Presentation for AAS (Talk time: 5min. Currently: 13min)

Talking points

Introductory slide

Motivation:

* The motivation for this project comes from recent observations of high redshiftstar forming galaxies, which have found high star formation rates and high ionization emission lines without any signs of AGN activity.

Methodology:

* These observations led to our guiding question: How can we reproduce the observed emission lines of starburst galaxies by altering various parameters within simulations?
  + To address this question, we adopt a two-step methodology: we first model the spectral energy distribution using the spectral synthesis code Starburst99 and then we model the observed spectrum with photoionization code Cloudy.
    - The parameters we vary in Starburst99 include the starburst age (0-8 Myr), star-formation rate (inst or cont), and stellar evolutionary track (we’ve tested the new Geneva rotation tracks).
    - Within Cloudy, we varied the hydrogen density, hydrogen ionizing photon flux, the metallicity of the cloud (0.2 to 5.0 solar metallicity), and the dust abundances.

SED:

* As we were trying to reproduce high ionization emission lines, we were searching for the evolutionary track that would result in the hardest continuum.
* At low metallicities (high redshift), we found that the hardness of the Genevarotation tracks decreased since the stars were beginning to skip the WR phase.
* However, we found that the Padova continuous track produced the hardest spectrum, whose SED you see here.
  + Note that it reached steady-state at around 4 Myr, so we’ve chosen the Padova track at 5 Myr (just beyond) as our baseline mode.

LOC:

* Once we adopted the Padova continuous SED, we began simulating the cloud region that surrounds star-forming areas.
* For this, we use Locally Optimally Emitting cloudy methodology.
  + The central idea behind an LOC model comes from the fact that emission seen from a distant observer reflects the *cumulative* emission of all clouds around a central ionization source. As first shown by Baldwin et al. (1995), this results in powerful selection effects: we observe the emission from clouds which are optimally tuned to those particular emission lines. Since the different emission lines optimally emit under vastly different physical conditions, the LOC model incorporates a wide range of ionizing fluxes and densities.

The first grid:

* Using the Padova continuous evolutionary track SED at 5 Myr and the LOC model, we have these equivalent width plots. Here you have just one of the many emission lines that we track, [O III] 5007.
  + Along the x axis, you see the range of hydrogen density which we have adopted. We begin our simulations at the low-density limit for most emission lines (which is ~100 cm-3) and go up to the peak critical density of the most extreme of the emission lines that we track (which is ~1010 cm-3).
  + Along the y axis, you see the range in hydrogen ionizing photon flux which we have adopted. We constrain these values based on observed fluxes in star-forming regions. We adopt a wide range of phi\_h values to ensure that high redshiftgalaxies fall within our range.
  + On the grid itself, the lighter coloring corresponds to less emission and the darker maroon is more. The equivalent widths are measure relative to the incident continuum at 4860 A (or Hbeta). The peak is denoted with the star and the value is printed beside it, while the solid lines represent increases of 1 dex.
  + Similar toFerguson et al. 1997 and other most recent studies, we adopt a simple step function for the grains on our LOC plane.
    - Below log(*φ*H) = 17, both graphites and silicates are able to exist, so we adopt Orion abundances.
    - Log(*φ*H) = 17 sublimates silicates, so we phase them out of these simulations.
    - Log(*φ*H) greater than 18 is hit enough to sublimate both types of grains, so we adopt no grains in this region and default to solar abundances.
  + Many of the emission lines we tracked, including the O III line displayed, had a similar basic trend across the LOC plane.
    - They emit in a narrow range of ionization parameters (which span from the bottom left to the top right corners of our grid). Thus, they have little emission in the bottom right corner of our grids and even less in the top left. This is because for low ionization parameters, the gas is under-ionized and the emission line does not emit efficiently, while for high ionization parameters, the gas becomes over-ionized and also does not emit efficiently.
  + Finally, the three colored polygons in the bottom left represent the parameter spaces of three other studies: Moy et al. 2001 in yellow, Kewley et al. 2001 in blue, and Levesque et al. 2010 in grey. All three of these studies were looking at low-redshift galaxies, whereas with our much broader parameter space, we are looking at emission from high-redshift galaxies.

The many grids:

* Following this methodology, we create an atlas of equivalent width plots, tracking emission lines from UV lines to IR fine structure lines. Here, I’m showing 16 of our optical emission lines.

The parameters slide:

* Returning back to our initial question: what are the various parameters we have to tune and vary to reproduce high ionization emission lines?
  + We’ve analyzed the effects of metallicity, dust, and star-formation history, so I’ll discuss these effects in my remaining time.

Metallicity comparison plot:

* We’ve constructed plots to display the effects of varying metallicity from 0.2 solar to solar to 5 times solar. As you can see, both of these optical emission lines decrease in strength as we increase metallicity.
  + One trend we noticed, and you can see it with the O III 5007 emission line, is that there’s a distinct pocket of little emission at high metallicity in the bottom left corner of our grid. This area on the LOC plane corresponds to local starburst galaxies. We suspect this is because the cloud is optically thick in this area. [IS THIS TRUE?]
  + Additionally, the step function that we’ve adopted for our grains becomes more prevalent with increasing metallicity. This is again clear in the O III 5007 emission plot at 5 solar metallicity around phi\_h 17-19.

