PULSAR PROFILES FROM A GRAPH PERSPECTIVE

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ASTRON

IN COLLABORATION WITH
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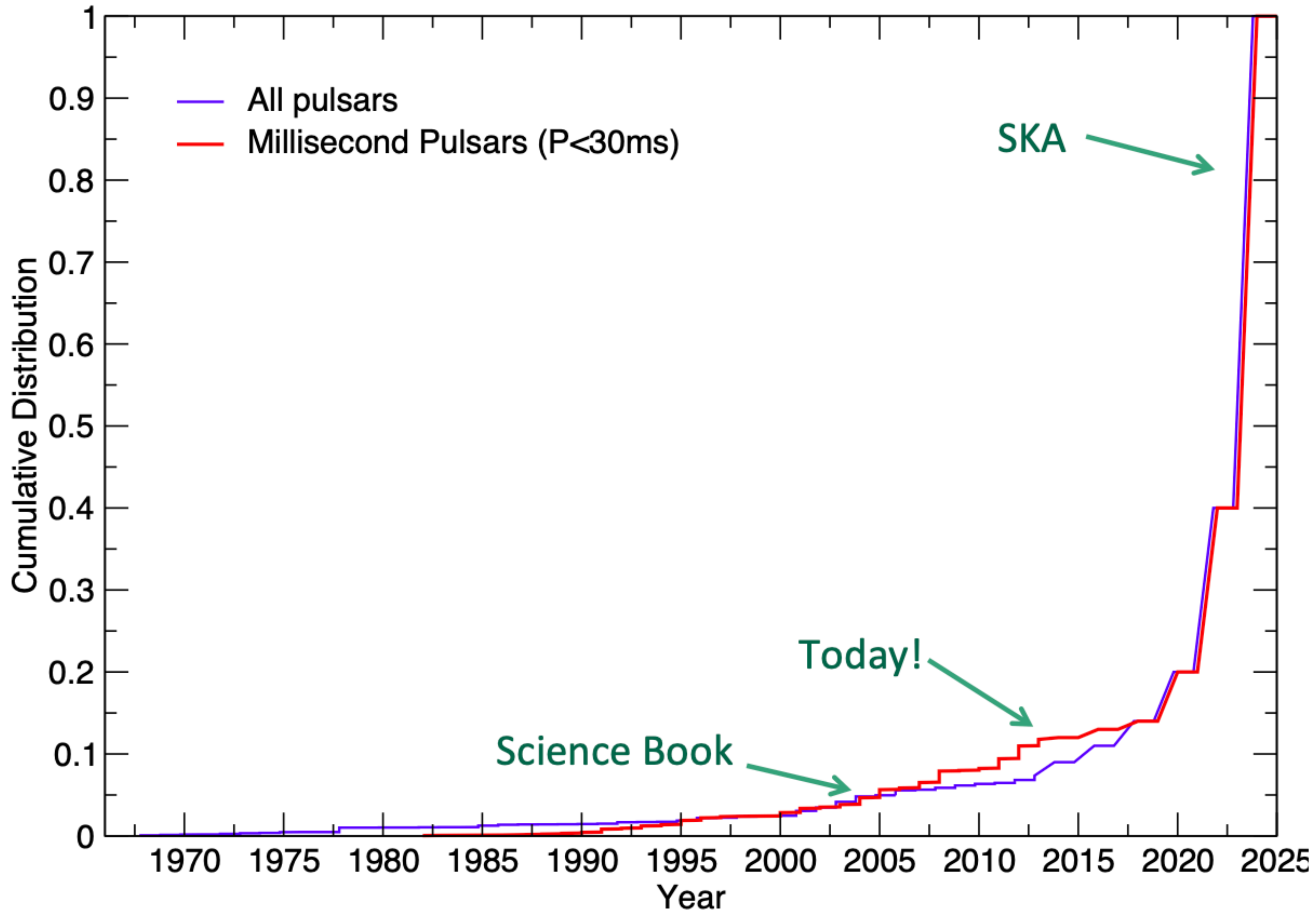
Pulsar science with the SKA

- Known population (~2,900) expected to increase with full SKA by more than 10-fold (good fraction expected during phase I)

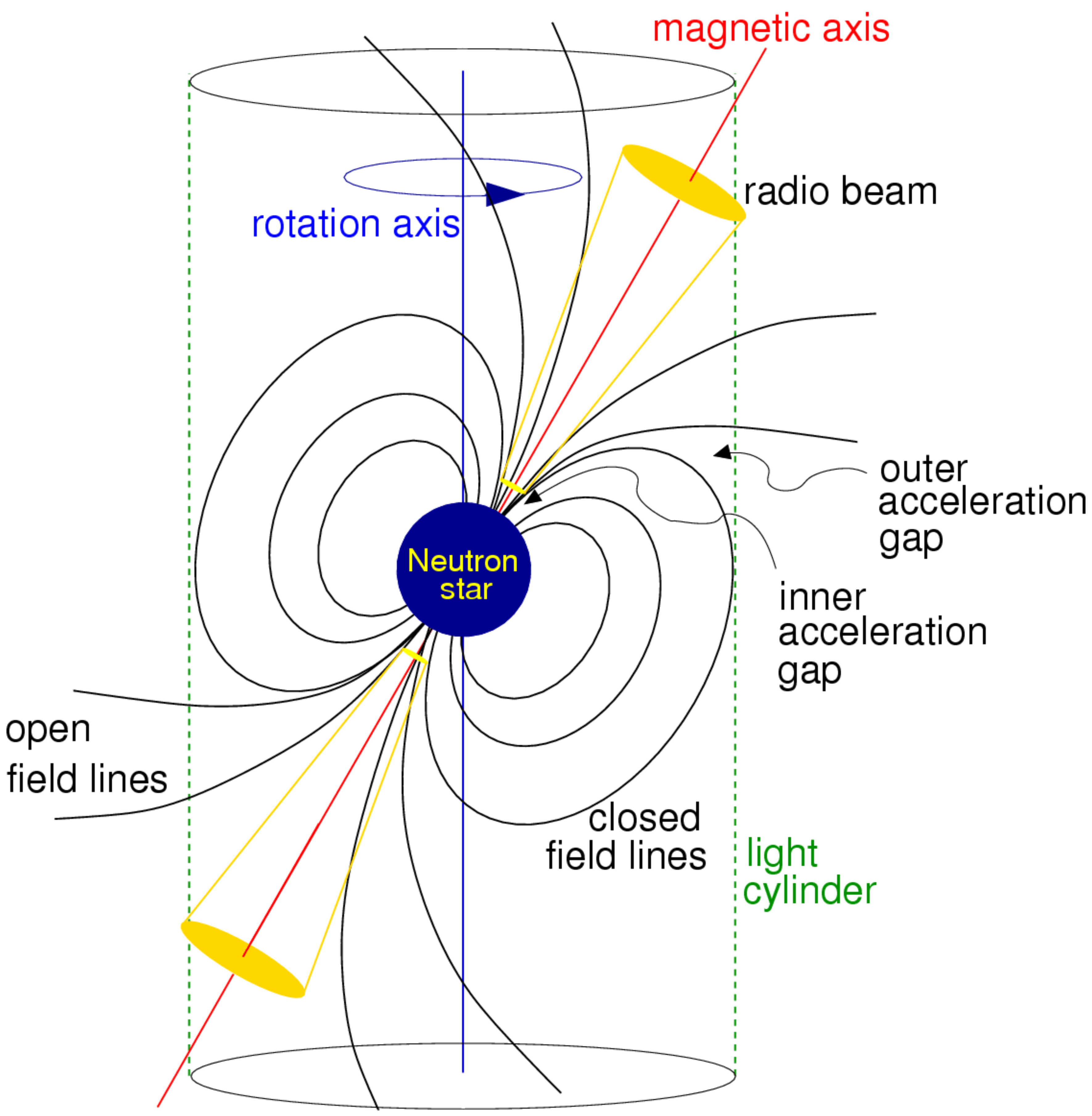
- Evaluate/develop automated methods requiring little to no human intervention

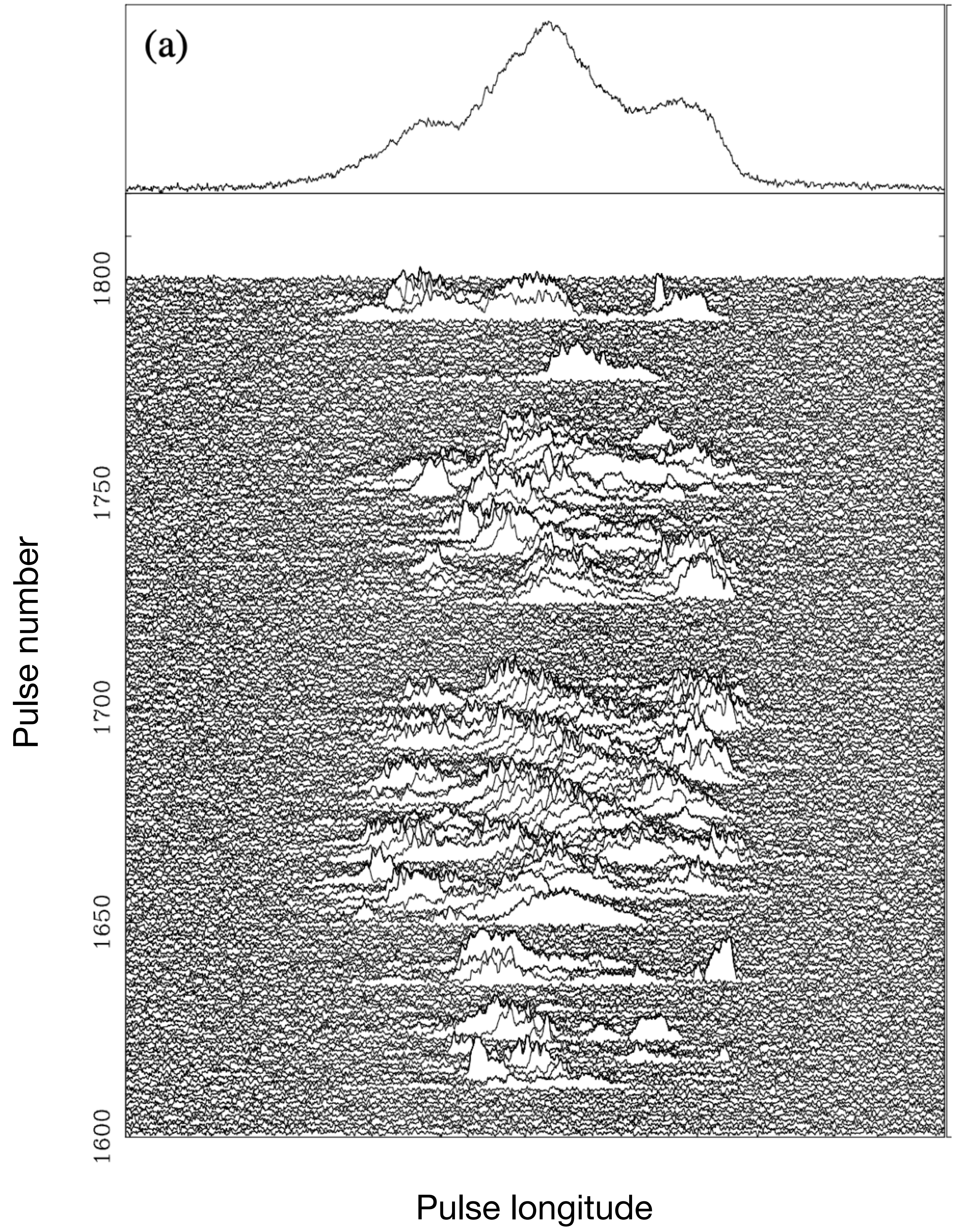
- Here, status of an on-going project to explore the task of automatically sequencing profiles



Kramer & Stappers (2015)

