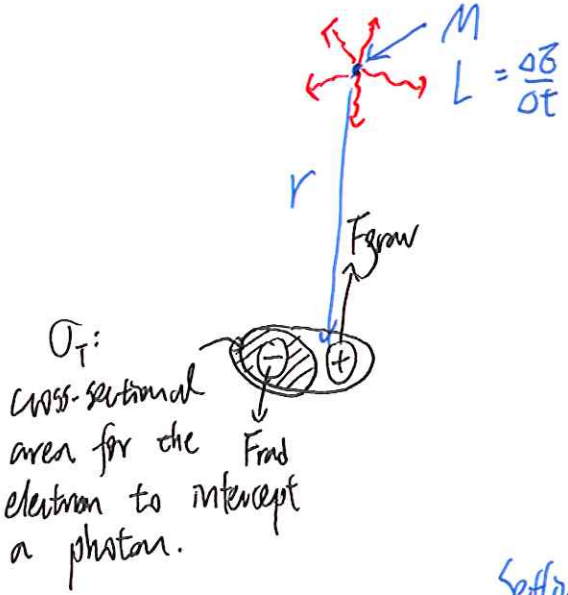
04-21-2016

In this lecture we will recap the concept of Eddington luminosity, and discuss the lifetime of Pop III star.

We have so far figured out; for Pop III stars:

$$M_* \sim 100\, M_\odot$$
$$R_* \sim 5\, R_\odot$$
$$T_{eff} \sim 10^5 K$$
$$L \sim 10^6 L_\odot \lesssim L_{Edd.}$$

- Eddington luminosity.



$$flux = \frac{\Delta E}{\Delta t \cdot \Delta A} = \frac{L}{4\pi r^2}$$

$$\frac{\Delta E}{\Delta t} = flux \times \sigma_T = \frac{L}{4\pi r^2} \cdot \sigma_T$$

$$F_{rad} = \frac{\Delta p}{\Delta t} = \frac{\Delta E}{c \cdot \Delta t}$$

Setting $F_{rad} = F_{grav}$,

$$L_{Edd} = \frac{4\pi c G M \cdot m_H}{\sigma_T}$$

OR

$$L_{Edd} = 10^{38}\ erg\ s^{-1} \cdot \left(\frac{M}{M_\odot}\right)$$

Then we discussed the luminosity of the LIGO gravitational wave source GW150914, 04-21-2016

Before merging:

$36M_\odot$ $29M_\odot$ → After merging $62M_\odot$

$\Delta E = 3M_\odot c^2$

$\Delta t \lesssim 1s.$

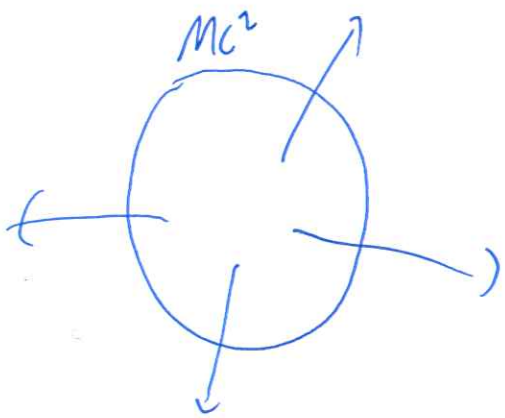
$$L_{GW} \simeq \frac{\Delta E}{\Delta t} \sim \frac{10^{54}\,erg}{1\,s} = 10^{54}\,erg\,s^{-1}$$

Compare $L_{Edd} = 10^{38} \cdot \left(\frac{M}{M_\odot}\right)$

$\sim 10^{40}\,erg\,s^{-1}$ $(62M_\odot \sim 100M_\odot)$

$\Rightarrow L_{GW} >> L_{Edd}$!

• Nature's Maximum Luminosity



$$L_{max} = Mc^2/\Delta t_{min}$$

$$\Delta t_{min} = \frac{R}{c} \quad \text{(causality)}$$

$$L_{max} = \frac{Mc^2}{R/c} = \frac{Mc^3}{R_{min}}$$

$$\rightarrow R_{min} \geq R_S = \frac{2GM}{c^2} \sim \frac{GM}{c}$$

$$\therefore L_{max} = \frac{Mc^2}{(GM/c^2)} = \frac{c^5}{G} = 10^{59}\,erg\,s^{-1}$$

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$L_{Einstein} = c^5/G$

— Einstein luminosity

• Lifetime of Pop III Star.

$$t_{*,Pop\,III} \simeq \frac{\Delta E}{L} \sim \frac{\Delta E}{L_{Edd}}$$

• Stars live off nuclear fusion

$$\Delta E_{nuc} = \eta_{fusion} \cdot Mc^2$$

$$\eta_{fusion} = 0.007 = 0.7\%.$$

$$\therefore t_{*,Pop\,III} \simeq \frac{\Delta E_{nuc}}{L_{Edd}} = \frac{\eta_{fusion} \cdot Mc^2}{L_{Edd}} \sim 3 \times 10^6\ yr$$

Compare to age of universe at $z = 20$

$$t_H(z=20) \sim 10^8\ yr.$$

⇒ Pop III Stars live fast !