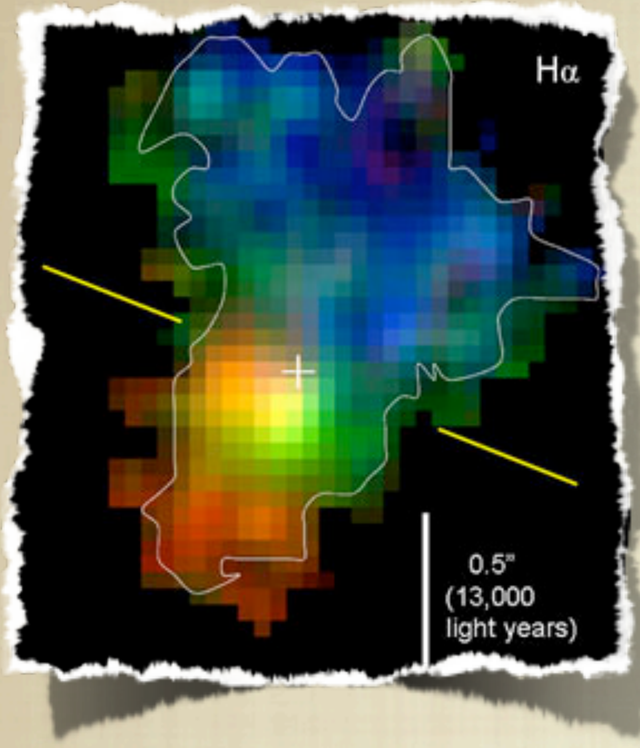
Cosmological Evolution of Gravitationally Unstable Galactic Disks

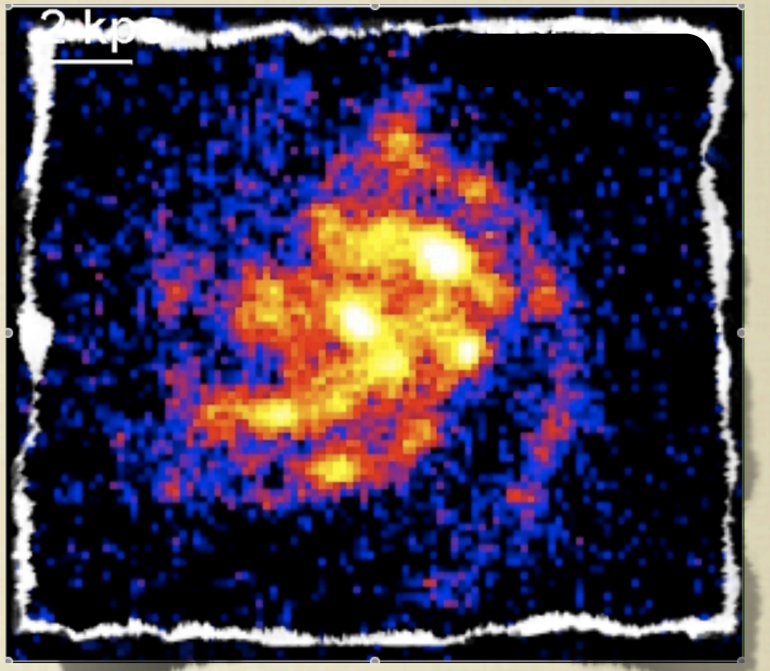
Marcello Cacciato
Minerva Fellow
@
Hebrew University
of Jerusalem

