AI Applications in Stellar Spectroscopy

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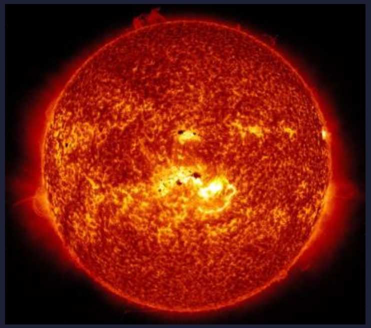
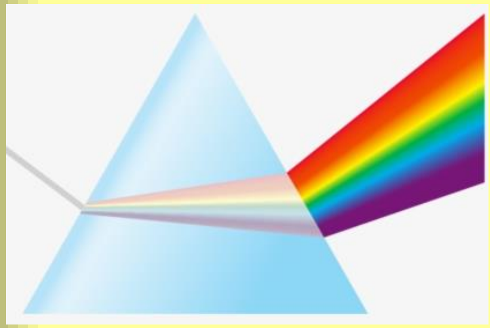
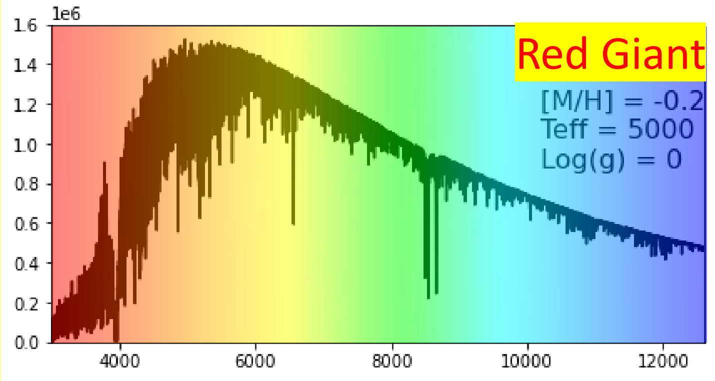
What is Stellar Spectroscopy?



Red Giant

- Stellar Spectrum
  - T_{eff} (Temperature)
  - g (Surface Gravity)
  - V_r (Radial Velocity)
  - $[M/H]$ (Metallicity)
  - Element Abundance
    - Carbon, Oxygen, Iron…



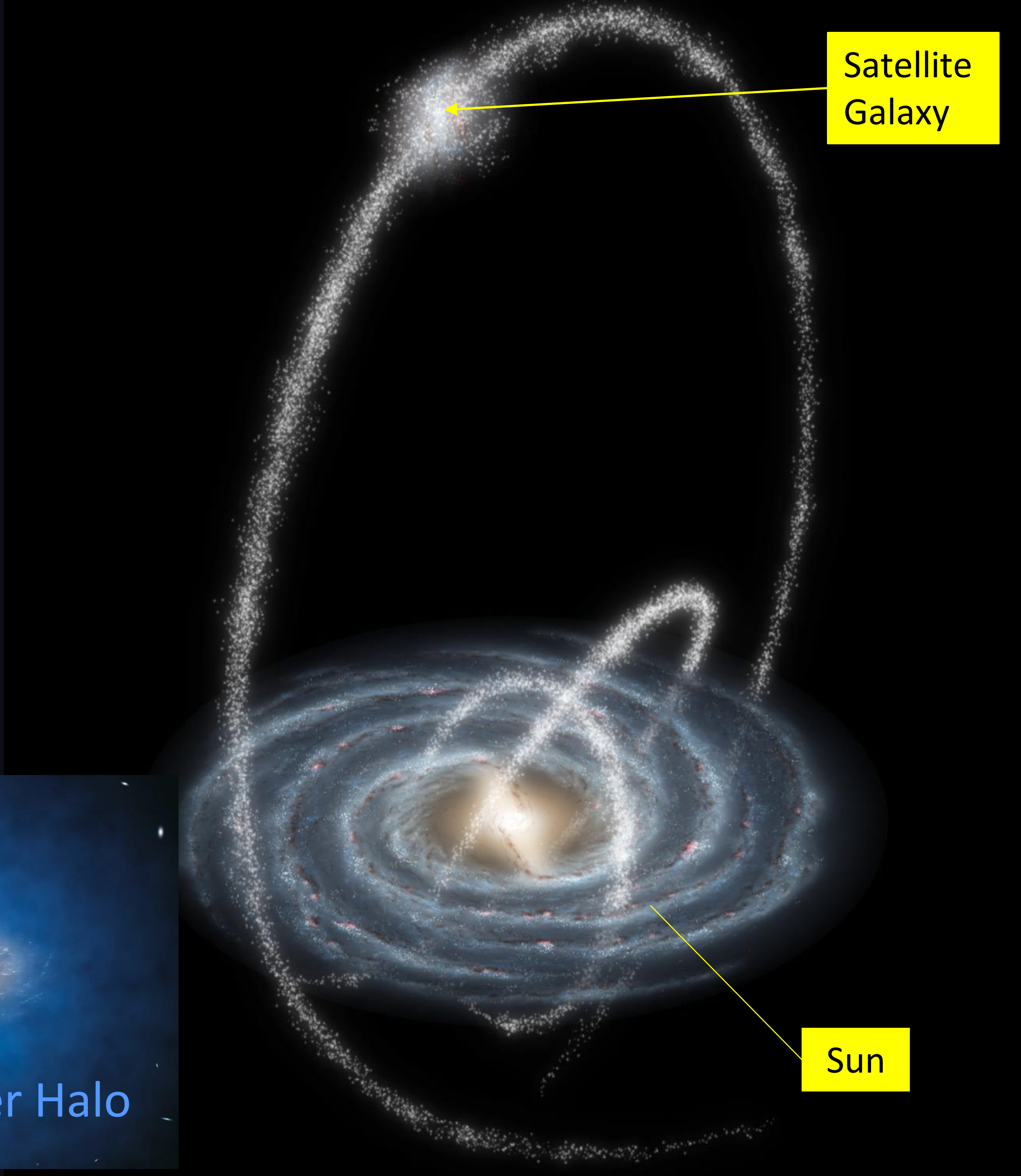


Prime Focus Spectrograph (PFS)

8.2m Subaru Telescope (Hawaii)

