

Interaction of the Streaming Instability and the Large-scale Gas Dynamics

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Yang & Johansen, ApJ, in press

arXiv: 1407.5995

Ornithology of Planetesimals: Part I

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Large-scale Gas Dynamics

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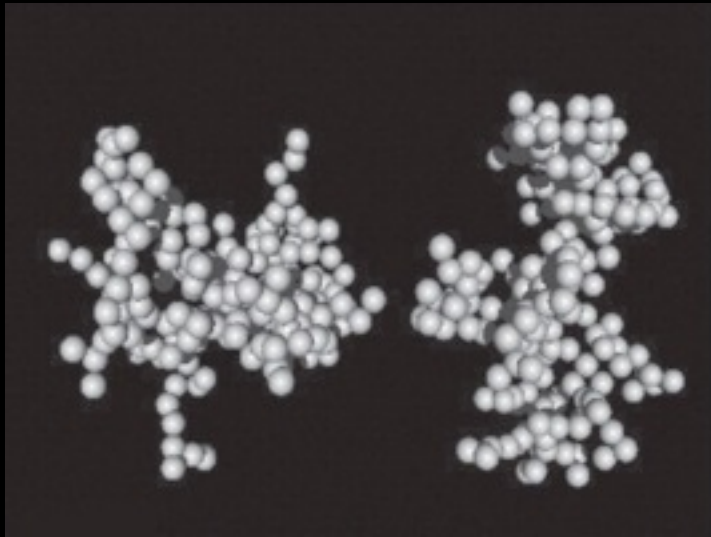
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Planet Formation

Core accretion

Dust Grains



$0.1-1\ \mu\text{m}$

Boulders



$0.1-1\ \text{m}$

Planetesimals



$0.1-100\ \text{km}$

Gravito-fragmentation



Protoplanetary Disk



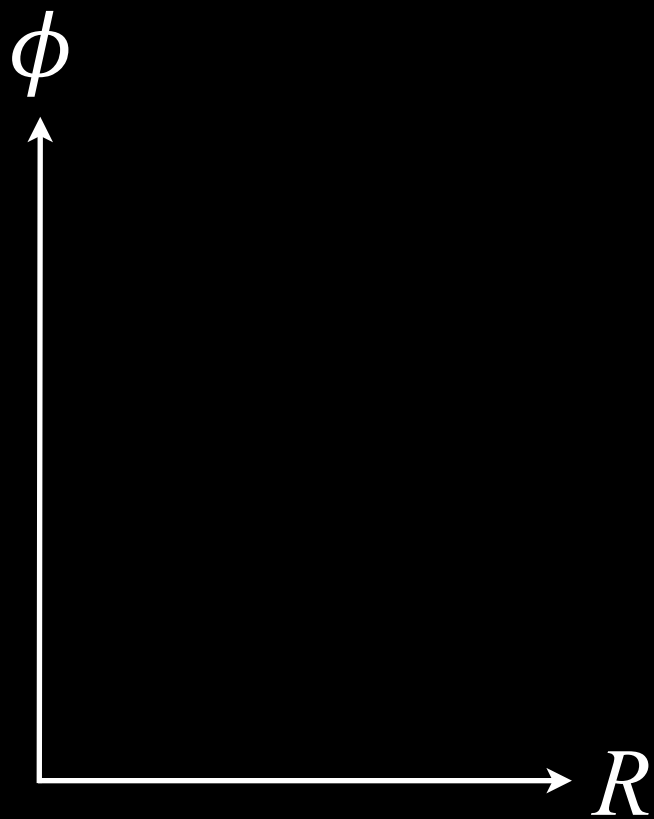
Gas Giants



Planetary Cores

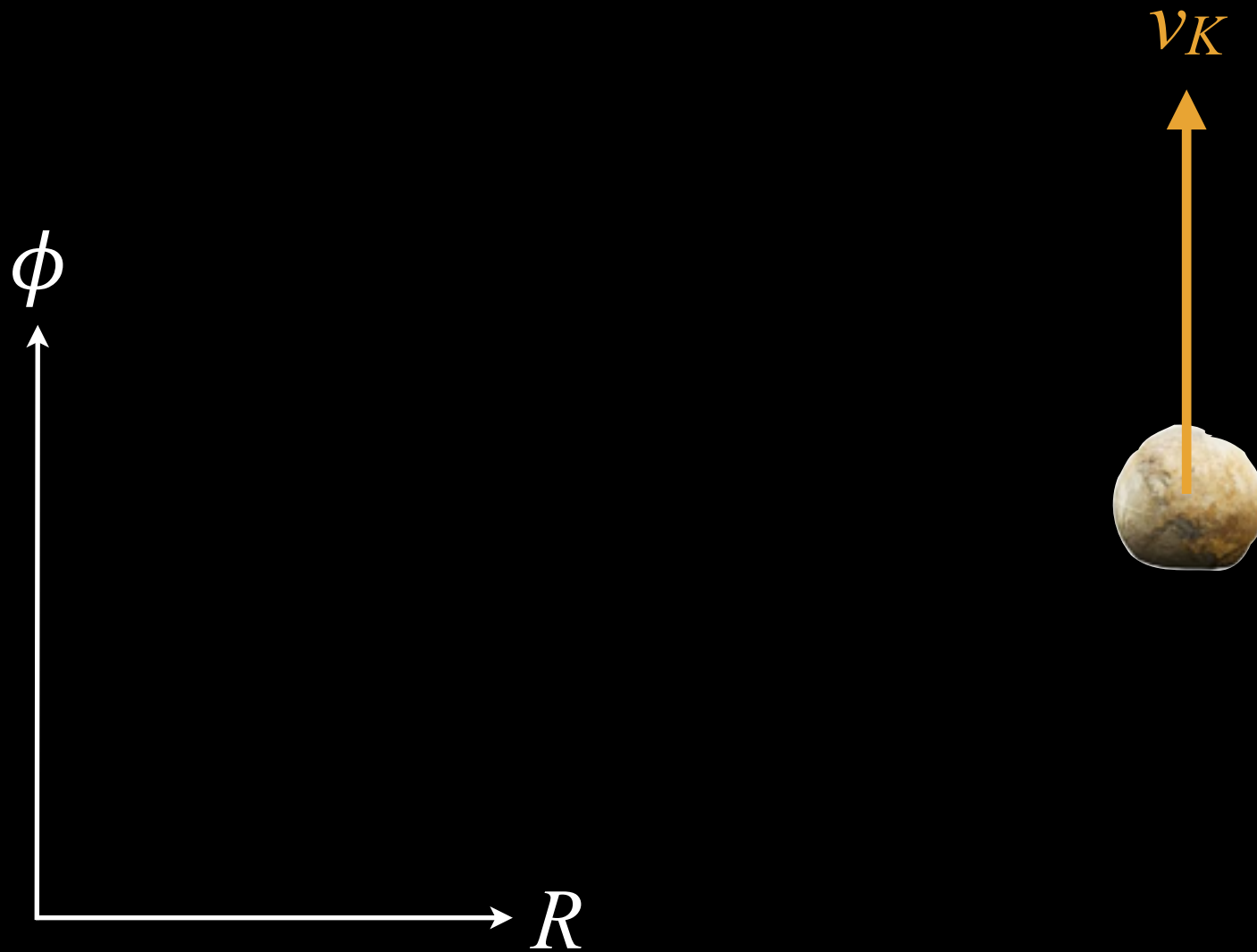
Meter-size Barrier

(Adachi, Hayashi, & Nakazawa 1976; Weidenschilling 1977)



