“Using a Gas Absorption Cell as a Radial Velocity Reference”

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Why a gas cell can be useful…

A gas cell imprints on each spectrum the behavior of optics and detector for the actual illumination conditions during that observation

Compensate for spectrograph instabilities.

Data analysis is nontrivial.

Planets still lurking in 15 years of existing data from slit spectrographs.

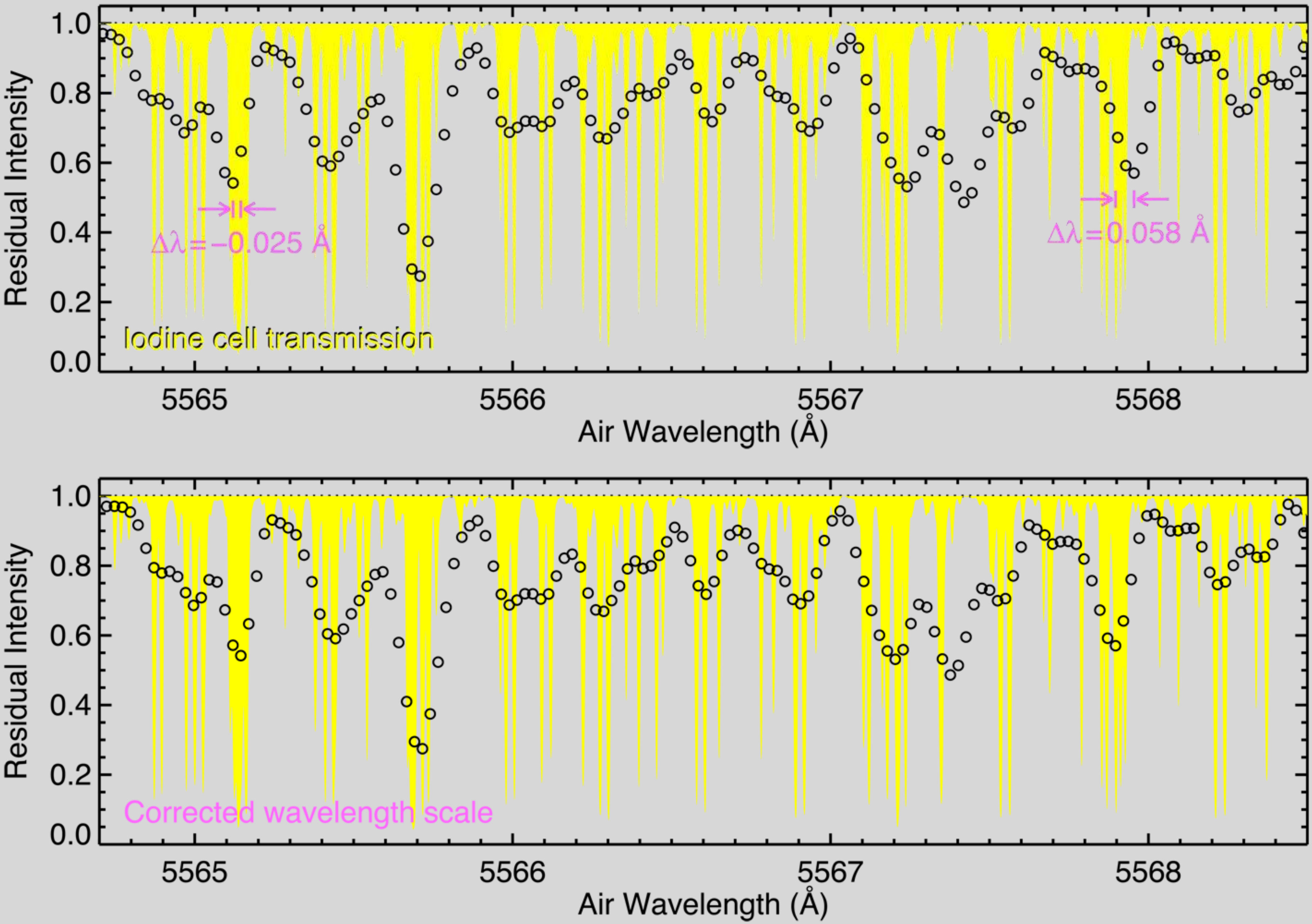
Outline

- Modeling observations
- Intrinsic stellar spectrum
- Iodine cell temperature
- Line spread function
- Residuals
- Results

