Low Luminosity BHs

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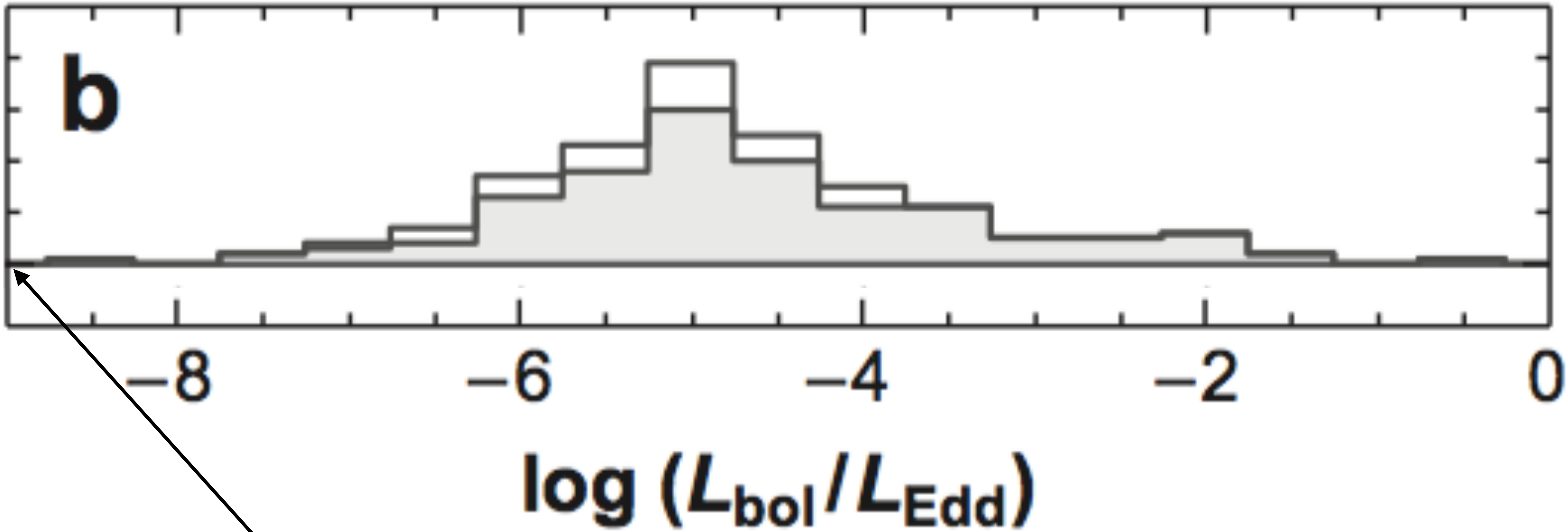
Outline

- LLAFs/RIAFs/ADAFs are very common
- at $t_{cool}/t_{visc} \lesssim 1$ thin disk forms; q-plot and state transitions
- galactic AGN feedback: thermal instability & cold gas; AGN jet-ICM sims.; going from kpc to 10^{-3} pc

LLAFs are common

from Palomar nearby galaxies survey [Ho 2008]



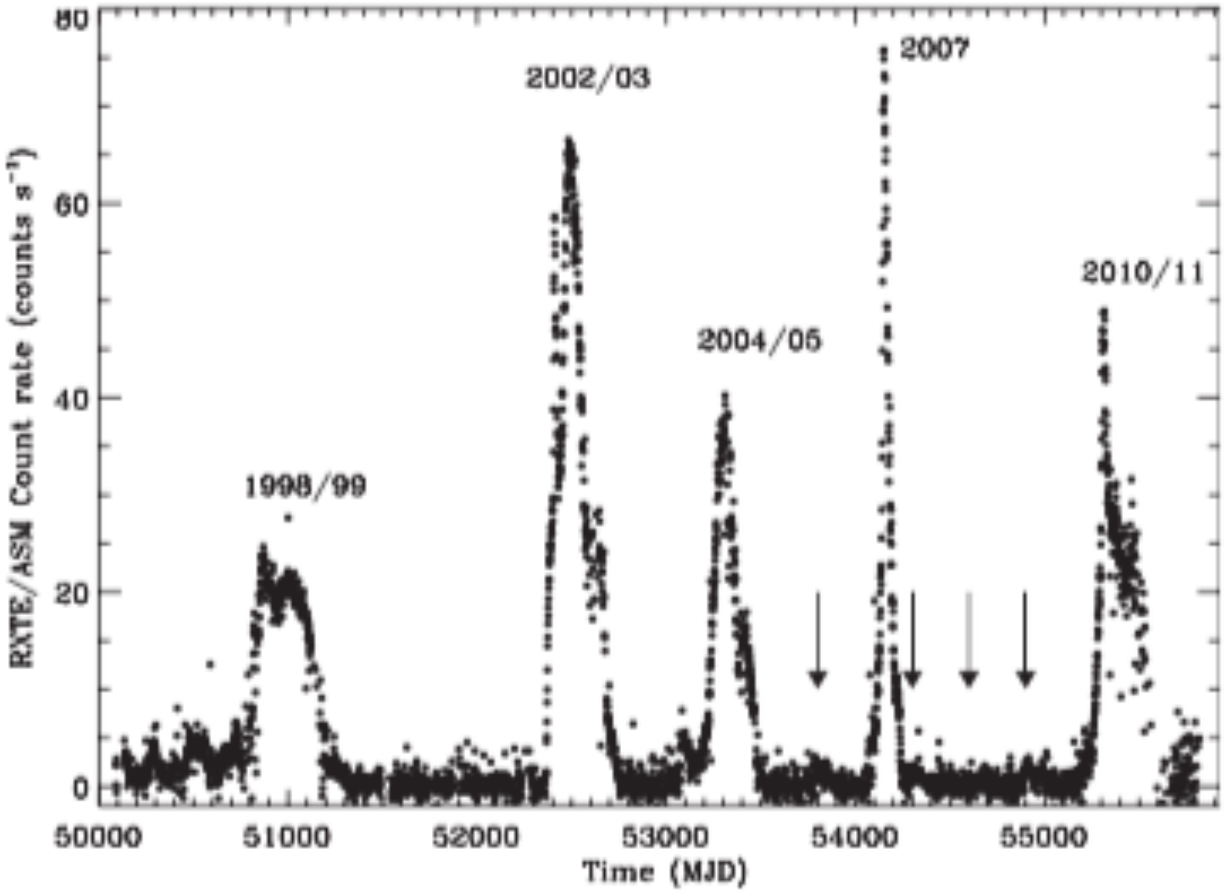
Sgr A*
L_{bol}~$5x10^{35}$ erg/s
in sub-mm; very well diagnosed;
plasma physics; e^- htg.; Mdot<<$Mdot_{Bondi}$

most nearby SMBHs are accreting at very sub-Eddington rates

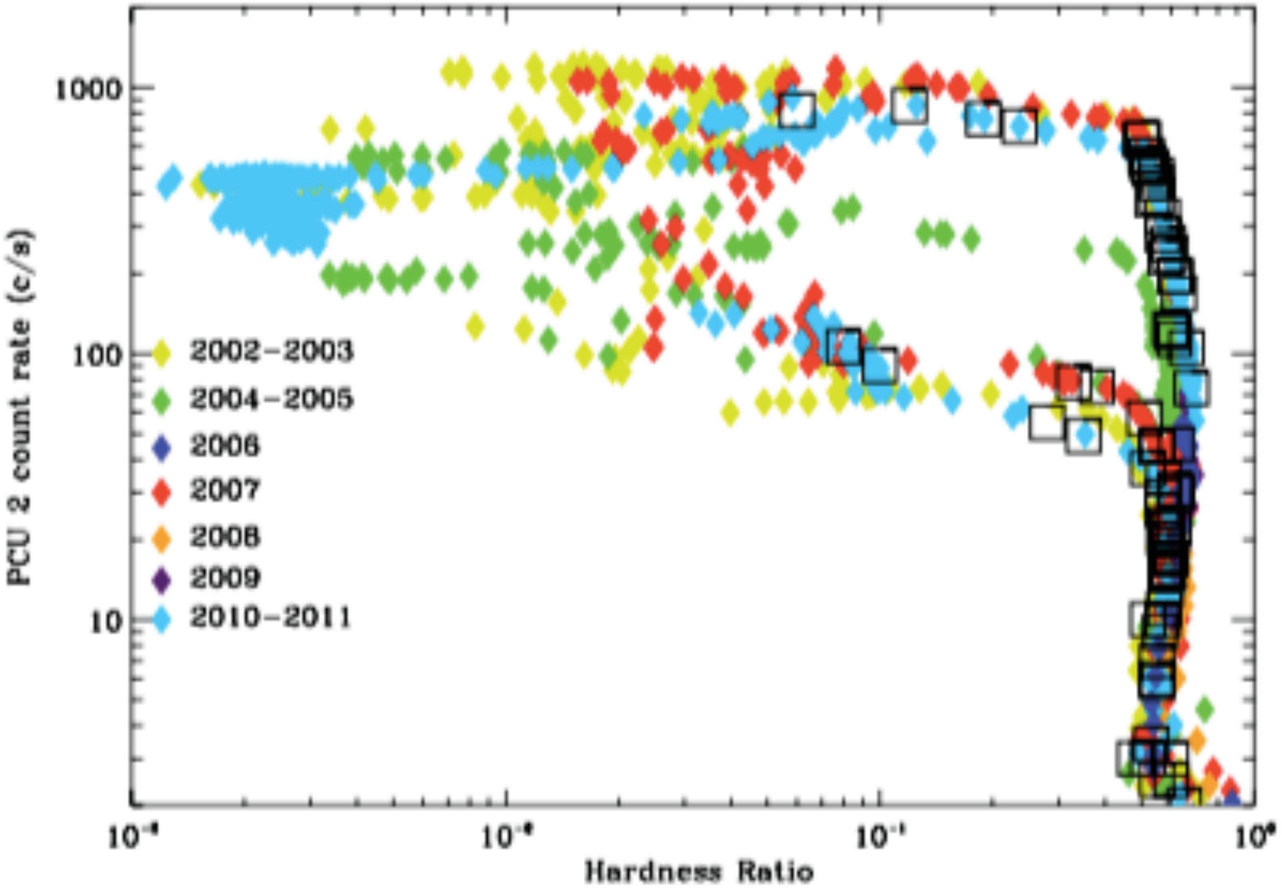
LLAFs are common

GX-339-4

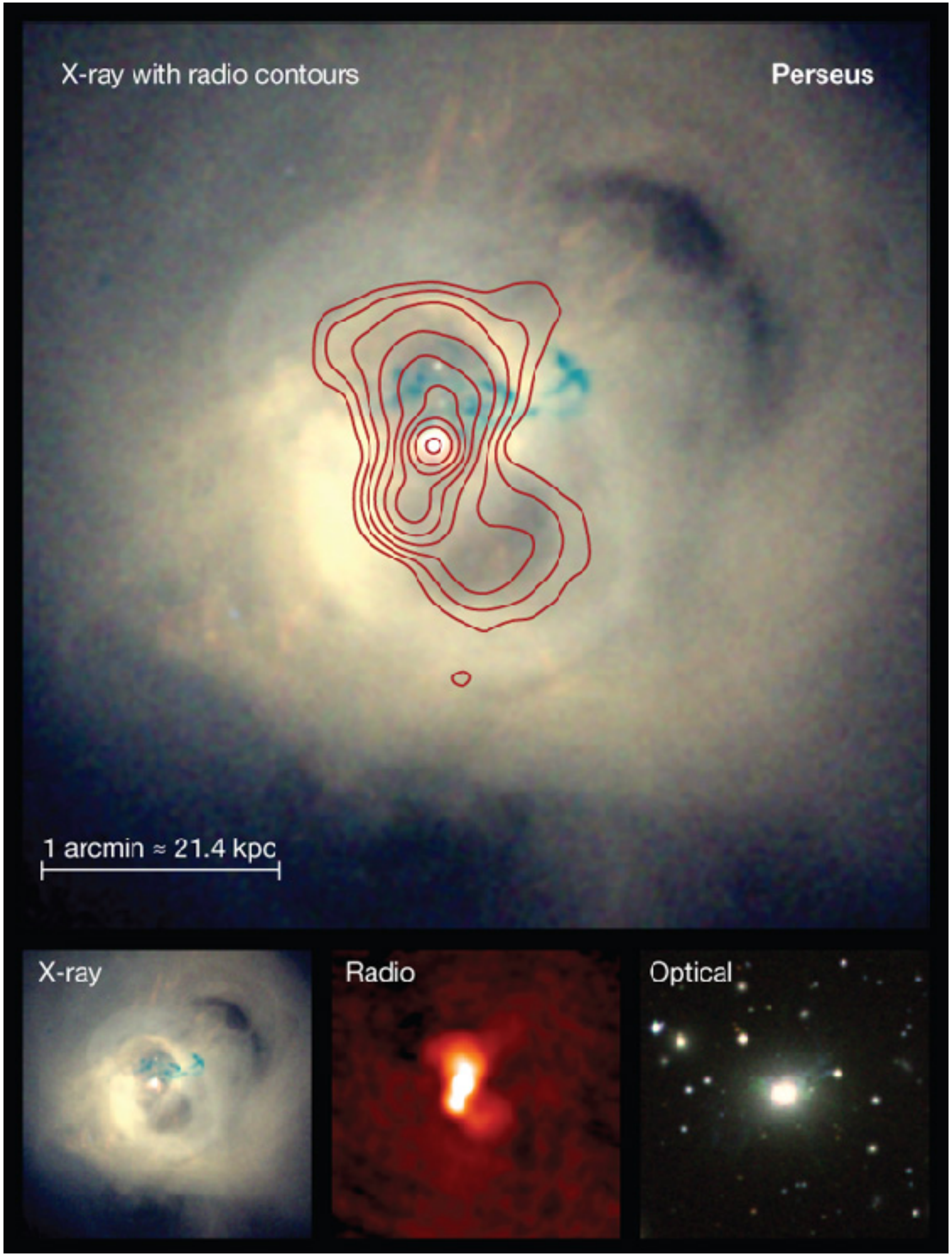
[Corbel et al. 2013]



