FORMATION OF CIRCUMPLANETARY DISKS

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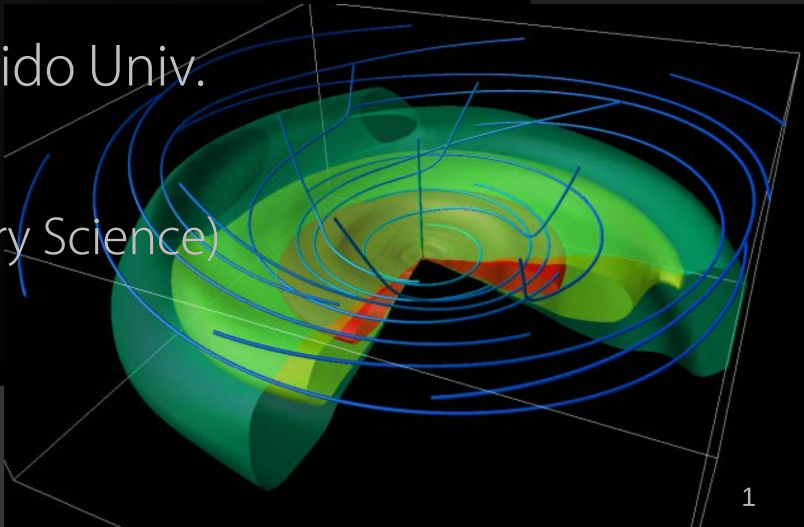


Tanigawa et al. 2012, ApJ, 747, 47

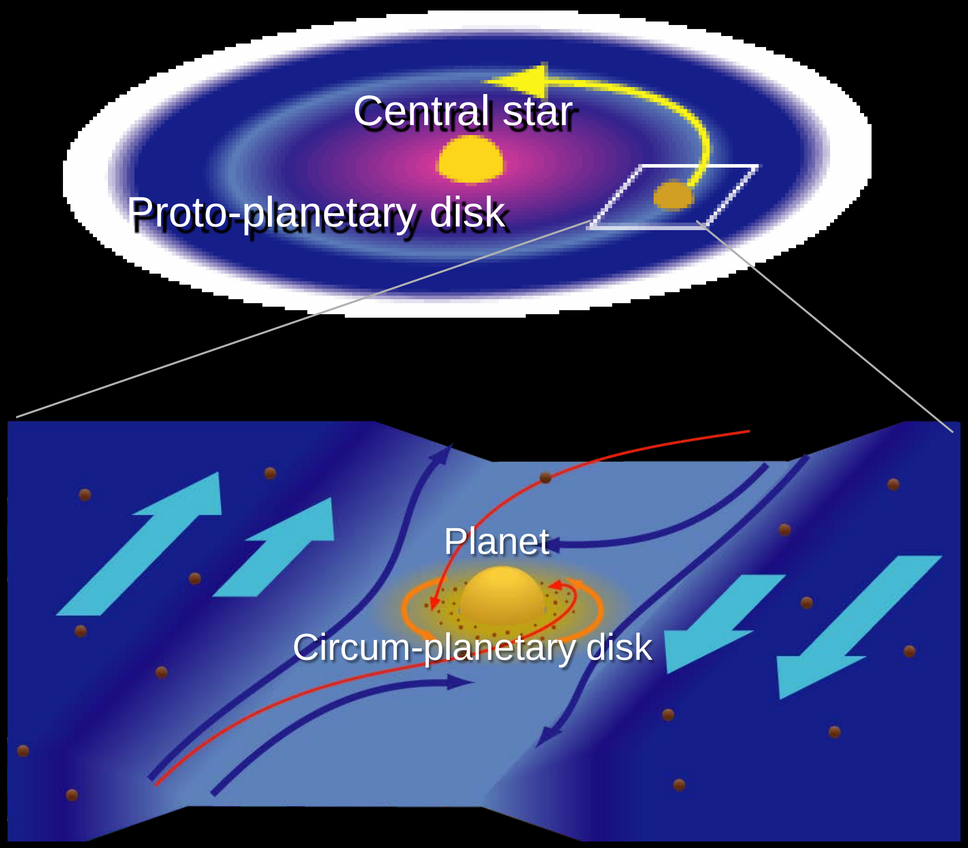
Satellites around Giant Planets

- 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 the outer planets

Regular satellites formed in circum-planetary disks



- Giant planet formation in proto-planetary disks
  - Gas accretion
  - → Circum-planetary disks
  - → Regular satellites

Jupiter and Galilean satellites

Disk structure?

Recent numerical simulations

- Insufficient resolution for satellite forming region
  - Require very high res. ($R_J \sim 1/10000\ a_J$)
- Not well analyzed

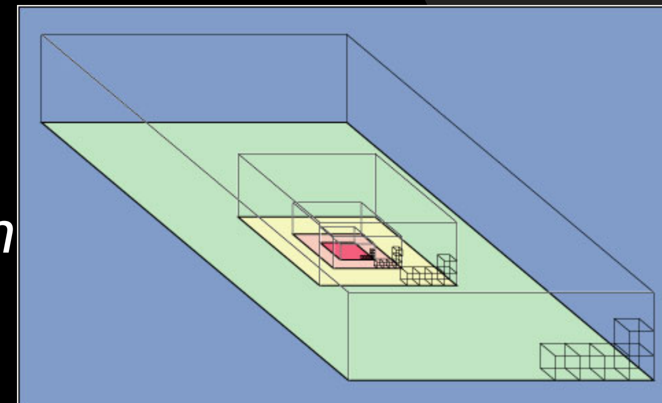
⇨ Difficult to understand satellite formation processes and the gas accretion mechanism

