GAS ACCRETION ONTO CIRCUM-PLANETARY DISKS

Tanigawa Takayuki
CPS / Hokkaido Univ.

Ohtsuki Keiji (CPS / Kobe Univ.)
Machida Masahiro (NAOJ)

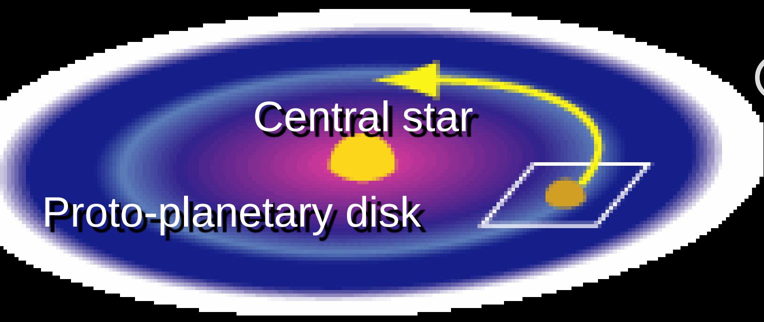
Satellites around Giant Planets

- Satellite systems commonly exist around giant planets
- Regular and irregular satellites
  - Regular satellites:
    - Most fraction of total satellite mass
    - Nearly coplanar and circular orbits
    - → Indicates formation in circum-planetary disks

Jupiter and Galilean satellites

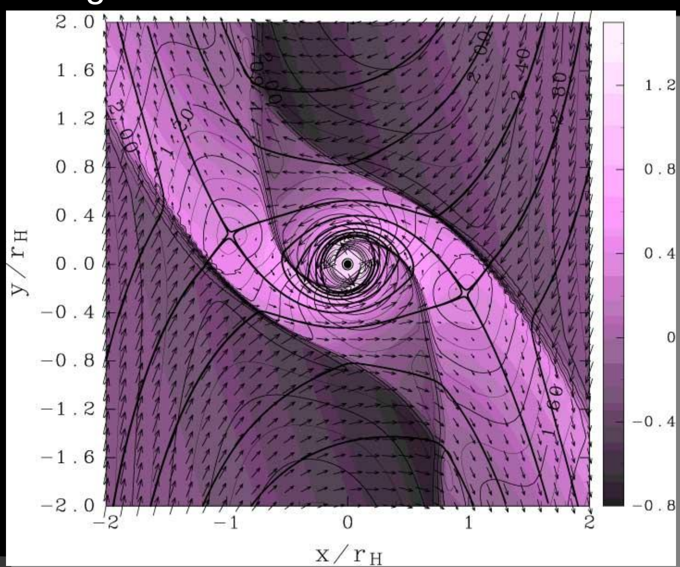
Satellites of outer planets

Formation of giant planets and the circum-planetary disks

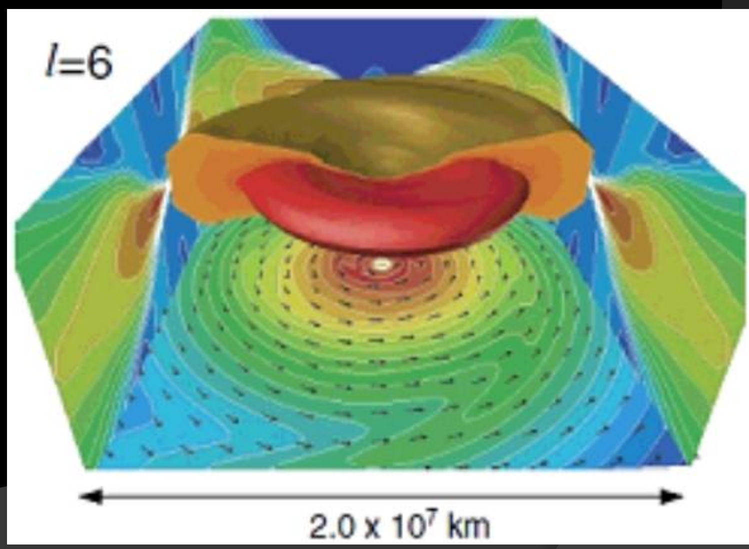


- Circum-planetary disks are natural by-products of giant planet formation

Tanigawa and Watanabe 2002



Machida 2009



Solid material is also supplied for sure?

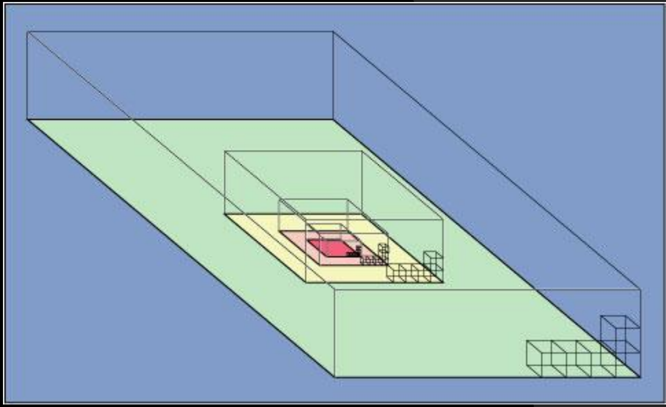
- Motion of solid material, which is the building material of satellites, is affected by gas
  - Larger size
    - Basically independent but weakly affected by gas drag.
  - Smaller size
    - Basically same motion with gas with slight deviation.

