ASTR232, Fall 2019
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Homework # 6

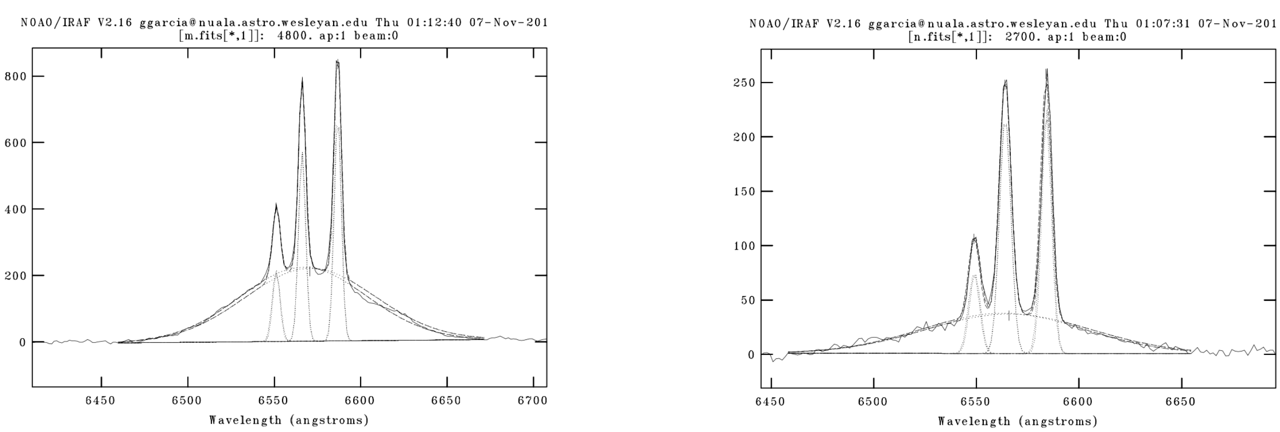
Problem 1a

Two AGN spectra are included with this assignment; both are for type 1 Seyfert galaxies. Using IRAF, measure the FWHM and luminosity of the broad Hα line to estimate the black-hole masses for the objects. The distances to the galaxies are 20.1 Mpc (m.fits) and 56.1 Mpc (n.fits). For these data, fluxes reported by IRAF have units of 10^{-17} erg cm^{-2} s^{-1}, and FWHM values are given in units of Ångstroms (which you need to convert to velocity).

You'll have to deblend the lines near Hα using the "d" function in IRAF's `splot` task. This might be tricky, so be sure to leave yourself enough time, and see me if you are not having success. Along with the values you calculate for the black hole masses, please hand in plots showing your emission-line fits. First, before doing any fitting, type `set stdplot=eps` in IRAF. This will send your plots to postscript files rather than the printer. Next, fit the blended emission lines with `splot`. Make sure you are sufficiently zoomed in around Hα, and overplot both the total fit and the fits for the individual components. Finally, when you are satisfied with the fitting, press the equal (=) sign (the plot window must be the active window). This will generate a file for your plot called "sgiXXXXX.eps."

Solution

Using IRAF, we find the flux of the Hα line in the `m.fits` and `n.fits` files. Using the deblend function to overlay gaussian fits to the broad lines, we produce the following:



(a) m.fits

(b) n.fits

Figure 1: Hα lines deblended for both spectra.

We get the following data from the fitting:

file	flux (10^{-17} erg cm^{-2} s^{-1})	gfwhm (Å)	dist(Mpc)
m.fits	20,402	86.16	20.1
n.fits	3,653	92.65	56.1

Using these values, we can use the Surrogate - Surrogate method[1] of computing black hole masses, which involves using the following equation:

$$\log\left(\frac{M_{BH}}{M_\odot}\right)=6.401+0.45\log\left(\frac{L(H\alpha)}{10^{42}}\right)+\log\left(\frac{\text{FWHM}(H\alpha)}{10^3\text{km/s}}\right) \tag{1}$$

[1] Xiao et al (2011)

