Understanding Clustering Algorithm Applied to Planetary Nebulae

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What are Planetary Nebulae?

Planetary nebulae (PNe) are **shells of ionized gas** with **white dwarfs at the center.**

How do PN form?

- Planetary nebulae form from intermediate-mass stars
- After a star expands into the red giant phase it will enter the AGB phase
- From the AGB phase, the star loses material that ends up in space
- After the star's core collapses the star dies and leaves ionized gas in space

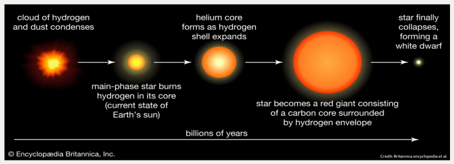

Figure 1: An image by Britannica Encyclopedia et al. showing the stellar evaluation of a main-sequence star that specifically becomes a planetary nebula with a white dwarf remnant

What are some important characteristics of PNe?

PNe can be either **symmetric** or **asymmetric**. Types of PNe shapes include but aren't limited to: Elliptical, Spherical, Bipolar, and Irregular.

- NGC 6543, also known as the Cats eye nebula, is elliptical and symmetric

X-ray Observations using Chandra

PNe are **observed by Chandra** in **x-rays** (≥0.5 keV)

The x-ray emission we can observe in planetary nebulae:

- Diffuse x-rays
- Point like x-rays

Hot Bubbles and Point-Like Sources

Hot bubbles are formed through **shocked winds and gas that collide** with each other.

- Hot bubbles emit soft X-rays from 0.3 to 1 keV

Point-like sources refer to the **compact X-ray emission near the white dwarf** at the **center of the planetary nebula**

- Point-like sources emit harder X-rays than hot bubbles

Figure 2: An image by Cha d in the visible wavelength with an x-ray overlay at the center of the PNe by Chandra x-ray telescope

The DBSCAN Algorithm

What are clusters?

- Clusters are groups of points with different population sizes
- In our case, our clusters consist of photons

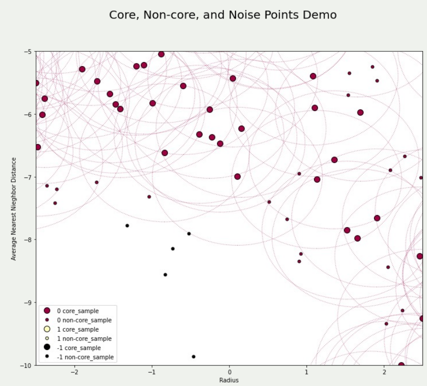

Figure 3: A Demo of how DBSCAN categorizes clusters using DBSCAN parameters such as epsilon (radius) and min_samples (number of nearest neighbors)

DBSCAN User Parameters

User parameters such as **epsilon (or eps)** and **minimum sample value (or min_samples)** are user parameters that **define the distance away from a chosen data point in correlation to the minimum number of points it takes to make a cluster.**

DBSCAN Parameter Results

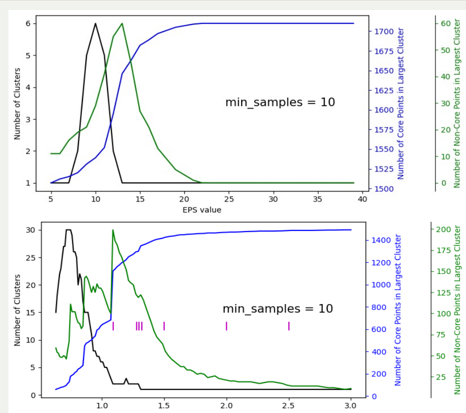

Figure 4: A full distribution graph of eps values (5–40) and a graph showing selected eps values (1–3) that highlight key behaviors in the number of clusters, core, and non-core points for \text{min_samples} = 10.

DBSCAN Parameter Results Cont'd

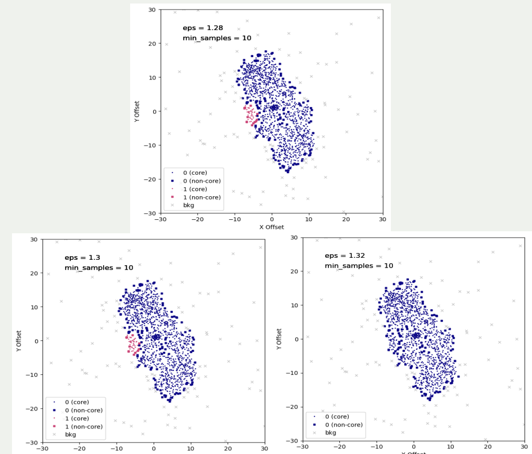

Figure 5: A DBSCAN visualization of cluster candidates of eps values (1.28, 1.3 and 1.32) all with the same min_sample value.

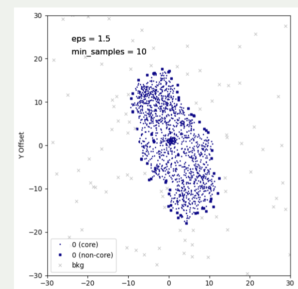

Figure 6: A DBSCAN visualization of cluster candidates of eps values (1.28, 1.3 and 1.32) all with the same min_sample value.

The DBSCAN Parameter Study and What's Next!

- Across the smaller selected ranges of eps, the best parameter fitting the data for NGC 6543 is eps = 1.5 and min_samples = 10
- This shows that you can use DBSCAN to cluster different sources of X-ray emission to further represent the hot bubble and the central source of NGC 6543
- In the future, a study could focus on what user parameters would best fit differing kinds of X-ray objects (ie: shape size, and brightness)

References

[1] R. Montez Jr. et al 2015 ApJ 800 8

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[5] L. Decin, M. Montargès et al 2020 Science 369, pp. 1443-1444.