Metallicity trends chart:

* More generally, as we move to higher metallicity, we see UV emission lines, especially metals, increasing. Since we scale nitrogen with metallicity ^ 2, we expect to see nitrogen emission increasing (and we do). However, as metallicity and nitrogen abundance increases, the temperature climbs, and the cooling shifts from carbon and oxygen to nitrogen and so the emission of O and C is suppressed.
* With the optical emission lines, the opposite trend is evident. As metallicity increases, metal abundance decreases. This counter-intuitive trend can be explained by the thermostat effect: though abundances increase when metallicity is increased, the amount of coolants also increases (especially in the case of nitrogen) and the cloud decreases in electron temperature. Emission line strengths are more strongly dependent on electron temperature than abundance, so the increase in coolants decreases the strength of the emission lines.
* Again the trend flips with the IR emission lines and emission lines become stronger with increasing metallicity. This is because when the electron temperature of the cloud is low, the cooling is shifted from the UV and optical lines and the IR lines are able to act as more efficient coolants. The mid and far-IR lines dominate the gas cooling and so emission lines like [Ar III] and [S III] nearly quadruple in emission.

Dust comparison plot:

* To analyze the effects of dust on our grids, we show emission lines on a dust free and dusty LOC plane. Note here that to avoid complications with grains on the plane, we have cut these plots off at phi = 17, before we begin to phase out any dust grains.
  + Most generally, our emission lines tend to emit at a wider range of ionization parameters when dust is not included in the simulations and since dust is formed from metals, we see less emission from such metals across our plane.

Dust comparison chart:

* The effects of dust are most prominent with the UV emission lines. Since dust absorbs UV emission, the emission of most of our lines decreases in strength with the introduction of dust.
* Many of our optical emission lines also decrease with the introduction of dust but there is minimal change shown by the IR lines.

SFH comparison plot:

* To compare emission while adopting various star-formation histories, we have tracked the peak equivalent widths of our emission lines.
  + It is worth noting that this peak emission could be at different areas on the LOC plan, but we are merely pulling the peak value at whichever area the emission is strongest and plotting it.
  + We have tracked Padova cont, inst (blue) and Geneva rotation cont and inst (pink) at 0 to 8 Myr in 2 Myr intervals.
  + Here, I’m showing two sets of optical emission lines which are on different y-axis scales to show the differences between the evolutionary tracks most effectively.
  + While adopting the Padova inst, many of our emission lines die off after 6 Myr which is to be expected from an instantaneous evolutionary track. The Geneva rotation inst track tends to allow the emission lines to emit longer, eventually dying off at 8 Myr and beyond.
  + Though many of the emission lines emit more strongly with the Geneva continuous rotation track, the Padova continuous track produces more high-ionization line emission. You can see this best with the Ne V line shown on the top panel.

SFH comparison plot

* We know that in these first couple years, O-type stars tend to dominate the luminosity of starburst galaxies.
  + In our simulations there is not much observable difference in emission lines’ peak equivalent widths evident between 0 and 2 Myr for the different evolutionary tracks. While most emission lines remain constant, weak optical high-ionization emission lines undergo the some change in emission over this period of time.
* From 4-6 Myr, stellar wind lines dominate the emission in the wavelength region from 1200 to 2000A.
  + These include UV carbon and oxygen emission lines. Generally, the optical and IR region lack features from hot stars but the UV emission lines tend to remain strong.
  + In our simulations of the Padova instantaneous track, the UV emission lines decrease on the order of 0.5-1 dex from 4-6 Myr. The optical and IR emission (for the same SFH) decrease on the order of 1.0-1.5 dex.
  + The Padova and Geneva continuous, however, tracks do not show much difference between bands of emission lines through age.
* After 5 Myr, the most massive stars in the starburst cool off and form Red Super Giants (RSGs). At 8 Myr, RSGs dominate the near-IR portion of the spectrum.
  + The Geneva rotation track UV lines begin falling off more rapidly beyond 6 Myr.

Summary (no slide):

* In the end, we find that our grids suggest a pocket of more extreme conditions or AGN activity when strong high-ionization emission lines are present in the local universe (since we were not able to reproduce these lines in the local region of the LOC plane).
* However, as we move to simulations at higher redshift, we find our grids better at reproducing high ionization emission lines.

JWST intro slide:

* Since the JWST is tuned for high redshift observations, we’d like to briefly discuss our predictions for coming JWST observations.
* We predict that moderately high ionization potential emission lines C III λ977 and N III λ991 will be useful diagnostics for JWST observations.
  + Given their moderate ionization potentials (24.4 eV and 29.6 eV respectively), these two ionization states will be easily formed given the rigorous amounts of star formation at high redshift and thus will serve as good diagnostics.

JWST analysis:

* These two emission lines emit with equivalent widths around 2 in dust-free conditions. Their emission decreases with dusty conditions and a pocket of no emission in the bottom left of the LOC grid is evident. This pocket, again, corresponds to conditions of the local universe.
* Recall that at JWST’s high redshift observations, we expect little dust, low metallicity, and little AGN contribution. It is under these conditions that these two lines optimally emit. C III and N III are not strong lines when adopting local nebular conditions, so they should only be detected for high redshift galaxies with low dust. We predict that JWST’s MIRI should easily detect these luminous emission lines at high redshifts.

End.