Calculating Black Hole Power

This image shows the large galaxy, NGC-6872, interacting with a smaller galaxy, IC-4970, located just above the center of NG-6872. These galaxies are located in the southern constellation Pavo, and about 300 million light years from the Sun. From tip to tip, NGC-6872 measures about 700,000 light years, making it nearly 3 times as big as the Milky Way. The image is a composite made by NASA's Spitzer and Chandra satellites, and a ground-based telescope. Although NGC-6872 is dramatically bigger, IC-4970 is the real 'player' in this collision because it contains a super-massive black hole, which is emitting energy as it absorbs interstellar gas and dust that has been gravitationally ripped from the larger galaxy. The X-ray power, alone, is about 450 million times the sun's total light output!

When black holes 'digest' gas, stars and other forms of matter that enter their event horizons, the energy that is produced as the matter falls in can be converted into heat in the orbiting 'accretion disk' that surrounds a black hole. The amount of heat energy that is emitted by the matter each second (power) can be detected at great distances as a brilliant source of light or other forms of electromagnetic radiation. The formula that approximately relates the rate of in-falling matter into a super-massive black hole (**R** in solar masses per year), to the emitted power (**L** in multiples of the sun's power) is given by $L = 1.1 \times 10^{12} R$ solar luminosities. (Note 1 solar mass = 2×10^{33} grams, and 1 solar luminosity = 4×10^{33} ergs/sec).

Problem 1 - What is the minimum accretion rate that is needed to account for the x-ray power of the black hole in the core of IC-4970?

Problem 2 - How much mass would have to be accreted in order for the supermassive black hole to have the same power as an average quasar with a luminosity of about 2 trillion times the luminosity of our sun?

Problem 3 - The supermassive black hole in the center of the Milky Way has an estimated output equal to 2,500 suns. About how fast is it accreting matter?

Problem 1 - What is the minimum accretion rate that is needed to account for the x-ray power of the black hole in the core of IC-4970?
Answer: $L = 1.1 \times 10^{12}$ R solar luminosities, and since Lx = 450 million solar luminosities, solving for R we get $R = 4.5 \times 10^{8} / 1.1 \times 10^{12}$ = **0.00041 solar masses per year**.

Problem 2 - How much mass would have to be accreted in order for the supermassive black hole to have the same power as an average quasar with a luminosity of about 2 trillion times the luminosity of our sun?
Answer: $R = 2.0 \times 10^{12} / 1.1 \times 10^{12}$ = **1.8 solar masses per year**.

Problem 3 - The supermassive black hole in the center of the Milky Way has an estimated output equal to 2,500 suns. About how fast is it accreting matter?
Answer: $R = 2{,}500 / 1.1 \times 10^{12}$ = **2.3×10^{-9} solar masses per year**

Note: The formula is derived by using $E = mc^2$ to convert the in-falling mass into energy, and for non-rotating 'Schwarschild' black holes, the conversion efficiency is 7%, so that only 7% of the available 'rest mass' energy of the in-falling material actually is converted into energy. If R is given in solar masses per year, then the energy liberated is equal to:

L = R (solar mass/year) x (2×10^{33} grams/solar mass) x $(3 \times 10^{10})^2 \times 0.07$
= 1.3 x 1053 R ergs/year

Since 1 solar luminosity =3.8×10^{33} ergs/sec, and 1 year = 3.1×10^{7} seconds we have:

L = 1.3×10^{53} ergs/year x (1 solar luminosity/ 3.8×10^{33}) x (1 year/3.1×10^{7} seconds) R

L = 1.1×10^{12} R solar luminosities.
where R is the accretion rate in solar masses per year.