PHYS 129L Final Project

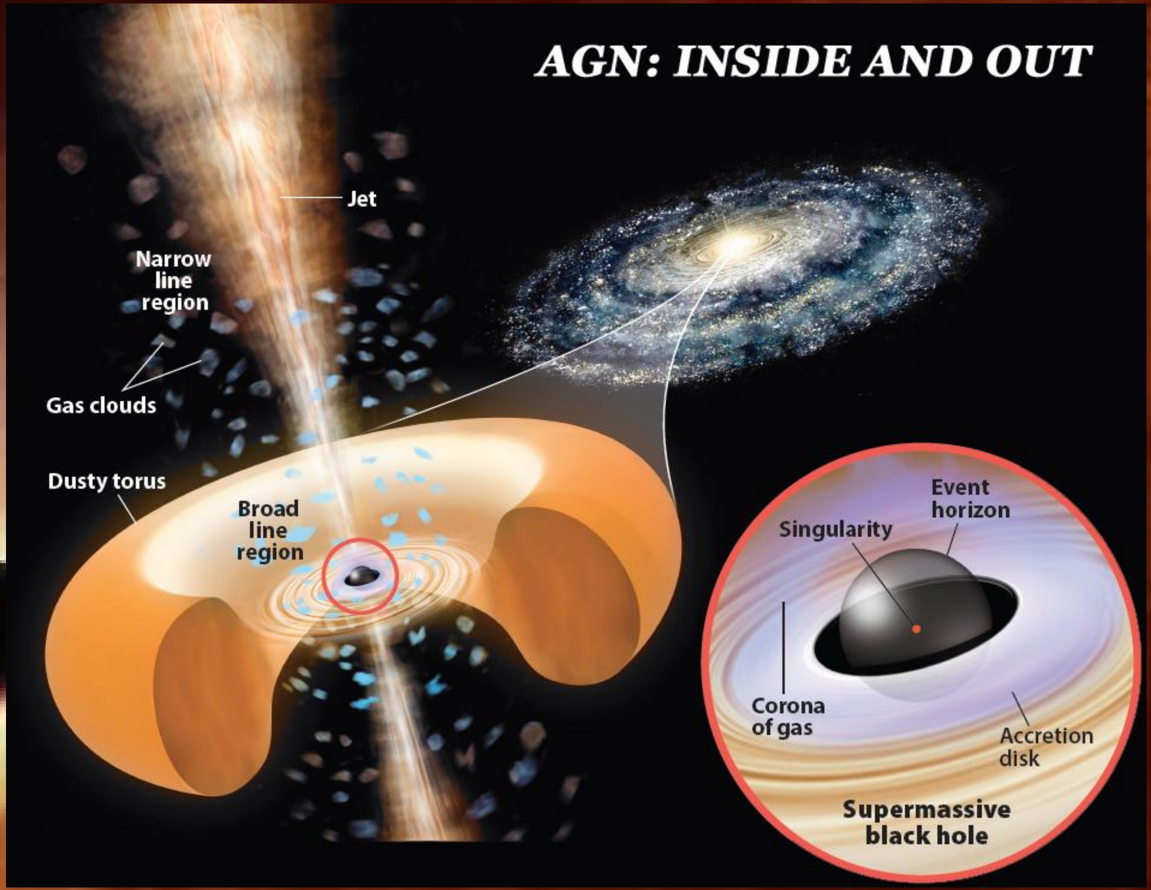
Active Galactic Nuclei (AGN) Host Galaxy Simulation and Spectra Modeling

Annabella Yang*

University of California, Santa Barbara

Introduction: AGN GALAXY

- An AGN is a compact region at the center of a galaxy that emits a significant amount of energy across the electromagnetic spectrum
- It is special because the luminosity is not produced by stars
- A galaxy hosting AGN is called an active galaxy
- These galaxies have incredible amount of energy



Introduction: Why Study AGN GALAXY?

- Super massive blackholes
- History of Universe
- How Blackhole evolves over time
- Environmental impact of clusters and galaxies

Goal for This Project

1, “Galaxy” Class

```
class Galaxy:
    '''initialize the galaxy'''
    def __init__(self, mass, position, velocity, black_hole_mass, initial_te
        self.mass = mass
        self.position = position
        self.velocity = velocity
        self.black_hole_mass = black_hole_mass
        self.initial_temperature = initial_temperature
        self.redshift = redshift
```

- Blackhole Accretion Model (Accretion Rate, Radiation, and Jet Production)
- Cooling and Heating Process (Cooling Rate, Heating Rate, and Temperature-time Evolution)
- Generating Spectrum (With Emission feature and noise)

2, Spectra Modeling
- Generate an AGN using the galaxy class I defined
- Fit the spectra using optimization
- Compare important parameters to observe any correlation

3, look at some implication

Some Useful Computational Methods in this Project:

Optimization: Used to fit the AGN galaxies

Monte Carlo Simulation: Used to find the correlation

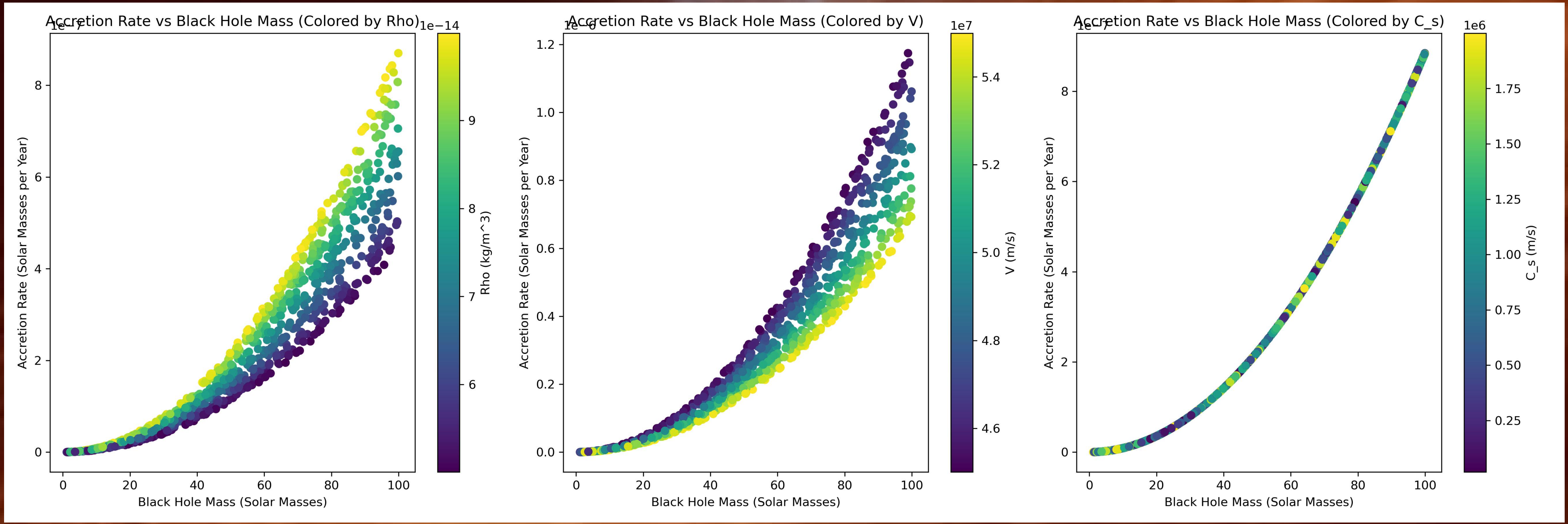
1st Model: Black Hole Accretion Model

$$\dot{M} = \pi \left(\frac{2G^2 M^2 \rho_\infty}{(v_\infty^2 + c_s^2)^{3/2}} \right)$$

