Disk Galaxies & Galactic Interactions

Chemical evolution & High-speed encounters
Tidal stripping & Dynamical friction
Galaxy merging & Cluster transformation

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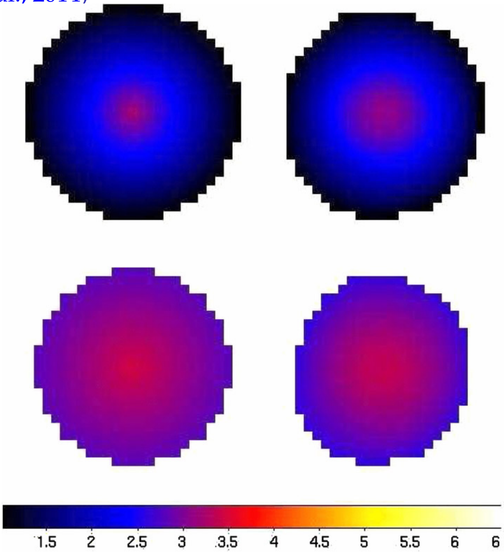
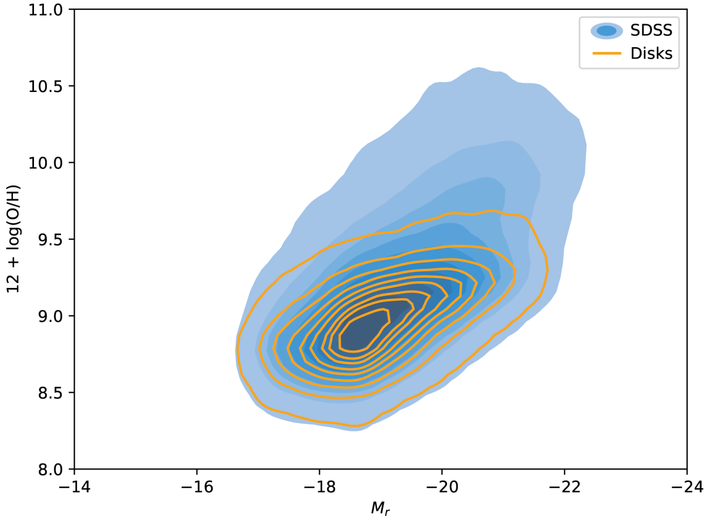
Stellar population gradients

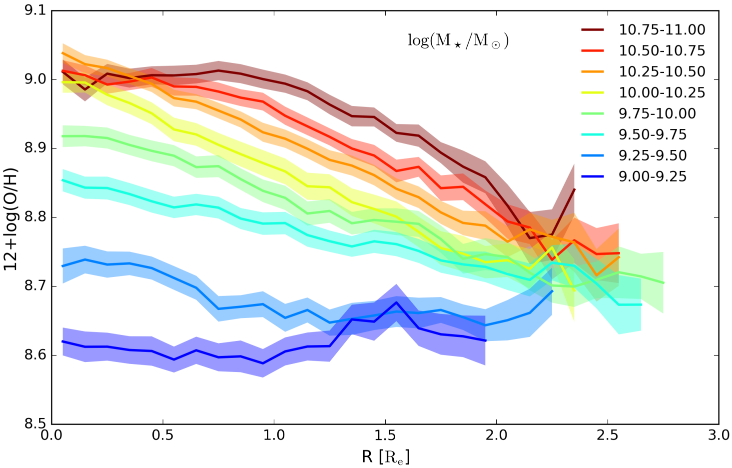
NUV-r color gradient (Pan et al., 2014)



Metallicity-Luminosity relation



Metallicity gradients



Belfiore et al. (2017)

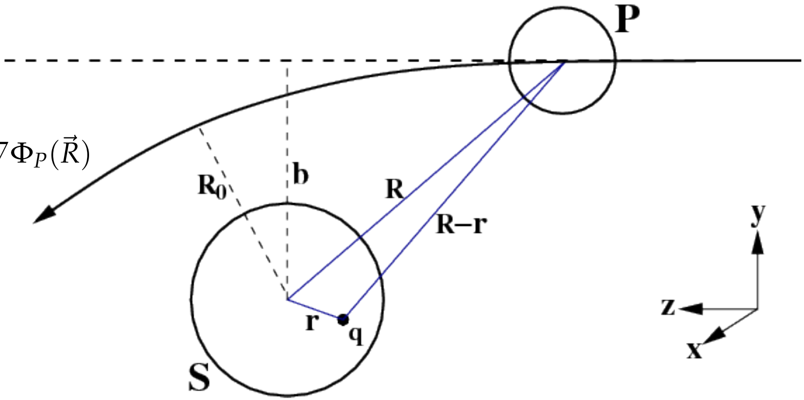
Collisionless interactions

Particle q experiences a tidal force per unit mass from P equal to

$$\vec{F}_{\rm tid}(\vec{r}) = -\nabla\Phi_P(|\vec{R}-\vec{r}|) + \nabla\Phi_P(\vec{R})$$

