Stellar Populations Produced in Gravitationally Unstable Disks

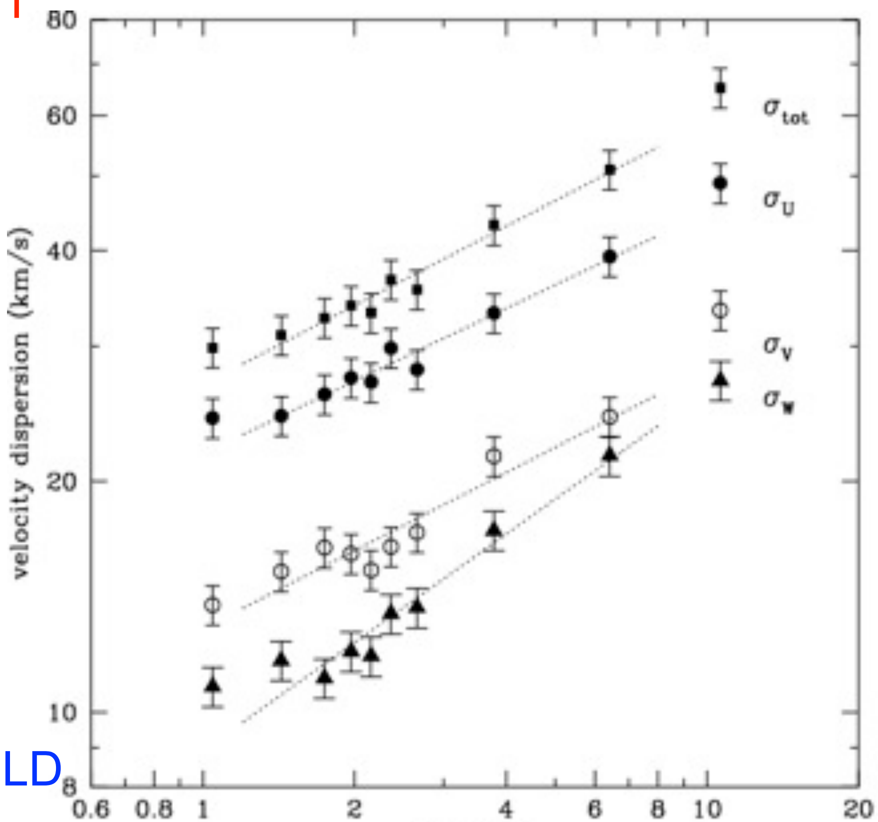
John Forbes

Galaxy Workshop - August 9, 2011

With Mark Krumholz and Andi Burkert

Thick Disks at Redshift Zero

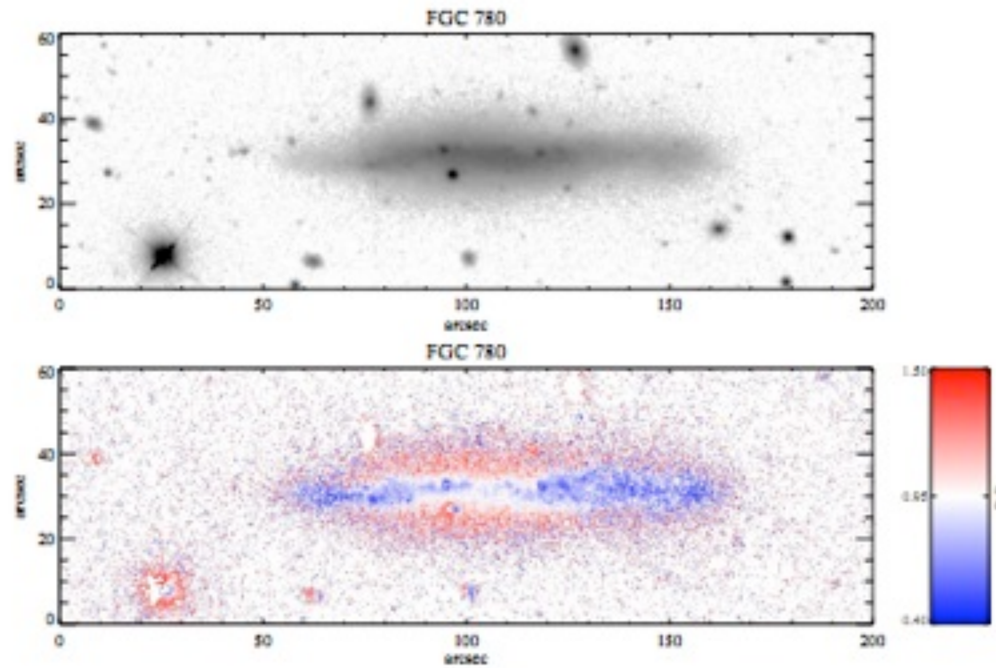
HOT



COLD

Age (Gyr)