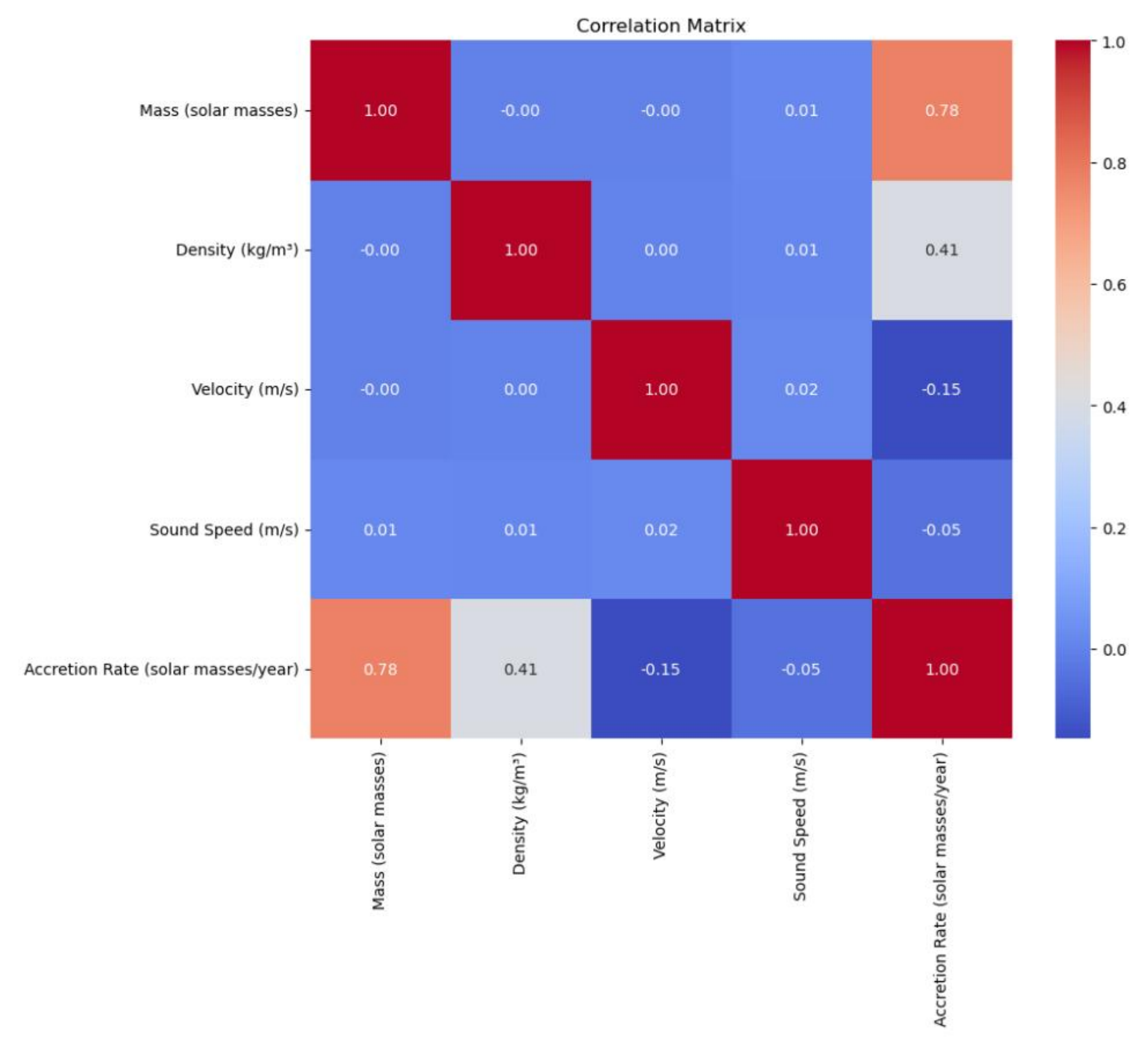
$\dot{M}$: Accretion rate
G : Gravitational constant
M : Mass of the accreting object
ρ_∞ : Density of the ambient medium (far from the accreting object)
v_∞ : Relative velocity between the object and the ambient medium
c_s : Sound speed of the ambient medium

Bondi-Hoyle-Lyttleton accretion rate model

Fixed Range:
$\rho \epsilon [5e-14, 1e-13]$
$v \epsilon [4.5e7, 5.5e7]$
$c_s \epsilon [1e4, 2e6]$



