Cosmological Evolution of Gravitationally Unstable Galactic Disks

Marcello Cacciato
Minerva Fellow
@ Hebrew University of Jerusalem

in collaboration with
Avishai Dekel
and
Shy Genel
Observe Disk Galaxies @ z~2

Disks rotating with $V \sim 200 \text{ km/s}$ and $\sigma \sim 50 \text{ km/s}$

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

Star formation rates $\sim 100 M_\odot / yr$
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 $M \sim 10^{12} M_\odot$ at $z \sim 2$ 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

Cosmological accretion

Migration inwards

Self-Regulated Marginally Unstable Disk
High Surface Density: Fragmentation and Migration

Stable disk accumulates mass

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

Disk "heats up"

High Velocity Dispersion makes disk stable:

Disk stops fragmentation and migration
ANALYTICAL MODEL

Mass Conservation
\[
\dot{M}_{\text{gas, disk}} \simeq \gamma_{\text{gas, acc}} \dot{M}_{\text{acc}} - \dot{M}_{\text{gas, inflow}} - (1 + \gamma_{\text{fbk}}) \dot{M}_{\text{SFR}}
\]
\[
\dot{M}_{\text{star, disk}} \neq \dot{M}_{\text{star, acc}} - \dot{M}_{\text{star, inflow}} + \dot{M}_{\text{SFR}}
\]

Energy Conservation
\[
\dot{E}_{\text{int, disk}} \simeq \dot{M}_{\text{disk, inflow}} V_{\text{circ}}^2 - \dot{E}_{\text{gas, dis}}
\]

Energy source: mass inflow in the potential well

Gravitational Heating of the stars

Gas dissipates in a dissipation timescale \( t_{\text{dis}} \equiv \gamma_{\text{dis}} t_{\text{dyn}} \)

Marginally unstable (Gas+Stars) Disk:
\[
Q_{2c}^{-1} = W_1 Q_*^{-1} + W_2 Q_{\text{gas}}^{-1} = 1 \quad \text{where} \quad W_i = f_i(\sigma_{\text{gas}}, \sigma_*, \Sigma_{\text{gas}}, \Sigma_*)
\]

Cosmological Evolution

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

- **If** Solution has $\sigma_{\text{gas}} > c_s \approx 10\text{km/s}$
  - **then** Update Values and Move to Step

- **else** Marginal Instability cannot be satisfied: Disk is labeled stable, evolution stopped.
1-COMPONENT: Disk always unstable

\[ \delta_{\text{disk}} \equiv \frac{M_{\text{disk}}}{M_{\text{tot}}} \sim \text{const} \]

SUM decreases with time due to the way radius and mass evolve.

\( \Sigma \) has a maximum at \( z \sim 1 \) because \( \sigma \propto V_{\text{circ}} \approx V_{\text{vir}} \)

Disk unstable at \( z=0 \)
Two Components

Initially unstable disks stabilize at later time 
($z_{\text{stab}} \sim 0.5$) 

~40% of baryonic mass in the disk

Red = Stars
Blue = Gas

Stellar Dominated Disks @ $z_{\text{stab}}$

Net Gas Cooling & Net Stellar Heating
The Role of Dissipation

$z_{\text{stab}}$ 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

$z_{\text{stab}}$ affected

$\gamma_{\text{gas,acc}} = 0.7$
$\gamma_{\text{dis}} = 3$
$\gamma_{\text{fbb}} = 1$
$\gamma_{\text{fbb}} = 3$
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 ($\sigma_{\text{star}} \sim 8 \sigma_{\text{gas}}$)

Due to disk depletion $\rightarrow$ gas dissipation
Future Perspectives

Model improvements

- Scatter in mass accretion: analytical merger trees
- Metallic dependence \(\rightarrow\) mass dependence

Comparison with Hydro-Simulations (HydroART) [in collaboration with D. Ceverino]
Thanks