

## BLACK HOLE EVAPORATION - REMNANTS OF THE BIG BANG

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We've seen that through radiation, a black hole can eventually evaporate in a time  $t_0$  :

$$t_0 = 2.0903 \times 10^{67} \left( \frac{M}{M_\odot} \right)^3 \text{ years} \quad (1)$$

where  $M_\odot$  is the solar mass. If we're going to observe black hole evaporation, its mass  $M$  must be considerably less than the sun's. Suppose black holes were formed during the big bang at  $13.7 \times 10^9$  years ago. If the black hole is just evaporating now, its mass would have been:

$$M = M_\odot \left( \frac{13.7 \times 10^9}{2.0903 \times 10^{67}} \right)^{1/3} \quad (2)$$

$$= 8.69 \times 10^{-20} M_\odot \quad (3)$$

$$= (8.69 \times 10^{-20}) (1.989 \times 10^{30}) \text{ kg} \quad (4)$$

$$= 1.728 \times 10^{11} \text{ kg} \quad (5)$$

To put this in perspective, this is equivalent to an asteroid, with a typical rocky density of  $\rho = 5000 \text{ kg m}^{-3}$ , with a radius of

$$R = \left( \frac{3M}{4\pi\rho} \right)^{1/3} \quad (6)$$

$$= 202 \text{ m} \quad (7)$$

To see how much energy is released in the final second of the black hole's life, we can start with the equation we had earlier from the Stefan-Boltzmann relation:

$$M^2 dM = - \frac{\sigma \hbar^4}{256\pi^3 k_B^4 G^2} dt \quad (8)$$

If we integrate this from  $t = 0$  to a time  $t_1$  one second before the present, at which time the black hole's remaining mass is  $M_1$ , then

$$\int_{M_0}^{M_1} M^2 dM = -\frac{\sigma \hbar^4}{256\pi^3 k_B^4 G^2} \int_0^{t_1} dt \quad (9)$$

$$\frac{1}{3} (M_1^3 - M_0^3) = -\frac{\sigma \hbar^4}{256\pi^3 k_B^4 G^2} t_1 \quad (10)$$

$$M_1 = \left[ M_0^3 - \frac{3\sigma \hbar^4}{256\pi^3 k_B^4 G^2} t_1 \right]^{1/3} \quad (11)$$

However,  $M_0^3$  is just  $\frac{3\sigma \hbar^4}{256\pi^3 k_B^4 G^2} t_p$ , where  $t_p$  is the present time, so that  $t_p - t_1 = 1$  s. Therefore the mass remaining 1 second before complete evaporation is:

$$M_1 = \left[ \frac{3\sigma \hbar^4}{256\pi^3 k_B^4 G^2} (t_p - t_1) \right]^{1/3} \quad (12)$$

$$= 341.38 (t_p - t_1)^{1/3} \quad (13)$$

In GR units, a time of 1 second is  $3 \times 10^8$  m so we get for the mass

$$M_1 = 2.28 \times 10^5 \text{ kg} \quad (14)$$

This is equivalent to

$$E = M_1 c^2 = 2.06 \times 10^{22} \text{ J} \quad (15)$$

which is about 500,000 times the energy released in an atomic bomb blast.

#### PINGBACKS

Pingback: Black hole radiation - mass as a function of time