Here, L(Hα) $= 4\pi d^2 f$ and FWHM($H\alpha$) $= \frac{c(gfwhm)}{6560}$.
Thus, plugging our values, we get for `m.fits`:

$$\log\left(\frac{M_{BH}}{M_\odot}\right)=6.401+0.45\log\left(\frac{4\pi(6.202\times10^{25}\text{cm})^2(20402\times10^{-17})}{10^{42}}\right)+\log\left(\frac{3\times10^5\cdot(86.16)/6560}{10^3\text{km}s}\right)$$

We get $\boxed{M_{BH}=2.5\times10^6 M_\odot}$
Plugging the values for `n.fits`:

$$\log\left(\frac{M_{BH}}{M_\odot}\right)=6.401+0.45\log\left(\frac{4\pi(1.7\times10^{26}\text{cm})^2(3656\times10^{-17})}{10^{42}}\right)+\log\left(\frac{3\times10^5\cdot(92.65)/6560}{10^3\text{km}s}\right)$$

We get that for n, $\boxed{M_{BH}=8.9\times10^6 M_\odot}$

Problem 2

The optical/UV/X-ray continuum of an AGN at $d_L = 283$ Mpc can be described as a single power law of the form $f_\nu = C\nu^\alpha$, where C is the normalization constant and the spectral index $\alpha = -1.5$. At the frequency corresponding to Hα, the continuum flux density is $f_\nu = 1.80 \times 10^{-27}$ erg cm^{-2} s^{-1} Hz^{-1}. Using this information, compute Q_{ion}, the number of ionizing photons per second emitted by the AGN. Also, compute $Q_{\text{H}\beta}$, the number of recombinations per second implied by the flux of the narrow Hβ line, which is $f(\text{H}\beta) = 2.38 \times 10^{-14}$ erg cm^{-2} s^{-1}. Is our direct view of the continnum source obscured? Explain.

Solution

We compute Q_{ion} and $\text{Q}_{\text{H}\beta}$ as follows:

Q_{ion}:

$$\text{Q}_{\text{ion}} = \frac{\Omega}{4\pi}\int_{\nu_0}^{\infty} \frac{L_\nu(\nu)}{h\nu}\, d\nu \tag{2}$$

We know that

$$L = 4\pi d^2 f \tag{3}$$

where d = 283 Mpc = 8.732×10^{26}cm and

$$f_\nu = C\nu^\alpha \tag{4}$$

Thus, plugging in everything, we get

$$\text{Q}_{\text{ion}} = \int_{\nu_0}^{\infty} \frac{4\pi d^2 C\nu^\alpha}{h\nu} d\nu$$

$$\text{Q}_{\text{ion}} = \frac{4\pi d^2 C}{h}\int_{\nu_0}^{\infty} \nu^{-2.5} d\nu$$

$$\text{Q}_{\text{ion}} = \frac{4\pi d^2 C}{h}\left(-(-\frac{1}{1.5})\nu^{-1.5}\right)$$

Plugging in $\nu_0 = 13.6\text{eV} = 3.288\times10^{15}\text{Hz}$, we get

$$\text{Q}_{\text{ion}} = \frac{4\pi d^2 C}{h}\frac{1}{1.5}(3.28\times10^{15})^{-1.5}$$

Now, plugging in, $C = \frac{1.8\times10^{-27}}{(4.57\times10^{14})^{-1.5}} = 0.00001$, and $h = 6.626\times10^{-27}$ergs/sec, we get

$$\text{Q}_{\text{ion}} = \frac{4\pi(8.732\times10^{26})^2(0.00001)}{6.626\times10^{-27}}\frac{1}{1.5}(3.28\times10^{15})^{-1.5}$$

$$\boxed{\text{Q}_{\text{ion}} = 5.1\times10^{52}\left(\frac{\Omega}{4\pi}\right)}$$

$\text{Q}_{\text{H}\beta}$:

$$\text{Q}_{\text{H}\beta} = \left(\frac{\alpha_{\text{tot}}}{\alpha_{\text{H}\beta}}\right)\frac{L_{\text{H}\beta}}{\text{h}\nu_{\text{H}\beta}} \tag{5}$$

We know

$$L_{H\beta} = 4\pi d^2 f \tag{6}$$

and

$$\left(\frac{\alpha_{\text{tot}}}{\alpha_{\text{H}\beta}}\right) = 8.5$$

.

