Lec 29: 11/28/2018

Supermassive Black Holes (Cont'd):

Nearby Objects:

Not all members of the AGN class are very powerful or very distant. Long jets or apparent superluminal motion are seen less frequently or not at all in more abundant low-luminosity objects. The evidence for a supermassive black hole is even stronger in such systems due to their proximity.

(1) The Galactic Center. The material within several parsecs of the nucleus shines in the radio as a three-armed spiral of highly ionized gas radiating a thermal continuum. At a distance of 3 lyr from the center the plasma moves at a velocity $\sim 105\ km\,s^{-1}$, requiring a mass concentration of $\sim 3\times10^{6}\ M_{\odot}$. The very bright pointlike source known as Sagittarius A^{*} defines the dynamical center of our galaxy. X-ray emission has been observed in our galaxy

from structures extending over kiloparsecs down to a fraction of a light year, with contributions from thermal and non-thermal, pointlike and diffuse sources. The high spatial resolution of the Chandra X-ray observatory allows for a separtion of the discrete sources from the diffuse X-ray components pervading the center of our galaxy. A fit to the X-ray emission, assuming optically thin Bremsstrahlung, yields the total inferred mass of $M_{gas} > 0.1 M_{\odot}$ for the emitting gas near Sgr A*. The hot plasma within a few parsecs of Sgr A* appears to be injected into the interstellar medium via stellar winds, and the diffuse X-ray emission provides an excellent probe of the gas dynamics near the black hole.

There is ample observational evidence for the existence of strong outflows in and around the nucleus (obtained via the measurement of emission line Doppler shifts). It reveals the presence of 500–1000 $km\,s^{-1}$ winds and number densities $\sim 10^{3-4}\,cm^{-3}$ near the mass ejecting stars. The implied total mass injection rate into the galaxy's central region is $\sim (3\text{-}4)\times 10^{-3}\,M_\odot\,yr^{-1}$. This helps us understand the low average accretion rate ($\sim 10^{-2}\,M_\odot\,yr^{-1}$) onto black holes at $z\simeq 0$. If the medium surrounding the central black hole contains little gas, then the accretion cannot grow at rates like those seen at high redshifts. Comprehensive numerical simulations of wind-wind interactions indicate creation of a complex configuration of shocks that efficiently convert the kinetic energy of outflows into internal energy of the gas. The resulting Bremsstrahlung emission produces the entire diffuse X-ray flux detected from the region near Sgr A* by Chandra. It turns out that the outflows bring the environment near the black hole into steady state within ~4,000 years. What we are seeing at the center of our galaxy may be quite typical of nearby galactic nuclei in which the gas content of the central medium has been largely depleted due to black hole accretion and star formation.

(2) M31*. At a distance of 780 kpc, the black hole known as M31* at the nucleus of the Andromeda galaxy is the nearest analog to Sgr A*. The nucleus of Andromea comprises a central dark matter distribution and three concentrations of star light. Two of these have been known for many years. Recent observations with the Hubble Space Telescope have confirmed the existence of a third stellar component. This latter one contains stars with the highest average circular rotation velocity measured so far in any galaxy (~1,700 $km s^{-1}$).

This implies a mass $\gtrsim 10^8 M_\odot$ for the central object. By using the X-ray emission, and assuming optically thin Bremsstrahlung radiation, one can estimate the temperature and density of the gas, thus the sound speed c_s, near the supermassive black hole. Within the Bondi-Hoyle accretion scenario, and for a typical 10% efficiency for converting accreting mass into radiation, we find a maximum luminosity of $\sim 3 \times 10^{40}$ erg s^{-1} from M31*, whereas the measured X-ray power is about 5 orders of magnitude smaller. This is not unique to M31*, rather it is a common trait among all nearby weak nuclei (including Sgr A*). It is an open question that why the quantity of gas captured does not provide an accurate indication of its emissivity. The possibilities are that either $\dot{m}$ changes with radius (hence not being constant), so that much of the captured matter escapes or is ejected before reaching the region where X-rays are produced, or the radiative efficiency of the plasma is very low.

(3) M 87*. The nucleus of M 87 provides another example of a weak AGN, but its mass is significantly larger than both Sgr A* and M31*. This giant elliptical galaxy contains a black hole of mass $\sim 3 \times 10^9 M_\odot$. The corresponding accretion rate is $\dot{M} \sim 0.1 M_\odot yr^{-1}$, which translates into a maximal luminosity of $\sim 5 \times 10^{44}$ erg s^{-1} (assuming a 10% efficiency). On the other hand, the implied X-ray power of the central point source is $\sim 7 \times 10^{40}$ erg s^{-1}, which is about four orders of magnitude less than theoretical prediction. However, in case of M 87*, there is a one sided jet. Most of the radiation in such relativistic outflows appears to

be produced by incoherent synchrotron and synchrotron-self-Compton emission in the radio and X-rays/γ-rays respectively. It is straightforward to estimate from the measured luminosity the kinetic power needed to sustain the observed radiative output over its full extent. For M87*, it is $\sim 10^{44}$ erg s^{-1}, which implies the accretion rate matches the overall energetics.