Astronomy from 4 perspectives: the Dark Universe

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play with data: rotation curves of galaxies

Observations of the rotation of disc galaxies is nowadays done in the Hα-line of hydrogen, because it reaches to much larger distances from the galaxy centre compare to the stellar light. In this exercise we have a look at a data set on low surface-brightness galaxies by W. de Blok, S. McGaugh and V. Rubin, Astronomical Journal 122, 2381 (2001).

1. flat rotation curves

Let's start by exploring Hα-data for low surface-brightness galaxies.

(a) Why is it a clever idea to focus on galaxies with a low (optical) surface brightness?

(b) What is the general relationship between rotation curve $v(r)$ and mass profile $\rho(r)$?

(c) A isothermal sphere with a core has the density profile $\rho(r)$,

$$\rho(r) = \rho_0 \left(1 + \left(\frac{r}{r_c}\right)^2\right)^{-1}, \tag{I}$$

with the central density ρ and the core radius r_c. The corresponding velocity profile $v(r)$,

$$v(r)^2 = 4\pi G \rho_0 r_c^2 \left(1 - \frac{r_c}{r} \arctan\left(\frac{r}{r_c}\right)\right), \tag{II}$$

with the gravitational constant $G \simeq 10^{-11}$ m^3/kg/s^2.

(d) Please show that the asymptotic value for v for $r \to \infty$ is $v_\infty = \sqrt{4\pi G \rho_0 r_c^2}$. Please check the units of the relation between v_∞ and r_c and ρ_0.

(e) Please use the script `rotplot.py` and plot a couple of rotation curves: Do they show the expected behaviour?

2. luminous and dark matter

With the script `rotfit.py` you can fit a model rotation curve to data. Take care to read off the distance d to the galaxy from the table, in order to convert r from arcseconds to kpc.

(a) Are the curves from the isothermal-sphere model providing a good fit to data?

(b) What are typical velocities v_∞, central densities ρ_0 and core radii r_c?

(c) What is the role of ϵ in the script? Why are the results not affected if ϵ is small enough?

Please continue by completing the table.

(d) Please try to find out if the mass to light-ratio M/L is large: For that purpose, estimate the total mass M in units of the solar mass $M_\odot = 10^{30}$ kg,

$$M = 4\pi \int_0^\infty r^2 \mathrm{d}r \, \rho(r), \tag{III}$$

and compare it to the total luminosity. For the integral, you can use the result

$$\int \mathrm{d}x \, \frac{x^2}{1+x^2} = \arctan(x) + \text{const.} \tag{IV}$$

Please truncate the integration at the tidal radius $10 r_c$. With the expression for the mass, please verify the relationship between orbital velocity v and distance r.

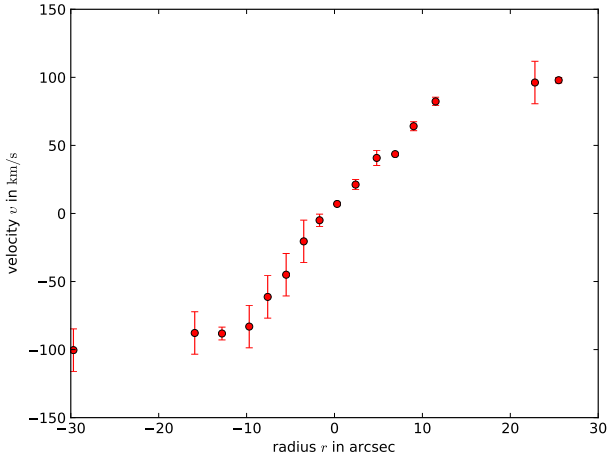

Figure 1: rotation curve $\upsilon(r)$ of the galaxy F568

(e) Then, please express the mass to light-ratio M/L in units of solar masses per solar luminosities $M_\odot/L_\odot$: The luminosity L in units of the solar luminosity $L_\odot$ follows from the difference of the absolute magnitudes,

$$\frac{L}{L_\odot} = 10^{0.4(\mathrm{Mag}_\odot - \mathrm{Mag})}, \tag{V}$$

you can find the values for Mag of the galaxies in the table, and use the literature value for $\mathrm{Mag}_\odot = 5.45$ in the same band (R-band) from the literature.

(f) Is there evidence for dark matter?

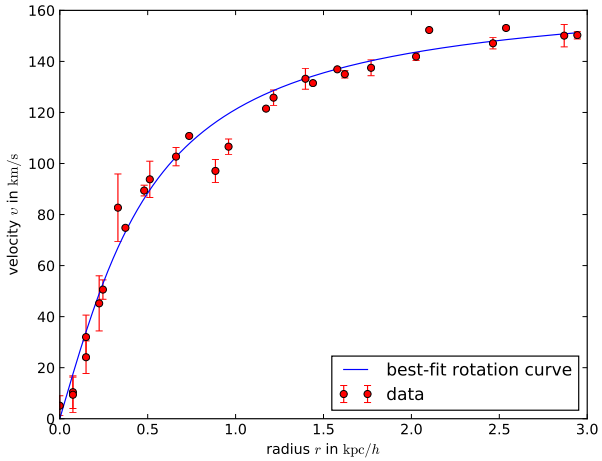

Figure 2: fit of a isothermal sphere rotation curve $\upsilon(r)$ to the galaxy U11557 at 22 Mpc distance, with the values $r_c = 0.412$ kpc and $\upsilon_\infty = 169$ km/s.

galaxy	d in Mpc	υ_∞ in km/s	r_c in kpc	M in $M_\odot$	Mag	M/L in $M_\odot/L_\odot$
E0140040	212				-21.6	
E0840411	80				-18.1	
E1200211	15				-15.6	
E1870510	18				-16.5	
E2060140	60				-19.2	
E3020120	69				-19.1	
E3050090	11				-17.3	
E4250180	86				-20.5	
E4880049	22				-16.8	
F563-1	45				-17.3	
F568-3	77				-18.3	
F571-8	48				-17.6	
F579-V1	85				-18.8	
F583-1	32				-16.5	
F583-4	49				-16.9	
U4115	3.2				-12.4	
U5750	56				-18.7	
U6614	85				-20.3	
U11454	91				-18.6	
U11557	22	169	0.412		-20.0	
U11583	5				-14.0	
U11616	73				-20.3	
U11648	48				-21.0	
U11748	73				-22.9	
U11819	60				-20.3	