Full Spectral Fitting:
Maximally extracting information from spectra

Yuan-Sen Ting
Hubble Fellow
Carnegie-Princeton-IAS Fellow

Institute for Advanced Study, Princeton
Princeton University
Carnegie Observatories
Fitting the *entire* spectrum

- Why is it necessary?
- How can it be achieved?
- What does it mean for stellar spectroscopy?
Why full spectral fitting is necessary
Are we using all information in spectra?
Are we using *all* information in spectra?

Clean, strong lines ✔️
Are we using *all* information in spectra?

- Clean, strong lines: ✓
- But blended features are usually excluded: ✗
Fitting strong/unblended features only harnesses $10\%$ of the spectral information.

Clean strong lines / all information

Elemental Abundance

APOGEE survey

YST+ 2016b
Fitting strong/unblended features only harnesses 10% of the spectral information.

Clean strong lines / all information

Unblended strong lines only contain 10% of the information.

APOGEE survey

Elemental Abundance

YST+ 2016b
Why high-resolution is thought to be necessary for stellar spectroscopy

Clean, strong lines

$R = \frac{\lambda}{\Delta \lambda} = 24000$
Most features are blended at \textit{low-resolution}.

\[ R = \frac{\lambda}{\Delta \lambda} = 6000 \]
Most features are blended at low-resolution

Need to fit the full spectrum

\[ R = \frac{\lambda}{\Delta\lambda} = 6000 \]
Fitting the full spectra is a *necessity*. Stars further away (cool giant stars) only have blended features.

e.g., most **MSE** sample will be the *cool M-giant stars*
M-dwarfs (e.g., exoplanet hosts) are cool. Their spectral features are mostly blended.
How full spectral fitting is made possible
Problems with classical "interpolation" methods
Problems with classical "interpolation" methods

- Need to fit all stellar parameters + elemental abundances *simultaneously*

\[ N_{\text{dim}} = 20 - 50 \]
Problems with classical "interpolation" methods

- Need to fit all stellar parameters + elemental abundances \textit{simultaneously}
  \[ N_{\text{dim}} = 20 - 50 \]
- Traditional interpolations require a "regular" grid of models
  \[ N_{\text{models}} \sim \exp(N_{\text{dim}}) \]
  \[ N_{\text{dim}} < 6 \]
Problems with classical "interpolation" methods

- Need to fit all stellar parameters + elemental abundances simultaneously
  \[ N_{\text{dim}} = 20 - 50 \]

- Traditional interpolations require a "regular" grid of models
  \[ N_{\text{models}} \sim \exp(N_{\text{dim}}) \]
  \[ N_{\text{dim}} < 6 \]

- Call for a fast and accurate "interpolation" method via an adaptive grid, emulator approach
Classical interpolation \( N_{\text{models}} \sim \exp(N_{\text{dim}}) \)
Classical interpolation $N_{\text{models}} \sim \exp(N_{\text{dim}})$
Generative models / emulators

\[ f(x,y) = ax + by + c \]
Generative models / emulators

\[ f(x,y) = ax + by + c \]

\[ N_{\text{models}} \ll \exp(N_{\text{dim}}) \]
Efficient "interpolation" via machine learning

The Payne

Also see The Cannon:
Ness+16, Casey+ 17
StarNet : Leung & Bovy, 2018

YST+ 2016b, 2017a,b, 2018a,c
Rix, YST+ 2016
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Emulators with neural networks

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Fitting 25D requires only 2000 model spectra

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YST+ 2016b, 2017a,b, 2018a,c
Rix, YST+ 2016
What does it mean for stellar spectroscopy
The Payne attains 2 times more *precise* elemental abundances for the APOGEE survey.
Most features are blended at low-resolution

Need to fit the full spectrum

Low resolution

\[ R = \frac{\lambda}{\Delta \lambda} = 6000 \]
The Payne measured 16 elemental abundances from LAMOST (MSE-like) low-resolution spectra. Classical method can only measure < 3 elements.

$$R = \frac{\lambda}{\Delta \lambda} = 1800$$
The Payne measured 16 elemental abundances from LAMOST (MSE-like) low-resolution spectra.

Precision = 0.05-0.15 dex

The Payne measured 16 elements

Precision = 0.05-0.15 dex

\[ R = \frac{\lambda}{\Delta \lambda} = 1800 \]
Xiang, YST+, in prep.

16 elements from 7 million low-resolution LAMOST spectra

Metallicity [Fe/H] vs. Abundance ratio [X/Fe]

\[ R = \frac{\lambda}{\Delta \lambda} = 1800 \]

Xiang, YST+, in prep. YST+ 2017b
Summary:

*Low-resolution spectra* (R=2,000–6,000) contain *extensive* information about > 20 elemental abundances (and stellar ages)

And the new generation of spectral fitting ideas can deliver them
How to deal with *imperfect* spectral models

i.e., are you sure that you are measuring Ca from Ca lines?
### Dealing with imperfect spectral models

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*Notvia* astrophysical correlation?
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## Dealing with imperfect spectral models

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Low-resolution spectra contain abundant information of various elemental abundances.

Relative $\sigma[X/H]$

- Robust spectral models
- 1 pixel / resolution element

Same exposure time
Same number of CCD pixels

YST+ 2017a
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Not much gain going beyond $R > 1000$

YSST+ 2017a
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Relative $\sigma[X/H]$  

Spectral Resolution

Not much gain going beyond $R > 1000$

YST+ 2017a