Purpose of this study

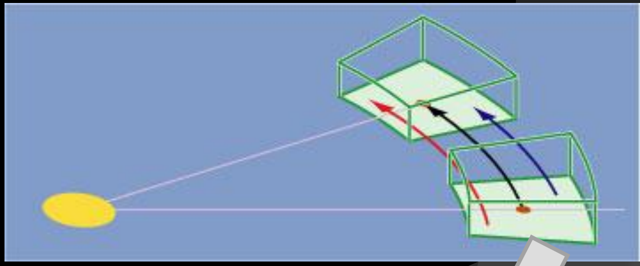
Analyze gas accretion flow and circum-planetary disk structure as a first step in order to understand how solid material, which builds satellites, is supplied to the circum-planetary disks

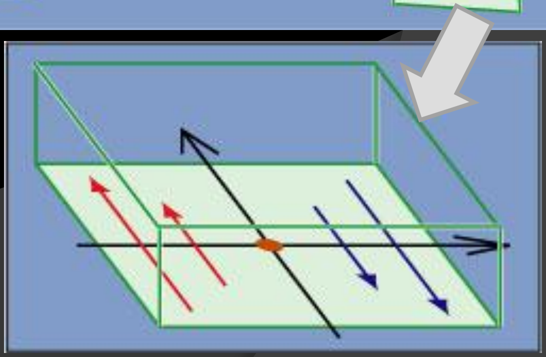
Numerical simulation

- 3D nested grid method
  - Computational domain 24*h* x 24*h* x 6*h*
    - (*h* is scale height)
  - Mesh : (64 x 64 x 16) x 11 levels
    - Effective mesh number : 65536 x 65536 x 16384
    - Minimum mesh size 0.00037*h*
      - About 1/4 of the present Jupiter radius at 5AU

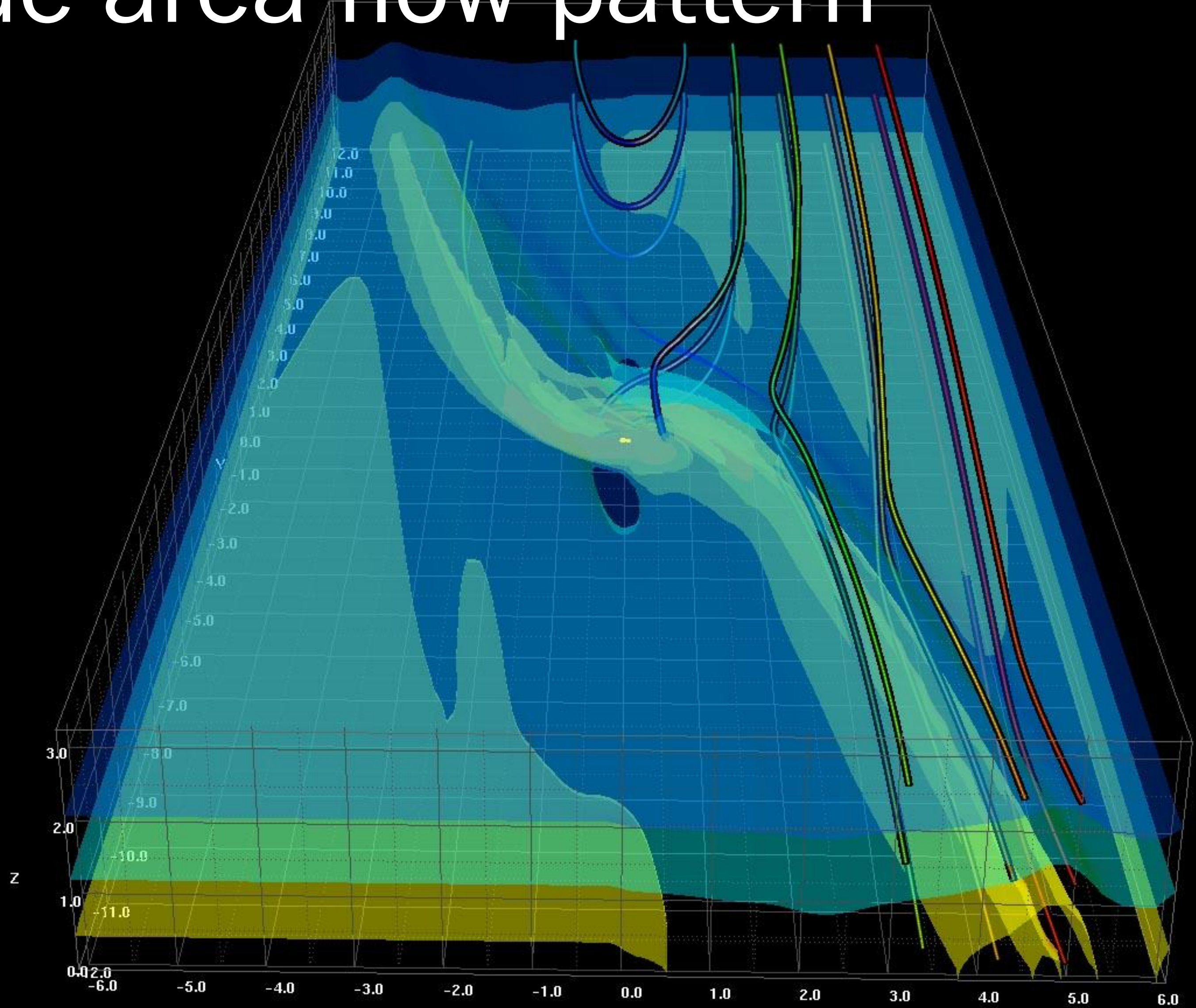


- Local co-rotating frame
- Isothermal and inviscid gas
- Treatment around the planet
  - Typical smoothing length : 0.0007*h*
  - Removes gas at the planet position



