Classification of pulsar's population Using Graph Theory

Iman Talebi

Supervisor: Dr. Seyed Mohammad Sadegh Movahed

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Shahid Beheshti University, Department of Physics

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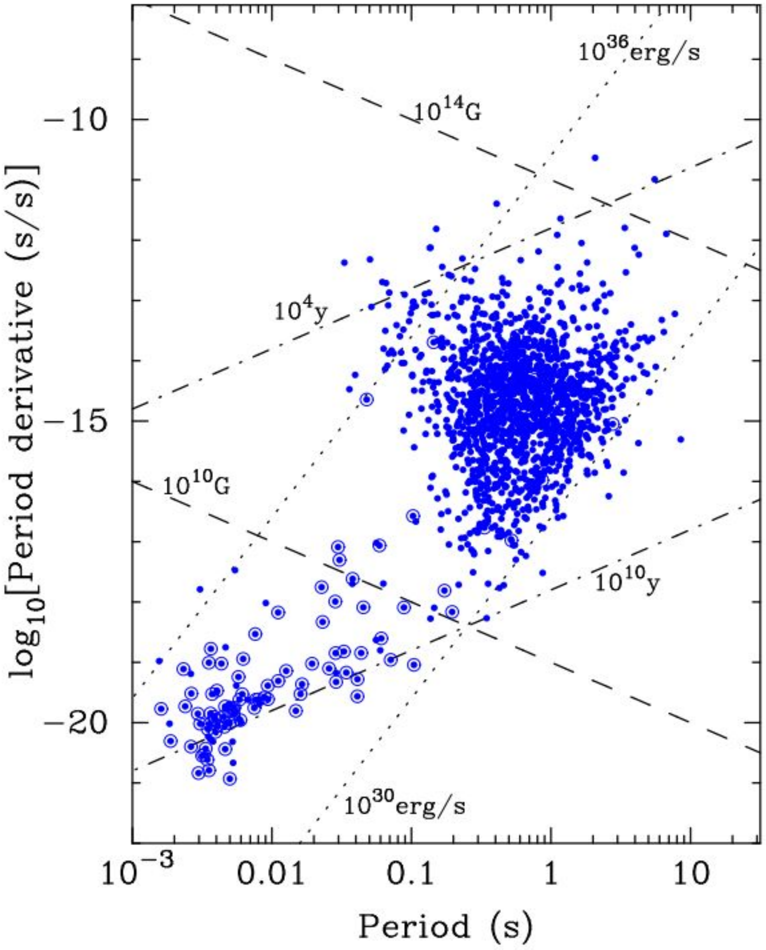
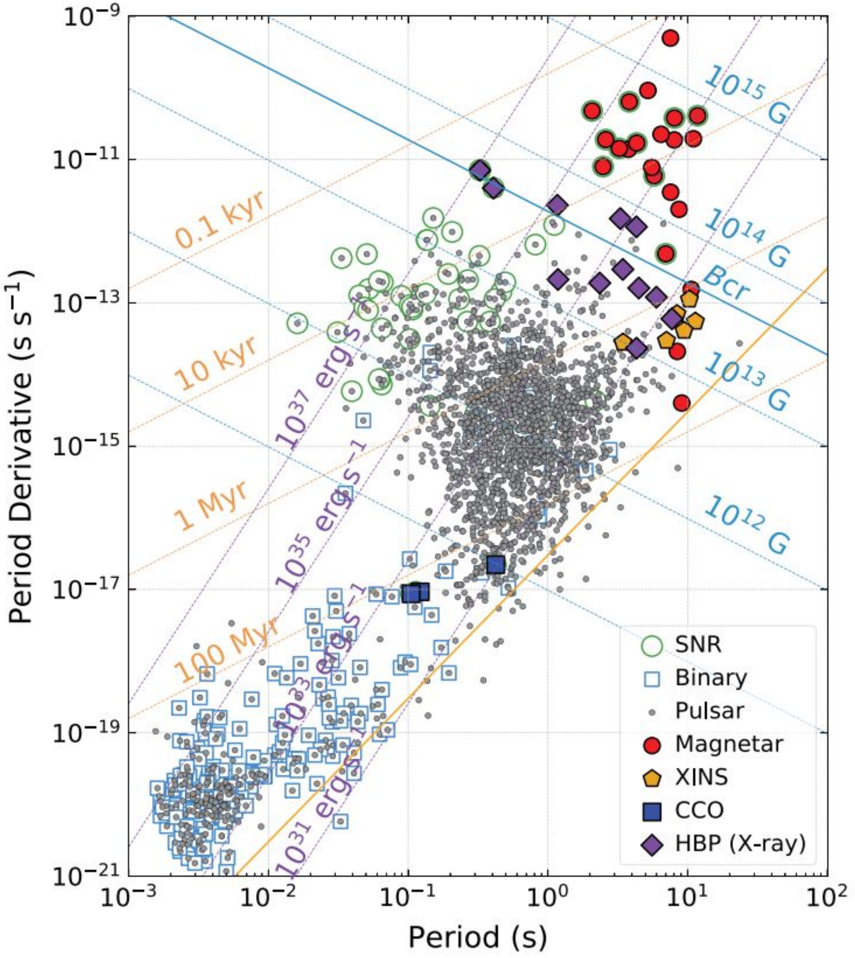
Part I:
Pulsars' Population Diversity