RXTE light curve



q-plot or HID diagram



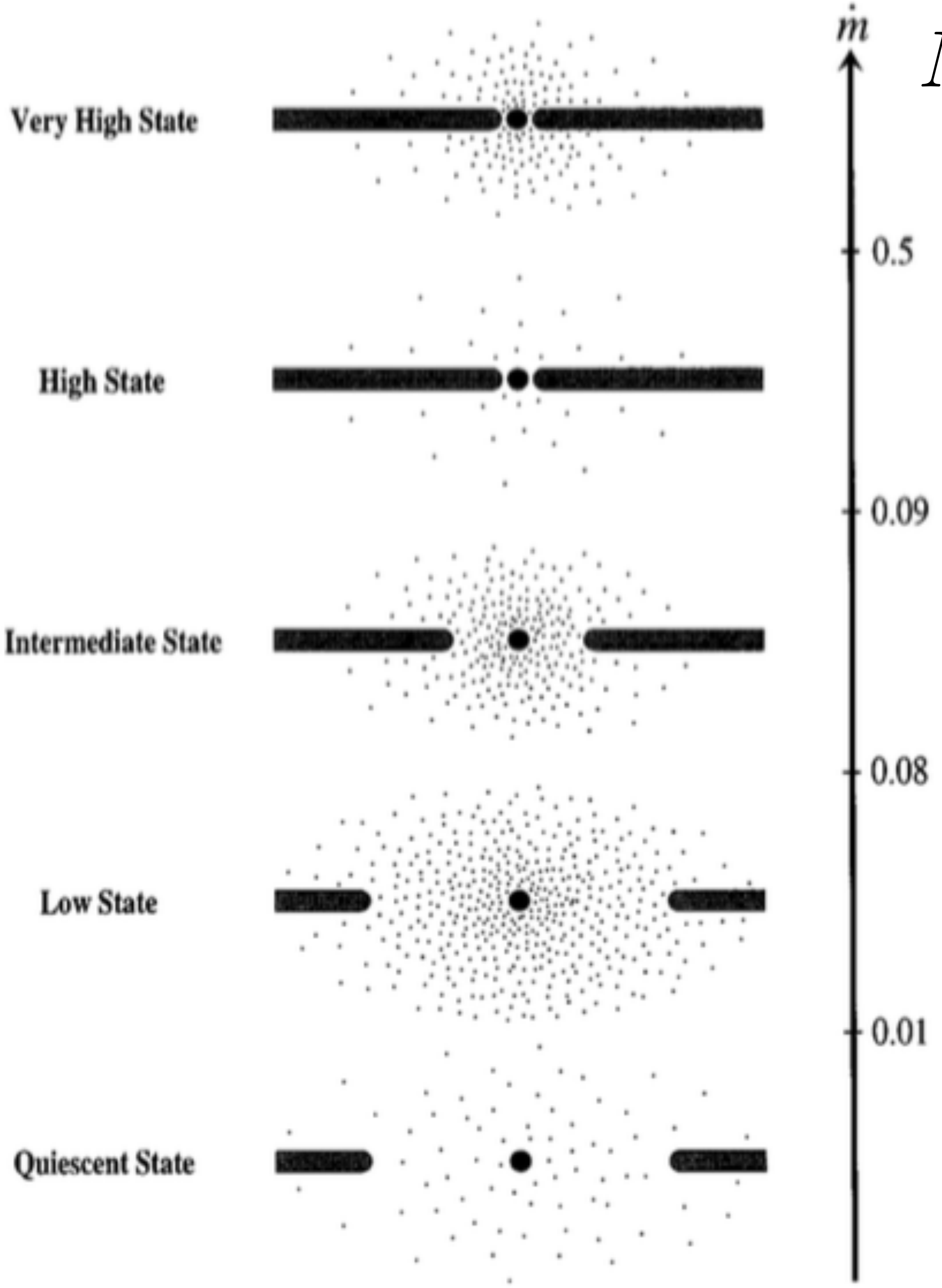
AGN fb

maintenance/radio-mode
feedback in clusters
& ellipticals

multiphase gas from
10s of K to $10^{7\text{-}8}$ K

condensation via local
thermal instability &
cold clouds feeding BHs

Cartoon picture



$\dot{M}/\dot{M}_{\mathrm{Edd}}$

[Esin et al. 1997]

Sgr A*
way down there

Radiatively inefficient accretion flow simulations with cooling: implications for black hole transients

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Numerical Sims.

Euler's eqs.
w. alpha-viscosity
& ff cooling

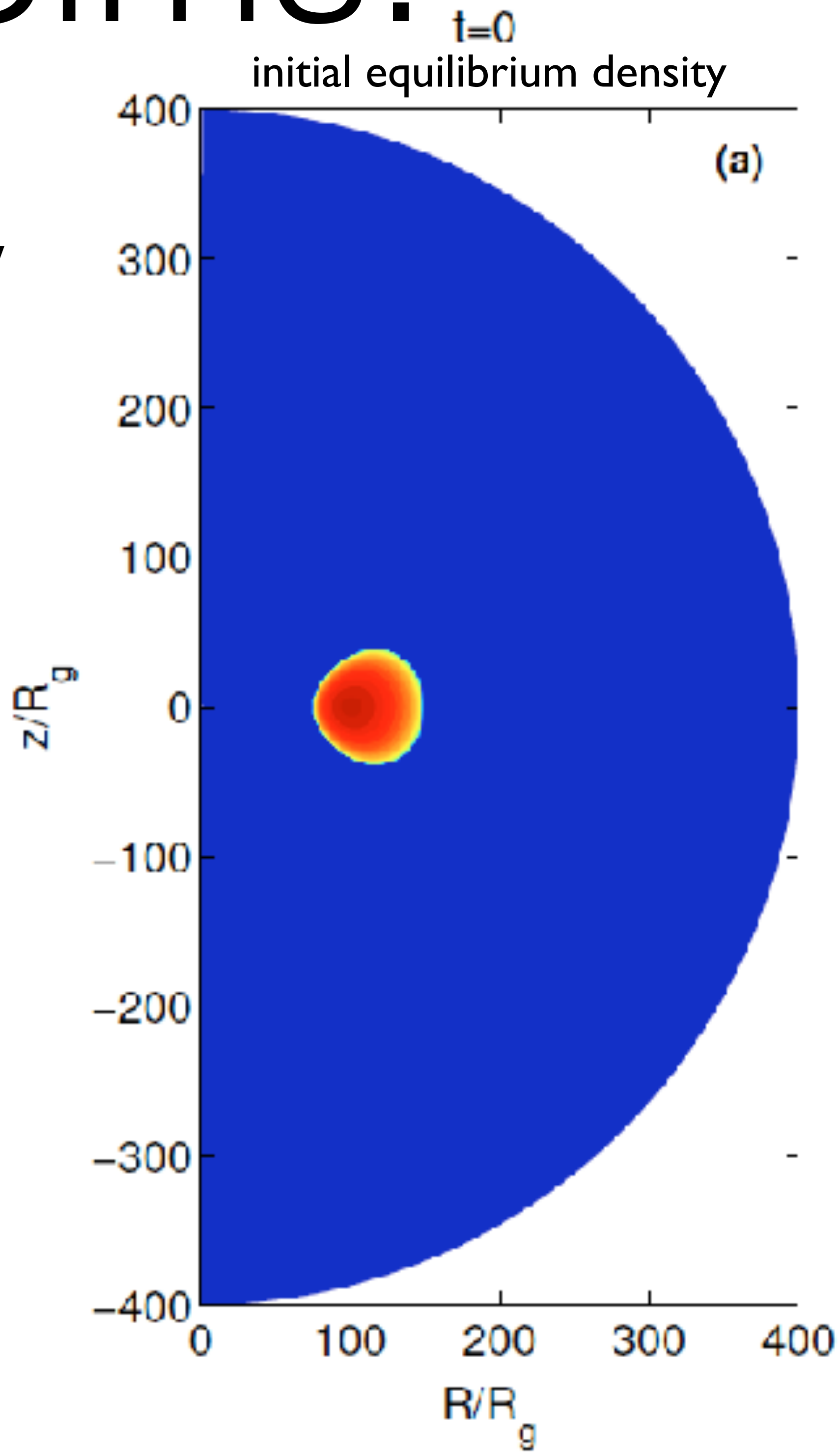
$$\frac{d\rho}{dt} + \rho \boldsymbol{\nabla} \cdot \mathbf{v} = 0,$$

$$\rho \frac{d\mathbf{v}}{dt} = -\boldsymbol{\nabla} P - \rho \boldsymbol{\nabla} \phi + \boldsymbol{\nabla} \cdot \boldsymbol{\sigma},$$

$$\rho \frac{d(e/\rho)}{dt} = -P \boldsymbol{\nabla} \cdot \mathbf{v} + \boldsymbol{\sigma}^2/\mu - n_e n_i \Lambda(T).$$

$$\phi = -\frac{GM}{r - R_g}$$

$$\sigma_{r\phi} = \sigma_{\phi r} = \mu r \frac{\partial}{\partial r}\left(\frac{v_\phi}{r}\right)$$



initial equilibrium density

caveats: actual transport is MHD; idealized cooling; 2D; no radiation transport

vary torus density to change Mdot
without cooling eqs. scale simply with M, Mdot

Numerical Sims.

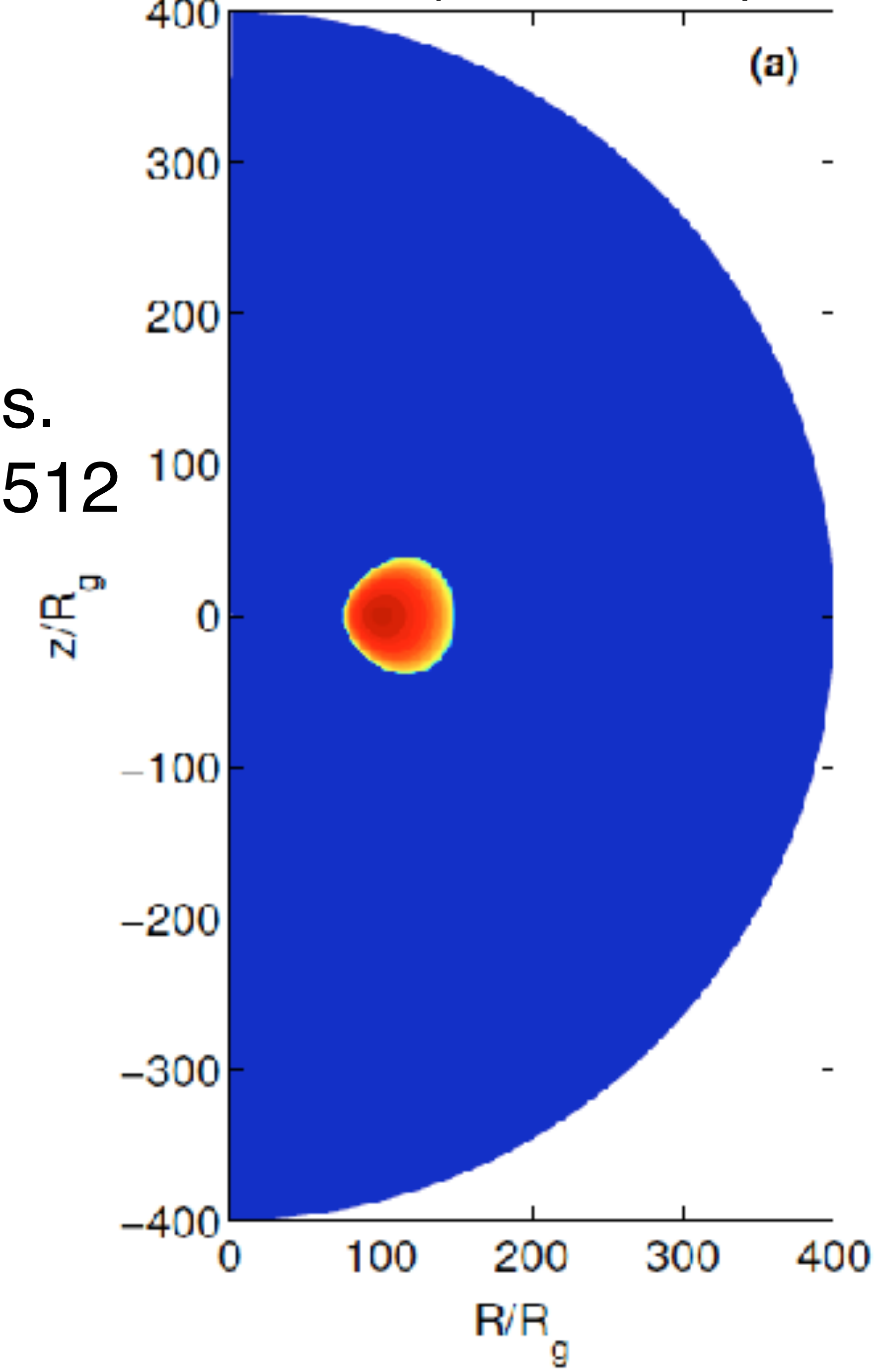
$$\frac{d\rho}{dt} + \rho \boldsymbol{\nabla} \cdot \mathbf{v} = 0,$$

$$\rho \frac{d\mathbf{v}}{dt} = -\boldsymbol{\nabla} P - \rho \boldsymbol{\nabla} \phi + \boldsymbol{\nabla} \cdot \boldsymbol{\sigma},$$

$$\rho \frac{d(e/\rho)}{dt} = -P \boldsymbol{\nabla} \cdot \mathbf{v} + \boldsymbol{\sigma}^2/\mu - n_e n_i \Lambda(T).$$

2D sims.
r-θ: 512x512

t=0
initial equilibrium density



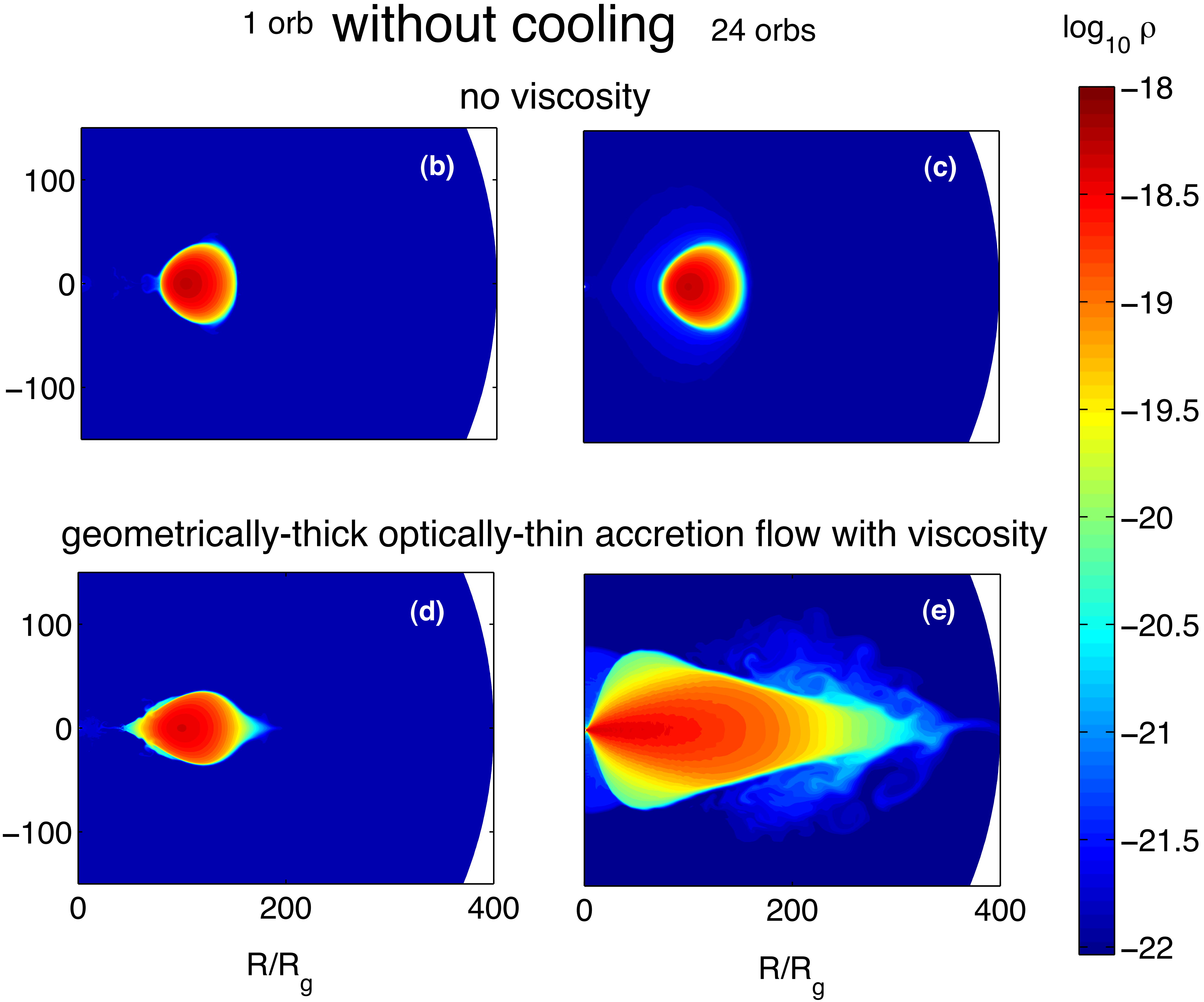
$$\phi = -\frac{GM}{r - R_g}$$

pseudo-Newtonian
potential; Sgr A*, 4e6 Msun

$$\sigma_{r\phi} = \sigma_{\phi r} = \mu r \frac{\partial}{\partial r} \left(\frac{v_\phi}{r} \right)$$