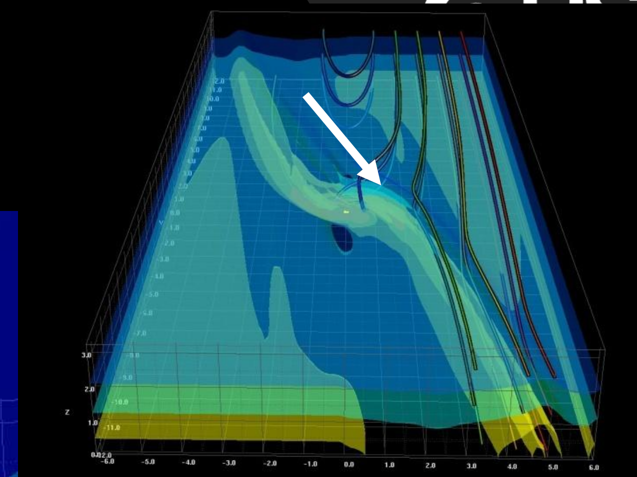


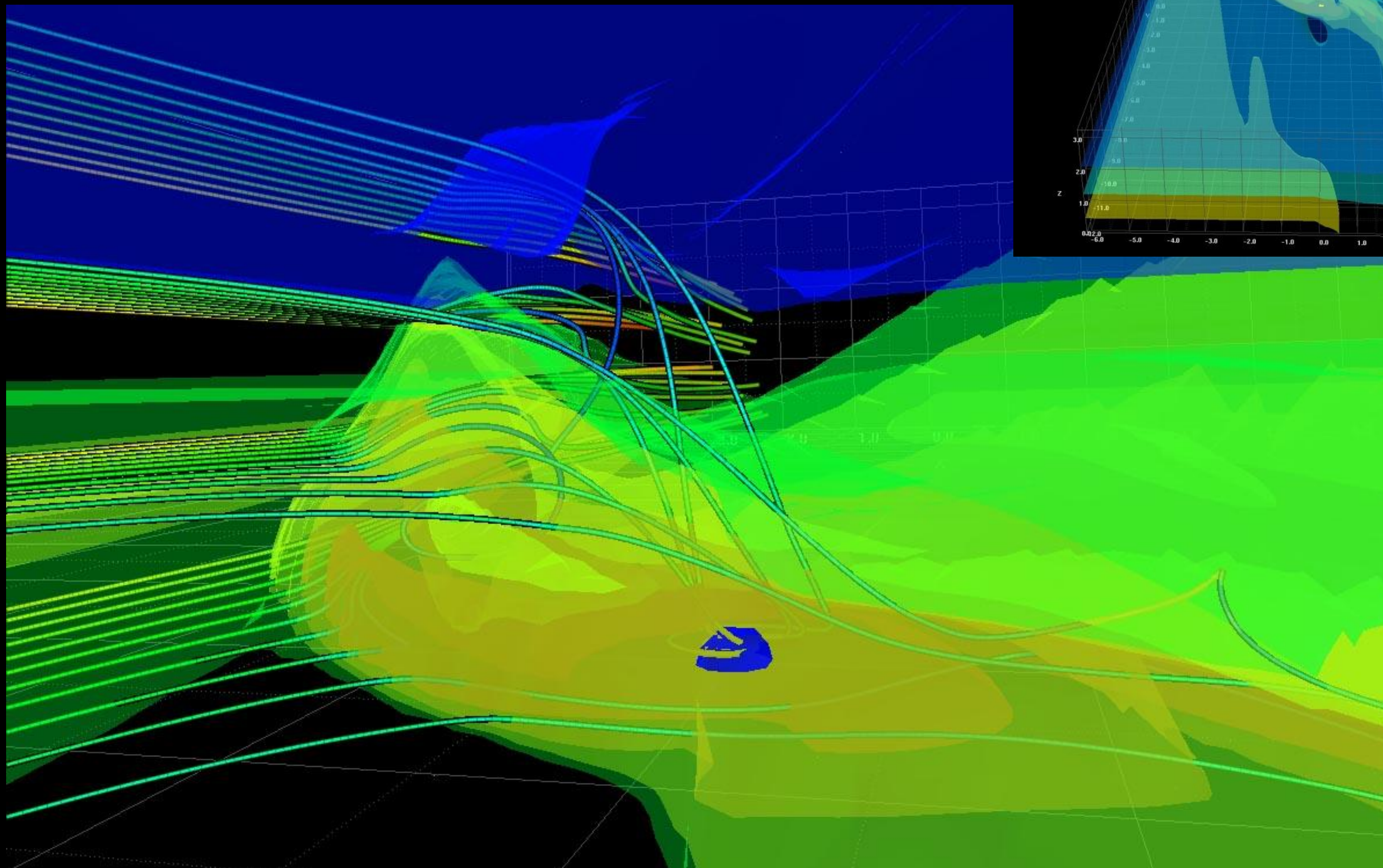
Wide area flow pattern



2D-like flow for outside of the Hill sphere

