Interpolation of Supernova Time Series Spectra with Optimal Transport

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Astronomy & Astrophysics

A novel optimal transport-based approach for interpolating spectral time series

Paving the way for photometric classification of supernovae

Mauricio Ramirez[1,2,⋆], Giuliano Pignata[3,2], Francisco Förster[2,4,5,6], Santiago González-Gaitán[7], Claudia P. Gutiérrez [10,11], Bastian Ayala[1,2], Guillermo Cabrera-Vives [2,12,13], Márcio Catelan[2,8,9], Alejandra M. Muñoz Arancibia[2,5], and Jonathan Pineda-García[1,2]

Importance

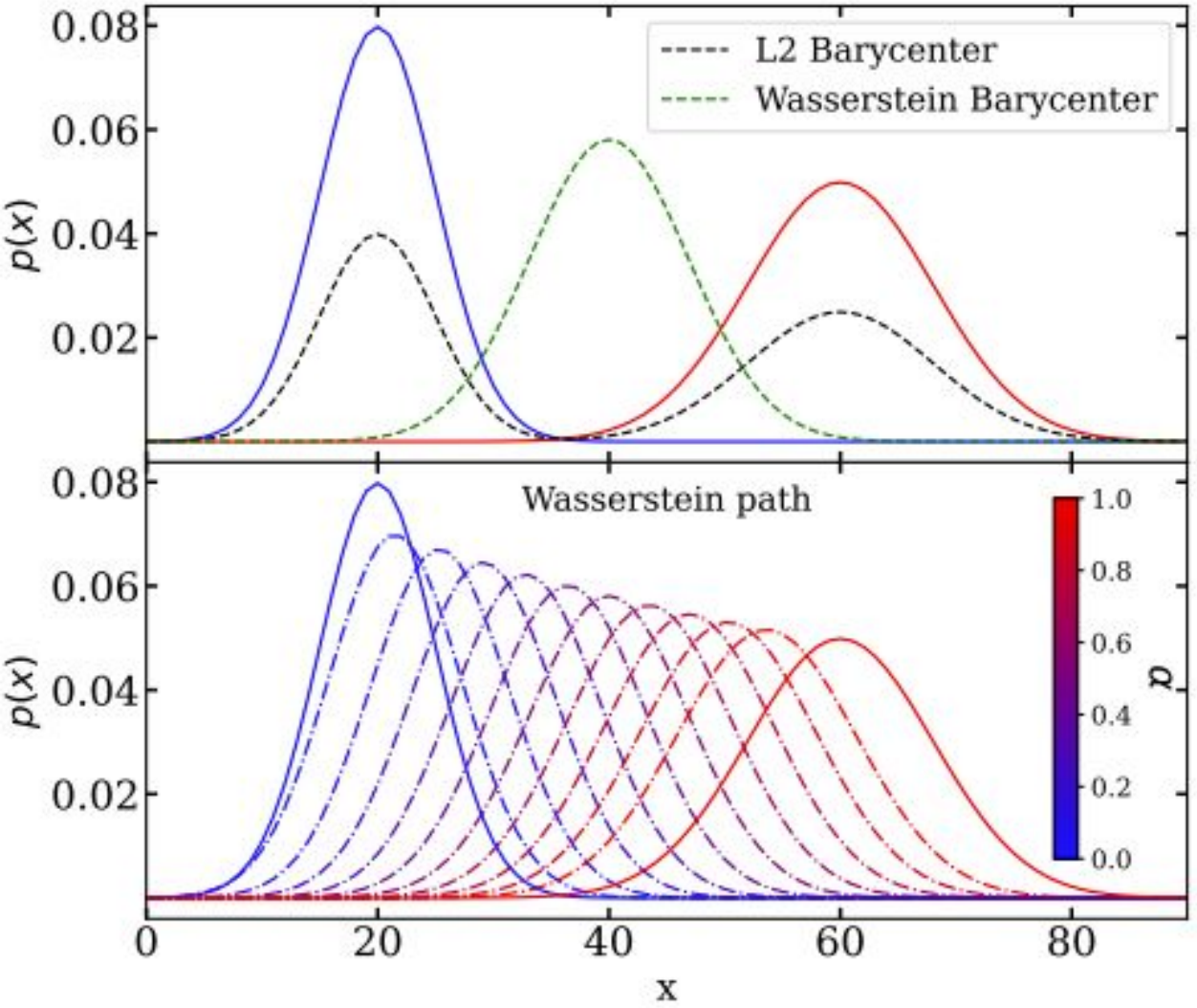
- Expect to observe many SNe in the future
- Type classification and photometric properties -> light curve fitting
- Importance of SNe in astronomy