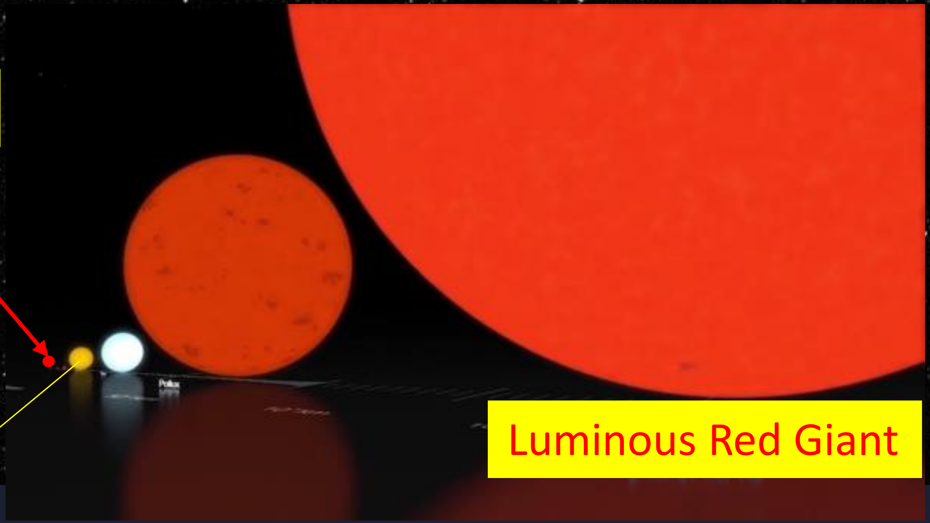
Why build this $80M spectrograph?

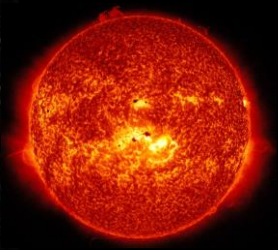
- Galactic Archaeology
  - Milky Way Formation
    - Satellite Galaxies
  - Dark Matter Halo Profile
- 8.2m Mirror → Faint Stars
- Wide Field → More Stars
- Must & Best

