

The Big Mama in M104

The biggest black holes are found in other galaxies, especially large ellipticals. The Doppler technique is the method of choice, but its implementation here is slightly different from the method used on exoplanets and binary stars. Below is a Hubble telescope spectrum (in the region containing the emission lines from ionized oxygen and nitrogen) of the center of the galaxy M104, the "Sombrero Galaxy". The top spectrum is a region around the very center, while the lower two spectra are regions just flanking the center.

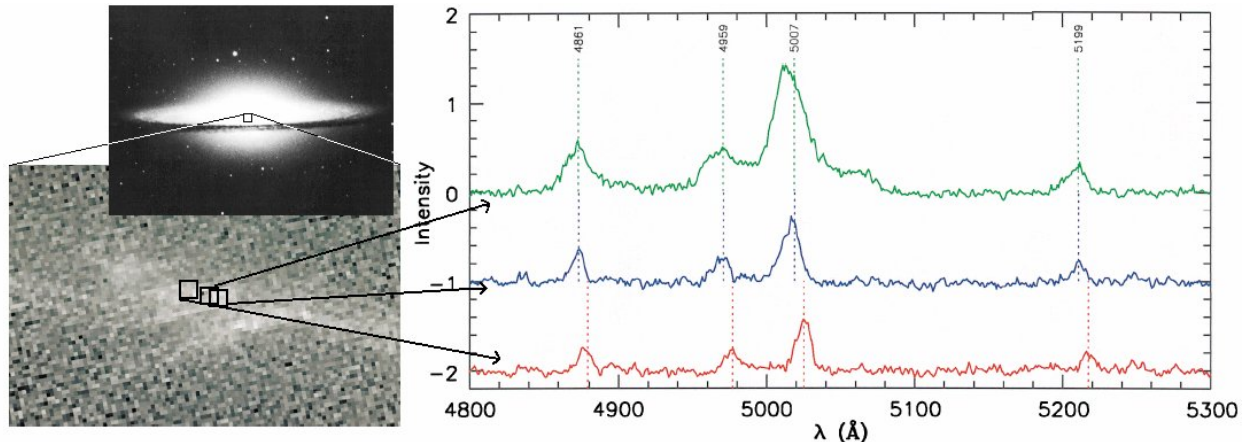


Figure modified from Kormendy et al., *Astrophysical Journal* (493) p.L91, Dec 1996

1. First of all, notice that *all* the lines are shifted somewhat to longer wavelengths. The numbers on top of the dotted lines indicate the rest (laboratory) wavelength in Angstroms, all of which are somewhat less than the observed line wavelengths. This is because, like most galaxies, M104 is receding from us due to the expansion of the universe. Use the peak wavelength of the *top* spectrum to calculate the wavelength shift $\Delta\lambda$ of an emission line of your choice due to the galaxy's overall recession.
2. Use this to calculate the redshift, $z = \Delta\lambda / \lambda$.
3. Now calculate the velocity in km/s using the Doppler formula, $v / c = \Delta\lambda / \lambda$ ($c = 300,000$ km/s.)
4. Use Hubble's law, $v = H_0 d$, to estimate the distance to M104 in megaparsecs. Hubble's constant is about 70 km/s/Mpc.
5. Now we want to calculate the *internal* motion of the gas in M104 that is generating these emission lines (that is, the motion of the gas relative to the center of M104, rather than relative to us). Using any one of the three spectra above, find the wavelength shift $\Delta\lambda$ of the *fastest-moving* gas in the part of the galaxy that was imaged.
6. Convert this to a measure of the orbital velocity of this gas.
7. The slit that took the spectrum above covered a region of M104 corresponding to about 500,000 AU in diameter, so we know the gas from #6 is *at least* this close to the central object. Using this knowledge, and the velocity above, we can get the mass. Kepler's third law says:

$$P^2 = \frac{4\pi^2}{G(m_1+m_2)} R^3$$

But we also know that for circular orbits, $2\pi R = vP$. Using CS-92 as a guide and assuming $m_1 \ll m_2$, rearrange some terms to come up with an expression for the mass m_2 in terms of v and R .

8. Use ratios, and the properties of the Earth's orbit around the Sun (v_E , R_E , and m_{Sun}), to get rid of the nasty constants in this expression.

$$\frac{m_1}{m_{\text{Sun}}} =$$

9. Earth's velocity around the Sun is $v_E = 30$ km/s or so, and R_E is 1 AU. Using these numbers and the equation from #8, calculate the approximate mass of the object at the center of M104 in solar masses.