Optimal Transport theory

- OT plan to get from initial to final distribution, $x_i \rightarrow y_i$
- Minimizing total cost

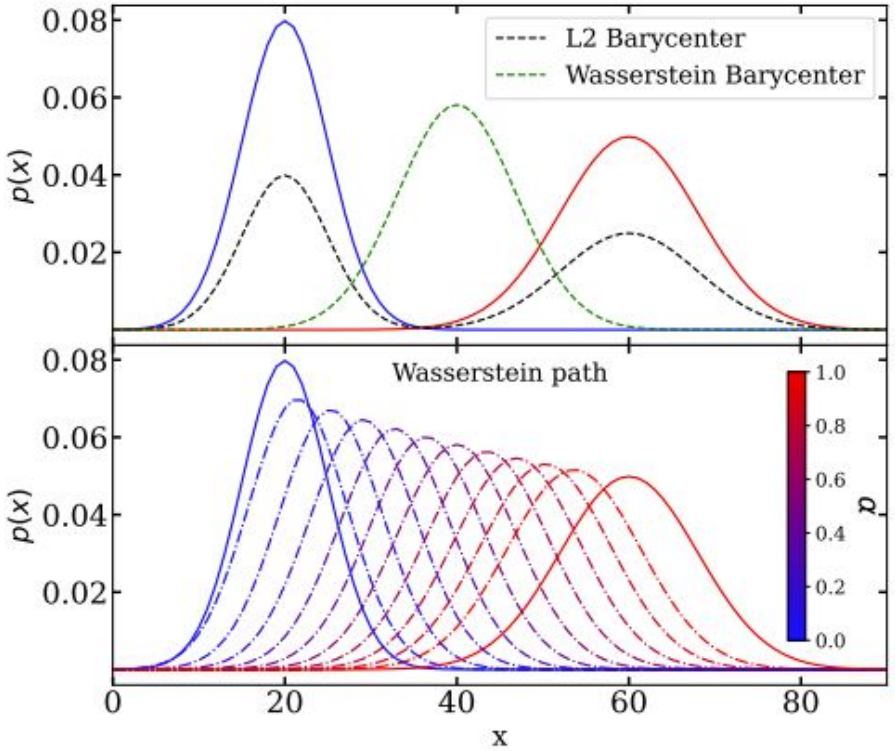
$$C_T = \sum_{i}^{n} c(x_i, T(x_i))$$

- What is cost?


L2 Barycenter
Wasserstein Barycenter
Wasserstein path
p(x)
x
α
0.08
0.06
0.04
0.02
0
20
40
60
80
1.0
0.8
0.6
0.4
0.2
0.0