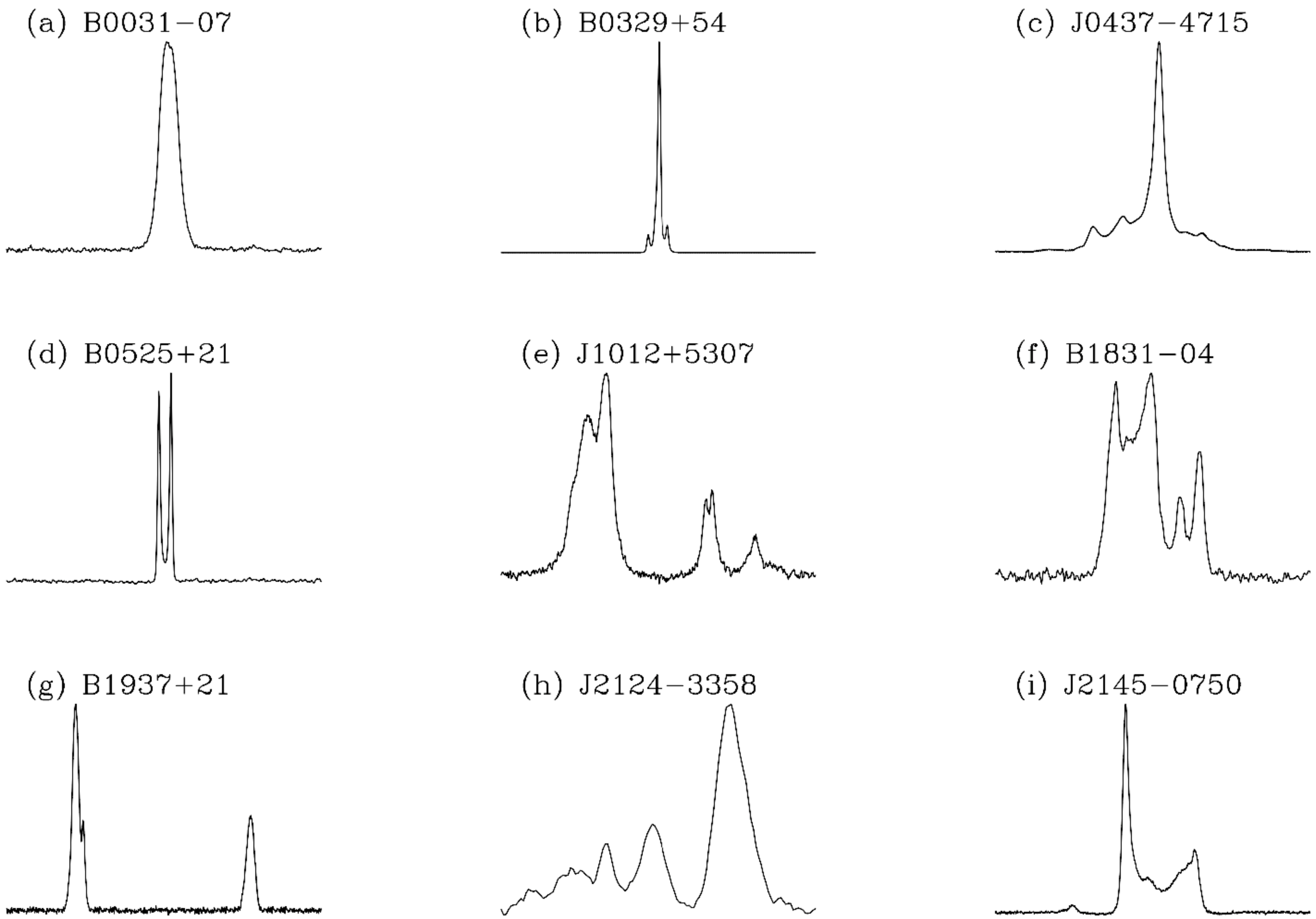
Pulsars & pulse profile



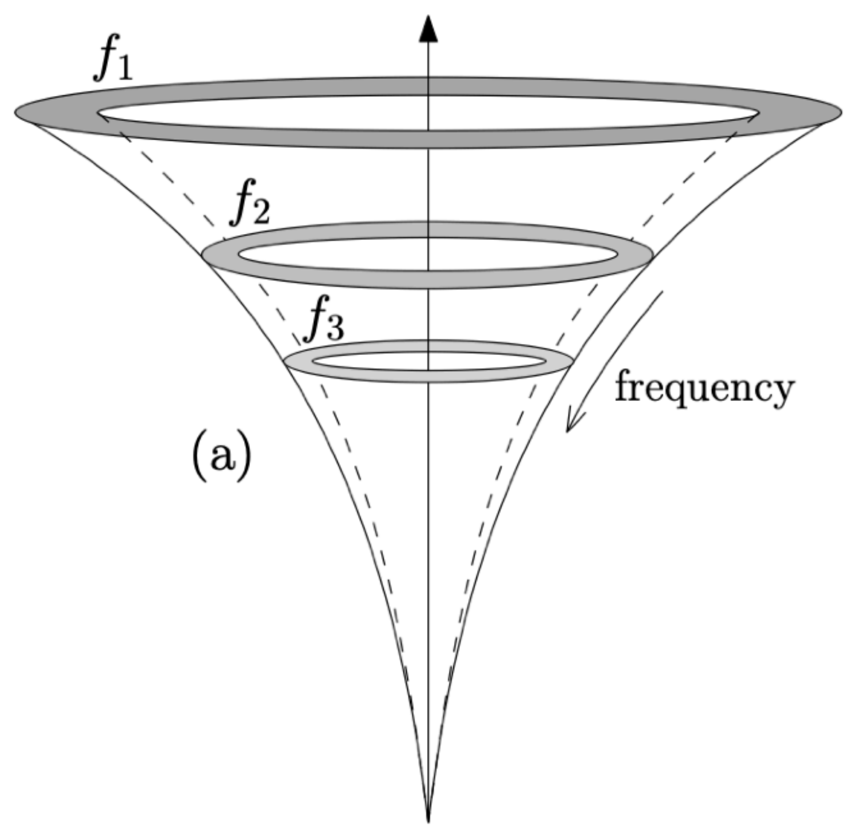


Lorimer & Kramer (2005)

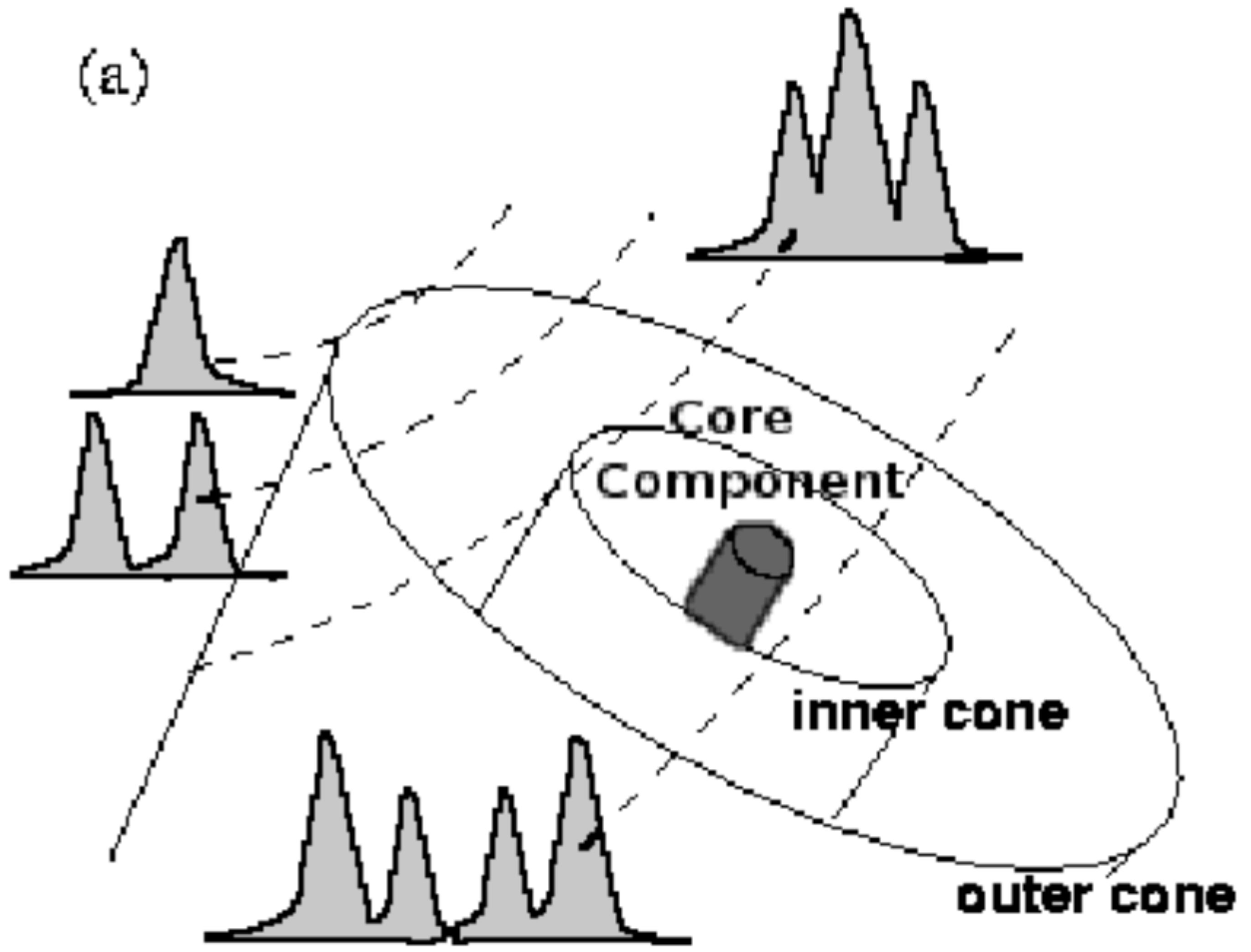
Profile, geometry & magnetosphere



Lorimer (2005)



Oswald *et al.* (2020)

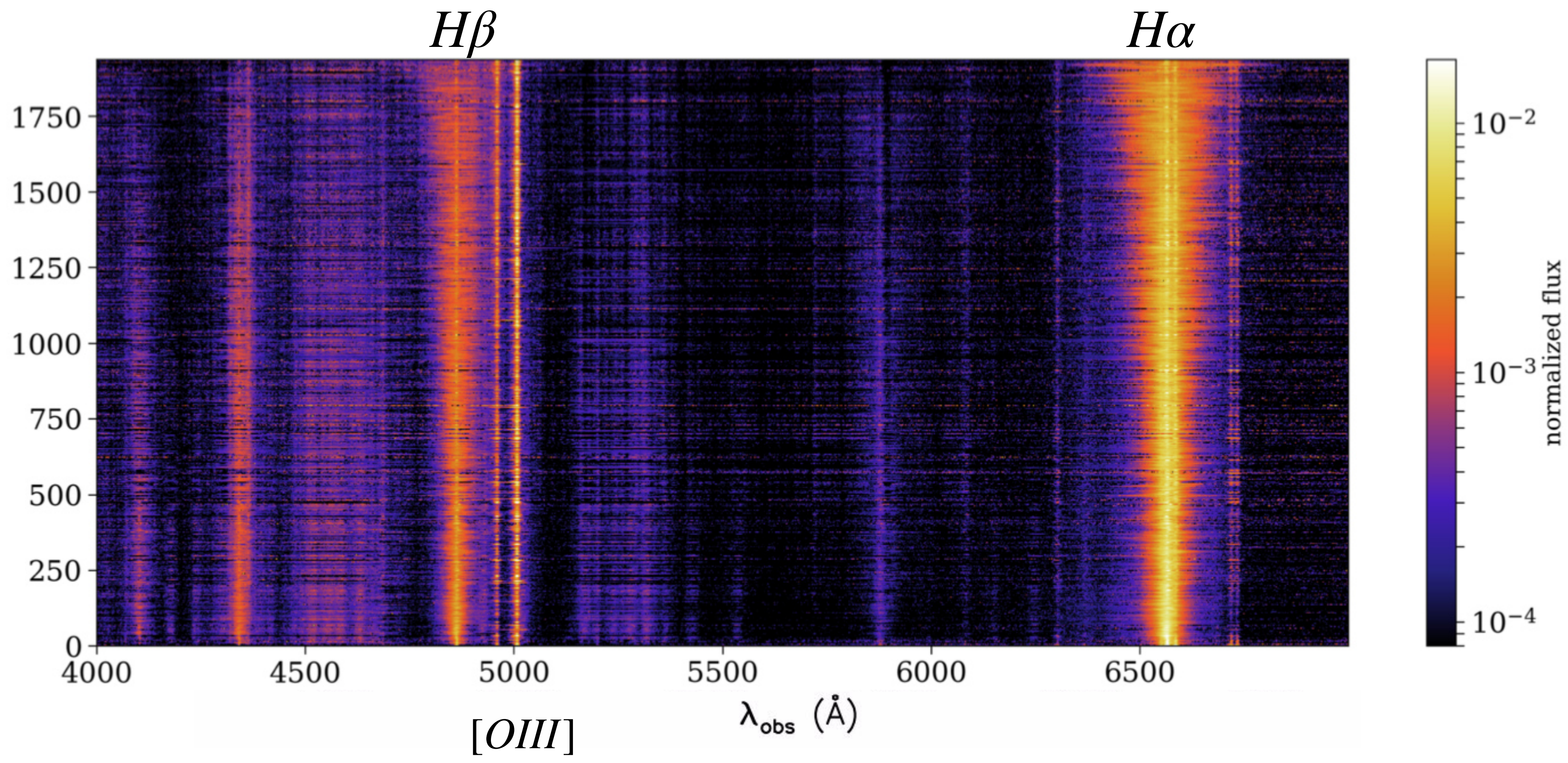


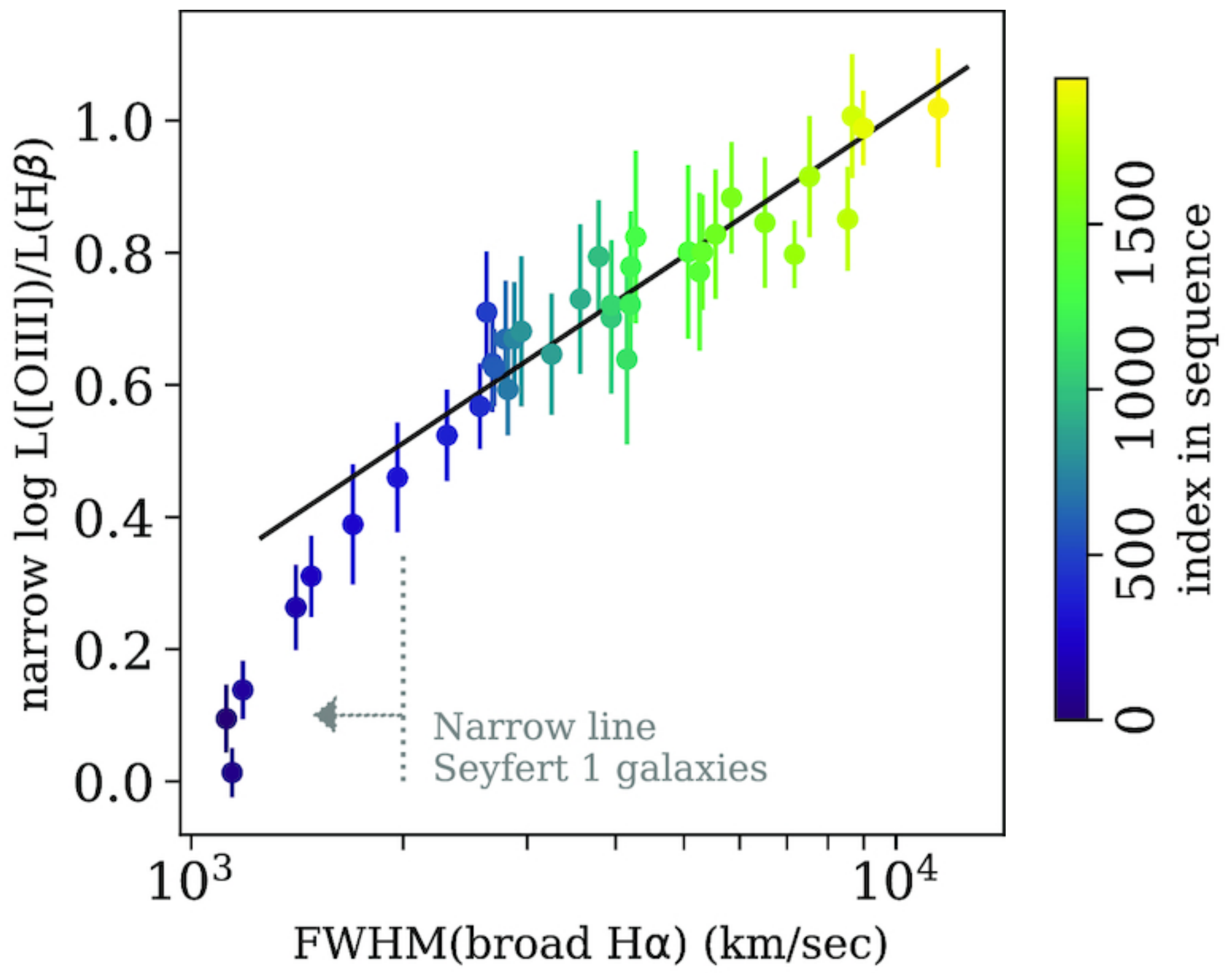
Lorimer & Kramer (2005)
modified by Maan (2014)