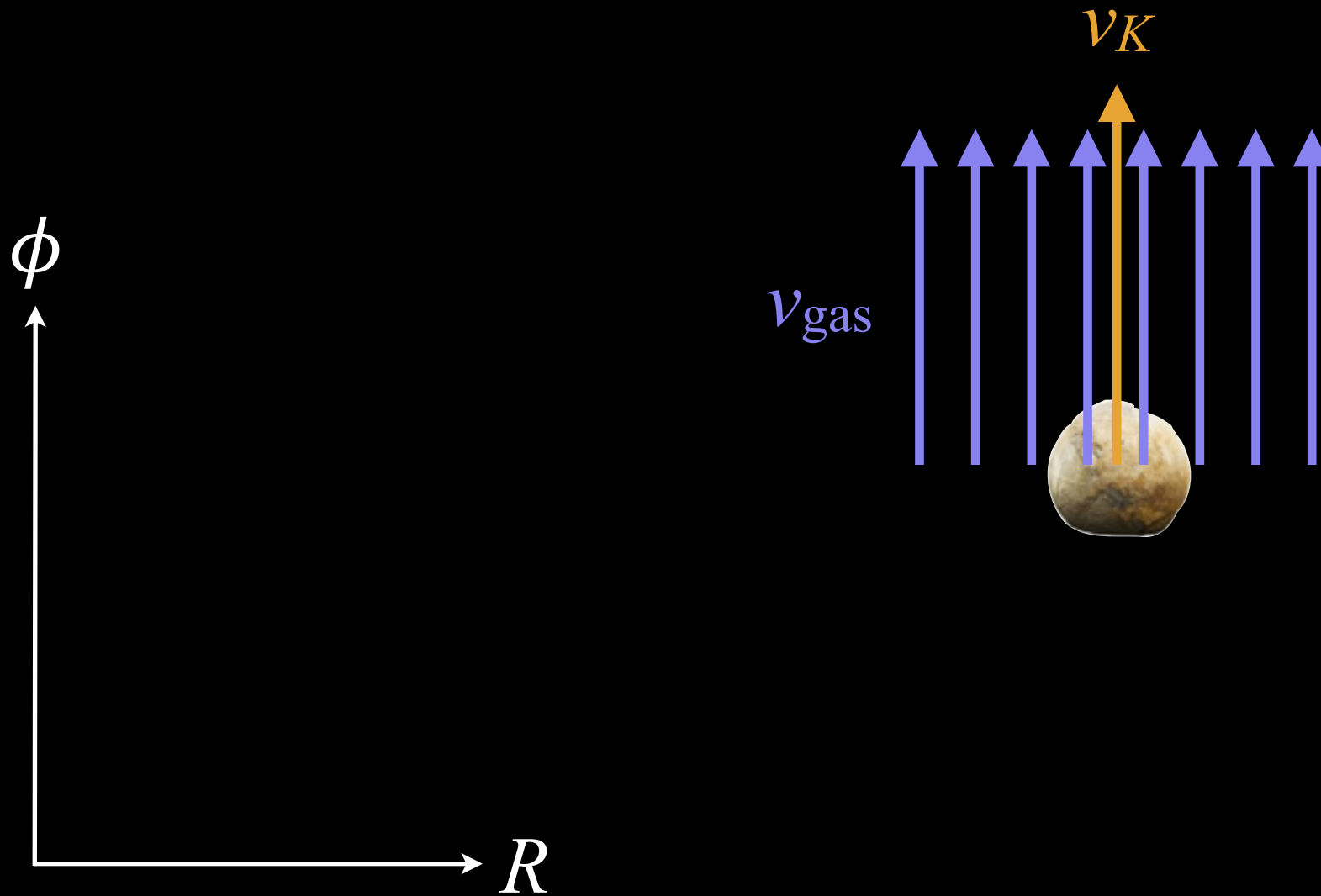
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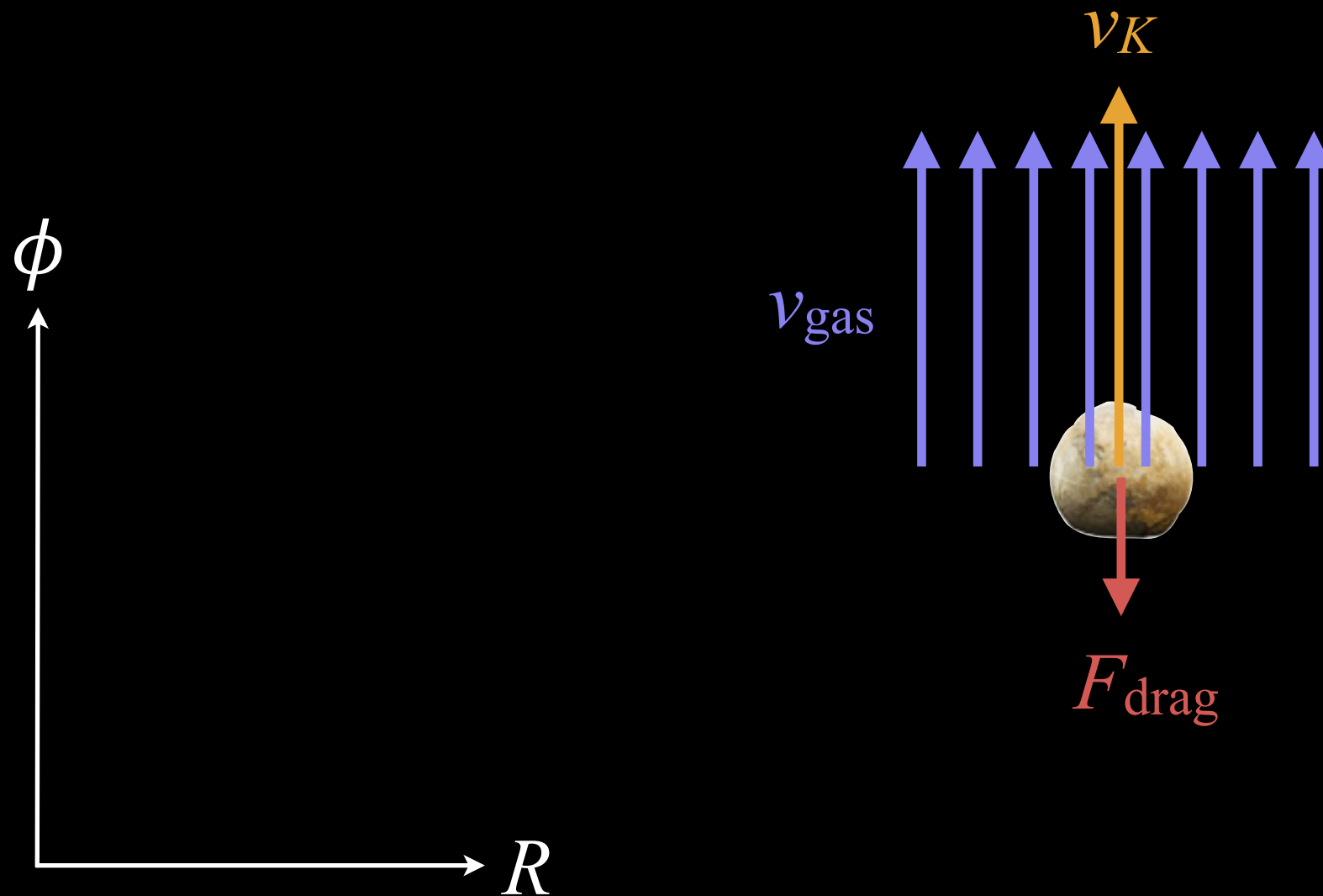
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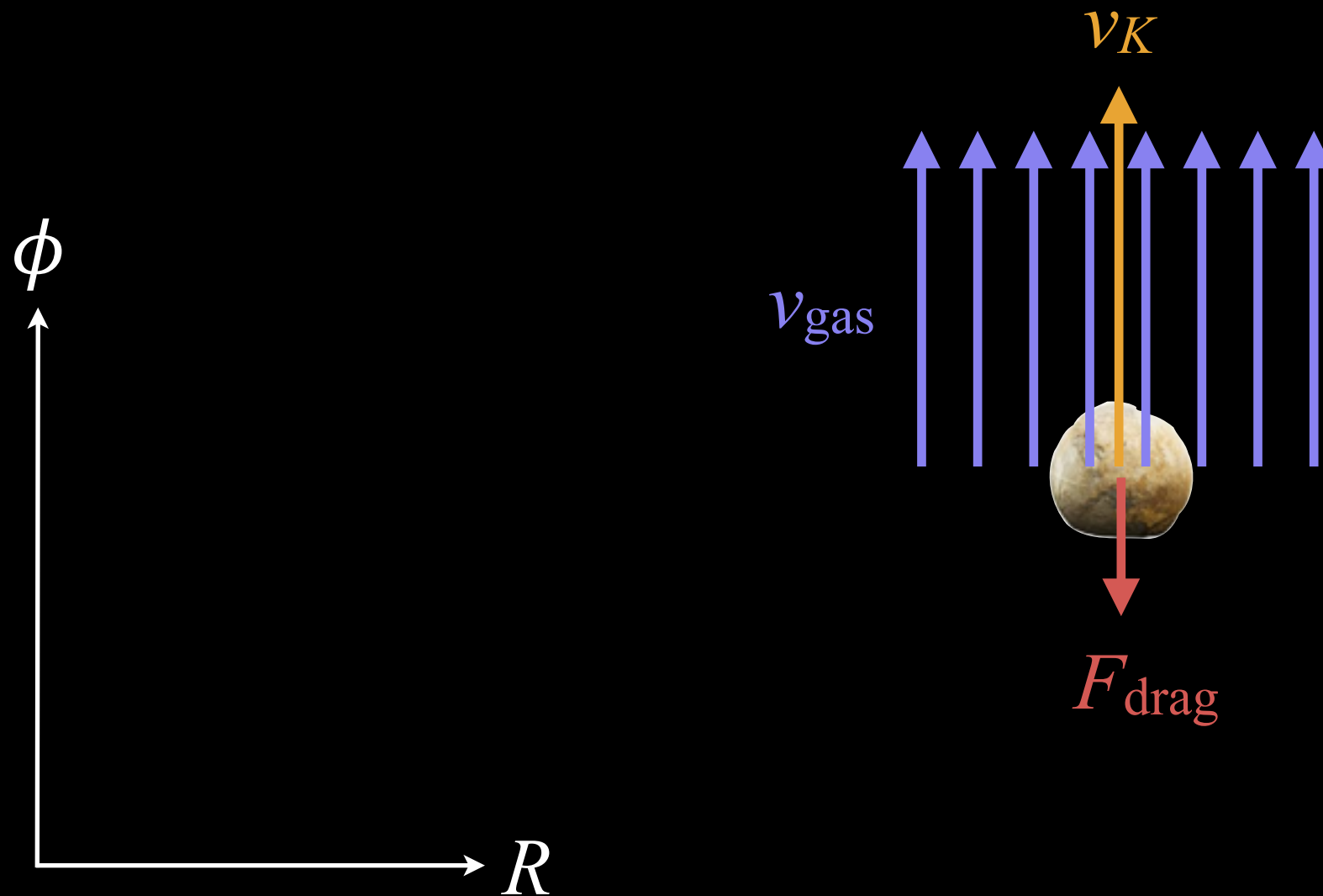
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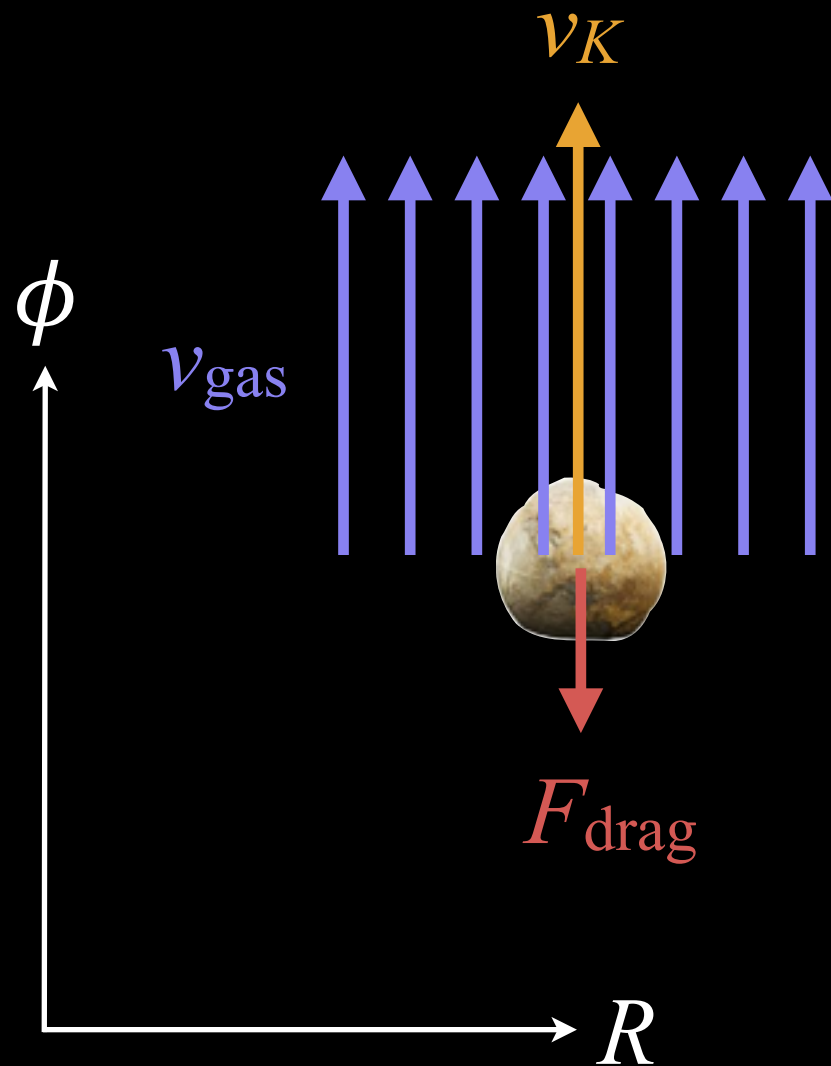
Meter-size Barrier