Close up to the Hill sphere



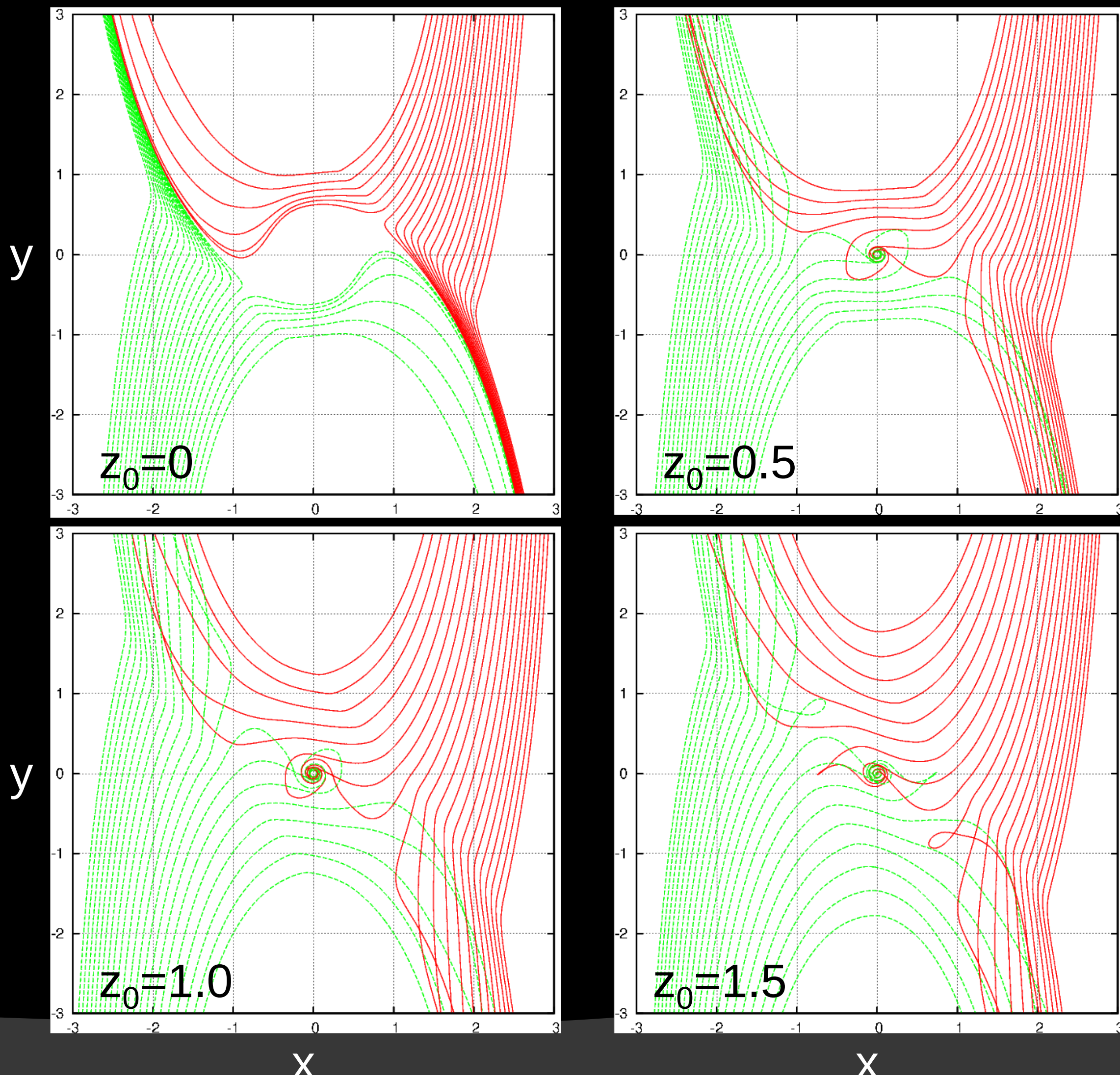


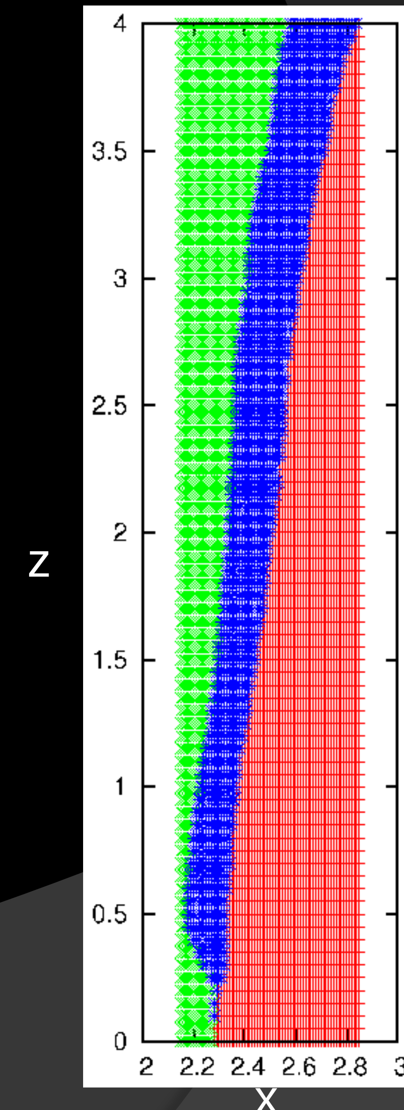
The outer shock disturbs the laminar flow

