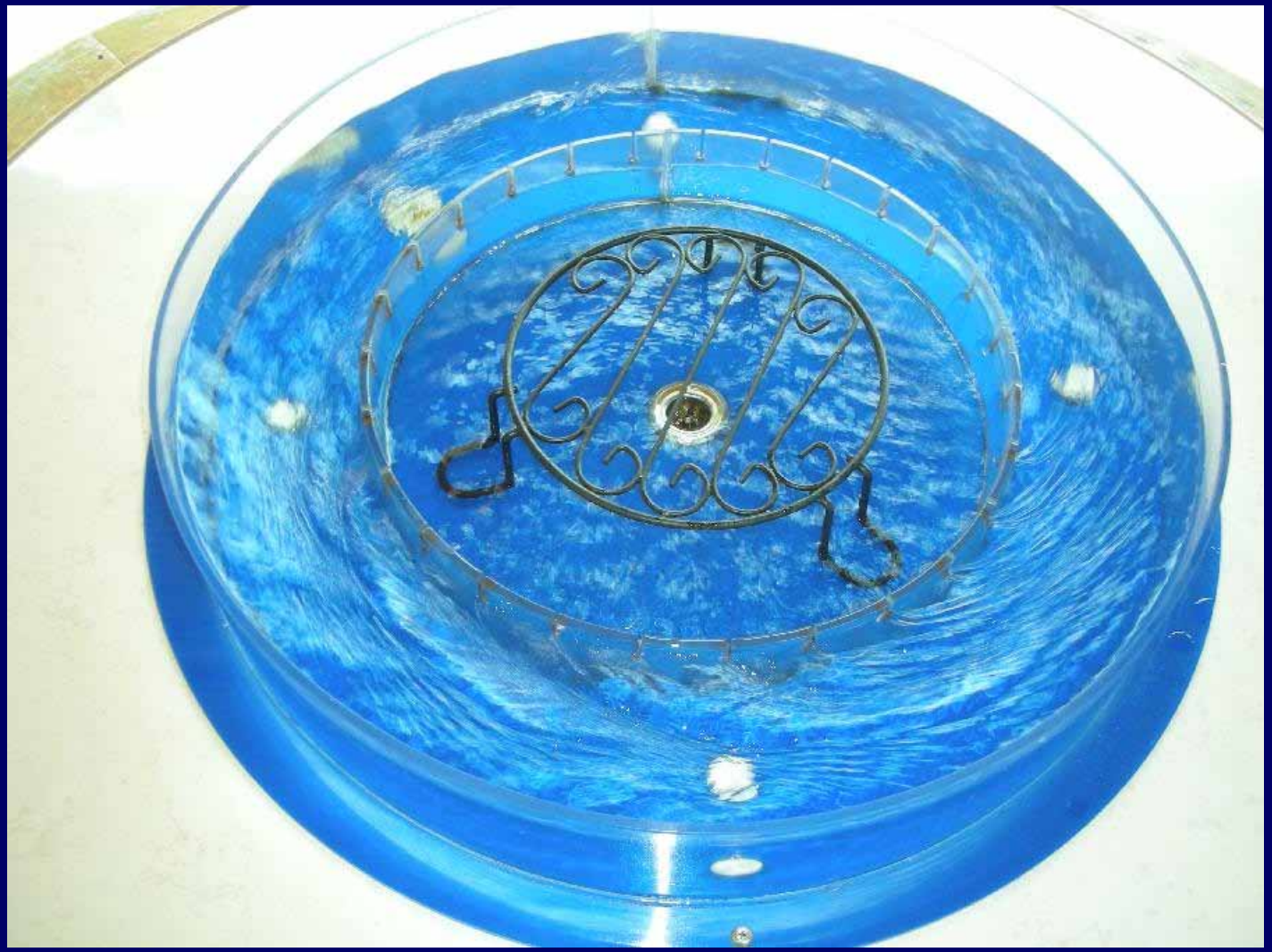
Galactic Shock
銀河衝撃波

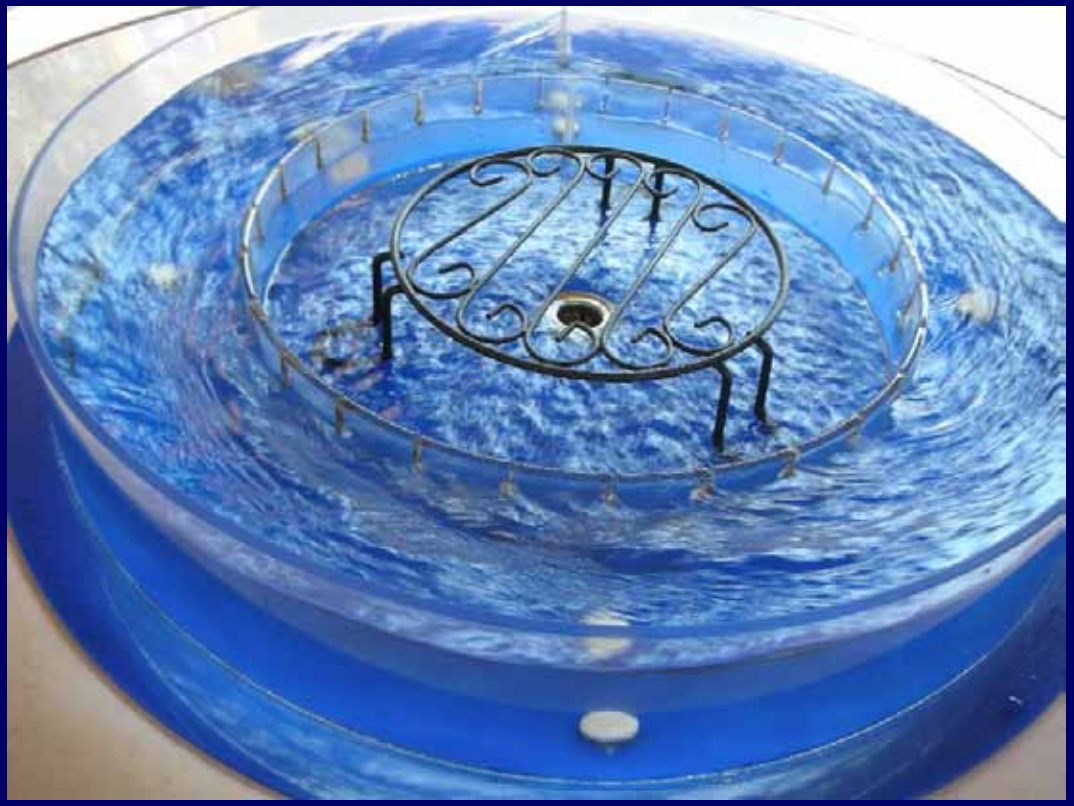
Spiral / Bar shocks

gvavity=g**+δg sin 2θ**

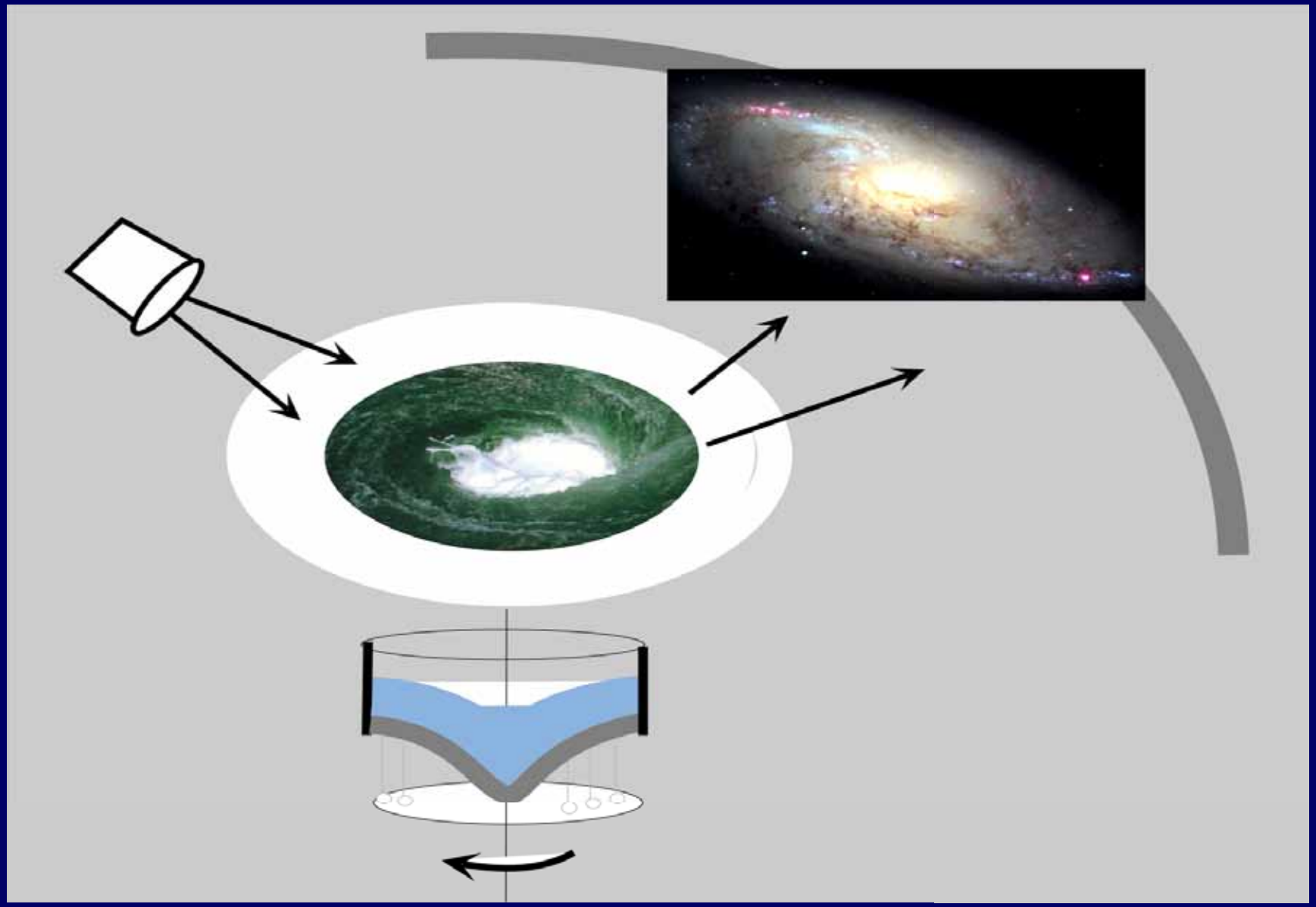


Vrot=const





Display



7.まとめ / Summary

銀河および宇宙流体における
波動･衝撃波現象の室内実験

LEC　Laboratory Experiment of Cosmic Hydrodynamics

銀河衝撃波 / Galactic spiral shock
連星、ブラックホール降着 / Binary/Blackhole Accretion
宇宙流体高次波動現象 / Higher-order waves
室内流体実験 / Laboratory hydrodynamical experiment
科学教育 / Education