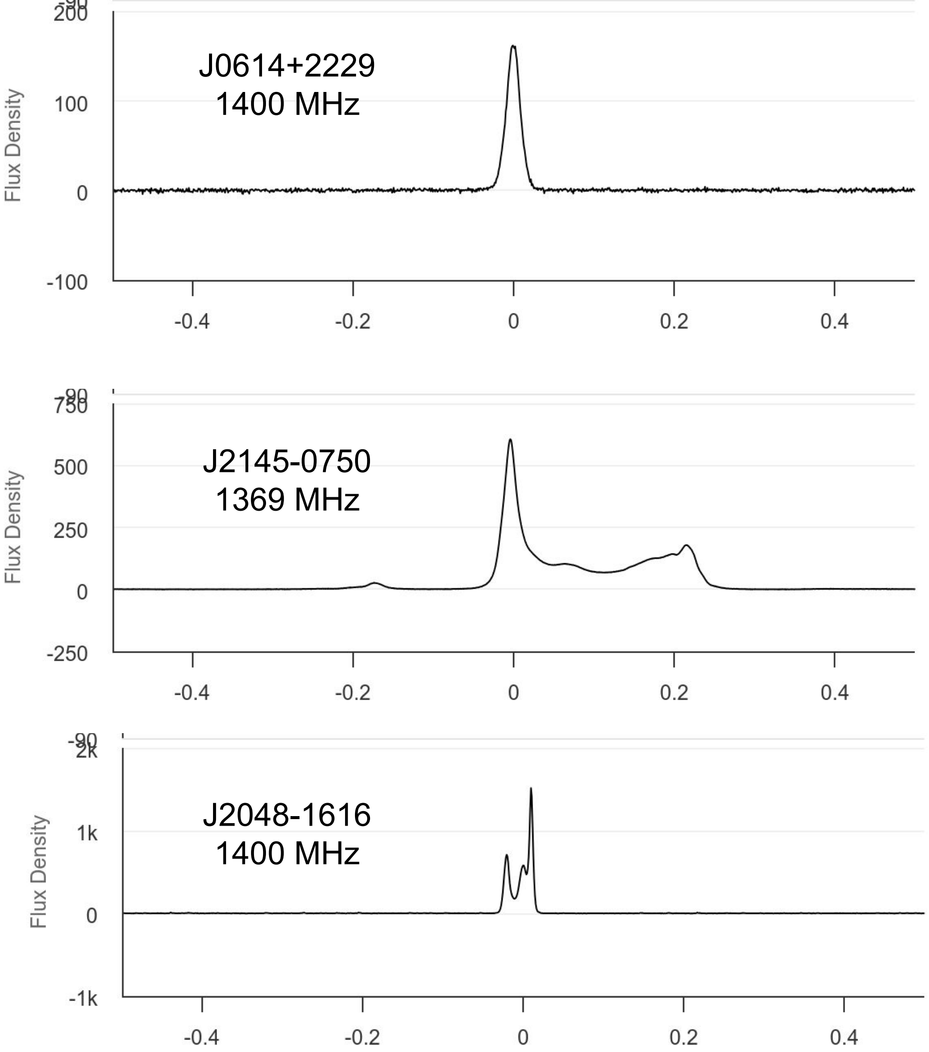


Lorimer, Duncan R. "Binary and millisecond pulsars." *Living reviews in relativity* 11 (2008): 1-90.