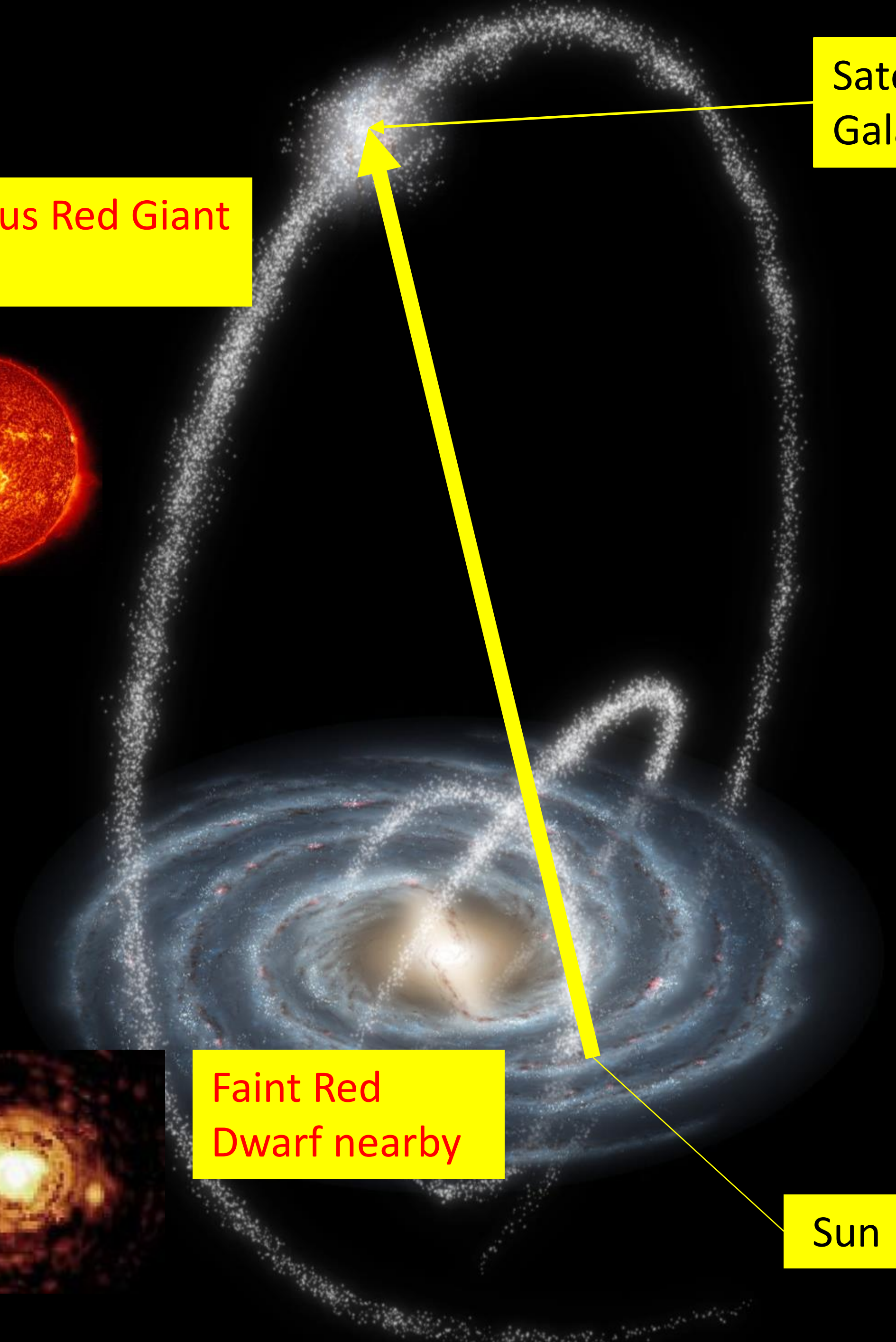


Target Selection Challange

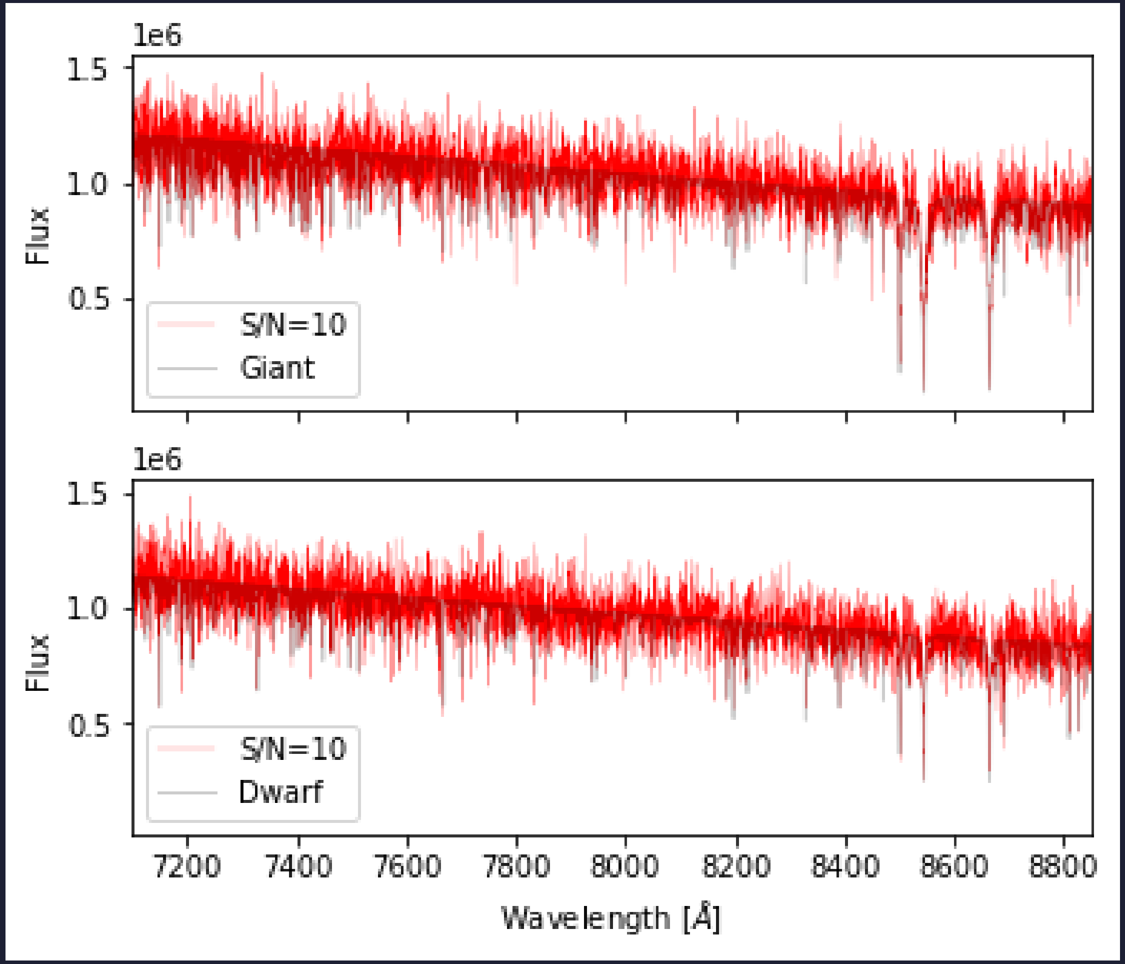
They all appear the same brightness & color to us.