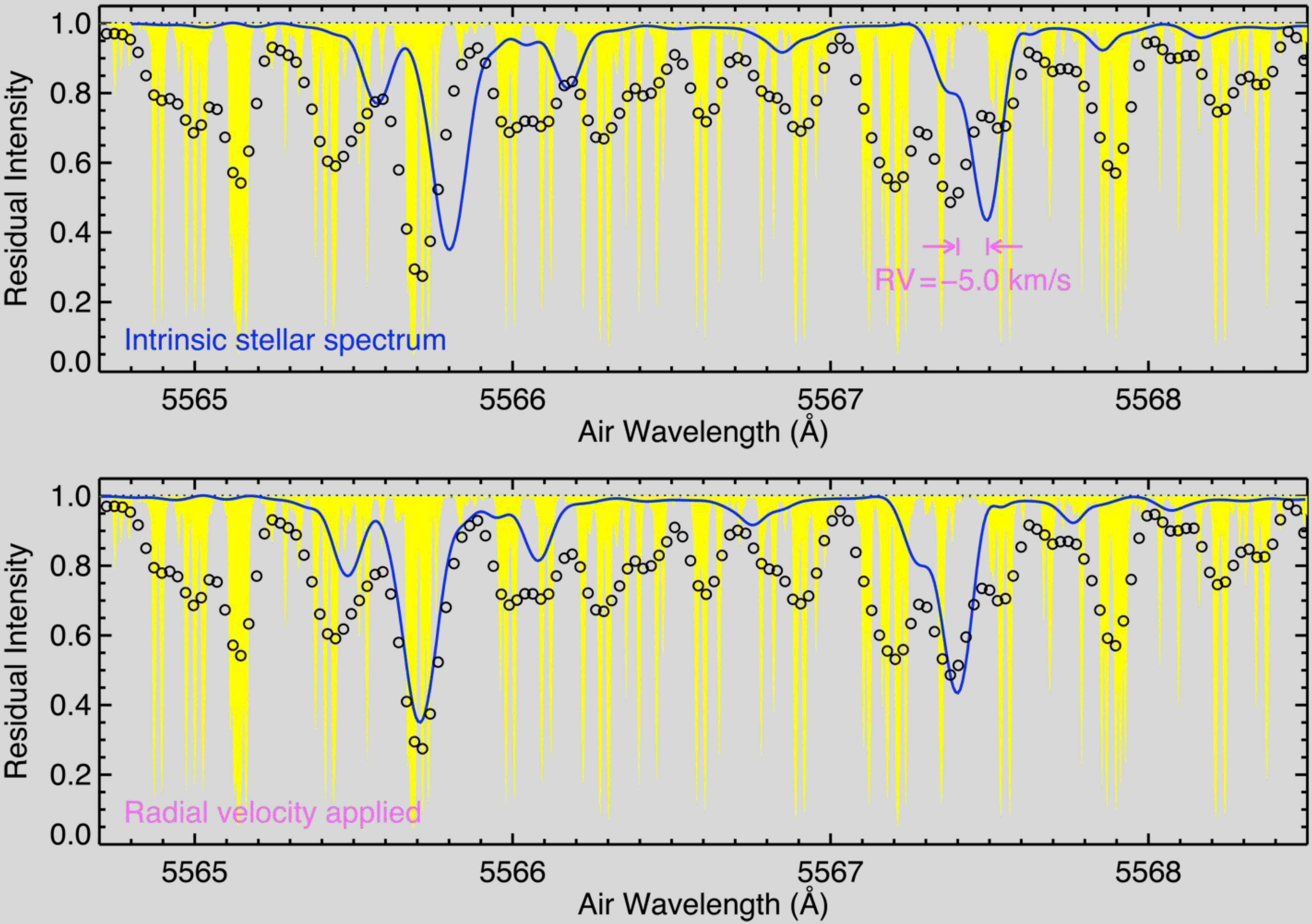
Using a Gas Absorption Cell

- Model calculation
  - Determine wavelength scale of observation
  - Shift intrinsic stellar spectrum by stellar radial velocity
  - Multiply by gas cell transmission spectrum
  - Convolve with local line spread function
  - Determine normalization function to match observation
- Free parameters for each observation
  - Wavelength scale
  - Stellar radial velocity
  - Normalization function
  - Line spread function

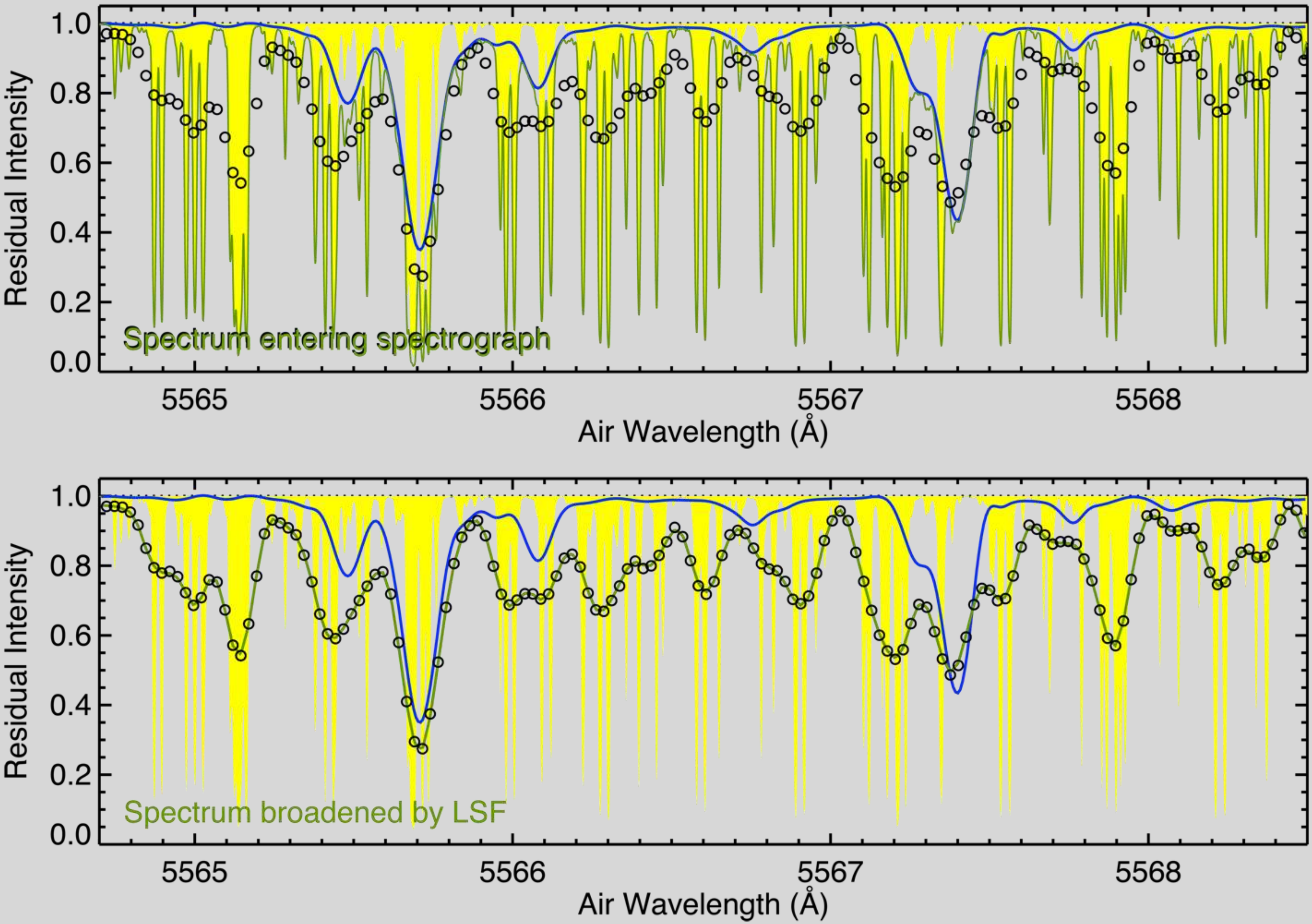
Wavelengths from Iodine Cell Absorption Lines