viscous stress required
for accretion in hydro

we choose $\upsilon \propto r^{1/2}$ independent of H/R

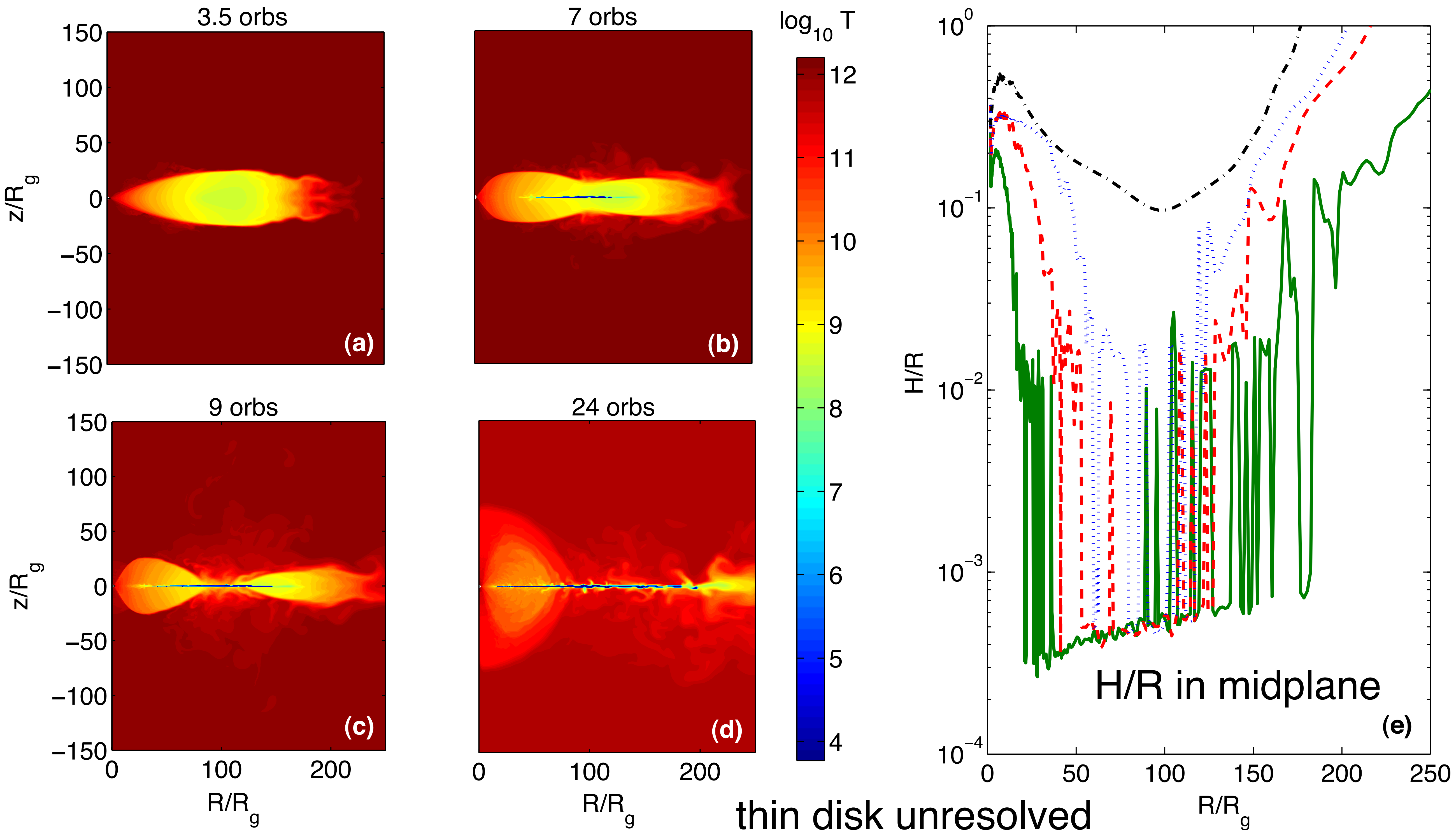


1 orb without cooling 24 orbs

no viscosity

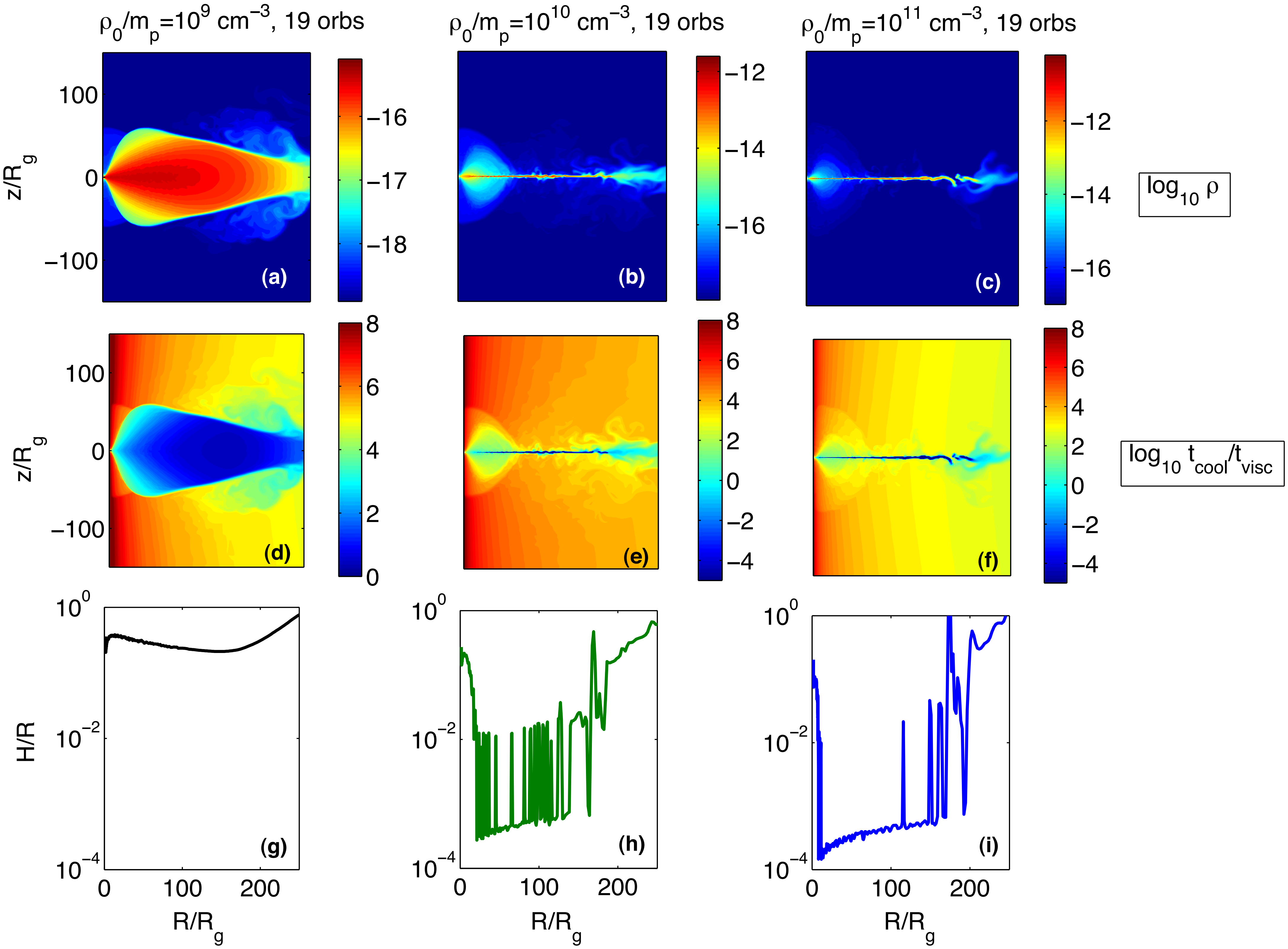
geometrically-thick optically-thin accretion flow with viscosity