Upper gas falls to the mid-plane after the shock

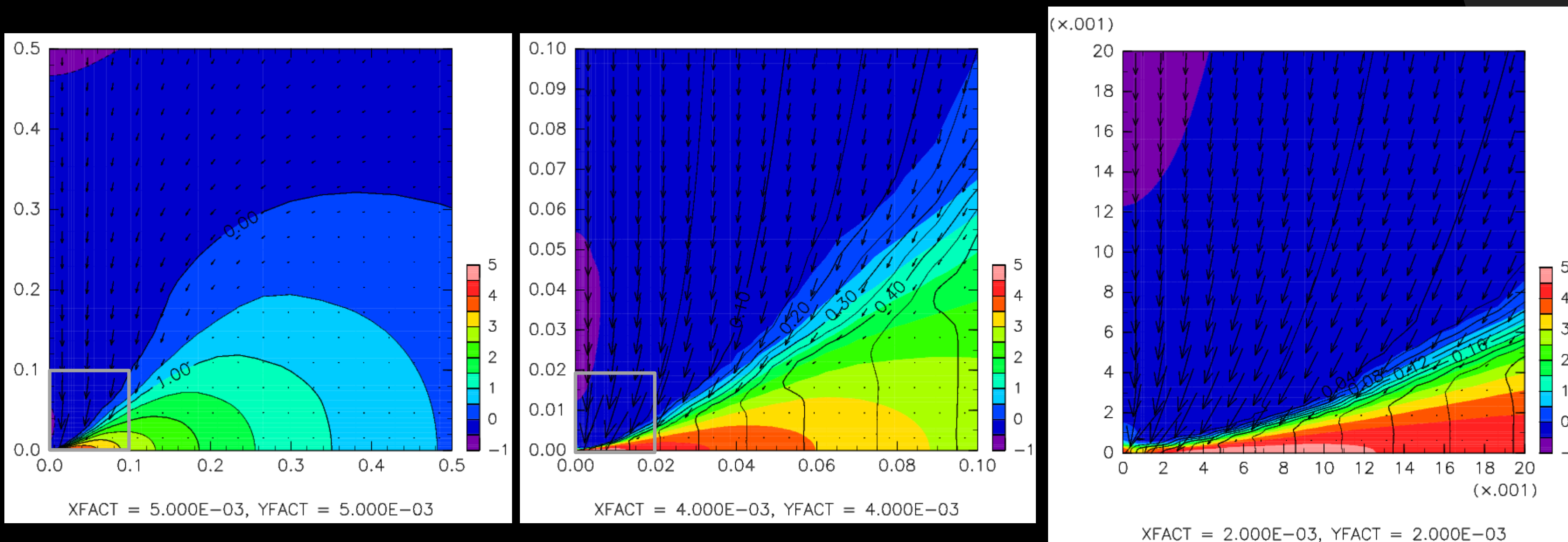
Streamlines for Gas Approaching to the Planet

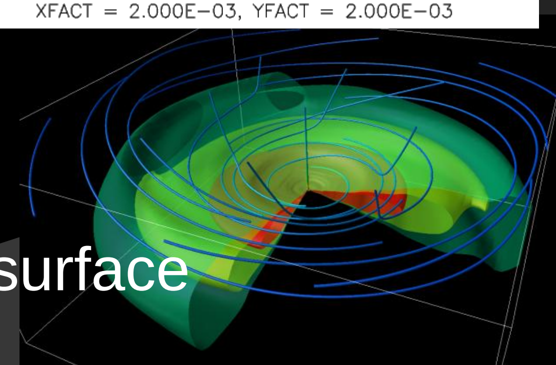
Passing
Accretion
U-tern





Disk structure (azimuthal average)