Rankin (1983)

Exploratory data analysis via Graph Theory

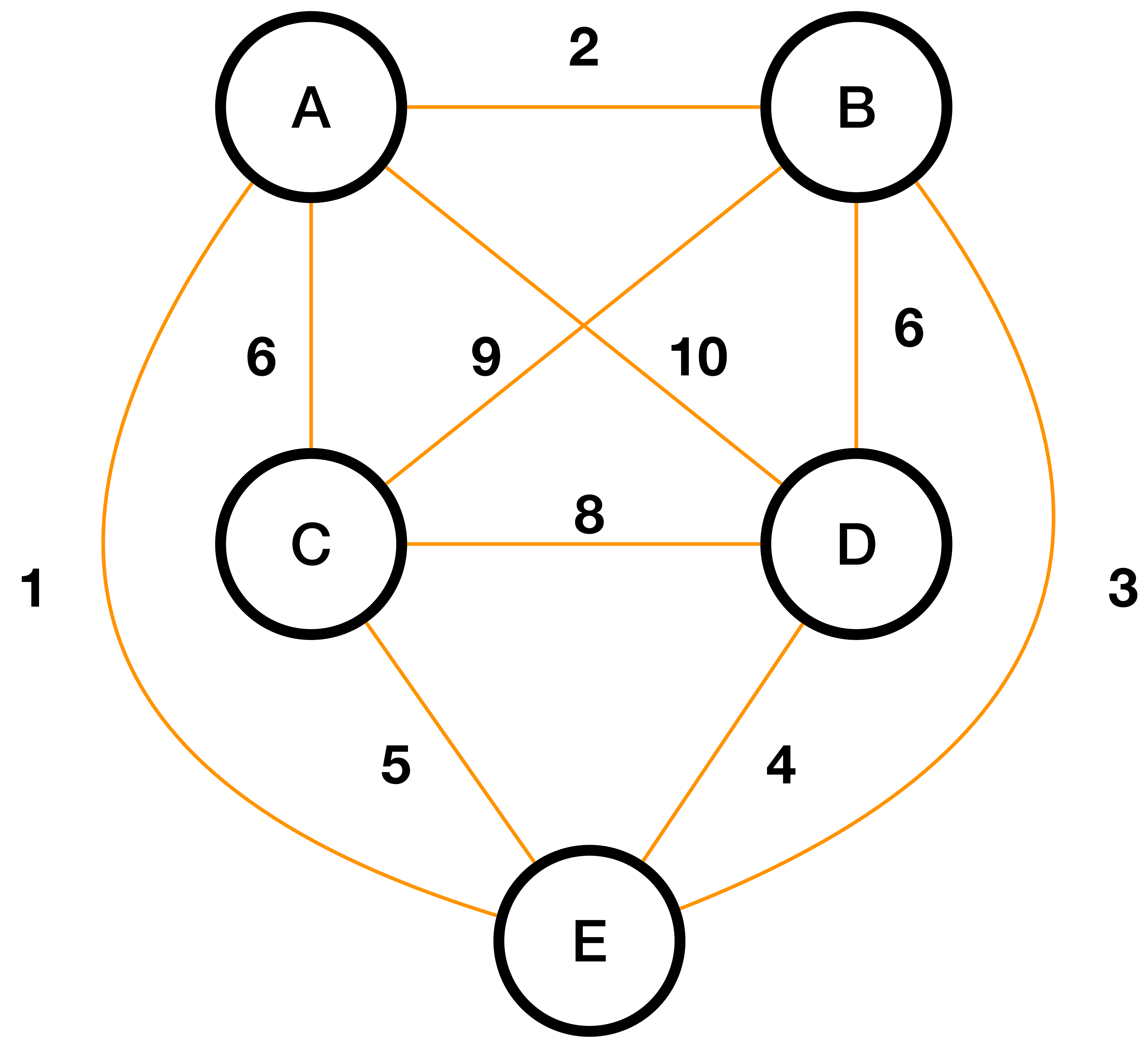
- Baron & Ménard (2019, 2020)
  - Sequencing 2000 AGN type I revealed unknown scaling relation between ionized gas and black hole mass
  - Scaling relation can be used to estimate black hole masses for Type II from narrow emission only
  - In a number of cases, outperforms dimensionality reduction techniques like t-SNE and UMAP





Data-driven approach via Graph Theory

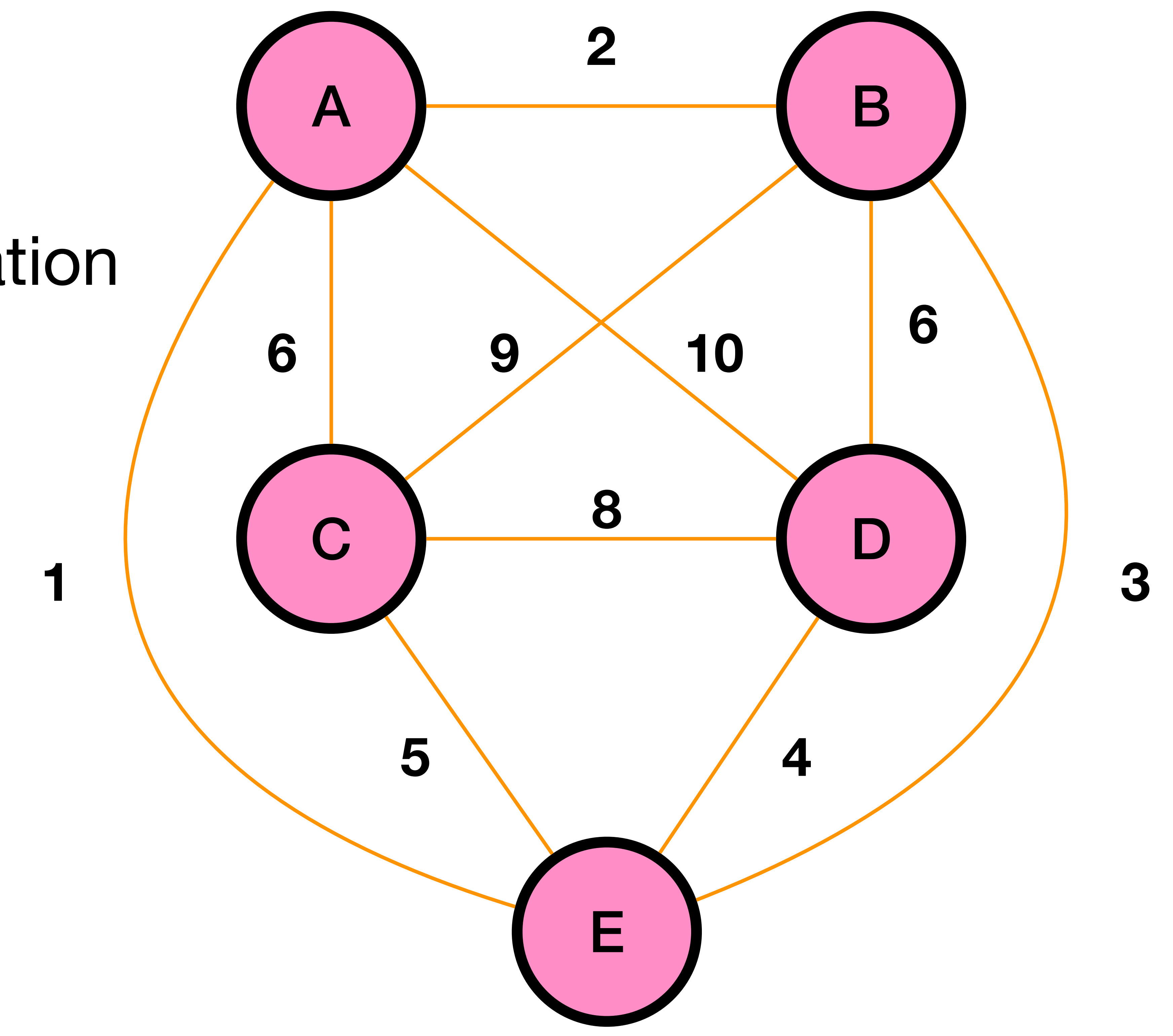
Complete (undirected) weighted graph



Data-driven approach via Graph Theory

Complete (undirected) weighted graph

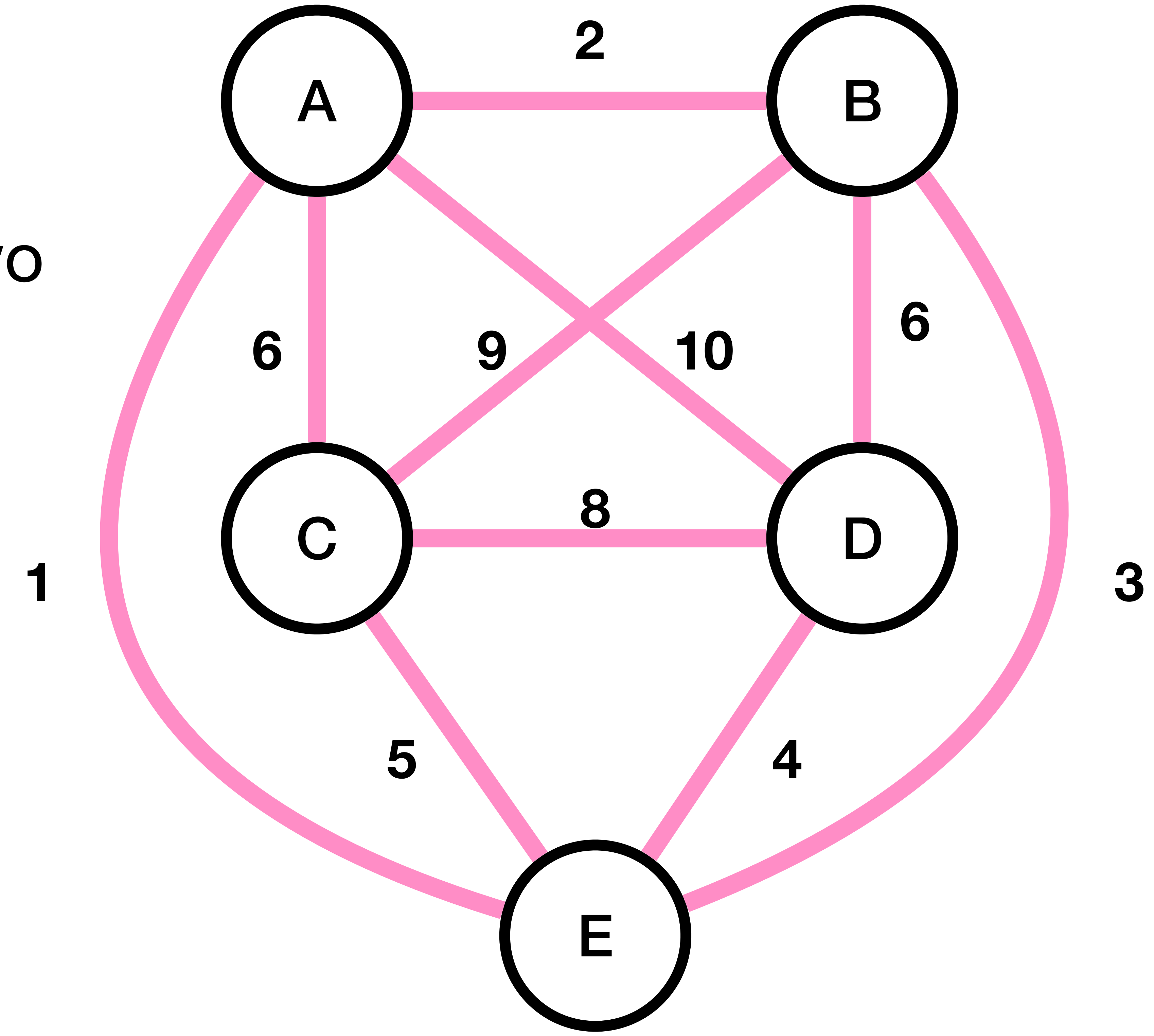
- **Vertices**
  - Represent pulsars
  - Set of vertices = Population



Data-driven approach via Graph Theory

Complete (undirected) weighted graph

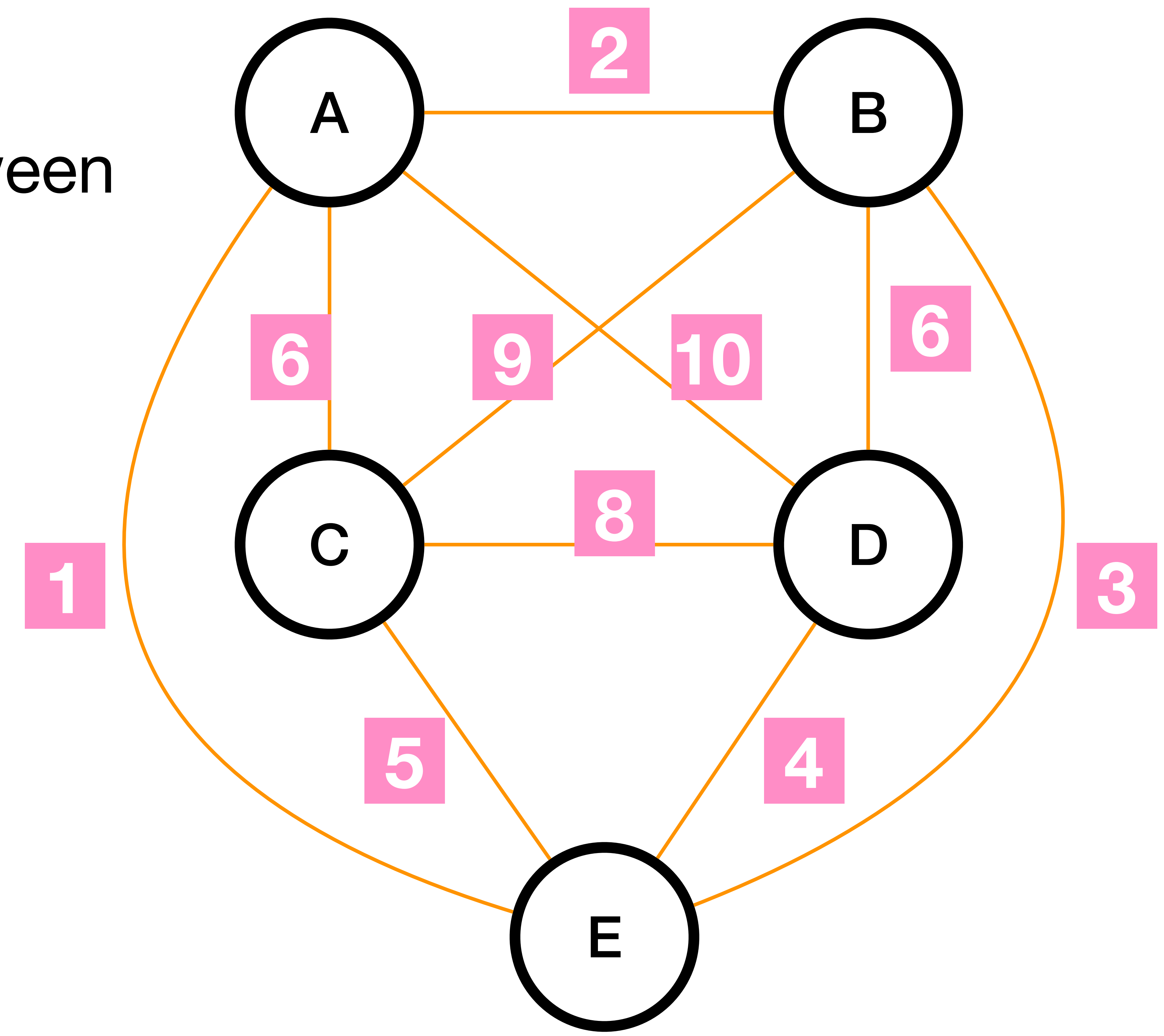
- **Edges**
  - Represent connection
  - Comparison between two pulsars