in collaboration with
Avishai Dekel
and
Shy Genel

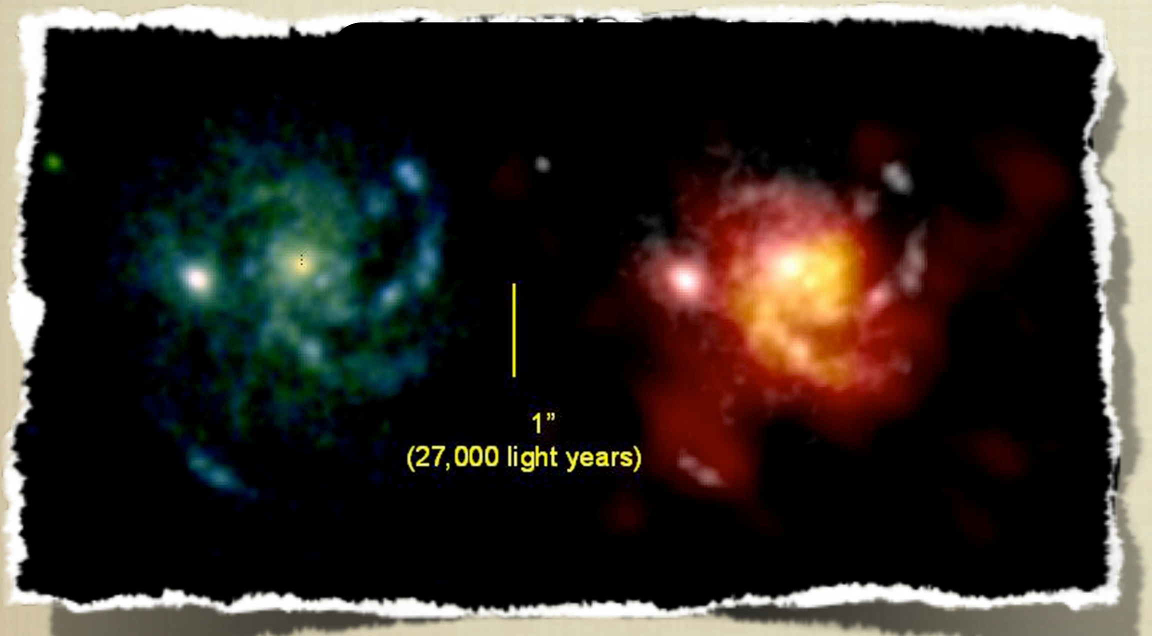
Observed Disk Galaxies @ z~2



Disks rotating with
V~200 km/s and σ~50 km/s

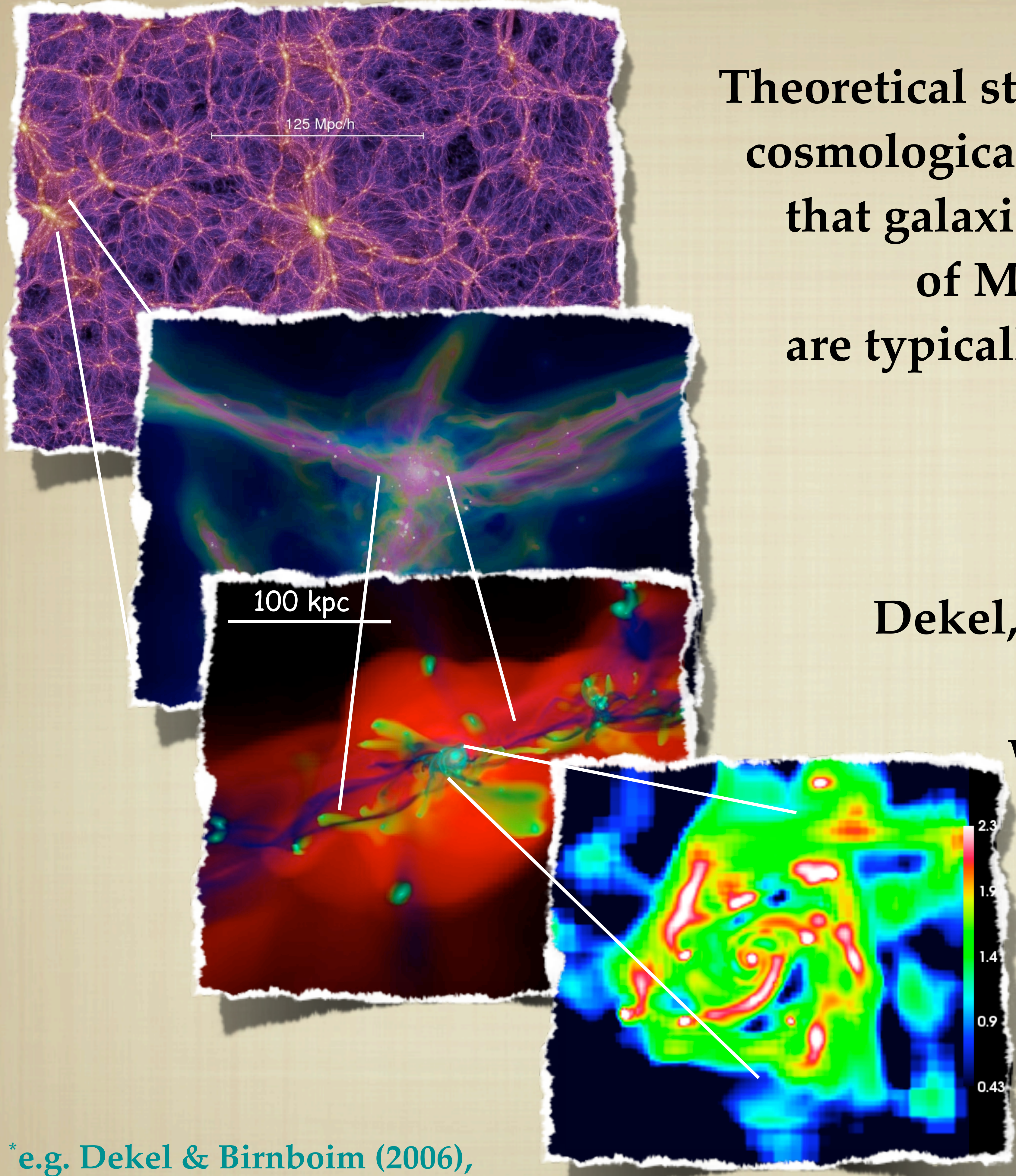


Several giant clumps of
~1kpc size and M~ $10^9 M_\odot$



Star formation rates ~$100 M_\odot / yr$
mainly occurring in the clumps

