440(Gyr)

t = 4.460(Gyr)

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The Origins of Disk Galaxies

Origins of the scaling relations The origin of the exponential disk

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University of Rochester

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Disk galaxy scaling relations



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Forming disks from relic angular momentum distribution

This model assumes that the angular momentum is not redistributed as the disk forms. Assuming that the gas has the same specific angular momentum distribution as the dark matter, and that the disk is non-self-gravitating in an isothermal sphere,

$$\Sigma_d(R) = \mu rac{M_d}{2\pi R_d'^2} \left(rac{R}{R_d'}
ight)^{-1} \left(1+rac{R}{R_d'}
ight)^{-2}$$

where μ is a free shape parameter and

$$R'_d \equiv \frac{\mathcal{L}_c}{V_c} = \sqrt{2}(\mu - 1)\xi^{-1}\lambda r_{\rm vir}$$

with $\xi = 1 - \mu \left[1 - (\mu - 1)\ln\left(\frac{\mu}{\mu - 1}\right)\right].$

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Forming disks from relic angular momentum distribution



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A viscous disk

The gas surface density will evolve into the stellar surface density via the star formation law,

$$\frac{\partial \Sigma_*}{\partial t} = \frac{\Sigma(R,t)}{t_*}$$

where t_* is the star formation time scale. The evolution of the gas surface density is governed by

$$\frac{\partial \Sigma}{\partial t} + \frac{1}{R} \frac{\partial}{\partial R} (\Sigma R v_R) = -\frac{\Sigma}{t_*}$$

and

$$\frac{\partial}{\partial t}(\Sigma R^2 \Omega) + \frac{1}{R} \frac{\partial}{\partial R}(\Sigma R^3 \Omega v_R) = \frac{1}{R} \frac{\partial}{\partial R} \left(\nu \Sigma R^3 \frac{\partial \Omega}{\partial R} \right) - R^2 \Omega \frac{\Sigma}{t_*}$$

By eliminating v_R and assuming that $\frac{\partial \Omega}{\partial t} = 0$,

$$\frac{\partial \Sigma}{\partial t} = -\frac{1}{R} \frac{\partial}{\partial R} \left\{ \frac{\frac{\partial}{\partial R} \left(\nu \Sigma R^3 \frac{\partial \Omega}{\partial R} \right)}{\frac{\partial}{\partial R} (R^2 \Omega)} \right\} - \frac{\Sigma}{t_*}$$

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Mechanism(s) producing thin disks

The stellar velocity dispersion is observed to increase with age. If stars are born close to the midplane, then a heating mechanism increases the velocity dispersion with time.

Possible heating mechanisms include

- Differential rotation between stars and GMCs
- Transient spiral arms

It is important to remember that the vertical structure is independent of galactocentric radius, so the responsible heating mechanism must be uniform across the entire galaxy.

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Mechanism(s) producing thick disks

The stellar components are old ($\gtrsim 10 - 12$ Gyr), metal-poor, and are enhanced in α -elements compared to thin-disk stars with similar metallicities.

The possible formation scenarios depend on the birth place of the constituent stars.

- Thin disk
- Thick disk (in situ)
- Externally



Disk instabilities

Global instabilities can cause a significant transformation of the overall disk structure.

Local instabilities determine if perturbations smaller than the disk size can grow.









Density contours of global instability nodes for a rotating disk (Dobbs & Baba, 2014)