In this study

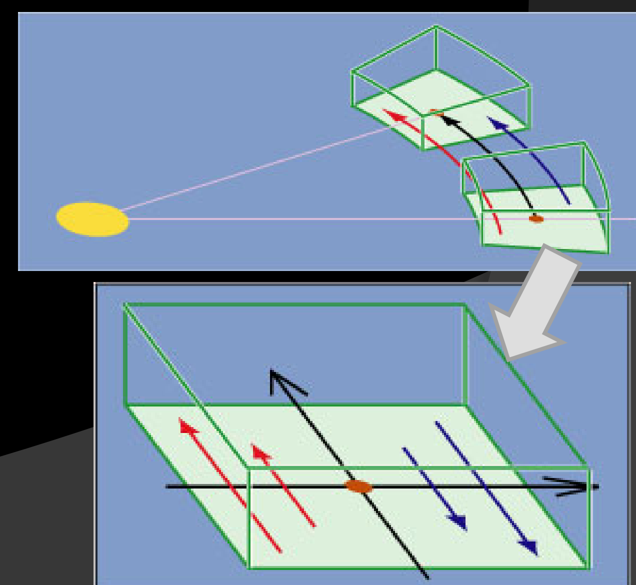
- Sufficiently high resolution for the satellite region
- In-depth analysis of the accretion flow

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)