1st Model: Black Hole Accretion Model



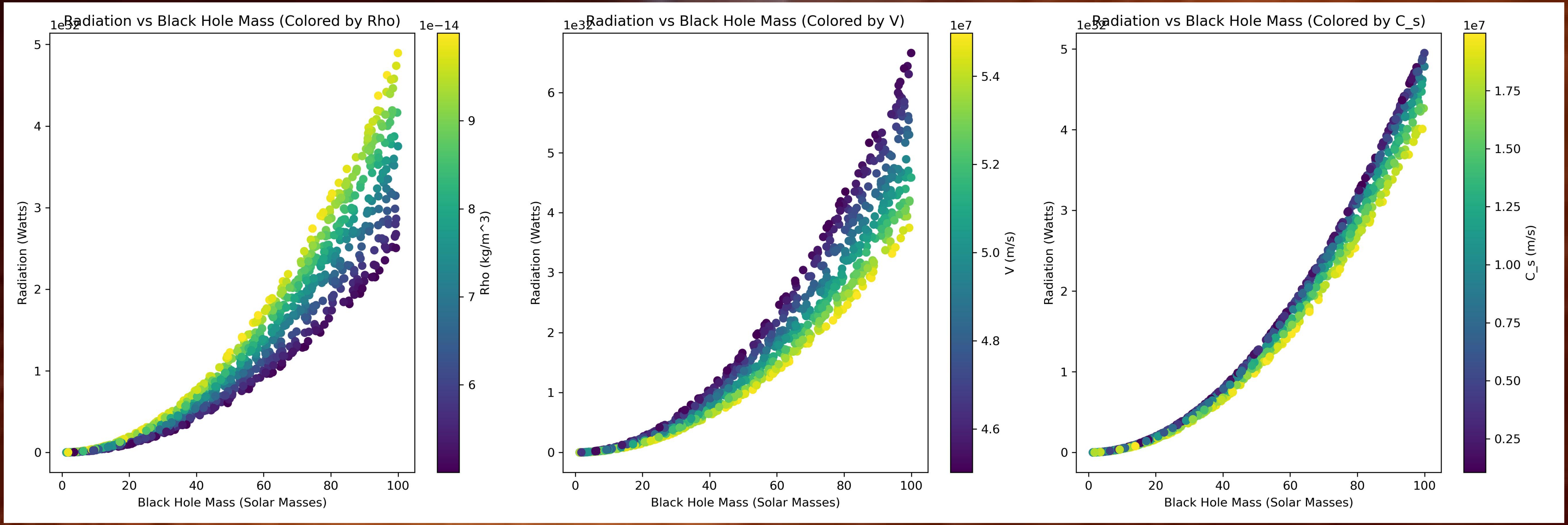
1st Model: Black Hole Accretion Model

$$Radiation = \epsilon \times \dot{M} \times 1.98847 \times 10^{30} \times c^2$$

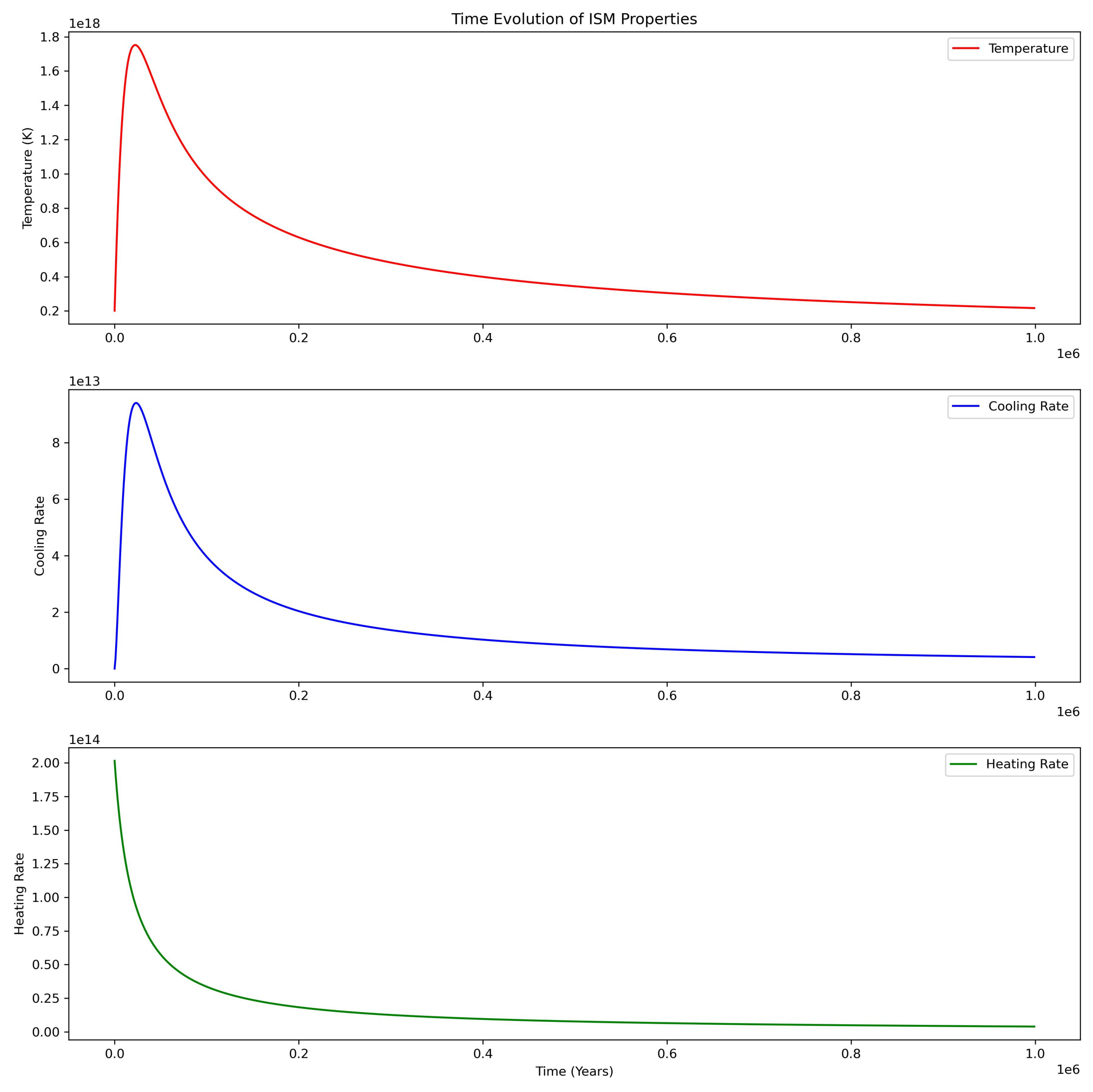
$\dot{M}$: Efficiency factor - typically around 0.1 for non-rotating black holes

c : speed of light

R_{acc} : accretion rate



2nd Model: Cooling and Heating Model



Cooling rate:
low/high temperature regime
proportional to density^2
heatig rate:
decay factor that display a decay over time
proportional to star formation rate
proportional to luminosity
proportional to density
temperature:
calculated by
(heating rate - cooling rate)xtimestep

2nd Model: Cooling and Heating Model

$$\rho(r) = \rho_0 (\frac{r}{r_0})^{-\alpha}$$

$\rho(r)$: The density as a function of radius from the center

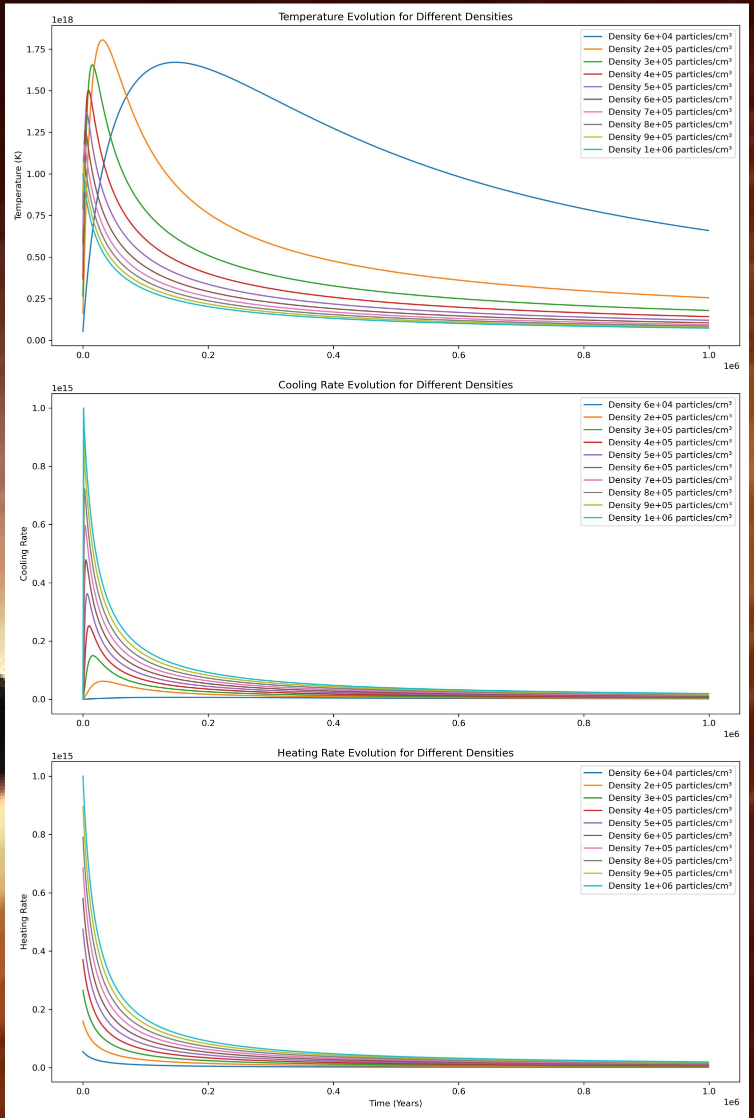
ρ_0 : the reference density, I here take it to be 1.0×10^5 particles per cubic centimeter