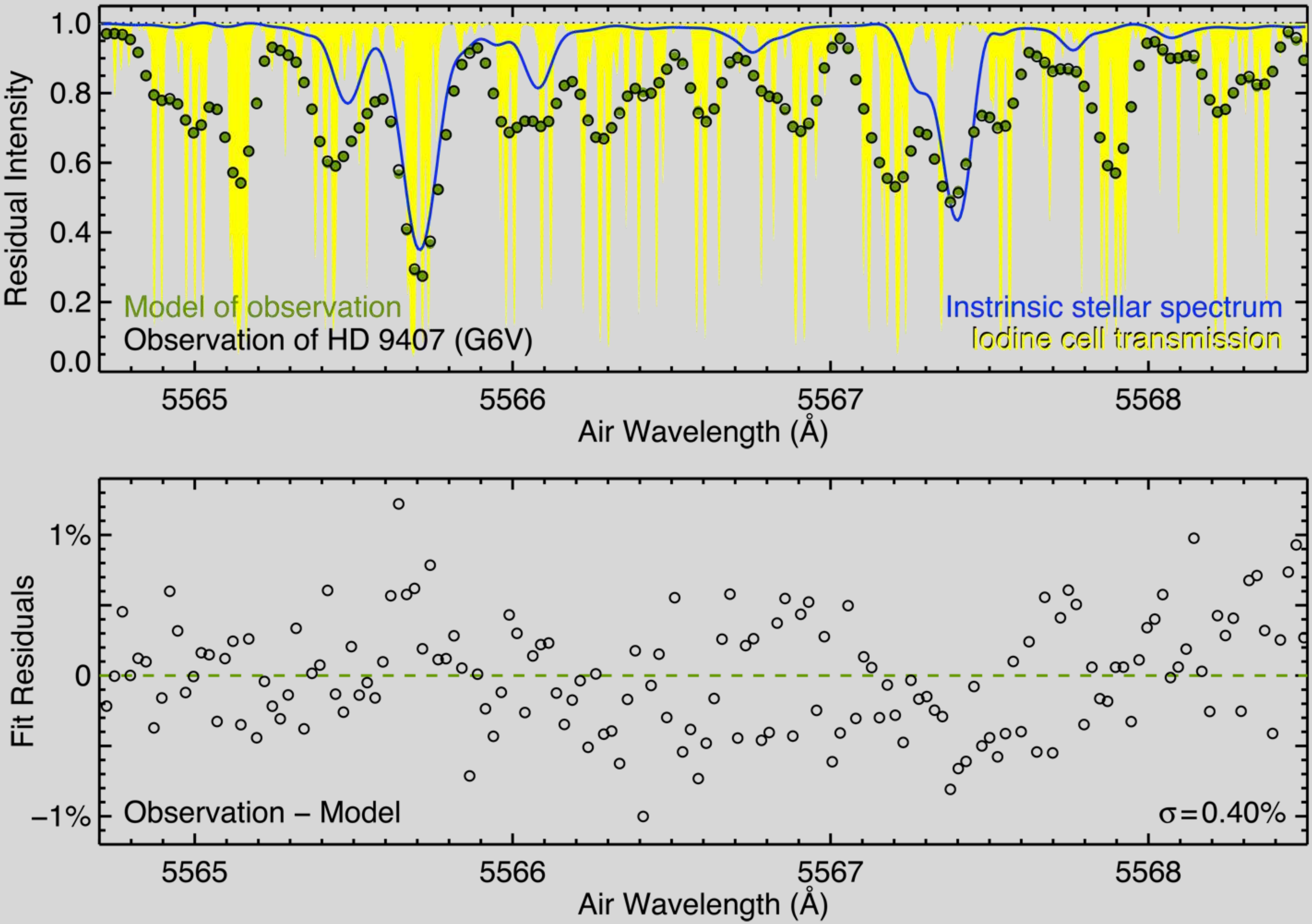
Velocity Shift of Intrinsic Stellar Sepctrum



Line Spread Function of Spectrograph



Constructed Model of Observation



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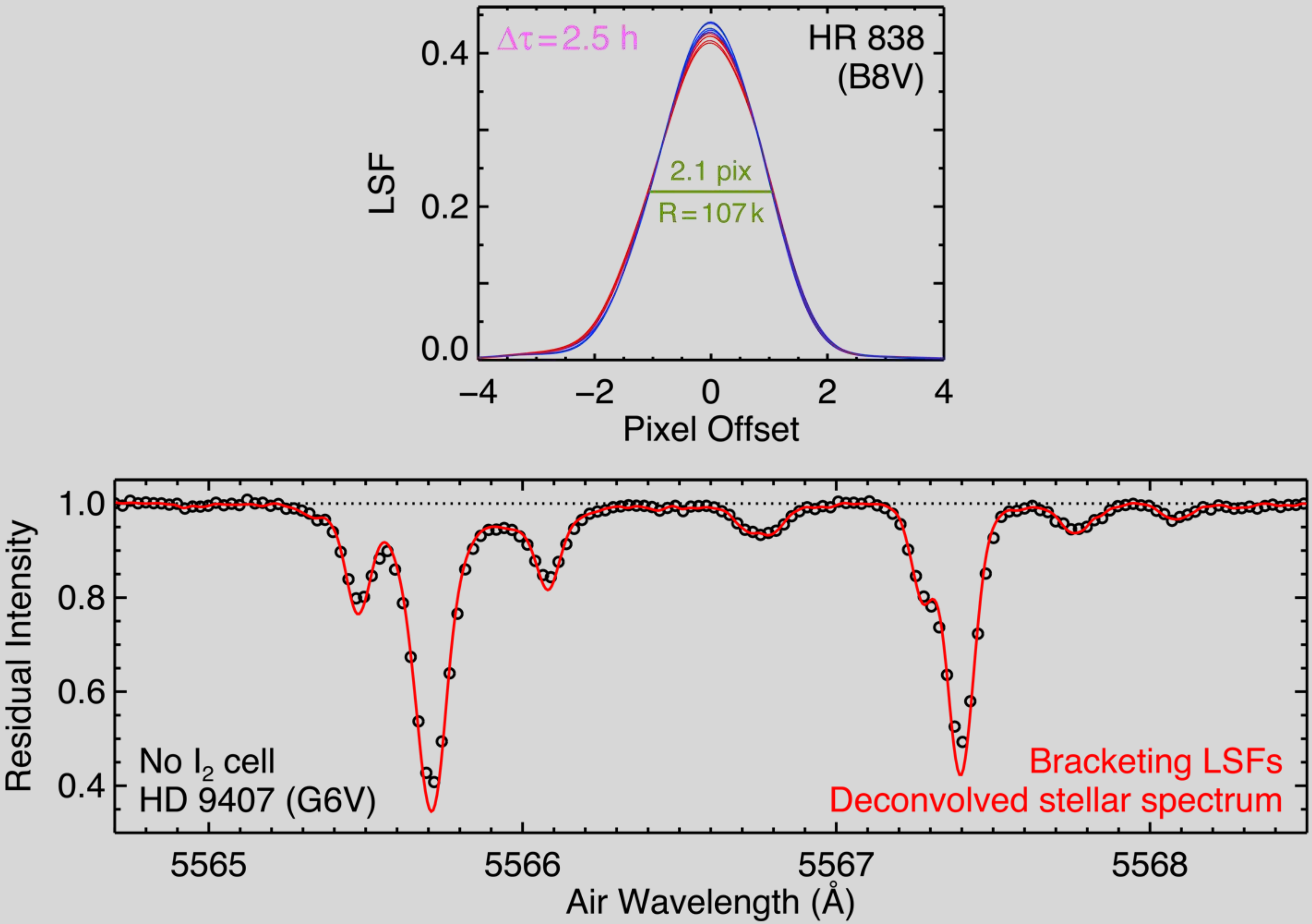
Three Ways to Determine the Intrinsic Spectrum