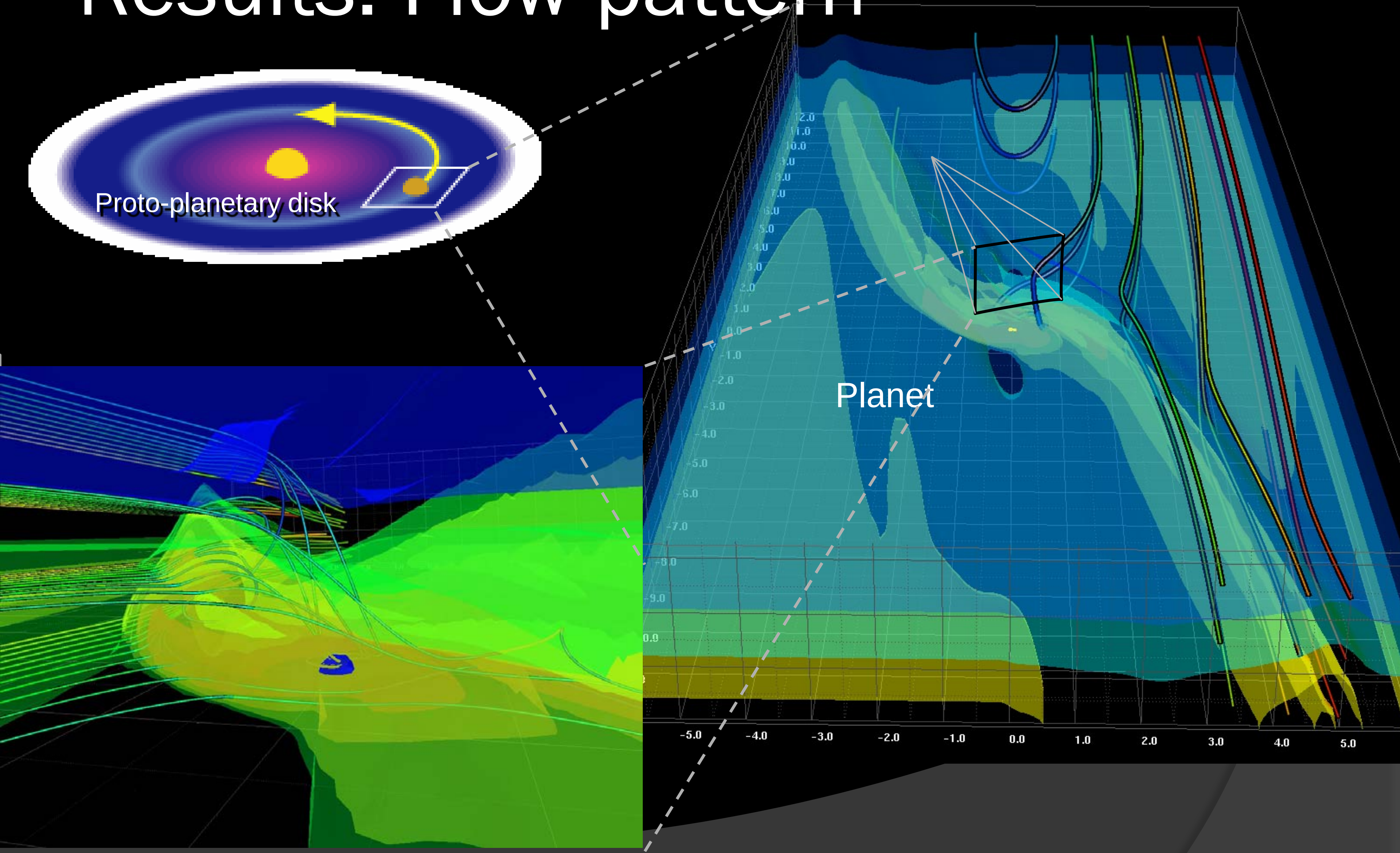


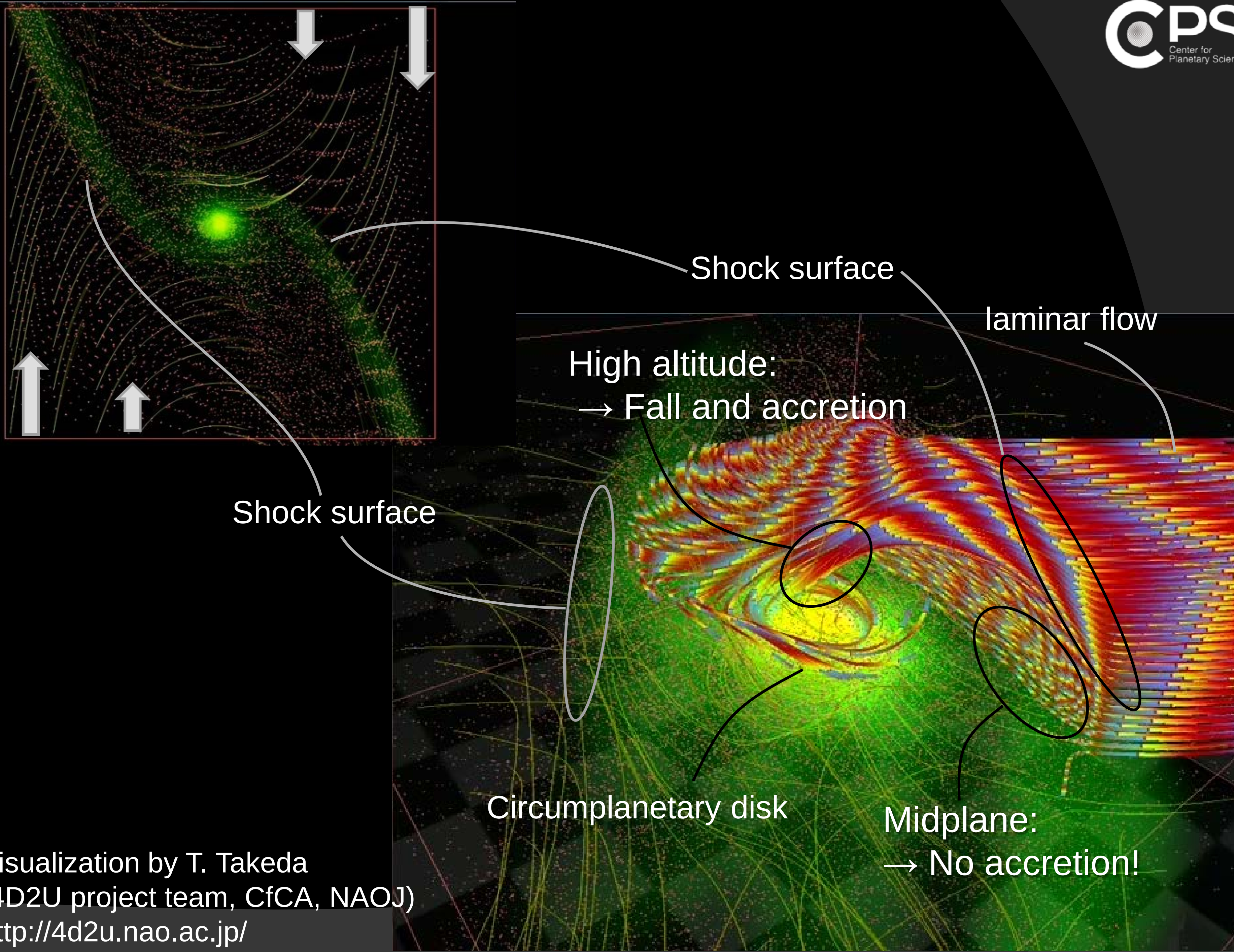
- Local co-rotating frame



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

Results: Flow pattern





Visualization by T. Takeda
(4D2U project team, CfCA, NAOJ)
http://4d2u.nao.ac.jp/