Genzel et al. (2006, SINFONI),
Forster-Schreiber et al. (2006, SINS), Elmegreen & Elmegreen (2005, UDF), Elmegreen et al. (2007, UDF)

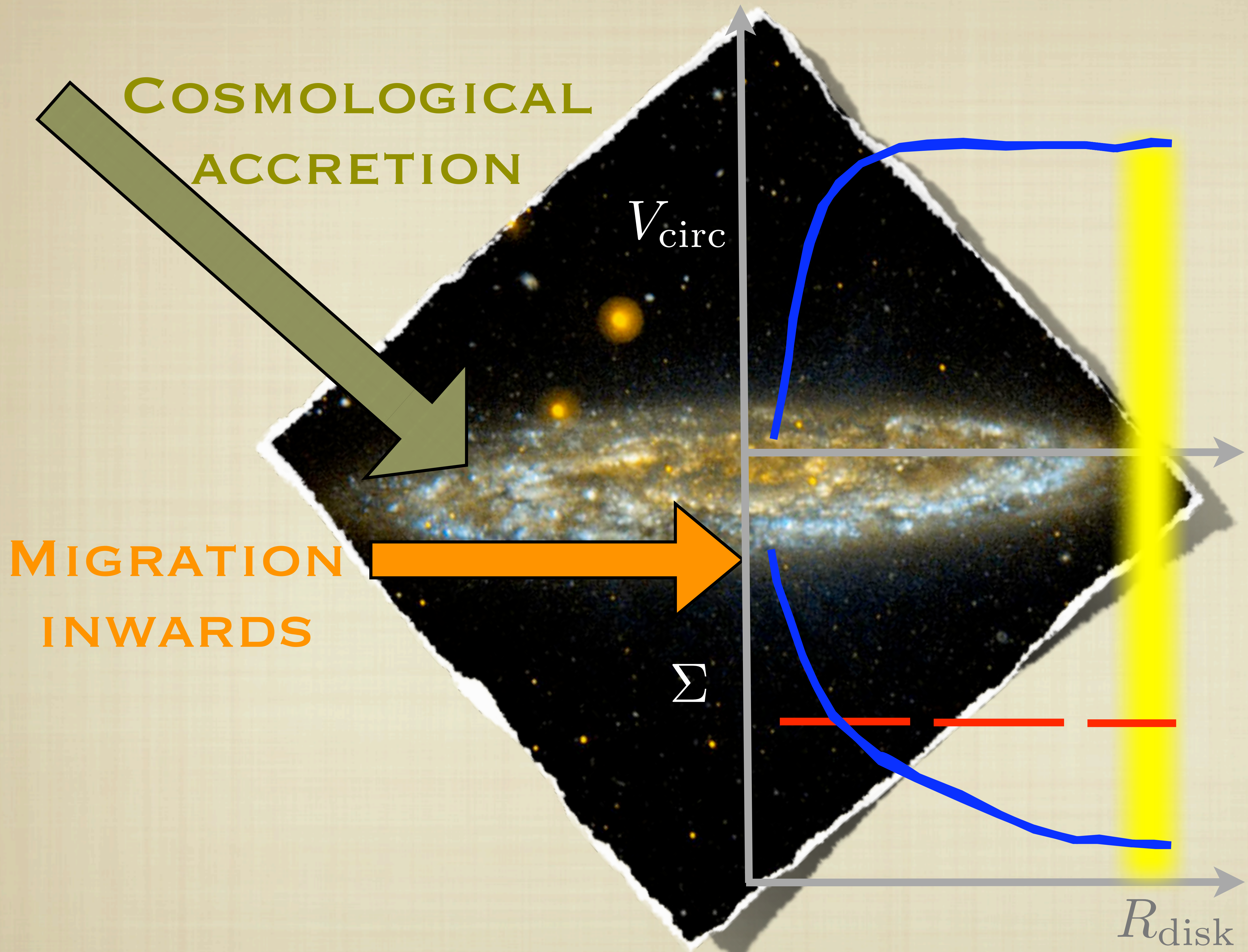


Theoretical studies and hydrodynamical cosmological simulations have shown that galaxies in dark matter haloes of M~ $10^{12} M_\odot$ at z~2 are typically Stream-Fed-Galaxies.