Nordström et al (2004)



Peter Yoachim's PhD Thesis (2007)

Older stars have higher velocity dispersions

The Usual Story

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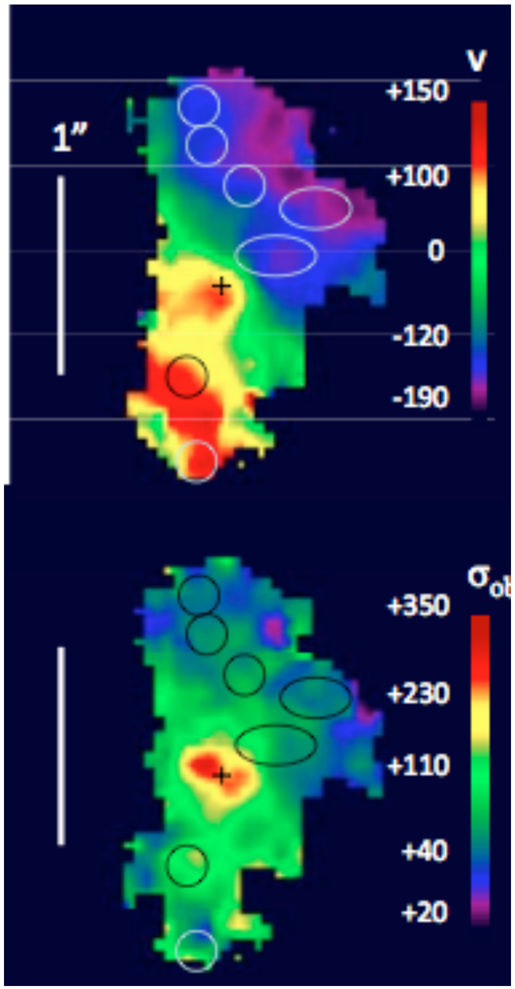
THICK DISK

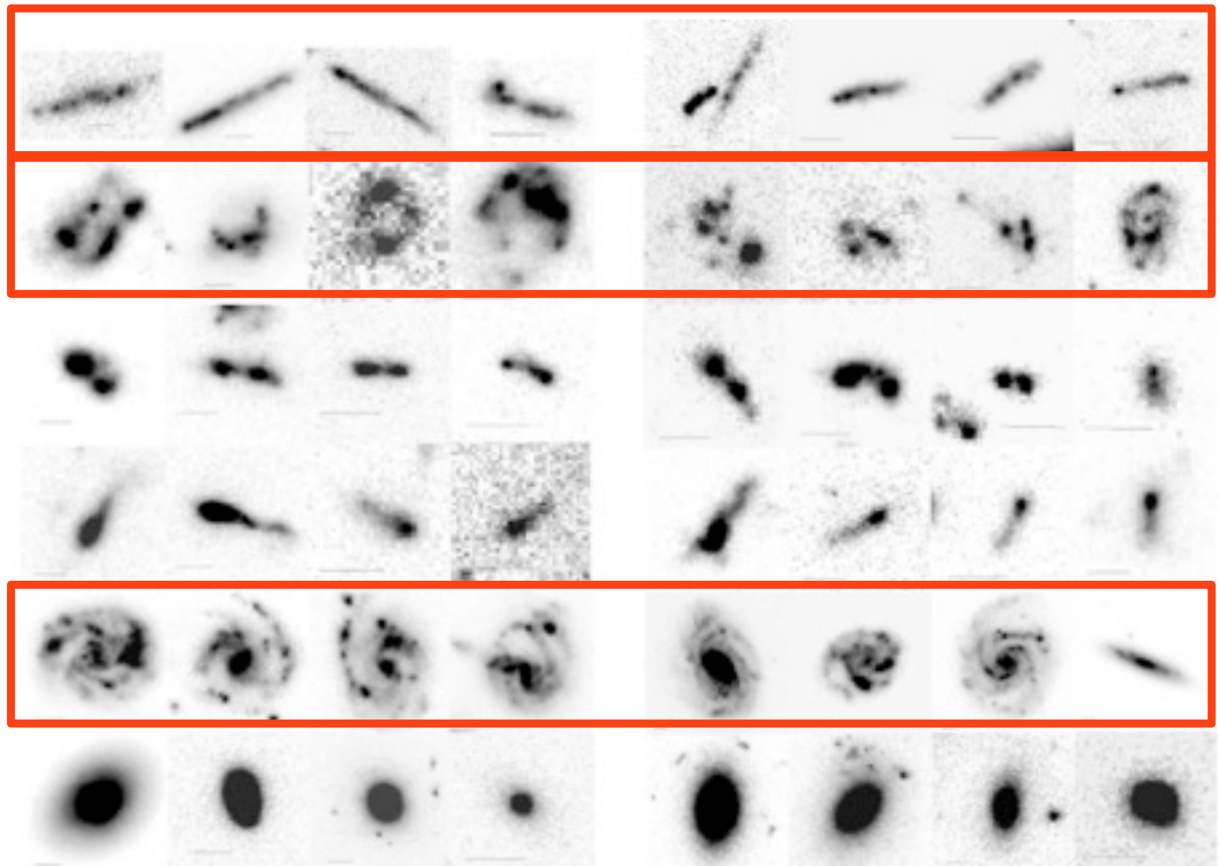
Two-body scattering
Minor Mergers
Perturbing galaxies
Spiral Waves

