Einführung in die Astronomie und Astrophysik 2

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Virial Theorem and Dark Matter — Hand in on May 26, 2011

6.1 Dynamic Evidence for Dark Matter

a) Globular clusters are gravitationally bound, dense stellar systems with half-light radii of typically $r_{1/2} \sim 5\,\mathrm{pc}$ and (one-dimensional) velocity dispersions $\sigma_{1/2}$ of roughly $6\,\mathrm{km\,s^{-1}}$. The total bolometric luminosity is $\sim 2.4 \times 10^{38}\,\mathrm{erg\,s^{-1}}$. Using the scalar virial theorem calculate the mass-to-light ratio Υ for a globular cluster in units of the solar mass-to-light ratio $\Upsilon_\odot = M_\odot/L_\odot$. (3 points)

b) The dwarf-spheroidal galaxy Draco - a satellite galaxy of our Milky Way - has a distance of about $d \approx 72\,\mathrm{kpc}$ and an estimated half-mass radius $r_{1/2}$ of about $5.7'$ on the sky. Draco has a luminosity of $L = 2.6 \times 10^5\,L_\odot$ and a (one-dimensional) dispersion velocity of $\sigma \approx 13.2\,\mathrm{km\,s^{-1}}$. Calculate the mass-to-light ratio Υ of the Draco galaxy and compare to a normal stellar population (as in the globular cluster considered above). Discuss *two* possible explanations for this value. (3 points)

c) Let us now apply the virial theorem to even larger systems, to clusters of galaxies. We follow the discussion of Fritz Zwicky in 1937 and focus on the Coma Cluster (see Zwicky, ApJ, 86, 217). He measured the relative velocities of about thousand galaxies in this cluster and determined their distance to the cluster center. He obtained a line-of-sight velocity dispersion of $\sigma_{\mathrm{LOS}} \approx 700\,\mathrm{km\,s^{-1}}$ and a radius of $625\,\mathrm{kpc}$. From these values, he estimated the total mass to be at least $\sim 5 \times 10^{13}\,\mathrm{M_\odot}$. And he concluded that the total mass-to-light ratio of the system is $\Upsilon \approx 500$.

Use the following Java applet to derive your own estimate of the mass-to-light ratio of the Coma Cluster:

`http://burro.astr.cwru.edu/JavaLab/clusters/ClustersApplet.html`

What is the gravitational mass you obtain and what is the corresponding value for Υ? Use a value of $H_0 = 72\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$ for the Hubble constant according to the current concordance model. Does your interpretation of the results change if you take recent x-ray observations into account, which reveal the presence of about $10^{14}\,\mathrm{M_\odot}$ of very hot, x-ray emitting intra-cluster gas? (4 points)