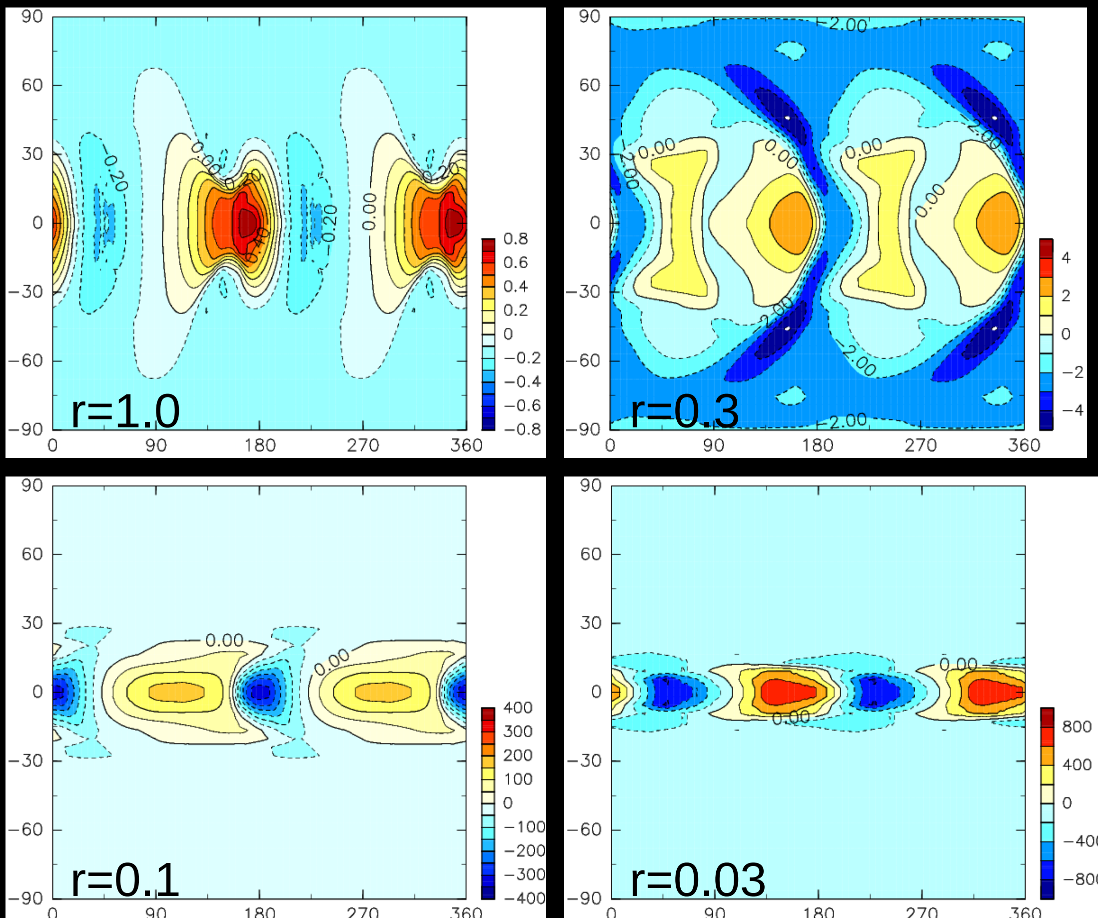
- Clear disk structure
- Thinner in inner region
- Large downward velocity above the disk surface

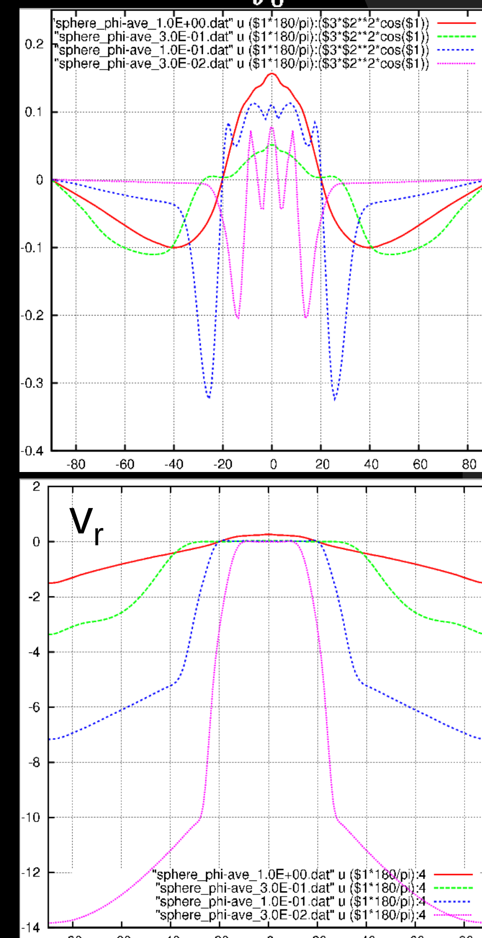
Analysis of the accreting direction

Center for Planetary Science

Mass Flux through spheres

$$r^2 \cos\theta \int_0^{2\pi} \rho v_r d\phi$$





- Midplane: Both of inward and outward stream
- High elevation angle: Only inward flow

- Midplane: Outward net flux
- Almost free fall velocity from high elevation angle gas

Discussion

Constant along stream lines except at the shock surfaces

= Tidal potential
+ Planet gravitational potential

Bernoulli integral

= Kinetic Energy + Enthalpy + Potential Energy

Accretion needs large energy dissipation, i.e., strong shocks

⇒ Needs large kinetic energy

In hydrostatic equilibrium : Enthalpy + Tidal potential = Const. (in z-direction)