Effects of cooling

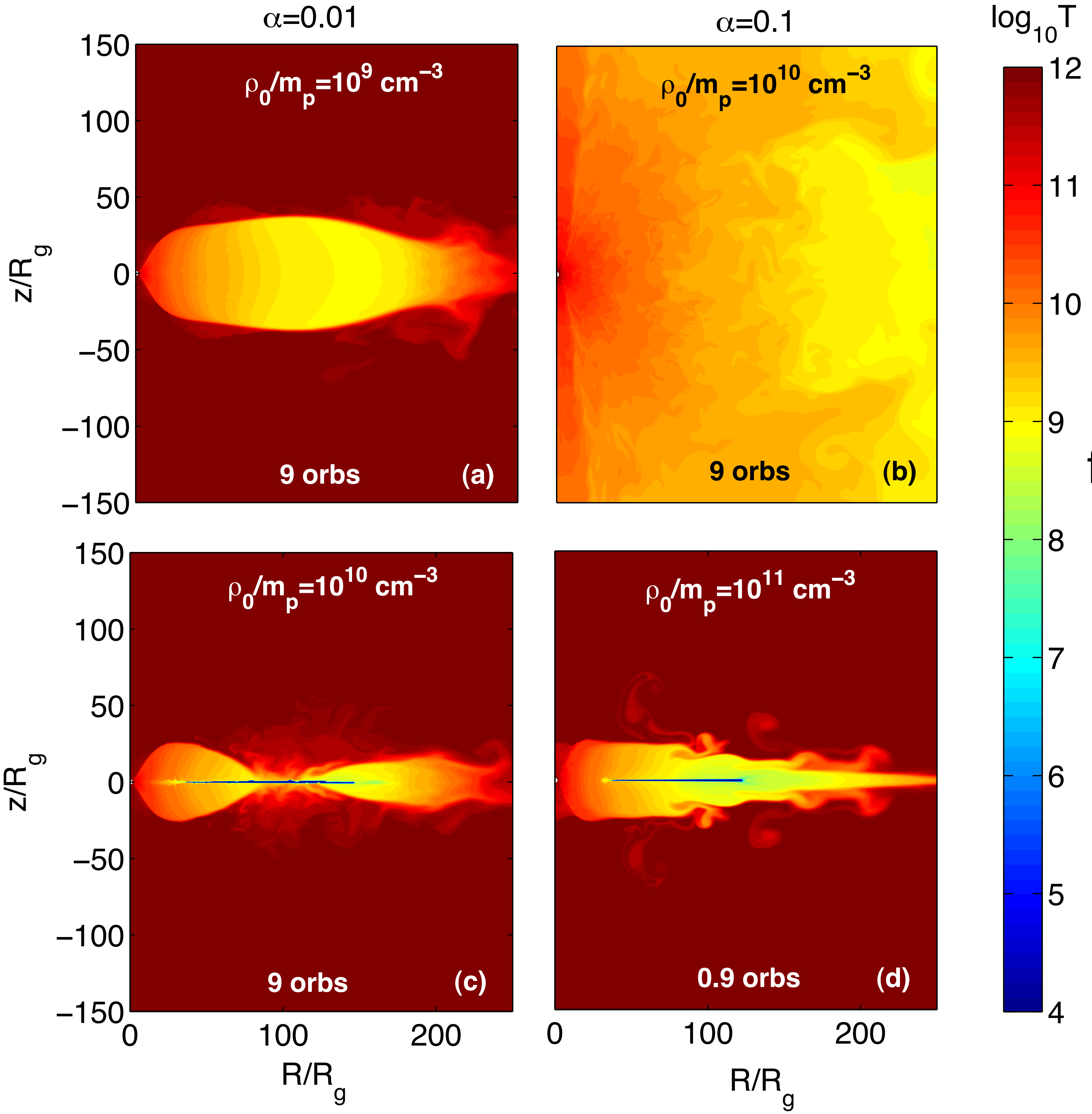


thin disk unresolved

$t_{cool}/t_{visc}<1$=>thin disk

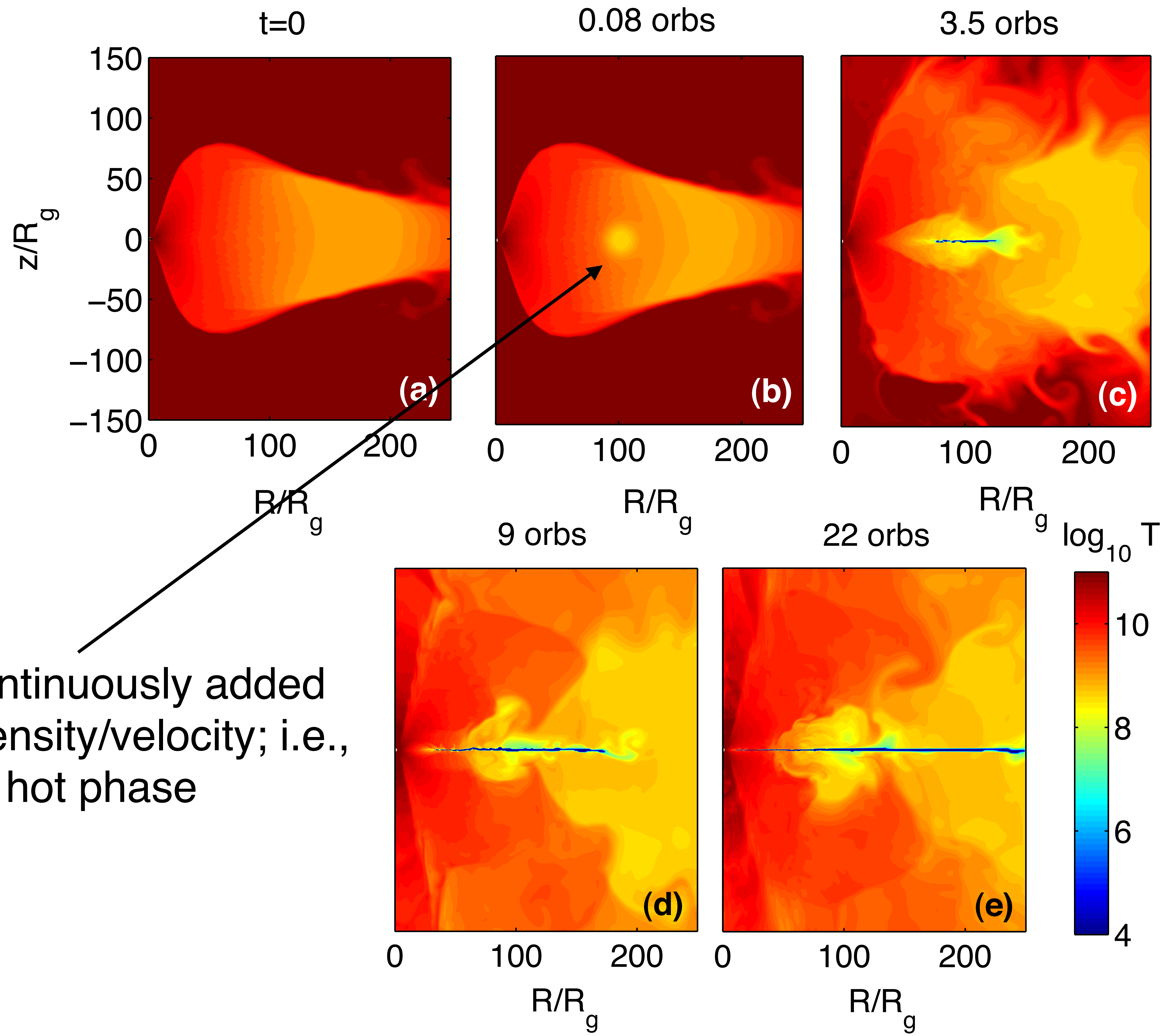


higher density for larger α



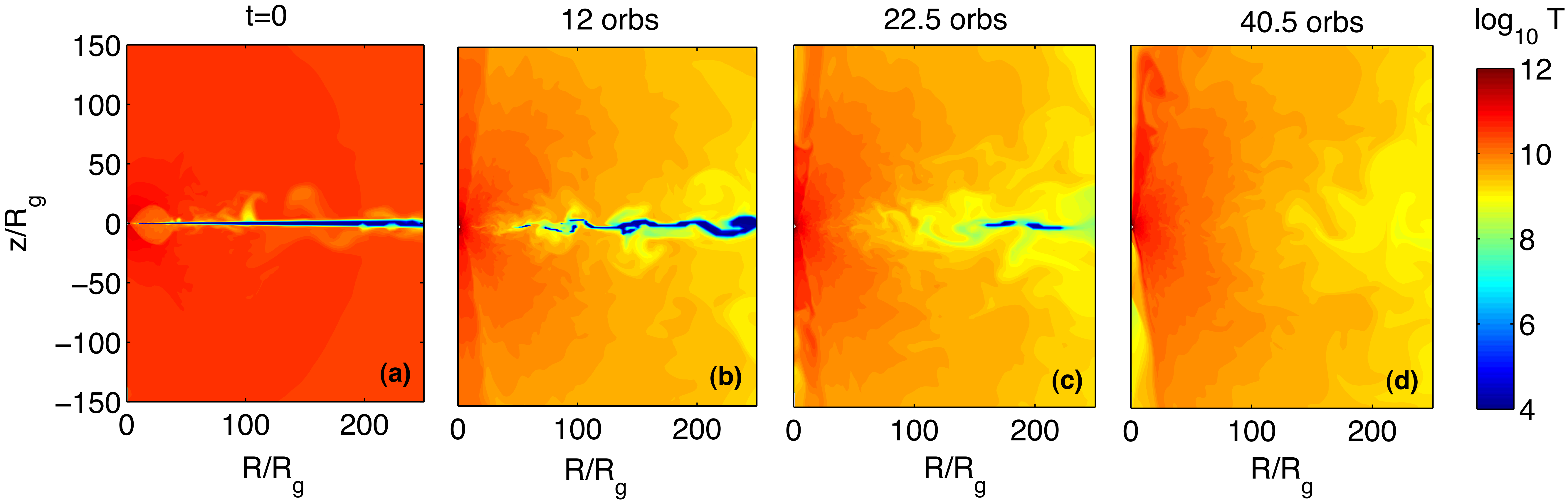
higher density required
for thin disk to form at high α
as expected from tcool/tvisc

RIAF to thin disk



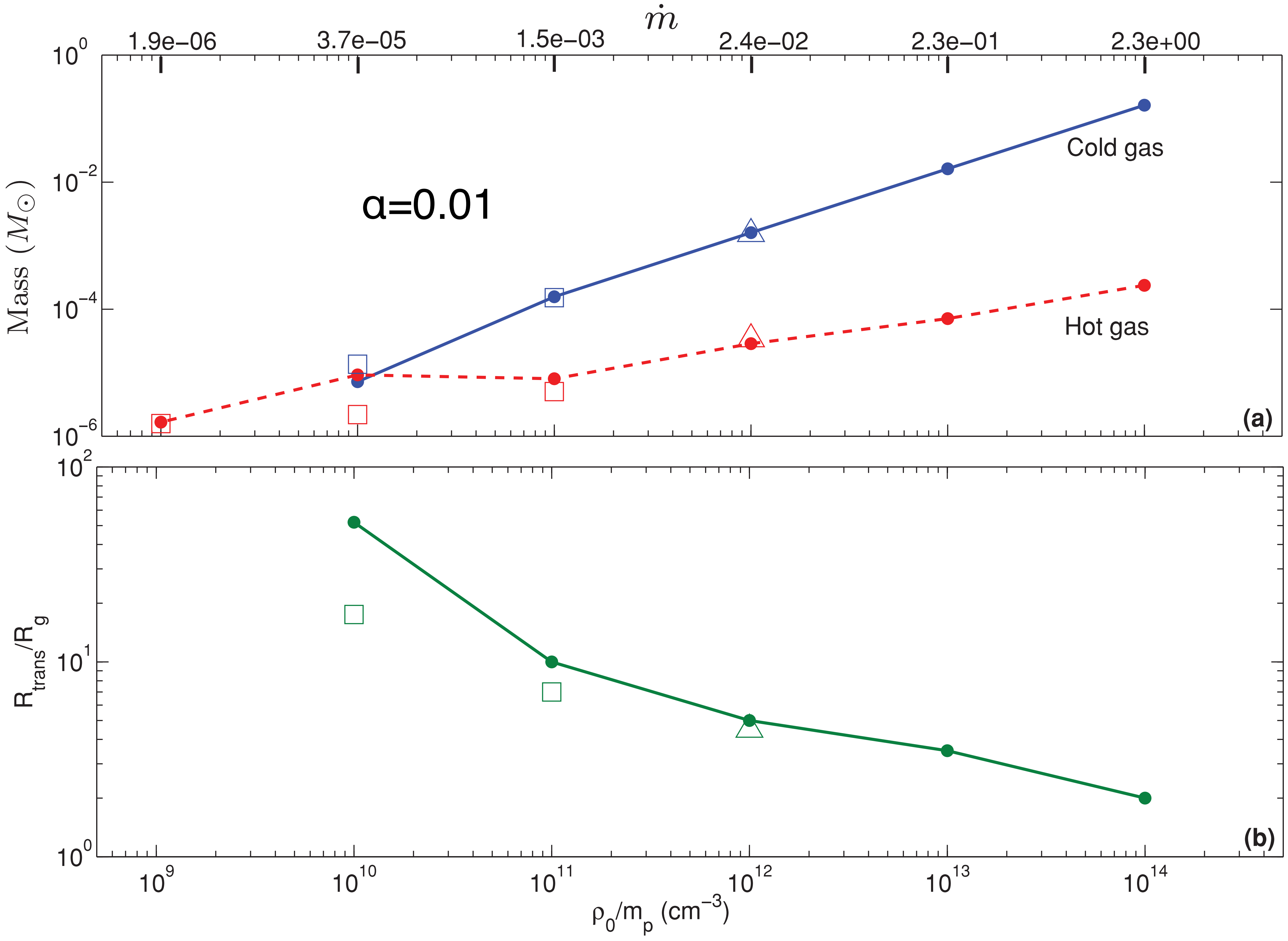
mass continuously added
at local density/velocity; i.e.,
in hot phase

Thin disk to RIAF

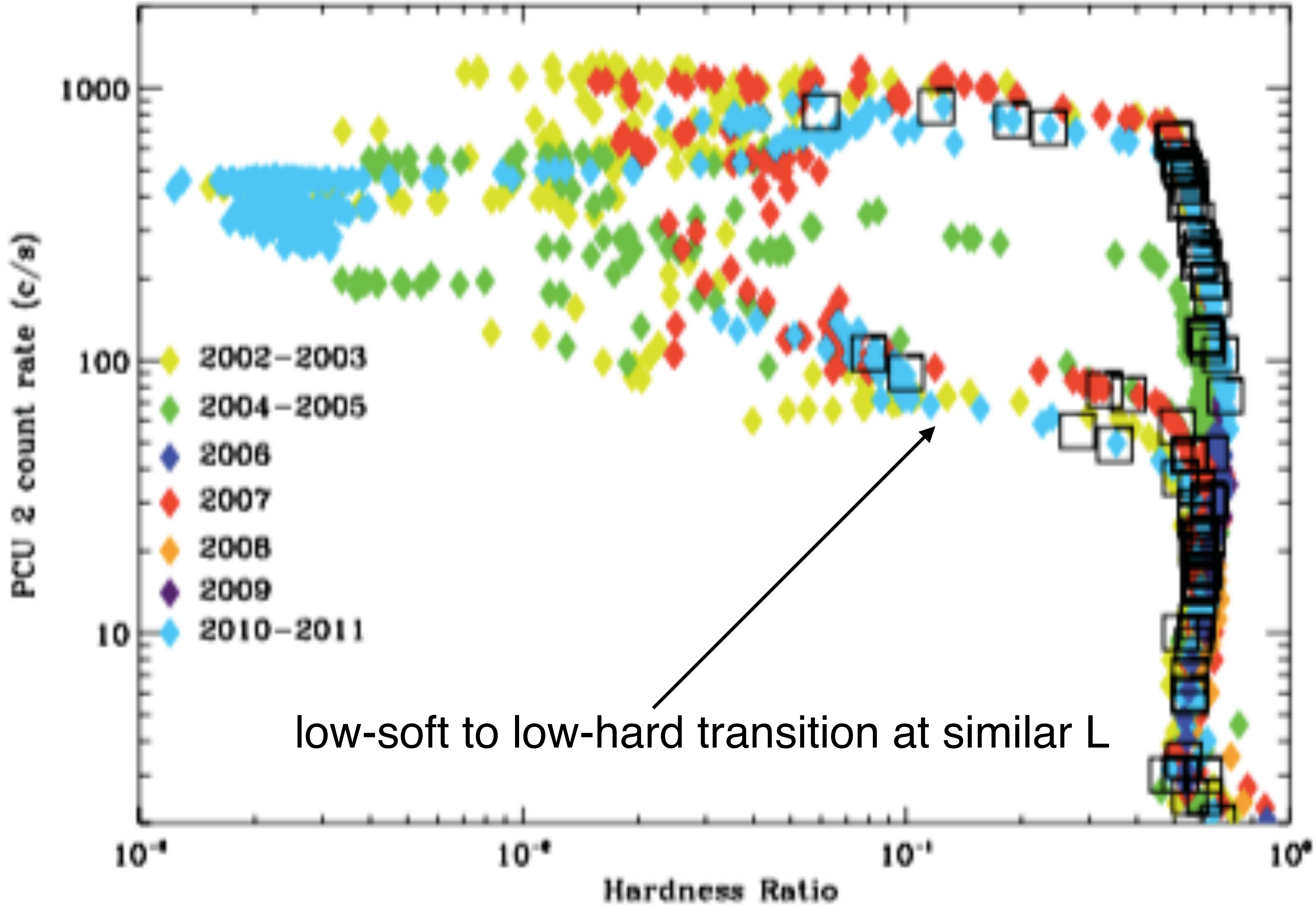


stop adding mass
cold gas is viscously depleted at ~ viscous time of mass peak
in reality outflows can also deplete thin AD

Transition radius vs mdot



q-plot hysteresis



low-soft to low-hard transition at similar L

our scenario

quite natural

mass addn. in hot phase

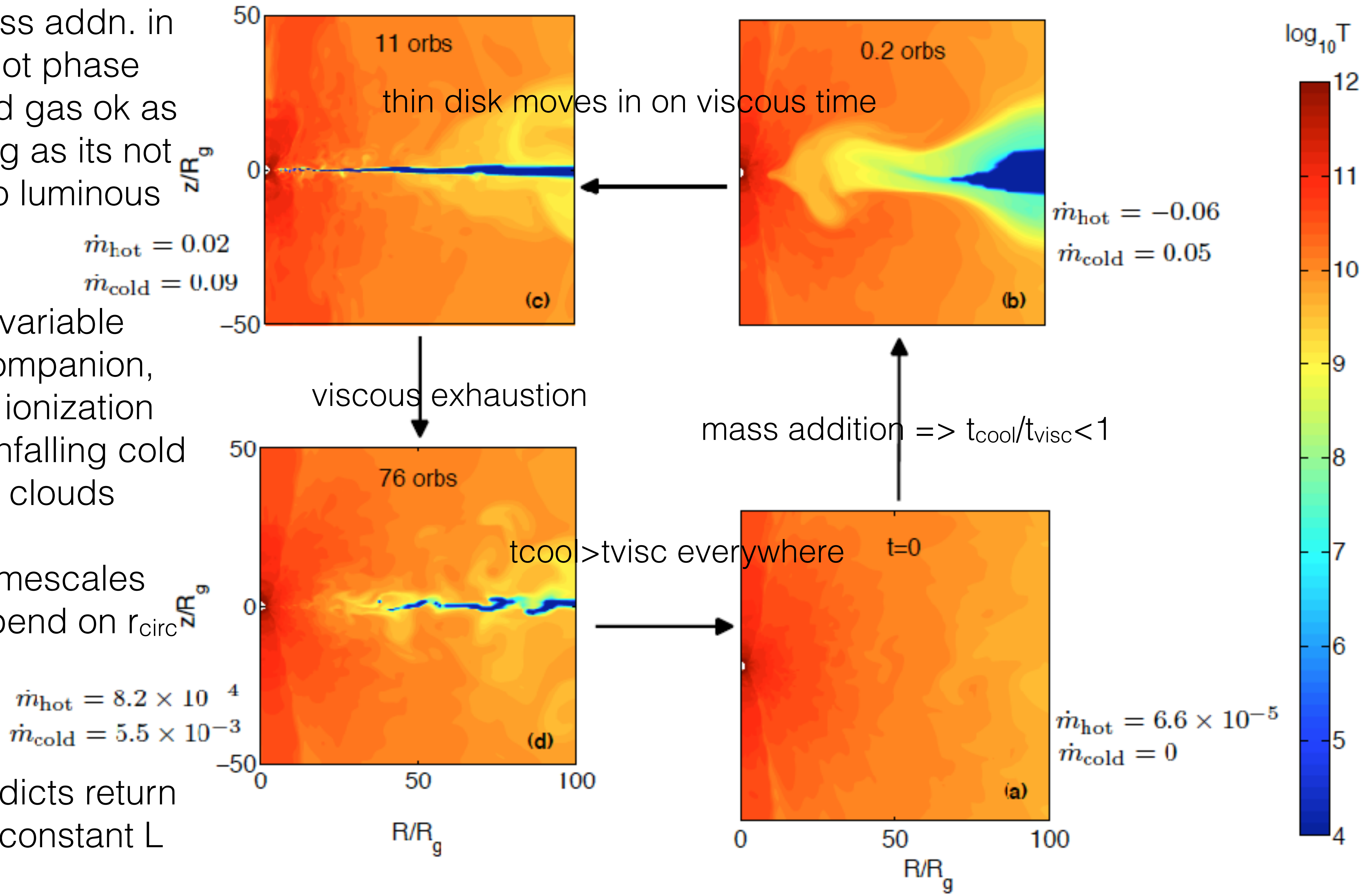
cold gas ok as long as its not too luminous

