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**Investigating the Temperature Effects of Grain and Metallicity Abundance in NLR AGN**

**Introduction**

Nebular clouds in star forming regions and active galactic nuclei (AGN) typically show electron temperatures around *Te* = 1.5E4K in the OIII emitting region (Osterbrock & Ferland 2006).

However, anomalously high values *Te* > 1.54x104 have been noticed in surveys for decades without a thorough explanation for the physical mechanism responsible for creating such conditions in narrow line emitting AGN (Shuder & Osterbrock, 1981, Komossa & Schulz 1997, Zhang et al., 2013, Richardson et al., 2014). While more recent work has started to address the topic head on, signatures of high Te have been present in small spectroscopic samples of AGN. Shuder & Osterbrock (1981) show Te > 1.7E4 K in 5 of the 12 galaxies for which they measure electron temperature. Shuder & Osterbrock do not include any models in their work, which leaves the question of why such high Te is observed in some galaxies (I don’t like how this is worded).

Komossa & Schulz (1997) investigated a larger data set, including 37 galaxies in their study. They also include models in their analysis, which includes assuming various properties of the cloud to predict emission lines, through which they can predict conditions within the cloud. Values are assumed for the spectral energy distribution (SED), the blackbody temperature for the background emission source, and a luminosity rate of hydrogen ionizing photons emitted by the galactic nucleus. Along with cloud distance from the emission source and hydrogen density (nH), these values can be used to calculate the ionization parameter U. The wide range of parameters varied leads to a range of log U between -6.58 and +0.42. Komossa & Schulz also vary the metallicity of the cloud, and stop their models once the hydrogen column density drops below a pre-determined value. These input parameters were used in a photoionization code called Cloudy, specifically version 84.03 (Ferland 1993). Cloudy then outputs emission line strengths for any requested lines, and these line strengths are used to determine conditions within the cloud. Talk about how their results work with Te, what were their temperature results? Explain that this is a normal approach to the models.

Dopita & Sutherland(1995) also model high temperature galaxies, but they employ shocks to reach those high temperatures, and claim in their abstract that they have solved the temperature problem. To model these shocks, they vary magnetic field strength from 2 < B/n1/2 < 4 μG, and shock velocity from 150 – 500 kms-1. They derive interesting results from their models, including an inverse relationship between shock velocity and electron temperature. Figure 2c shows shock models with a velocity < 500 km s -1 and without a precursor have log[OI]6300/Hα > -1.0, and a range of log[OIII]5007/Hβ between 0.25 and -0.25, meaning though these lower velocity shocks produce high electron temperature (high enough to reach out hottest data points, but what’s the actual Te?), these models fall inside the LINER category on diagnostic diagrams. This result is not surprising, because as we have mentioned, LINERs are shocked AGN.

* Look at Figure 2s and pull out comparisons of their sim placement/our data

Though this shock heating provides high electron temperatures, nearly all of these shock heated galaxies are LINERs, or low ionization narrow emission line regions. LINERs are shock heated AGN, but these results do not provide an explanation for the high temperature non-LINER AGN (clean up the wording). Be specific, which plots am I looking at, etc. explain that the temperature problem is high temperature in AGN, not LINERs.

Groves, Dopita & Sutherland (2004) incorporate dust in their models in an attempt to increase electron temperature due to photoelectric heating, which at the time was a new approach. This group also uses the MAPPINGS III code (citation and edition? They don’t give one)instead of CLOUDY to do their models. Notably, they include a narrower range of parameters than Dopita & Sutherland in 1995. They vary nH from 102 – 104 cm-3, metallicity from 0.25 – 4 times the solar value, and power law index α from -1.2 to -2.0. Dust content is varied from XXX-XXX, and the ionization parameter U is varied from -4.0 < log U < 0.0 in intervals of -0.3, -0.6, and -1.0 dex(should this be -4.0 – 0 to stay consistent with my notation above?).

