Star formation in forming galactic disks under UVB by RSPH

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Susa ApJ 684, 226, 2008

Ultraviolet Background (>13.6eV)

- Physical processes
  - ✓ heating : T ∼10^4 K
  - ✓ ionization+dissociation

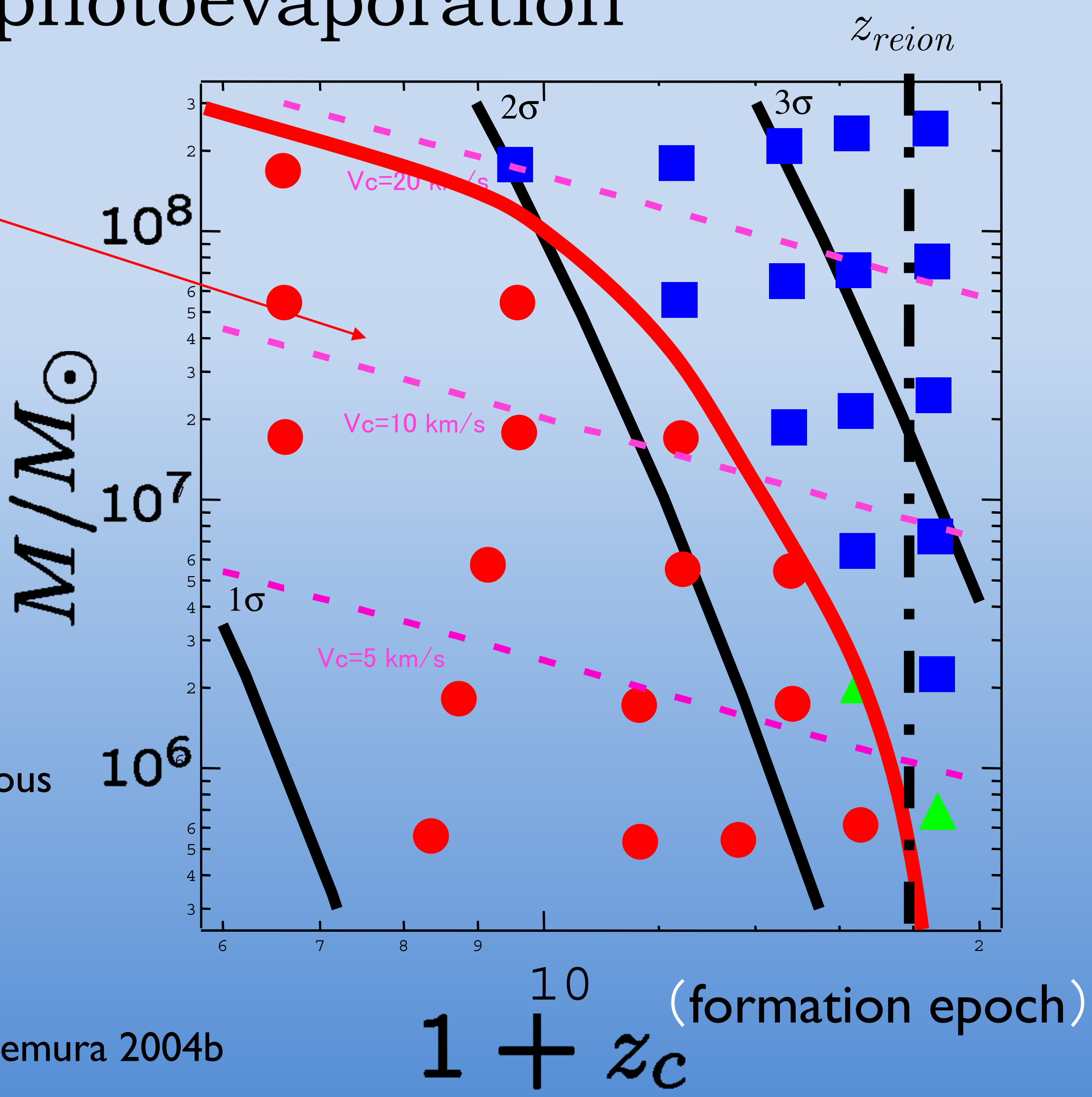
- strength
  - ✓ I_{21} < 0.01 @ z > 6
  - ✓ I_{21}= 0.1 - 1 @ z= 2 – 5
  - ✓ I_{21}=0.01- 0.001 @ z=0

⇒ Keep the gas in the proto-galaxies hot (∼ 10^4 K).

Feedback on star formation?

Low mass gals.(<10^8Msun) → photoevaporation

Photoevaporated



M<10^8 Msun and
Δ<2σ
→ Cannot evolve into luminous galaxies

Susa & Umemura 2004b

Aim of this work

- Assess the effects of UVB on massive DM halos with Tvir > 10^4K. Star formation in these systems are regulated or not ?

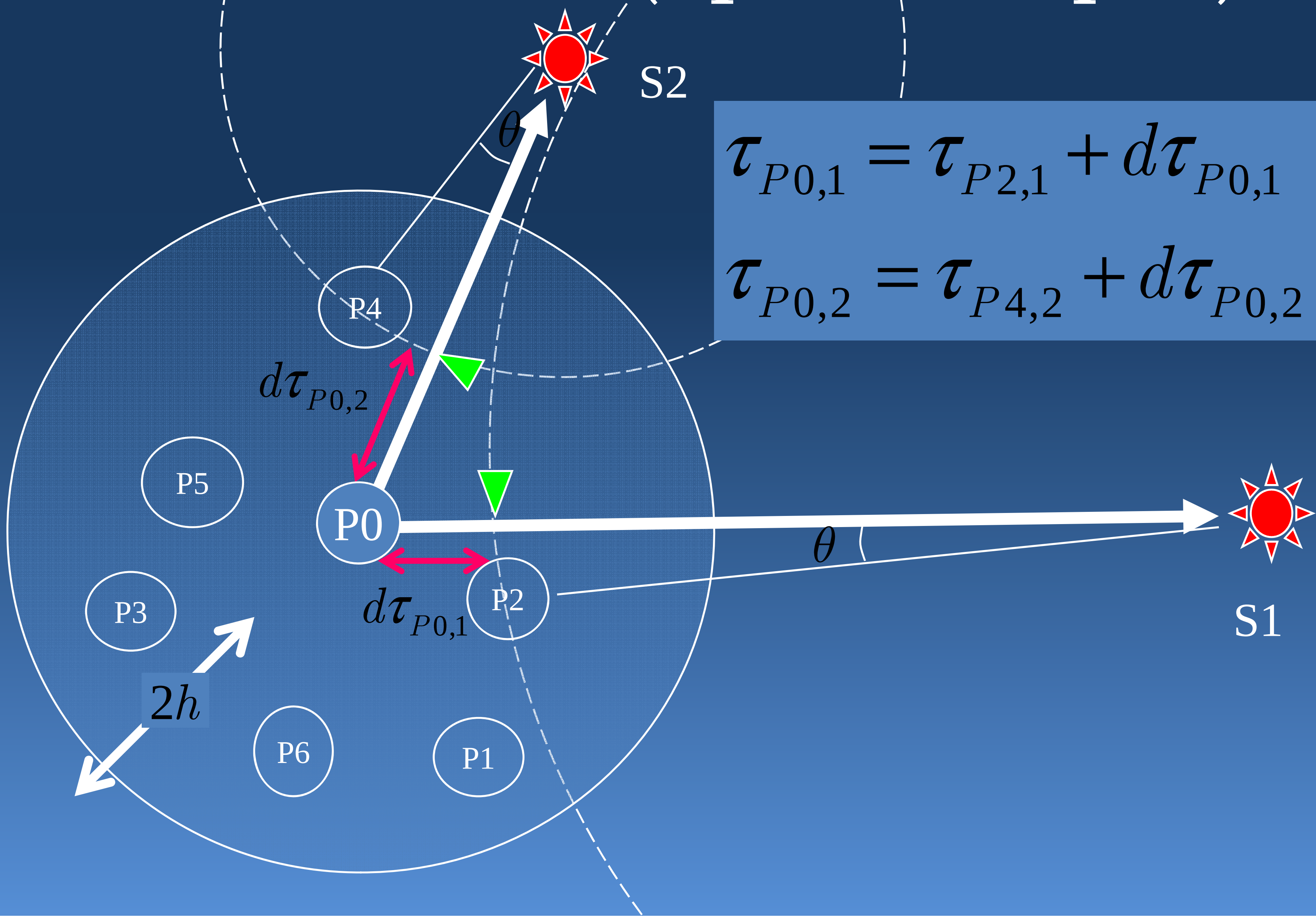
As a first step, we investigate the stability of gas disks in massive halos under UVB, utilizing radiation hydrodynamics simulations.