r_0 : reference radius, I here take it to be 1 parsec

r : the radius from the center, in unit of parsec

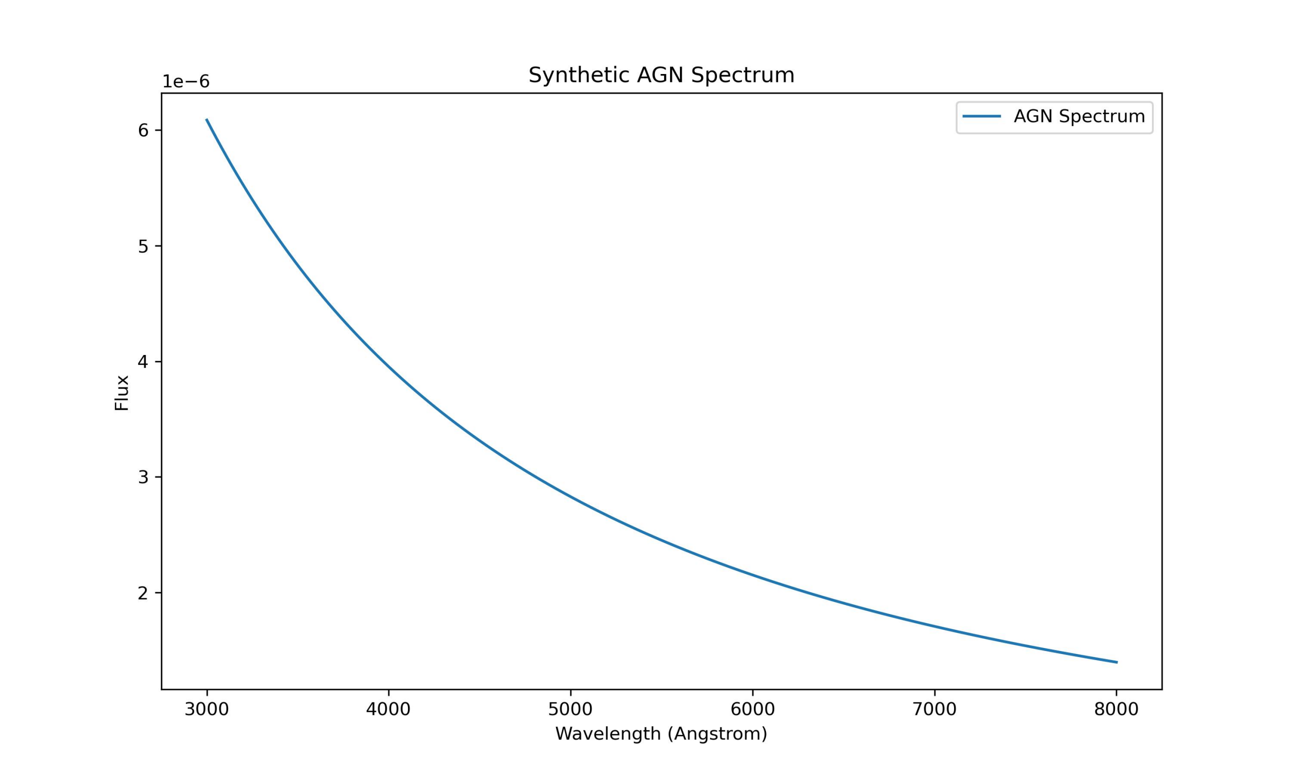
α : the index of this power law, I here take it to be 1.5, this varies for different galaxies

- As density increases, the heating rate increases, the cooling rate increases as well, and the overall temperature peaks lower and decays faster.
- In the center of an AGN galaxy, the density is extremely high, and as the radius goes out, density decreases.
- Thus, towards the center of an AGN galaxy, the temperature peaks higher and decays slower
- Combining with our previous model, this makes sense.



3rd Model: Generating a Spectra for AGN galaxy

1, Generate a power-law continuum



Emission lines:

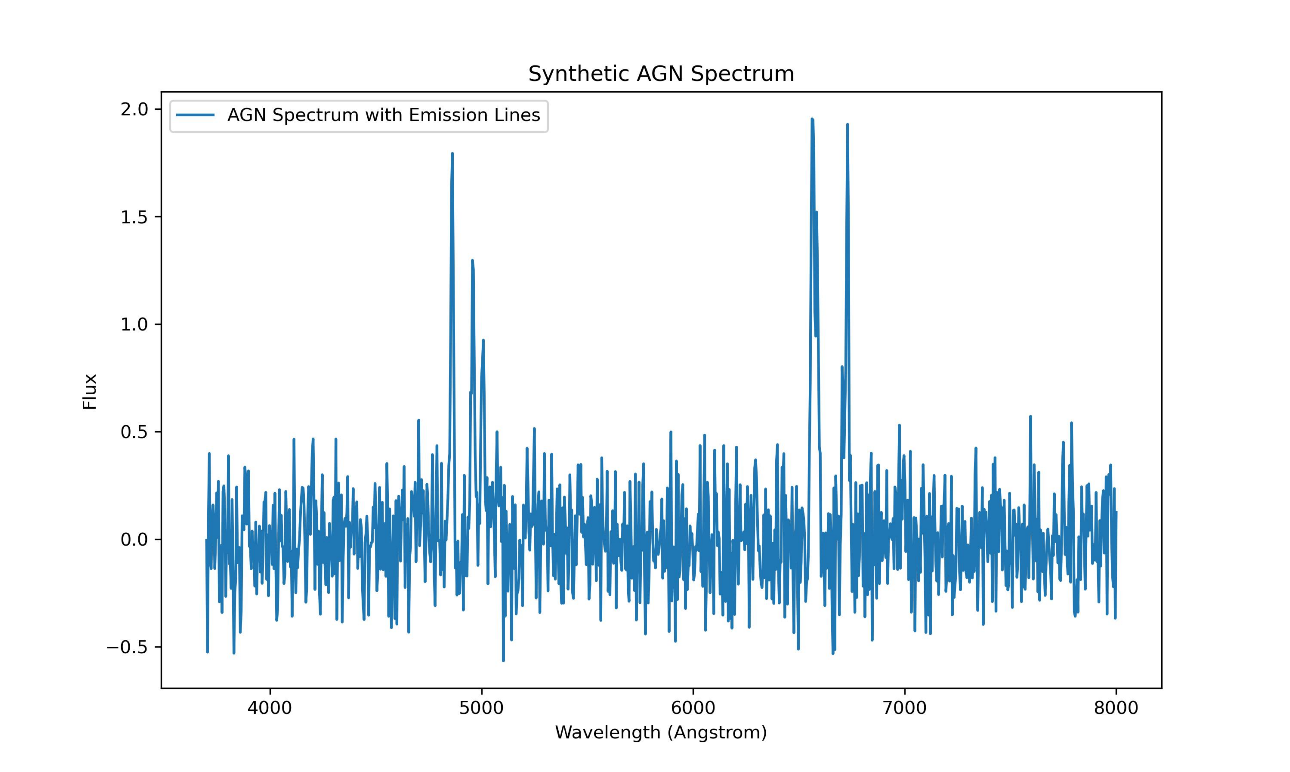
H_alpha	6563Angstrom
H_beta	4861Angstrom
OIII_5007	5007Angstrom
OIII_4959	4959 Angstrom
NII_6584	6584 Angstrom
SII_6716	6716Angstrom
SII_6731	6731Angstrom

