**Key points from Lecture 20 of ASTR 350**

1. Stellar-mass black holes are born from core-collapse supernovae, and don't acquire much more mass later even if they accrete from a companion. In contrast, supermassive black holes start from much smaller "seeds" and grow a lot from there.
2. Supermassive black holes are tightly correlated with their host galaxies. This suggests that the two evolved in tandem. This is surprising given that SMBHs are so low-mass and small compared with the galaxies, but it suggests that feedback (probably from jets) from accreting SMBHs affects their galaxies.
3. There are some SMBHs that are quite high-mass ($\sim 10^9\ M_\odot$) very early (some have been seen at redshift $z = 7.5$, which is only $\sim 700$ million years after the Big Bang). Where did they come from?
4. Not from primordial black holes shortly after the Big Bang; not enough mass. Not from dark matter accretion, although because that doesn't generate radiation it isn't limited by the Eddington luminosity; dark matter can't easily accrete because it can't easily lose angular momentum.
5. Moreover, if you start with a stellar-mass black hole (say, $\sim 10 - 100\ M_\odot$) and accrete continuously at the Eddington rate, you can't get to $10^9\ M_\odot$ by 700 million years after the Big Bang. That's because stars take at least 200 million years to form, and then the time to reach $10^9\ M_\odot$ at a standard efficiency of $\eta = 0.1$ (recall that this is defined so that the luminosity from a mass accretion rate $dM/dt$ is $L = \eta(dM/dt)c^2$) is more than 600 million years.
6. So there are two paths: (a) accrete with lower efficiency, because if the system is at the Eddington luminosity, the time to double the mass is proportional to the efficiency, or (b) start with a much higher mass (i.e., a more massive seed), more like $10^5\ M_\odot$ than $10\ M_\odot$. No one is sure of the answer.
7. Some specific possibilities include beginning with a massive seed from the collapse of a star cluster, or a supermassive star. Something Alex Dittmann (current UMd grad student) and I have suggested is that there may be many stellar-mass black holes in AGN disks; accreting those doesn't generate luminosity, so they lower the efficiency. Many people are working on ideas!