RSPH code

Susa 2006 (http://ads.nao.ac.jp/abs/2006PASJ...58..445S)

- Parallel BH Tree
- SPH
- Domain decomposition : ORB
- RT solver (Ray-Tracing)
- Implicit solver for reactions and energy equation
- H2
- On-the-Spot approximation (Case B recom.)
- Multiple sources (～< 10)
- Any Spectrum

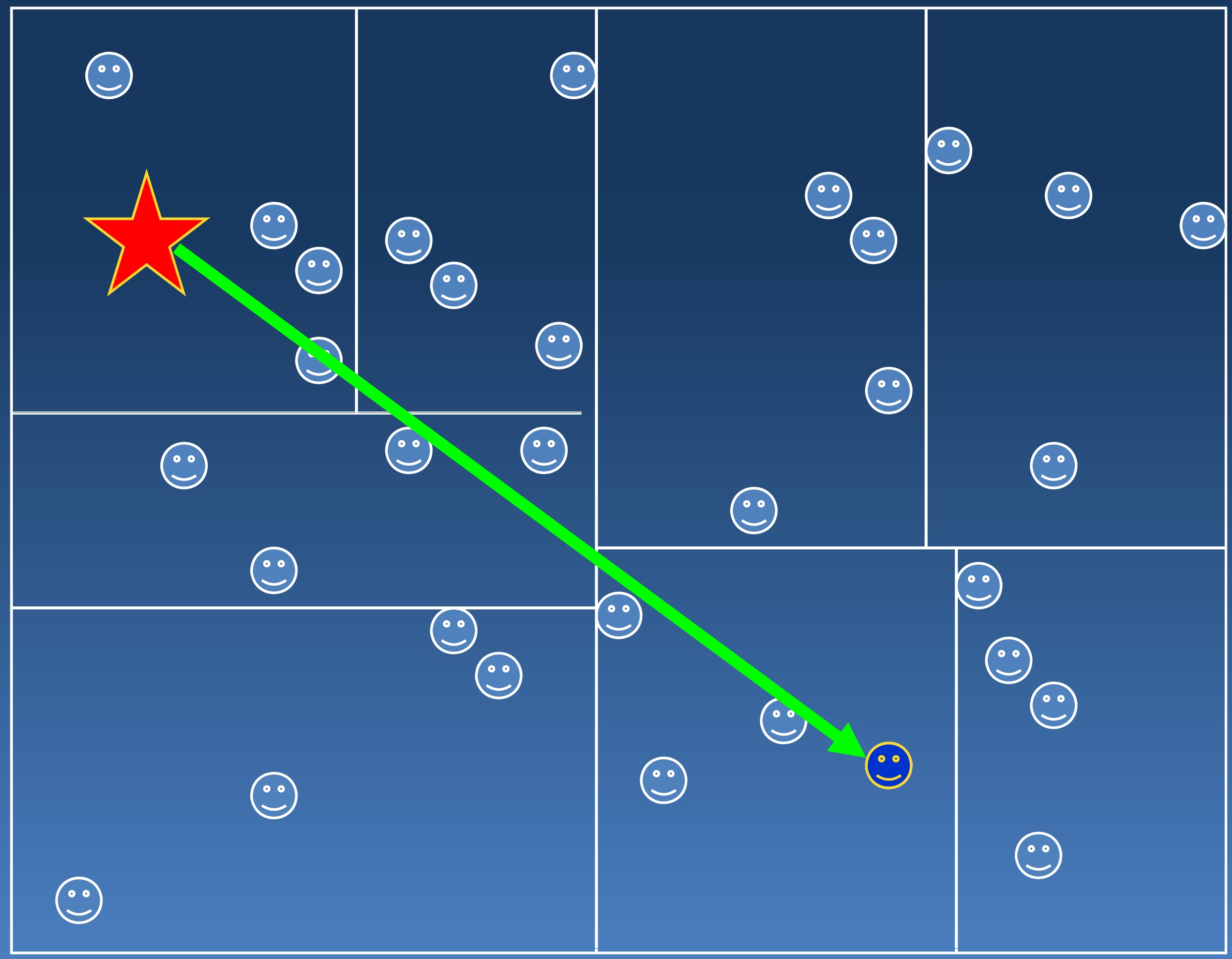
RT solver (optical depth)



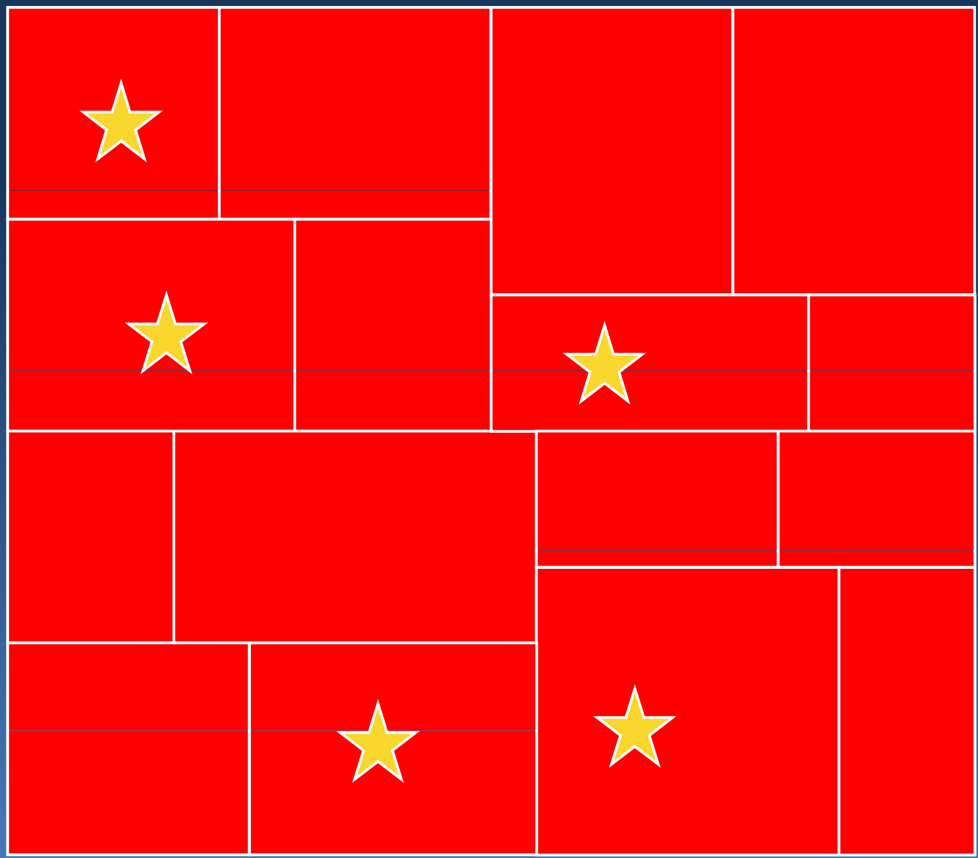
$$\tau_{P0,1} = \tau_{P2,1} + d\tau_{P0,1}$$

$$\tau_{P0,2} = \tau_{P4,2} + d\tau_{P0,2}$$

Parallelization : Domain decomposition (O R B)



