Physics 343 – Spring 2020
Project # 5: Identifying AGN from emission-line spectroscopy

Emission lines from interstellar gas in a galaxy can provide a wealth of information about its chemical composition (e.g., "metallicity" as represented by the abundance of oxygen relative to hydrogen) and prevailing physical conditions (e.g., temperature and density). Emission lines can also reveal what physical processes are influencing those physical conditions — and in particular, whether atoms are being ionized by newly formed stars (i.e., in H II regions) or by accretion onto supermassive black holes (i.e., active galactic nuclei, or AGN). The basis for such a distinction is that AGN can produce arbitrarily high-energy photons capable of raising atoms to very high ionization states (i.e., stripping off many electrons), whereas young stars only produce photons up to energies corresponding to their surface temperatures. An important reference for the classification of optical emission-line spectra is the paper of Baldwin, Phillips, & Terlevich (1981, PASP, 93, 5), whose Figure 5 plotting the "BPT diagram" of [O III] λ5007/Hβ vs. [N II] λ6583/Hα shows how specific line ratios can be used to trace ionization state and identify AGN.

An additional tool for identifying AGN in emission-line spectra is the measurement of line *widths* (especially for the Balmer α or "Hα" line, which is typically the brightest emission line in a galaxy's optical wavelength spectrum). Broad ($\Delta v \geq 1000\,\mathrm{km\,s^{-1}}$) emission lines are produced when gas deep in a supermassive black hole's potential well is moving at very high velocities, and are not plausibly produced by other mechanisms. It can however be challenging to detect broad Hα emission, because emission from ionized gas in the immediate vicinity of a black hole may be "outshone" by emission from less rapidly moving gas on larger scales, and because it can be tricky to disentangle the emission from a galaxy's stars and from its gas.

For this project, you will be using both of the techniques described above to identify AGN within a sample of bright northern galaxies. For the first part of your analysis, you will use observations of the full sample of 418 galaxies to identify candidate AGN on the basis of emission line ratios. Starting from the tab-delimited file Project5_DataTable_1.tsv, which can be read into a spreadsheet or a programming environment of your choice, you should do the following:

1. Determine whether there are any galaxies you feel should be excluded from your analysis on the basis of limited or poor-quality data.

2. Plot the "BPT diagram" described above for all of the galaxies in the sample that you did not exclude.

3. On the basis of their location in the BPT diagram, identify galaxies whose gas is mainly being ionized by young stars, those whose gas is mainly being ionized by AGN, and those whose gas is being ionized by a combination of both.

4. Determine whether the location of a galaxy in the BPT diagram (and its status as star-formation-powered or AGN-powered) is correlated in any way with (a) the [O III] λ5007/[O I] λ6300 emission line ratio, which is a measure of ionization state; (b) the Hα/Hβ emission line ratio, which is a measure of dust content; (c) the Hα luminosity; (d) the Hα equivalent width (i.e., line-to-continuum ratio); and (e) the [N II] λ6583

velocity width. Please comment on the possible implications of any correlations you identify (or the lack thereof).

In addition, for the set of ten spectra of emission-line galaxies *and* the ten spectra of associated "partner" absorption-line galaxies that will be provided to you in ASCII format (which can be read into a spreadsheet or a programming environment of your choice), you should do the following:

1. For each pair of spectra, determine the appropriate wavelength shift and intensity scaling needed to subtract the (stellar-only) absorption-line partner spectrum from the emission-line spectrum, in order to produce a star-free version of the latter after subtraction.

2. After obtaining a star-free emission-line spectrum, isolate the Hα and [N II] portion of the spectrum, and decompose the line profile into a combination of narrow and/or broad velocity components. Please discuss how you determine whether a broad velocity component is present, and any uncertainties that attach to your determination of its width.

3. For any galaxies where you conclude a broad Hα velocity is present, determine whether there is any correlation between the width and the luminosity *of the broad component.* (You will be provided with a distance estimate for each galaxy in your sample, which which you can convert flux to luminosity.) Please comment on the possible implications of such a correlation (or the lack thereof).