Major Mergers
Direct Accretion of Stars
Scattering off Molecular Clouds
Popping Clusters

High-z disks aren't thin!



Genzel+ 2011

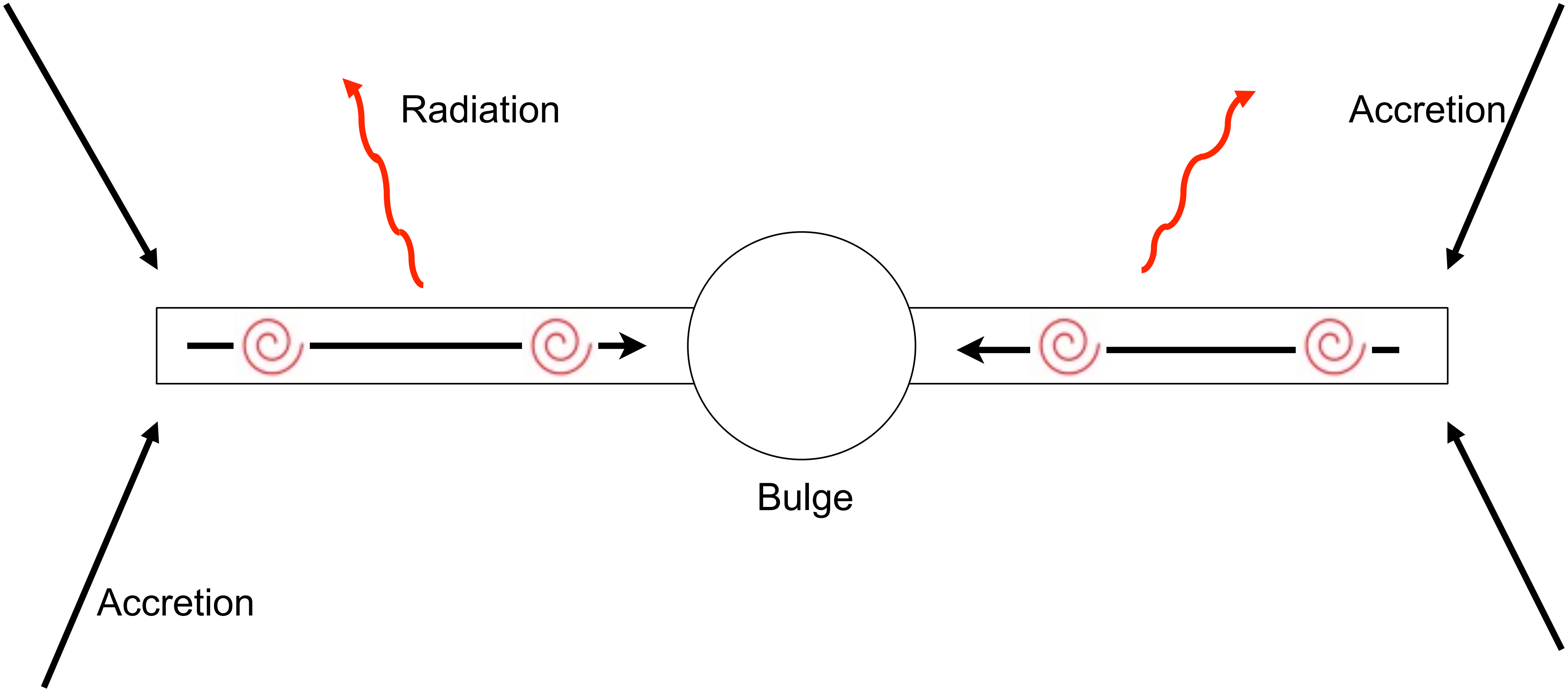


Elmegreen+ 2005

Model Overview

- Goal: Simulate disks self-regulated near Q=1 over cosmological times
- Assumptions:
  - The disk is axisymmetric and thin
  - Fixed radius, circular velocity, and potential
  - Q=1 at all radii at all times
- Variables
  - Gas: $\Sigma(r,t)$ $\sigma(r,t)$ $Z(r,t)$
  - Stars: $\Sigma_*(r,t)$ $\sigma_*(r,t)$ $Z_*(r,t)$

Dynamics in a Q~1 Disk



Maintaining Gravitational Instability

- Formally, changes in the gas state variables depend on the torque:

$$\mathcal{T} = \int 2\pi r^2 T_{r\phi} dz$$