Dekel, Sari & Ceverino (DSC 2009) propose a scenario where the evolution of Stream-Fed-Galaxies is driven by cold streams, disk instability and the growth of a central spheroid.

*e.g. Dekel & Birnboim (2006), Keres et al. (2005)

The General idea



Self-Regulated Marginally Unstable Disk

Self-Regulated Marginal Instability

high Surface Density:
fragmentation and Migration

disk "heats up"

$$Q = \frac{\kappa\sigma}{\pi G \Sigma} = 1$$

Stable disk accumulates mass

High Velocity Dispersion makes disk stable:
Disk stops fragmentation and migration

Analytical Model

- **Mass Conservation**

$$\dot{M}_{\rm gas,disk} \simeq \gamma_{\rm gas,acc}\,\dot{M}_{\rm acc} - \dot{M}_{\rm gas,inflow} - (1+\gamma_{\rm fdbk})\,\dot{M}_{\rm SFR}$$

$$\dot{M}_{\rm star,disk} \simeq \dot{M}_{\rm star,acc} - \dot{M}_{\rm star,inflow} + \dot{M}_{\rm SFR}$$

- **Energy Conservation**

$$\dot{E}_{\rm int,disk} \simeq \dot{M}_{\rm disk,inflow}\,V_{\rm circ}^2 - \dot{E}_{\rm gas,dis}$$

  - Energy source: mass inflow in the potential well
  - Gravitational Heating of the stars
  - Gas dissipates in a dissipation timescale $t_{\rm dis} \equiv \gamma_{\rm dis}\, t_{\rm dyn}$

- **Marginally unstable (Gas+Stars) Disk:**

$$Q_{2c}^{-1} = W_1 Q_\star^{-1} + W_2 Q_{\rm gas}^{-1} = 1 \quad \text{where} \quad W_i = f_i(\sigma_{\rm gas}, \sigma_\star, \Sigma_{\rm gas}, \Sigma_\star)$$

Krumholz & Burkert (2010), Jog & Solomon (1984), Rafikov (2001), Romeo & Wiegert (2011)