The rate of change of energy gained by q as a result of this encounter is

$$\frac{dE_q}{dt} = \vec{v}\cdot\vec{F}_{\rm tid}(\vec{r})$$



Impact of a collisionless interaction

Take τ_{tide} to be the time it takes for the tide to rise, and $\tau_{\text{enc}} \simeq \frac{R_{\text{max}}}{V}$ is the duration of the encounter, then when

$\tau_{\text{enc}} \gg \tau_{\text{tide}}$ the effects of the approach and encounter cancel, resulting in no net energy change.

$\tau_{\text{enc}} \lesssim \tau_{\text{tide}}$ the body lags behind the interaction, resulting in a torque on the system and a transfer of energy between the two bodies.

Galaxies and dark matter halos are both collisionless systems, so $\tau_{\text{tide}} \sim \frac{R}{\sigma}$.

High-speed encounters

In a coordinate system centered on S, the tidal force per unit mass is

$$\vec{F}_{\rm tide}(\vec{r}) = \frac{GM_P}{R^3}(2x'\hat{x} - y'\hat{y} - z'\hat{z})$$

Transforming back into (x, y, z) and integrating

$$\vec{F}_{\rm tide} = \frac{d\vec{v}}{dt}$$

we find that

$$\Delta\vec{v} = \frac{2GM_P}{v_P b^2}(-x\hat{x} + y\hat{y})$$

Aside: The virial theorem

For gravitationally bound systems in equilibrium, the total energy is always equal to half of the time-averaged potential energy:

$$\langle E \rangle = \frac{1}{2}\langle U \rangle$$

Since $\langle E \rangle = \langle K \rangle + \langle U \rangle$,

$$\begin{aligned} \langle E \rangle &= -\langle K \rangle \\ \langle K \rangle &= -\frac{1}{2}\langle U \rangle \\ \langle U \rangle &= -2\langle K \rangle \end{aligned}$$

Tidal radius

Ignoring the orbital motion of the satellite, its tidal radius is

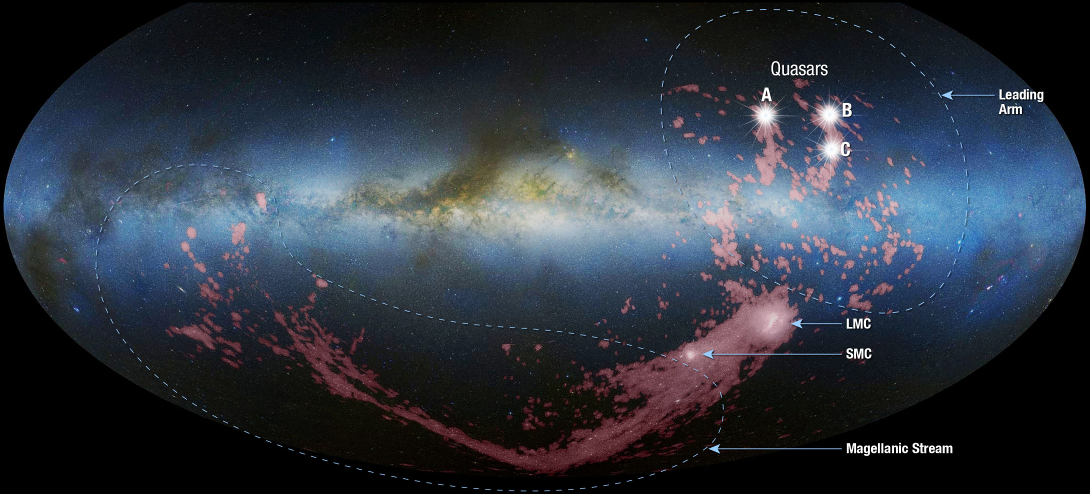
$$r_t = \left(\frac{m}{2M}\right)^{1/3} R$$

Accounting for the centripetal acceleration due to the satellite being in orbit, the tidal radius is

$$r_t = \left(\frac{\frac{m}{M}}{3 + \frac{m}{M}}\right)^{1/3} R$$

Tidal streams

Magellanic Stream (ESA/Hubble)



Tidal streams

Sagittarius Stream (S. Koposov & SDSS-III)