(Adachi, Hayashi, & Nakazawa 1976; Weidenschilling 1977)



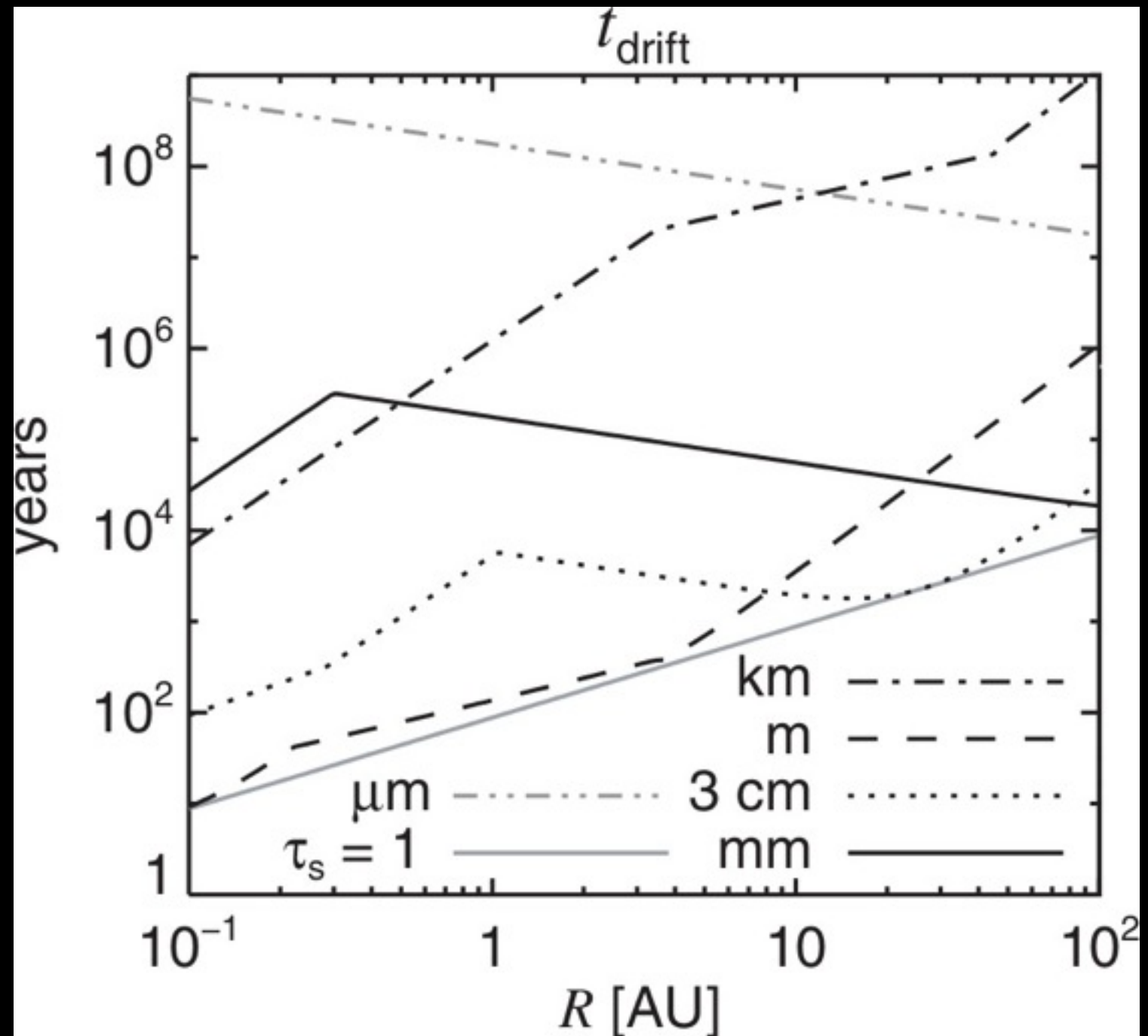
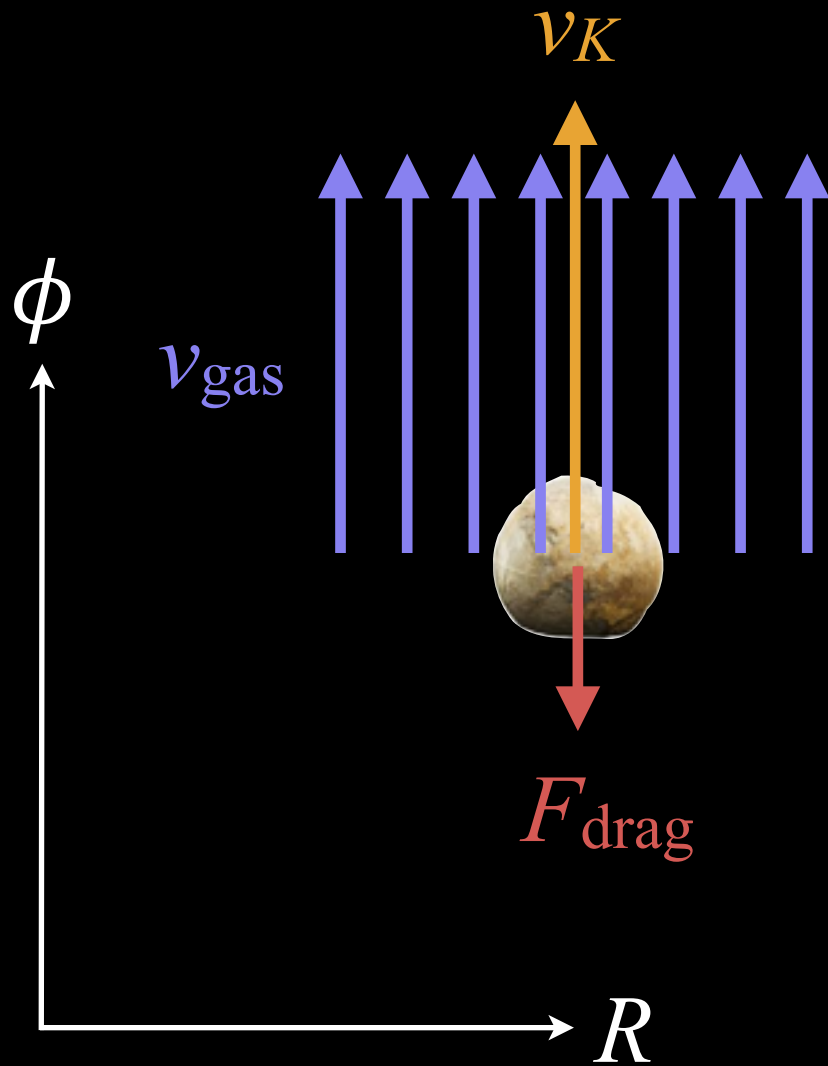
Meter-size Barrier

(Adachi, Hayashi, & Nakazawa 1976; Weidenschilling 1977)