Cosmological Evolution

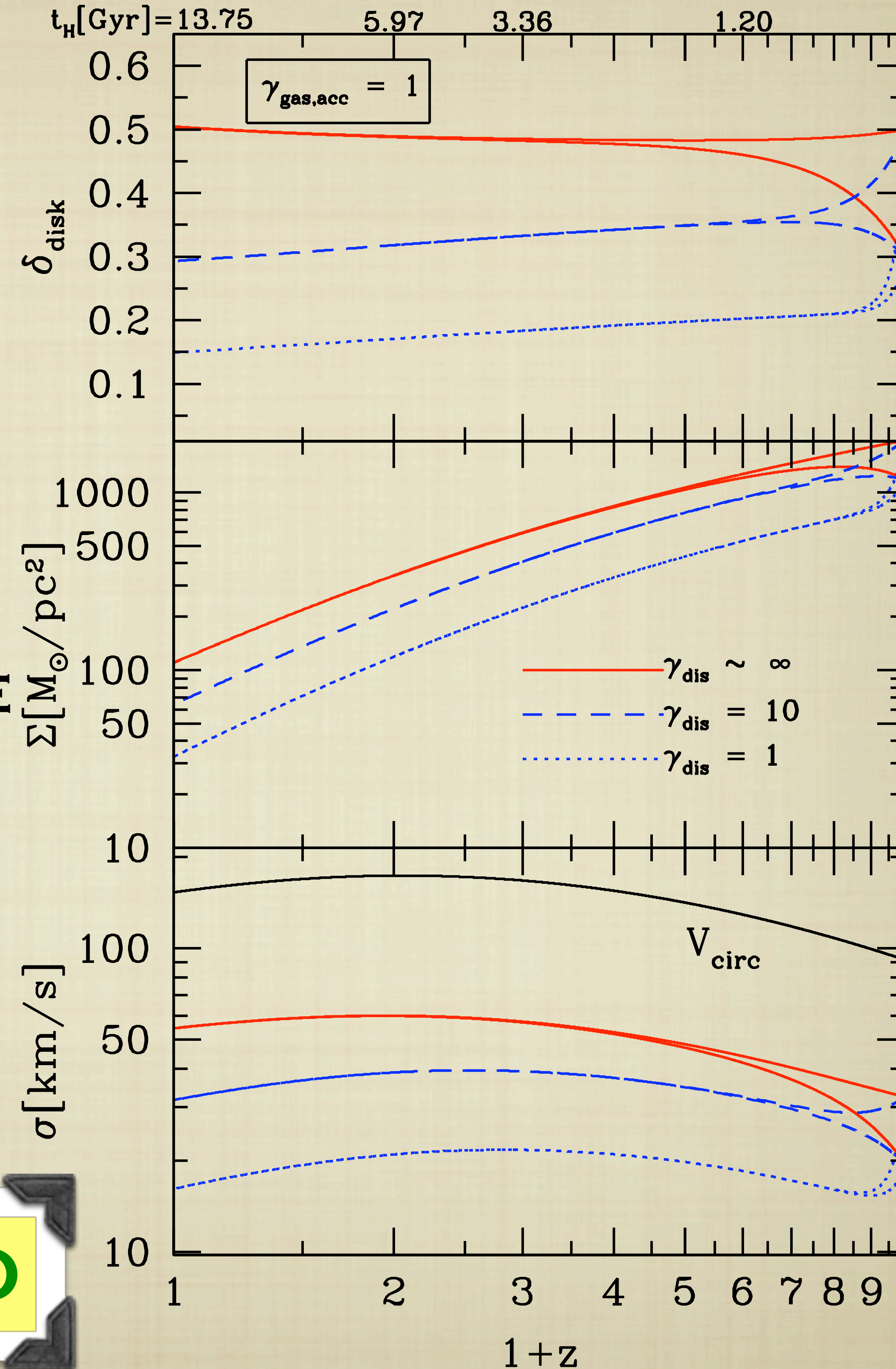
A Solve the System of differential equations at current cosmological time (4 unknowns: $\sigma_{\rm gas},\ \sigma_\star,\ \Sigma_{\rm gas},\ \Sigma_\star$)

- **If** Solution has $\sigma_{\rm gas} > c_{\rm s} \approx 10{\rm km/s}$