3rd Model: Generating a Spectra for AGN galaxy

1, Generate a power-law continuum
2, Consider emission lines
3, Add noise

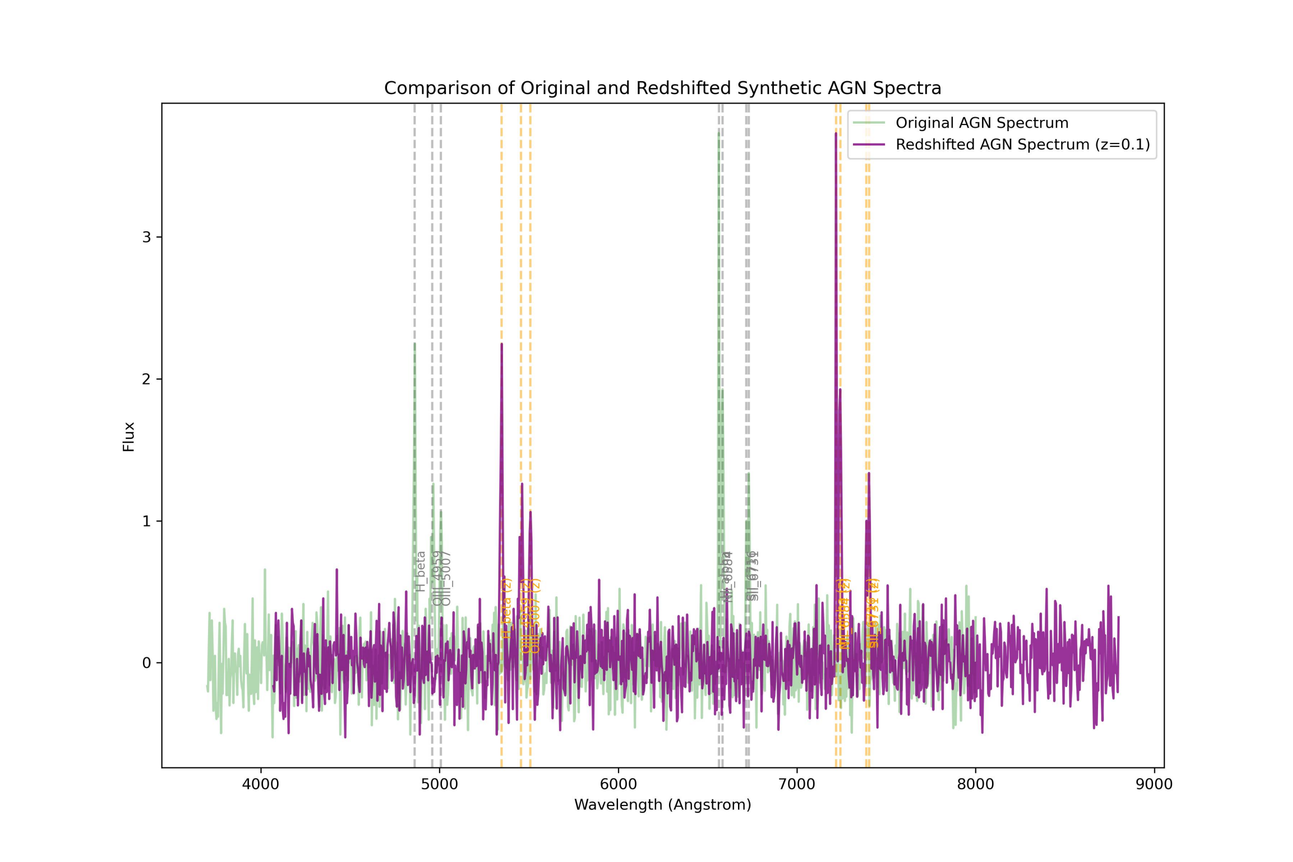
Emission lines:

H_alpha	6563Angstrom
H_beta	4861Angstrom
OIII_5007	5007Angstrom
OIII_4959	4959 Angstrom
NII_6584	6584 Angstrom
SII_6716	6716Angstrom
SII_6731	6731Angstrom



3rd Model: Generating a Spectra for AGN galaxy

1, Generate a power-law continuum
2, Consider emission lines
3, Add noise
4, Redshift



Emission lines:

H_alpha	6563Angstrom
H_beta	4861Angstrom
OIII_5007	5007Angstrom
OIII_4959	4959 Angstrom
NII_6584	6584 Angstrom
SII_6716	6716Angstrom
SII_6731	6731Angstrom

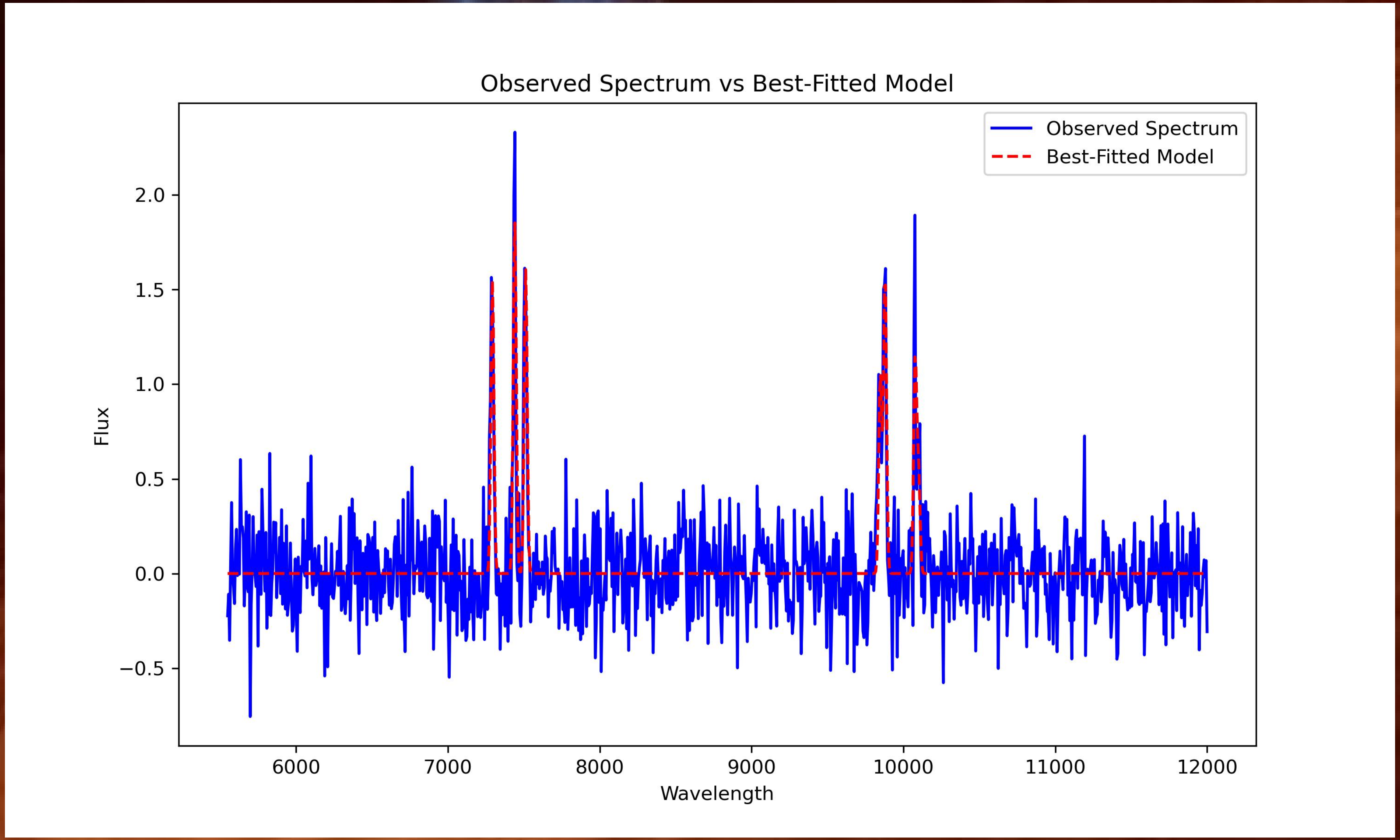
Optimization and Spectra Modeling

Spectra modeling is significant for studying gakaxies because it gives us information about a various things. Some typical ones includes:

