Observational Cosmology - Assessed Exercise 3

Observations of a poor galaxy cluster at a redshift of about 0.047 show that most of the optical light comes from the 10 brightest galaxies. Recession velocities (with a typical accuracy of 100 km s^{-1}) and x, y positions in arcminutes relative to the cluster centre, are measured as follows:

Galaxy	x (arcmin)	y (arcmin)	v (km s^{-1})
1	1	0	14260
2	-21	7	13180
3	-17	-27	14510
4	-4	14	13760
5	-8	-6	14190
6	7	26	14270
7	24	2	13680
8	12	-17	13450
9	6	3	14030
10	10	-9	14130

For simplicity, you may take all these galaxies to have the same apparent blue magnitude of 15.7.

X-ray observations of the cluster show that it is filled with approximately isothermal hot gas with temperature $T = 2.0 \pm 0.2 \times 10^7$ K, and density profile $\rho(r) = \rho_0(1 + (r/r_c)^2)^{-\alpha}$, with a small 'core radius', $r_c \approx 3'$, and $\alpha = 1.0$, with negligible error. This gas is detected as far as the 'virial radius' ($r \approx 28'$) out to which the cluster is expected to have reached dynamical equilibrium.

1. Calculate the total blue luminosity of the system in units of solar luminosities, given that the absolute blue magnitude of the sun is $M_B = +5.41$.
   If you do not have an astronomy background (and possibly even if you have!) you may need to revise magnitudes for this section. See advice for 'Students with little astrophysics background' on the course Home Page.

   N.B. You should use $H_0 = 70$ km $s^{-1}Mpc^{-1}$ throughout this exercise. [20%]

2. Use the virial theorem to calculate the total mass of the cluster. You may use the form

$$\overline{v^2} = 0.4\frac{GM}{R_{1/2}},$$

   as given in section 4.3.5 of Bothun (but note that Bothun's equation 20 in this section is wrong by several orders of magnitude). Here $\overline{v^2}$ is the mean squared 3D velocity of the galaxies in the cluster frame (which is three times the line-of-sight velocity dispersion), and $R_{1/2}$ is the half-mass radius, which you may take to be the radius of a circle enclosing half of the galaxies in projection on the sky. [25%]

3. Apply the equation of hydrostatic equilibrium

$$\frac{dP}{dr} = -\frac{GM(< r)\,\rho}{r^2}$$

to the gas, to calculate the total mass within the virial radius. [25%]
(*Hint: note that* $r \gg r_c$ *at the virial radius, which simplifies the maths.*)

4. Comment on the possible origin of any disagreement between the mass estimates you obtain from from (2) and (3). [10%]

5. Calculate the mass-to-light ratios (in solar units) using both the virial and X-ray masses, and comment on the results. Is this a typical galaxy cluster? [20%]

Note that your solutions do not need to be word processed, but they do need to be legible and clearly explained. There is no page limit on your solution here.

Warning: *be <u>very</u> careful to watch (and quote) your units during this exercise – it involves quite a mixture.*

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