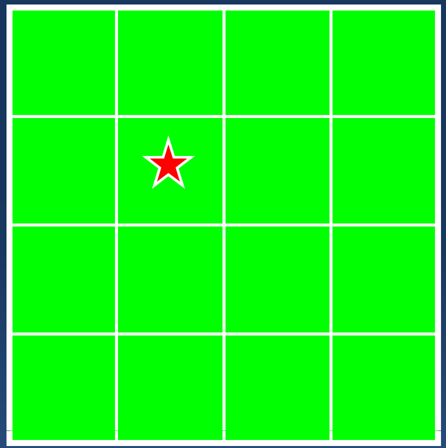
Parallelization of τ evaluation



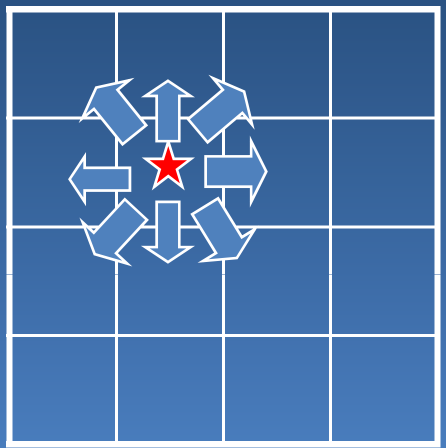
MWF like parallelization

Reduction of "waiting time" #1

Heinemann et al. astro-ph/0503510

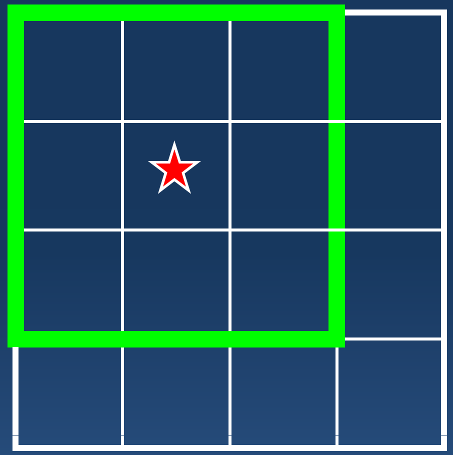


1. Evaluate the optical depth at every processer
Assuming the optical depth of boundary particle
Is zero.

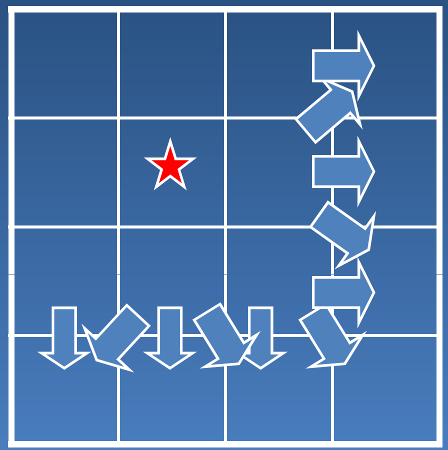


2. Send the optical depth at the boundary of the
Node which contain the source to the
surrounding nodes.

Reduction of “waiting time” #2

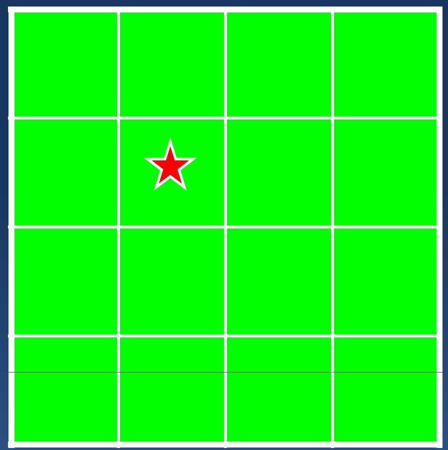


3. Evaluate the optical depth only at the opposite side boundary of the nodes which have Received the data.



4. Send the optical depth at the boundary again.

Reduction of “waiting time” #3



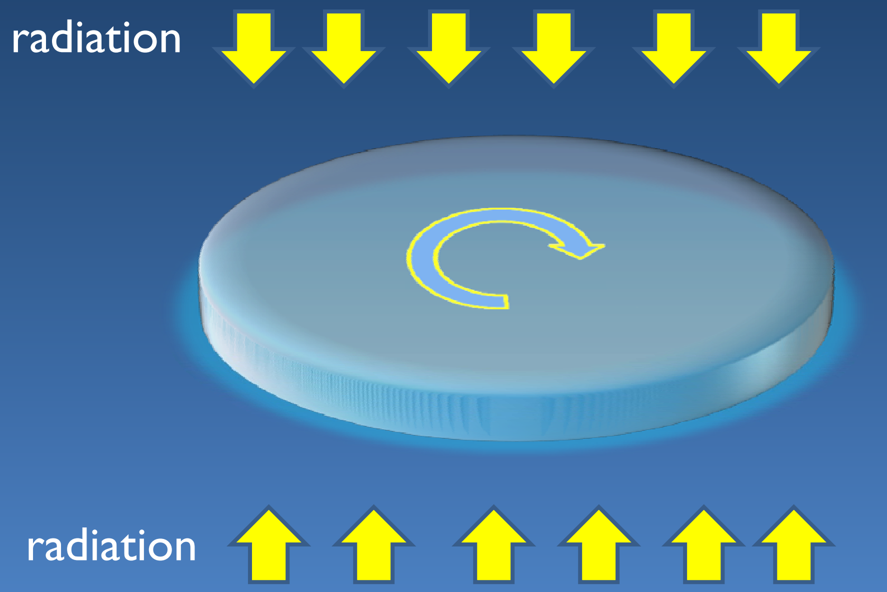
5. Using the boundary data, re-evaluate the Optical depth for all of the particles.

The model

$$\Phi_{\rm ext}(r) \equiv -\left(\frac{27}{4}\right)^{1/2}\left[\frac{v_1^2}{(r^2+a_1^2)^{1/2}}+\frac{v_2^2}{(r^2+a_2^2)^{1/2}}\right]$$

$$v_1 = v_2 = 100\,{\rm km\,s^{-1}}, \quad a_1 = 0.3\,{\rm kpc}, \quad a_2 = 5\,{\rm kpc}$$

Same as Wada & Norman 2007
except rotation velocity



Uniform disk with slight perturbations

$H = 100\,{\rm pc}$

$\rho_{\rm ini}$: $0.05, 0.1, 0.3 M_\odot {\rm pc}^{-3}$

$I_{21} = 0$ or 1

$R_{\rm disk} = 3\,{\rm kpc}$

$T_{\rm min} = 300\,{\rm K}$

$m_{\rm sph} = 110 M_\odot$

Resolution

Mass resolution :

$$\sim 2N_{\rm nei} m_{\rm SPH} = 1.1\times 10^4 M_\odot$$

Maximally resolved density: ($M_J \sim M_{res}$)

$$n_{\rm H,res} = \frac{3}{4\pi m_{\rm p}} \left(\frac{5k_{\rm B}T_{\rm min}}{2Gm_{\rm p}} \right)^3 \frac{1}{\left(2m_{\rm SPH}N_{\rm nei}\right)^2} \left(\simeq 235{\rm cm}^{-3}\right)$$