- Observe directly with R ~ 300 000 spectrograph

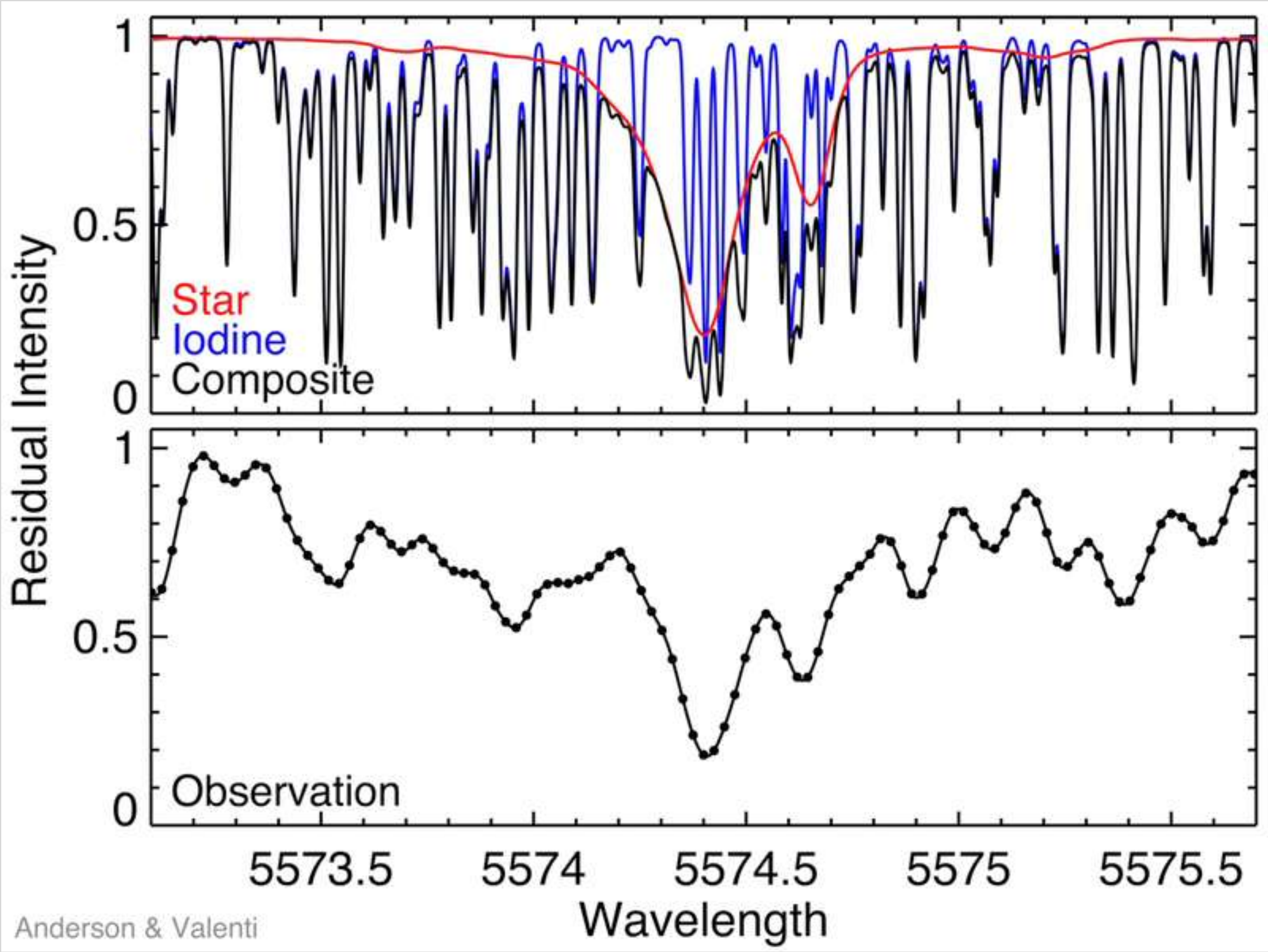
- Deconvolve using contemporaneous LSF
  - Observe B stars with iodine to get an LSF
  - Observe target star without iodine
  - Deconvolve to get intrinsic stellar spectrum
  - Assumes LSF is stable between observations

- Deconvolve using simultaneous LSF
  - Observe target star several/many times with iodine
  - “Grand solution” gives LSF and intrinsic stellar spectrum
  - Still working to understand and tune the algorithm