1. **composition and chemical elemental abundances**: from analyzing a spectra of a galaxy, we can tell from the emission and absorption lines which components exists in the galaxies, also, the ratio between certain emission lines give us the chemical elemental abundances, which reveals the history of the galaxy because some element are more produced in certain age or phase of galaxy evolution.
2. **redshift**: by looking at the obvious emission and absorption lines from a galaxy's spectrum, we can compare it with the wavelength of that element in the rest frame spectrum, and by using $1 + z = \frac{\lambda_{observed}}{\lambda_{rest}}$, we can find the redshift of the galaxy, and thus how far the galaxy is from us.
3. **stellar population**: since different stars have very different physical properties, we can tell from the spectra which kind of stars do the galaxy have and thus better understand the stellar populations of certain types of galaxies.
4. Spectra modeling also plays critical roles in **understanding black holes of AGN**, **studying dark matter and dark matter halo**, and p**roviding insights into the temperature and density**. Thus we want to understand how AGN galaxies look like and potentially build AGN galaxy spectrum.

Optimization and Spectra Modeling

Best-fit Model. Input redshift: 0.5; model redshift: 0.5005. Error within 0.01 for all redshift up to 10



Optimization and Spectra Modeling

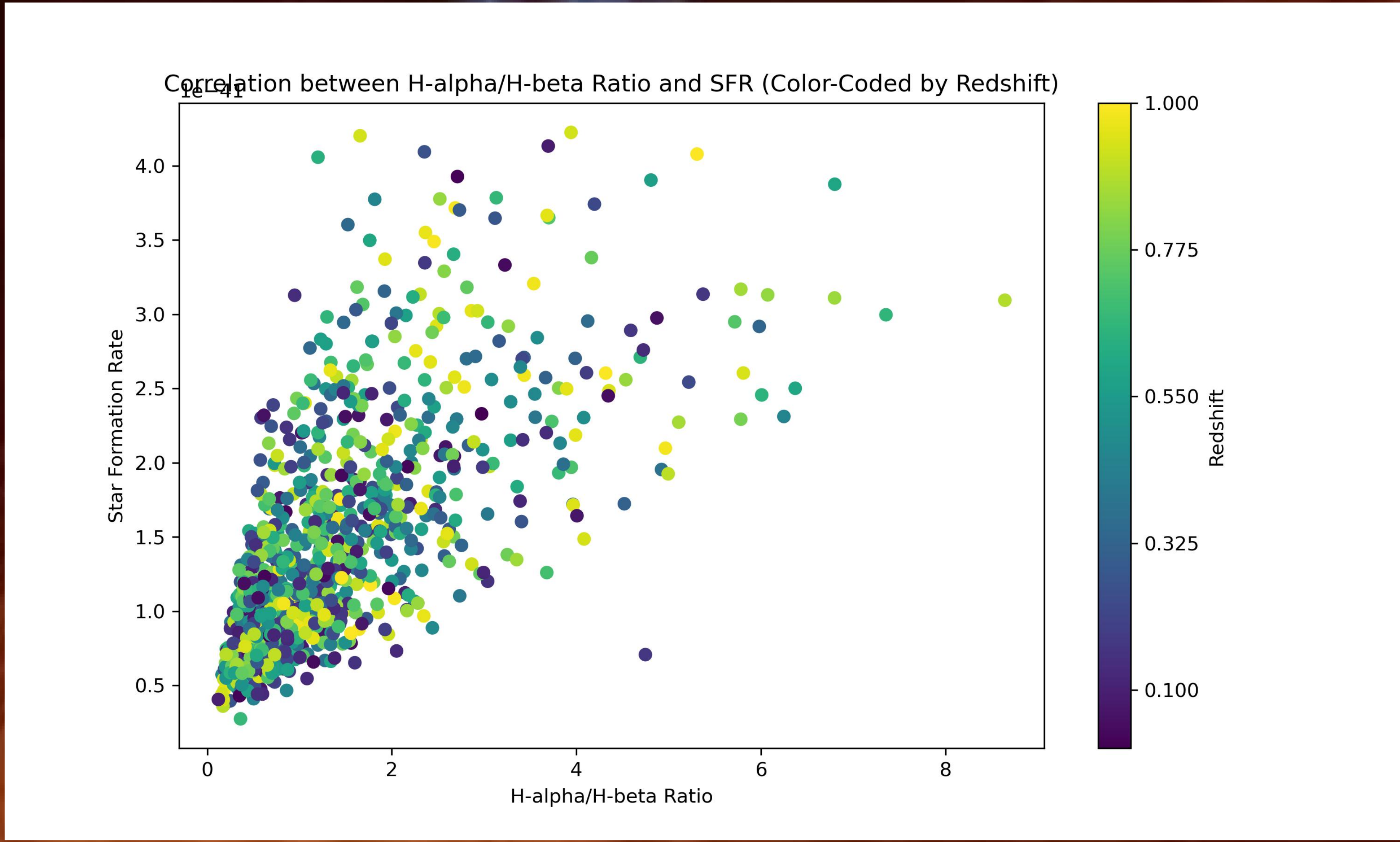
It also calculates the line intensity, which allow us to calculate the **star formation rate** and **alpha abundance**

```
Best fit redshift: 0.5005005005005005
Best fit line intensities: [26.30618675 38.87781463 40.25987717 46.56667712 39.87182771 28.19842191
 13.08592734]
```

By using the Galaxy class, I generated 1000 AGN galaxies in the redshift range [0.01, 1] with corresponding spectra.
Then I fit each of the spectra and find the intensity for emission lines.
I calculated the star formation rate and H-alpha/H-beta ratio for each of the galaxy...