  - **then** Update Values and Move to Step A
- **else** Marginal Instability cannot be satisfied: Disk is labeled stable, evolution stopped.

1-Component: Disk always unstable

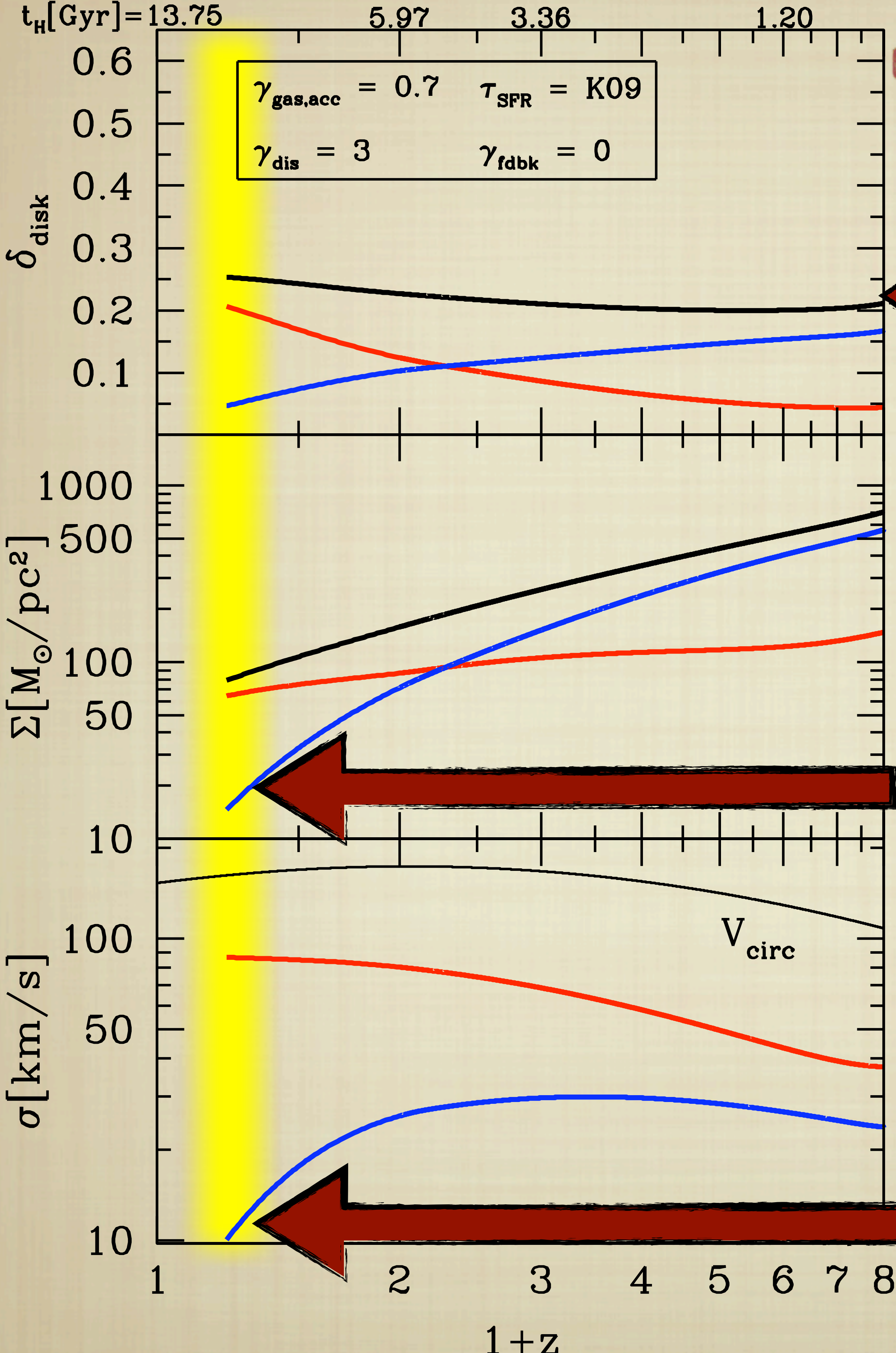
$$\delta_{\rm disk} \equiv \frac{M_{\rm disk}}{M_{\rm tot}} \sim {\rm const}$$