variable companion, H ionization

TI, infalling cold clouds

timescales depend on r_{circ}

predicts return at constant L



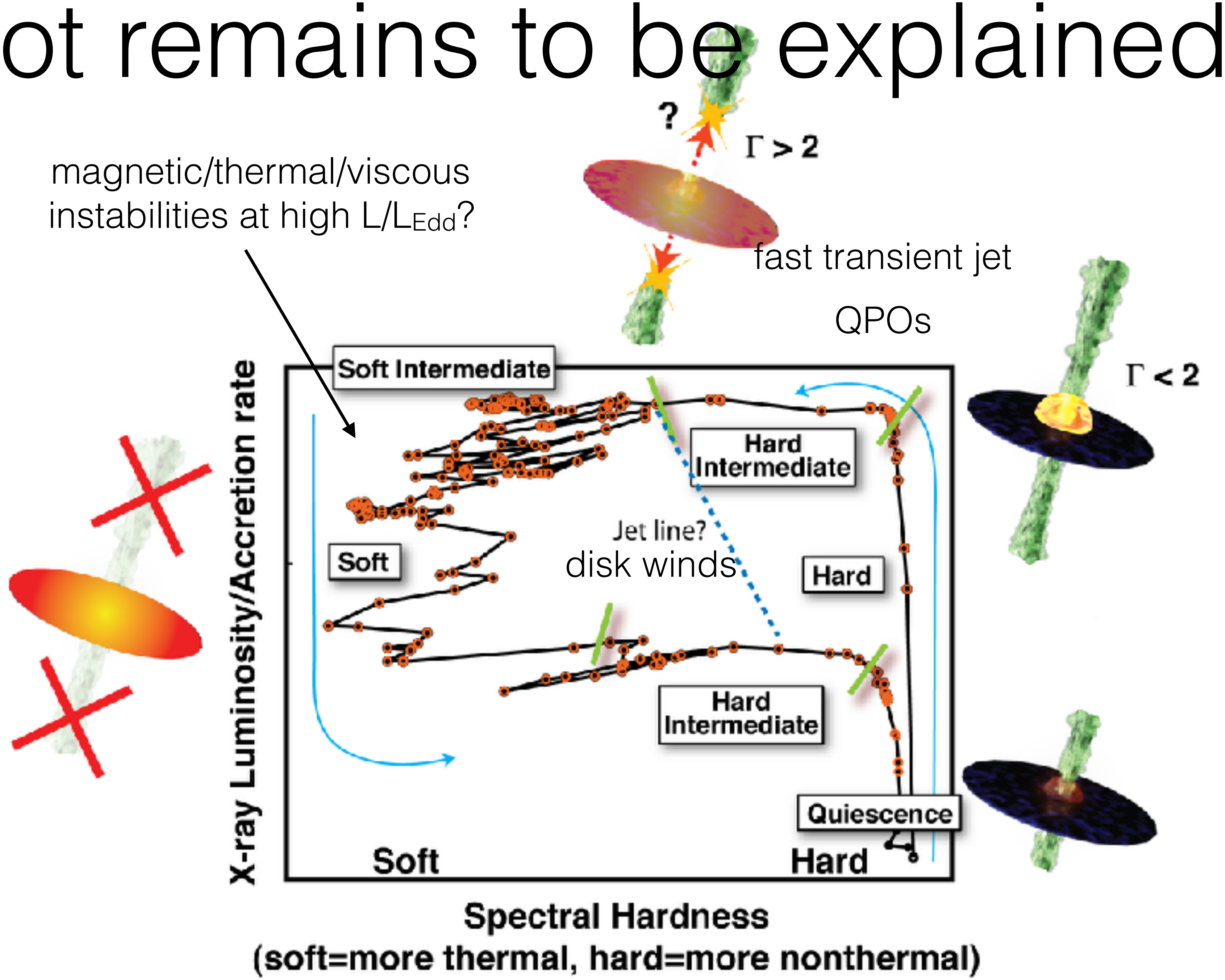
thin disk moves in on viscous time

viscous exhaustion

mass addition => $t_{cool}/t_{visc}<1$

tcool>tvisc everywhere

lot remains to be explained!



magnetic/thermal/viscous instabilities at high L/L_{Edd}?