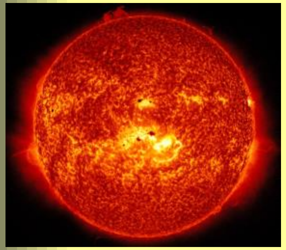


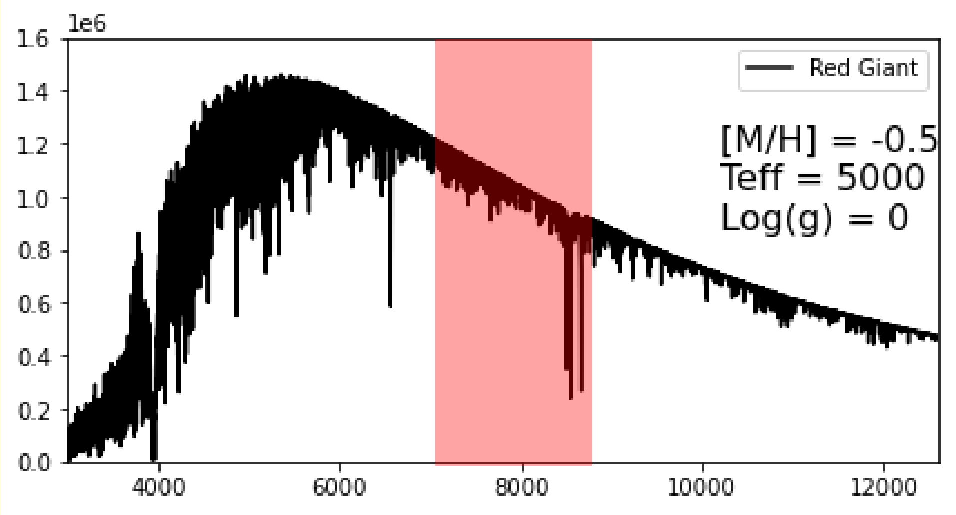


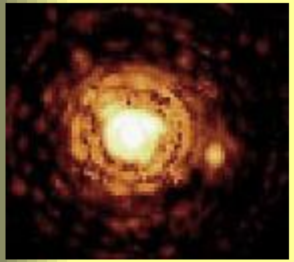
Raw Noisy Spectra

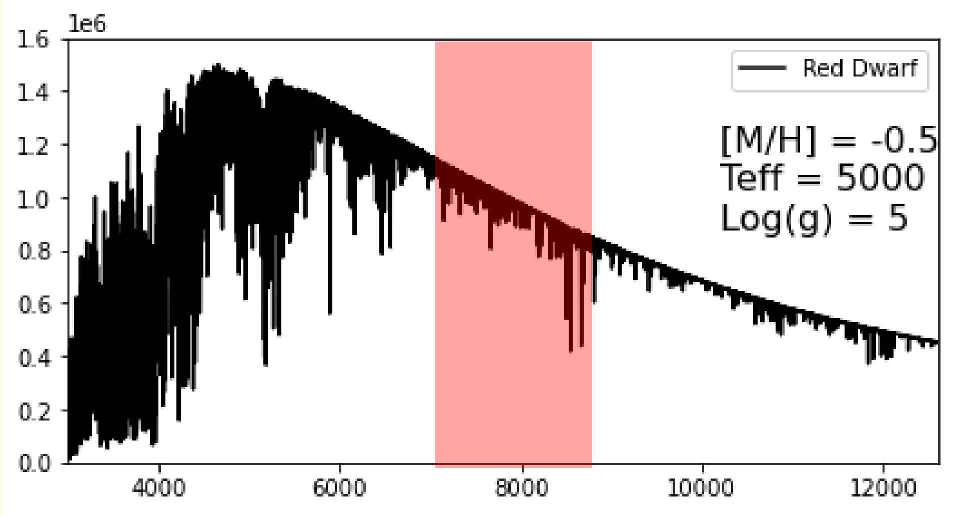


Noiseless Model Spectra

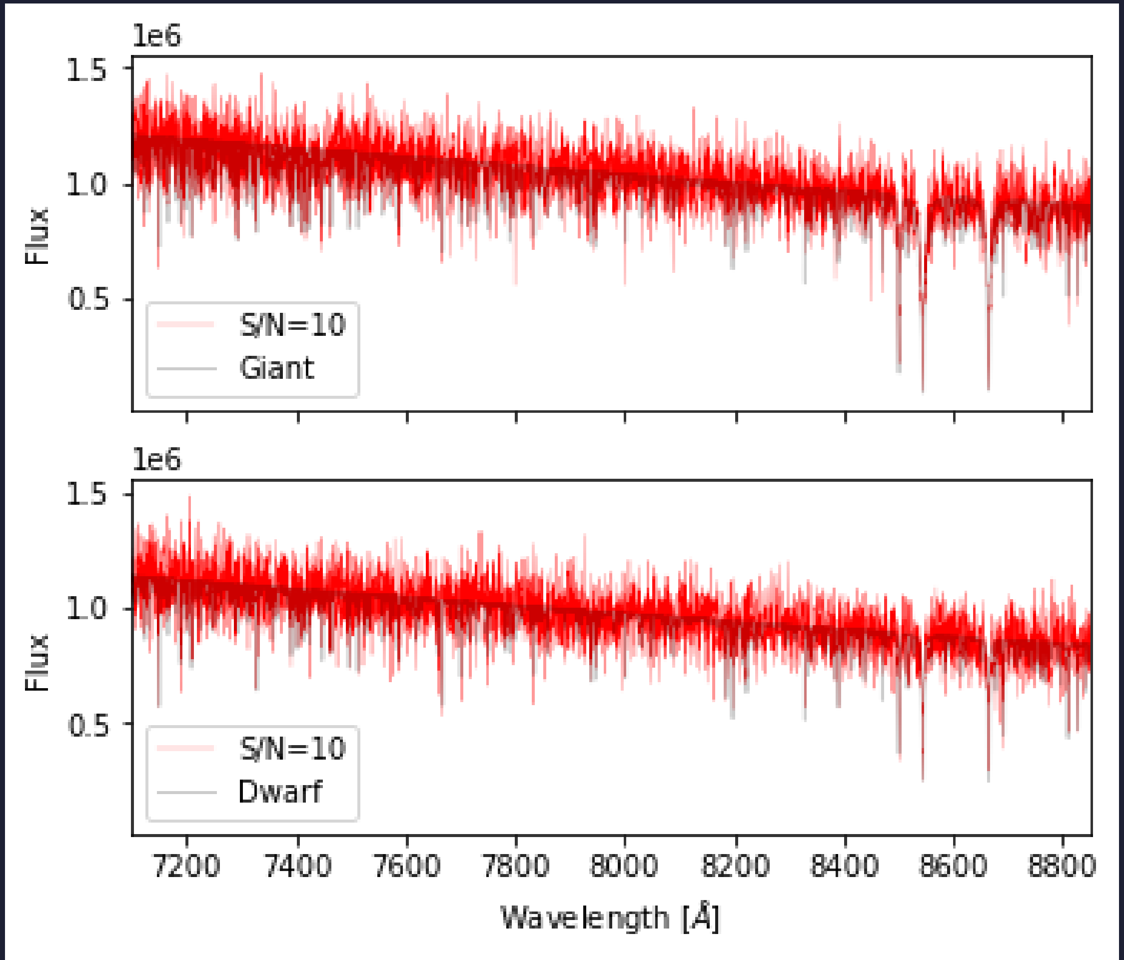




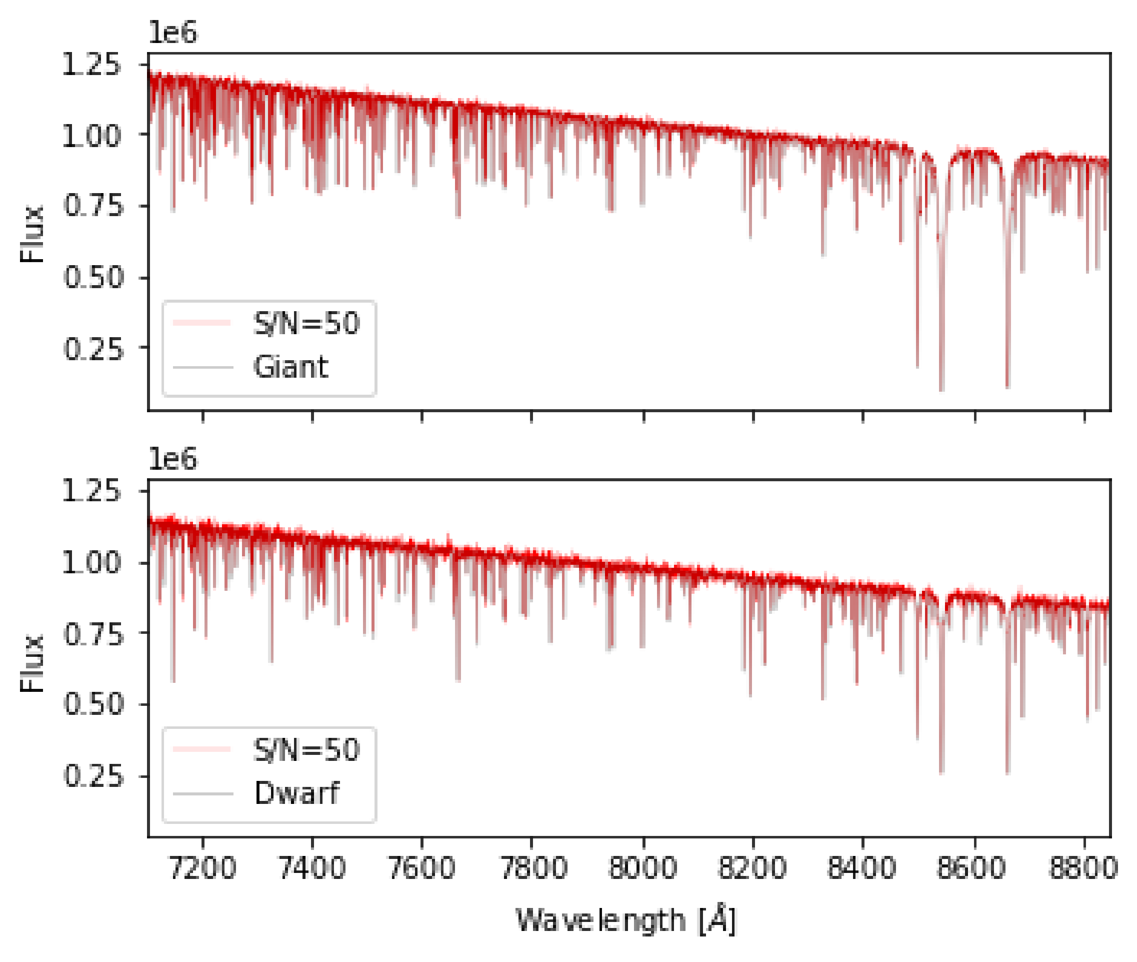




Raw Noisy Spectra



Exposed for O(hrs)



