Stellar Populations Produced in Gravitationally Unstable Disks

John Forbes
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With Mark Krumholz and Andi Burkert
Thick Disks at Redshift Zero

Older stars have higher velocity dispersions


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The Usual Story

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  THIN DISK →

  SOMETHING HAPPENS →

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  SOMETHING HAPPENS → THICK DISK

  Two-body scattering  Major Mergers
  Minor Mergers     Direct Accretion of Stars
  Perturbing galaxies Scattering off Molecular Clouds
  Spiral Waves       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

Radiation

Accretion

Bulge
Maintaining Gravitational Instability

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

\[ T = \int 2\pi r^2 T_{r\phi} dz \]

• 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

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

• Gas Dissipation
  • Supersonic turbulence decays in a crossing time

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

Krumholz & Tan 2007
Stellar Migration

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

$$\frac{dQ_s}{dt}_{\text{mig}} = \frac{2 - Q_s}{T}$$

- $T \sim 5$ 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 $\sim 1$ 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