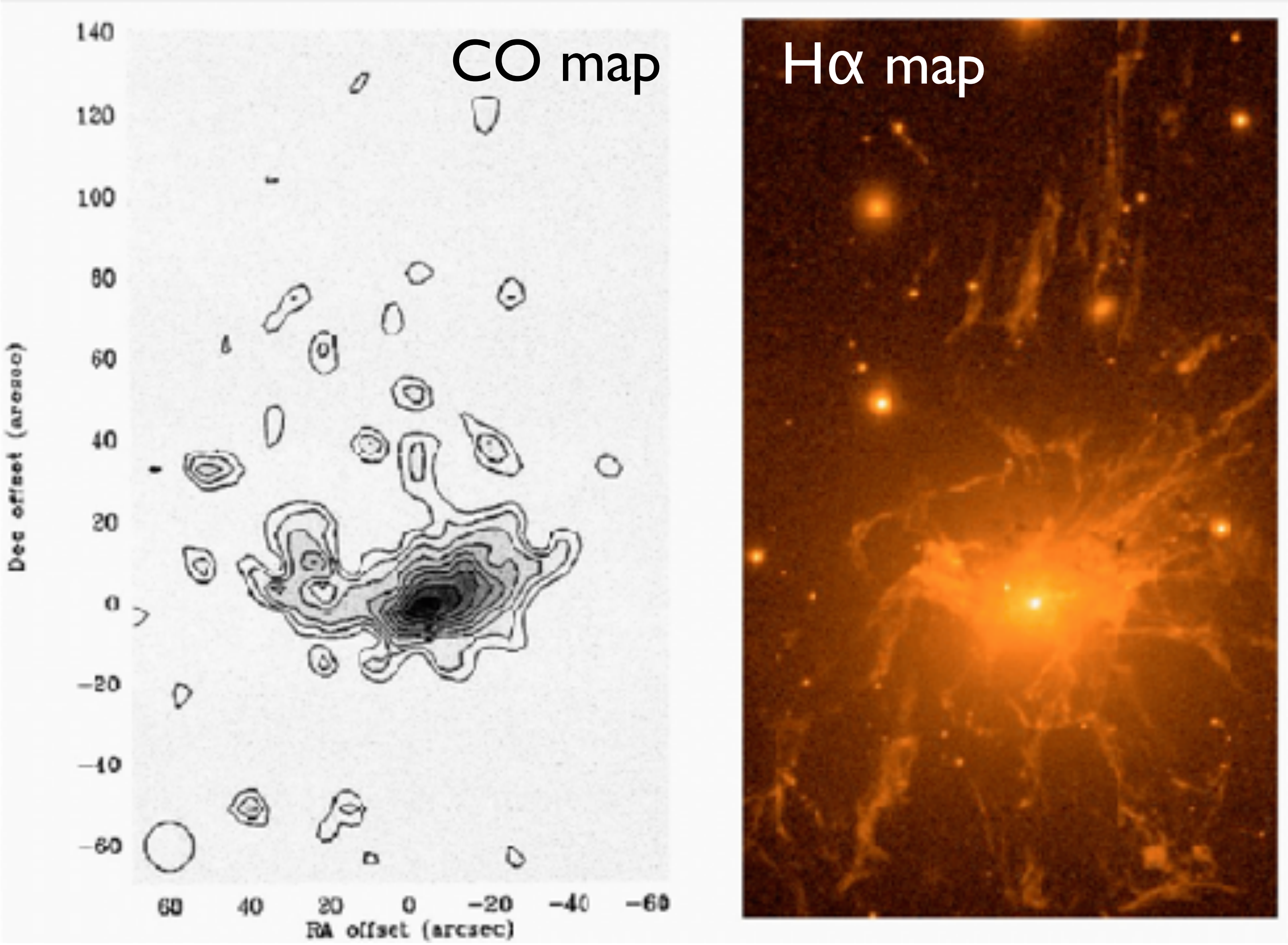
fast transient jet

QPOs

disk winds

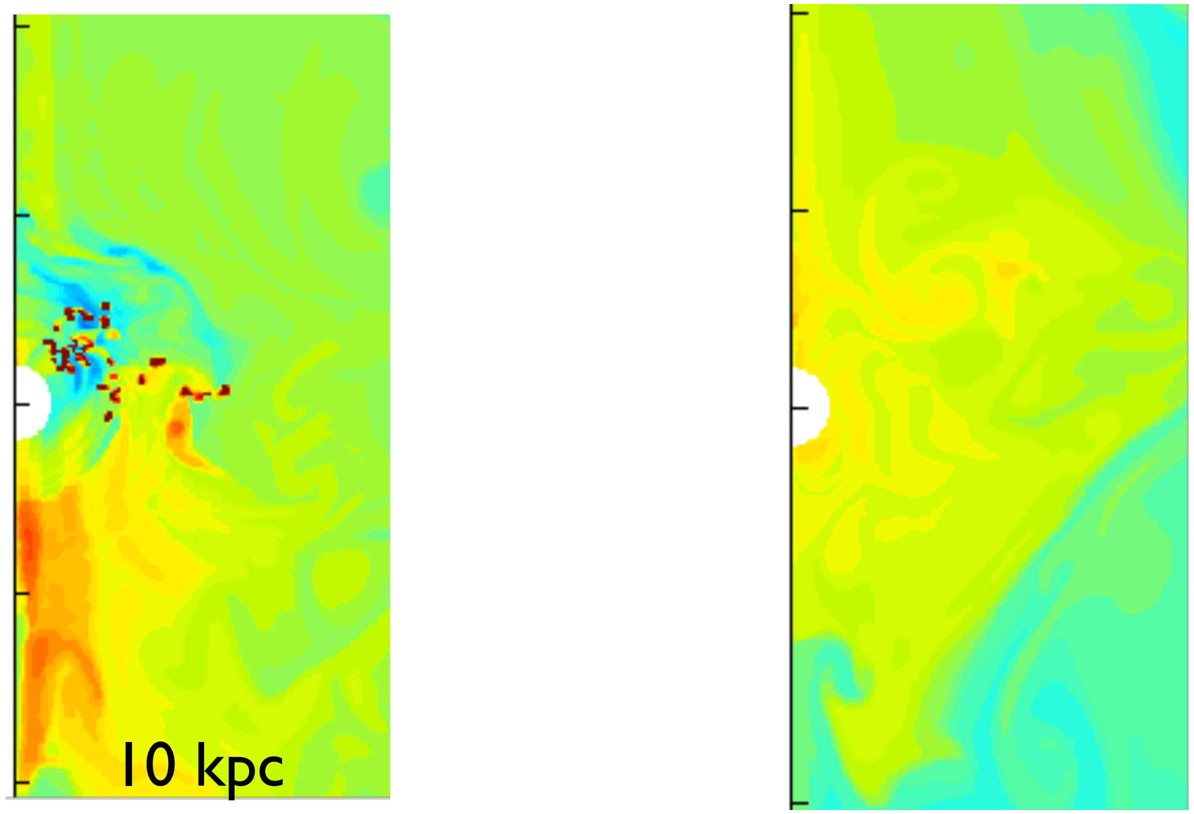
AGN fb in clusters/EGs

kinetic/maintenance/radio-mode



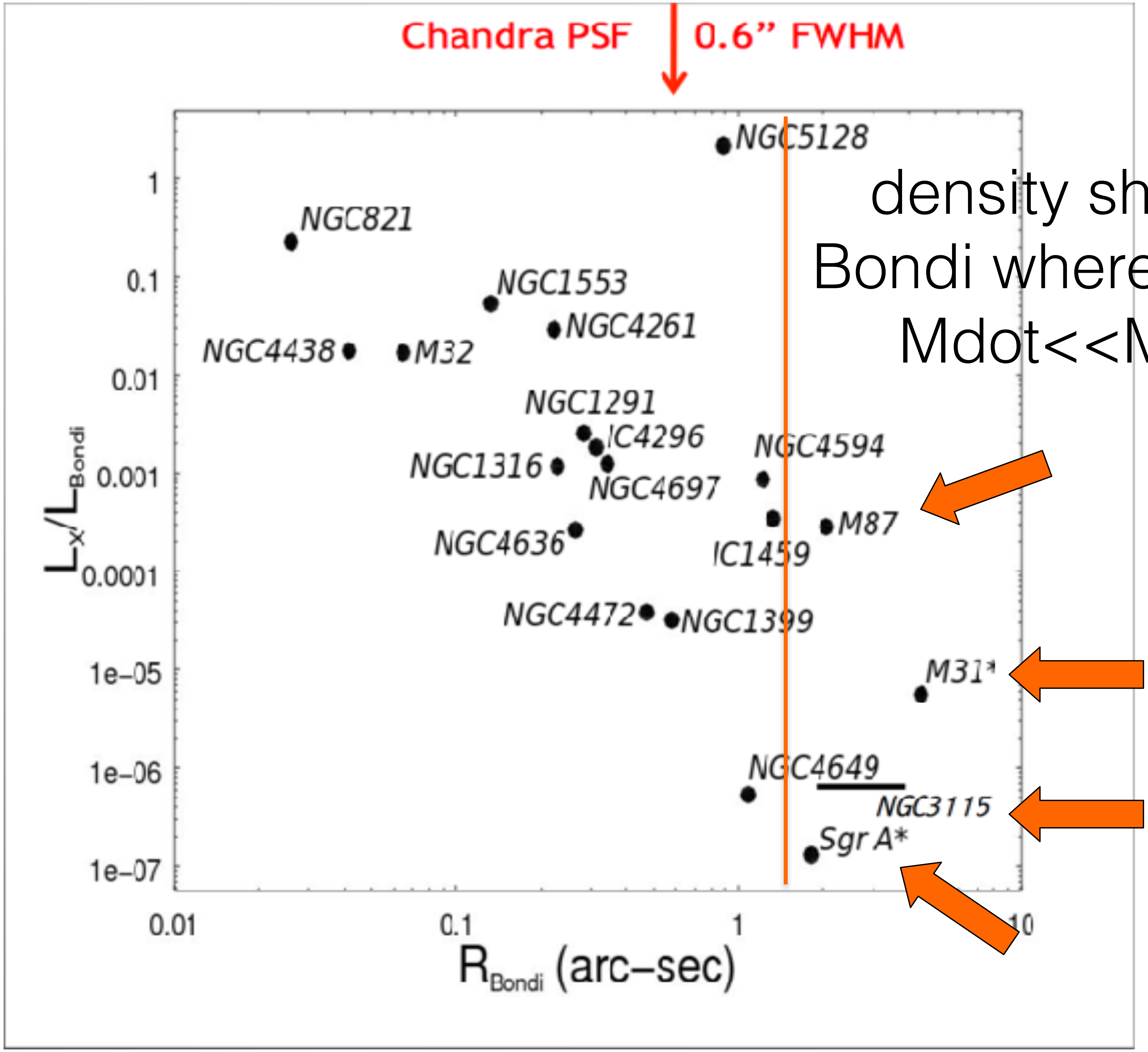
Perseus

cold filaments condense when $t_{cool}/t_{ff} \lesssim 10$



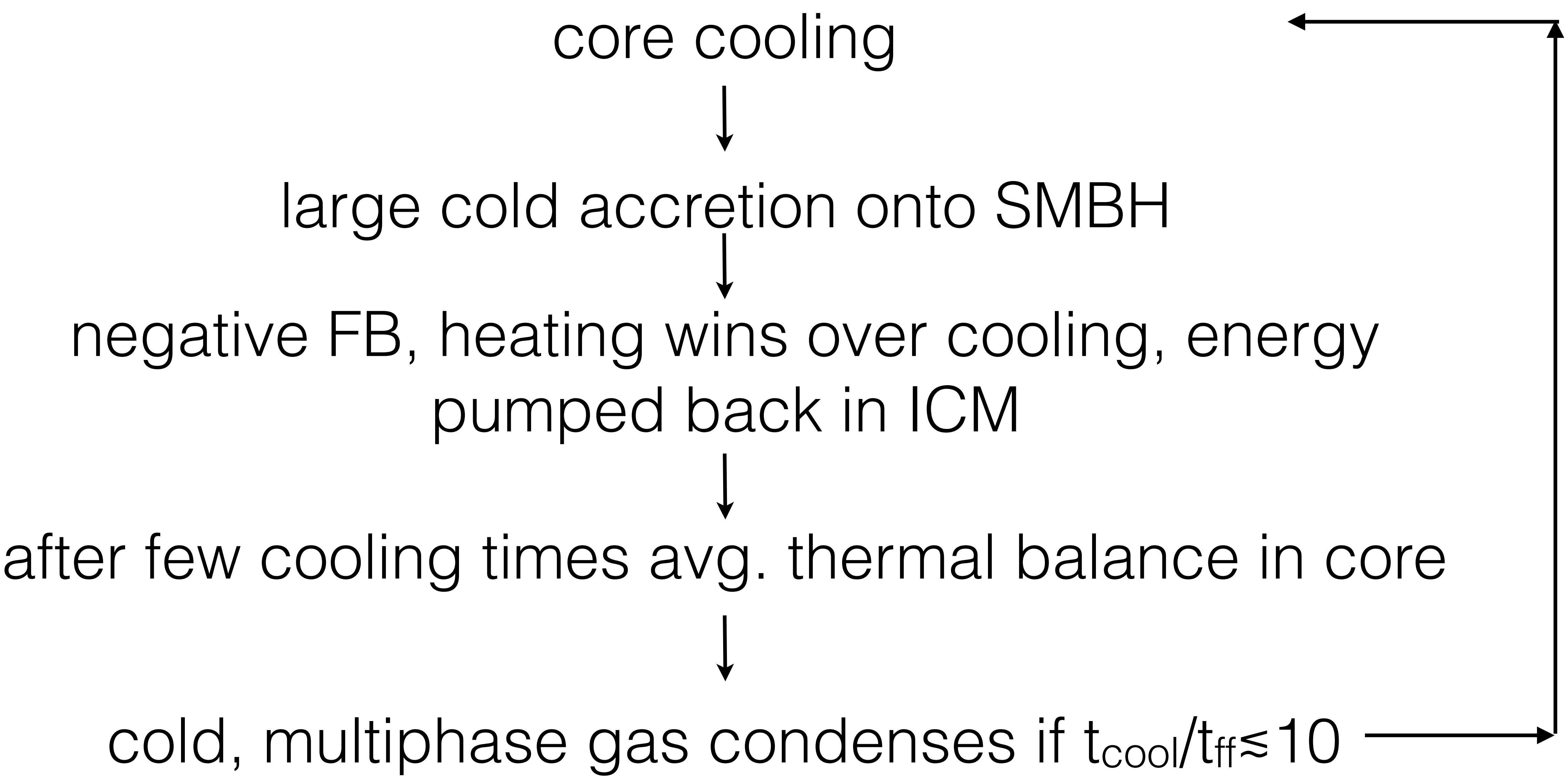
condensation of cold gas fundamentally changes accretion onto SMBH; stochastic accretion instead of smooth accretion from hot phase

Bondi accretion can't work



density shallower than Bondi wherever measured Mdot<<Mdot_Bondi

AGN feedback cycles



core cooling

large cold accretion onto SMBH

negative FB, heating wins over cooling, energy pumped back in ICM

after few cooling times avg. thermal balance in core

cold, multiphase gas condenses if $t_{cool}/t_{ff} \lesssim 10$

cooling & AGN jet heating cycles in cool-core clusters

AGN jet-ICM sims.

Deovrat Prasad

AGN jet-ICM sims.

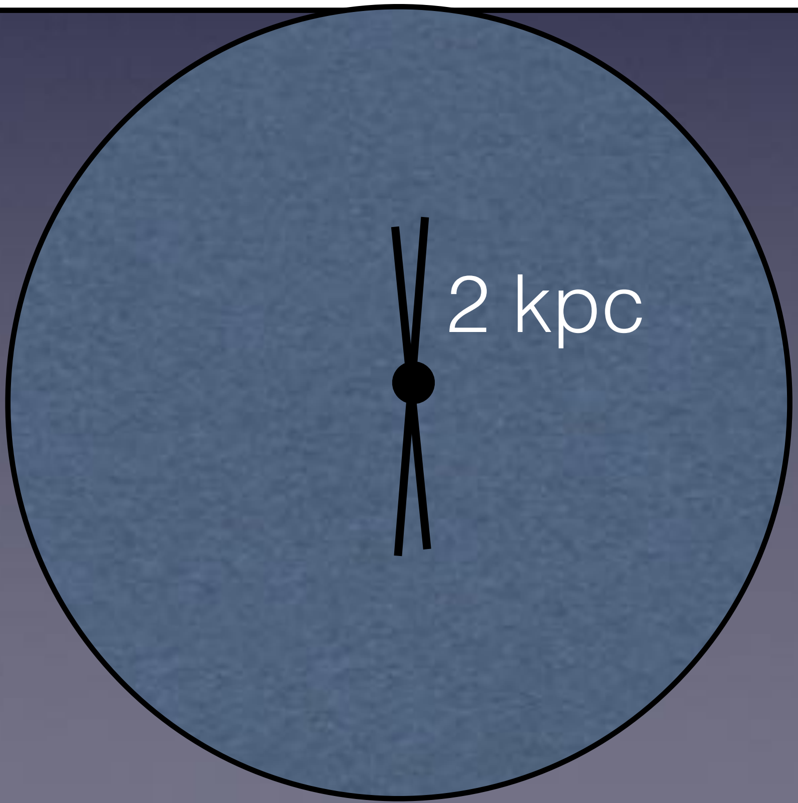
$$\frac{\partial \rho}{\partial t} + \nabla \cdot \rho \mathbf{v} = S_\rho$$

mass

$$\rho \left(\frac{\partial \mathbf{v}}{\partial t} + \mathbf{v} \cdot \nabla \mathbf{v} \right) = -\nabla p - \rho \nabla \Phi + S_\rho v_{\rm jet} \hat{\mathbf{r}}$$

momentum

$$\frac{p}{\gamma - 1} \frac{d}{dt} \ln(p/\rho^\gamma) = -n^2 \Lambda$$

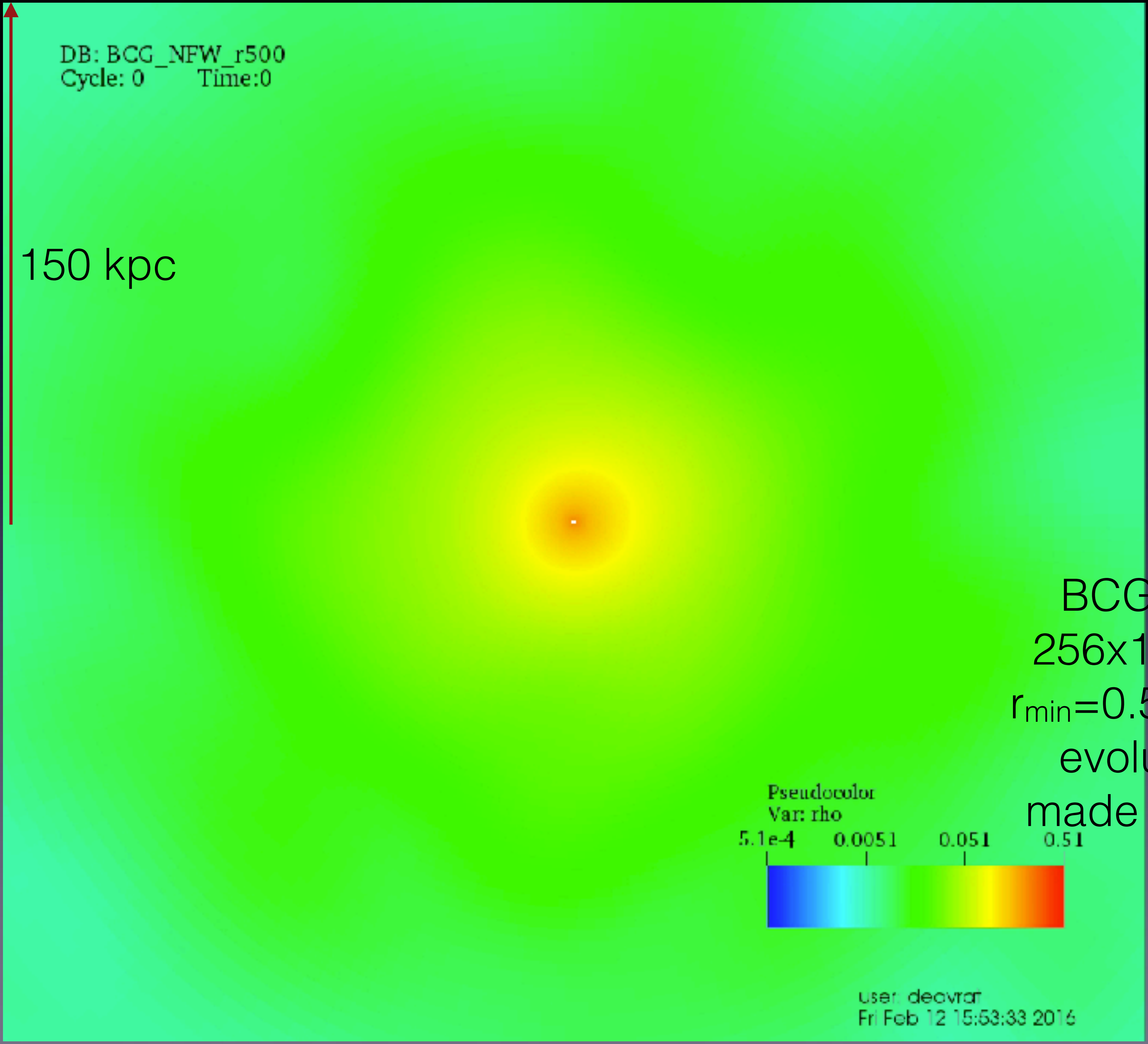


source term applied in a small bipolar cone at the center: opening angle of 30^0, size 2 kpc

$$\dot{M}_{\rm jet} v_{\rm jet}^2 = \epsilon \dot{M}_{\rm acc} c^2$$

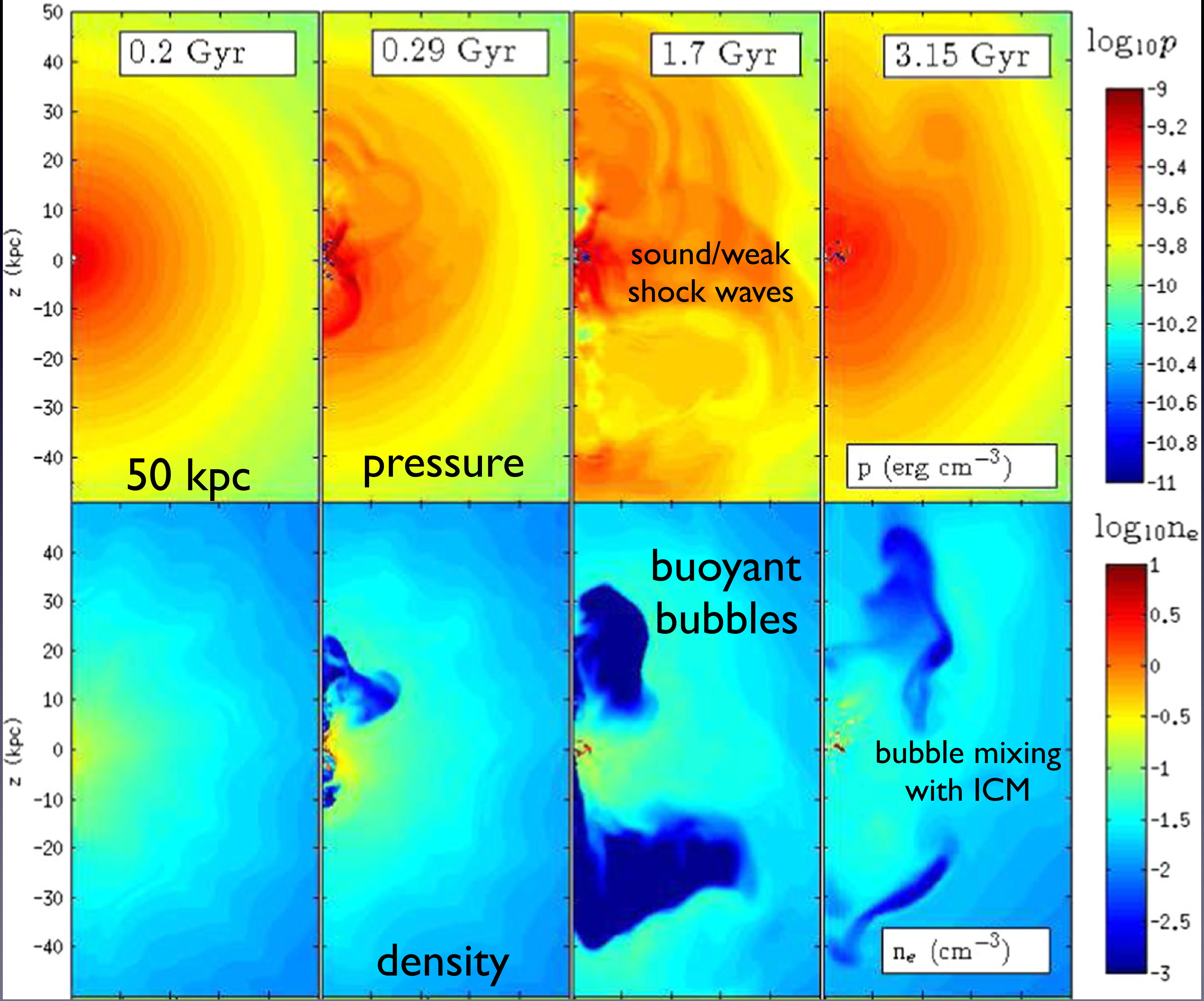
$v_{\rm jet}=0.1c$, $\varepsilon=6\times10^{-5}$, $r_{\rm in,out}=1$, 200 kpc
robust to variations