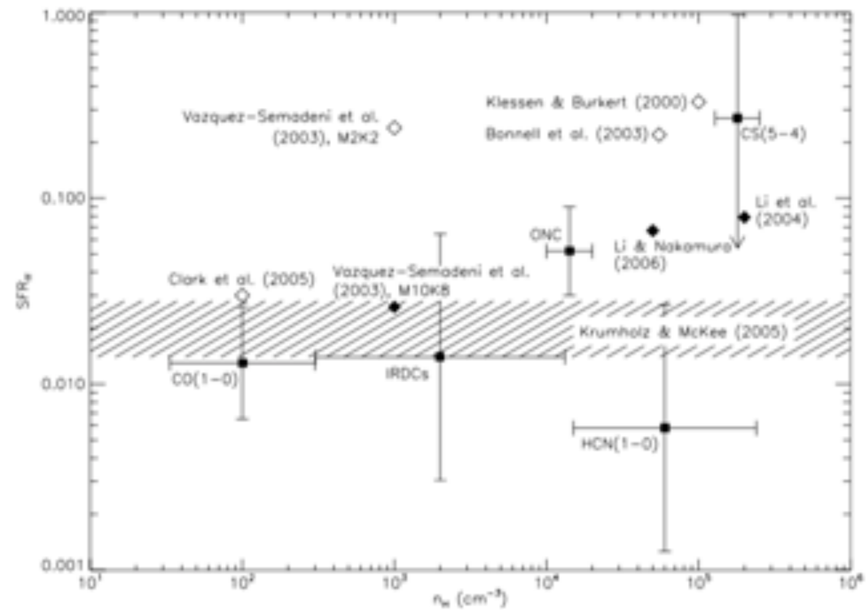
- So, set the torques such that Q=1, or dQ/dt=0

$$\frac{dQ}{dt} = \frac{\partial Q}{\partial \Sigma}\frac{\partial \Sigma}{\partial t} + \frac{\partial Q}{\partial \sigma}\frac{\partial \sigma}{\partial t} + \frac{\partial Q}{\partial \Sigma_*}\frac{\partial \Sigma_*}{\partial t} + \frac{\partial Q}{\partial \sigma_*}\frac{\partial \sigma_*}{\partial t} = 0$$

Physical Ingredients

- Star Formation

$$\dot{\Sigma}_*^{SF} = \epsilon_{ff} f_{H_2} \Sigma \sqrt{G\rho}$$



Krumholz & Tan 2007

- Gas Dissipation
    - Supersonic turbulence decays in a crossing time

$$\mathcal{L} = \eta \Sigma \sigma^2 \Omega \left(1 - \frac{\sigma_t^2}{\sigma^2}\right)^{3/2}$$

