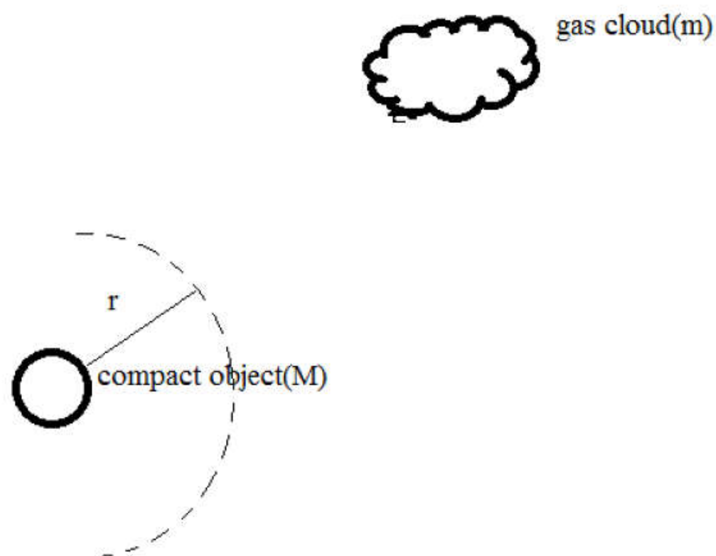
Luminosity of AGNs: Accretion

- Active galactic nuclei(AGNs) are the most luminous objects in the universe. Recent data confirm the theoretical idea that the power source is accretion into a massive black hole. The massive black hole that attracts the surrounding gas by its gravitational force and liberates gravitational energy as radiation.

Accretion:



- Let's consider a system with a compact object of mass M and radius R(M/R is large). A gas cloud of mass m, at an infinite distance is moving towards the compact object under its gravitational influence. The difference in the potential energy when the cloud move from infinity to a distance r leads to the release of energy:

$$\Delta E_{accretion} = \frac{GMm}{r} \tag{1}$$

where M/r indicates the compactness of the object.

- The more compact the object, more is the energy released due to accretion.
- We can rewrite the energy released due to accretion in terms of schwarzschild radius as,

$$\Delta E_{accretion} = \left[\frac{R_{schwarzchild}}{2R}\right] mc^2 \tag{2}$$

where $\frac{R_{sc}}{2R} = \eta$ is the accretion efficiency. It has a typical value of $\eta < 0.5$. If R=$5R_{sc} \Rightarrow \eta = 0.1$

- Hence, we obtain the energy released due to accretion as $\Delta E_{accretion} = 0.1mc^2$
- We know $\Delta E_{fusion} = 0.07mc^2$, which implies accretion is more efficient a process than nuclear fusion.

Eddington Luminosity:

- There is a natural limit, known as the Eddington limit and named alter the famous astronomer, Sir Arthur Eddington, to the luminosity L that can be radiated by a compact object of mass M. Let's take a case of spherical accretion. The force due to gravitation and radiation are :

$$F_G = \frac{GM(m_p + m_e)}{r^2} \tag{3}$$

$$F_{radiation} = \sigma_T \frac{L}{4\pi r^2 c} \tag{4}$$

- For the accretion process to happen, force due to gravitation > force due to radiation at any given point.

$$\sigma_T \frac{L}{4\pi r^2 c} \leq \frac{GM(m_p + m_e)}{r^2} \tag{5}$$

$$\Rightarrow L \leq \frac{GM(m_p + m_e)4\pi c}{\sigma_T} \approx \frac{GMm_p 4\pi c}{\sigma_T} \tag{6}$$

- We, hence, define the Eddington Luminosity, the maximum luminosity allowed through accretion as,

$$L_{Eddington} = \frac{GMm_p 4\pi c}{\sigma_T} \approx 1.26 \times 10^{38} \left(\frac{M}{M_\odot}\right) ergs \tag{7}$$

Eddington Accretion Rate:

The Eddington accretion rate is the accretion rate for which the compact object radiates at the Eddington luminosity. As we discussed earlier, the luminosity of the central object is derived from accretion of matter into it. Let's consider a compact object is accreting mass from its surroundings at a rate $\frac{dm}{dt}$. We can express this as a fraction of the rest-mass energy and the luminosity is given as,

$$L = \frac{\Delta E_{accretion}}{t} = \frac{\eta_{accretion} mc^2}{t} \tag{8}$$

Hence, we have the accretion rate for any given luminosity as,

$$\frac{dm}{dt} = \frac{L}{\eta c^2} \tag{9}$$

The Eddington accretion rate is $\frac{L_{Eddington}}{\eta c^2}$

$$\frac{dm}{dt} \approx 0.18 \left(\frac{L}{10^{46} ergs/s} \right) M_{\odot} yr^{-1} \tag{10}$$

Luminosity of a quasi stellar object(QSO) is $\sim 10^{44} ergss^{-1}$. Hence, the accretion rate for a Quasar is $0.18 M_{\odot} yr^{-1}$

Let's consider a super massive black hole of mass $10^8 M_{\odot}$

$$R_{sc} = \frac{2Gm}{c^2} \approx 10^{11} m \tag{11}$$

$$\rho_{SMBH} = \frac{10^8}{10^{11}} = 10^5 kgm^{-3} \tag{12}$$

So, at a distance of $R \sim 5R_{sc}$

$$\Delta E_{accretion} = \left[\frac{R}{2R_{sc}} \right] mc^2 = 2.5mc^2 \tag{13}$$