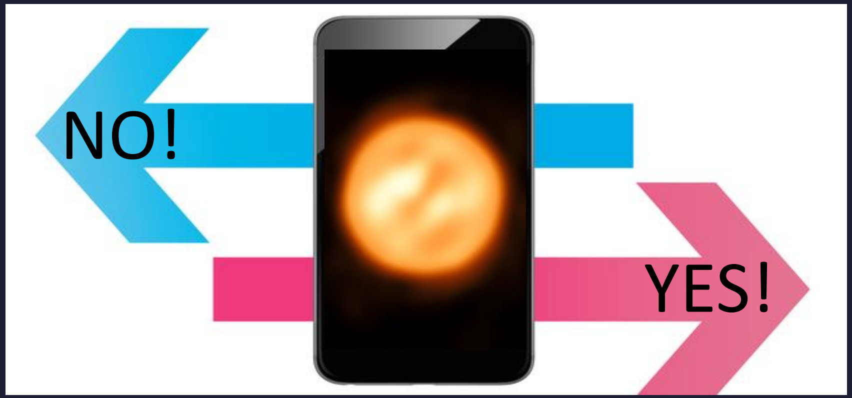
Spectrum Analysis:

O(hours) Get high SNR Spectrum from Spectrograph

O(mins) Parameter fitting with traditional methods

Early Stopping Criteria

- We can move the fiber if the target is not interesting.
  - Is the target a member?
  - Too noisy to extract info?
  - More info to extract?
- **Rapid Feedback Loop**



Time is the most expensive factor in spectroscopy

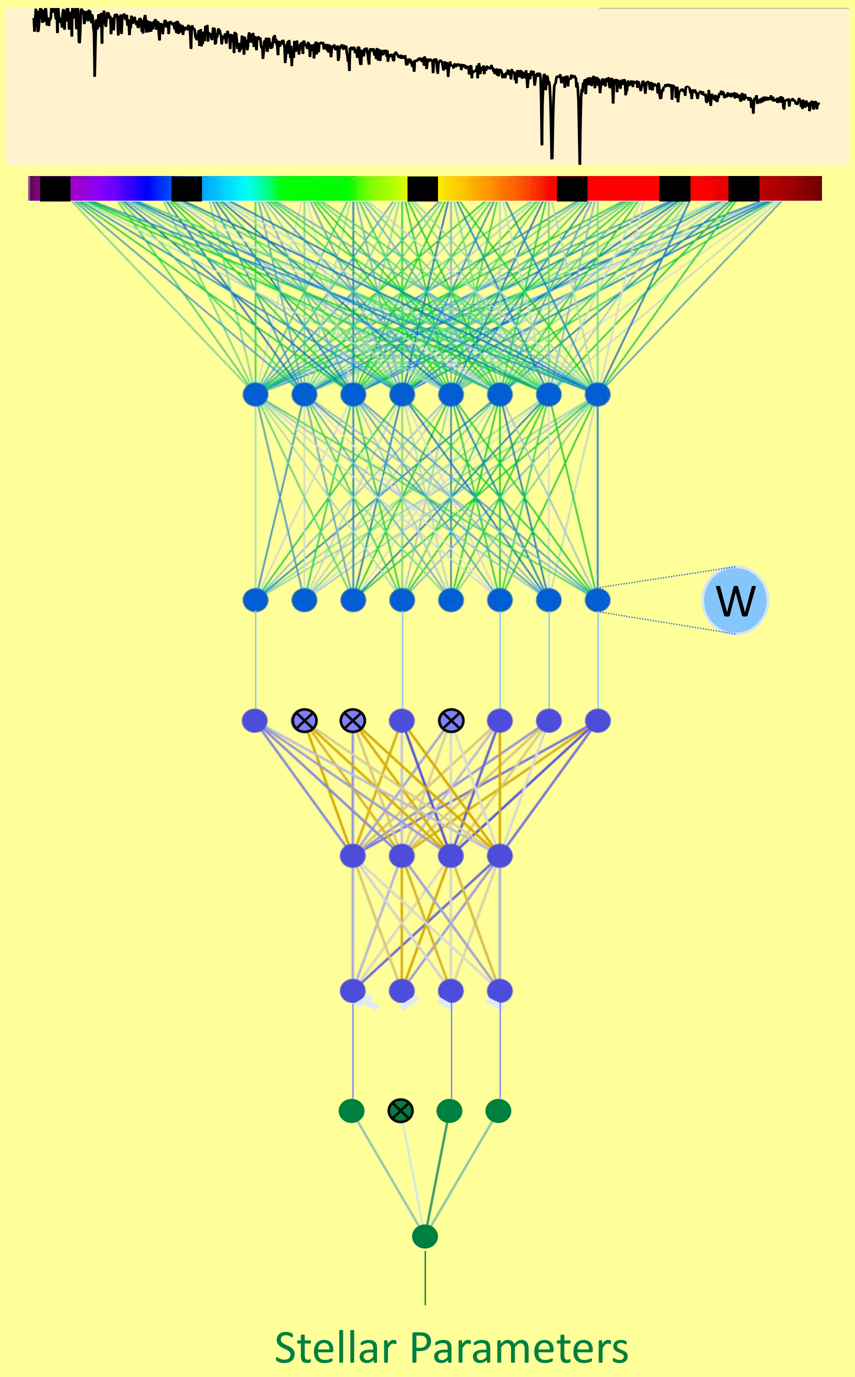
	\$80M to build \$100k / night
	~100 nights
	2400 fibers only
	Maximize Scientific Utility of Observation

- ➢ Milky Way formation
- ➢ Dark Matter Halo Profile
- ➢ ….