Density movie



BCG+NFW in PLUTO
256x128x32 in (logr,θ,ϕ)
r_{min}=0.5 kpc, r_{max}=0.5 Mpc
evolution for ~2.8 Gyr
made by Deovrat Prasad

r-θ slices



50 kpc

pressure

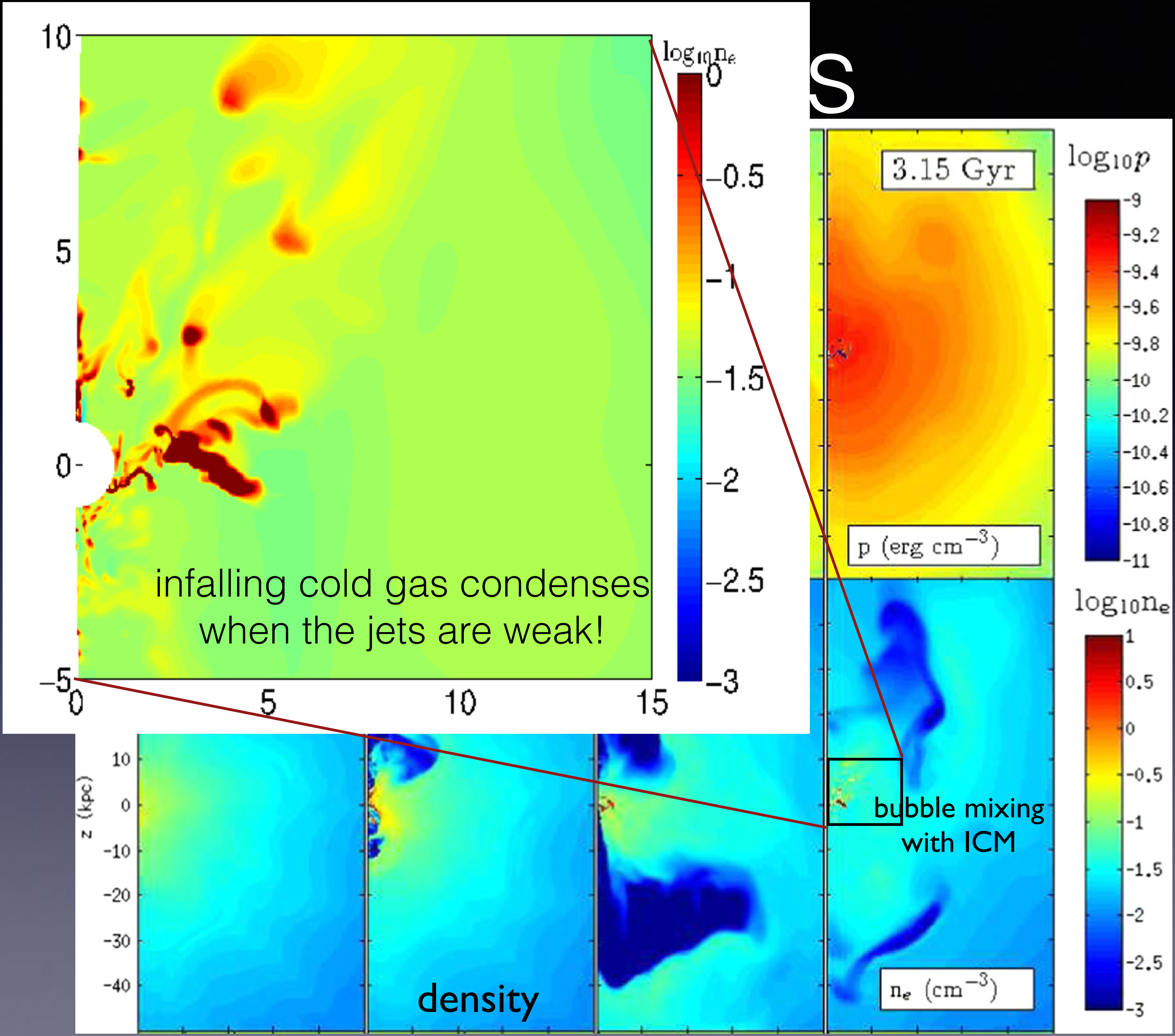
sound/weak shock waves

density

buoyant bubbles

bubble mixing with ICM

S



infalling cold gas condenses when the jets are weak!

bubble mixing with ICM

density

Angular momentum problem

$$t_{\rm visc} \sim \frac{1}{\alpha(H/R)^2\Omega_K}$$

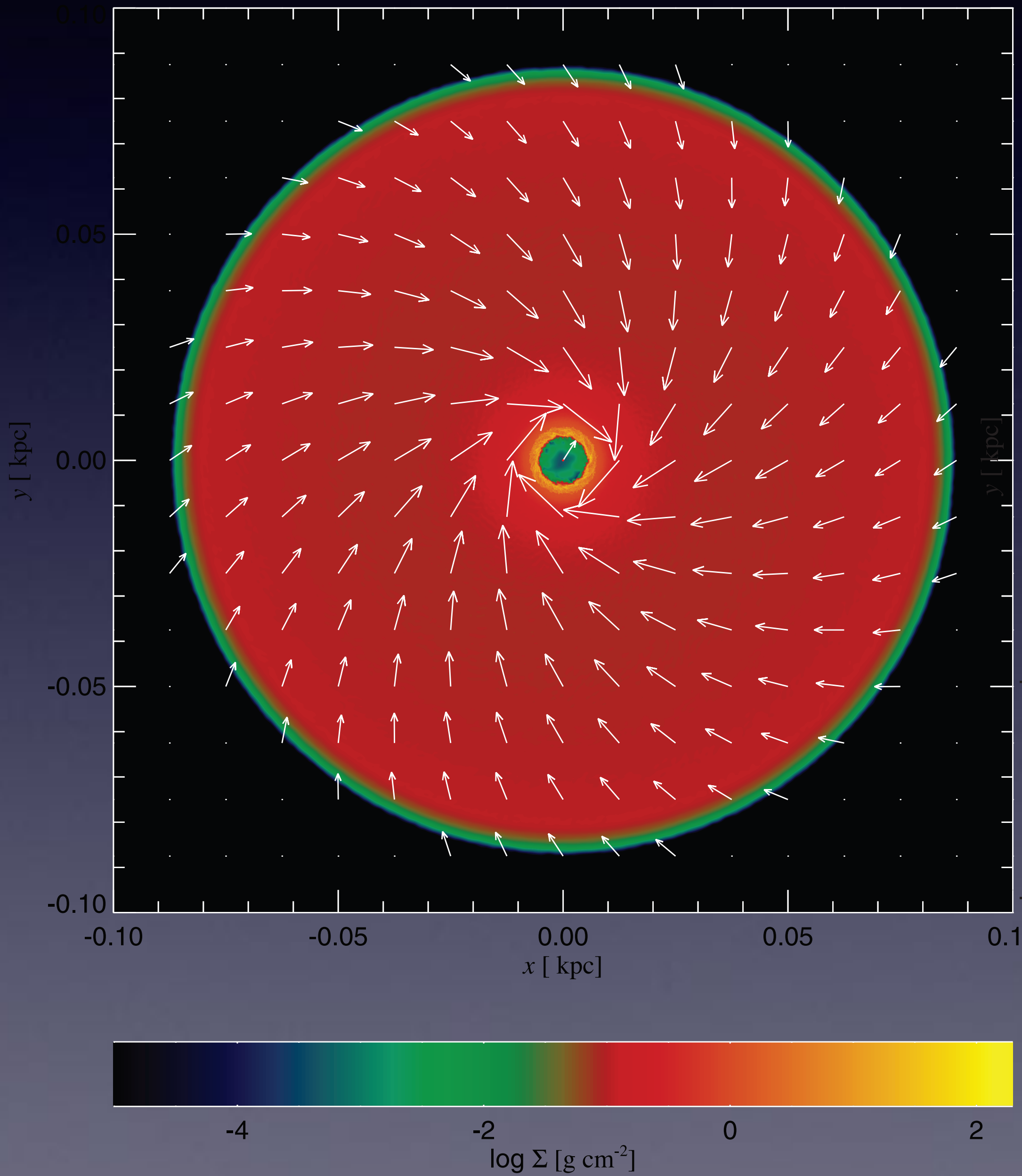
too long if $H/R \sim 10^{-3}$,
of standard AGN thin disks
moreover, star formation
where M_d/M_{BH} exceeds H/R

$$t_{\rm visc} \sim 4.7\ {\rm Gyr}\ \left(\frac{R}{1{\rm pc}}\right)^{3/2}\left(\frac{H/R}{0.001}\right)^{-2}\left(\frac{\alpha}{0.01}\right)^{-1}$$

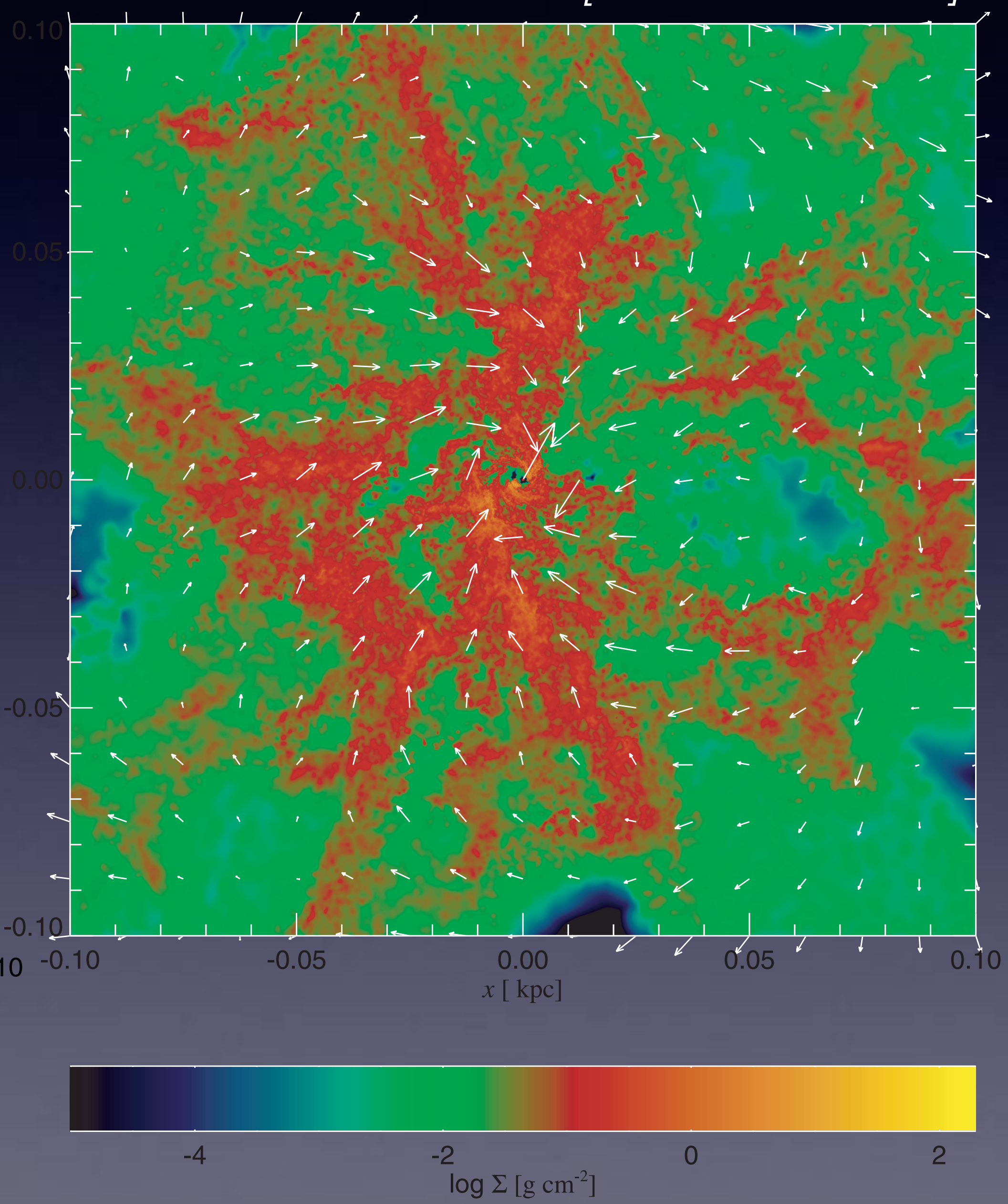
must avoid a large thin disk
$t_{\rm visc}$ < core cooling time

Stochastic accretion

[Hobbs et al. 2011]

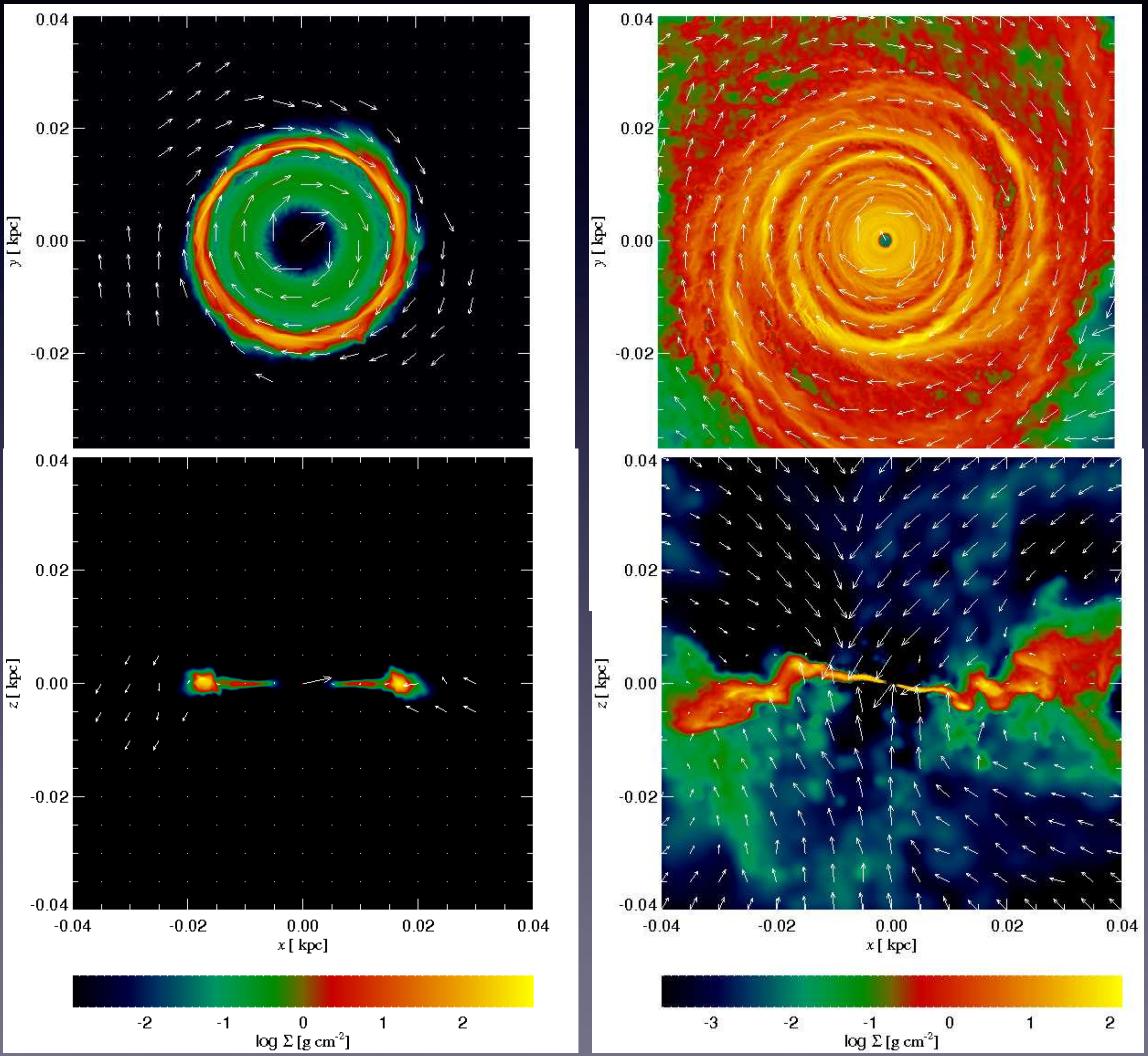


large, laminar disk



turbulent flow ($\sigma \approx v_\Phi$) extending down to small r

Stochastic accretion



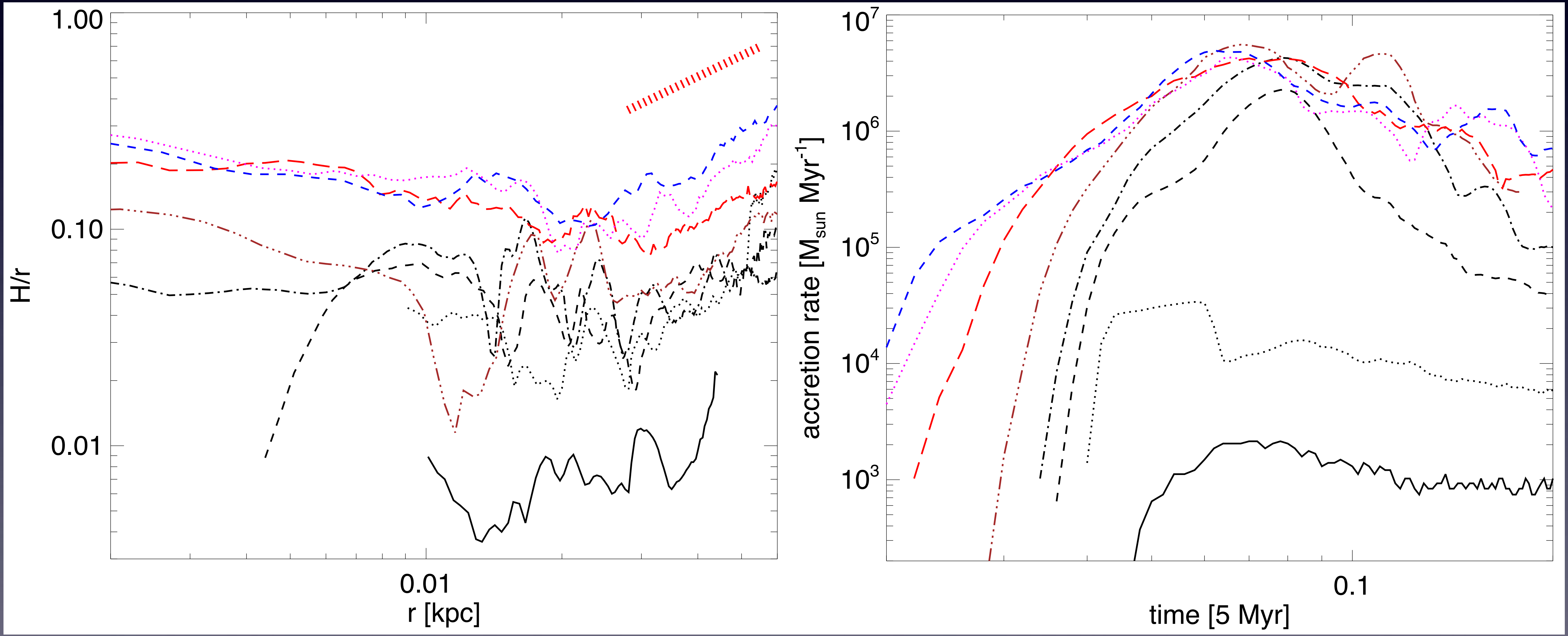
[Hobbs et al. 2011]