- Σ decreases with time due to the way radius and Mass evolve
- σ has a maximum at z~1 because $\sigma \propto V_{\rm circ} \approx V_{\rm vir}$



Disk unstable at z=0

Two Components



INITIALLY UNSTABLE DISKS STABILIZE AT LATER TIME (z_{STAB}~0.5)

~40% OF BARYONIC MASS IN THE DISK

RED = STARS

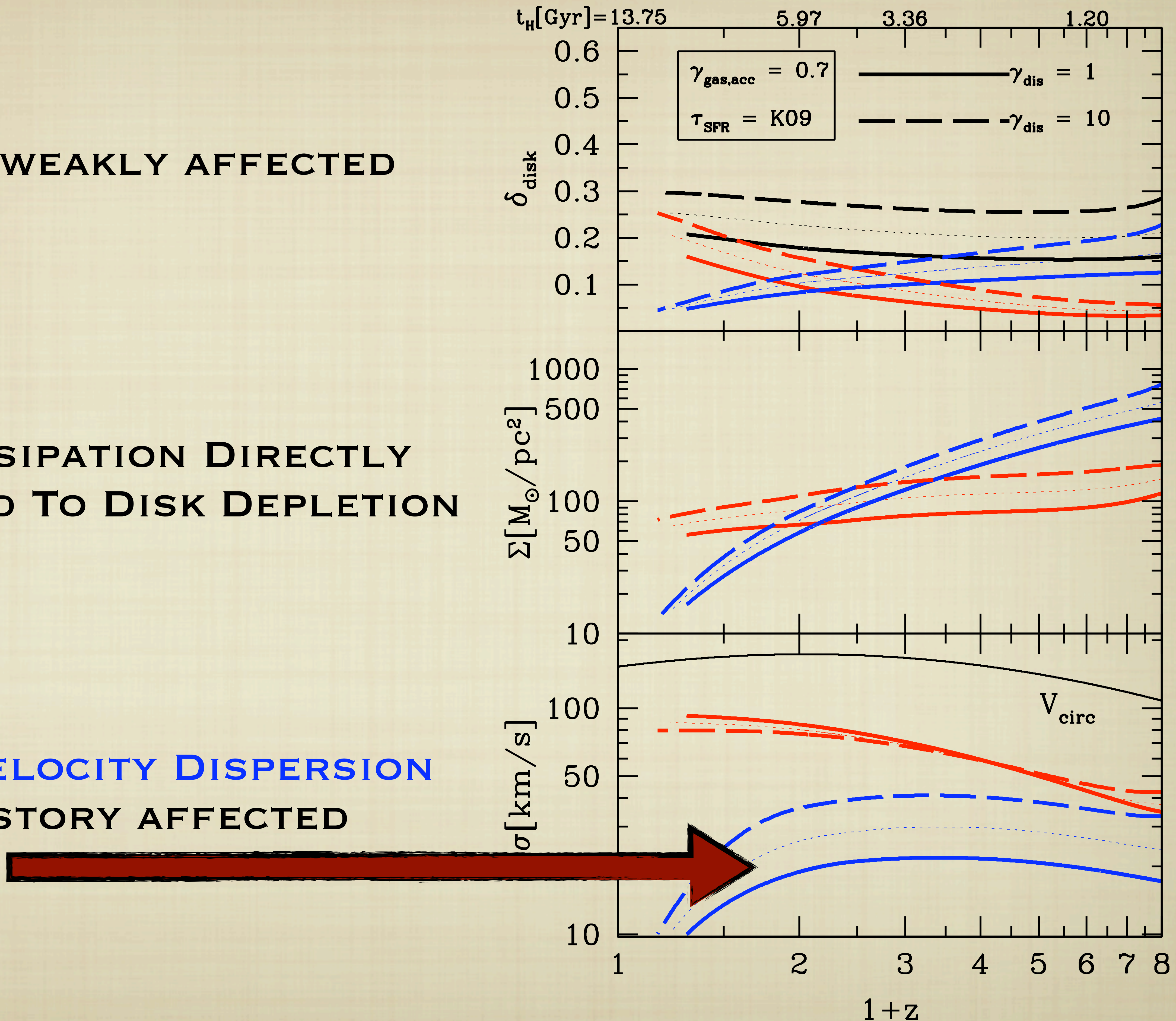
BLUE = GAS

STELLAR DOMINATED DISKS @ z_{STAB}

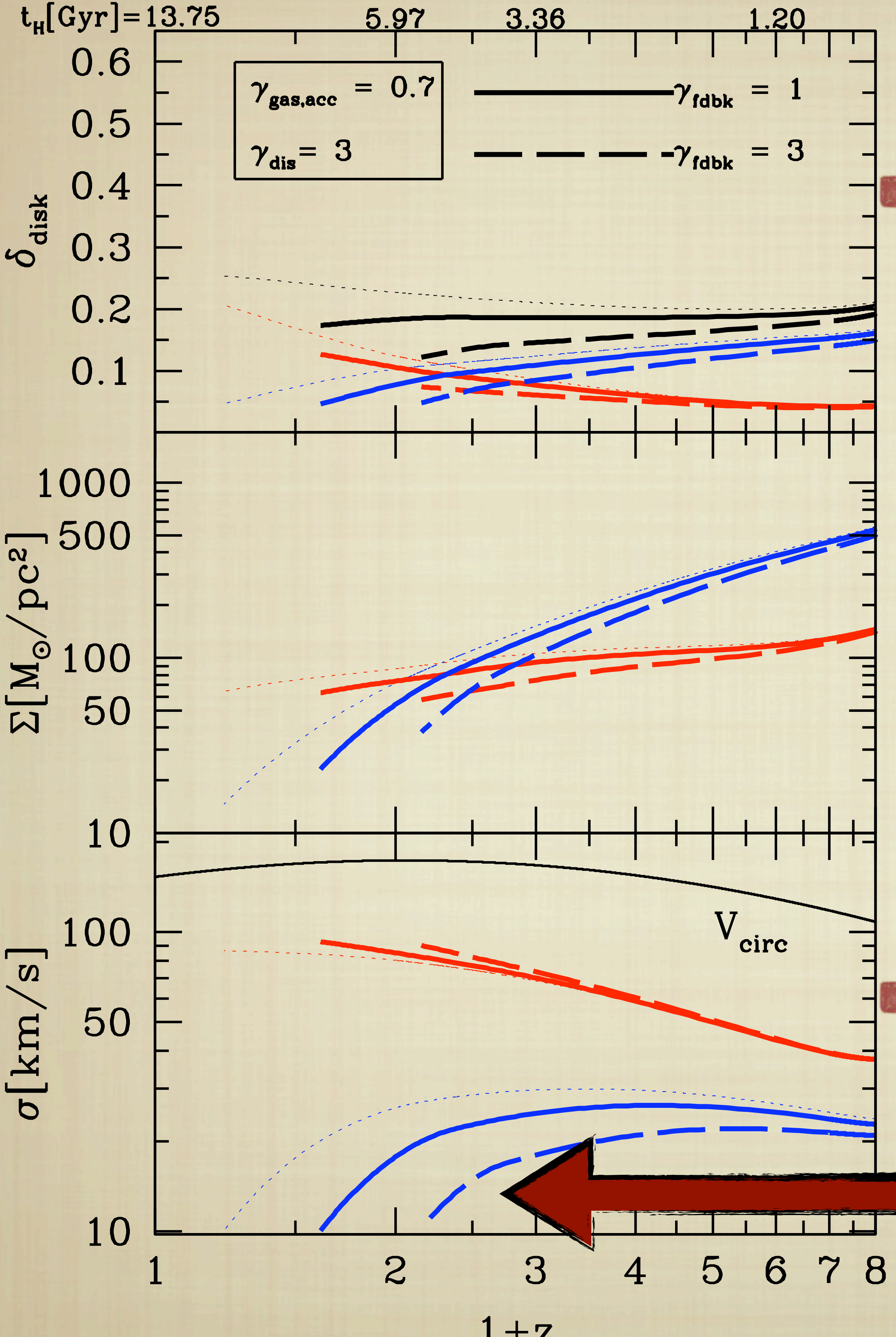
NET GAS COOLING & NET STELLAR HEATING

The Role of Dissipation

- z_{stab} weakly affected
- Dissipation Directly Related To Disk Depletion
- Gas Velocity Dispersion History affected



The Role of Outflows



- Outflows imply:
  - Less Gas in the Disk +
  - Less Star Formation =

  - Less Massive Disks