Thus, we get:

$$Q_{H\beta} = 8.5\frac{4\pi d^2 f}{h\nu_{h\beta}}$$

Plugging in all values, we get:

$$Q_{H\beta} = 8.5\frac{4\pi(8.732\times10^{26})^2(2.38\times10^{-14})}{(6.626\times10^{-27})(6.16\times10^{14})}$$

$$\boxed{Q_{H\beta} = 4.74\times10^{53}}$$

Taking the ratio of our answers:

$$\boxed{\frac{Q_{H\beta}}{Q_{ion}} = \frac{\Omega}{4\pi} = 9.29 < 1}$$

Thus, because the ratio is greater than 1, we conclude that there is obscuration of the continuum source.

Problem 3a

Assuming continuous accretion at the maximal rate (ie, L = L_{Edd}), derive a formula for $\text{M}_{\text{BH}}(t)$, the mass of the black hole versus time t, in terms of the initial black-hole massM_0 and η.

Solution

We start with the following two equations:

$$L_{BH} = \eta\dot{M}_{BH}c^2 \tag{7}$$

and

$$L_{edd} = 1.38\times10^{38}\left(\frac{M_{BH}}{M_\odot}\right) \tag{8}$$

Subbing in L_{edd} for L_{BH}, we get

$$1.3\times10^{38}M_{BH} = \eta\frac{dM_{BH}}{dt}c^2$$

Rearranging,

$$\int_{t_0}^{t} \frac{1.3\times10^{38}}{\eta c^2} dt = \int_{M_0}^{M} \frac{1}{M_{BH}} dM_{BH}$$

This produces

$$\frac{1.3\times10^{38}}{\eta c^2} t = \ln(\frac{M_{BH}}{M_0})$$

Raising both sides by an exponential and rearranging produces:

$$M_{BH} = M_0 e^{\frac{1.3\times10^{38}}{\eta c^2} t}$$

We note that the exponential must be unit less, so we must convert 1.3×10^{38} ergs s^{-1} M$_0^{-1}$ to m^2 g^{-2}.
Thus, we get 1.38×10^{38}ergs s^{-1} M$_0^{-1}$ = 6.5 m^2 g^{-2}.
This gives us our final answer:

$$\boxed{M_{BH} = M_0 e^{\frac{6.5}{\eta c^2} t}} \tag{9}$$

Problem 3b

Assuming $\eta = 0.1$ and $M_0 = 20M_{\odot}$, compute the amount of time Δt required to grow a black hole to a mass of $M_{\rm BH} = 2\times10^9 M_{\odot}$.

Solution

Rearranging equation 8 to solve for t:

$$t = \ln(\frac{M_{BH}}{M_0}) \frac{\eta c^2}{6.5}$$

Plugging in our values:

$$t = \ln(\frac{2\times10^9}{20}) \frac{0.1(2.998\times10^8)^2}{6.5}$$

$$\boxed{t = 2.55\times10^{16} \text{ secs} = 8.08\times10^8 \text{ years}}$$

This is within the time frame of the universe.

Problem 3c

If a black hole of this mass is associated with quasar at $z = 7.1$ and the maximum amount of time available for it to grow is $\Delta t = 6\times10^8$ yr (ie - the time between $z = 20$ and $z = 7.1$), what would be the minimum possible value of the seed mass M_o?

Solution

Rearranging equation 8 to solve for M_0, we get

$$M_0 = \frac{M_{BH}}{e^{\frac{(6.5)(t)}{\eta c^2}}}$$

We plug in our values, where $t = 6\times10^8$yr $= 1.8\times10^{16}$ sec:

$$M_0 = \frac{2\times10^9}{e^{\frac{(6.5)(1.8\times10^{16})}{0.1(2.998\times10^8)^2}}}$$

$$\boxed{M_0 = 4442.9 M_{\odot}}$$

This would be very improbable in today's universe.