Deconvolution using Contemporaneous LSF

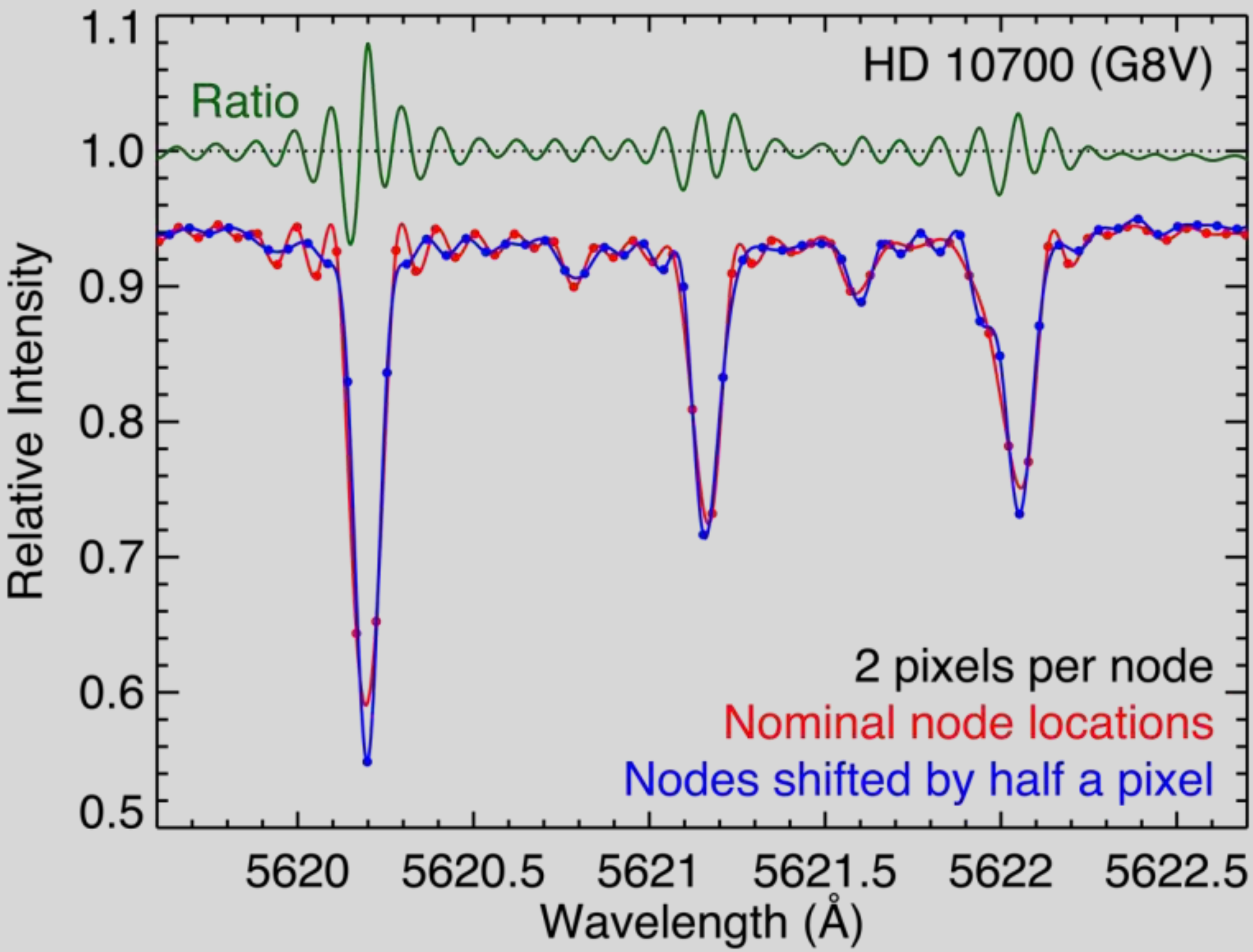


Plenty of Constraints for Grand Solution



New Code

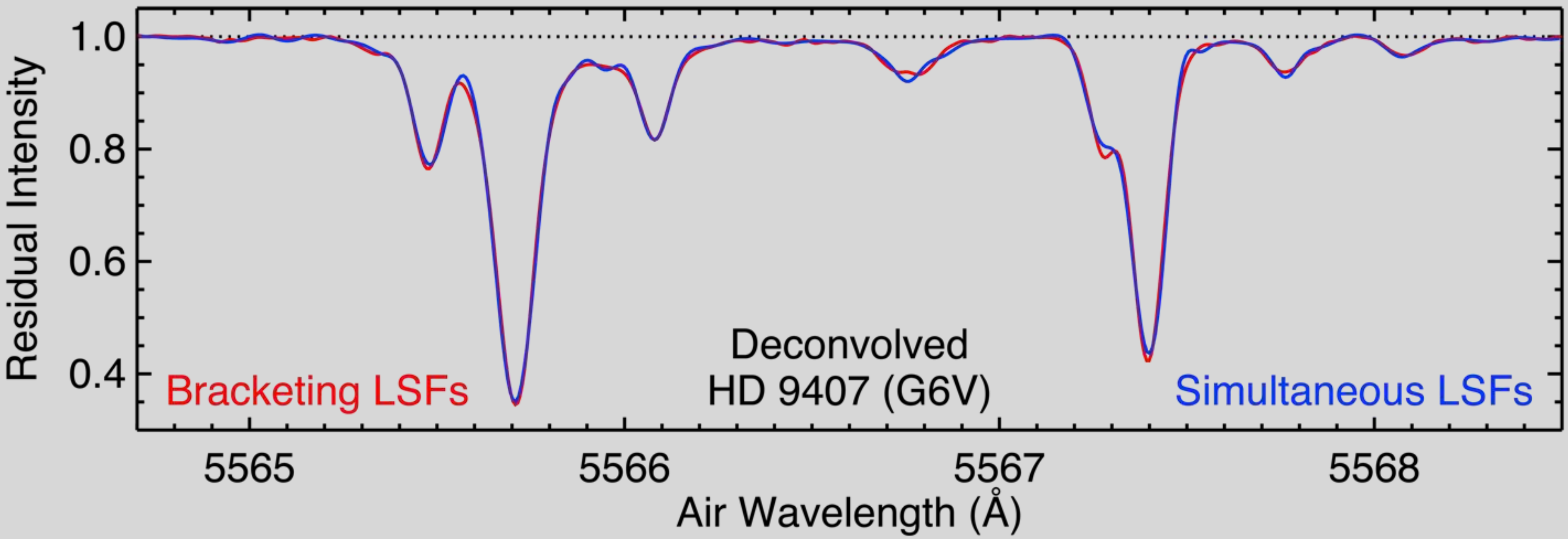
Stellar Spectrum Rings if Nodes Too Far Apart

