Exercises — 11

The impact of strong stellar-driven outflows on rotation curves of low-mass galaxies

1. Calculate the stellar baryon conversion efficiencies, and compare with predictions from semi-empirical models (e.g., Moster et al. 2013)
2. Derive the circular velocity from Kepler's third law
3. Use the above expression and plot the rotation curves (circular velocity vs radial distance from galaxy center, out to ~ 20kpc) for all matter, and DM, gas and stars separately. Explain the differences with and without stellar-driven outflows.
4. Plot maximum circular velocity vs stellar mass (Tully Fisher relation), indicate the observed relation (e.g., Avila-Reese et al. 2008)

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Helpful instructions/information:

- Stellar baryon conversion efficiency: $M_{stellar}/(f_{bar}*M_{halo})$,
  - stellar mass are star particles within 1/10 R_{vir},
  - halo mass are DM particles within R_{vir},
  - f_{bar} can be calculated from cosmological parameters
- Kepler's third law: centripetal force equal to gravitational force
- You will get six ascii-files:
  - two of them containing star particles,
  - two of them gas particles and
  - two of them DM particles.
- The two different files per particle type correspond to two different simulation runs, adopting different stellar feedback models ("nomw" and "winds", see next slide for more explanation)
- These ascii files have the following format (code units as before):

particle mass, x_position, y_position, z_position

- The positions are centered to the main galaxy (center of mass: x=0.0, y=0.0, z=0.0)

Further information
2 cosmological hydrodynamic zoom-in simulation of a low-mass halo at z=0 with and without stellar-driven outflows

- WMAP3 cosmology, IC details described in Oser+10, Hirschmann+12 (Halo 3852)
- Run with a modified version of Gadget-2, for code details see *Hirschmann+13*
- *Grav* softening DM: 800pc; grav softening gas/stars: 400pc; Number of neighbours: 100
- M_{halo}= 3e11 $M_{\odot}$/h, R_{vir}= 109 kpc/h,
- *First simulation run with thermal stellar fb* (weak effect, *termed as "nomw" in the ascii file name*)
- *Second simulation run with* momentum-driven winds ("kicked" gas particles, decoupled from hydrodynamics for some time, *termed as "winds" in the ascii file name*)
- Both runs are taken from *Hirschmann+13*

Solution — 1. Calculate the stellar baryon conversion efficiencies, and compare with predictions from semi-empirical models (e.g., Moster et al. 2013)

Stellar baryon conversion efficiency = $\dfrac{M_{\rm stellar}}{f_{\rm bar} M_{\rm halo}}$,

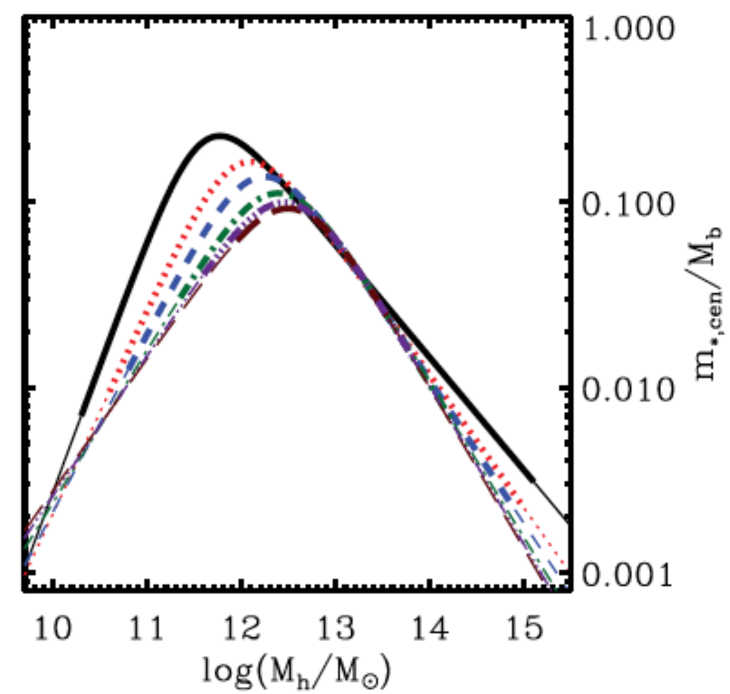
where $f_{\rm bar} = \dfrac{\Omega_b}{\Omega_m} \sim 0.158$,

with $\Omega_b = 0.04087$ and $\Omega_m = 0.259$ from WMAP3 (Spergel et al., 2007)

Stellar baryon conversion efficiency:

- **winds** model: 0.302
- **nomw** model: 1.079
- prediction: 0.19

where the prediction is taken out of Moster et al. (2013) for a halo mass of $M_{\rm halo}$ = 3e11 $M_\odot/h$



We conclude that the result for the **winds** model is in good agreement with the prediction of Moster et al. (2013), while for the **nomw** model, we instead get an unphysical high value.