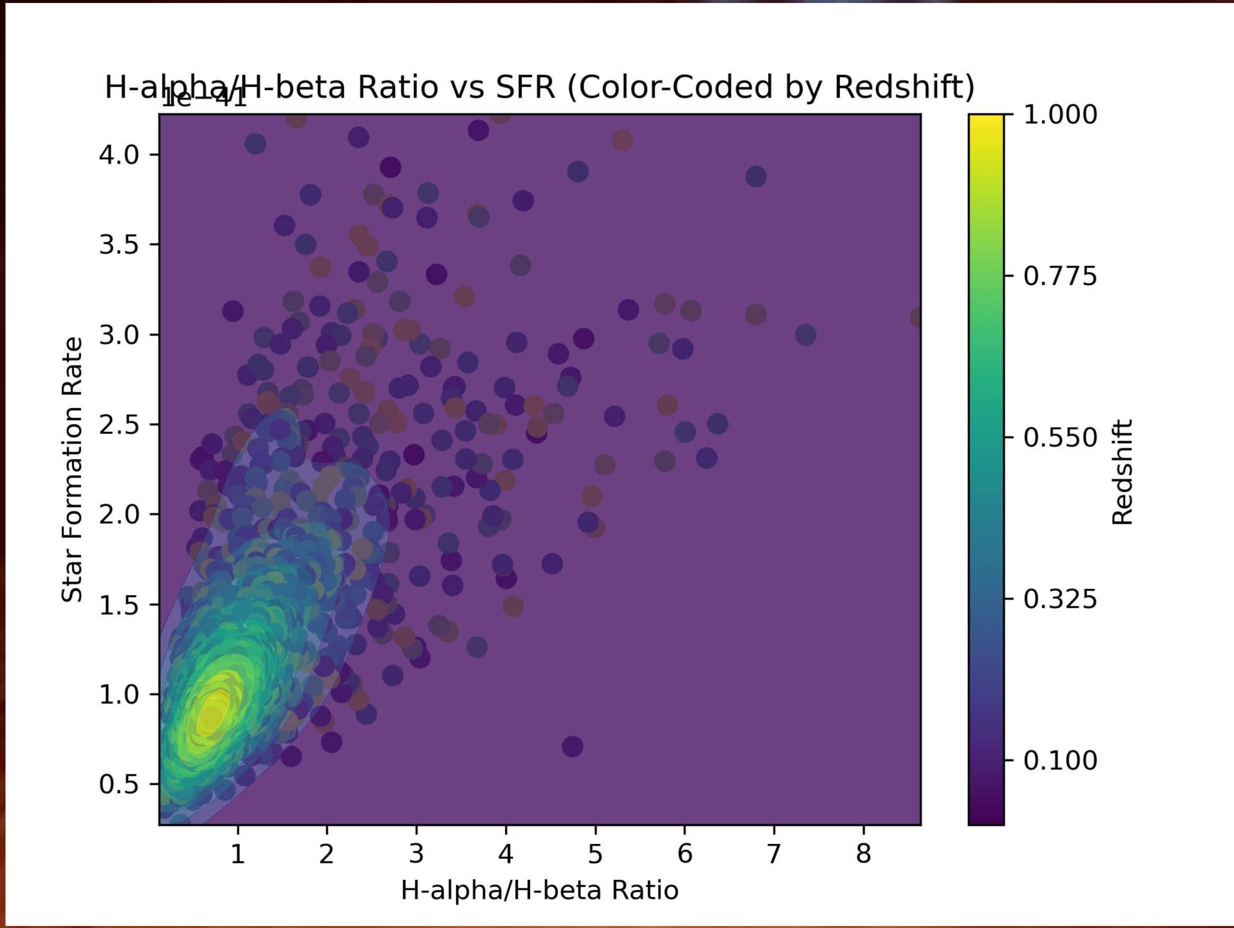
Optimization and Spectra Modeling

And Plotted them out!



Optimization and Spectra Modeling

Contour plot: better visualize the density of data point for large sample

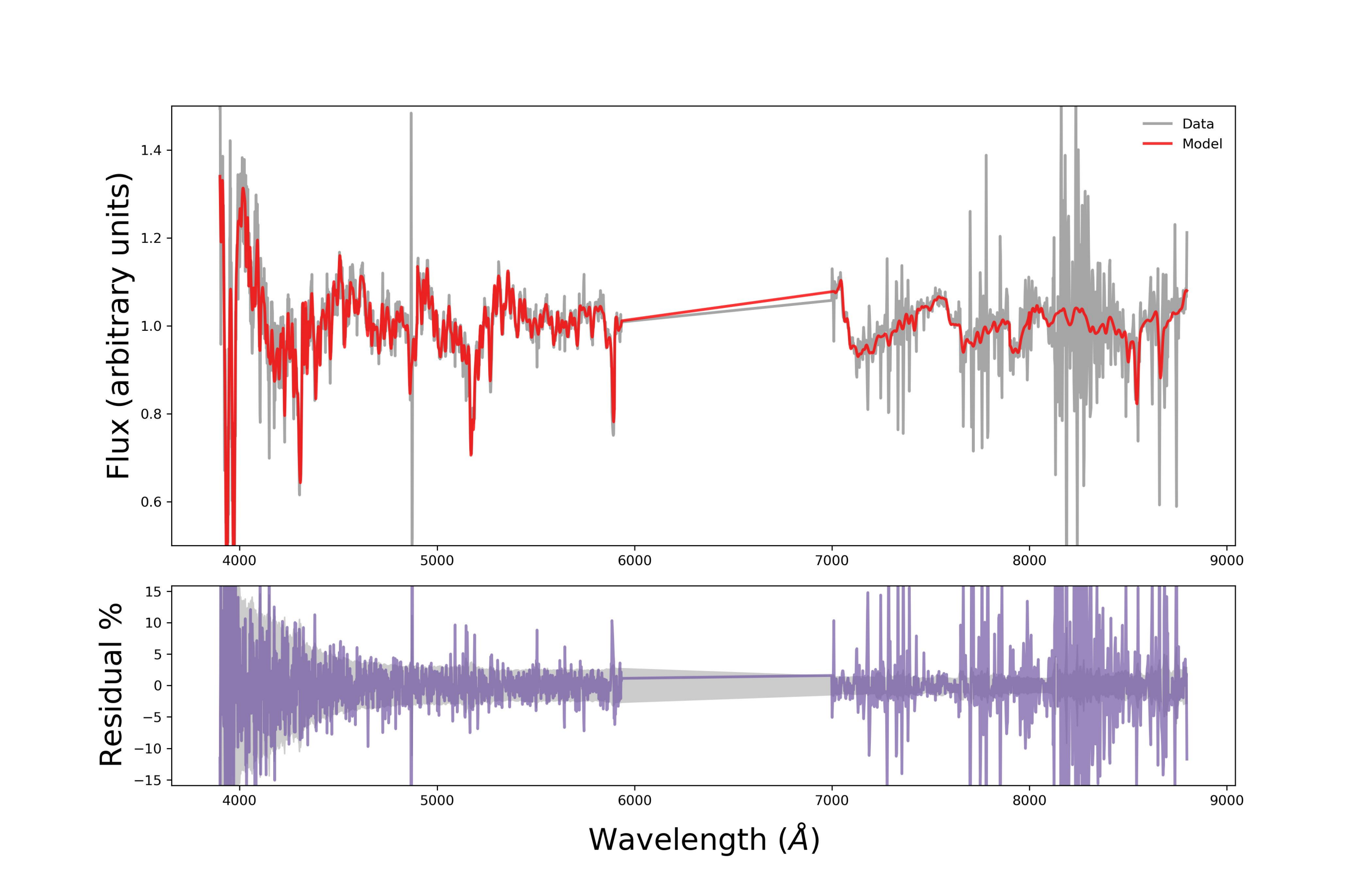


- Most of the datapoints lies on low H-alpha/H-beta ratio and low star formation region
- It has an overall trend that SFR increases as H-alpha/H-beta ratio increases.

Relation to Physics and Implication

Finding the correlation between stellar population

- Monte Carlo Simulation
- ALF code by Conroy et al. 2012 and Conroy et al. 2018
- Generate Parameters
  - Age (log(age))
  - Metallicity ([Z/H])
  - Alpha enhancement ([α/Fe])
  - Chemical elemental abundance
    - Carbon, Nitrogen, Oxygen, Magnesium, Silicon, Calcium, Titanium, and Sodium.