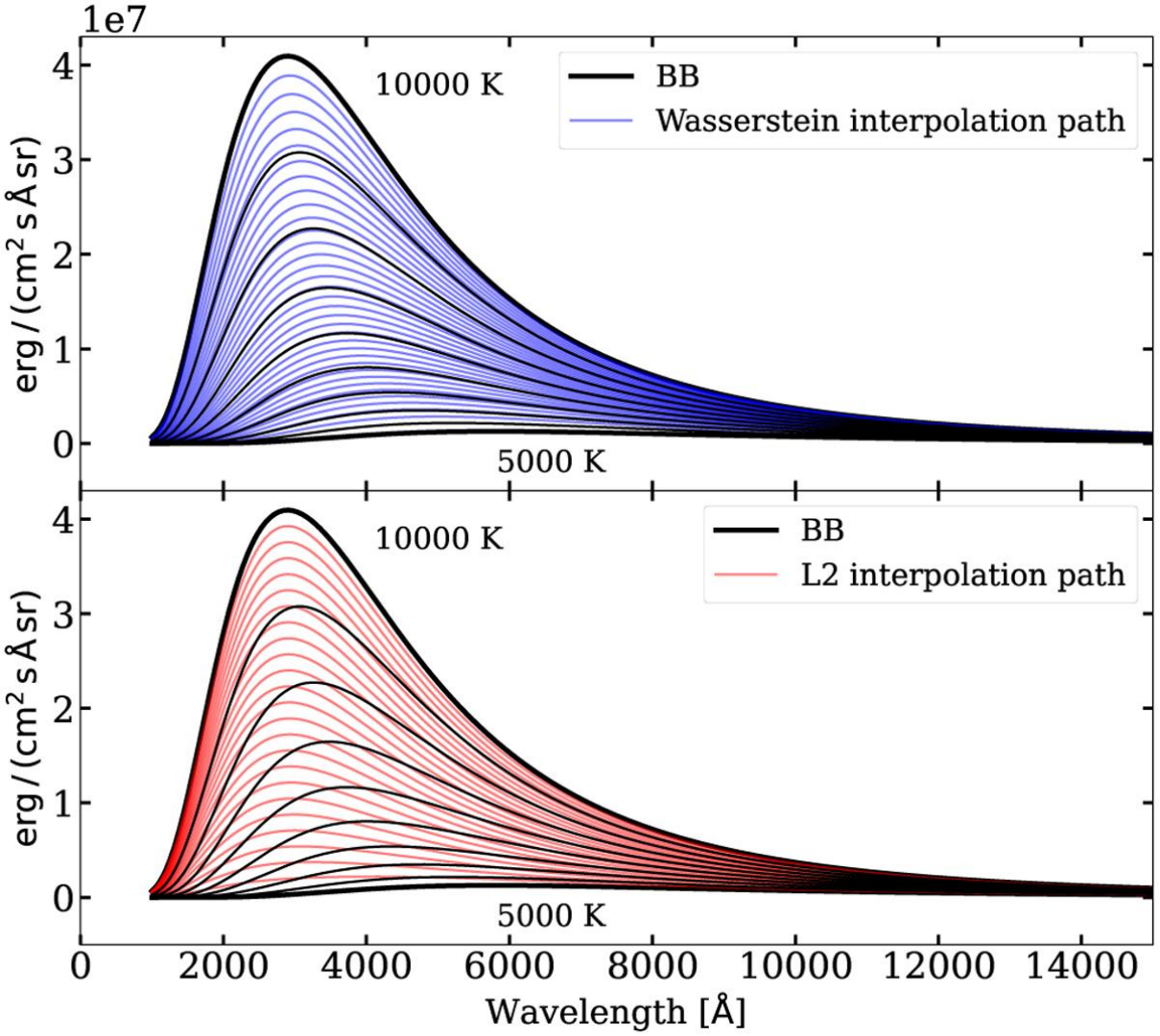
Visual illustration

- Wasserstein distances
- Weighted by α
- Comparing with L2

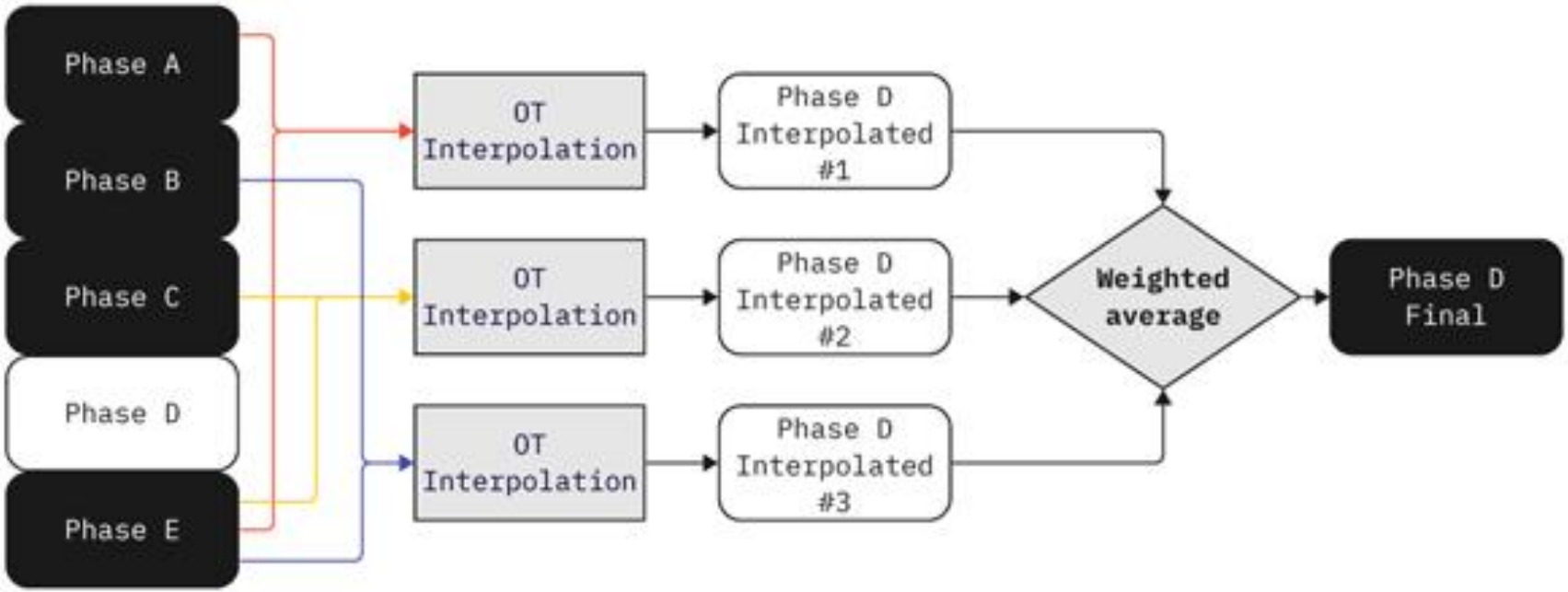


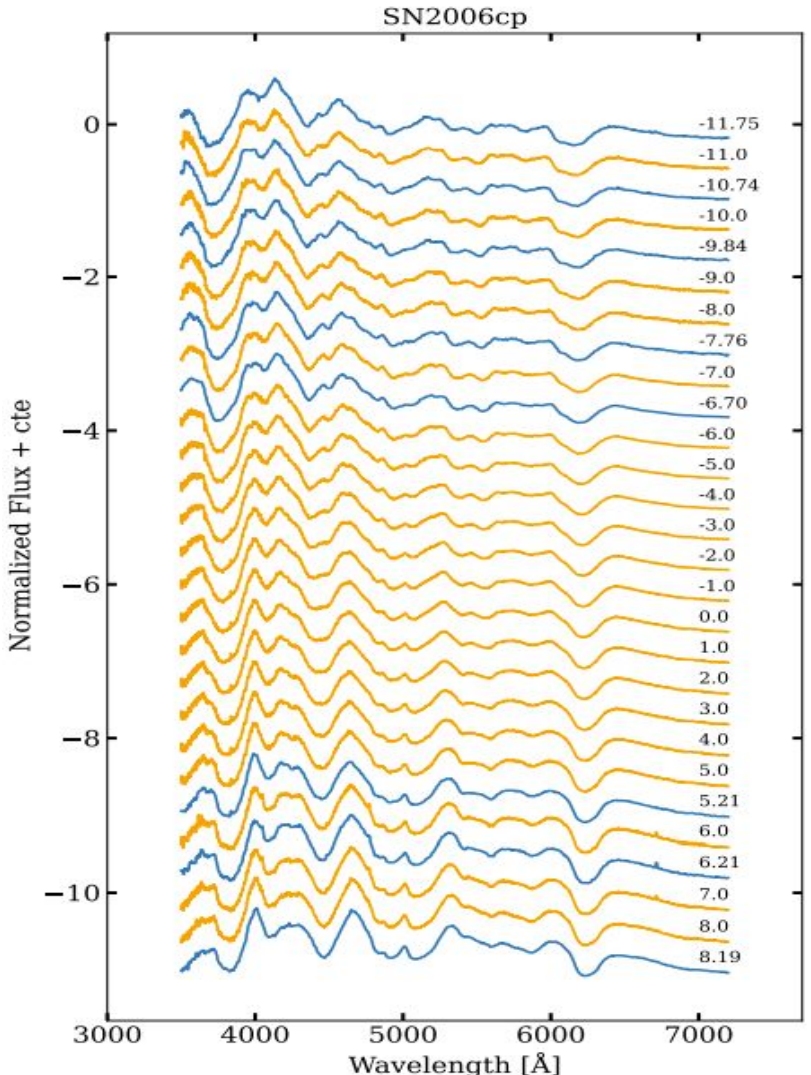
The Wasserstein distance

”(Finding the Wasserstein barycenter) is like finding a middle point, not in terms of physical distance, but in terms of how much you would have to change each distribution to reach this middle point.”


1e7
10000 K
BB
Wasserstein interpolation path
5000 K
erg / (cm² s Å sr)
10000 K
BB
L2 interpolation path
5000 K
erg / (cm² s Å sr)
0
1
2
3
4
0
2000
4000
6000
8000
10000
12000
14000
Wavelength [Å]

Results


Phase A
Phase B
Phase C
Phase D
Phase E
OT Interpolation
OT Interpolation
OT Interpolation
Phase D Interpolated #1
Phase D Interpolated #2
Phase D Interpolated #3
Weighted average
Phase D Final


SN2006cp
Normalized Flux + cte
Wavelength [Å]
0
−2
−4
−6
−8
−10
3000
4000
5000
6000
7000
-11.75
-11.0
-10.74
-10.0
-9.84
-9.0
-8.0
-7.76
-7.0
-6.70
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
5.21
6.0
6.21
7.0
8.0
8.19

Conclusion

- Transportation Theory and OT has a wide range of uses

- This paper highlighted one method, accomplished through interpolation, for astrophysical purposes

Reference

M. Ramirez et al., A novel optimal transport-based approach for interpolating spectral time series: Paving the way for photometric classification of supernovae
691:A33, November 2024. doi: 10.1051/0004-6361/202449170