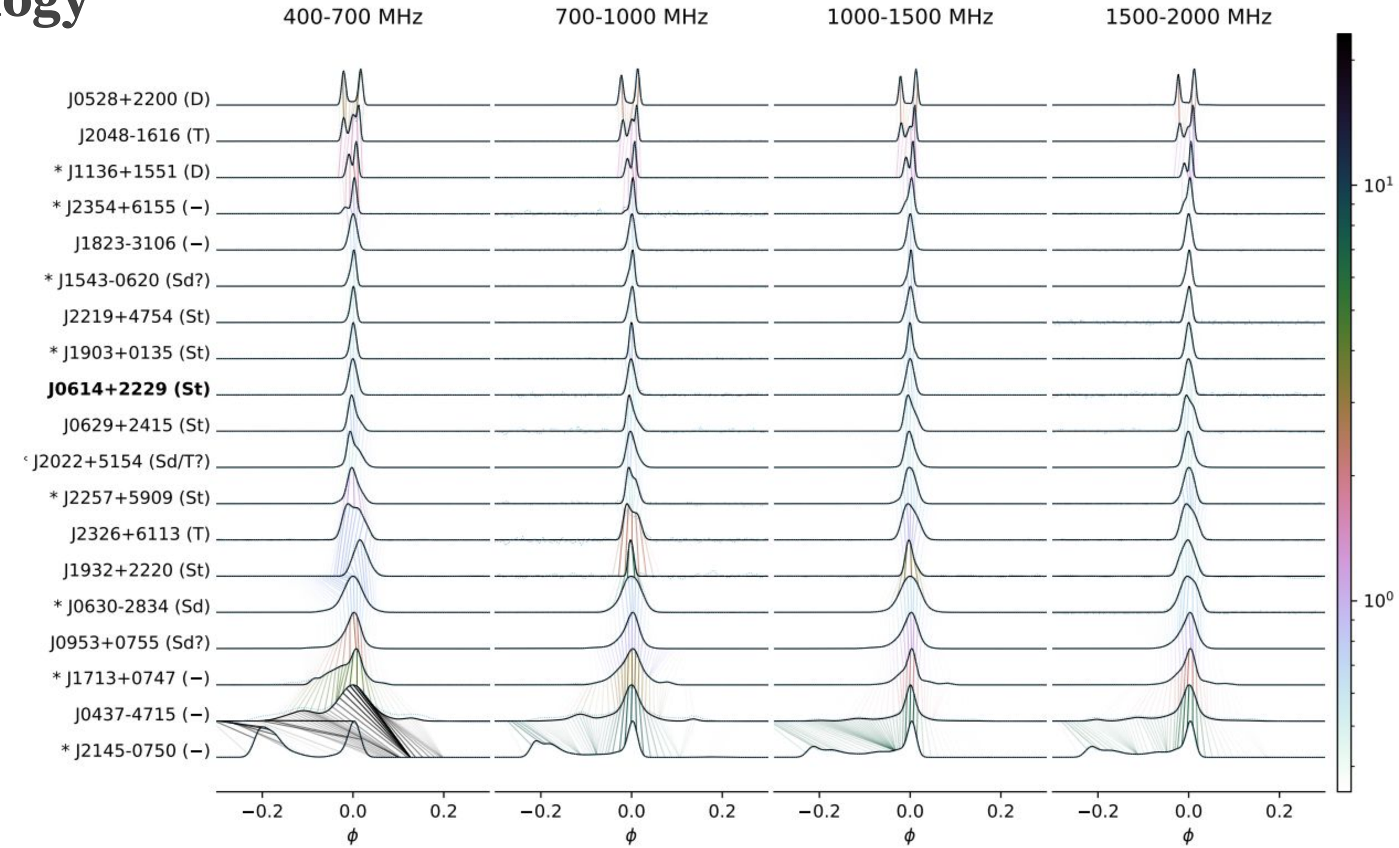
Enoto, Teruaki, Shota Kisaka, and Shinpei Shibata. "Observational diversity of magnetized neutron stars." *Reports on Progress in Physics* 82.10 (2019): 106901.

Diversity of Pulse Profiles' (PPs) Morphology



https://psrweb.jb.man.ac.uk/epndb/

Diversity of Pulse Profiles' (PPs) Morphology



Vohl, D., J. van Leeuwen, and Y. Maan. "Topology of Pulsar Profiles (ToPP)-I. Graph theory method and classification of the EPN." *Astronomy & Astrophysics* 687 (2024): A113.

Part II:
Classification via Graph theory

Graph Theory

Topology of Pulsar Profiles (ToPP)

I. Graph theory method and classification of the EPN

D. Vohl[1,2], J. van Leeuwen[1], and Y. Maan[3,1]

[1] ASTRON, Netherlands Institute for Radio Astronomy, Oude Hoogeveensedijk 4, 7991 PD Dwingeloo, The Netherlands
e-mail: d.vohl@uva.nl
[2] Anton Pannekoek Institute for Astronomy, University of Amsterdam, PO Box 94249, 1090 GE Amsterdam, The Netherlands
[3] National Centre for Radio Astrophysics, Tata Institute of Fundamental Research, Pune 411007, Maharashtra, India

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ABSTRACT

Some of the most important information on a radio pulsar is derived from its average pulse profile. Many early pulsar studies were necessarily based on only a few such profiles. In these studies, discrete profile components were linked to emission mechanism models for individual stars through human interpretation. For the population as a whole, profile morphology must reflect the geometry and overall evolution of the radio emitting regions. The problem, however, is that this population is becoming too large for individual intensive studies of each source. Moreover, connecting profiles from a large collection of pulsars rapidly becomes cumbersome. In this article, we present ToPP, the first-ever unsupervised method to sort pulsars by profile-shape similarity using graph topology. We applied ToPP to the publicly available European Pulsar Network profile database, providing the first organised visual overview of multi-frequency profiles representing 90 individual pulsars. We found discrete evolutionary tracks varying from simple single-component profiles at all frequencies towards diverse mixtures of more complex profiles with frequency evolution. The profile evolution is continuous, extending out to millisecond pulsars, and does not fall into sharp classes. We interpret the profiles as being a mixture of pulsar core-cone emission type, spin-down energetics, and the line-of-sight impact angle towards the magnetic axis. We show how ToPP can systematically classify sources into the Rankin empirical profile scheme. ToPP comprises one of the key unsupervised methods that will be essential to exploring upcoming pulsar census data, such as the data expected from the Square Kilometer Array.