Relation to Physics and Implication

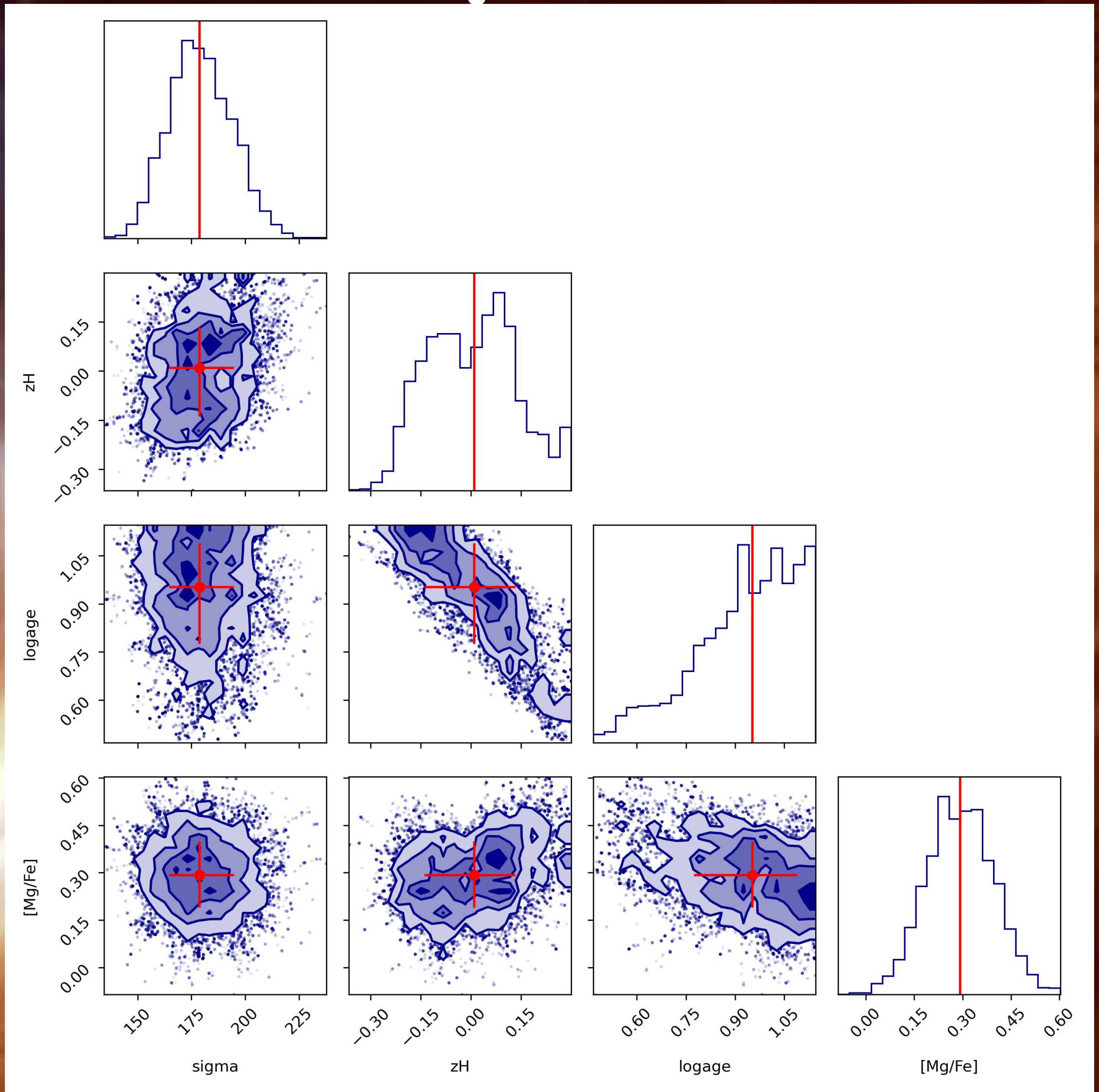
- Monte Carlo Simulation
- ALF code by Conroy et al. 2012 and Conroy et al. 2018

• age (logage)

• metallicity ([z/H])

• velocity dispersion (sigma)

• alpha enhancement ([Mg/Fe])



Relation with this course

- Based on a subfield of physics
- Used Python techniques such as defining a “Class”
- Unix Skill: using unix command to run the ALF code
- Computational Skill: Optimization, Monte Carlo Simulation, Pearson Correlation
- Implicabable: spectra fitting example

Conclution

- I have created a “Galaxy” Class that allows me to generate random AGN galaxy with accretion model, cooling/heating model, and spectra
- The accretion rate is most closely related to black hole mass, it increases as black hole mass increases, same as radiation
- As density increases, the heating rate increases, the cooling rate increases as well, and the overall temperature peaks lower and decays faster
- Using optimization, I can fit the spectra and calculate redshift within an error 0.01
- SFR increases as H-alpha/H-beta ratio increases
- Using spectra modeling on real datasets, we can find the correlation between parameters

References

- Choi, J., Dotter, A., Conroy, C., Cantiello, M., Paxton, B., & Johnson, B. D. (2016). Mesa isochrones and Stellar Tracks (mist). I. Solar-scaled models. The Astrophysical Journal, 823(2), 102. https://doi.org/10.3847/0004-637x/823/2/102
- Conroy, C., Graves, G. J., & van Dokkum, P. G. (2013). Early-type Galaxy archeology: Ages, abundance ratios, and effective temperatures from full-spectrum fitting. The Astrophysical Journal, 780(1), 33. https://doi.org/10.1088/0004-637x/780/1/33
- Conroy, C., Villaume, A., Dokkum, P. G. van, Lind, K., https://orcid.org/0000-0002-1590-8551, C. C., https://orcid.org/0000-0003-1887-0621, A. V., & https://orcid.org/0000-0002-8282-9888, P. G. van D. (2018, February 21). IOPscience. The Astrophysical Journal. https://iopscience.iop.org/article/10.3847/1538-4357/aaab49
- Li, Y., Ruszkowski, M., & Bryan, G. L. (2016, November 16). AGN heating in simulated cool-core clusters. arXiv.org. https://arxiv.org/abs/1611.05455
- Panda, S. (2022, February 16). Parameterizing the AGN radius–luminosity relation from the eigenvector 1 viewpoint. Frontiers. https://www.frontiersin.org/articles/10.3389/fspas.2022.850409/full
- Sanchez-Blazquez, P., Peletier, R. F., Jimenez-Vicente, J., Cardiel, N., Cenarro, A. J., Falcon-Barroso, J., Gorgas, J., Selam, S., & Vazdekis, A. (2006). Medium-resolution Isaac Newton Telescope Library of empirical spectra. Monthly Notices of the Royal Astronomical Society, 371(2), 703–718. https://doi.org/10.1111/j.1365-2966.2006.10699.x
- Stone, J. M., & Norman, M. L. ZEUS-2D: A Radiation Magnetohydrodynamics Code for Astrophysical Flows in Two Space Dimensions. I. The Hydrodynamic Algorithms and Tests. 1992a, ApJS, 80, 753. 1992b, ApJS, 80, 791
- Tanner, R., & Weaver, K. (2022, January 20). Simulations of AGN driven galactic outflow morphology and content. arXiv.org. https://arxiv.org/abs/2201.08360

Conclution

- I have created a “Galaxy” Class that allows me to generate random AGN galaxy with accretion model, cooling/heating model, and spectra
- The accretion rate is most closely related to black hole mass, it increases as black hole mass increases, same as radiation
- As density increases, the heating rate increases, the cooling rate increases as well, and the overall temperature peaks lower and decays faster
- Using optimization, I can fit the spectra and calculate redshift within an error 0.01
- SFR increases as H-alpha/H-beta ratio increases
- Using spectra modeling on real datasets, we can find the correlation between parameters

Thank you for watching! Any Question?