ang mom cancellation in stochastic accretion

smaller disk with short enough acc time

Stochastic accretion

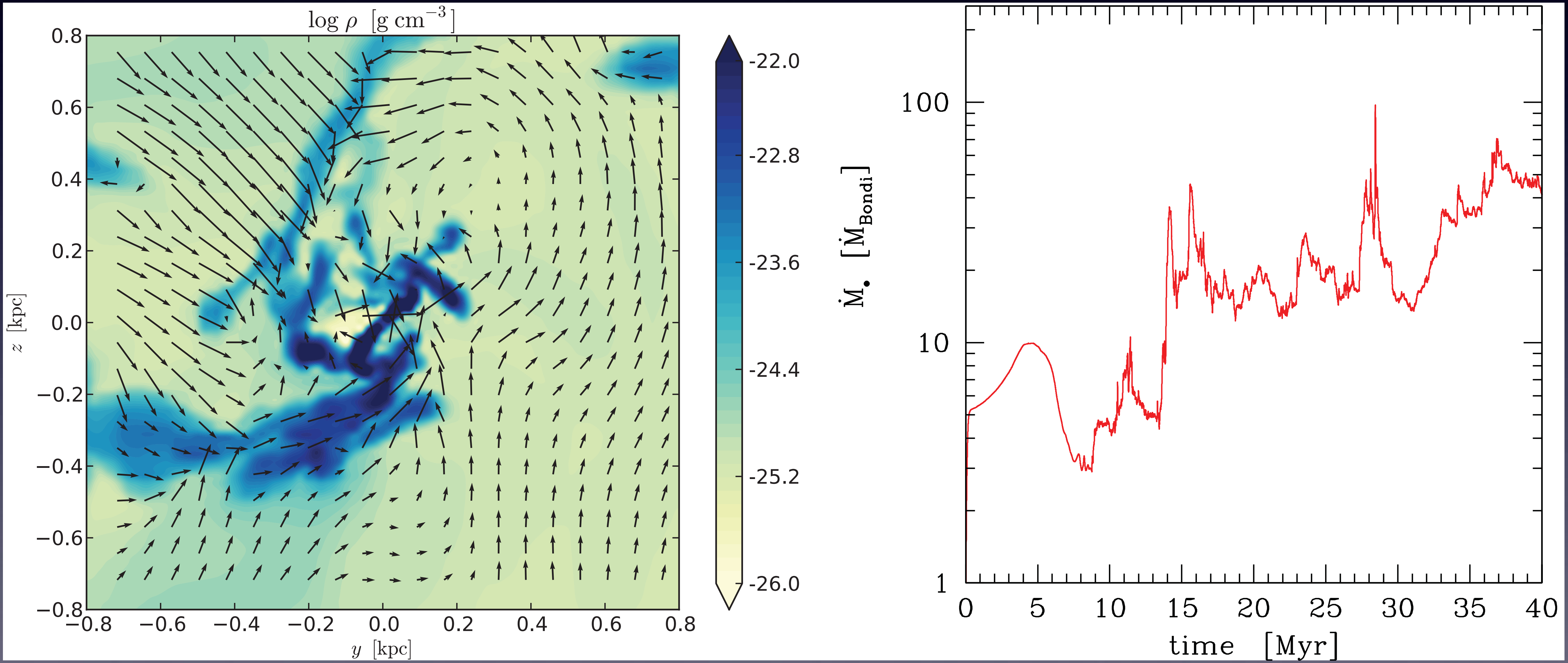
[Hobbs et al. 2011]



H/R large enough to prevent fragmentation; M_{dot} larger by 10^3!

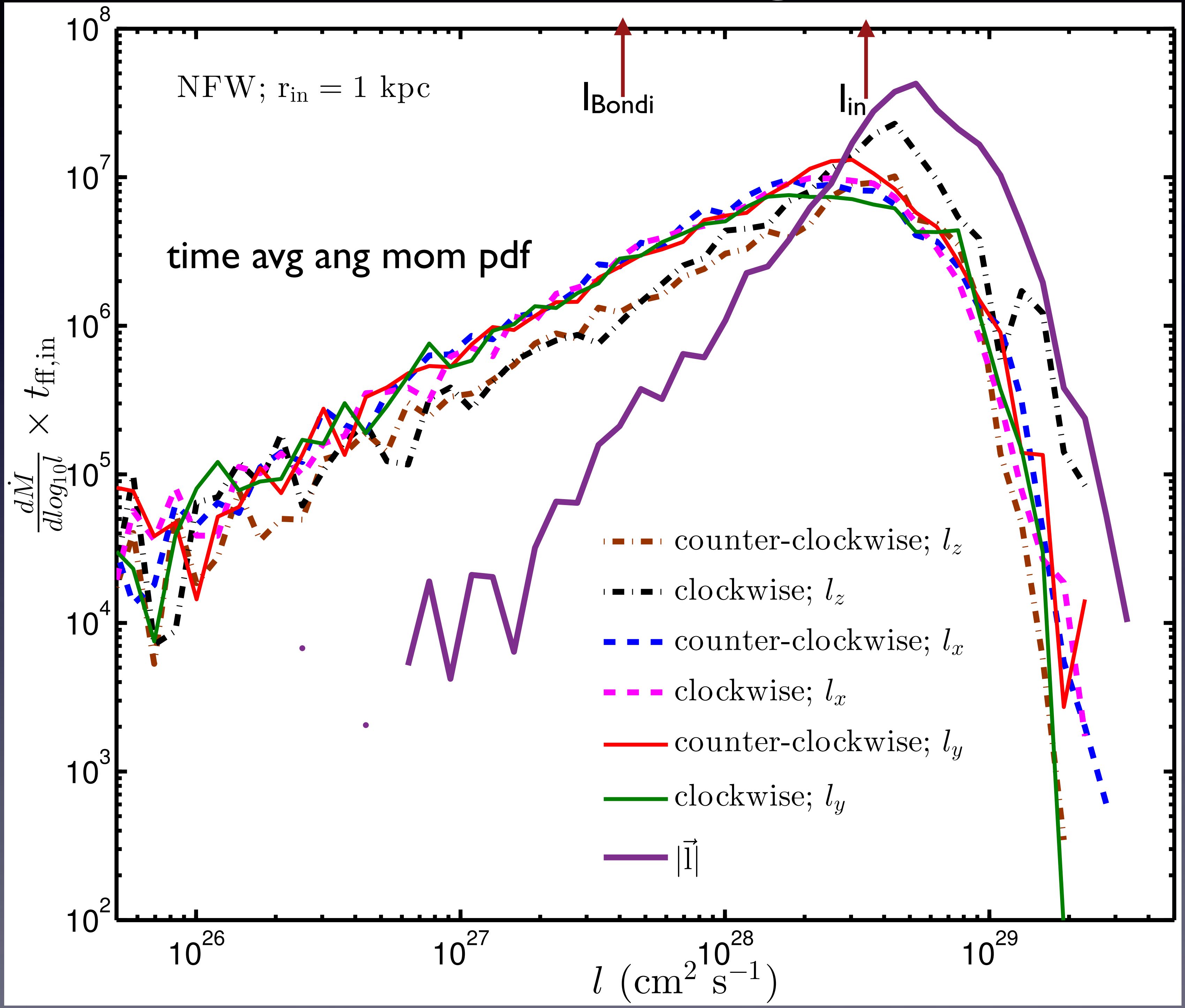
Stochastic accretion

[Gaspari et al. 2013]



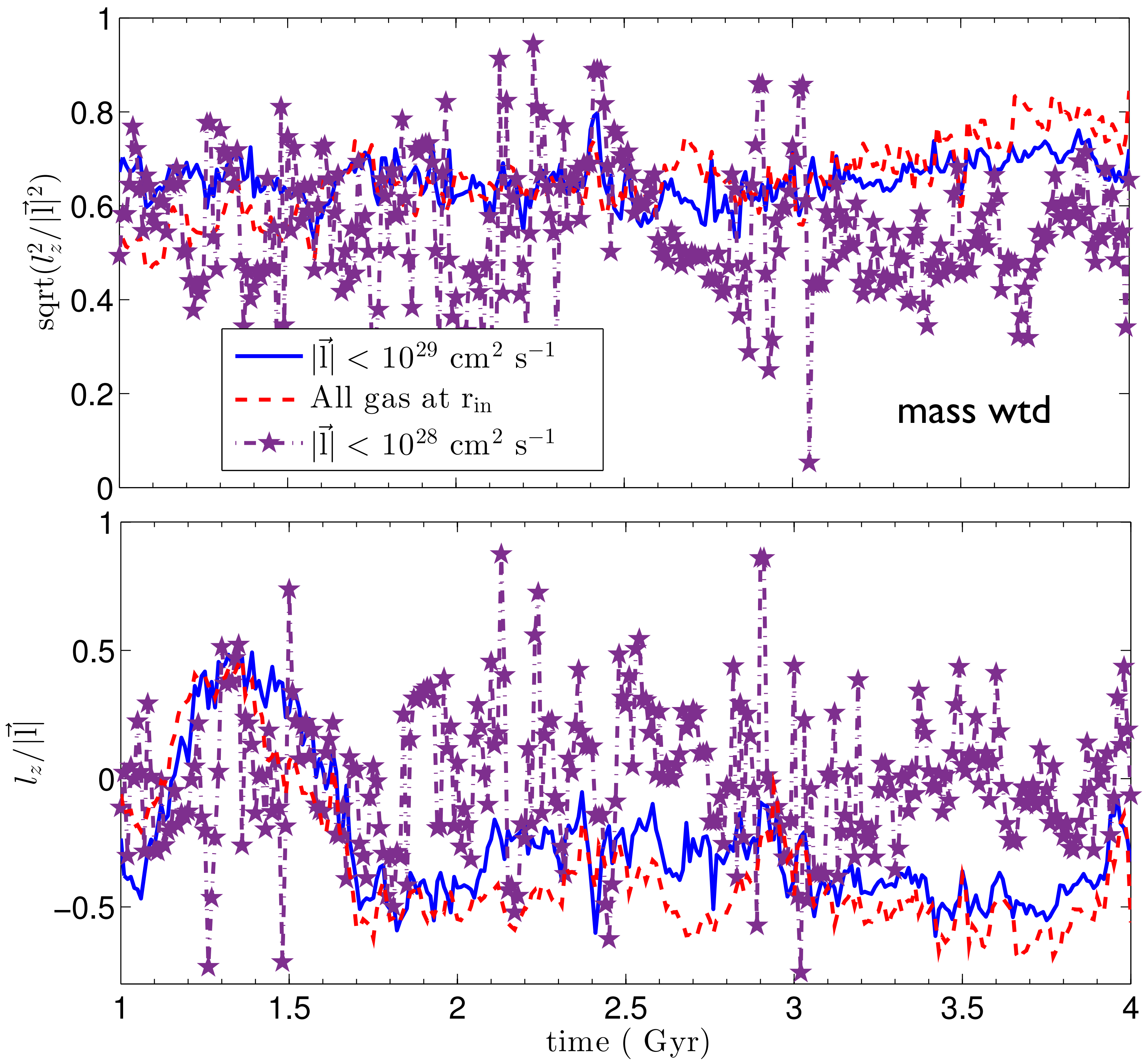
instantaneous M_{dot} can be up to 100 time the Bondi value based on sims with idealized turbulence, what abt with jets?

cold l-distr in jet sims



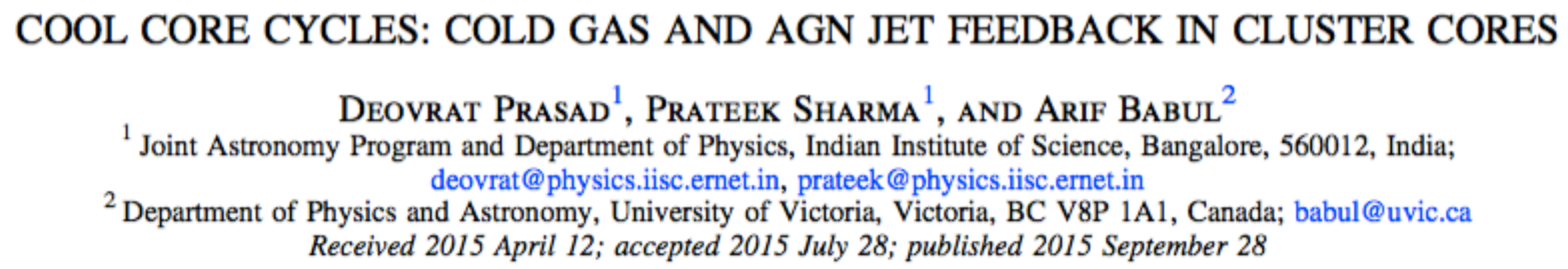
our jet-ICM simulations show that stochastic cold accretion may be realized

time variability of l



low l gas angular momentum changes on < core cooling time

check these out!



COOL CORE CYCLES: COLD GAS AND AGN JET FEEDBACK IN CLUSTER CORES

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AGN jets driven stochastic cold accretion in cluster cores

arXiv:1611.02710

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Summary

- a scenario to explain q-plot: which process adds hot gas? predicts transition back to quiet state at constant L; much more to know: QPOs, jets, disk winds,…

- cold cloud feedback drives radio mode feedback; cool core cycles

- next frontier: feeding SMBH from ~1 kpc to 10^{-3} pc; angular momentum cancellation; H/R of turbulent disks; fragmentation/SF; state of multiphase inflow as it moves deeper in;…

Thank You