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Dark Matter vs. Visible Matter in the SPARC Galaxy Sample

Modeling the visible mass of a galaxy

1. Can you find a galaxy in the sample that has a dense central bulge component? What would this look like in the surface brightness plot?

    Galaxy NGC7814, also known as “Little Sombrero”, has a dense central bulge. This is seen as an additional linear steep graph in the surface brightness plot; as the radius from the center of the galaxy increases the surface brightness decreases. This indicates there are extremely hot stars at radii closer to the center of the galaxy and then the temperature beings to decrease as the radius becomes larger.

Determining the distribution of visible and dark matter in a galaxy

2. Rewrite the equation for rotational velocity so that it is expressing the mass enclosed M in terms of G, v_{rot}, and r.

$$M_{enclosed} = \frac{(v_{rot}{}^2 * r)}{G}$$

3. What is the volume of the spherical shell S_{12} that is defined by radii r_1 and r_2? The volume of a sphere is given by $V_{sphere} = (4/3)\ \pi\ r_3$

$$V_{S_{12}} = \tfrac{4}{3}\pi(r_2{}^3 - r_1{}^3)$$

4. What is the mass enclosed within the spherical shell S_{12} ?

$$M_{S_{12}\ enclosed} = \frac{(v_2{}^2 * r_2 - v_1{}^2 * r_1)}{G}$$

5. What is the average density of matter in the shell S_{12}? Remember: density = mass/volume.

$$Average\ Matter\ Density\ in\ S_{12} = \frac{3(v_2{}^2 * r_2 - v_1{}^2 * r_1)}{4\pi G(r_2{}^3 - r_1{}^3)}$$

6. Look at the plot you produced for the density distribution of the total/dark/visible mass. Depending on the galaxy you are looking at, the density of visible matter might be calculated to be *higher* than the total density in the central region of the galaxy (this effect will also be evident in your rotation curve plot). How is this possible? (Ask your TA if you're not sure.)

   In NGC7814's density plot, the density of visible matter is seen to be higher than the total density in the central region of the galaxy. This may be due to the total density in the central region being underestimated, which would mean that there is a mass to light ratio less than one in the central region (less mass is observed than luminosity in central region).

7. Around what radius (in kpc) does the dark matter density dominate over the visible matter density? If you go back to the file 'galaxy_sample_summary.txt' in your text editor, you can look up the effective radius R_{eff} (defined as the radius within which half of the total luminosity is contained) and the stellar disk radius R_{disk}. These are columns 7 and 9, respectively. Write their values below. How do these radii compare to the radius at which dark matter becomes the dominant component of the mass density?

   In the Little Sombrero galaxy at 14.0 kpc from the center of the galaxy the dark matter density dominates over the visible matter density. The effective radius of NGC7814 is at 1.0 kpc and the stellar disk radius is at 0.343 kpc. Half of the total luminosity is contained closer to the center of the galaxy and the stellar disk is seen at a radius much closer to the center of the galaxy.

Can the rotation curves be explained without the need for dark matter?

8. If you assumed that all stars were like the sun, i.e. they had mass-to-light ratios of Y=1, then what would the mass be for a galaxy that was observed to have a luminosity $L=10^{11}$ M_{sun}?

$$M = 10^{11} M_{sun}$$

9. Do red dwarfs have mass to light ratios greater than or less than 1?

   Red Dwarfs have mass to light ratios greater than 1.

10. If the stellar content of a galaxy with $L=10^{11}$ M_{sun} was predominantly composed of red dwarfs, would you estimate it to have a higher or lower mass in stars than you did in (2)?

    If the galaxy is predominantly composed of red dwarfs, it would have a **higher mass in stars** than before.

11. Does the value of $Y=1M_{sun}/L_{sun}$ seem like a reasonable value to use? Do you think it should be higher or lower?

    The mass to light ratio should be higher than one.

12. If you wanted to change the mass-to-light ratio and try to fit the observed rotation curve using only the visible matter, could you simply scale the entire visible rotation curve up or down by multiplying it by your new value of Y? If not, by what factor should you scale the stellar velocity curve?

    In order to fit the observed rotation curve using only the visible matter, you could scale the entire visible rotation curve up and down by multiplying it by the new value of mass to light ratio. The stellar velocity curve should also be scaled by the discrepancy of the observed and calculated rotational speeds of visible matter.

13. What is the value of Y that gives the lowest χ^2 per degree of freedom for your galaxy when you try to fit the data with the visible matter only? What is the χ^2 per degree of freedom in this fit?

    Galaxy: NGC7814 “Little Sombrero”

Y (mass to light ratio) = 1.461

Chi squared per degree of freedom = 77.02983704520398

14. The python notebook is set up to make it pretty efficient for you to examine different galaxies in the dataset. Look at as many different galaxies as you can in the remaining time, and try to fit the observed rotational speeds in each of them with visible matter only by playing with the value of the mass-to-light ratio. Are there any galaxies that can be fit without the need for dark matter (χ_2 per degree of freedom <1)? If you find any, write their names down and take note of their galaxy type.

Galaxy Name	Type	Mass to light Ratio	Chi squared per degree of freedom
D512-2	Irregular - Im	2.21	0.9507651650058855
F561-1	Irregular "Magellanic" Spiral -Sm	0.9	0.6352477401718724
F563-V1	Irregular - Im	1.0	0.17410504733432194
F563-V2	Irregular - Im	6.1	0.49263563458701864
F567-2	Irregular - Sm	1.9	0.29975905493872046
F574-2	Irregular - Sm	0.6	0.10001591843163175

15. What value(s) of Y seem to fit the data the best when you try to match the total rotational speeds by changing the mass-to-light ratio? Do these seem to be consistent with the range of mass-to-light ratios that we think the typical star might have?

Y values (best fit) : 0.6 to 6.1

These mass to light ratios are the best fit for irregular galaxies (Sm and Im).