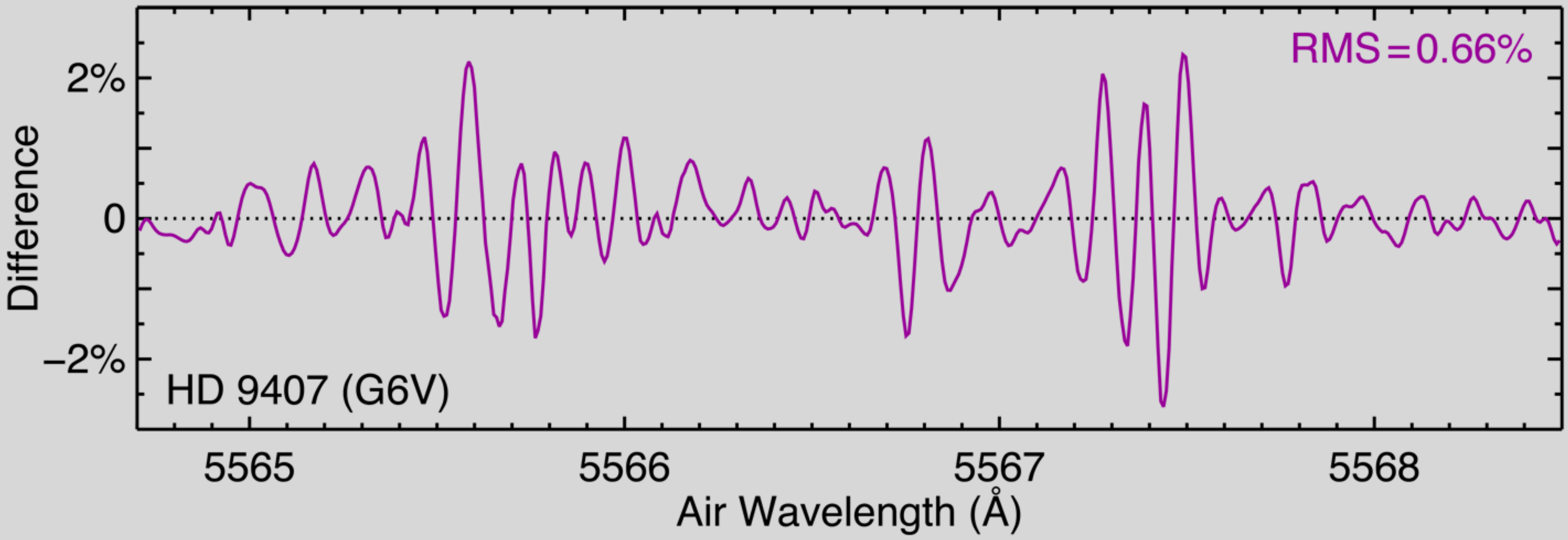


Same Set of Reduced Spectra
Completely New Analysis Code

New Code

Stellar Spectra Deconvolved Two Different Ways





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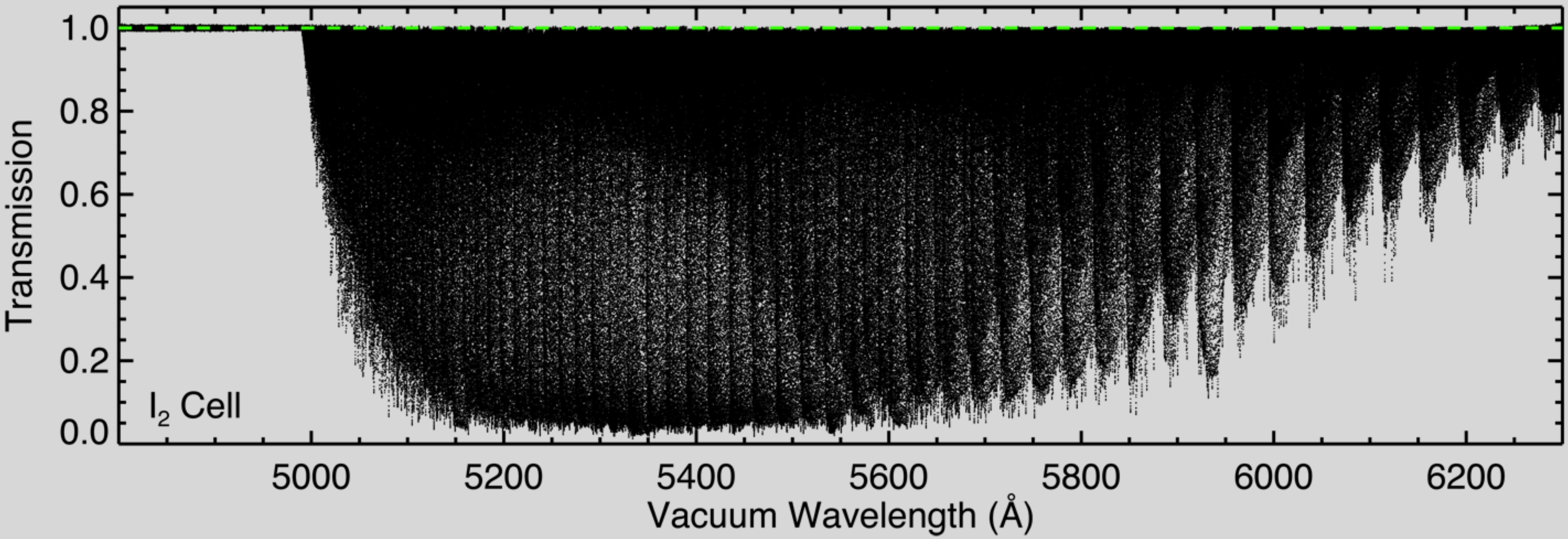
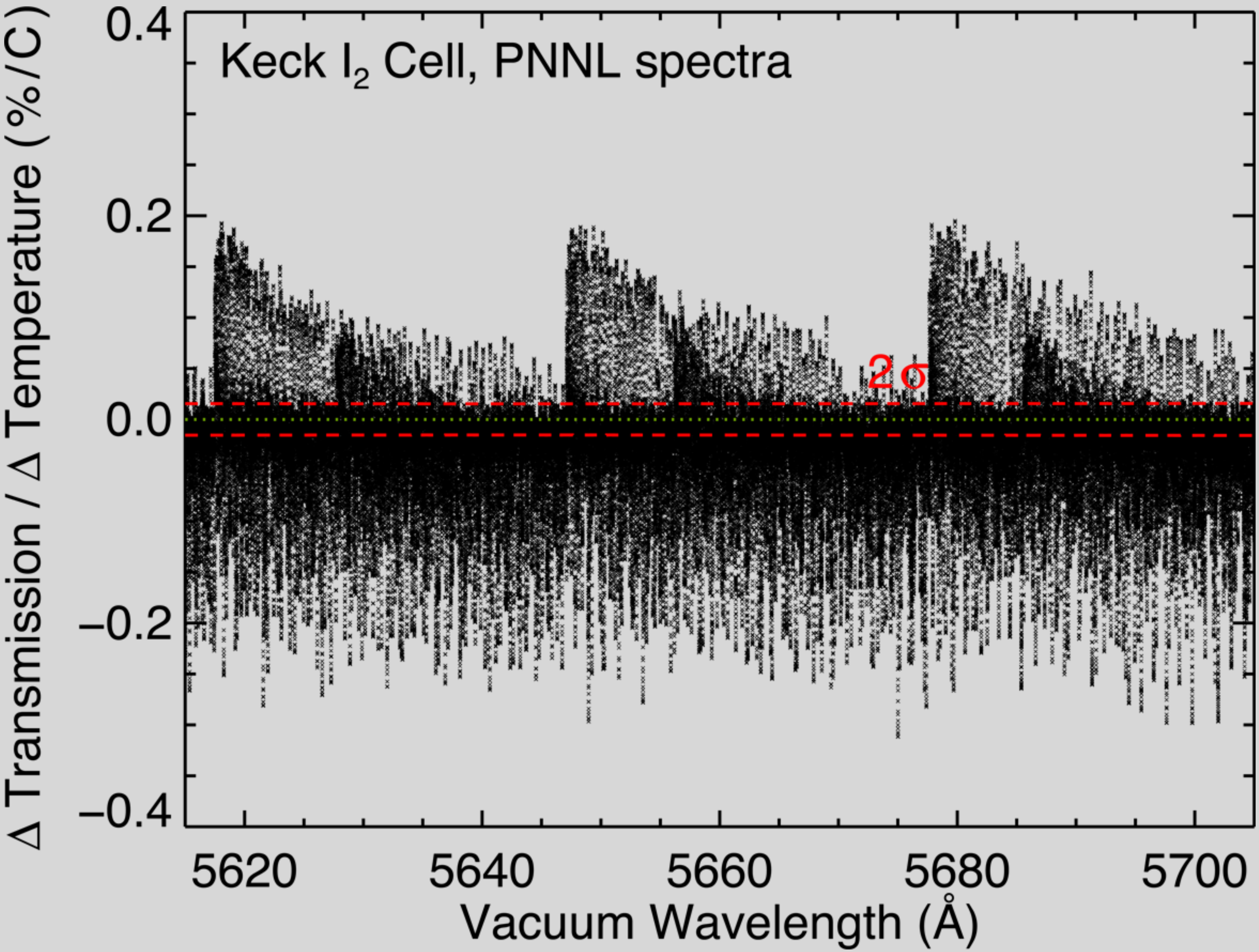
Transmission Spectrum of Keck Iodine Cell