Data-driven approach via Graph Theory

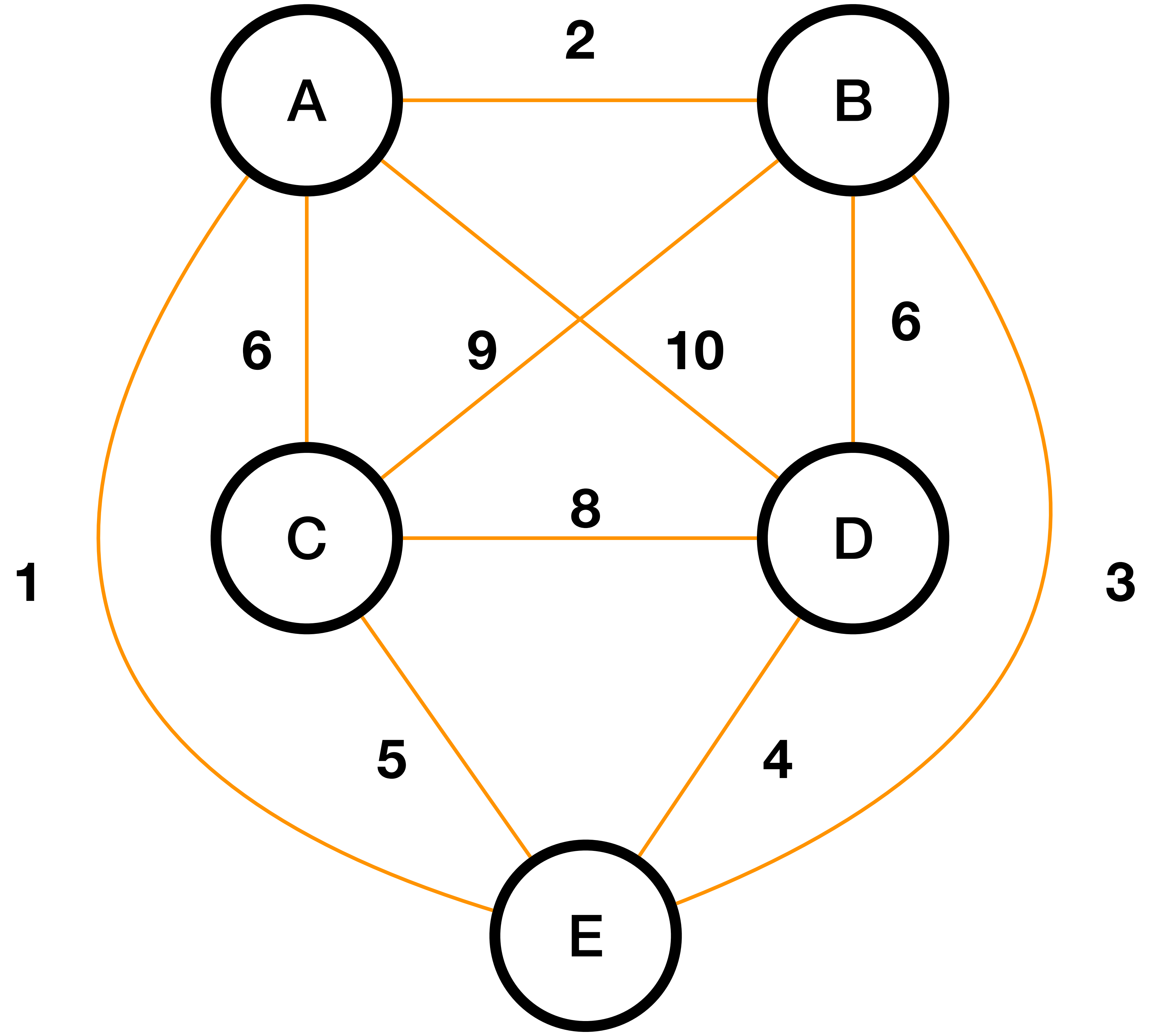
Complete (undirected) weighted graph

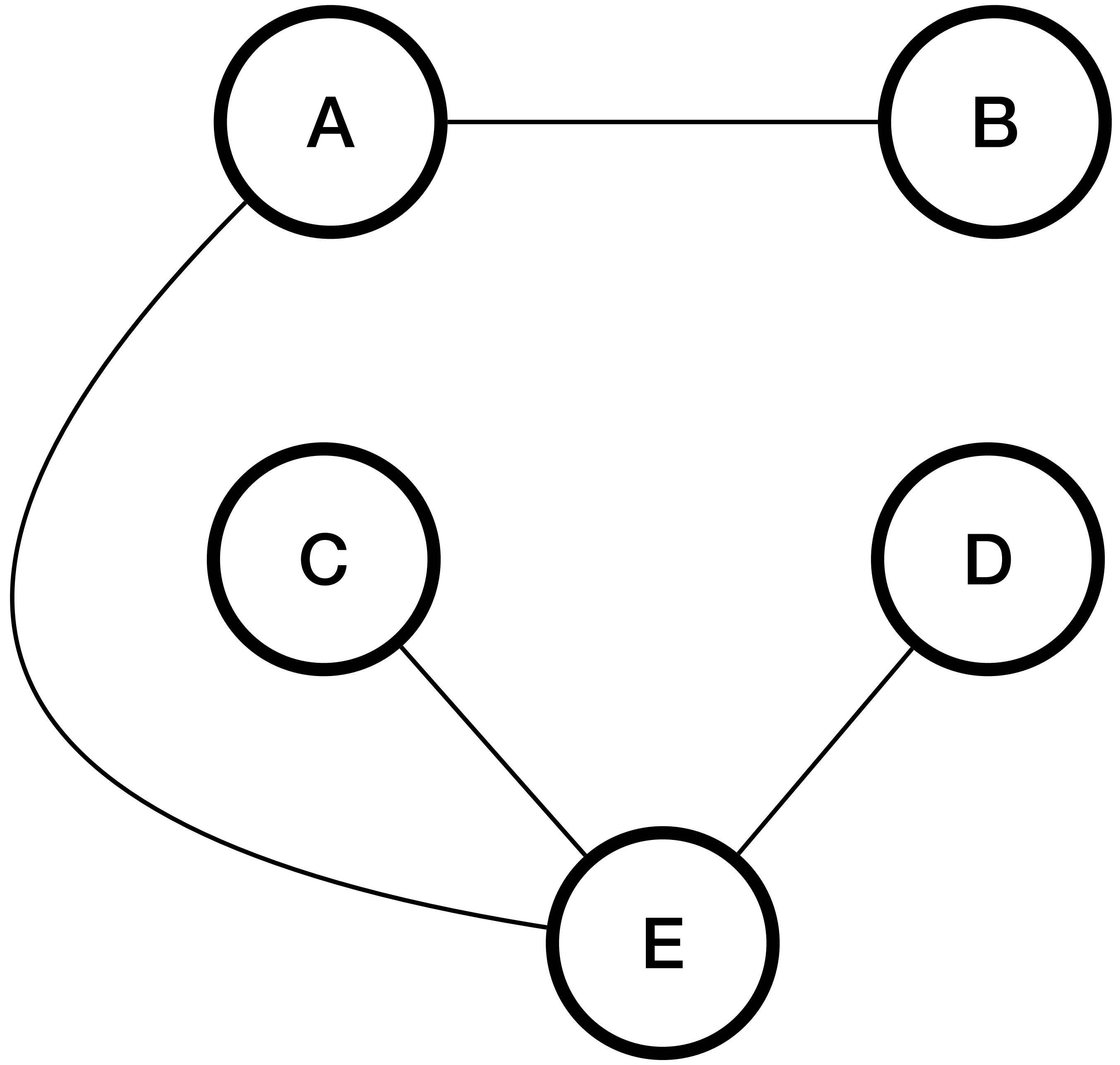
- **Weights**
  - Similarity/distance between pulsar pairs
  - Need to define what to measure as distance



Data-driven approach via Graph Theory

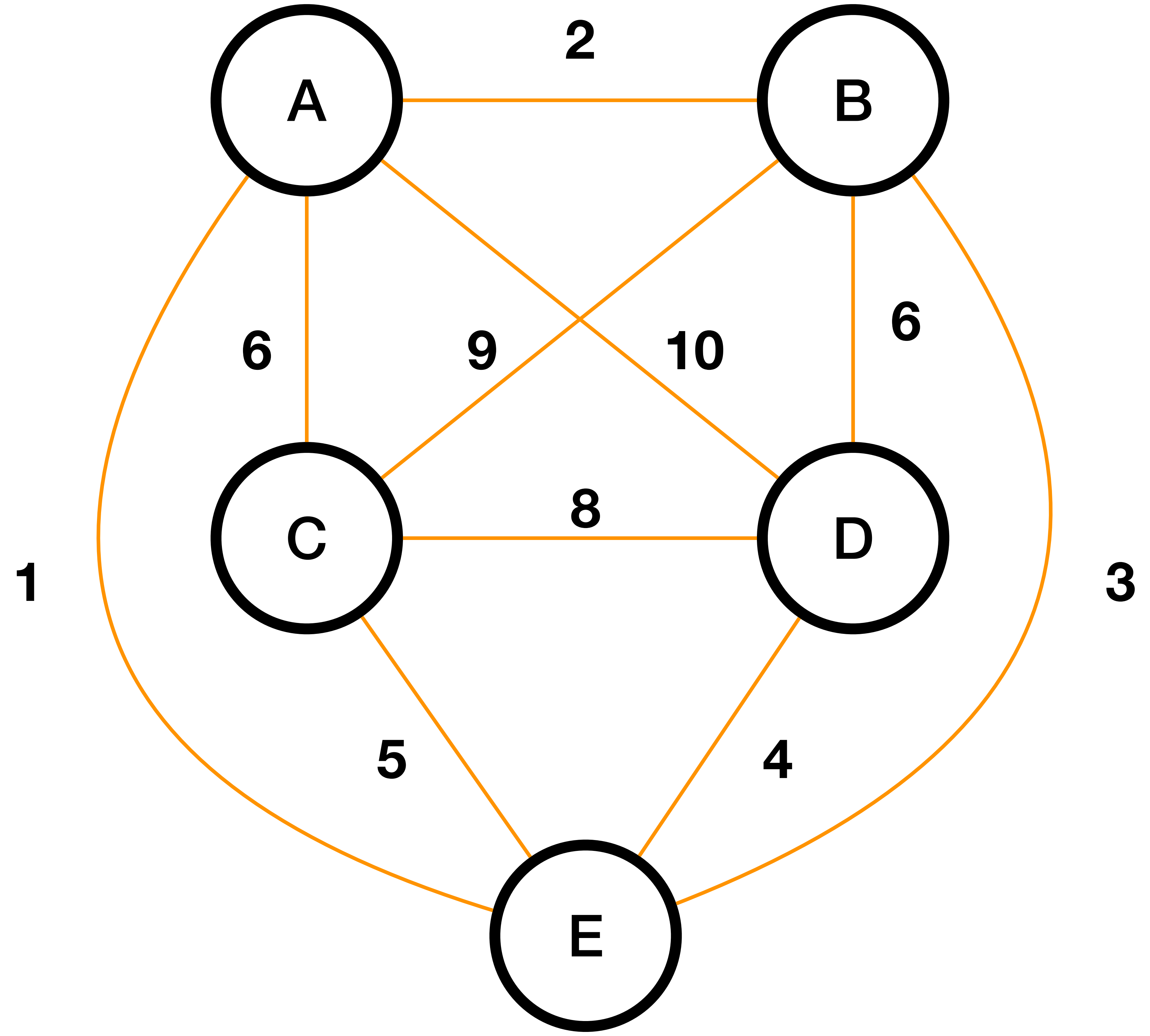
Solution space minimization: Minimum Spanning Tree