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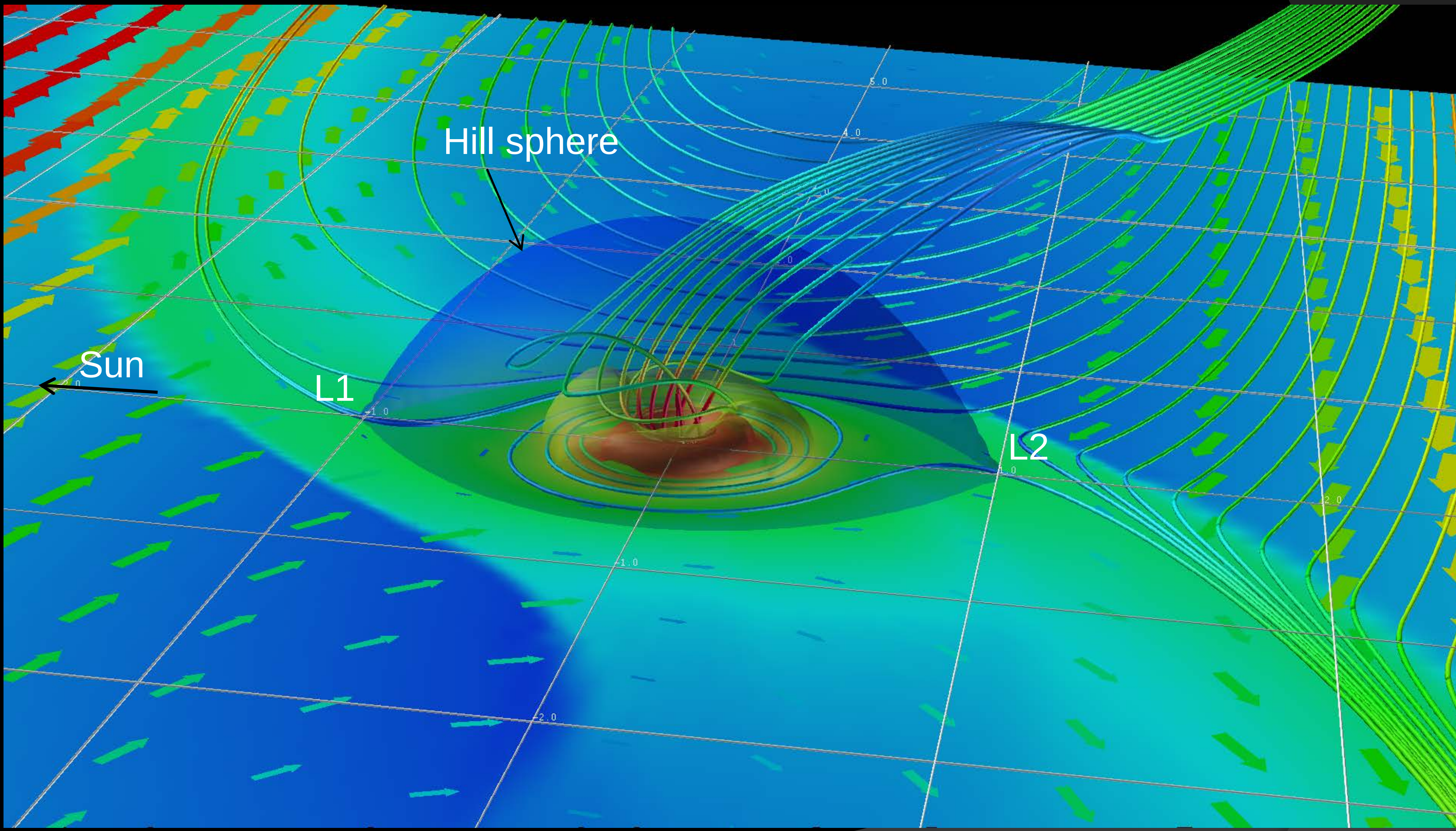
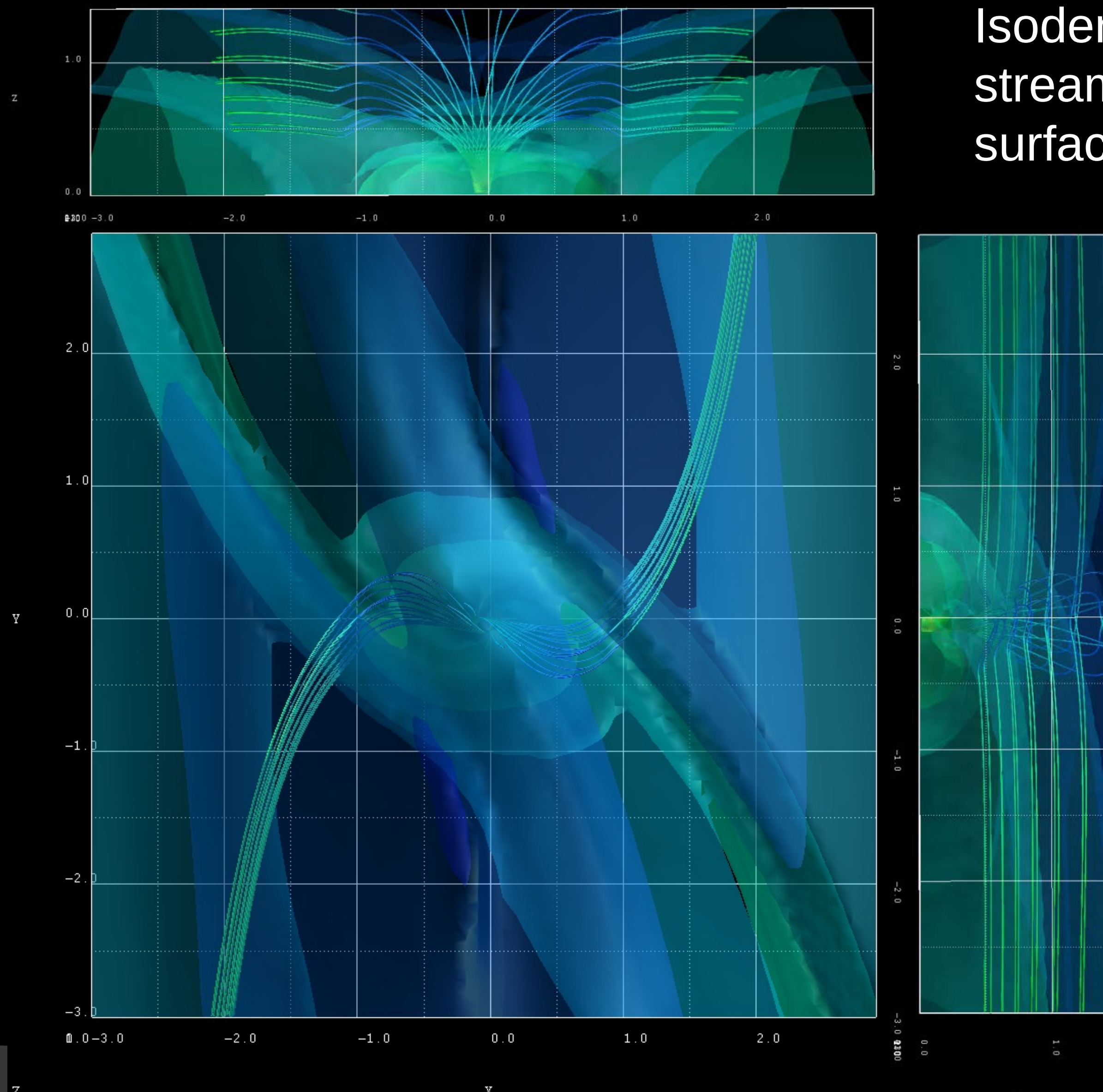


