34 Astro notes 2018/11/16 - Fri - AGN: Accreting Supermassive Black Holes

34.1 AGN Essential Phenomenology and Nomenclature

Quasars:
One of the original phenomena was "Quasi-stellar Radio Sources" – QSRs or "Quasars". These were sources of radio emission with counterparts at other wavelengths did not show extension - therefore being star-like instead of galaxy-like. Can emit hundreds of times as much energy as a galaxy. First high-redshift objects.

Seyferts:
There are also more nearby galaxies called Seyferts that showed a compact bright emission line source embedded in a galaxy. Again very bright and "star-like" (unresolved)

All types of sources can show narrow or broad+narrow emission lines.

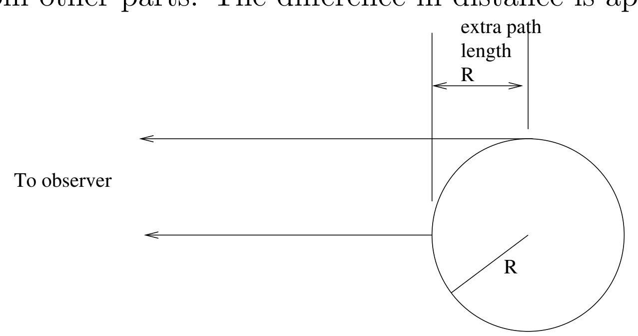
Note that, as mentioned before, redshift arises from the expansion of the universe:

$$\frac{R_{obs}}{R_{emit}} = 1 + z$$

where R is the "scale factor" that will appear in the spacetime metric when we get to cosmology. This allows the expansion rate of the universe to change, since the spectral shift doesn't depend on the motion of the galaxies, and so can change after the light is emitted. Quasars are found out to redshift 5 or 6, when the average distance between galaxies was 6 times smaller than it is today.

34.2 Size of central engine

Rough size of the emission region can be inferred from variability timescale. Consider a sphere of radius r whose brightness varies all together. There will be a light delay for the brightening. i.e. light from the closer edge of the sphere will reach the observer before light from other parts. The difference in distance is approximately R.



So the time delay for brightening/dimming is related to the size by

$$\Delta t = \frac{R}{c}$$

Since this light source might be moving away at relativistic speed, for high redshift, it is important to include a possible time dilation factor, so that

$$R = \frac{c\Delta t}{\gamma}$$

Using $\Delta t \approx 1$ hour, a typical value of AGN variability, and $\gamma \sim 1$, The radius is (AU=1.5×10^{11} m)

$$R \simeq 3 \times 10^8 \text{ m/s}(3600 \text{ s}) = 10^{12} \text{ m} = 7 \text{ AU} .$$

So there must be some object that would fit well within the solar system that can steadily emit a hundred times the luminosity of a galaxy, of order 10^{39} W. i.e. it must be relatively small on galaxy scales. Not much bigger than a giant star.

34.3 Luminosity Limit

There is a limit to radiated energy above which any object will start to lose matter Above this limit, the radiation pressure on a particle (electron-proton pair) is larger than the gravitational pull. Eddington limit:

$$L_{\text{Edd}} \simeq 10^{31} \text{ W} \left(\frac{M}{M_\odot}\right)$$

For the high luminosity of a quasar, $L = 5 \times 10^{39}$ W, this gives as *lower* limit for the mass:

$$M > \frac{L}{10^{31} \text{ W}} M_\odot \simeq 3 \times 10^8 M_\odot$$

Such a large mass in such a small space strongly implies the presence of a supermassive black hole. If we assume that the object is a black hole of this mass, we get the Schwarzchild radius:

$$R = \frac{2GM}{c^2} \simeq 10^{12} \text{ m} = 7 \text{ AU}$$

So the mass inferred from the luminosity limit in combination with the size imply a supermassive black hole, of typical mass $10^8 M_\odot$.

34.4 Efficiency

What is the most efficient way to convert matter into energy? Nuclear fusion of H to Fe releases a little under 10MeV per proton. That's about 10 MeV per 1000 MeV of rest mass energy or around 1%. By comparison a maximally spinning black hole can have material release energy down to $r = 0.5R_S$. This would give an energy release, for a mass m that makes it to the inner edge of the accretion disk

$$\frac{GM}{2r} m \simeq \frac{GMm}{GM/c^2} = mc^2$$

in reality its not quite the whole amount. What one gets is about 40% of rest mass enery. This leads to an expression for the accretion luminosity in terms of the mass-energy of the infalling material and an efficiency parameter, η,

$$L_{\text{disk}} = \eta \dot{M} c^2$$

where $\eta \simeq 0.4$. This is far mor efficient (in terms of energy release per mass) than nuclear fusion.