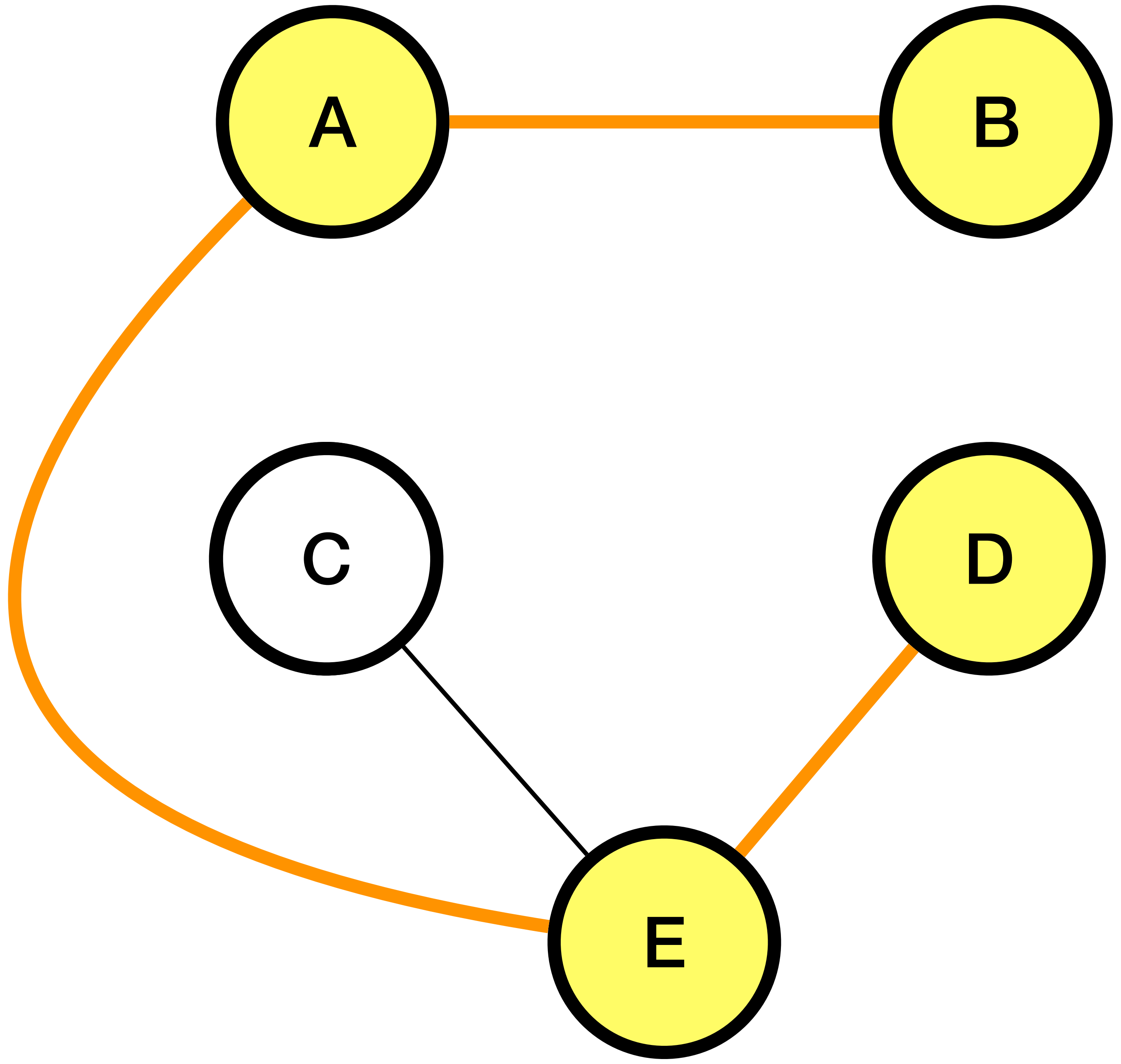




Data-driven approach via Graph Theory

Trends: longest manifold





Experiment

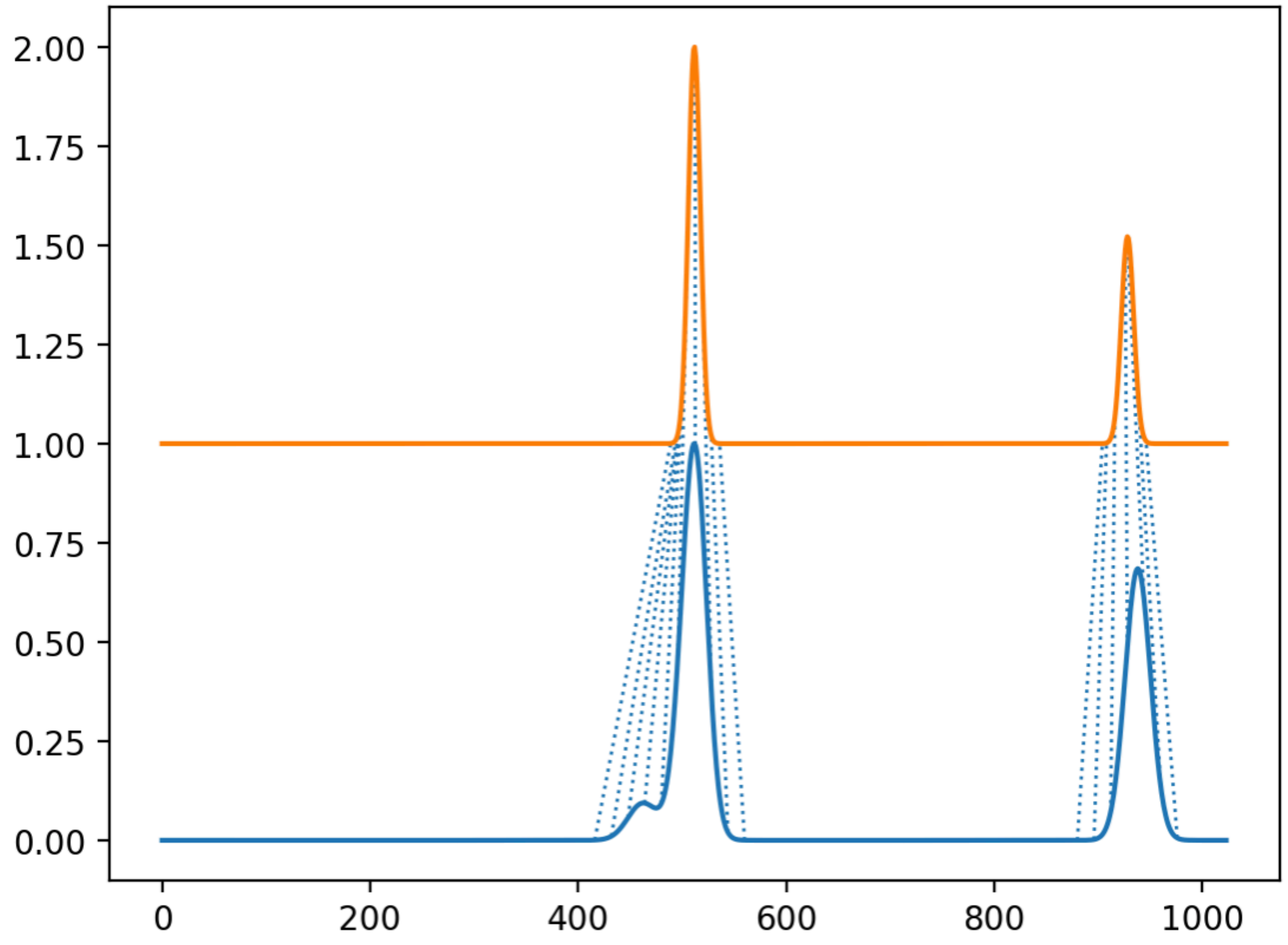
- **EPN database**
  - Heterogeneous (sampling, S/N, …)
    - 840 pulsars, 2458 profiles, 77 references

- **Subset of 79 pulsars**
  - S/N > 20
  - IQUV
  - 4 Frequency bins (MHz)
    - [400,700)
    - [700,1000)
    - [1000,1500)
    - [1500, 2000)

Special thanks to Michael Keith for help with accessing EPN database

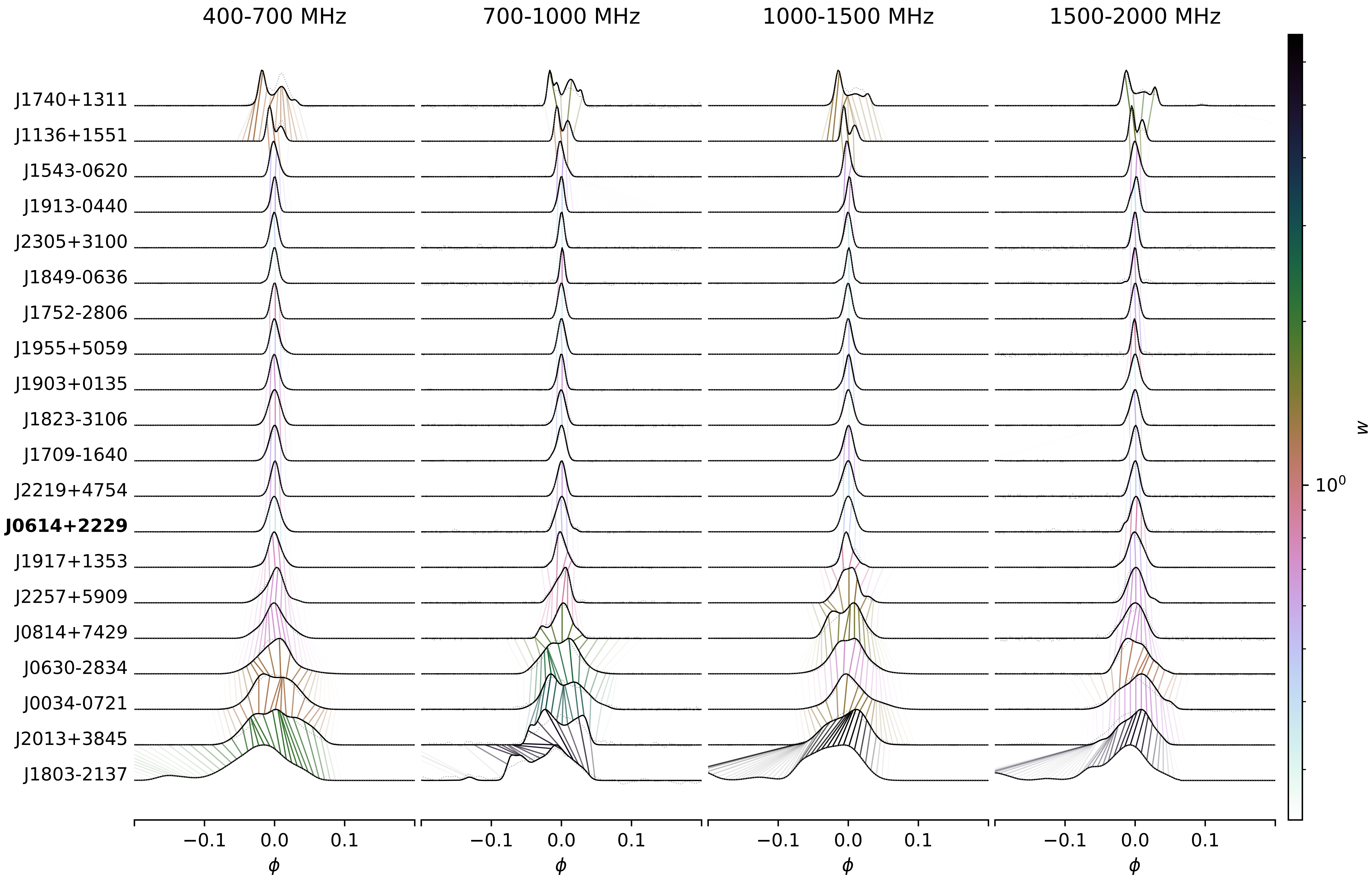
Distance metric

- **Dynamic Time Warp**
- Compare profiles from 2 pulsars (Stokes I) at a given frequency bin
- Average distances from 4 bins
- (Not yet considering polarization)