- Lower Gas Velocity Dispersion

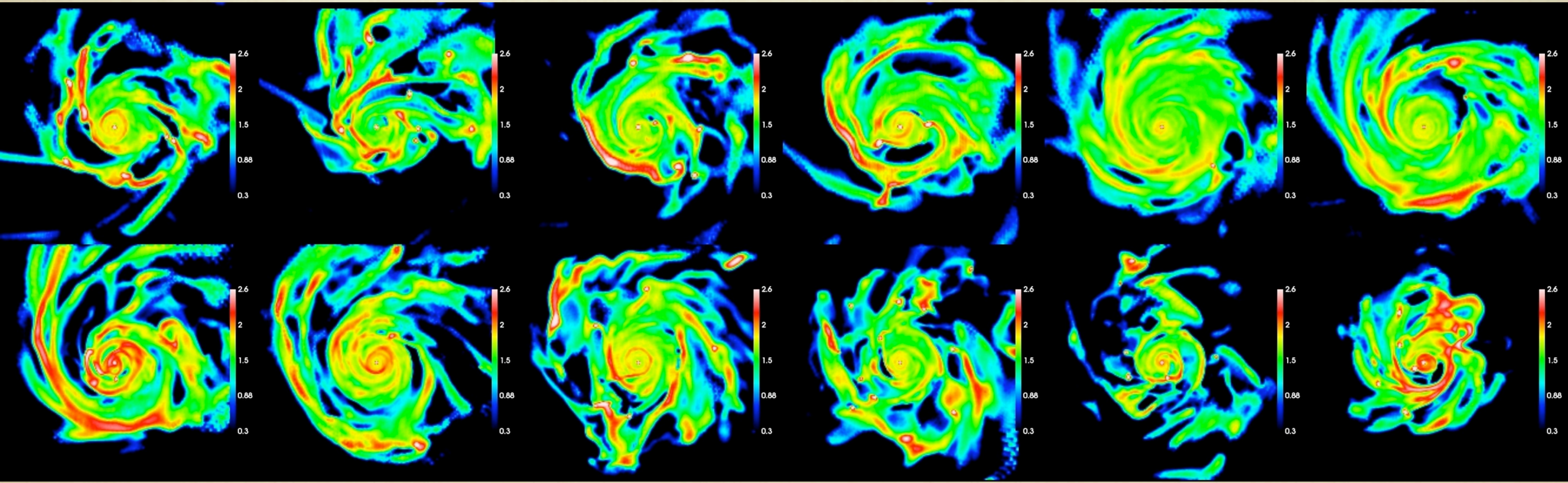
Z_{STAB} AFFECTED

Conclusions

- Analytical Model to follow the cosmological evolution of gravitationally unstable disks
- "Violent" Disk Instability in high z galaxies is a robust prediction
- initially unstable disks stabilize by z~0.5
  - due to higher stellar mass fractions (~0.8)
  - due to "dynamically hot" stars $(\sigma_{\rm star} \sim 8\,\sigma_{\rm gas})$
  - due to disk depletion <---> gas dissipation

Future Perspectives

- Model improvements
  - scatter in mass accretion: analytical merger trees
  - metallicity-dependence <--->mass dependence
- Comparison with Hydro-Simulations (HydroART) [in collaboration with D. Ceverino]



Thanks