Solution — 2. Derive the circular velocity from Kepler's third law

Kepler's third law states that:

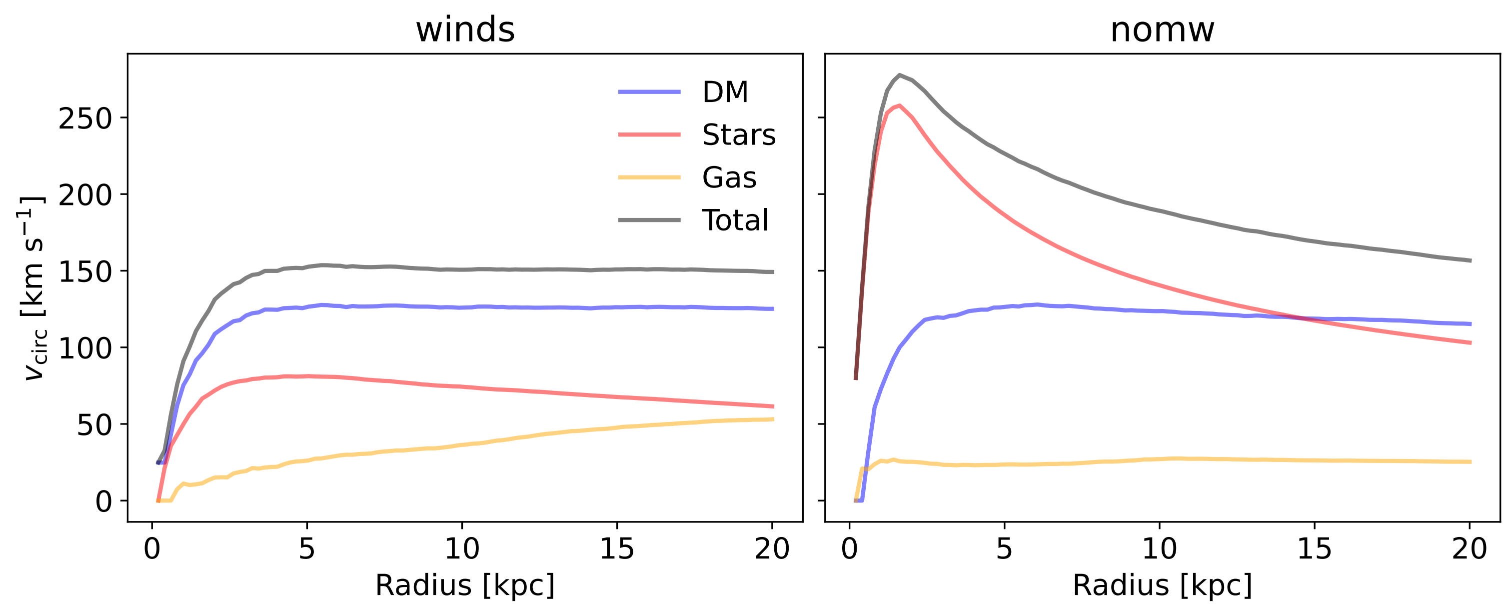
$$\frac{a^3}{T^2} = \frac{G(M+m)}{4\pi^2}.$$

For a circular orbit where $a = r$, $T = (2\pi r)/v_{\rm circ}$ and $M >> m$, Kepler's law gives us that

$$\frac{r^3}{\left(\frac{2\pi r}{v_{\rm circ}}\right)^2} = \frac{GM}{4\pi^2} \quad \Rightarrow \quad v_{\rm circ} = \sqrt{\frac{GM}{r}}.$$

Solution — 3. Use the above expression and plot the rotation curves (circular velocity vs radial distance from galaxy center, out to ~ 20kpc) for all matter, and DM, gas and stars separately. Explain the differences with and without stellar-driven outflows.

In the **nomw** model, i.e. in the case of weak feedback, the central mass of the galaxy is dominated by stars, while in the **winds** model with strong feedback, the mass profile is always dominated by DM. This is because strong stellar-driven outflows are very powerful in suppressing SF in lower mass galaxies (via heating and ejection of gas).



Solution — 4. Plot maximum circular velocity vs stellar mass (Tully Fisher relation), indicate the observed relation (e.g., Avila-Reese et al. 2008)

In the figure below, we show the Tully Fisher relation from Avila-Reese et al. (2008): $\log(v_{max}) = a + b^*\log(M_{stellar})$, where a = -0.639, b = 0.058, with the standard deviation = 0.058, together with the two galaxies with different stellar feedback models.

The **winds** model is within one standard deviation of Avila-Reese et al. (2008), and therefore agrees very well with the Tully Fisher relation. The **nomw** model instead show a too high v_{max} relative to its stellar mass. This is because of extreme SF, making the rotation curve and thus the max. rotation velocity, dominated by the (too large) central stellar component.