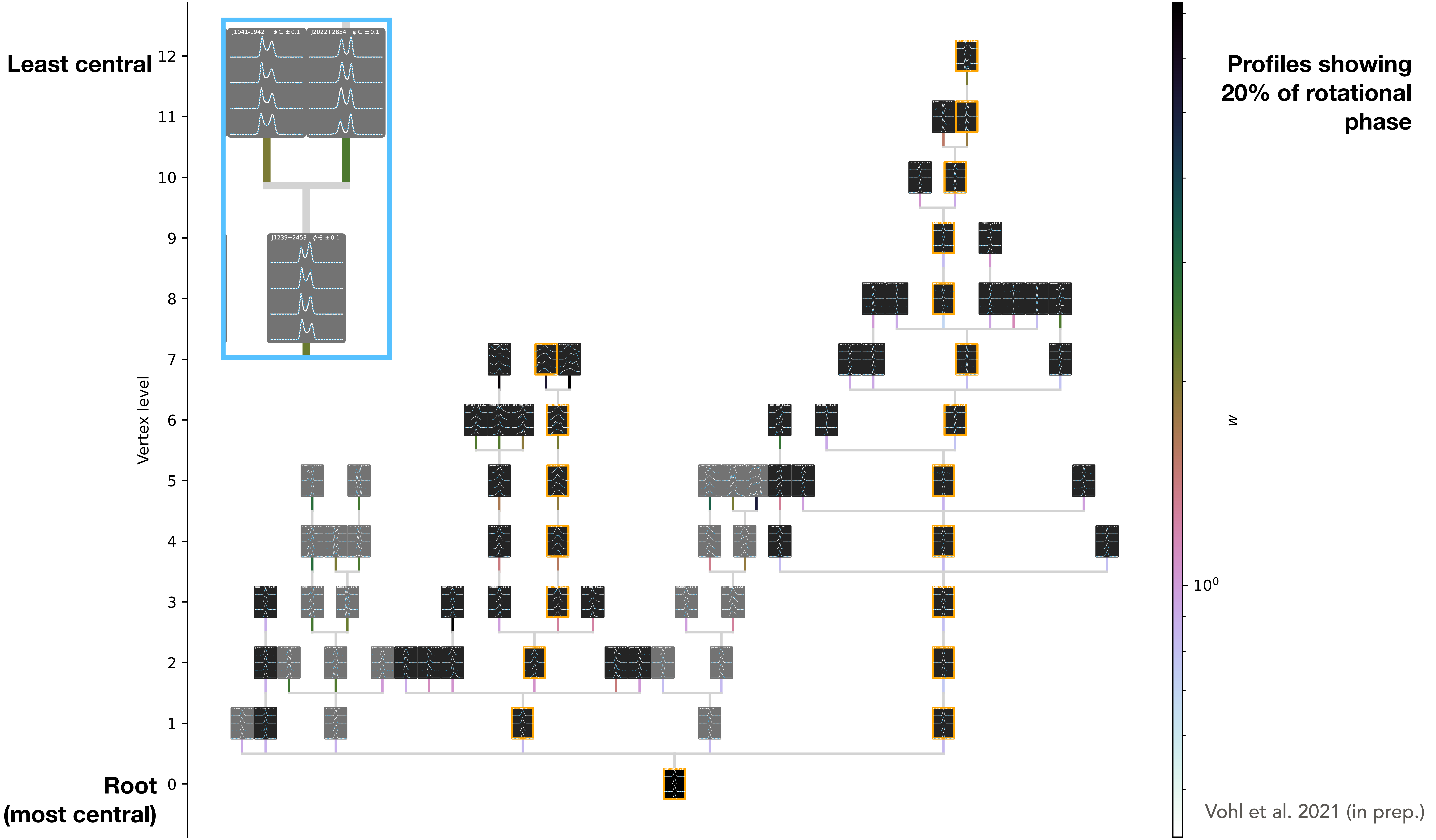


Longest sequence

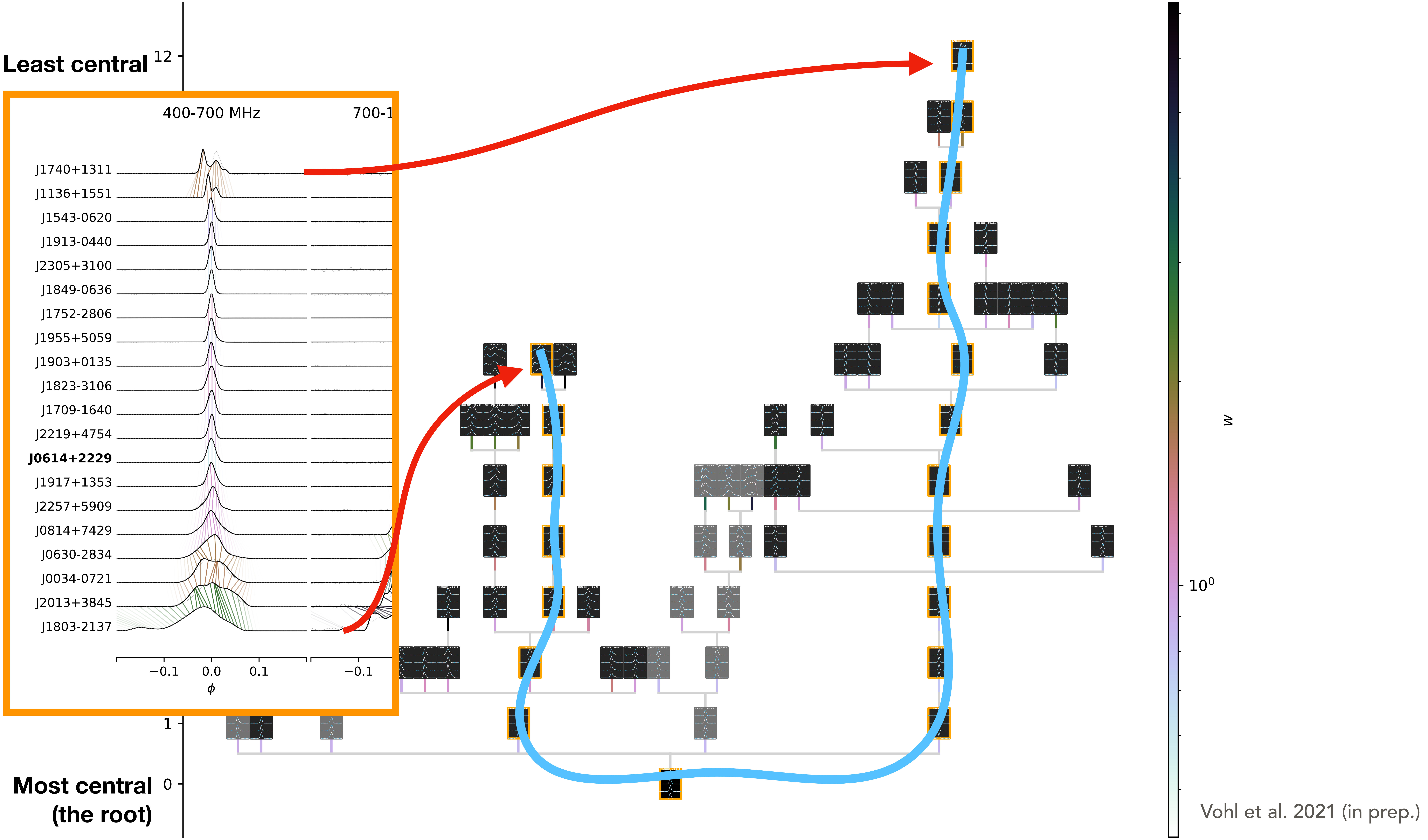
- Shape evolution
- Short sequence relative to |V| (20 out of 79)
- Sign of multi-class?

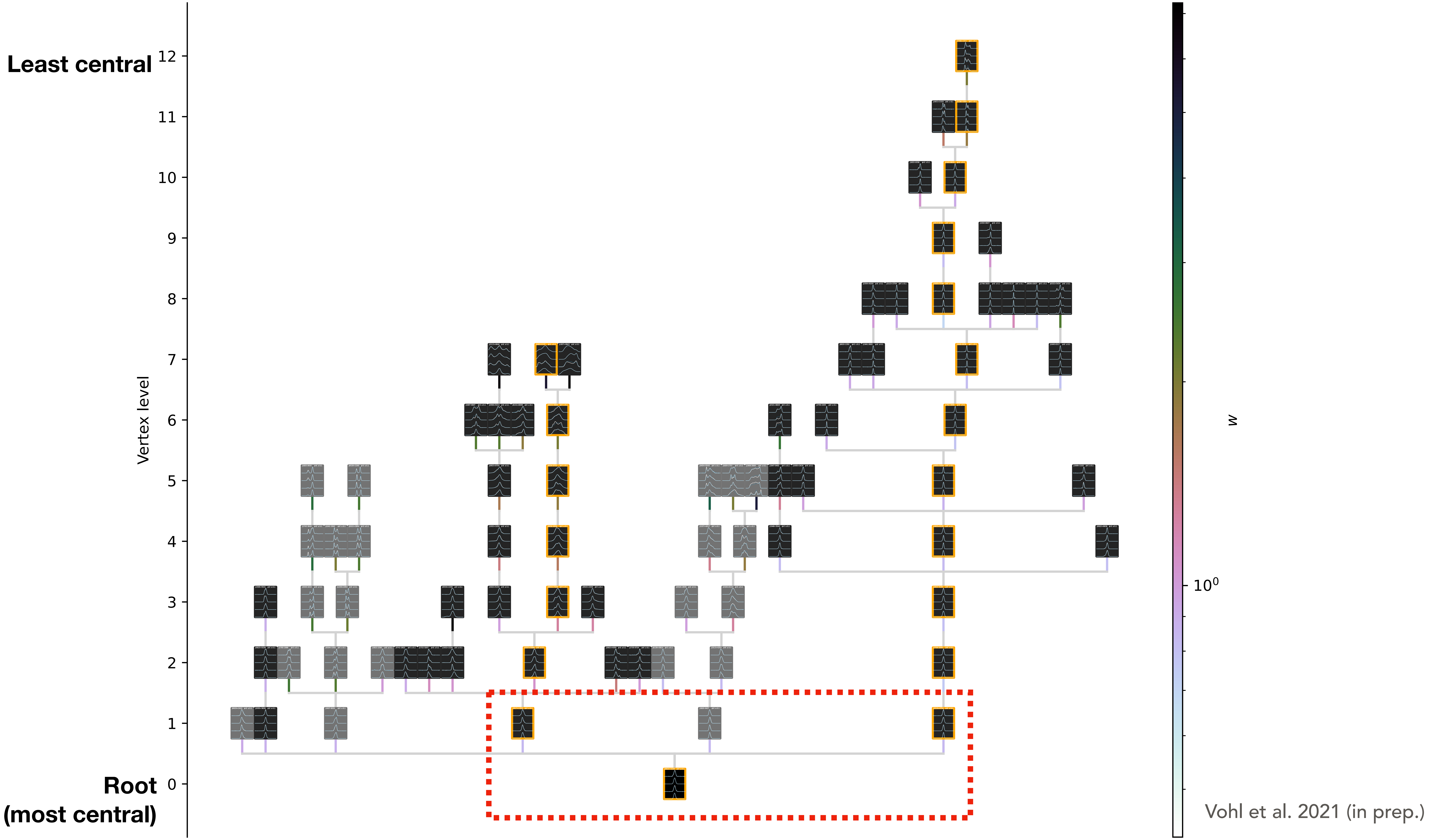


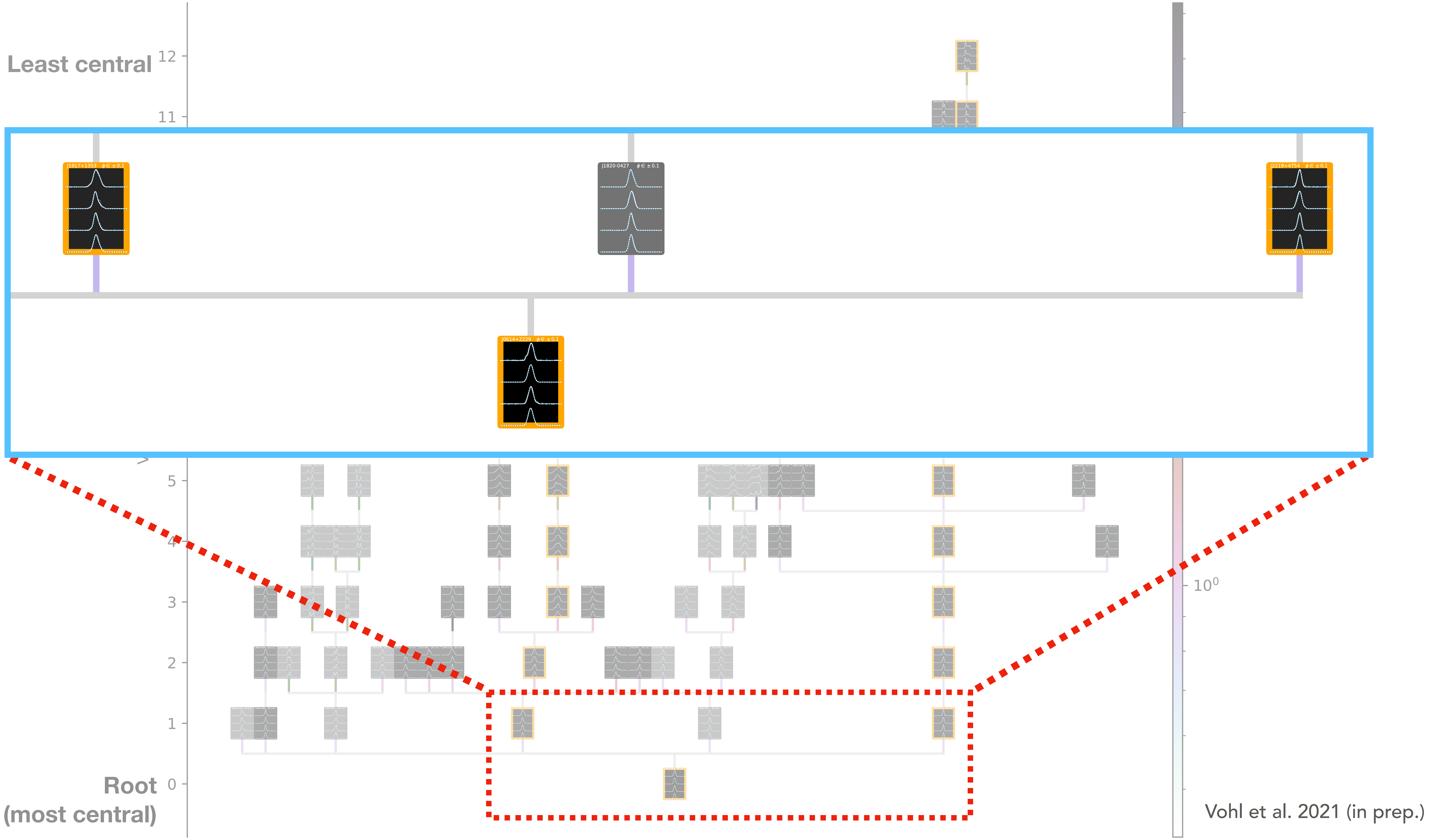
Vohl et al. 2021 (in prep.)



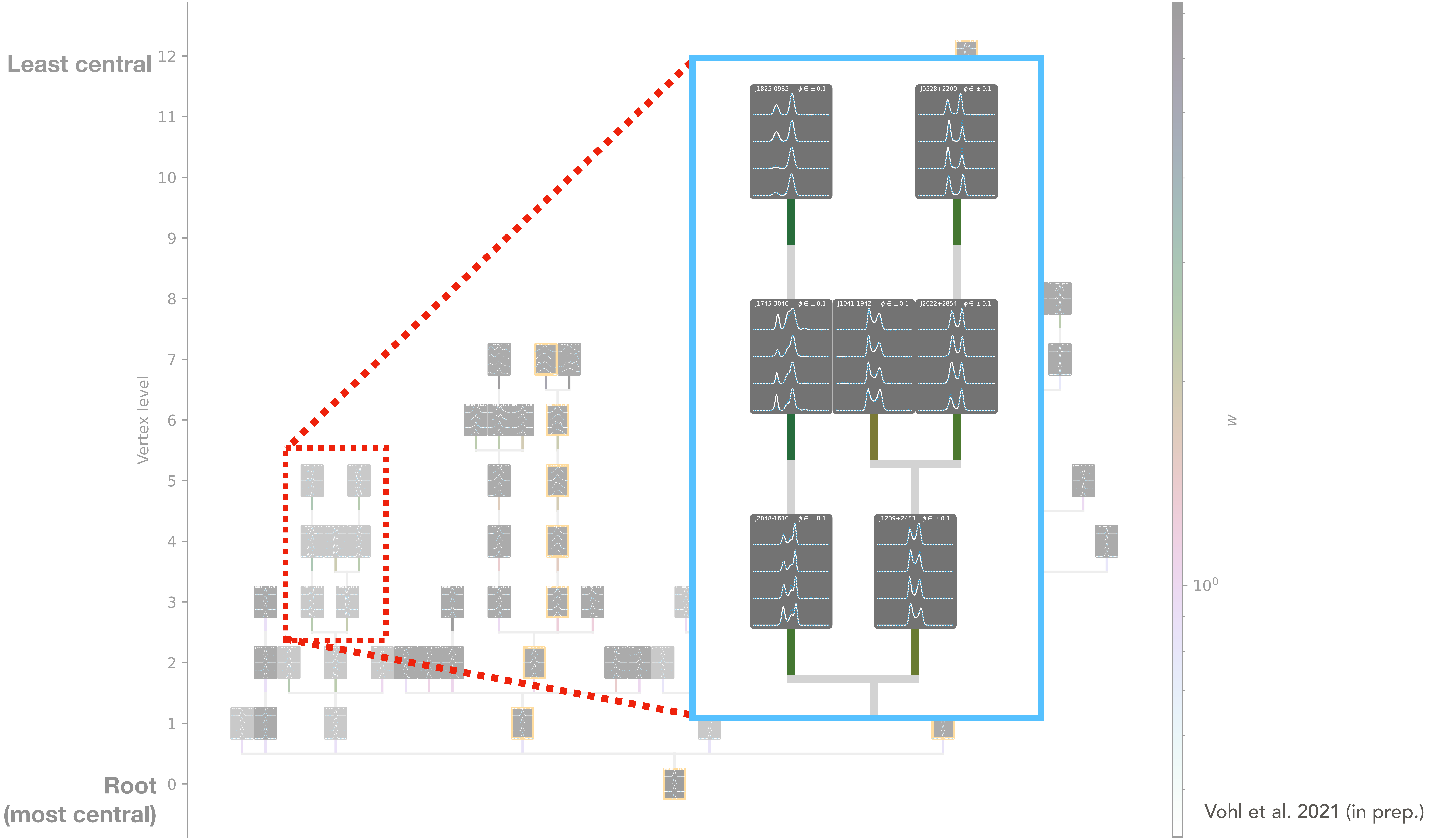
Least central
Root
(most central)
Vertex level
J1041-1942 $\phi \in \pm 0.1$
J2022+2854 $\phi \in \pm 0.1$
J1239+2453 $\phi \in \pm 0.1$
Profiles showing 20% of rotational phase
w
10^0
Vohl et al. 2021 (in prep.)