Key words. methods: data analysis – pulsars: general

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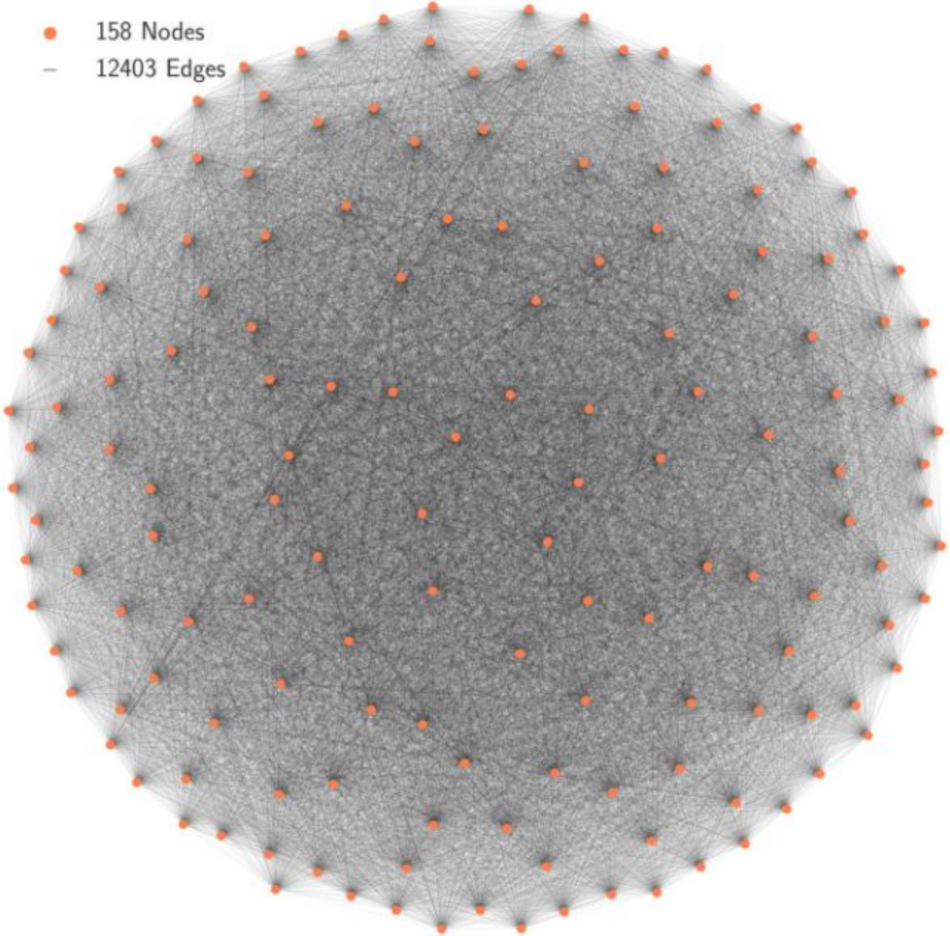
Graph Theory

- **G (V, E, W)**
  - Vertices or Nodes (**V**) → Pulsars
  - Edges or Links (**E**) → Connection Between Vertexes
  - Weights (**W**) → Relationship between Vertexes that linked together



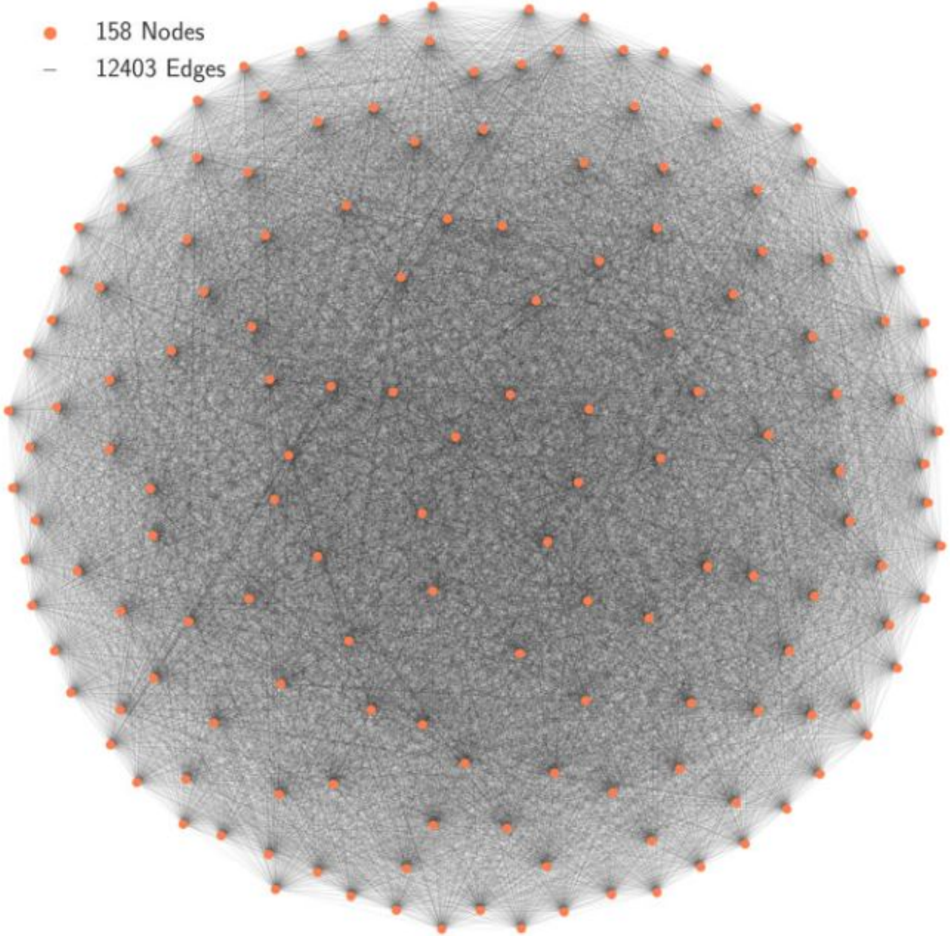
García, Carlos R., Diego F. Torres, and Alessandro Patruno. "Visualizing the pulsar population using graph theory." *Monthly Notices of the Royal Astronomical Society* 515.3 (2022): 3883-3897.