Bring in the AI guy

- Spectrum analysis
  - O(hours)   High SNR Spectra
  - O(mins)   Parameter fitting
- AI:
  - Input – Raw, Noisy Stellar Spectra
    Output – Physical Parameters

  - O(mins) Noisy Spectra
  - O(ms)   NN inference



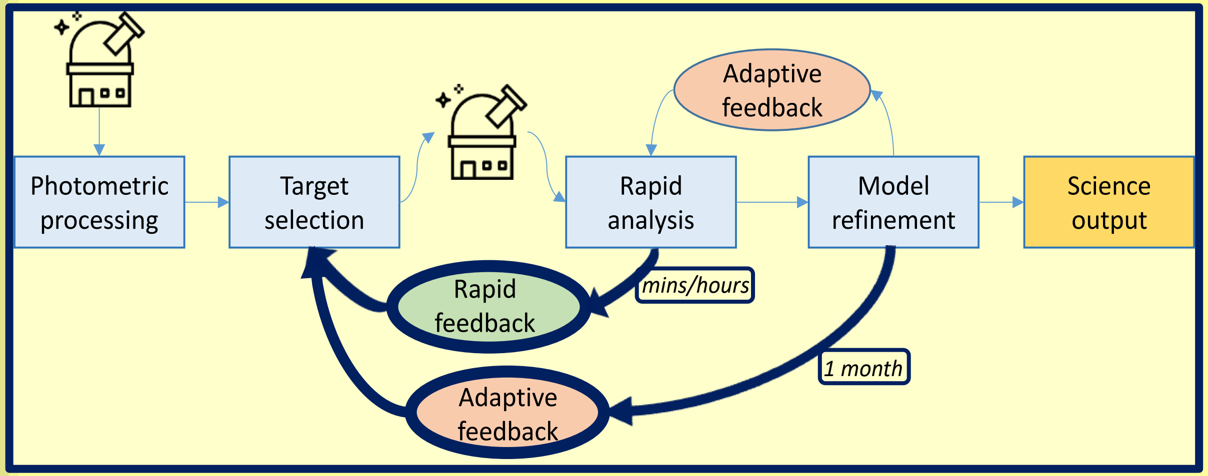
Adaptive Feedback Loop

Data Unknown beforehand

- Update algorithm in real time
- Online learning for target selection

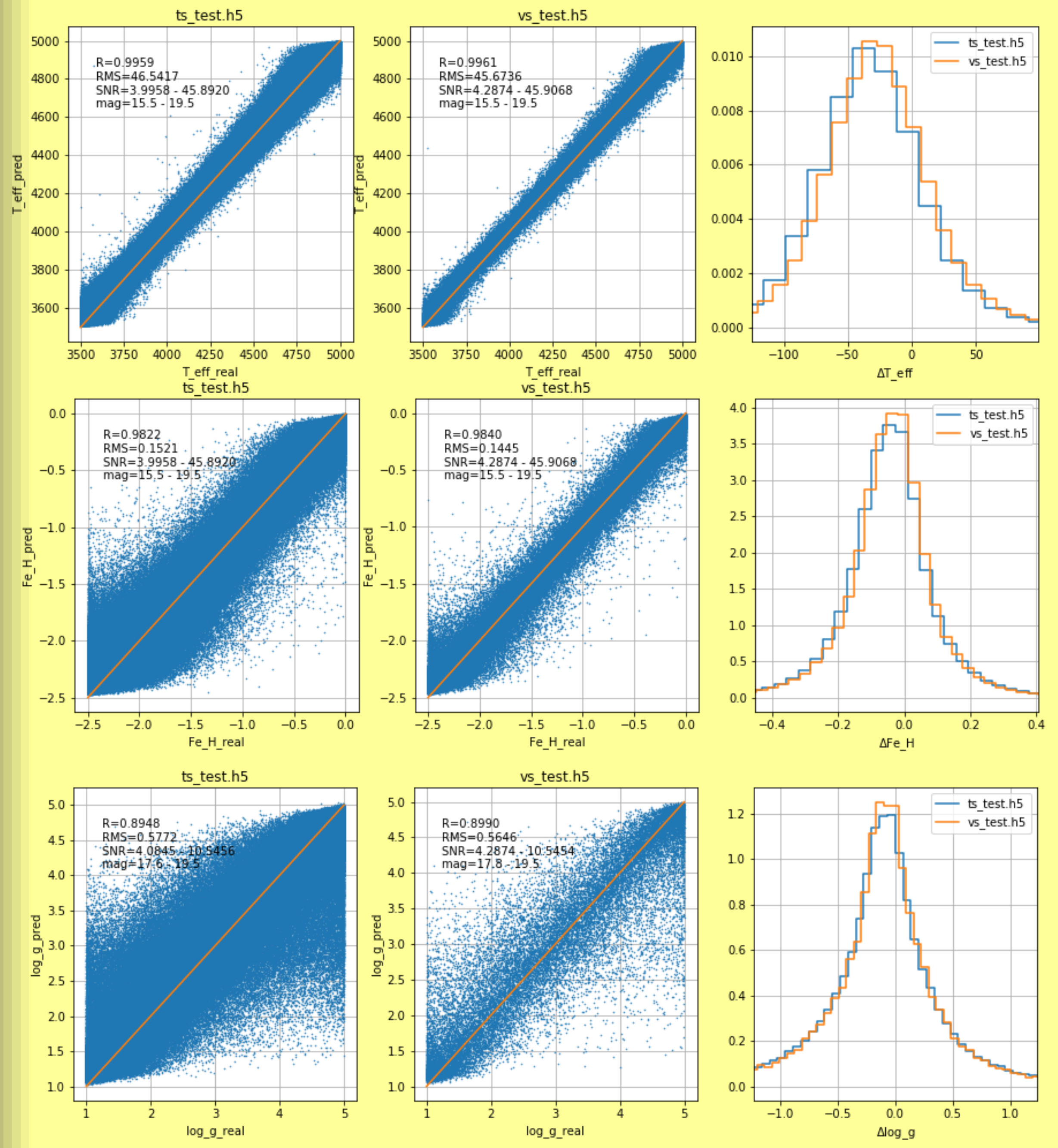
AI Solution

- AI Telescope
- Just like controlling self-driving cars, AI is helping us to run our scientific instruments more optimally.