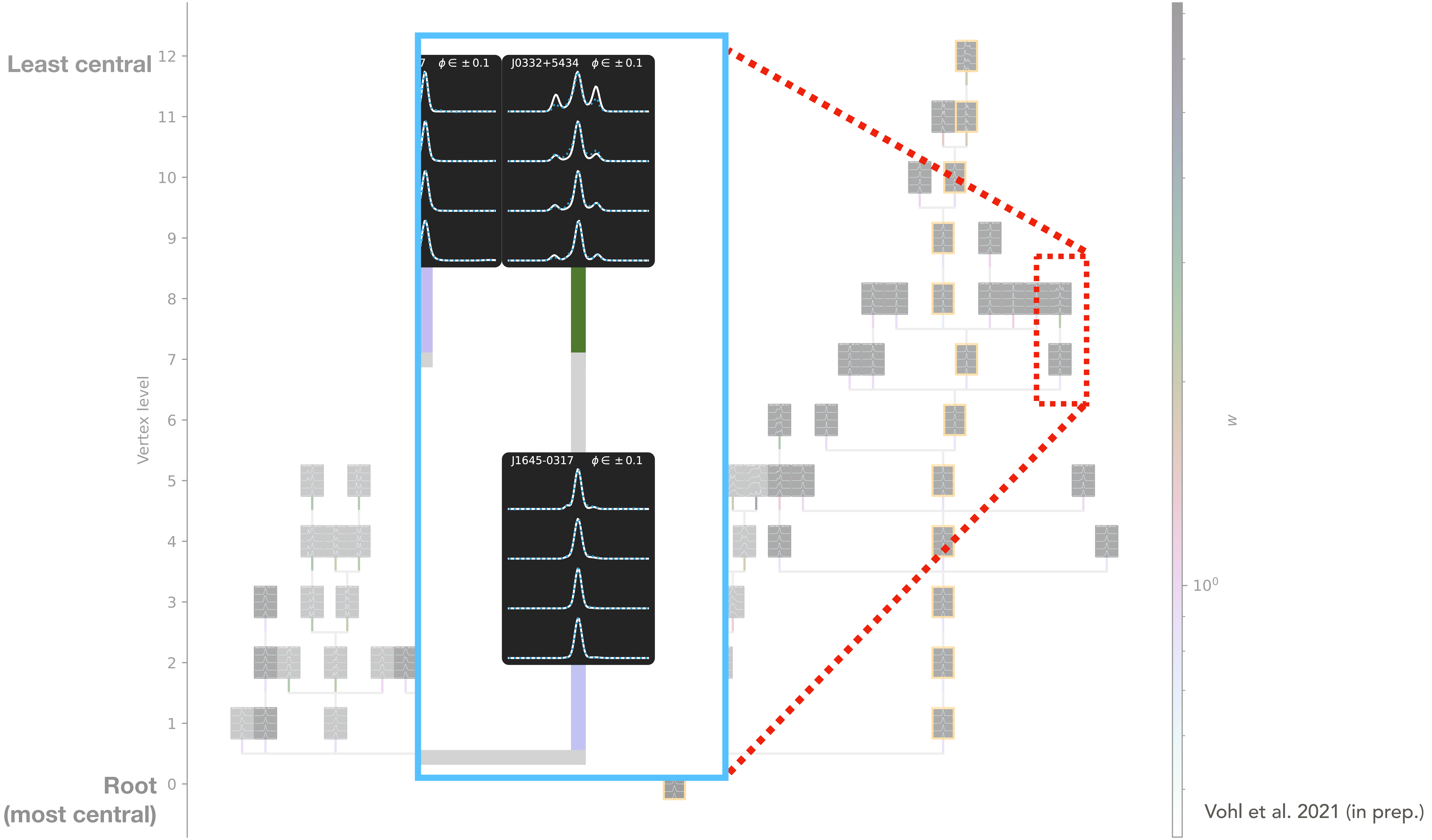

Least central
Most central
(the root)
400-700 MHz
700-1
J1740+1311
J1136+1551
J1543-0620
J1913-0440
J2305+3100
J1849-0636
J1752-2806
J1955+5059
J1903+0135
J1823-3106
J1709-1640
J2219+4754
J0614+2229
J1917+1353
J2257+5909
J0814+7429
J0630-2834
J0034-0721
J2013+3845
J1803-2137
−0.1
0.0
0.1
−0.1
ϕ
12
1
0
w
10^0
Vohl et al. 2021 (in prep.)


Least central
Root
(most central)
Vertex level
0
1
2
3
4
5
6
7
8
9
10
11
12
w
10^0
Vohl et al. 2021 (in prep.)

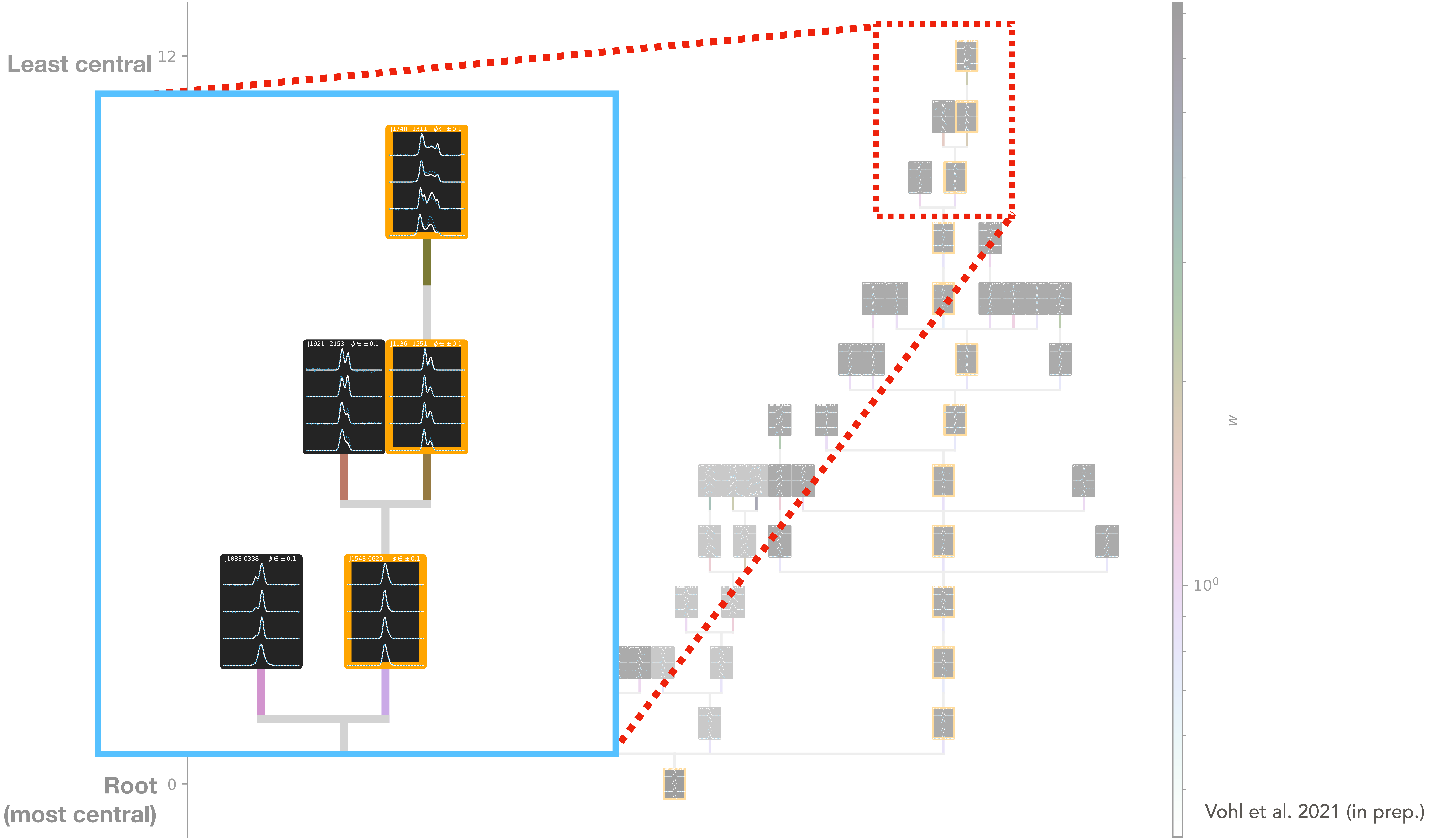


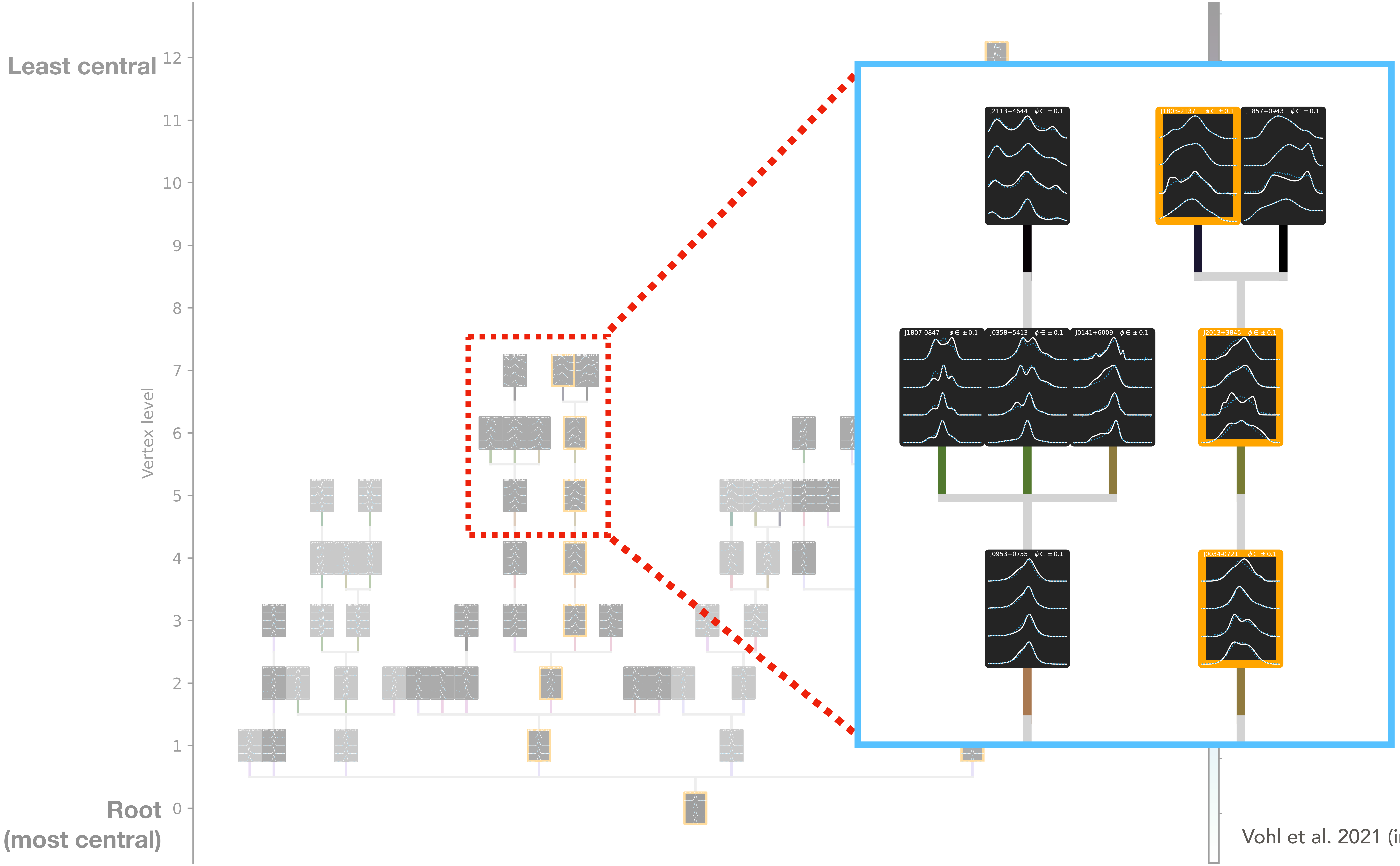
Least central
12
11
5
4
3
2
1
0
Root
(most central)
J1917+1353 ϕ ∈ ±0.1
J1820-0427 ϕ ∈ ±0.1
J2219+4754 ϕ ∈ ±0.1
J0614+2229 ϕ ∈ ±0.1
10^0
Vohl et al. 2021 (in prep.)


Least central
Root
(most central)
Vertex level
J1825-0935 ϕ ∈ ±0.1
J0528+2200 ϕ ∈ ±0.1
J1745-3040 ϕ ∈ ±0.1
J1041-1942 ϕ ∈ ±0.1
J2022+2854 ϕ ∈ ±0.1
J2048-1616 ϕ ∈ ±0.1
J1239+2453 ϕ ∈ ±0.1
w
Vohl et al. 2021 (in prep.)