Graph Theory:
Defining Edges and Weights

- **Based on Pulsar's features**
  - Euclidean Distance

$$d_{nm} = \sqrt{\sum_{j=1}^{N}(v_{jn} - v_{jm})^2}$$

  - **"v"** → vertex
  - **"N"** → Number of Features
  - **"n, m"** → Two Vertexes (Pulsars)



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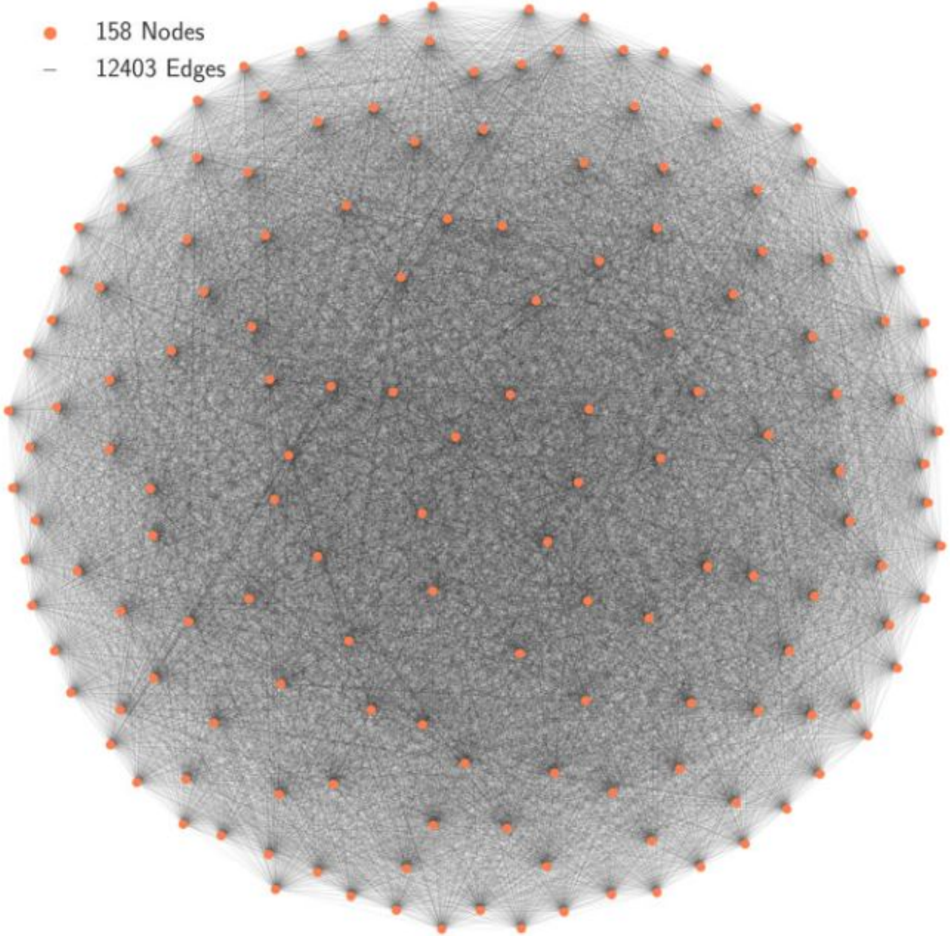
Graph Theory:
Defining Edges and Weights

- **Based on PPs of Pulsars:**
  - Defining a measure to encode the (dis-)similarity between two PPs. (**Similarity measure Definition**)
  - **Weighting** the edges based on this Similarity measure.



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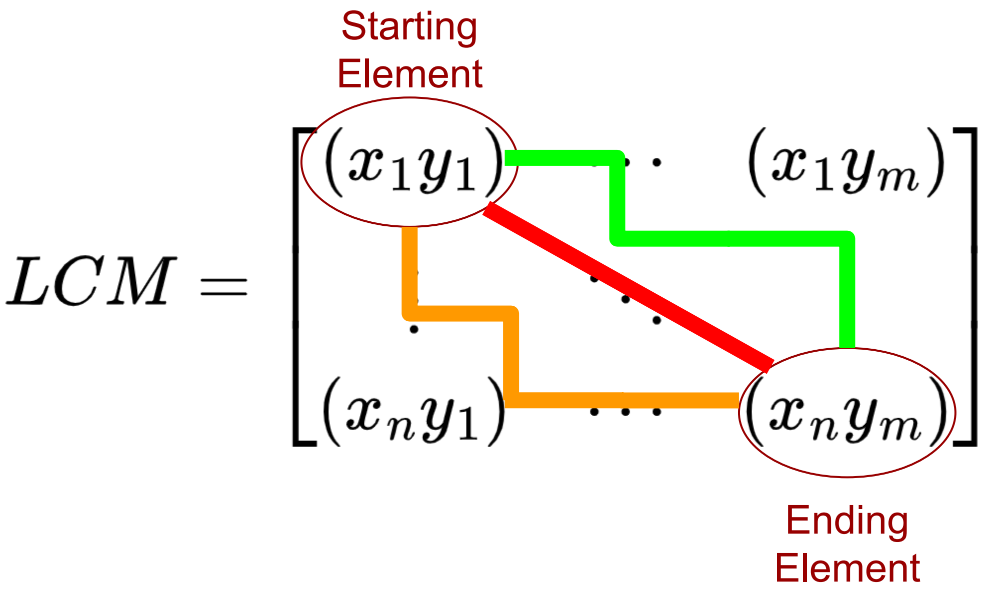
Graph Theory:
Defining Edges and Weights
Similarity between two PPs