Meter-size Barrier

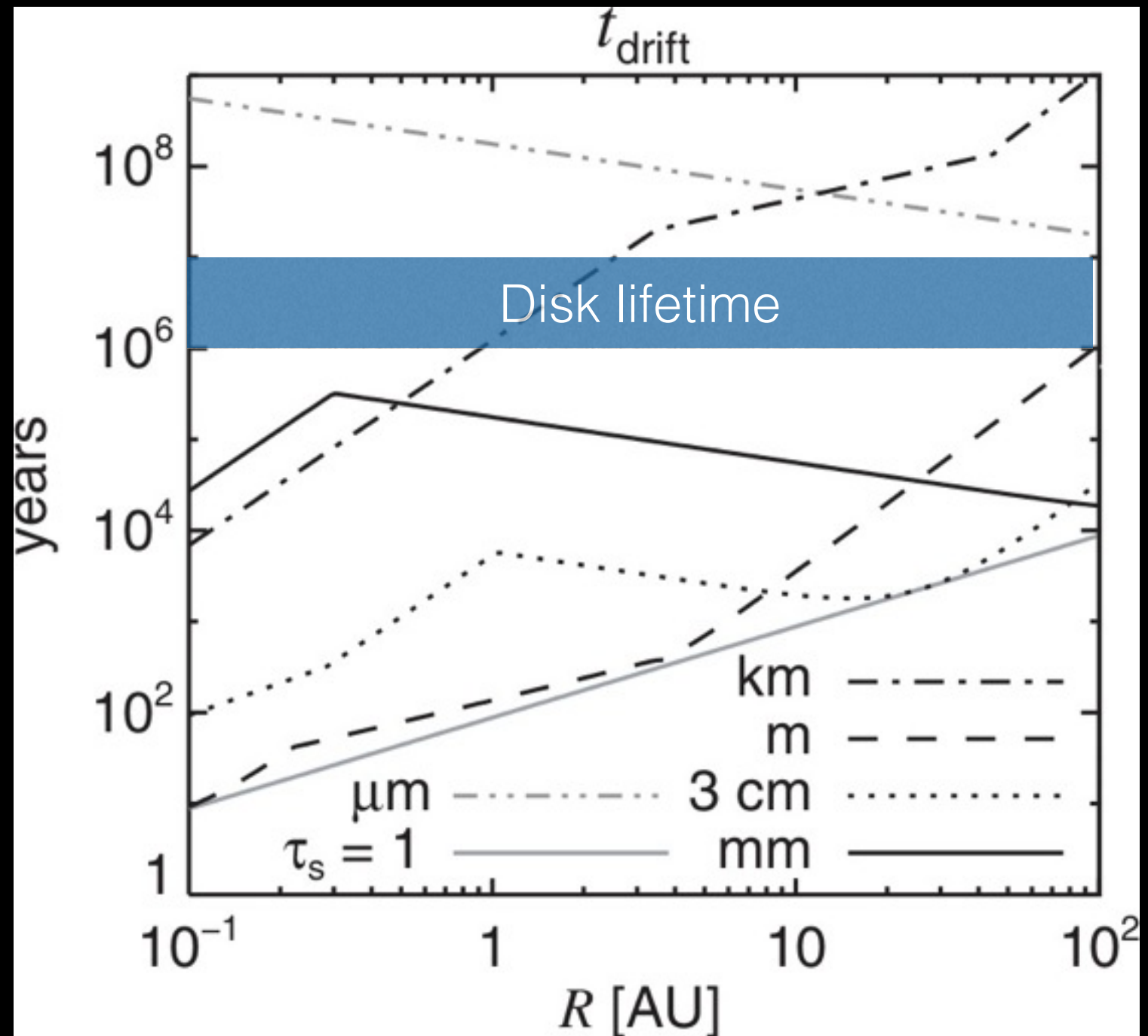
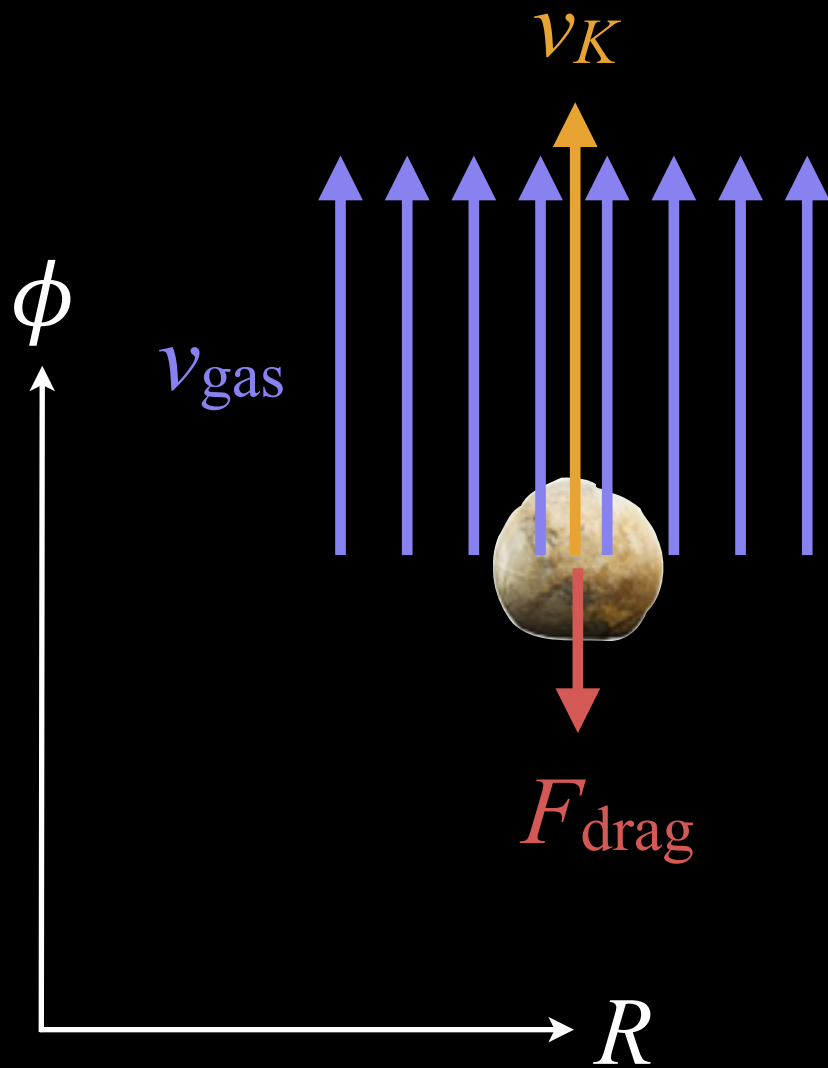
(Adachi, Hayashi, & Nakazawa 1976; Weidenschilling 1977)



Youdin (2010)

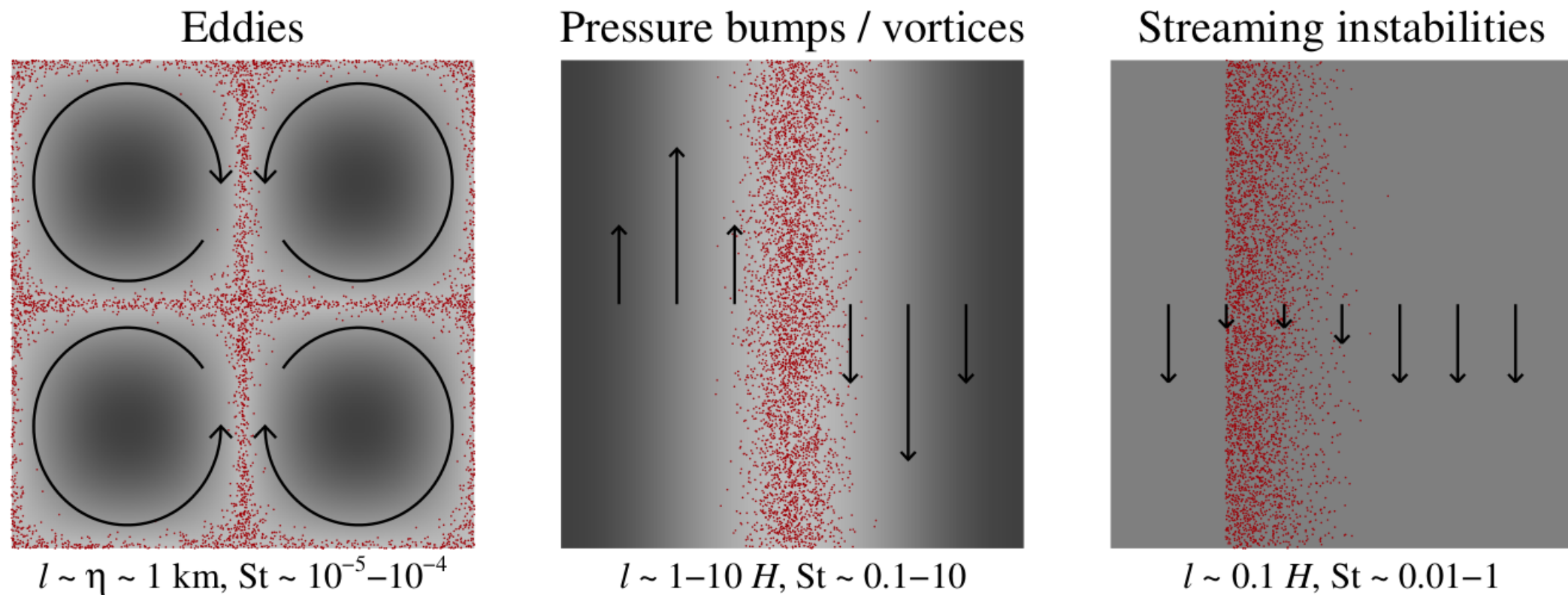
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Youdin (2010)