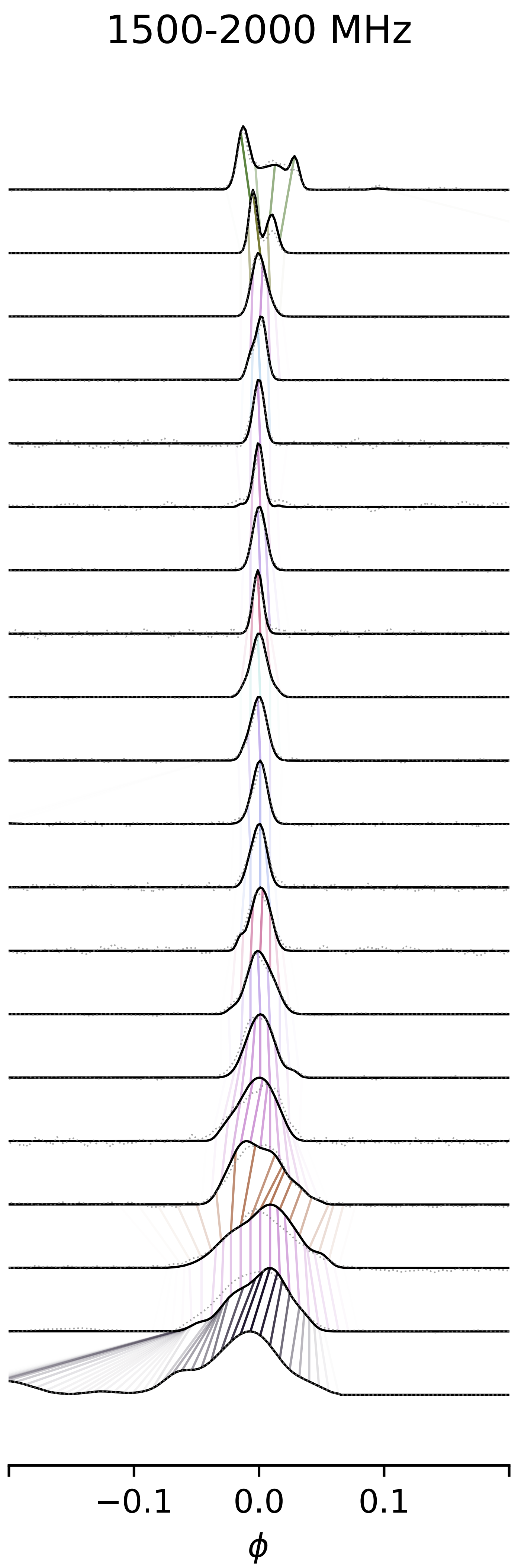
Least central
Root
(most central)
Vertex level
12
11
10
9
8
7
6
5
4
3
2
1
0
7 $\phi \in \pm 0.1$
J0332+5434 $\phi \in \pm 0.1$
J1645-0317 $\phi \in \pm 0.1$
w
10^0
Vohl et al. 2021 (in prep.)

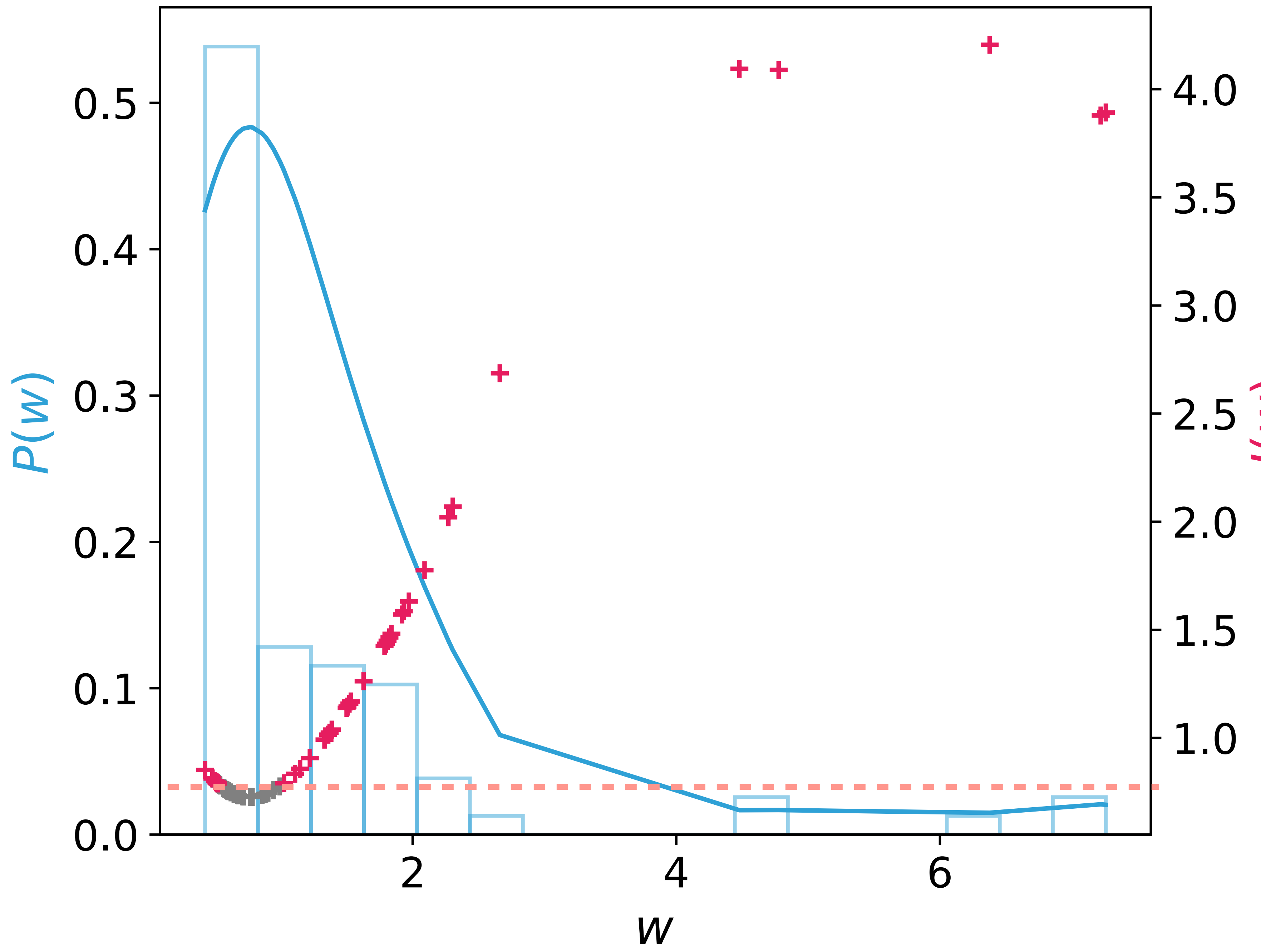

Least central
12
Root
(most central)
0
J1740+1311 $\phi \in \pm 0.1$
J1921+2153 $\phi \in \pm 0.1$
J1136+1551 $\phi \in \pm 0.1$
J1833-0338 $\phi \in \pm 0.1$
J1543-0620 $\phi \in \pm 0.1$
10^0
w
Vohl et al. 2021 (in prep.)



Vohl et al. 2021 (in prep.)

Redundancy: edge contraction

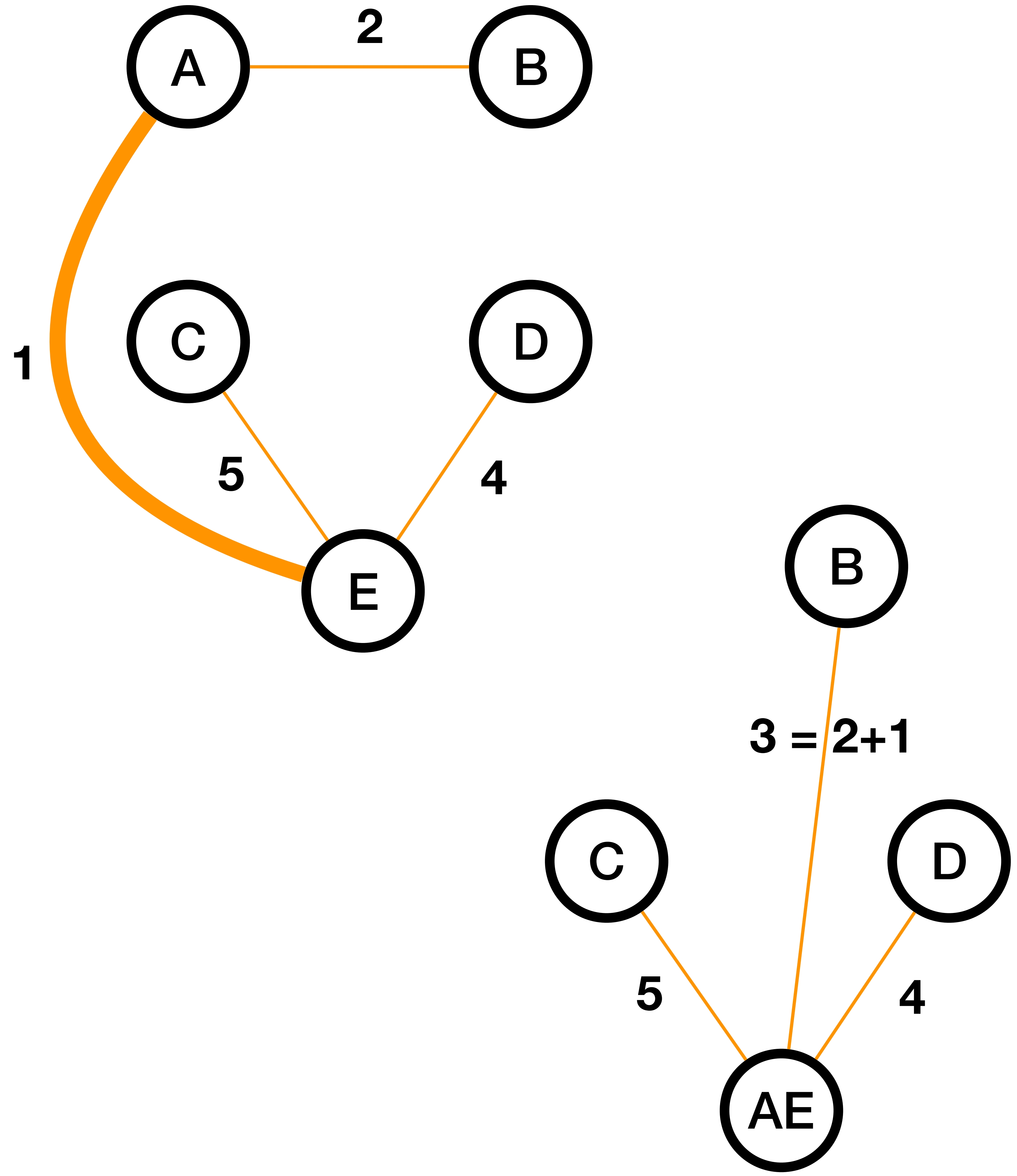




Information content carried by w is given by

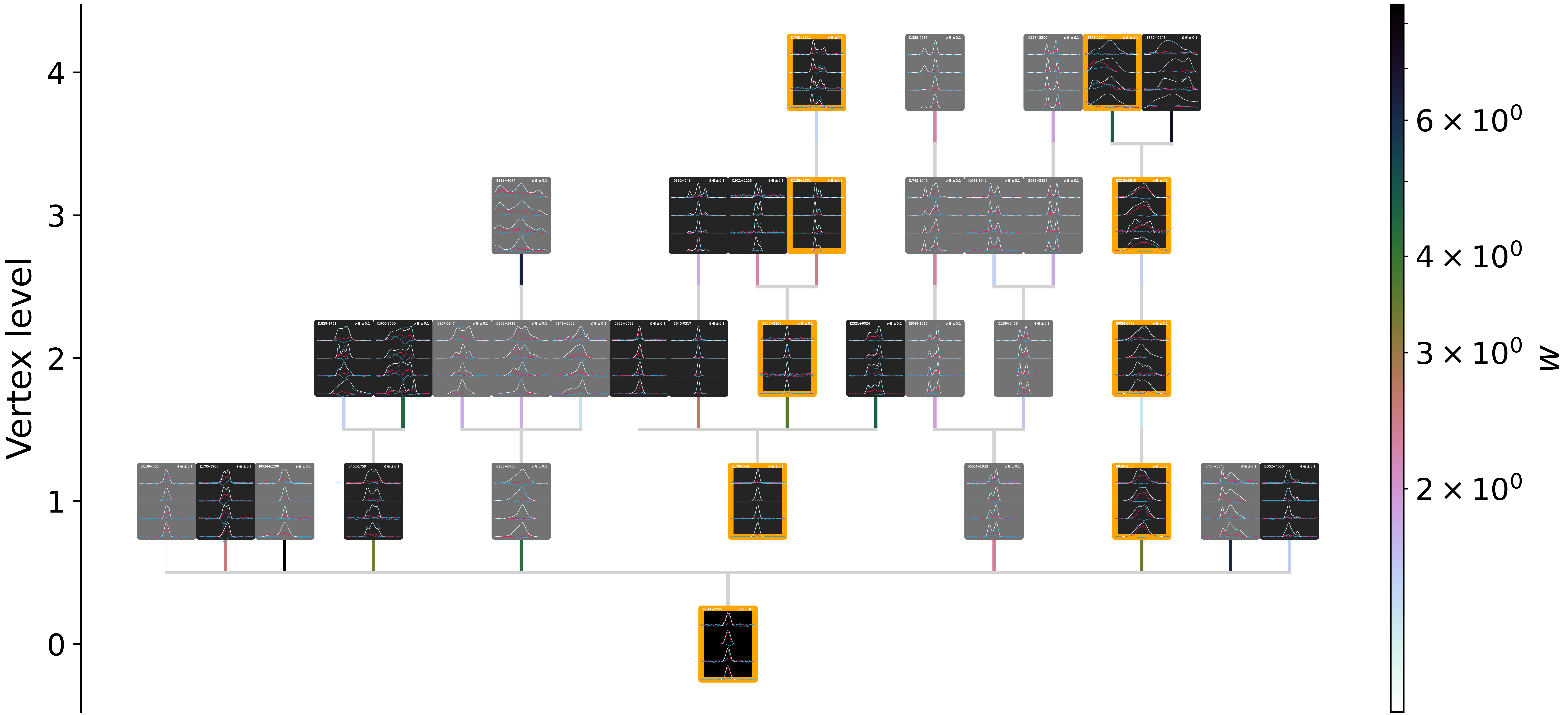
$I(w) = -\log P(w)$

Threshold at median $I(W)$



Vohl et al. 2021 (in prep.)

Contracted MST



Vohl et al. 2021 (in prep.)

Summary

- SKA's **large N** will require automated methods
- Method to investigate pulsar population through their profiles, to evaluate, e.g.
    - If core-cone emission is a distinction or a gradual scale
- Method can be applied to (repeating) **FRBs** profiles too
- Next steps: utilise polarization and uncertainties in similarity measure
- Flexible python codebase to handle, process, and analyse pulse profile population
    - Custom visualisations (e.g. N-ary tree)
- Questions/comments : **vohl@astron.nl**

netherlands eScience center
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