- **Dynamic Time Warping (DTW) algorithm:**
    - Finding Euclidean distance between any two point of the the two PPs and constructing **Local Cost Matrix (LCM)**.
    - Finding a path from adjacent elements of LCM such that summation of them become minimum which is called **Warping path**.



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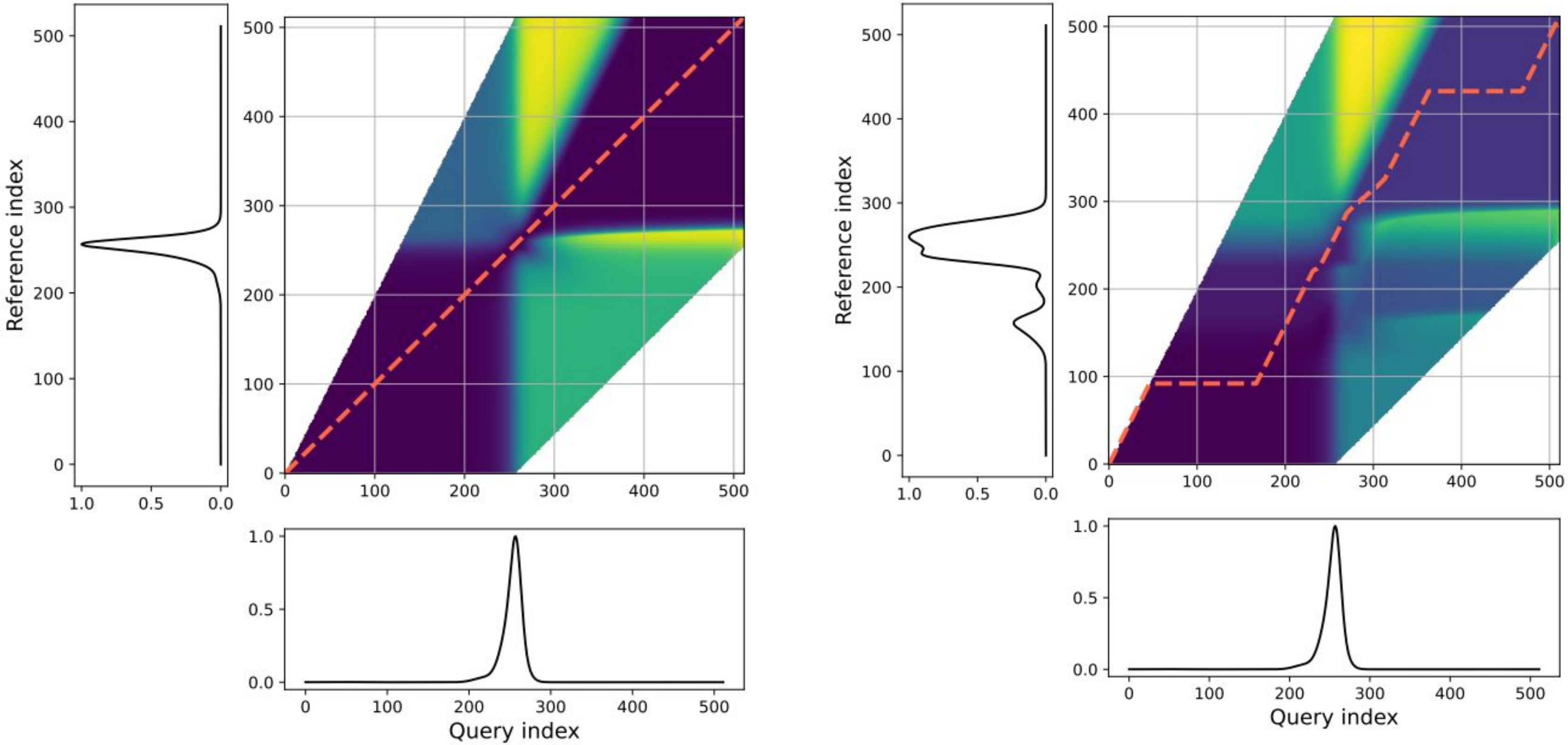
Graph Theory:
Defining Edges and Weights