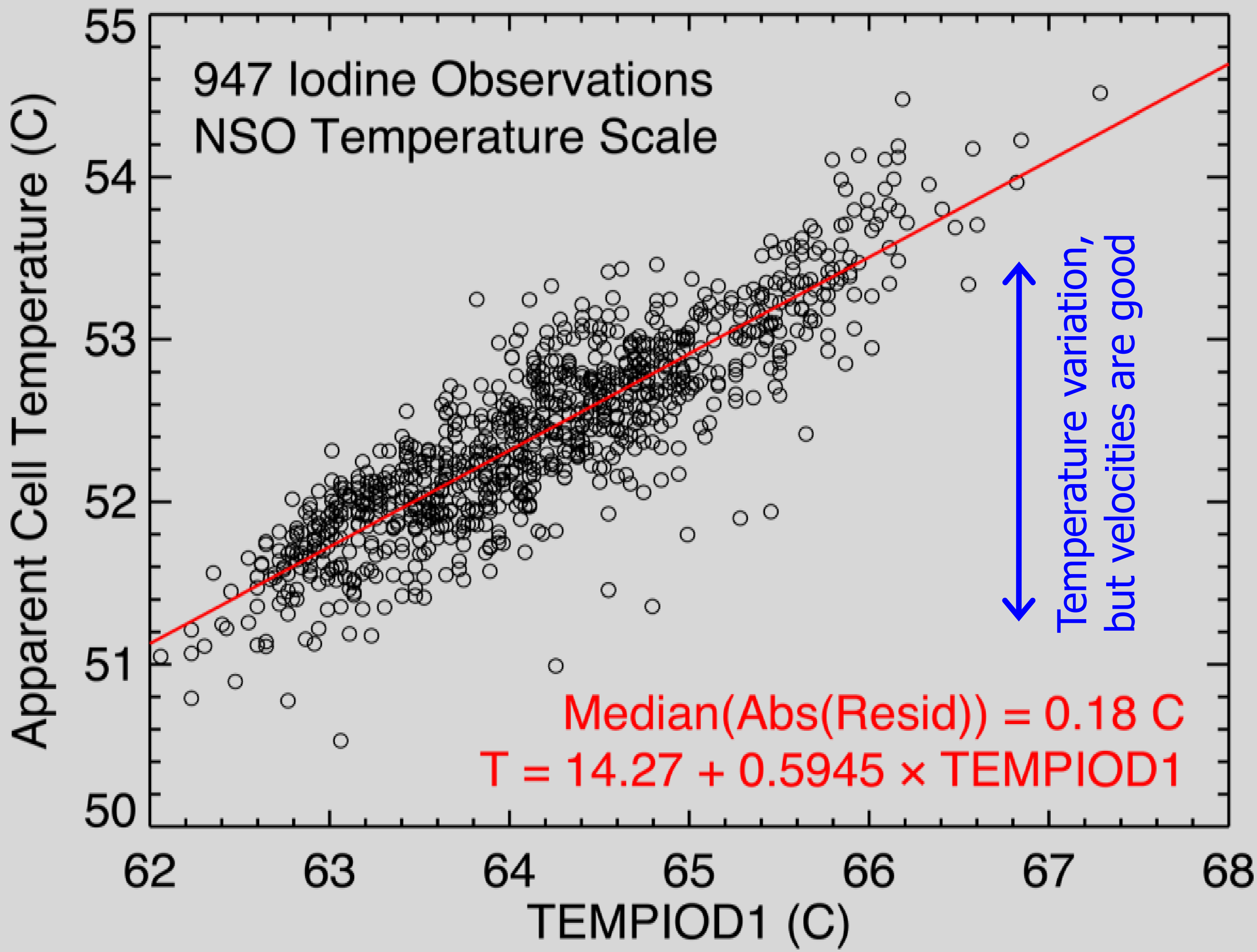


- FTS spectra at three iodine cell temperatures
  - 50, 55, and 60 C
  - Interpolate to other temperatures as needed