Accreting Gas

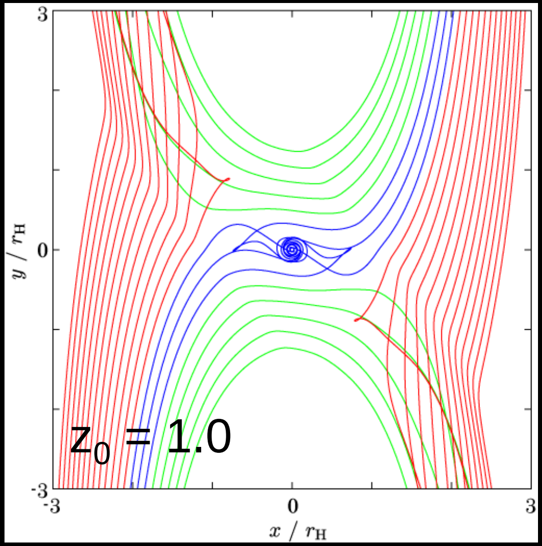


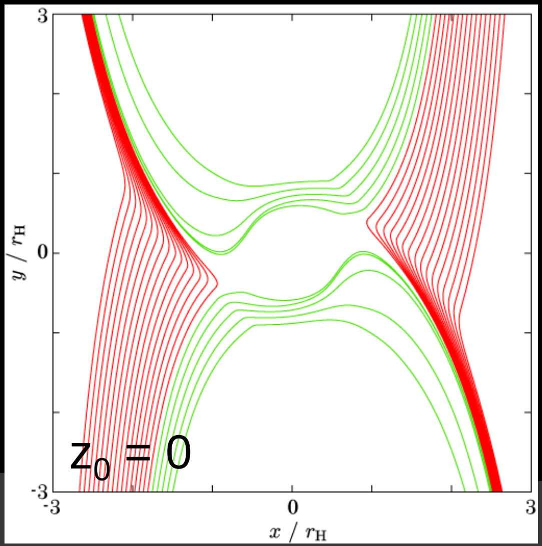
Isodensity surface and streamlines that reach the disk surface at r=0.05

Position of the upstream:

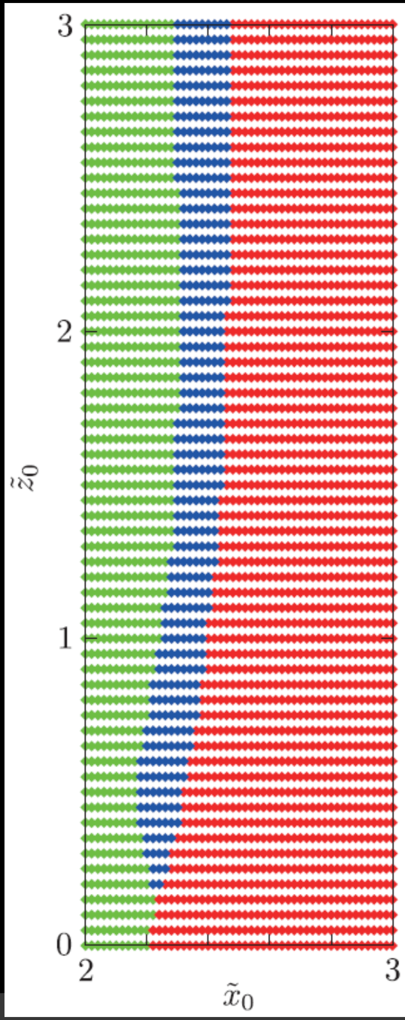
x: Narrow band around x~2
z: Wide distribution for z>0.5