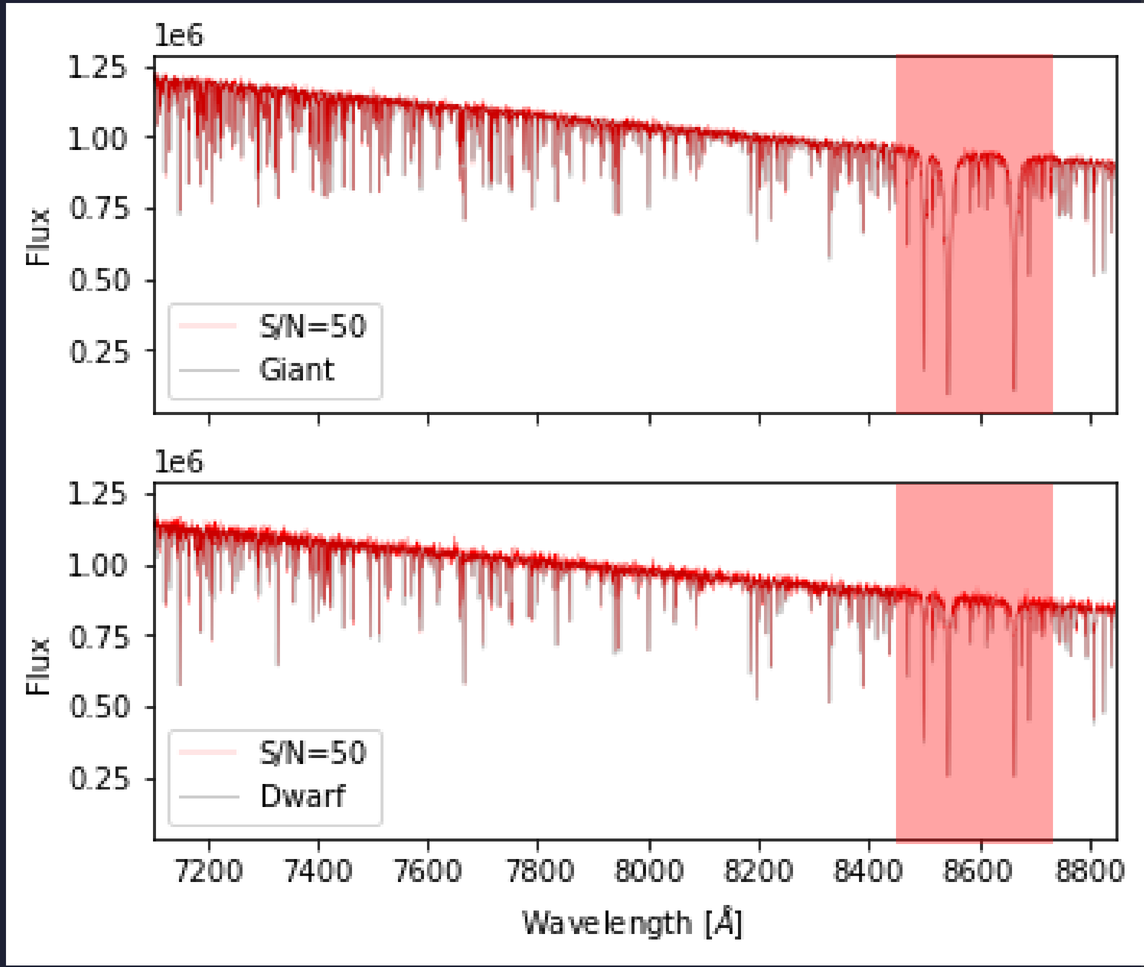


AI Problem

- Artificial Idiot
  - Physics Informed AI
- Overfitting
  - Large enough training set
  - Noise realization



Sparsity



Feature Engineering

- Most pixels are noise
- Few informative pixels live in a union of subspaces
- Lick indices
- How do extract key features?

How to extract key pixels?

Analyze each pixel/line at a time

- Time consuming and Computationally intensive.

Analyze entire spectra all together

- Low accuracy because majority of the pixels carry mostly noise.

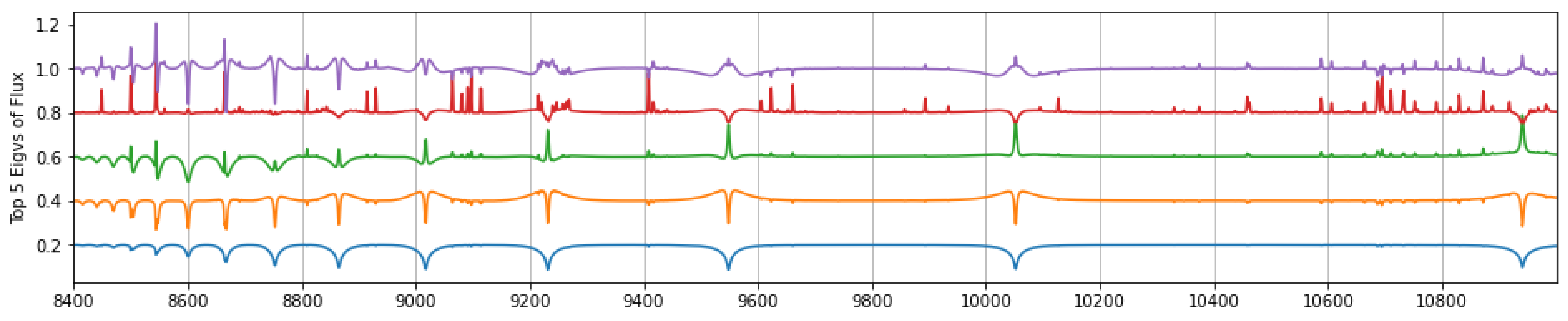
Sweet Spot

PCA

1. Group pixels that change together along the parameter space
2. Drop pixels that carry mostly noise
3. Do it automatically.