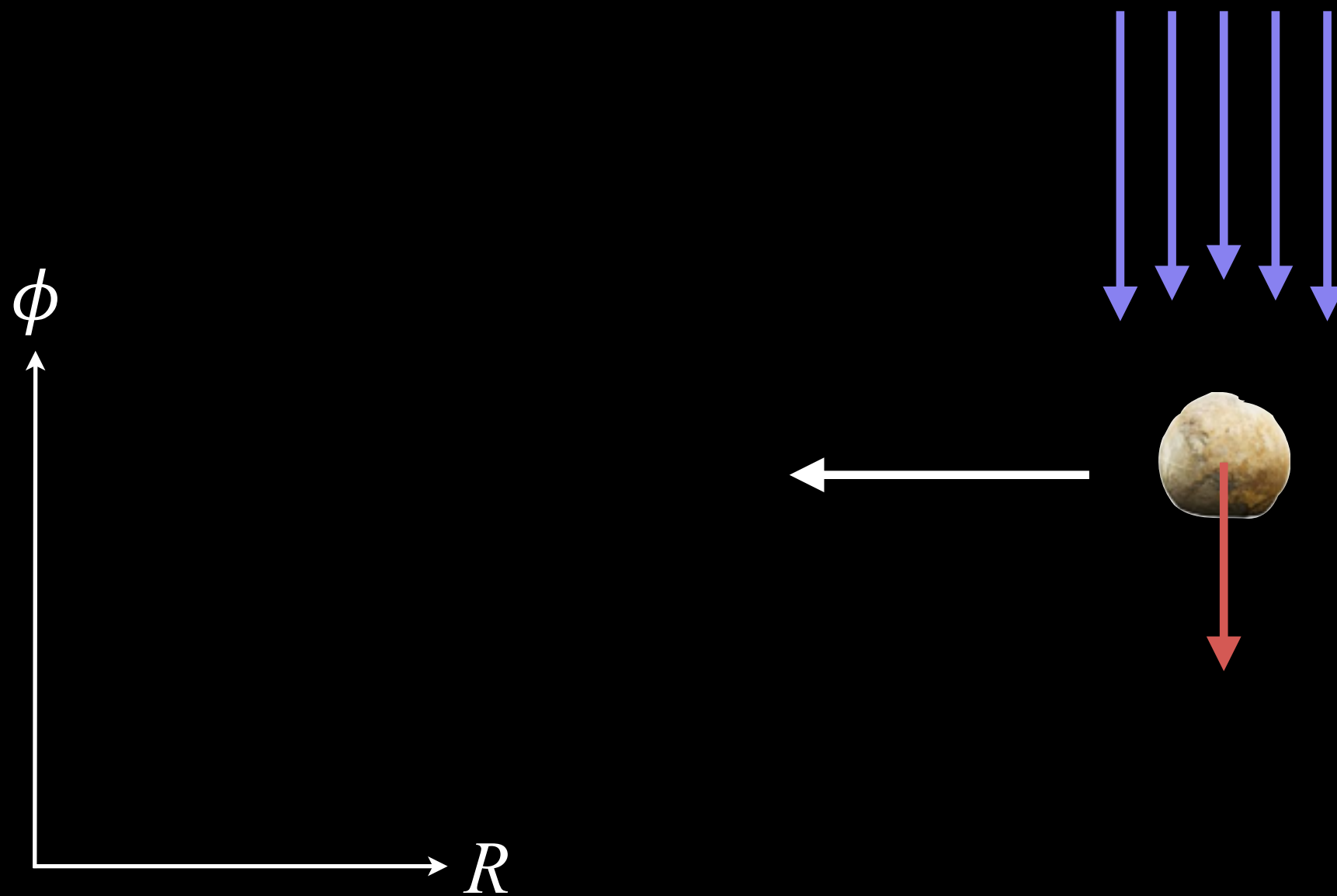
Particle concentration



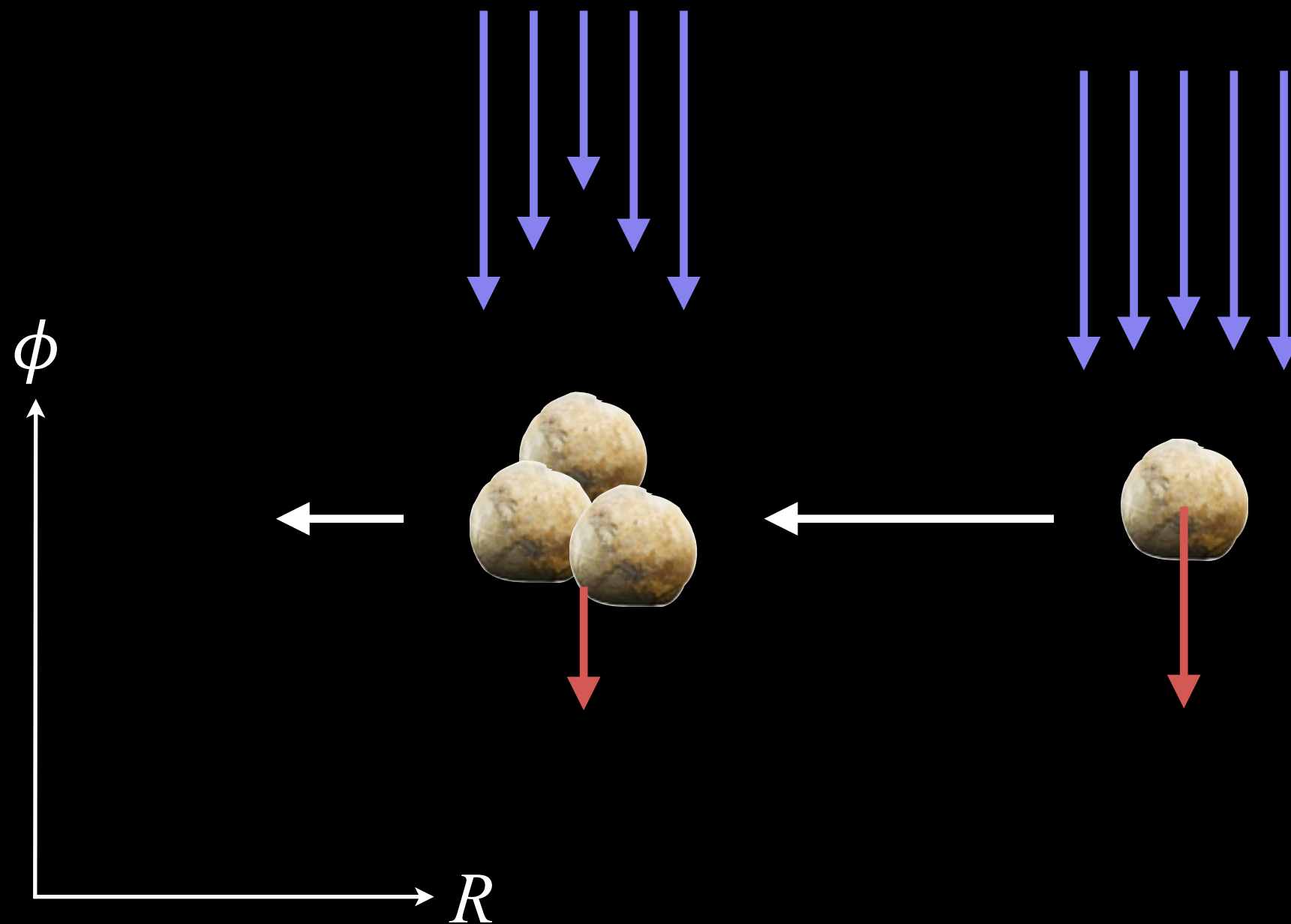
Three ways to concentrate particles: (Johansen et al., 2014, arXiv:1402.1344)

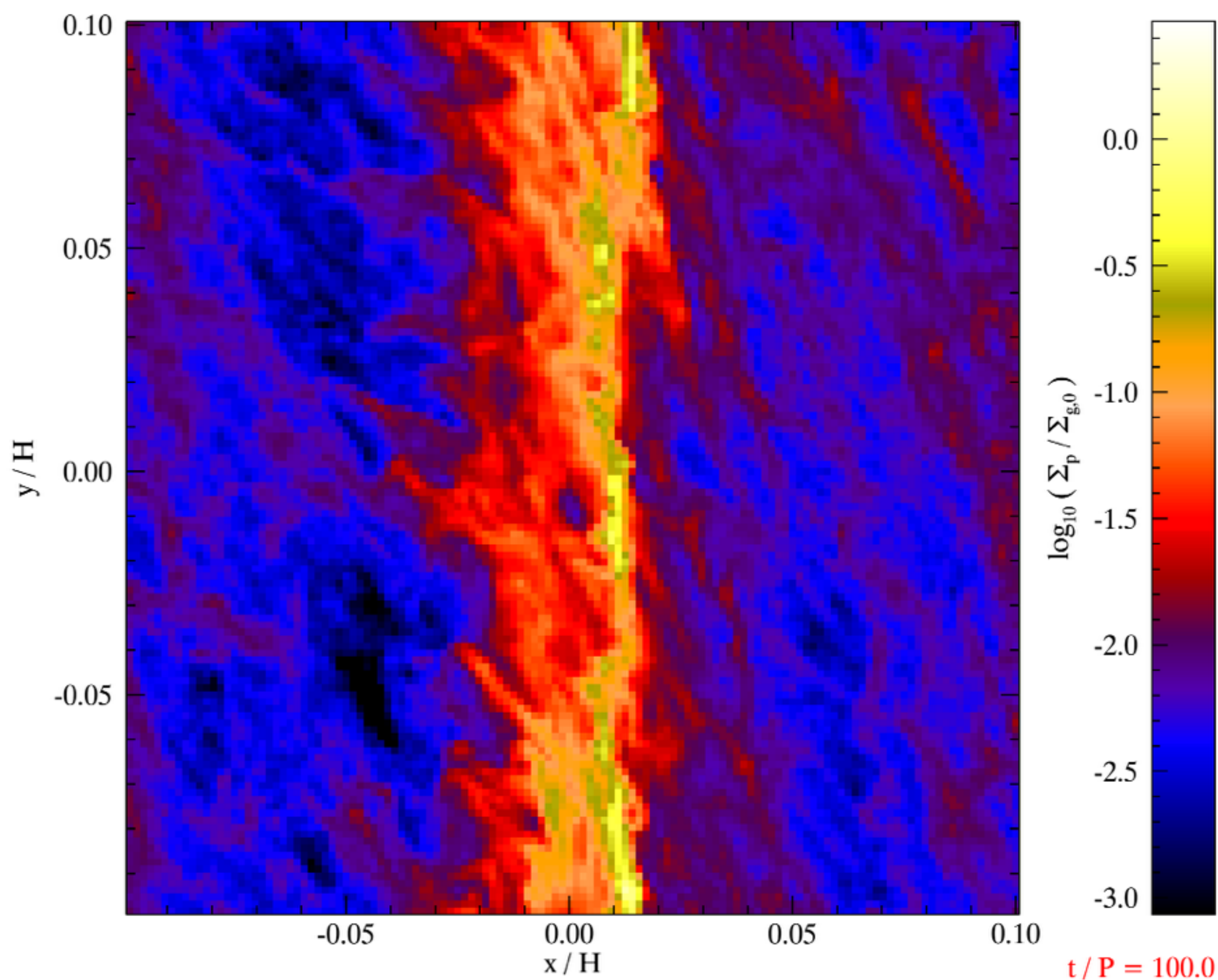
- ▶ Between small-scale low-pressure eddies
(Squires & Eaton, 1991; Fessler et al., 1994; Cuzzi et al., 2001, 2008; Pan et al., 2011)
- ▶ In pressure bumps and vortices
(Whipple, 1972; Barge & Sommeria, 1995; Klahr & Bodenheimer, 2003; Johansen et al., 2009a)
- ▶ By streaming instabilities
(Youdin & Goodman, 2005; Johansen & Youdin, 2007; Johansen et al., 2009b; Bai & Stone, 2010a,b,c)