Streamlines for Gas Approaching to the Planet

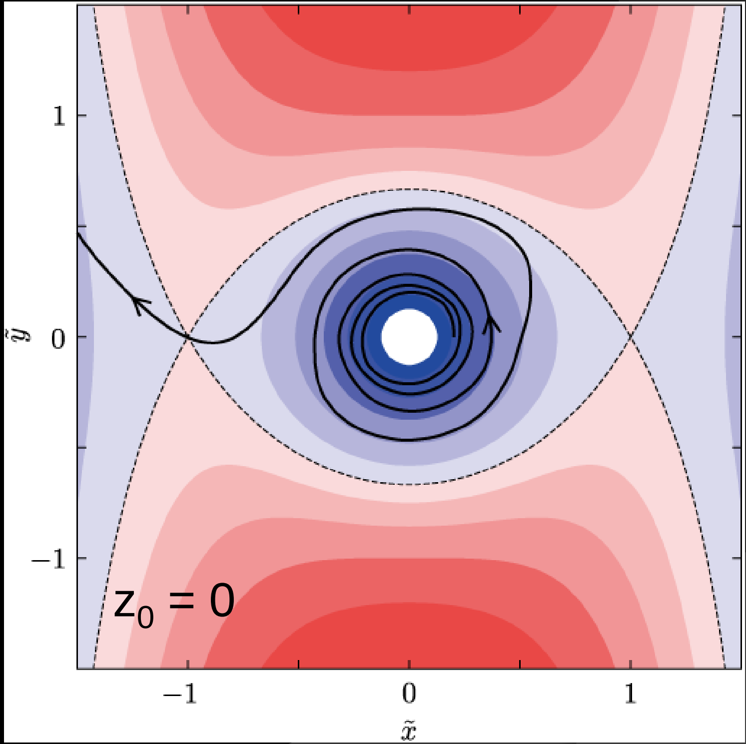




U-turn, Accretion, Pass



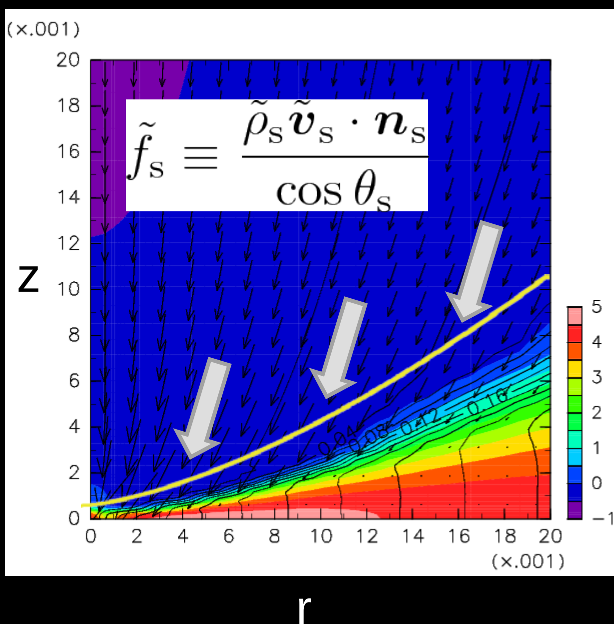
Streamline in the Hill sphere



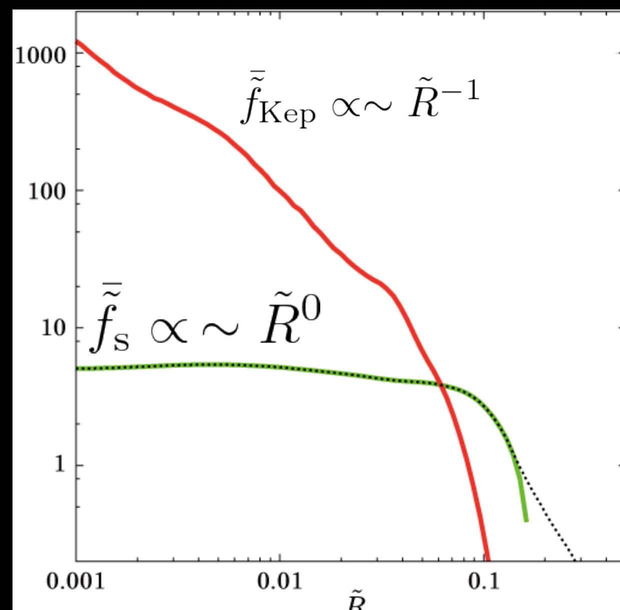
→ No accretion in the midplane.

Distribution of Mass and Angular Momentum Accretion

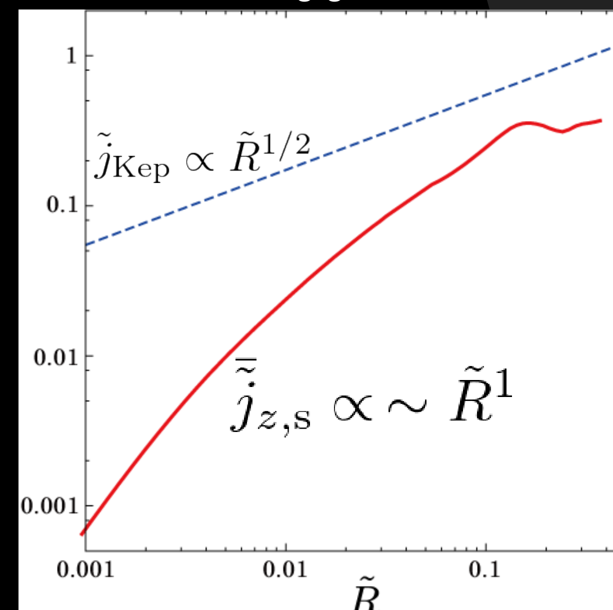
Azimuthally-averaged density and velocity



