Welcome

Hello! and thank you for coming to my talk, today. My name is Alex Wheaton, and I'm going to talk about AGNs, tidal disruption events, star formation, and the relationships between all three.

The aim of my project was to investigate the statistical behaviour of the star formation in the host galaxies of tidal disruption events.

Motivation

I was given access to the spectra and photometry for eight galaxies which hosted tidal disruption events within the past few years. There's a small table of them here, and as you can see, they are all similarly of low magnitude and moderate redshift. Because they are all at redshifts ¡0.1, we can say that they are approximately the same age as our own Milky Way.

At these distances, they occupy very little real estate on a CCD, but the XSHOOTER instrument on the Very Large Telescope provides us with very high resolution spectra from these objects.

Active Galactic Nuclei (AGN)

Now, if you're in the physics department you are probably familiar with the fact that most galaxies are host to a supermassive black hole at their centres. The vast majority of these, including our own Milky Way, emit little to no light which we can detect, and are said to be "quiescent", but a small percentage of galaxies have a core luminosity which is a significant fraction of the luminosity of the whole.

Active Galactic Nuclei (AGN)

The spectral energy distribution of this luminosity is broad featuring peaks in the X-ray, UV, and IR with strong and very broad emission lines. This type of spectrum is not explicable solely by blackbody emission, and so is believed to be the emission from matter accreting onto the surface of a black hole, at a variety of temperatures and orbital velocites.

The Starburst-AGN Connection

Now, for decades, a correlation between nuclear activity in distant galaxies star formation in those galaxies has been emerging. Many AGN have host galaxies with atypically blue spectra, indication recent star forming activity (more on that in a moment). And as you can see from this figure, there is a tight relationship between total stellar luminosity and black hole mass. In other words, and positive correlation between star formation and black hole accretion.

The recent component of star formation is referred to as a ”starburst”—a short period of abnormally high star formation which occurs long after most of the stellar mass in a galaxy is formed.

Possible mechanisms?

There are a couple of proposed mechanisms for this action. It’s possible that radiation from AGN activity heats interstellar gas such that it can not collapse gravitationally to form new star. It also might be that stellar wind shuts of the supply of fuel to AGN. But since these processes take place over the course of billions of years, we can only see individual galaxies in a snapshot. They are either active or not, they are star forming—or they are not. We can’t observe the dynamics of this process.

Tidal Disruption Events

Now, another type of nuclear activity is a tidal disruption event, or TDE for short. This occurs when a single star makes a close orbital approach of an otherwise quiescent black hole. Tidal forces on the star rip it apart. Some material falls into the black hole and the rest is jettisoned on a wide orbit. This process produces a brief but intense increase the nuclear luminosity, which then fades over a matter of days to months. In contrast to typical AGN activity and star formation, this type of event is a transient—we can watch it happen in real.

But how are tidal disruption events related to star formation? In this project, I’ve used the XSHOOTER data on TDEs from the Very Large Telescope to investigate whether or not the host galaxies of transient tidal disruption events exhibit the same statistical behaviour as those of always-on AGN.

The BAGPIPEs Module

To do this, I employed the BAGPIPEs Python module, authored in 2019 by one of Royal Observatory’s very own, to infer the star formation histories of the TDE hosts from their spectra.

The BAGPIPEs Module

BAGPIPEs has two main functions. First, it allows you to define the functional form of a simulated galaxies star formation history, in stellar mass formed per unit time, over the history of the universe. From that prior, it can simulate that galaxy's spectrum as it would appear to us in the present day.

The BAGPIPEs Module

It can also do the inverse: take in a real, observed spectrum from a galaxy and infer from this a distribution of posterior star formation histories.

Stellar Population Dating

It does this using stellar population dating, whereby the ratio of flux from massive blue stars is compared to that from less massive red stars to make assumptions about when the stellar population formed.

The reason this works is because very massive, blue stars live much shorter than their smaller counterparts, so galaxies with a high number density of blue stars necessarily must have had recent star formation. The problem with this, as you can see from this table, is that stellar lifetimes increase dramatically with decreases in initial mass.

Stellar Population Dating

So the number O and B type stars in a given galaxy can give you detailed information about the past billion years. But while the next smallest A type stars are on the main sequence, it's difficult to determine whether they were formed a billion years ago or three billion. As you go down the spectral classification types, the problem only gets worse. As this table illustrates, the universe is mostly populated by main sequence red dwarfs, which live for many many billions of years.

Stellar Population Dating

So before I applied BAGPIPES to the TDE data, wanted to do some tests to see what it was really capable of detecting. I initially tried to look for signatures of star formation than just the ratio of blue to red light in the host galaxies.

So I simulated a galaxy with a simple, Gaussian star formation component, at many different points in time, from a distant redshift 2.2 to the near present z=0.01.