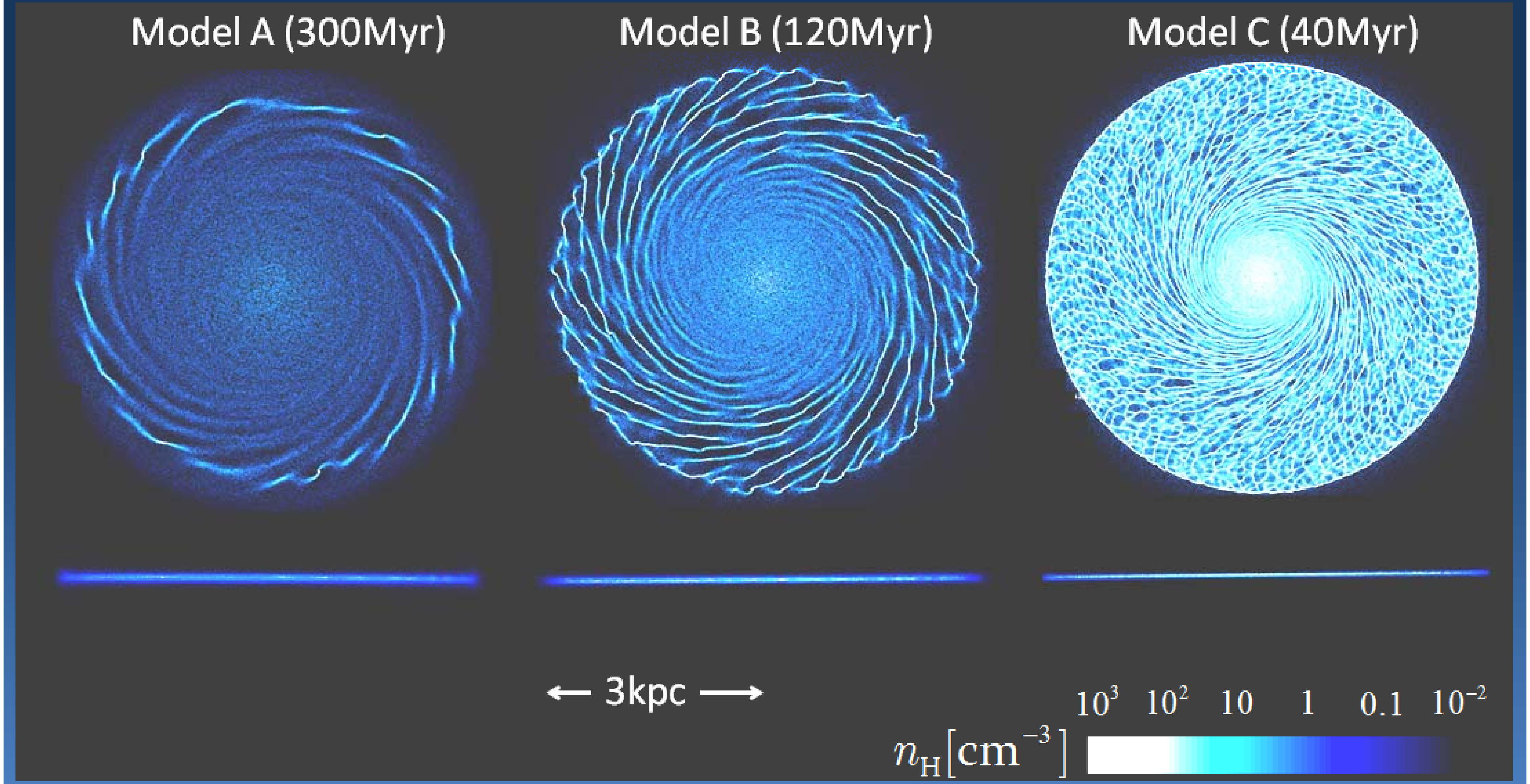
Gravity Softening: (∼minimal SPH softening)

$$\varepsilon = \frac{1}{2} \left(\frac{3N_{\rm nei}m_{\rm SPH}}{4\pi m_{\rm p} n_{\rm H,res}} \right)^{1/3} \left(\approx 3{\rm pc}\right)$$

Bate & Burkert 1997

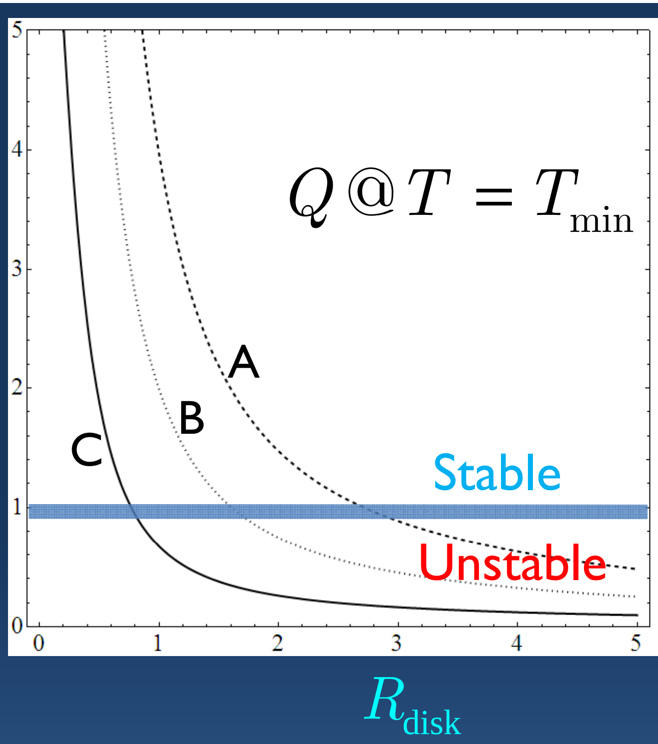
montage: I_{21}=0

$N_H = 6.6\times10^{20}\,\mathrm{cm}^{-2}$ $N_H = 1.3\times10^{21}\,\mathrm{cm}^{-2}$ $N_H = 4.0\times10^{21}\,\mathrm{cm}^{-2}$

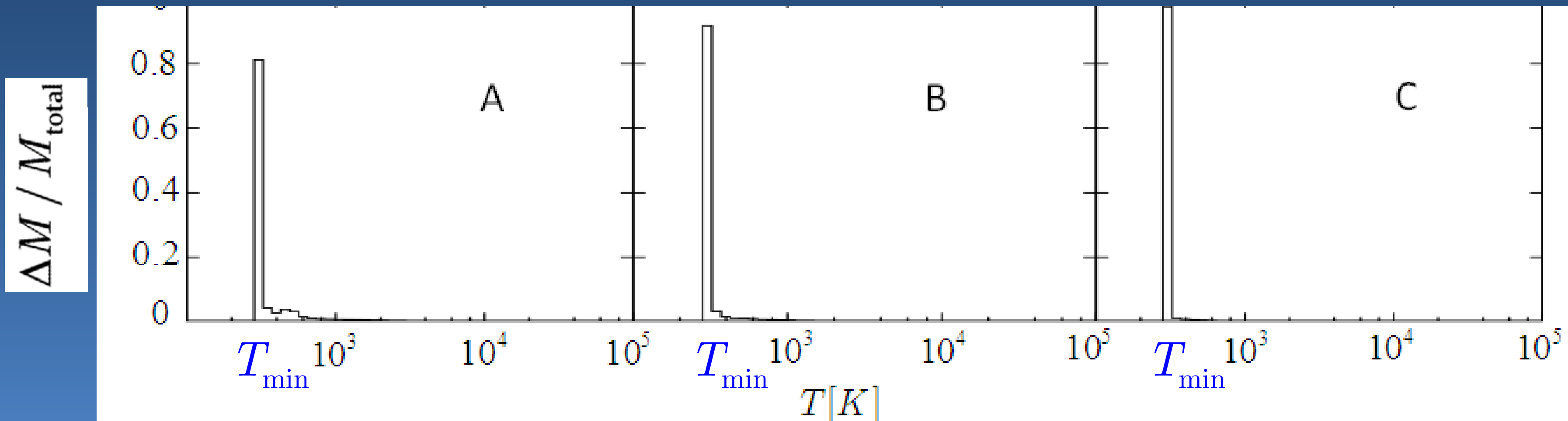


Disks in all modes (A、B、C) are unstable → fragmentation & star formation

Toomre Q and the tmperature PDF (I21=0)