Accretion flux onto the disk surface



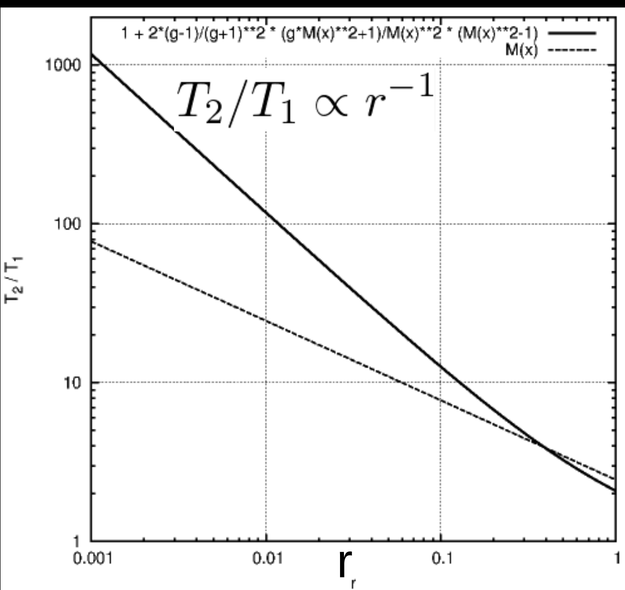
Mean specific angular momentum of the accreting gas

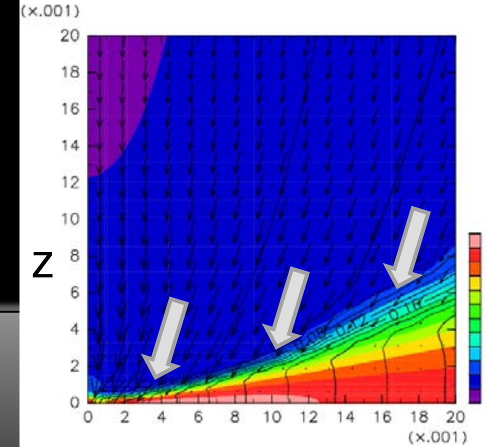


Distribution of mass and angular momentum accretion rates can be well described by power-law functions!

Temperature of the disk surface

$$\frac{\text{Post-shock temperature}}{\text{Pre-shock temperature}}$$





Pre-shock temperature

Rankine-Hugoniot relationship

$$\frac{T_2}{T_1} = 1 + \frac{2(\gamma - 1)}{(\gamma + 1)^2} \frac{\gamma M_1^2 + 1}{M_1^2} (M_1^2 - 1)$$

Free-fall velocity

$$M_1 \simeq \sqrt{6\tilde{r}_{\rm H}^3/\tilde{r}}$$

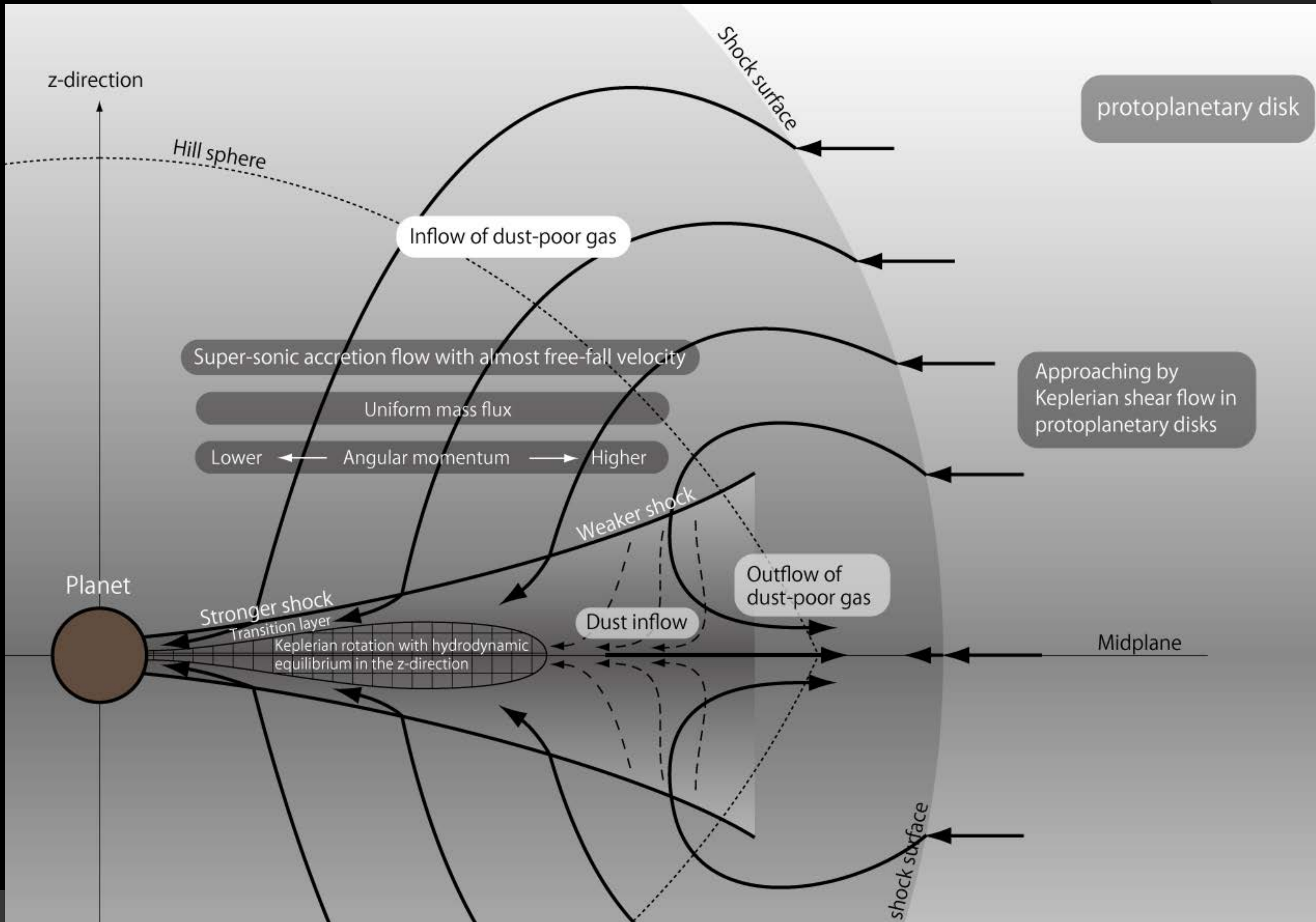
Ex. at r = 10R_J (~0.01r_H) → T_2/T_1 ~ 100