Streaming Instability



Streaming Instability





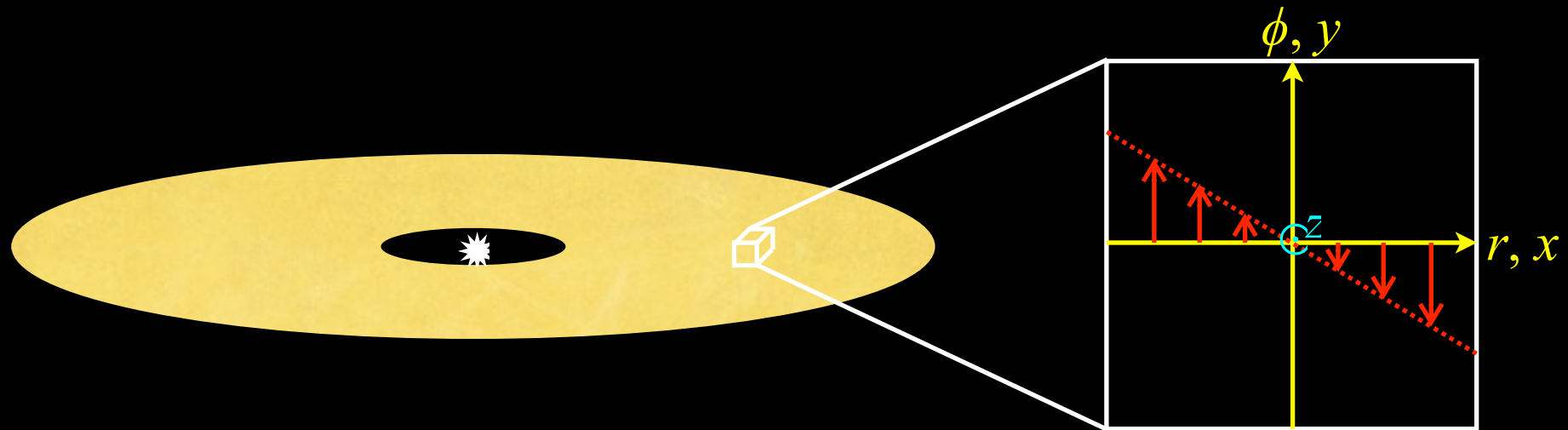
What We Know

- It works with both laminar *(Johansen et al. 2009; Bai & Stone 2010b)* and turbulent *(Johansen et al. 2007; Balsara et al. 2009; Kato et al. 2012)* disks.
- It can create Ceres-sized or smaller planetesimals by direct gravitational collapse *(Johansen et al. 2007, 2012)*.
- There exists a critical solid-to-gas ratio *(Johansen et al. 2009; Bai & Stone 2010b)*.
- This ratio depends on the radial pressure gradient of the gas *(Bai & Stone 2010a)*.

More Questions

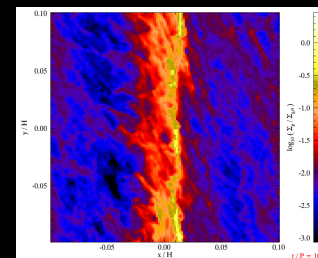
- The initial mass function of planetesimals? *(next talk)*
- Millimeter-sized particles? *(next talk)*
- Only one planetesimal forming belt? *(this talk)*
- Does it interact with more complicated environment of the gas disk?

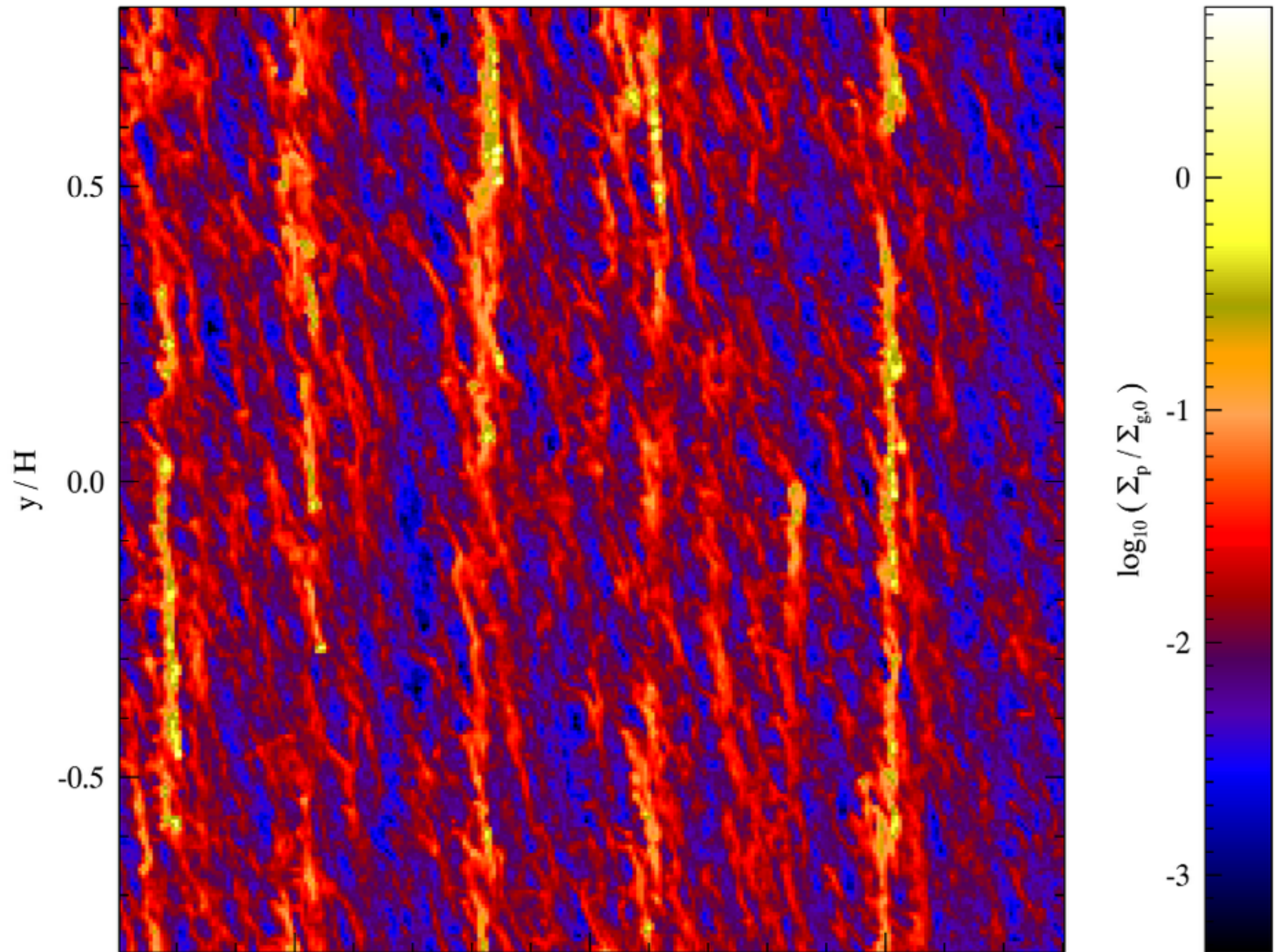
Model Setup



- Local shearing box approximation
- Gas and particles with vertical gravity and two-way friction.
 - Non-magnetized, isothermal equation of state.
 - Radial pressure gradient with $\Delta v = 0.05c_s$.
 - Solid-to-gas ratio: 2%.
 - Frictional stopping time: $0.05P$ ($\tau_s \sim 0.3$).
 - Box dimensions: $0.2H \times 0.2H \times 0.2H$ to $1.6H \times 1.6H \times 1.6H$.
- The Pencil Code