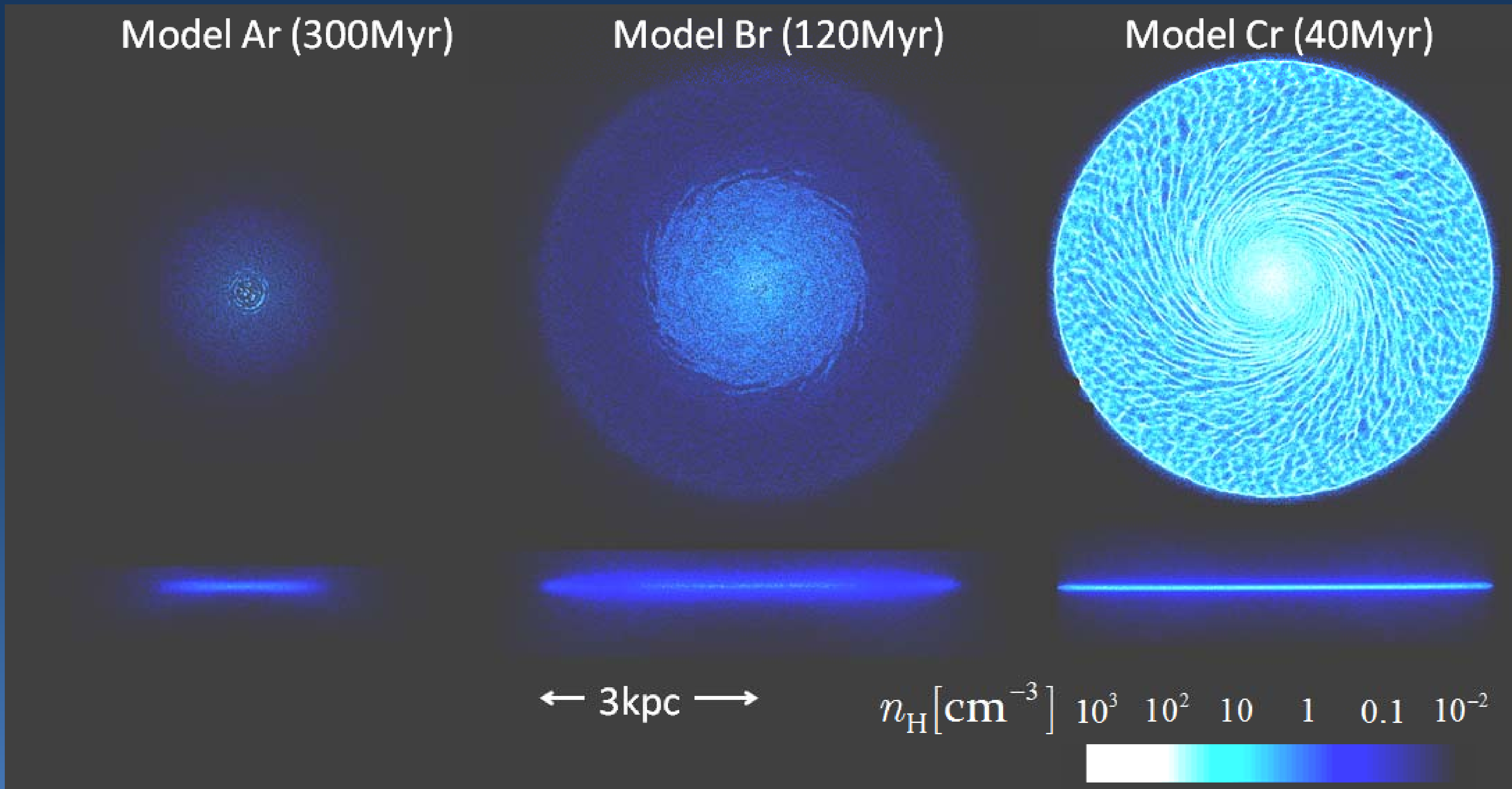


$$Q = \frac{c_s \kappa}{\pi G \Sigma}$$



montage: $I_{21}=1$

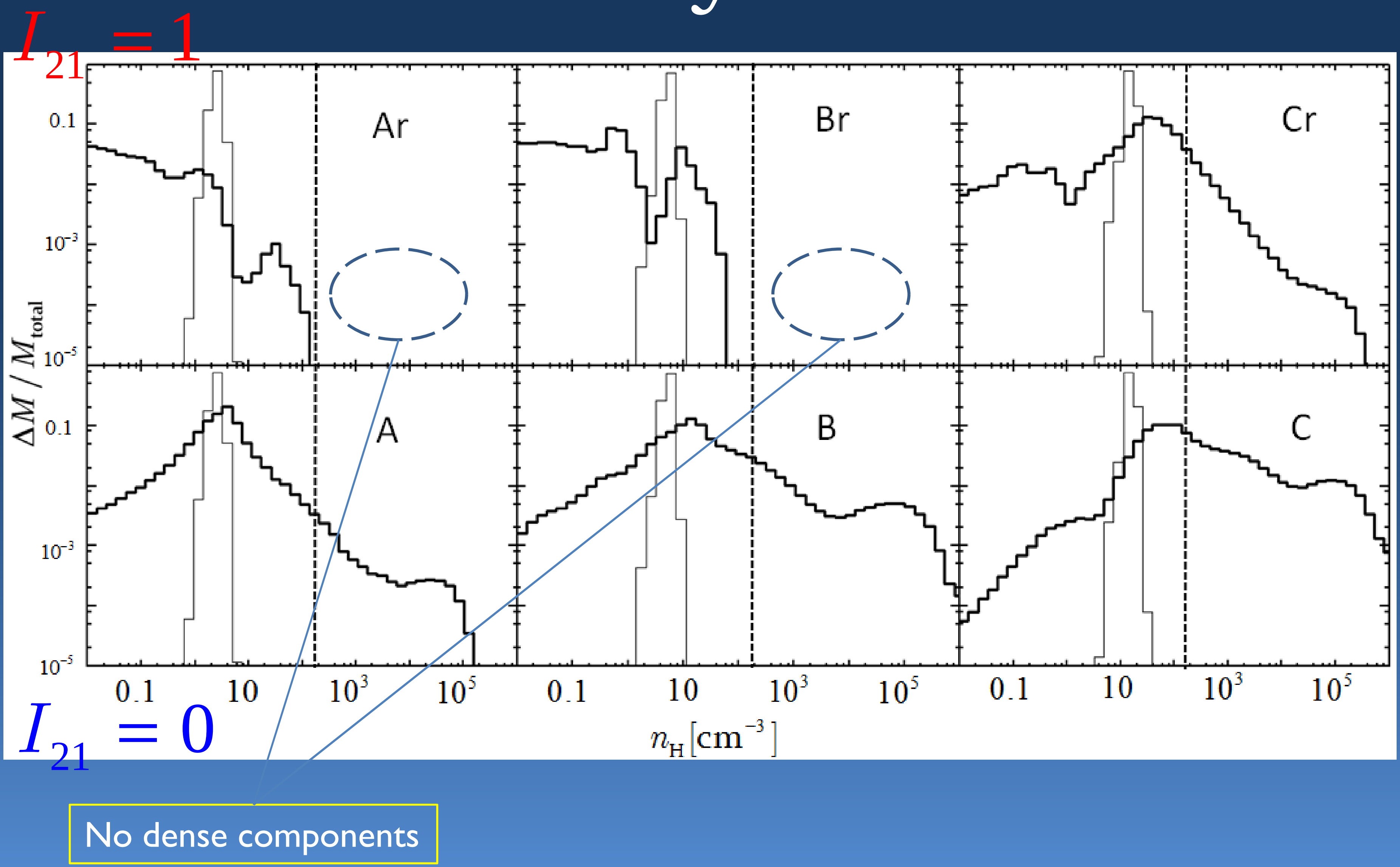
$N_H = 6.6\times10^{20}\,\mathrm{cm}^{-2}$ $N_H = 1.3\times10^{21}\,\mathrm{cm}^{-2}$ $N_H = 4.0\times10^{21}\,\mathrm{cm}^{-2}$



A, B : stable → star formation is strongly suppressed.