When T_1 = T_{neb} = 100K, T_2 ~ 10000K

Equilibrium temperature (blackbody)

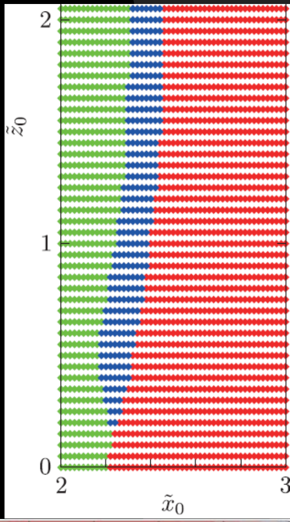
$$\frac{1}{2} v^2 f_{\rm s} = \sigma_{\rm SB} T^4 \longrightarrow T \simeq 1000 \left(\frac{r}{10 R_{\rm J}} \right)^{-1/4} \left(\frac{M_{\rm p}}{M_{\rm J}} \right)^{1/2} \left(\frac{a}{5{\rm AU}} \right)^{-3/4} \left(\frac{\alpha_{\rm dep}}{1} \right)^{-1/4} [K]$$

Discussion: Disk Structure

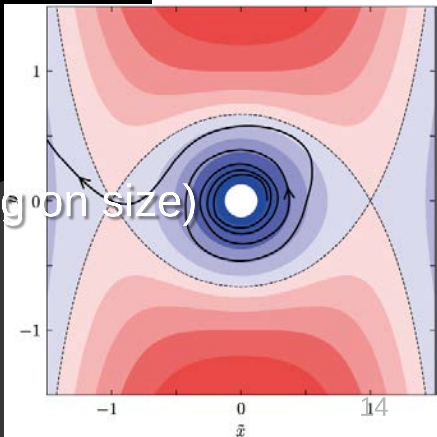


Applications

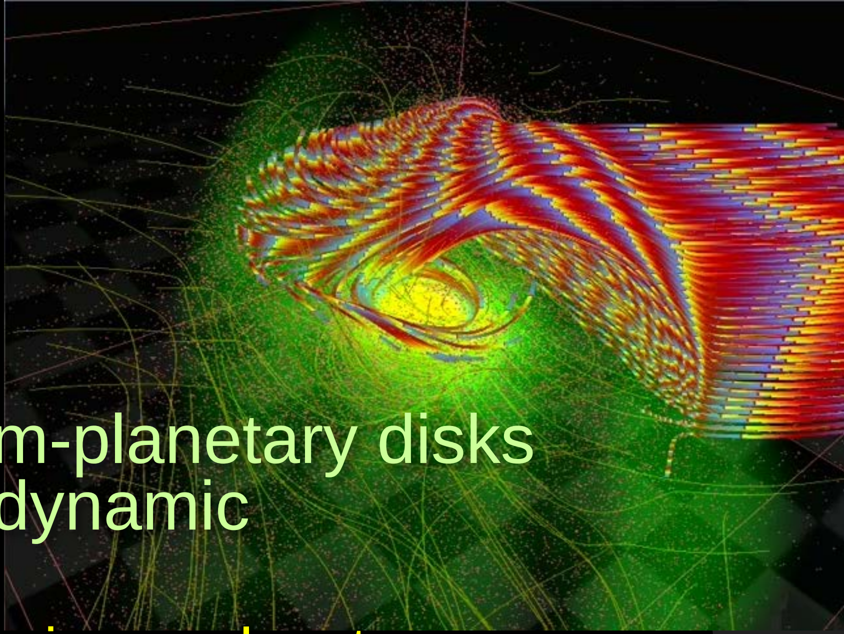
- Long-term evolution model of circum-planetary disks for satellite formation processes
  - ex. 1D viscous evolution model
    - viscosity and source term
      - Dust property → Ohmic resistivity → Viscous coefficient
        - Fujii et al. 2011, *ApJ in press* + Okuzumi and Hirose 2011, *ApJ in press.*
    - We now have the two ingredients to construct models!



- Heavy elements of Jupiter and Saturn
  - 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?
      - → Opposite sense??
      - → How about satellite material?
  - Gas in circumplanetary disk can escape from the Hill sphere
    - Solid materials do not necessarily escape together (depending on size)
      - Enhance dust/gas ratio?



Summary



- Gas accretion flow onto circum-planetary disks by very high-resolution hydrodynamic simulation.
  - Accreting gas jumps over dense circum-planetary disks and falls directly into the vicinity of planets.
    - → Well accelerated by planet gravity
    - → Effective energy dissipation through strong shocks
  - No accretion in the midplane and outflow from the Hill sphere
    - → Possible mechanism to change dust/gas ratio of circumplanetary disks and parent planets
  - Distribution of gas and angular momentum accretion
    - Well described by power-law functions
    - → 1D viscous disk evolution model