Stellar Migration

- When Q_s < ~2, transient spirals heat the stars
- This requires a net inward migration by conservation of energy
- Rate of inward migration set by assuming:

$$\left.\frac{dQ_s}{dt}\right|_{mig} = \frac{2 - Q_s}{T}$$

- T ~ 5 orbital times

Sample Run

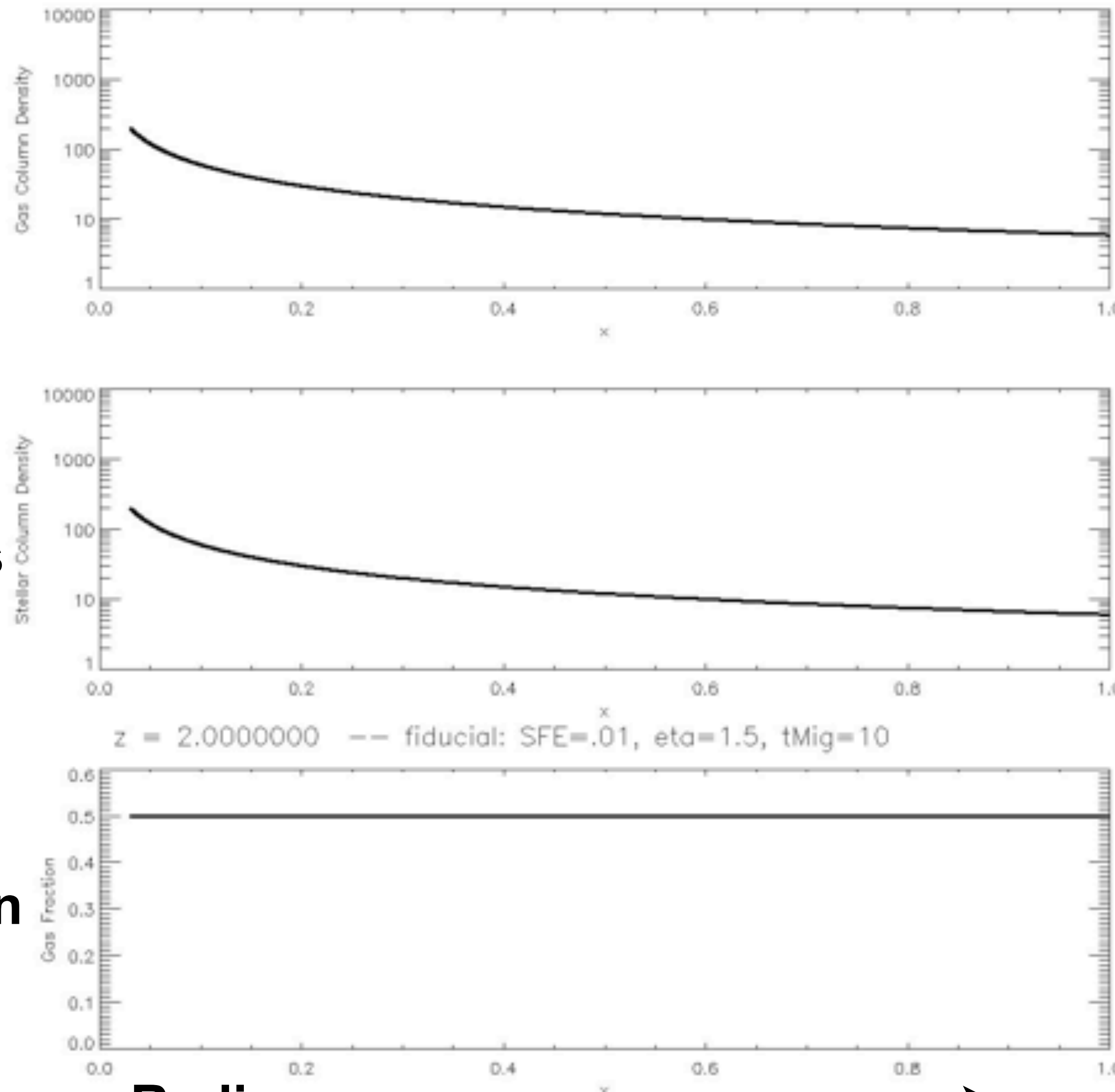
- Smoothed Milky-Way like accretion history (Bouche+ 2010)
- Starting z=2
- Disk radius = 10 kpc
- Circular velocity = 220 km/s
- Star-formation efficiency per free-fall time= 0.01
- Stellar Migration Time = 10 outer orbits
- Maximal gas dissipation (all turbulent KE radiated in a scale height crossing time)