～ Thermal energy ⇒ Not enough to form strong shocks

⇒ Planet gravitational energy is necessary

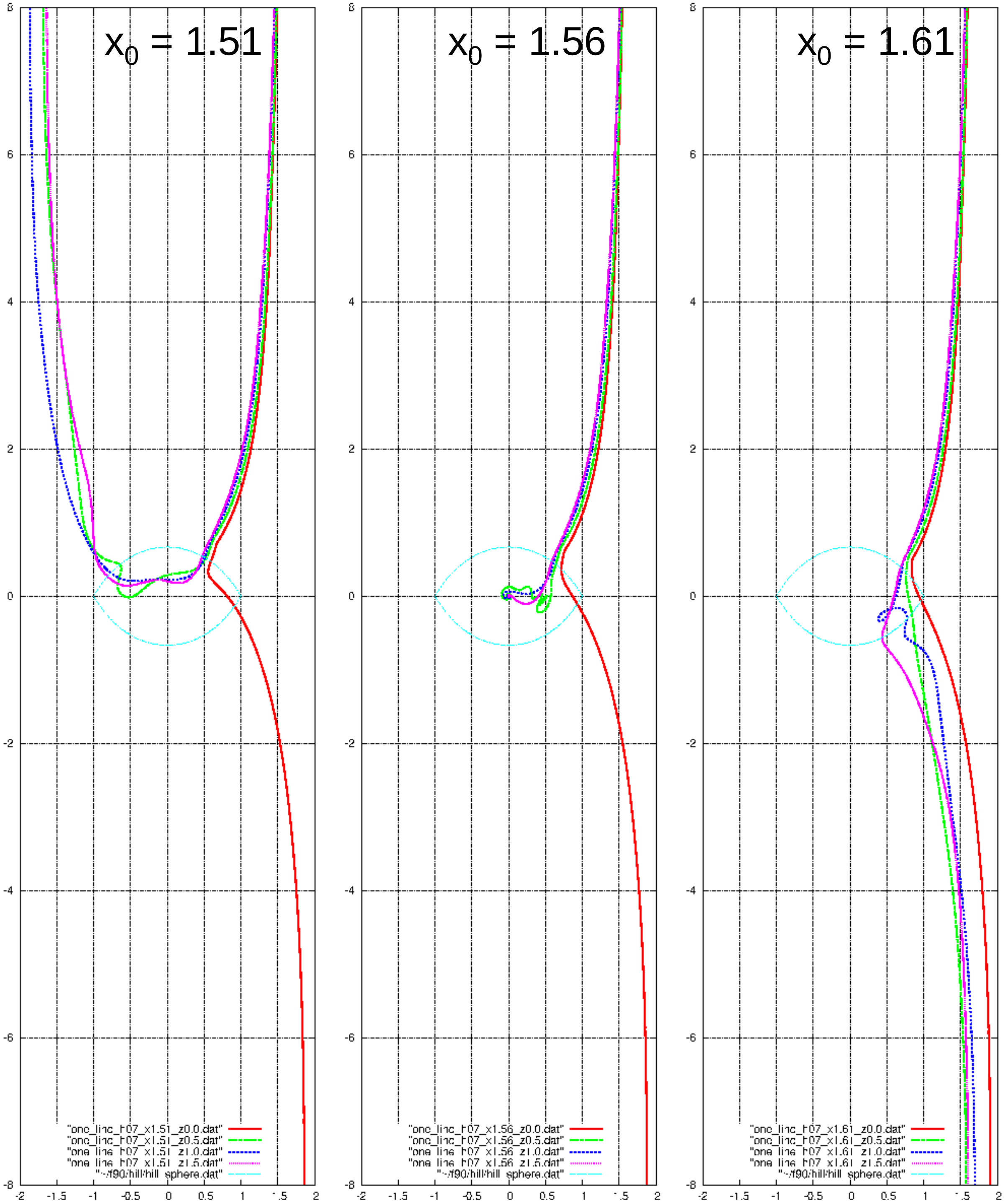
Gas near the mid-plane : high-density region, i.e., circum-planetary disks

→ Planet gravitational energy is consumed to enhance enthalpy.

→ Difficult to have large kinetic energy.

Upper gas : Jump over the high density region (circum-planetary disks) and the potential energy can be used to enhance kinetic energy