C: still unstable
→fragmentation & star formation

Density PDFs

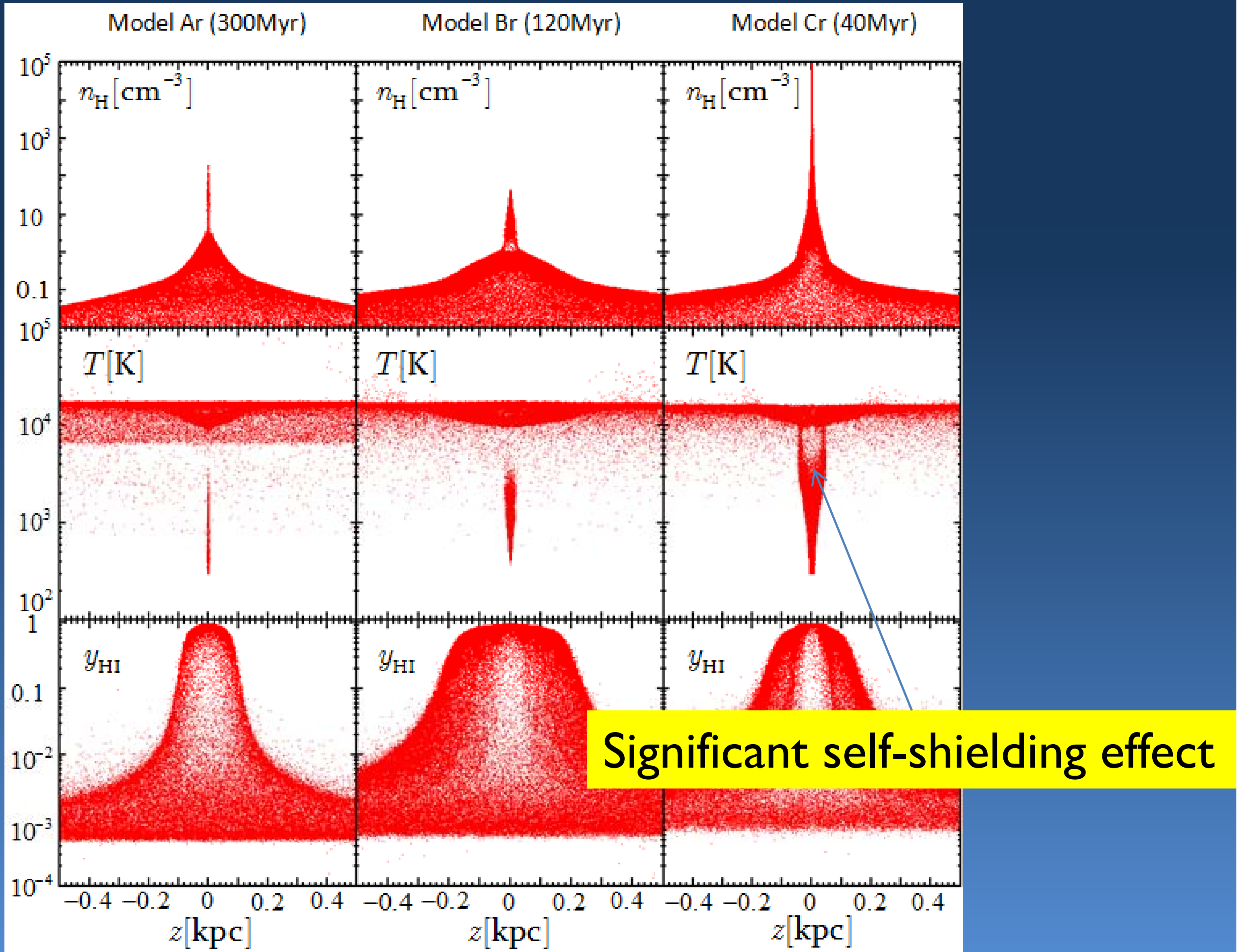


Distribution along z-axis

density

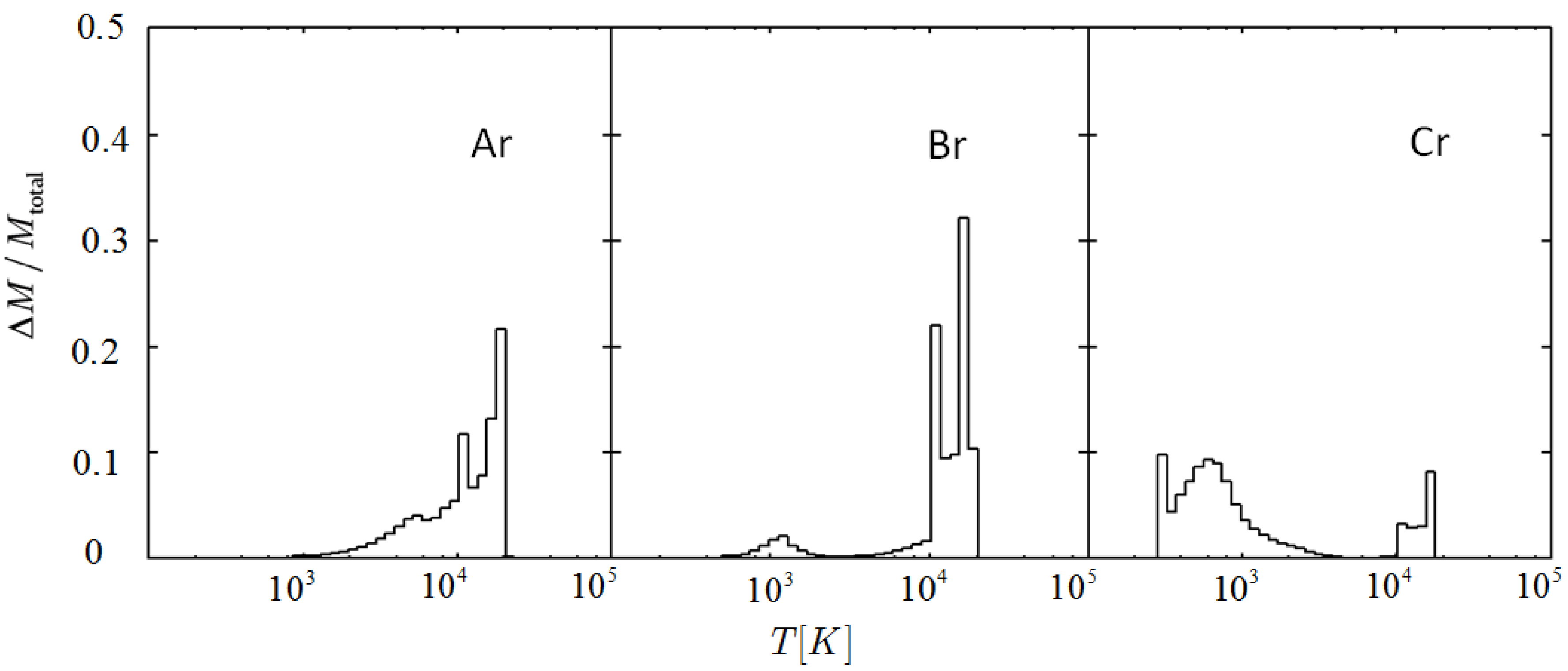
temperature

HI



Temperature PDFs

Mass fraction ($\Delta M / M_{total}$) per $\Delta \log T = 0.06$



Ar, Br : unshielded →
Hot component dominates
→ large Q → stable

Cr: shielded →
Cold component dominates
→ small Q → unstable

Threshold column density for self-shielding

Photoheating rate = Cooling rate below 10^4 K

$$N_{\rm H,sh} \simeq \frac{1}{y_{\rm HI}\sigma_{\nu_{\rm L}}} \left(\frac{2\pi I_{\nu_{\rm L}} \sigma_{\nu_{\rm L}} \nu_{\rm L}}{3 n_{\rm H} \Lambda_{\rm H_2}} \frac{\Gamma(\beta)}{1+\beta} \right)^{\frac{1}{\beta}}$$