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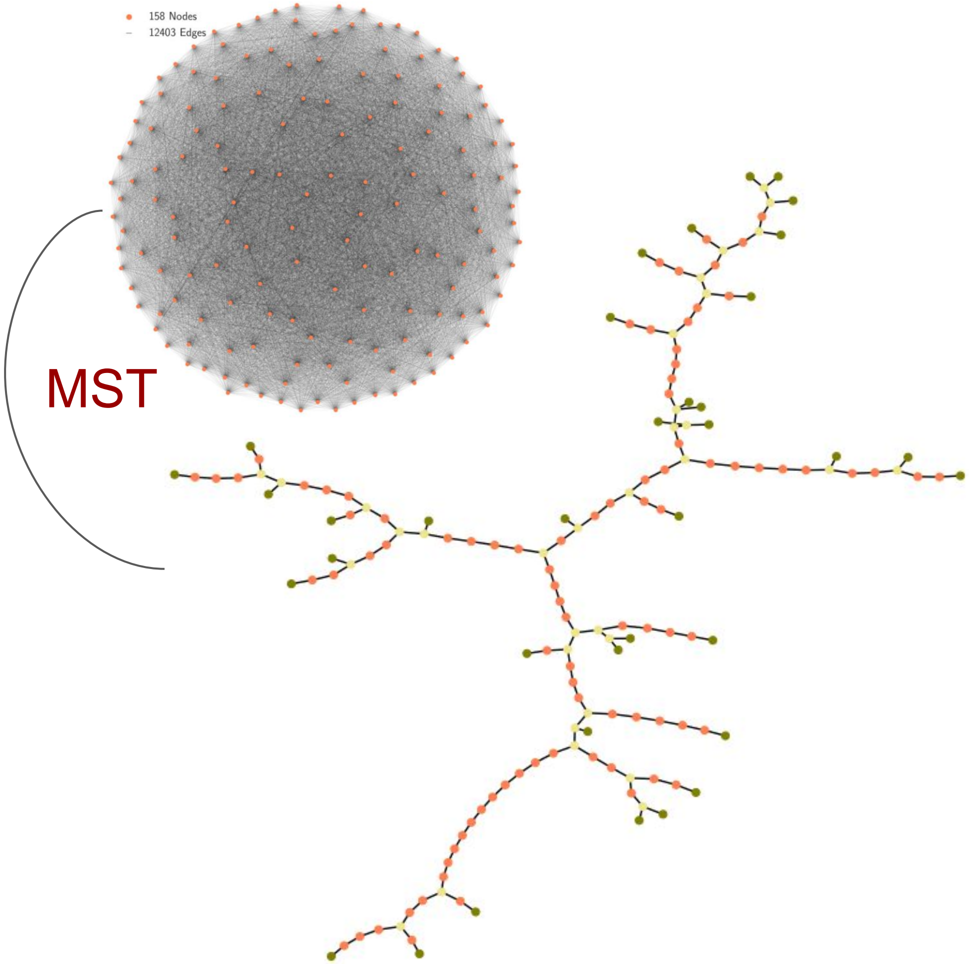
Graph Theory:
Minimum Spanning Tree (MST)

- **MST of a Graph:**
    - **T(V, E_T, W_T)** is a ***Subgraph*** of **G(V, E, W).**
    - **T** is the shortest possible path (with minimum weight) in the **G** such that include all the nodes of **G**
    - **T** is a ***path*** in **G** with ***no cycle*** (starting from a node and reach itself).
    - **MST** extracts ***cluster of vertices*** such that ***total distance between all nodes*** in the graph become ***minimum***.



