Stellar Energy Feedback & Disk Galaxies

Kinetic energy from stars
Mass components
Angular momentum
Formation of disk galaxies

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University of Rochester

Energy feedback from stars

Three modes of stellar energy feedback:

- Radiation
- Neutrino emission
- Mass flow

Kinetic energy in stellar wind is

$$L_{\mathrm{wind}} = \frac{1}{2}\dot{M}v_{\infty}^{2}$$

where $v_{\infty} \equiv$ the terminal velocity.

Disk galaxies

Components of a disk galaxy include

- Disk of stars, dust, and cold gas with spiral arms and, sometimes, a central bar
- Central bulge
- Stellar halo
- Dark halo

Observations of disk galaxies indicate that

- Brighter disk galaxies are larger, redder, rotate faster, and have smaller gas fractions
- Disk galaxies have flat rotation curves
- The surface brightness profile of the disk is exponential
- There is a color and metallicity gradient in the disks, from redder, higher metallicities towards the center to bluer, lower metallicities at the edges.

Infinitesimally-thin exponential disk

Surface mass density:

$$\Sigma(R) = \Sigma_0 e^{-R/R_d}$$

where $R_d \equiv$ the scale radius of the disk.

Total mass:

$$M_d = 2\pi\Sigma_0 R_d^2$$

Gravitational potential:

$$\Phi(R,z) = -2\pi G\Sigma_0 R_d^2 \int_0^\infty \frac{J_0(kR)e^{-k|z|}}{[1+(kR_d)^2]^{3/2}}\, dk$$

Exponential disk with exponential thickness

Mass density distribution:

$$\rho(R,z) = \rho_0 e^{-R/R_d} e^{-|z|/z_d}$$

so that the gravitational potential is then

$$\Phi(R,z) = -2\pi G \Sigma_0 R_d^2 \int_0^\infty \frac{J_0(kR)}{[1+(kR_d)^2]^{3/2}} \frac{e^{-k|z|} - (kz_d)e^{-|z|/z_d}}{1-(kz_d)^2} dk$$

Problem: $\frac{\partial \rho}{\partial z}$ is not continuous at $z = 0$.

Exponential spheroid

Mass distribution:

$$\rho(r) = \rho_0 K_0\left(\frac{r}{R_d}\right)$$

(derived using the Abel integral equations), with $\rho_0 = \frac{\Sigma_0}{\pi R_d}$.

Gravitational potential:

$$\Phi(R,z) = \frac{GM_d}{\pi R_d^2}\int_0^\infty \frac{tK_1\left(\frac{t}{R_d}\right)}{(\tau+1)\sqrt{\tau+q_d^2}}d\tau$$

where q_d is the intrinsic flattening of the disk and

$$t = \sqrt{\frac{R^2}{\tau+1}+\frac{z^2}{\tau+q_d^2}}$$

Isothermal sheet

Assume that the vertical density distribution is locally isothermal, so that the stellar distribution in the vertical direction is

$$f = \frac{1}{\sqrt{2\pi}\sigma_z} e^{-E_z/\sigma_z^2}$$

where

$$\sigma_z = \text{velocity dispersion of the stars in the vertical direction}$$
$$E_z = \tfrac{1}{2}v_z^2 + \Phi(R, z)$$

The mass density of the disk is then

$$\rho(R, z) = \rho(R, 0)\,\mathrm{sech}^2\left(\frac{z}{2z_d}\right)$$

where $\rho(R, 0) = \frac{\Sigma(R)}{4z_d}$ and $z_d = \frac{\sigma_z^2(R)}{2\pi G\Sigma(R)}$.

Disk rotation curves

Model: axisymmetric disk with a spherical dark matter halo

For spherical systems,

$$V_c^2(r) = r\frac{d\Phi}{dr} = \frac{GM(r)}{r}$$

$$V_c(r) \propto \begin{cases} r^{-1/2} & \text{for point mass} \\ \text{constant} & \text{for } \rho(r) \propto r^{-2} \\ r & \text{for uniform sphere} \end{cases}$$

When the disk is axisymmetric, $V_c^2(R) = R\left(\frac{\partial\Phi}{\partial R}\right)_{z=0}$

The circular velocities from each of the mass components are additive, so

$$V_c^2 = V_{c,b}^2 + V_{c,d}^2 + V_{c,h}^2$$

CDM cosmology: NFW profile

Predicted based on cosmological simulations of cold dark matter, the resulting density of dark matter halos follows the Navarro-Frank-White (NFW) profile,

$$\rho(r) = \rho_{\rm crit} \frac{\delta_{\rm char}}{\left(\frac{r}{r_s}\right)\left(1 + \frac{r}{r_s}\right)^2}$$

where $r_s \equiv$ the scale radius and $\delta_{\rm char} \equiv$ the characteristic overdensity.

The corresponding circular velocity is

$$\frac{V_{c,h}(r)}{V_{\rm vir}} = \sqrt{\frac{1}{x} \frac{\ln(1+cx) - \frac{cx}{1+cx}}{\ln(1+c) - \frac{c}{1+c}}}$$

where $x = r/r_{\rm vir}$, $c \equiv$ the halo concentration parameter, and $V_{\rm vir} = \sqrt{GM_{\rm vir}/r_{\rm vir}}$.

Rotational velocity of a thin exponential disk

$$V_{c,d}^2(R) = 4\pi G\Sigma_0 R_d y^2[I_0(y)K_0(y) - I_1(y)K_1(y)]$$

where

$y =$ $R/2R_d$

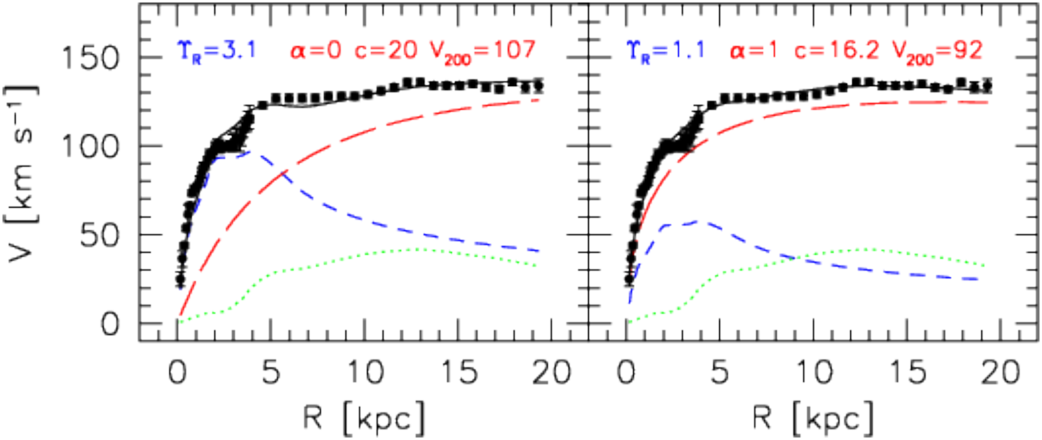
I_n, K_n are the modified Bessel functions of the first and second kinds, respectively

If we assume that the disk is composed of only stars, then

$R_d =$ the scale length of the stellar light

$\Sigma_0 =$ ΥI_0, where $\Upsilon \equiv$ the stellar mass-to-light ratio and $I_0 \equiv$ the central surface brightness.

Disk-halo mass degeneracy



Blue: stellar disk; Green: gas disk; Red: dark matter halo