3) The Soltan Argument

If SMBHs gain their mass through accretion, then the total amount of AGN light is directly related to the mass accreted.

That is, $m = \int \dot{m}\, dt = \frac{1}{\eta c^2} \int L\, dt = \frac{1}{\eta c^2} LT$ assuming a constant L throughout T

So, the BH mass density accreted is

$$\rho_{BH} = \frac{1}{\eta c^2} \iint L\, n(L, z)\, dL\, dt$$

where $n(L,z)\,dL$ is the comoving # density of AGN of luminosity L at redshift z.
(t & z can be related thru cosmology)

The $\iint$ can be related to the observed # counts
i.e, the # of AGNs w/ luminosity L in $z \rightarrow z+dz$
w/ fluxes $S \rightarrow S+dS \rightarrow N(S,z)\,dS\,dz = n(L,z)\,dL \frac{D_L^2}{(1+z)^2}\, dr$

where r is a comoving radial distance & D_L is the luminosity distance

For bolometric L's & S's, $L = 4\pi D_L^2 S$ & $dr = c\,dt\,(1+z)$

$$\therefore \rho_{BH} = \frac{1}{\eta c^2} \iint \frac{4\pi \cancel{D_L^2} S}{c\,\cancel{(1+z)}} \frac{(1+z)^{\cancel{2}}}{\cancel{D_L^2}} N(S,z)\, dS\, dz$$

$$\rho_{BH} = \frac{4\pi}{\eta c^3} \iint (1+z)\, S\, N(S,z)\, dS\, dz$$

- Very tricky to get bolometric corrections

- Very tricky to get bolometric corrections
- need to account for <u>all</u> AGNs (even obscured)
- if measure LHS, can estimate mean value of η

5) Salpeter timescale

Luminosity of BH powered by accretion:

$L = \eta \dot{M} c^2$ is limited by

$$L_E \simeq 10^{38}\left(\frac{M}{M_\odot}\right) \text{erg s}^{-1} = A\left(\frac{M}{M_\odot}\right)$$

So, $$\dot{M} = \frac{L}{\eta c^2} = \frac{L}{L_E}\frac{L_E}{\eta c^2} = \left(\frac{L}{L_E}\right)\frac{A}{\eta c^2}\left(\frac{M}{M_\odot}\right)$$

ie, the growth of the SMBH mass: $\frac{dM}{dt} = \left(\frac{L}{L_E}\right)\frac{A}{\eta c^2}\left(\frac{M}{M_\odot}\right)$

$$M_\odot \frac{d\left(\frac{M}{M_\odot}\right)}{dt} = \left(\frac{L}{L_E}\right)\frac{A}{\eta c^2}\left(\frac{M}{M_\odot}\right)$$

$$\int_0^{M/M_\odot} \frac{d(M/M_\odot)}{0} = \left(\frac{L}{L_E}\right)\frac{A}{M_\odot \eta c^2}\int_0^t dt$$

$$\ln\left(\frac{M}{M_\odot}\right) = \left(\frac{L}{L}\right)\frac{A\,t}{M_\odot \eta c^2}$$

$$\left(\frac{M}{\ }\right) \qquad \left[\left(\frac{L}{L_E}\right)\frac{A}{M_\odot \eta c^2}\right]t \qquad t/\tau$$

$$M_\odot) = e \quad \cdots \quad = e$$

where τ = Salpeter time $= \dfrac{M_\odot \eta c^2}{A\left(\frac{L}{L_E}\right)} = 4.5\times10^7 \left(\dfrac{\eta}{0.1}\right)\left(\dfrac{L}{L_E}\right)^{-1}$ yrs

We observe quasars at $z \sim 6$, when $t_{univ} \simeq 10^9$ yrs.