→ Possible only for the gas falling directly to the disk surfaces at the vicinity of the planet.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"one_line_h07_x1.61_z1.5.dat"
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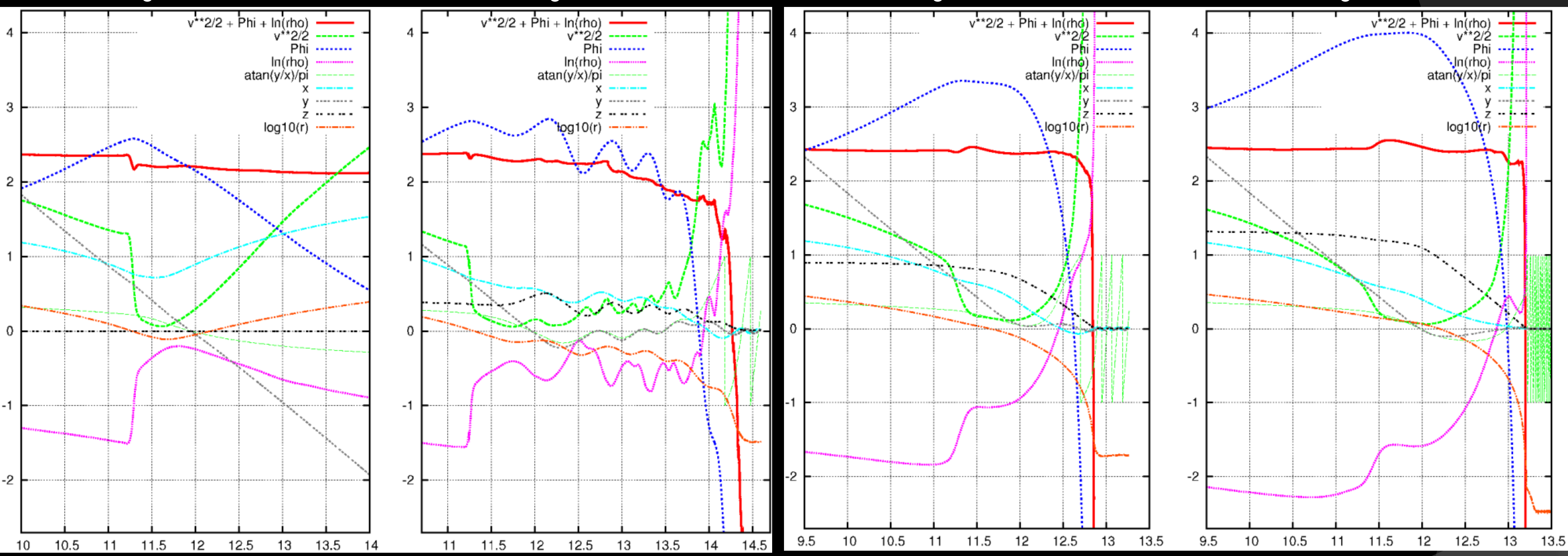
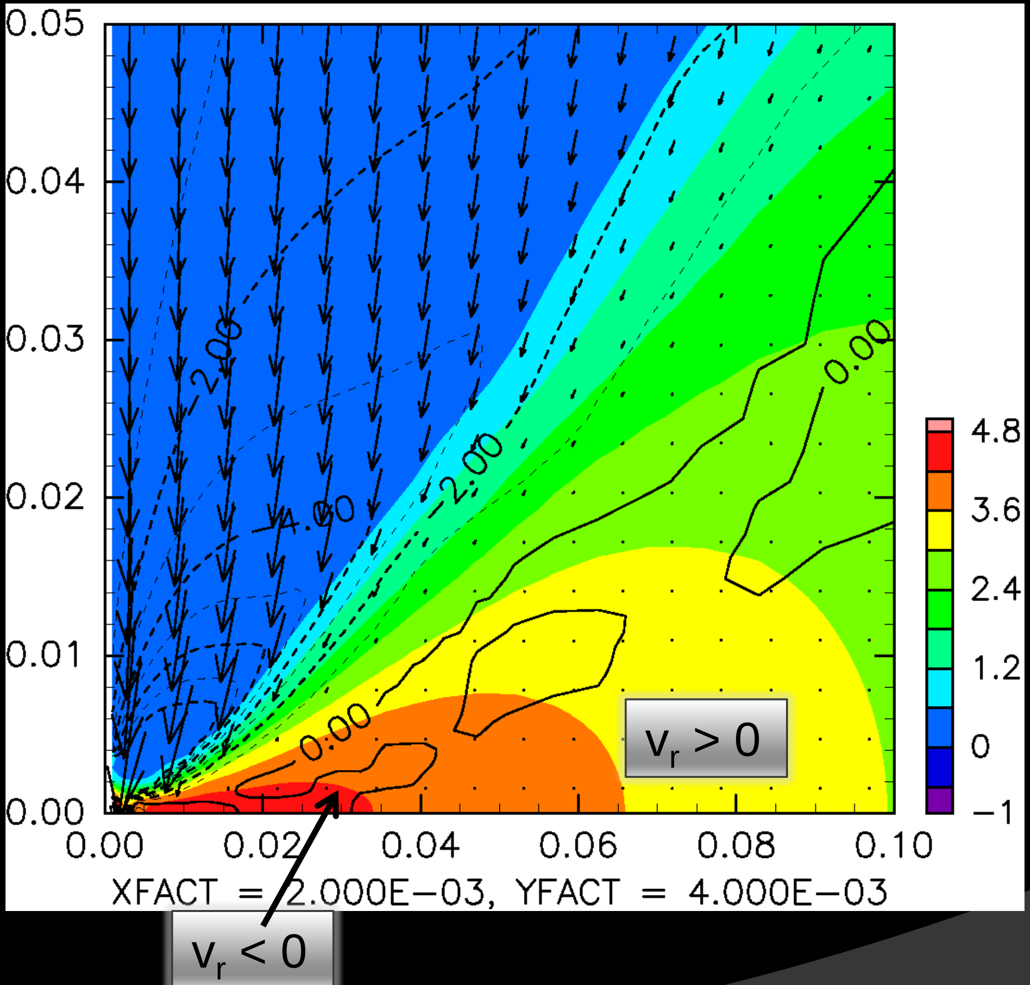
Streamlines inside the accretion band（$x_0 = 1.56$）

$z_0 = 0.0$ $z_0 = 0.5$ $z_0 = 1.0$ $z_0 = 1.5$



Large energy dissipation when the accreting gas hits onto the disk surface

Circum-planetary disk structure r-z plane (Φ-average)



Contours : v_r

Tone : $\log_{10}$(rho)

$v_r < 0$? at r < 0.03?

Summary

- Gas accretion flow structure to the giant planet
  - Jump over dense circum-planetary disks and directly into vicinity of planets, not through dense circum-planetary disks
    - → Well accelerated by planet gravity
    - → Effective energy dissipation through strong shocks
  - Difficult to accelerate near mid-plane because of dense circum-planetary disks
    - → Weak energy dissipation
    - → Not easy for accretion

- Application for planet and satellite formation
  - Gas near mid-plane is difficult for accretion
    - Sediment dust seems to be difficult to supply
      - Difficult to supply material for satellites?
      - Decreases dust/gas ratio of the parent bodies?
    - Very small dust is supplied to the vicinity of the planet
      - → Formation region of satellites?