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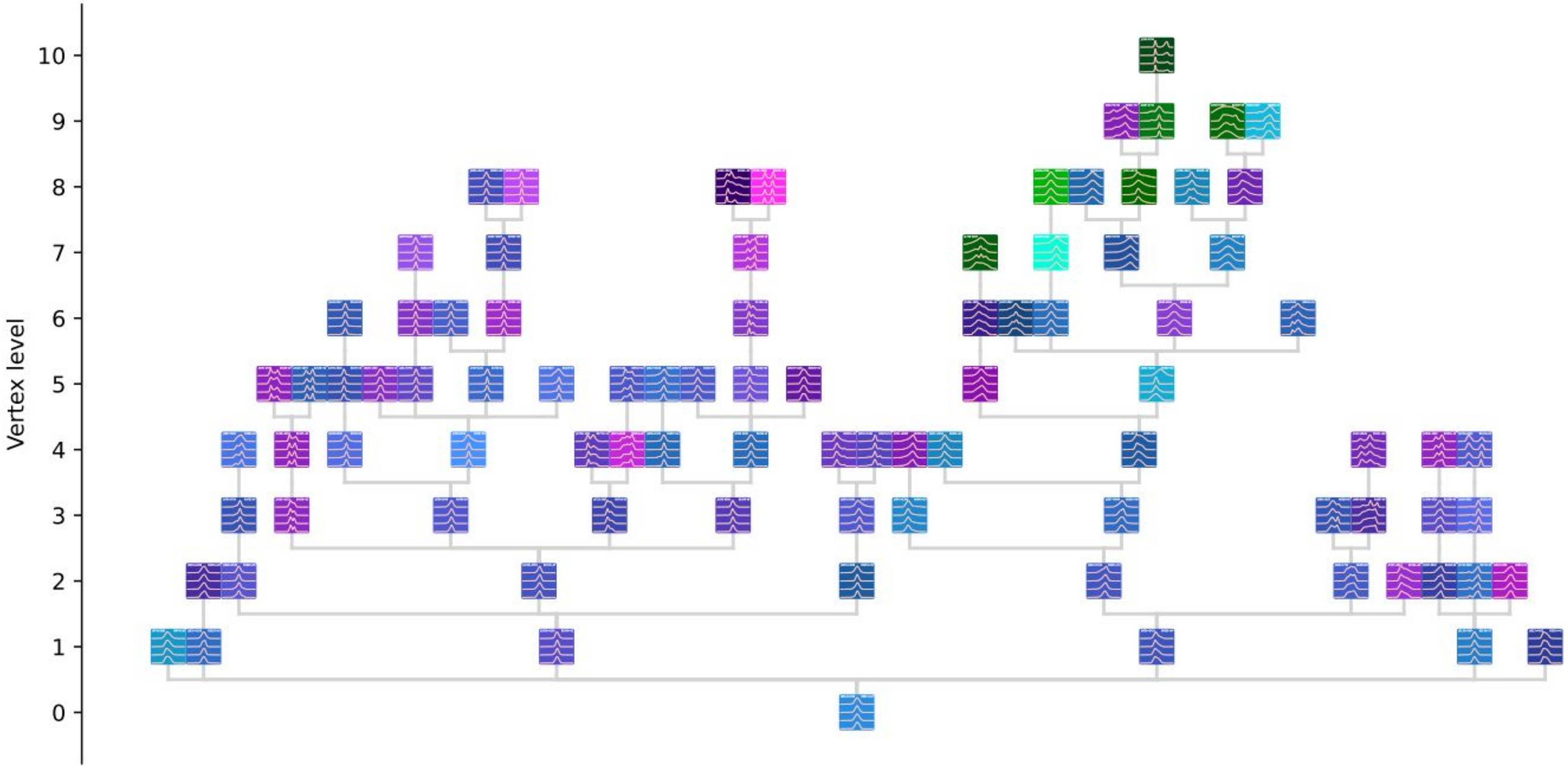
Graph Theory:
MST of Pulsars Based on Similiarity between their PPs



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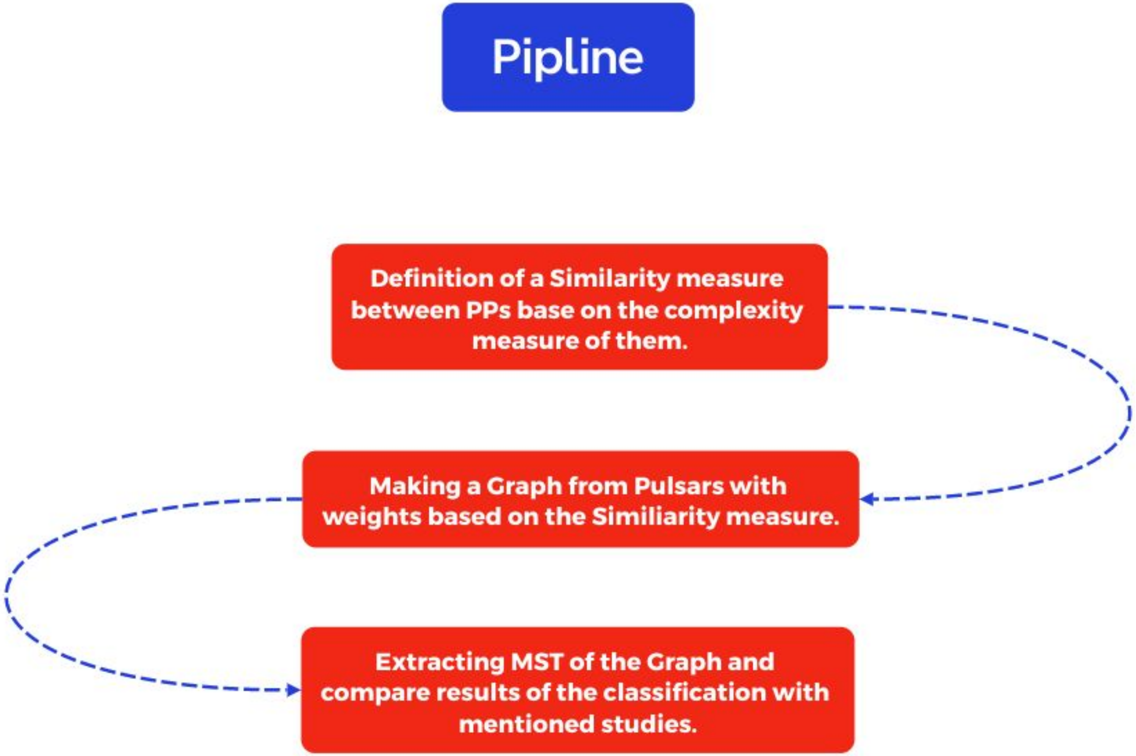
Part III:
The Conclusion

Conclusion



Pipline
Definition of a Similarity measure between PPs base on the complexity measure of them.
Making a Graph from Pulsars with weights based on the Similiarity measure.
Extracting MST of the Graph and compare results of the classification with mentioned studies.

Thanks for your attention.