$$I_\nu \propto \nu^{-\alpha}$$

$$\beta \equiv 1 + (\alpha - 1)/3.$$

Using the present assumptions ($\alpha = 1$, $I_{21} = 1$), we have

$$N_{\rm H,sh} \simeq 7 \times 10^{20} {\rm cm}^{-2} \left(\frac{I_{21}}{1}\right) \left(\frac{n_{\rm H}}{1{\rm cm}^{-3}}\right)^{-1} \left(\frac{y_{\rm HI}}{0.5}\right)^{-1} \quad (6)$$

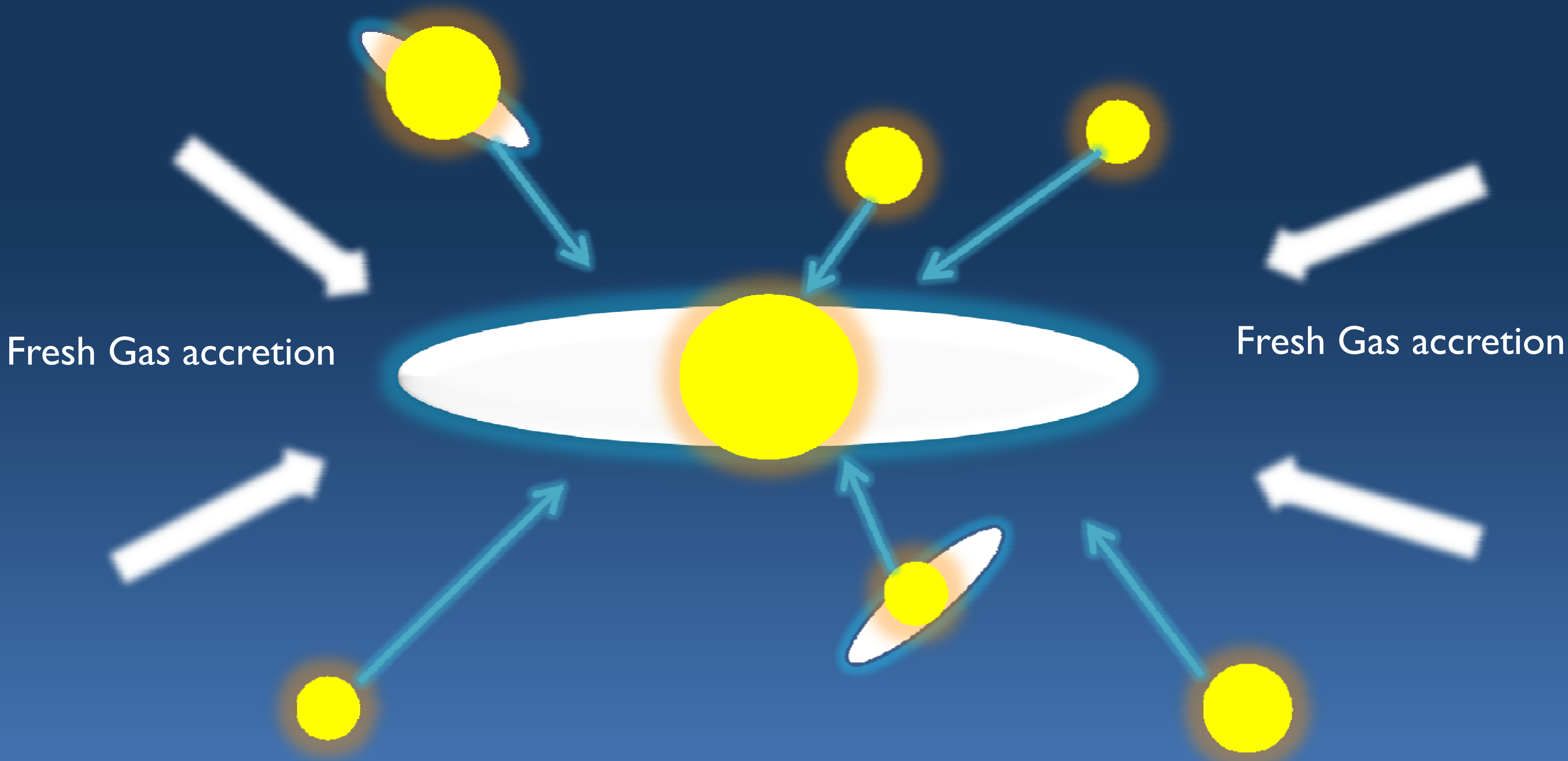
Numerical results : $N_{H,sh} \sim 1\text{-}4 \times 10^{21} {\rm cm}^{-2}$

Can UVB photons suppress the SF in disks hosted by massive dark halos?

Yes, they can .

The threshold column density of the disk is $\sim 10^{21} \mathrm{cm}^{-2} (I_{21}/1)$