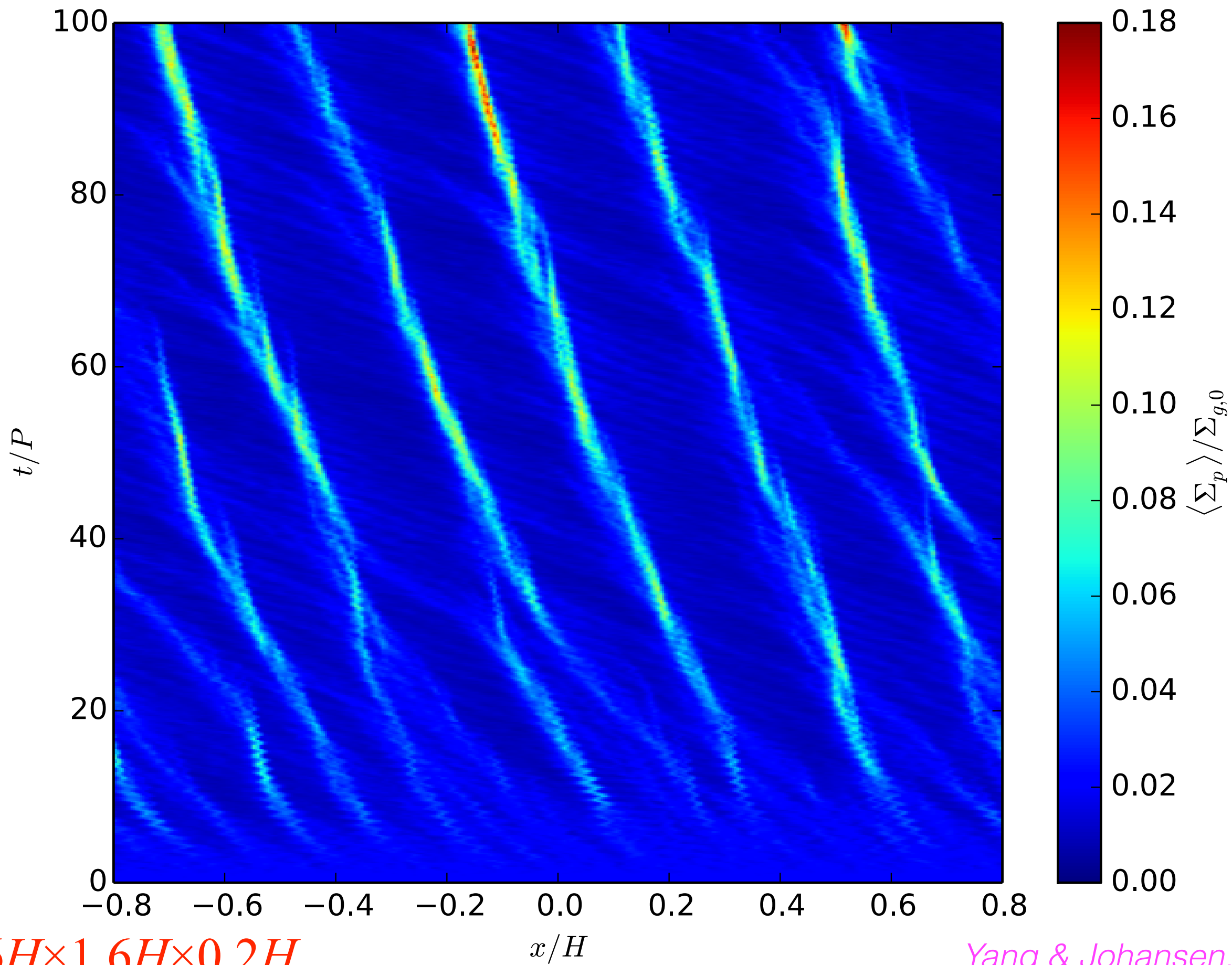
$$L_z = 0.2H$$





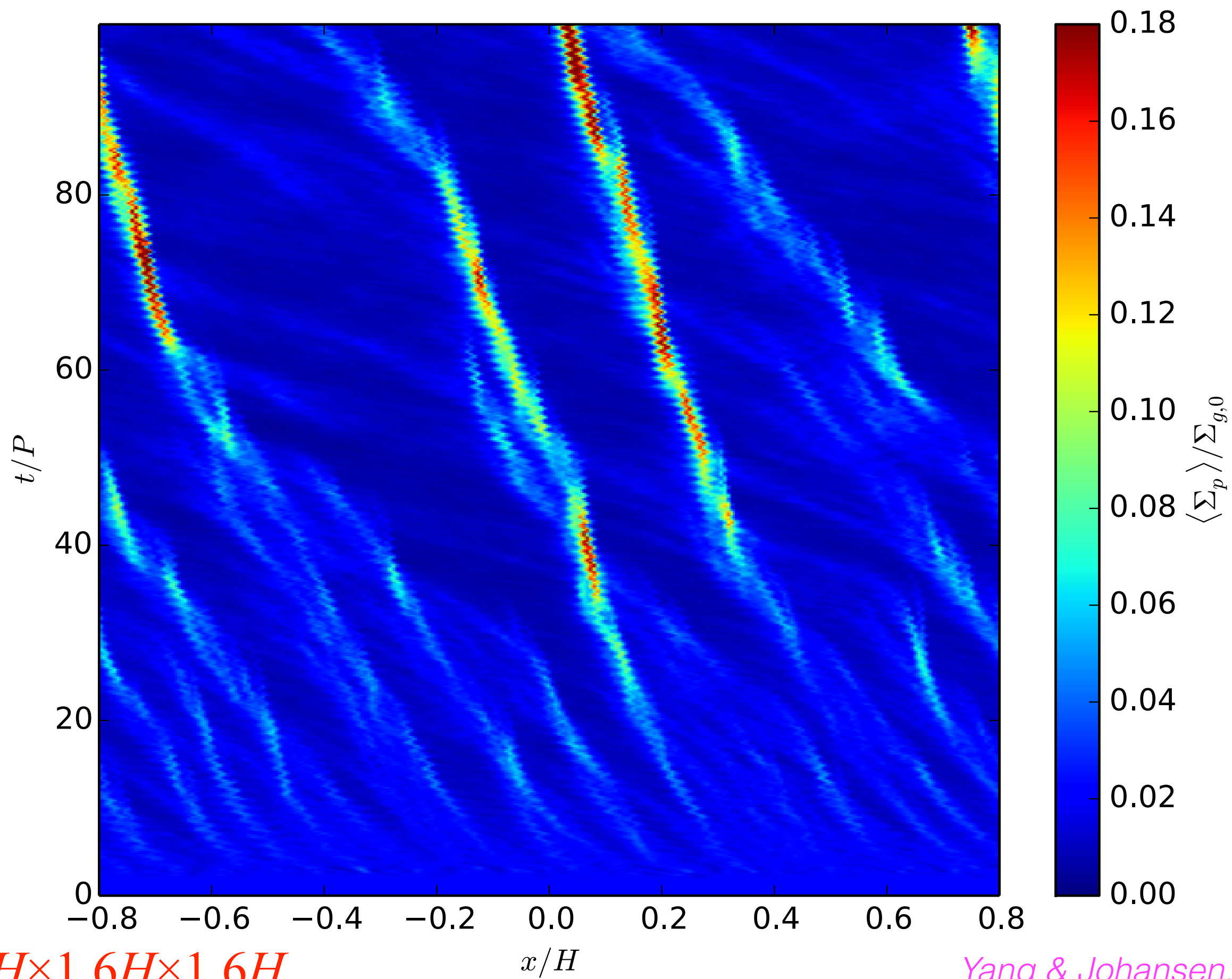
$L_z = 0.2H$

$t/P = 100.0$



$1.6H \times 1.6H \times 0.2H$

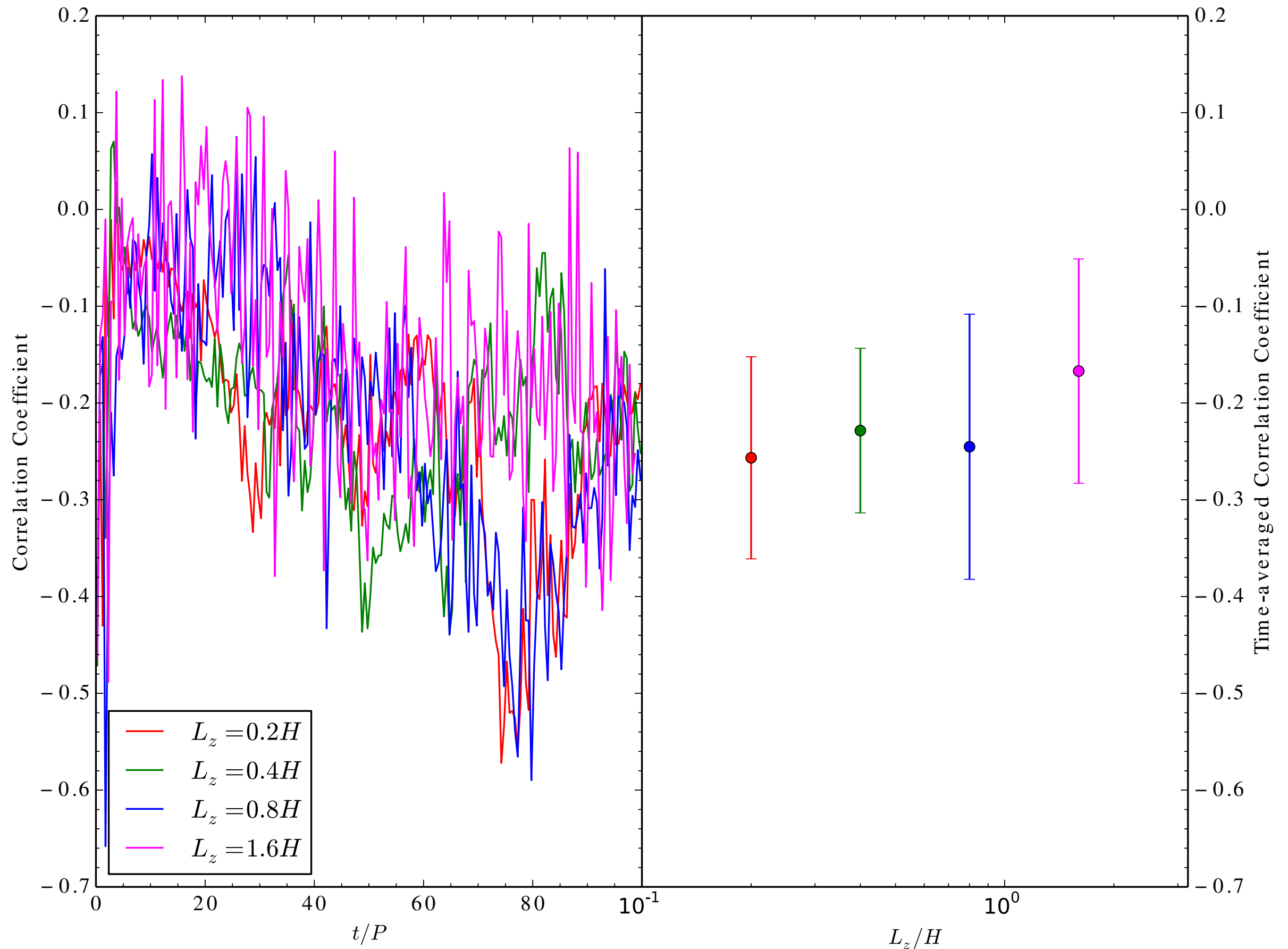
Yang & Johansen, in press



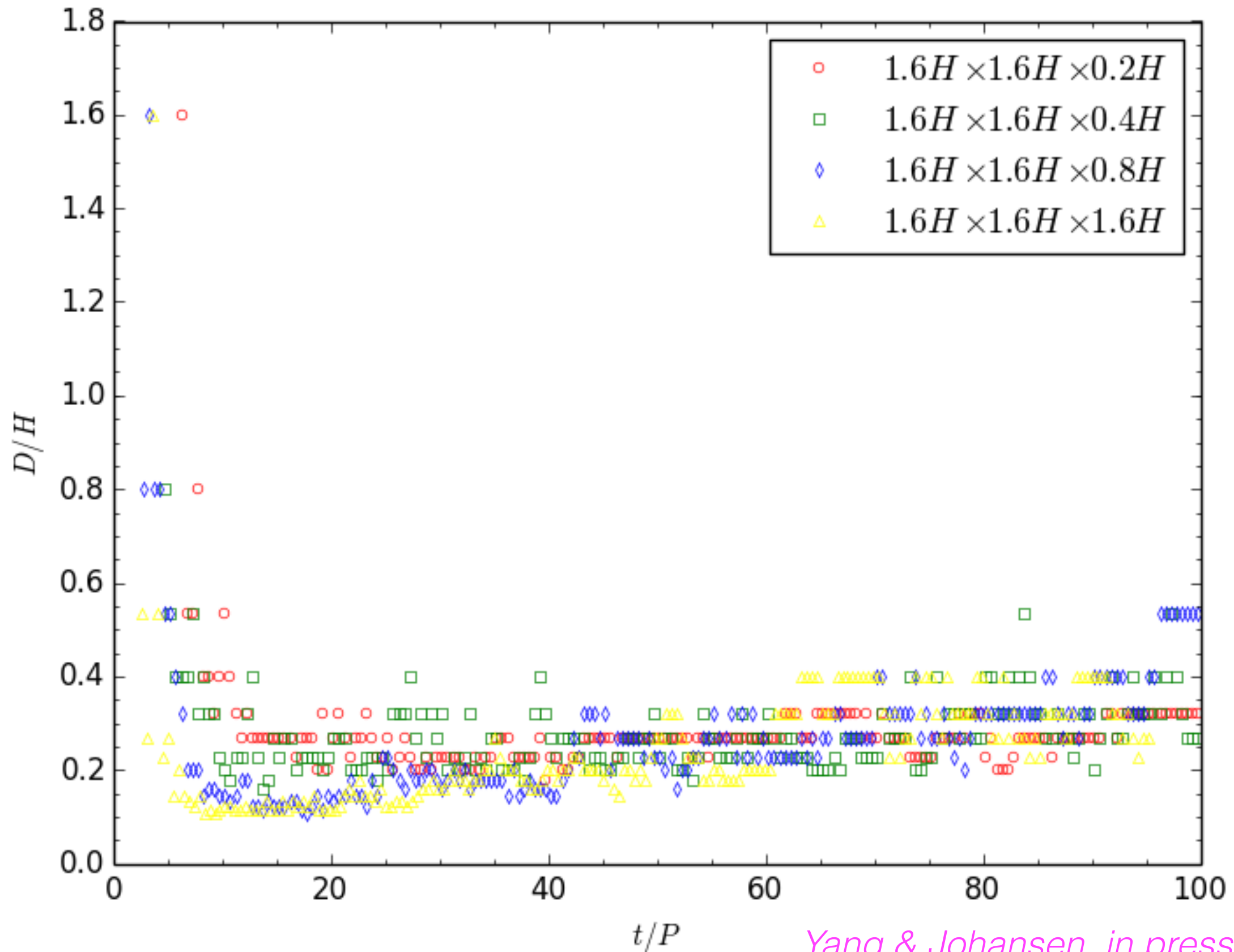
$1.6H \times 1.6H \times 1.6H$

Yang & Johansen, in press

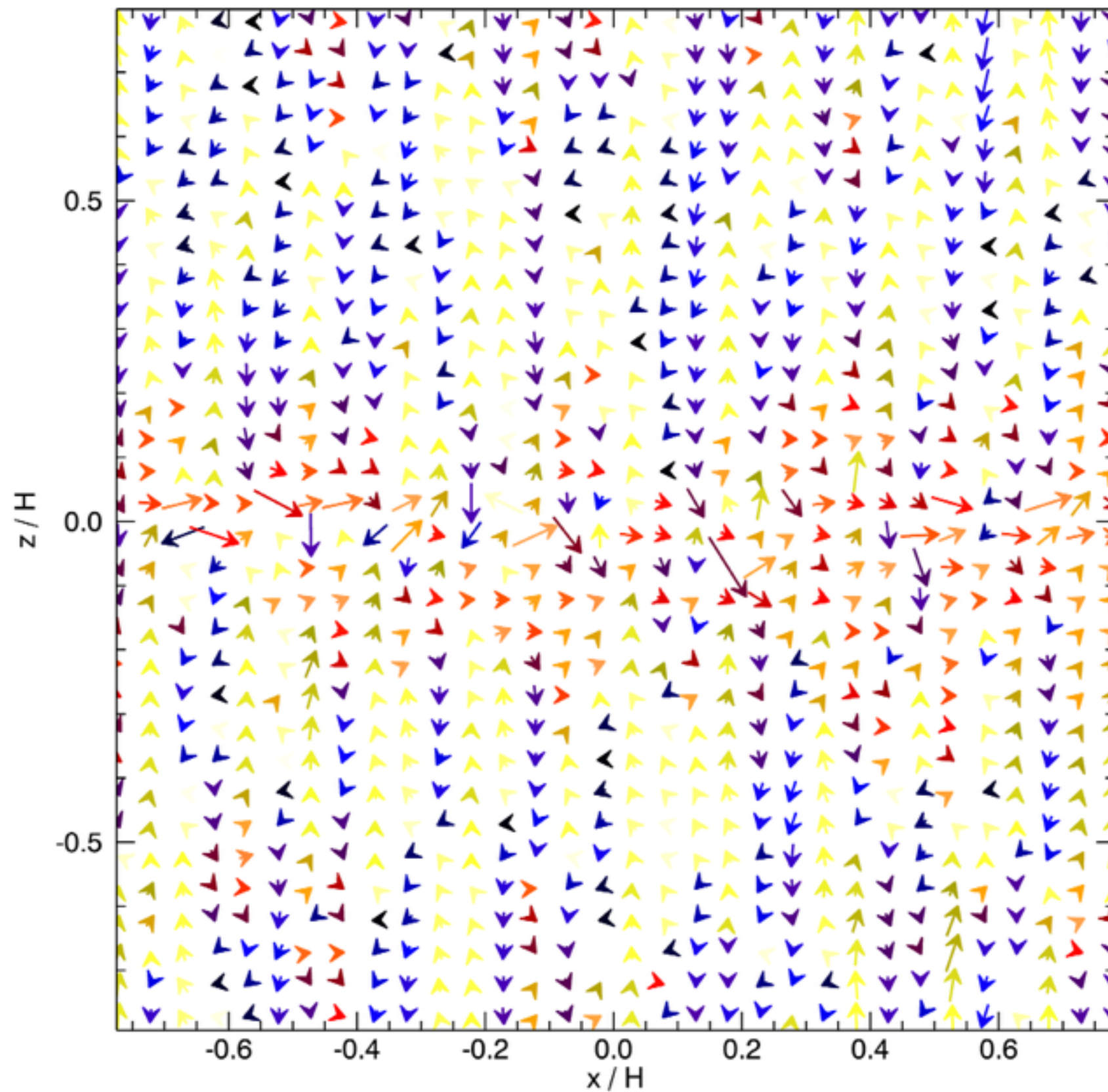
Gas-solid Correlation



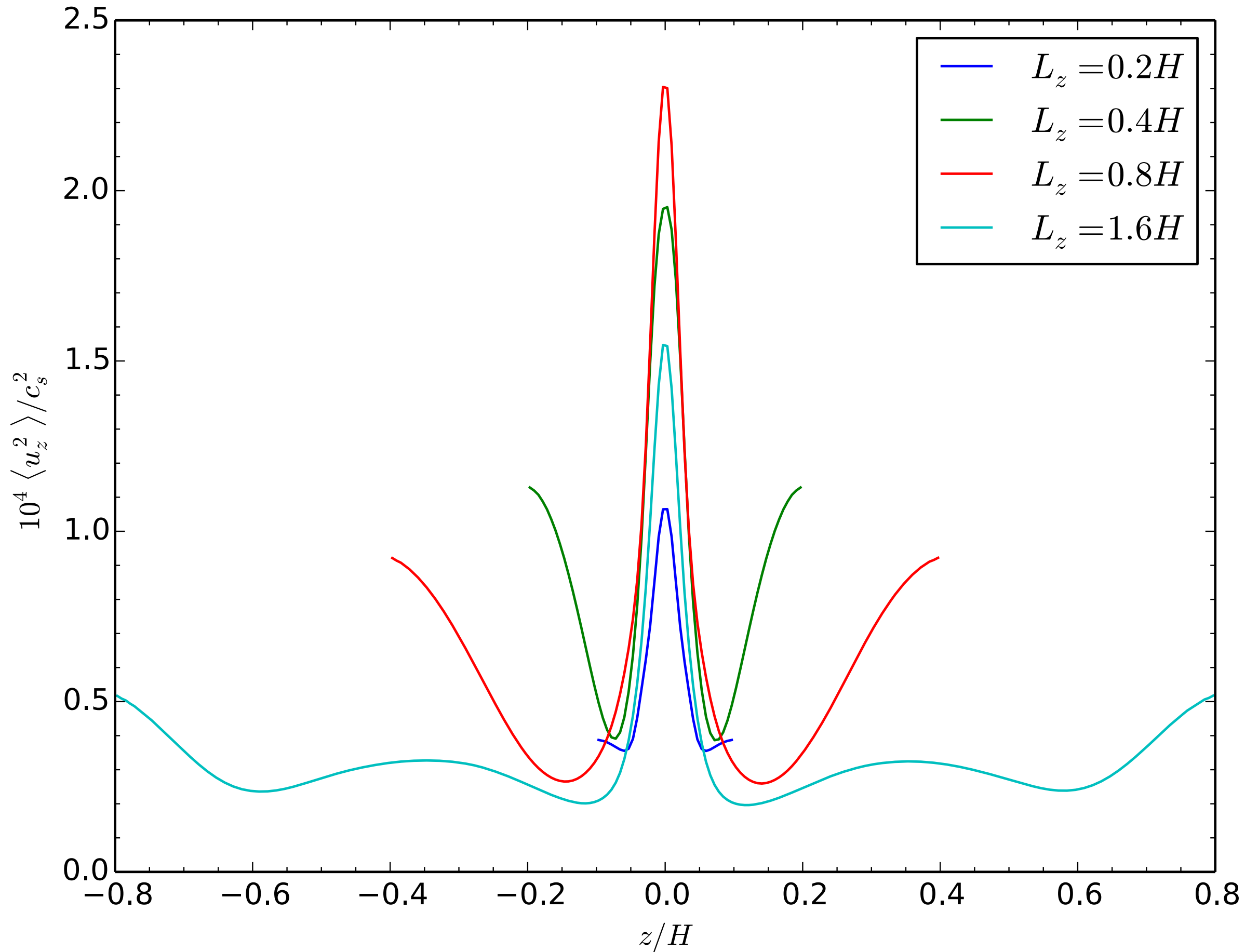
Radial Separation of Particle Filaments



Velocity Field of the Gas



Vertical Motion of the Gas



Concluding Remarks

- Radial separation of planetesimal formation
 - Size of the initial feeding zone of the planetesimals.
 - The composition of the asteroids probes the chemical inhomogeneity of the natal protoplanetary disks down to this scale.
- Large-scale gas-solid interaction
 - Non-trivial dynamics of the streaming instability when in MHD/HD unstable disks.