Column Density Evolution

Gas

Stars

Gas Fraction



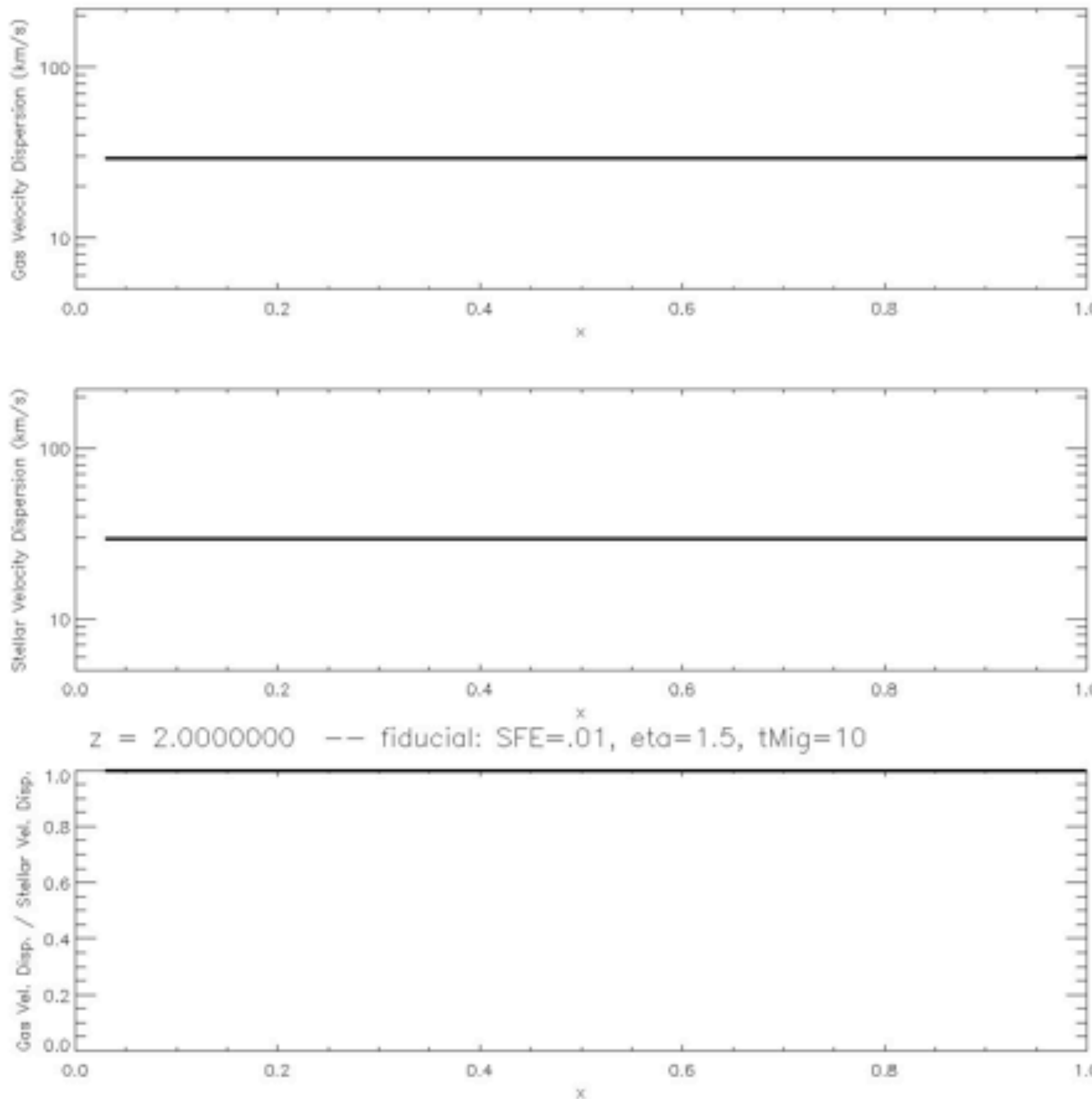
Radius

Velocity Dispersion Evolution

Gas

Stars

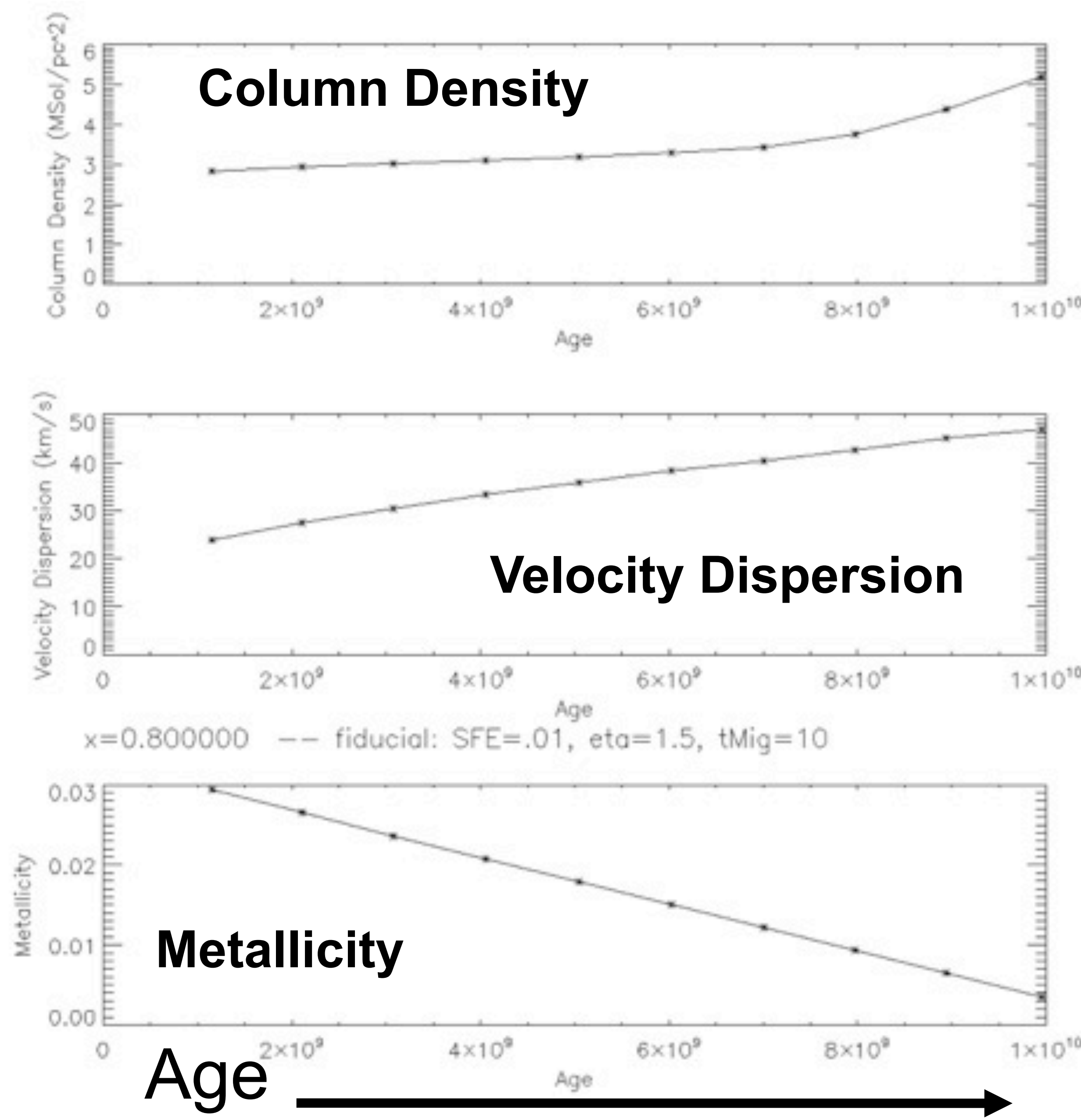
Gas/Stars



Radius →

Stars

- Solar neighborhood
- At z=0



Summary and Outlook

- 1-D simulation of gravitationally unstable galaxies from z=2 to z=0 on 1 CPU in ~1 hour [look for JF, Krumholz, & Burkert (2011, in prep)]
- Near-term Applications
  - Age-velocity dispersion- metallicity correlation
  - Parameter studies (dissipation, star formation, halo size)
  - More realistic accretion histories
- Longer-term extensions
  - Self-consistent evolution of circular velocity, radius
  - More sophisticated treatment of metals