Hierarchical GF

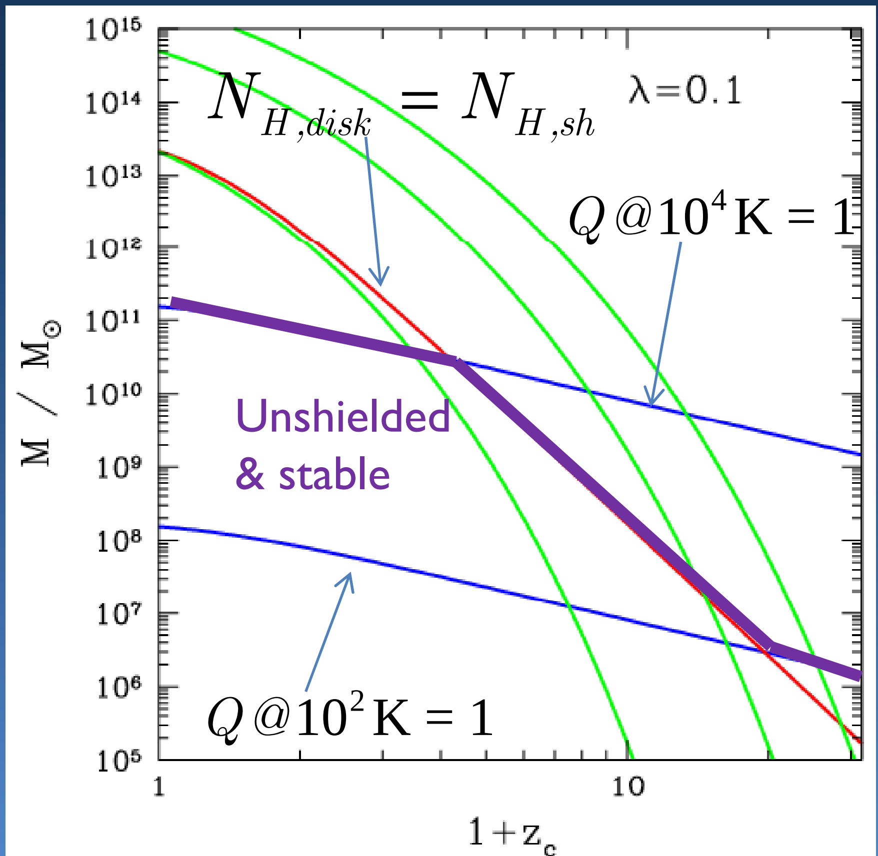


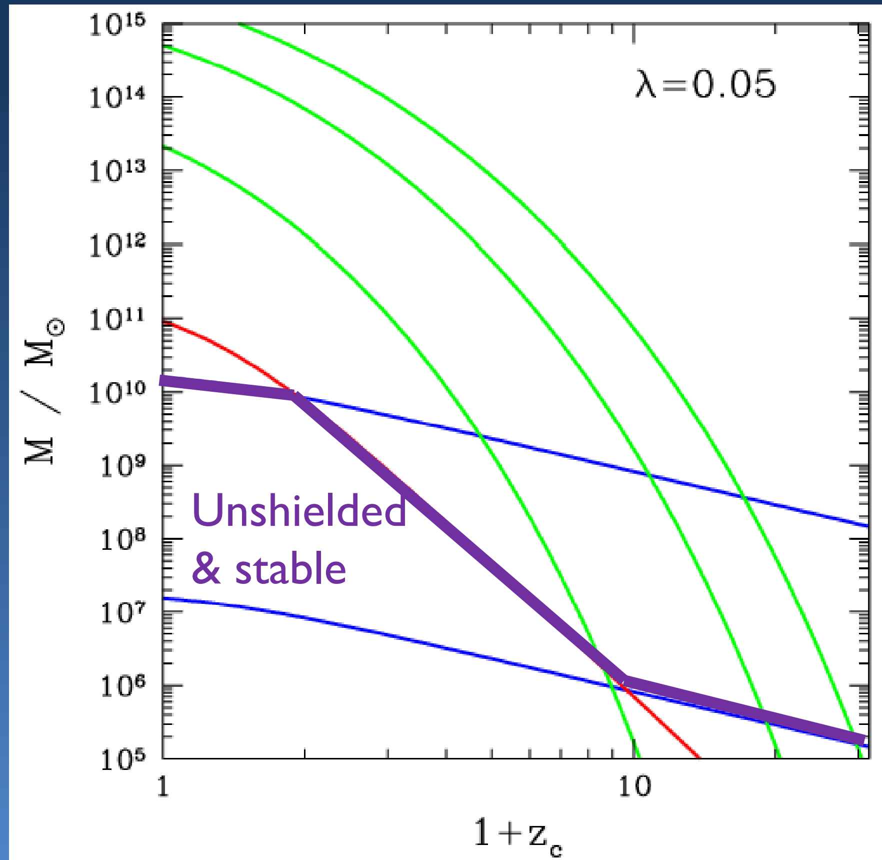
- ✓ Dynamical effects of merging (shock induced SF etc.)
- ✓ Inhomogeneous distribution of heavy elements
- ✓ Radiation from forming stars in building blocks, AGN

Analytical model of Cosmological disks (1/2)

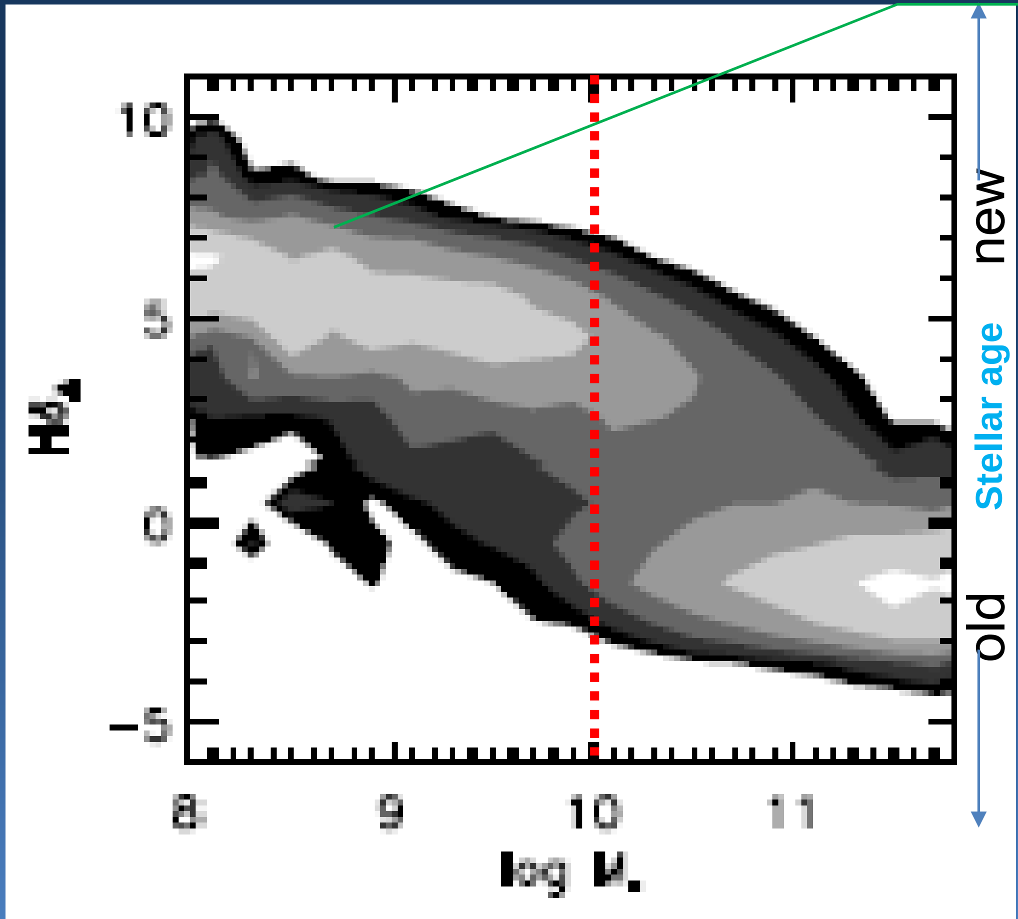
- Dark halos parameterized by (z_c, M, λ)
- Assume half of the baryons settle onto the galactic disk
- Keplar rotation & hydrostatic equilibrium in z-direction
- $N_{H,\,disk} > N_{H,sh}$?
- Q >1 ?

Analytical model of Cosmological disks (2/2)





Downsizing of galaxies



(Kauffman, G. et al, MNRAS, 341, 54, 2003)

Resent SF for galaxies with Mstar < 10^{10}Msun

Some process to delay the SF in less massive galaxies is required.

Photoheating

Summary

- We perform radiation hydrodynamics simulations on the fragmentation of galactic disks under the ultraviolet radiation background.

- We find that ultraviolet radiation field strongly suppress the star formation in the disks in case the photoheating is not shielded enough.

- In our simulations, we find a threshold column density of the disk ($\sim 10^{21}(I_{21}/1)\mathrm{cm}^{-2}$) above which the fragmentation is not suppressed.

- Presence of such critical threshold would be one of the reason for the so-called down-sizing problem in nearby galaxies.