* I don’t see their dust ranges anywhere in the section with parameters – it’s on the plots but where are the ranges?
* Does Figure 14 show inverse relationship between grains and Te?? Higher grains give higher 4363 ratio? Same with Figure 15
* But they mention dust alleviates some of the temperature problem

**Richardson 2014**

* Komossa & Schulz drastically overestimate OI emission so it’s likely low ionization AGN have low density gas with high Te. Why?
* Decreased metallicity gives less cooling and higher Te, studied by Komossa & Schulz and shown to be true, but these cases might be rare
* Grains increase heating and can reproduce high ionization Te, but miss the mark with highest ionization data
* Cosmic rays had a negligible effect on Te ratio
* What specific points am I pulling from this paper? There’s a lot of reference to the papers I’ve mentioned above but not sure what specific pieces I should be writing about
* Lots of talk about how changing different parameters influences ionization and matching the ionization levels of the data, is that what I’m writing about, and if so, how should I tie that in to what I have so far?

To model these clouds in the narrow line region, some photoionization source is assumed, such as the accretion disk around a central supermassive black hole in active galactic nuclei (AGN), or stellar radiation in star forming galaxies. This ionizing radiation will go through the gas cloud, and spectra is measured from this cloud. Reasonable ranges for parameters of the cloud are assumed such as ionization parameter, metallicity, hydrogen density, grain content etc. from previous literature. We can input these conditions into a computer program called CLOUDY that will output emission lines for a galaxy with the given input characteristics. [show realistic ranges in parameters, those predict common temps, show evidence.]. As Zhang, Liang and Hammer (2013) mention, there has been no clear explanation of the temperature problem, and most attempts to explain it have relied on unrealistic combinations of parameters. Komossa & Schulz (1997) attempted to solve this problem by increasing density, but their density values caused inconsistencies in other measurements, specifically OI values. Richardson et al. (2014) investigated the possibility that the temperature problem is actually a density problem causing false readings in the temperature sensitive line ratios, but determined that this was not actually the case.

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EVERYTHING BELOW THIS LINE IS METHODS]

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Our research focuses on this temperature problem in narrow line region (NLR) emitting Active Galactic Nuclei (AGN) [move farther down]

Our research uses data from the Sloan Digital Sky Survey as well as constraints on galaxy types established in Kewley et al. to separate our data set by galaxy type. Interestingly, our data set contains no LINERs. Shock-wave heating is a possible heating mechanism, but LINERs are shocked AGN, so because we have no LINERs, we do not explore shocks.

We plot our SDSS data set on a collection of diagnostic diagrams in order to categorize them by characteristic conditions and type. The most popular and useful of these is the BPT Diagram, presented by Baldwin, Phillips and Terlevich in 1981. The BPT Diagram is a log[OIII] λ5007/Hβ vs. log[NII] λ6584/Hα plot that conveniently separates AGN from Star Forming (SF) galaxies, composites, and ambiguous objects, all of which are contained in our data set. log[OIII] λ5007/Hβ is a hydrogen density and ionization sensitive line ratio, and log[NII] λ6584/Hα is primarily sensitive to ionization. We used this log[NII] λ6584/Hα ratio again when we separate our galaxies by temperature, in a log[OIII] λ5007/4363 vs. log[NII] λ6584/Hα plot. This neatly categorizes our galaxies by their temperature, as 5007/4363 is a temperature sensitive emission line ratio. The high temperature outliers in our data set are apparent in this temperature plot, and we use it to compare with our simulations and check the temperature of our simulations. By comparing different iterations of simulations with these plots of our data set we are able to see the effects of changing different parameters, which helps us decide how to adjust our simulations. These plots also ensure that we are using realistic values of our parameters, and likely observed conditions, by showing us whether our simulations match our data.

ZLH find the high Te Seyfert 2 show low metallicity Fig 7

LINERs and composites show Te “far too high to be explained by only stellar photoionization”

Some strong [O III] λ4363 emission Seyfert 2 galaxies with Te > 15 000 K can be fitted with dusty AGN model grids at low metallicity (i.e. Z/Z ∼ 1).

**References**

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