Example: Blue Horizontal Branch (BHB)

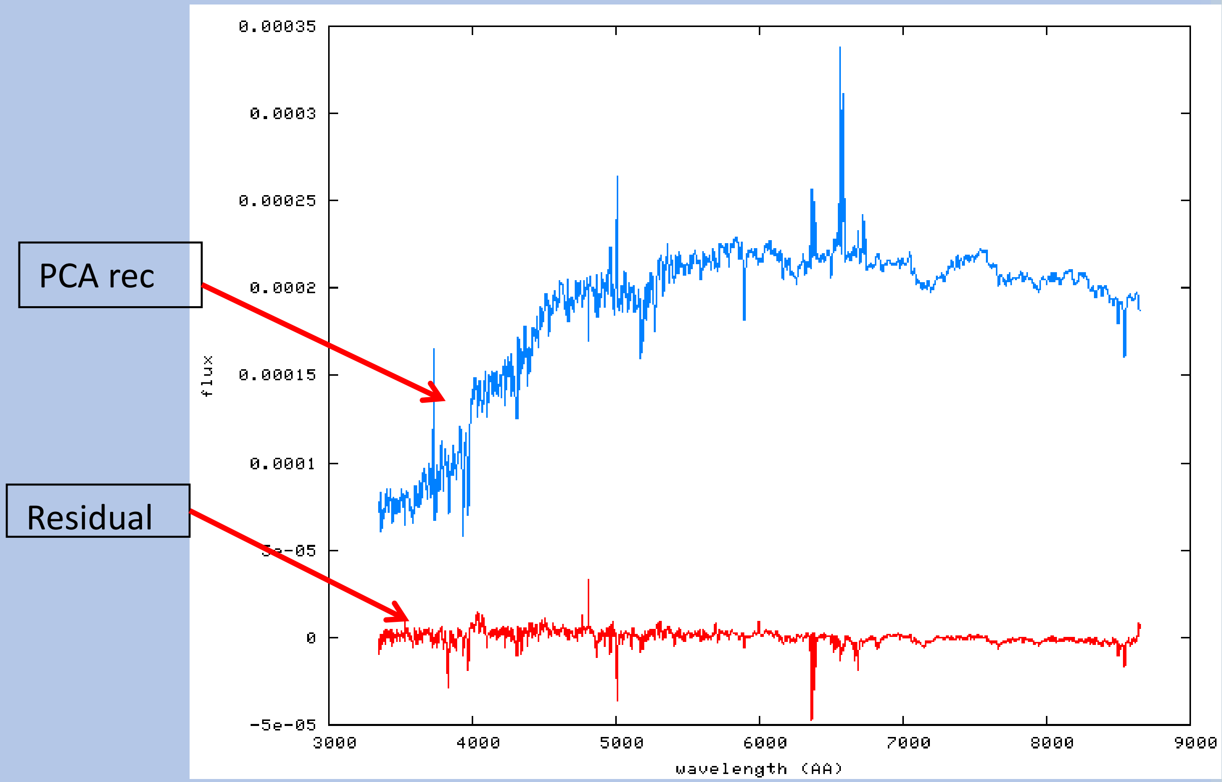
- PCA on normalized BOSZ stellar models in Blue Horizontal Branch.
  - Done in log space as absorption lines are additive (Optical depth)
- 1st PC: → Teff
- 2nd, 3rd PCs: → Log g
- 4th, 5th PCs: → [Fe/H], [O/M]



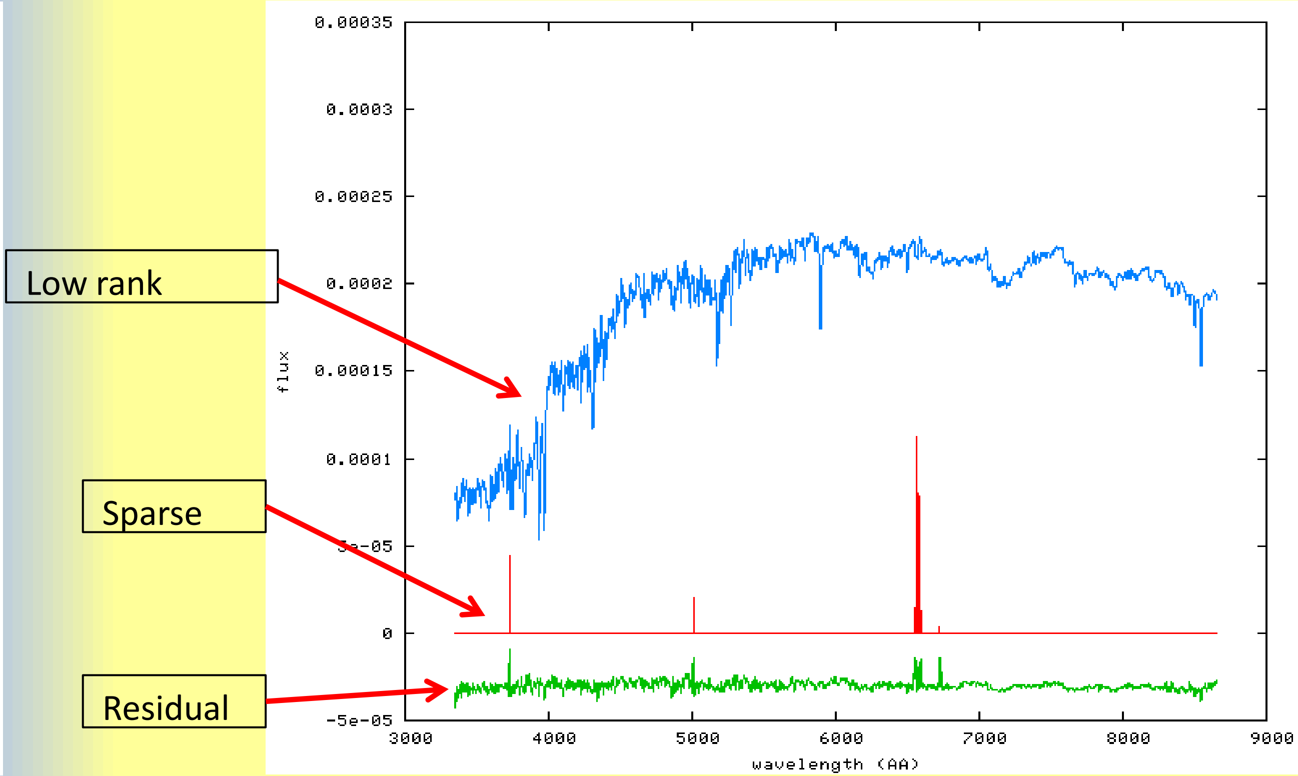
Principal component pursuit

- Slowly varying continuum + absorption lines
- Highly variable “sparse” emission lines
  - spiky noise bias standard PCA

PCA



PCP



I.Csabai (2010)

Other projects

- building generative models for stellar spectra
- building variational autoencoders on intelligently engineered features
- applying these to aid Bayesian Hierarchical Modeling for the actual target selection
- developing a reinforcement learning feedback loop for dynamically changing target selections.

Conclusion

- Next Generation AI-telescope powered by deep learning, augmented with insights from astrophysics, computer science and articial intelligence.
- Instead of controlling self-driving cars, the AI is helping us to run our scientific instruments more optimally.
- With such powerful tool, we hope to tackle hard science problems