This is the variance in flux at various wavelength as the star formation is evolved towards the present. Although I had hoped that certain emission lines would indicate past star formation, I actually found that most metal lines vary LESS than the overall spectrum, which is mostly affected in the blue region.

Looking at deltas of these flux values rather than the variance, unfortunately yields similar results.

SFH Inference - What is possible?

I next decided to do some blind testing of BAGPIPES fitting ability—wherein I simulated a spectrum with a known SFH, then piped that spectrum back through the fitter to see if I could reconstruct the SFH from the spectrum, without any prior knowledge of it.

R1: Entire Parameter Space with Two Components

I failed several times. My first attempt, which I'll call R1 here, allowed the fitting routine to explore almost the entire parameter space of star formation history.

This is a 13-dimensional fit, that is there are 13 parameters simulated—from the mass and age of the different components, to their shape, metallicity, and other galactic properties like velocity dispersion and nebular emission.

Fitting a two component model with both a bulk component and burst that are allowed to vary over the whole history of the host usually misses the burst component, instead favouring a younger bulk component in the posterior than in the prior, to account for the blue stars produced in the burst.

R2 & R3: Iterative Fitting

To make my fit a little more physically realistic, I insisted that the burst component be younger than the bulk component. I did this by first fitting a one component bulk formation to the spectrum, and then testing to see whether refitting with the addition of a younger burst improved the fit.

R2 & R3: Iterative Fitting

Here you can see the fit (on the bottom) misses the burst in the prior (on top). Instead, it favours a younger, single component of bulk formation, and that adding a burst component doesn't shift the older one to the age in that of the prior.

Selecting Physically Reasonable Priors

So I went back to the drawing board. Clearly, the fit needed narrower constraints. I went to the literature, and found that as we peer into the cosmos at high redshift galaxies, star formation actually peaks at a time called "cosmic noon", around redshift 3-4.

If I insisted that this be the case in my posterior star formation histories, perhaps I could avoid the erasure of the burst component in the fit.

R4: Fixed Old Component, Free Burst Component

With that in mind, I devised a new set of priors, insisting that most of the stellar mass be formed in an earlier era, and letting the burst float freely over the parameter space. If a nonzero burst mass was detected, I could reliably infer the existence of young, high mass stars in the host. If the burst mass was found to be near zero, then the stellar population must be old indeed.

Selecting Physically Reasonable Priors
R4: Fixed Old Component, Free Burst Component

At this time, I also refined some other parameters be be consistent with literature values for my the redshifts and Hubble Morphologies of my TDE hosts.

Blind Fitting Results with R4 Priors

Finally, I began to successfully detect the starbursts. Here you can see one such "blind fit", again with the "true" SFH on top, and the fitted one on the bottom.

Blind Fitting Results with R4 Priors

When a burst of sufficient mass *is* present in the prior, it detects them, although sometimes it struggles to pin down the age of bursts older than 3 billion years.

Blind Fitting Results with R4 Priors

Importantly, fitting with these priors doesn't give false positives. When there is no burst in the prior, it doesn't show up in the fit either.

Blind Fitting Results with R4 Priors

Very low mass bursts, such as this one, are sometimes missed.

Blind Fitting Results with R4 Priors

Bursts of moderate mass (around 10 to the 8 solar masses) are detected, but their mass sometimes underestimated, as you can see here. I thought this might be due to the fit favouring longer decay times for older component, so that some blue stars are accounted for by ongoing formation instead of the burst.

Correlated Parameters

Upon investigation though, I found that the old component decay time and burst mass were not very strongly correlated, so the reason for mass underestimation still merits some study.

Application to XSHOOTER Data

Now confident in the reliability of fits performed with these priors, I turned BAGPIPEs on the TDE data, which of course has no "known" SFH. Here are some of my results:

Application to XSHOOTER Data

As you can see, the TDE hosts exhibit strong evidence of recent starburst activity, with star formation rates much higher than the typical ambient rate of 2-3 solar masses per year.

Application to XSHOOTER Data

Almost all of the fits find old components which are consistent with observational evidence for star formation at cosmic noon, and with burst components consistent with present day starburst galaxies.

Application to XSHOOTER Data

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Conclusions

In summary, it seems that starburst activity in the past 3 billion years of a galaxy's history is inferable with some reliability, given that certain assumptions about what constitutes a physically realistic SFH are made. With that in mind, I've applied this to the spectra of several TDE hosts, and found that they indeed seem to share the statistical behaviour of in-transient AGN.

Future Applications

With that said, it's important to note that eight samples available to me for this project are not nearly a large enough sample size to draw this conclusion. This "proof of concept" has applications for larger research projects, and it would certainly be valuable to apply fits with the R4 priors to larger sample size, with priors more carefully tailored to host morphology, and to compare these results to quiescent galaxies with similar morphologies.

With those questions, I'll conclude my talk! Thank you for coming, and questions?