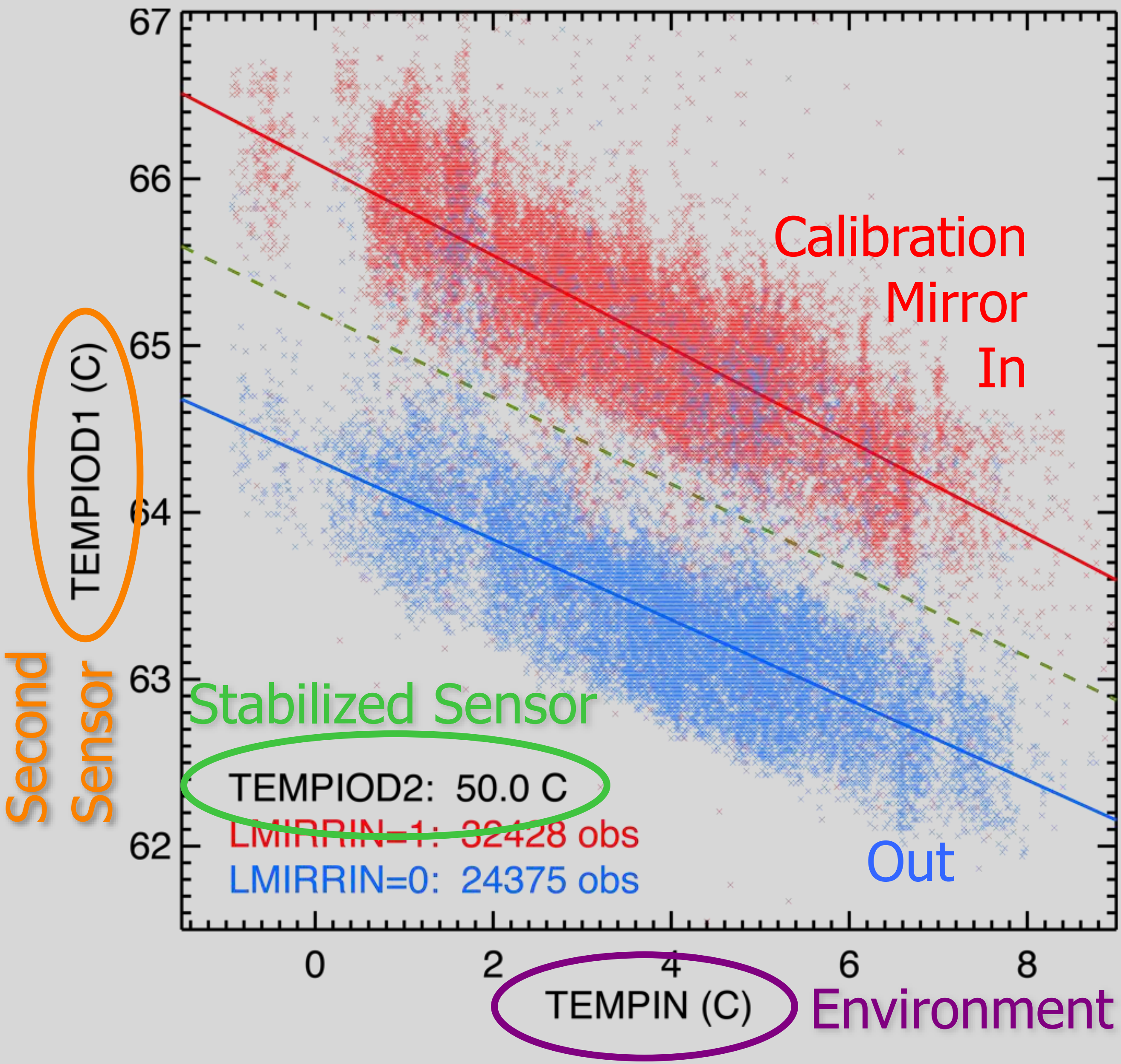
Temperature Sensitivity of Iodine Lines



Iodine Cell Temperature vs. TEMPIOD1

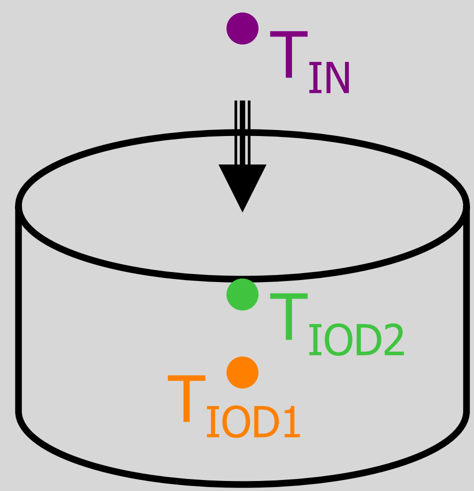


Environment Can Affect Gas Cell Temperature



Thermal Control

Radiative Cooling



Control Sensor

Second Sensor

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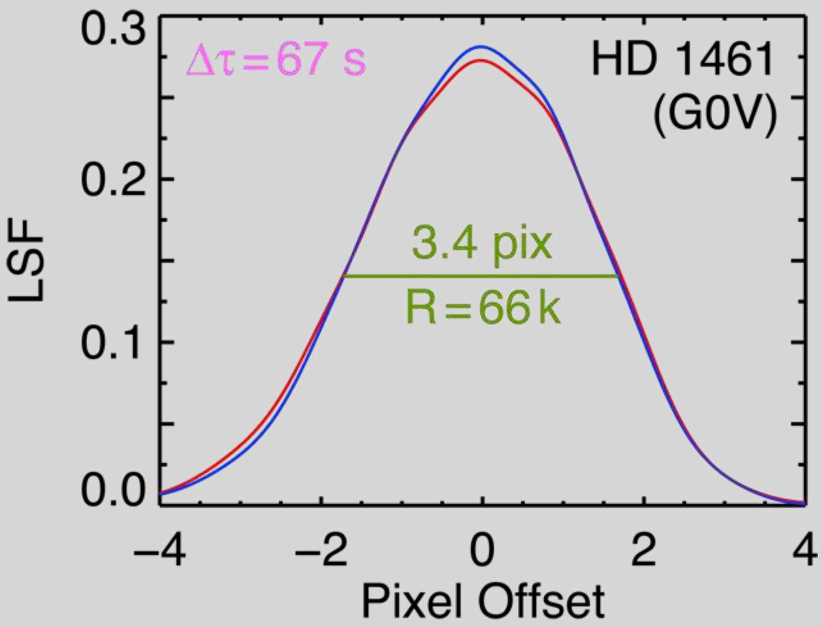
LSF Changes For Each Exposure

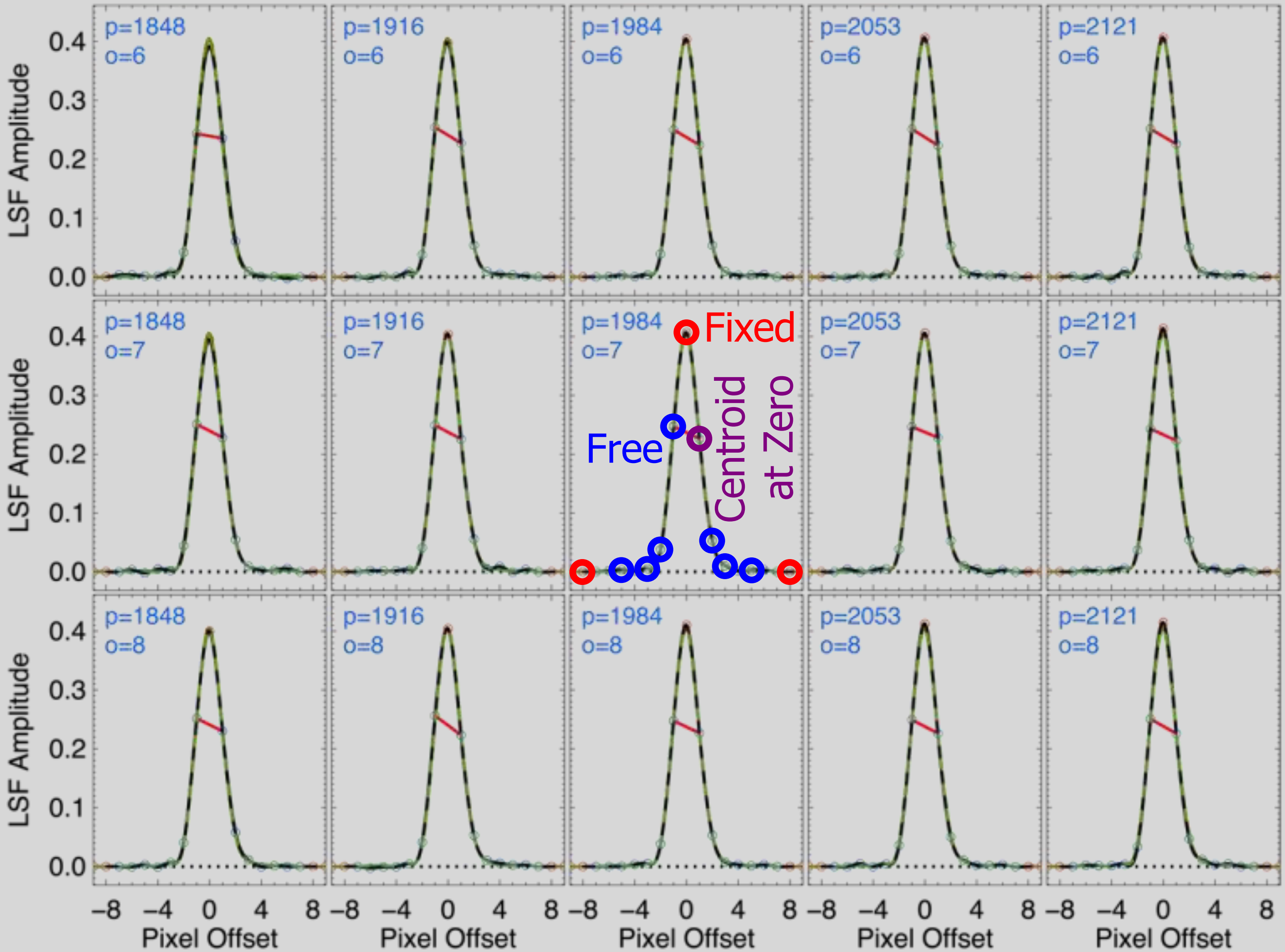


- Consecutive exposures
  - 67 second cadence
- Raw LSF shift
  - 0.0039 pixels
  - 5.2 m/s
- After modeling I_2
  - 0.5 m/s
  - Factor of 10 better

LSF Variations for Consecutive Exposures

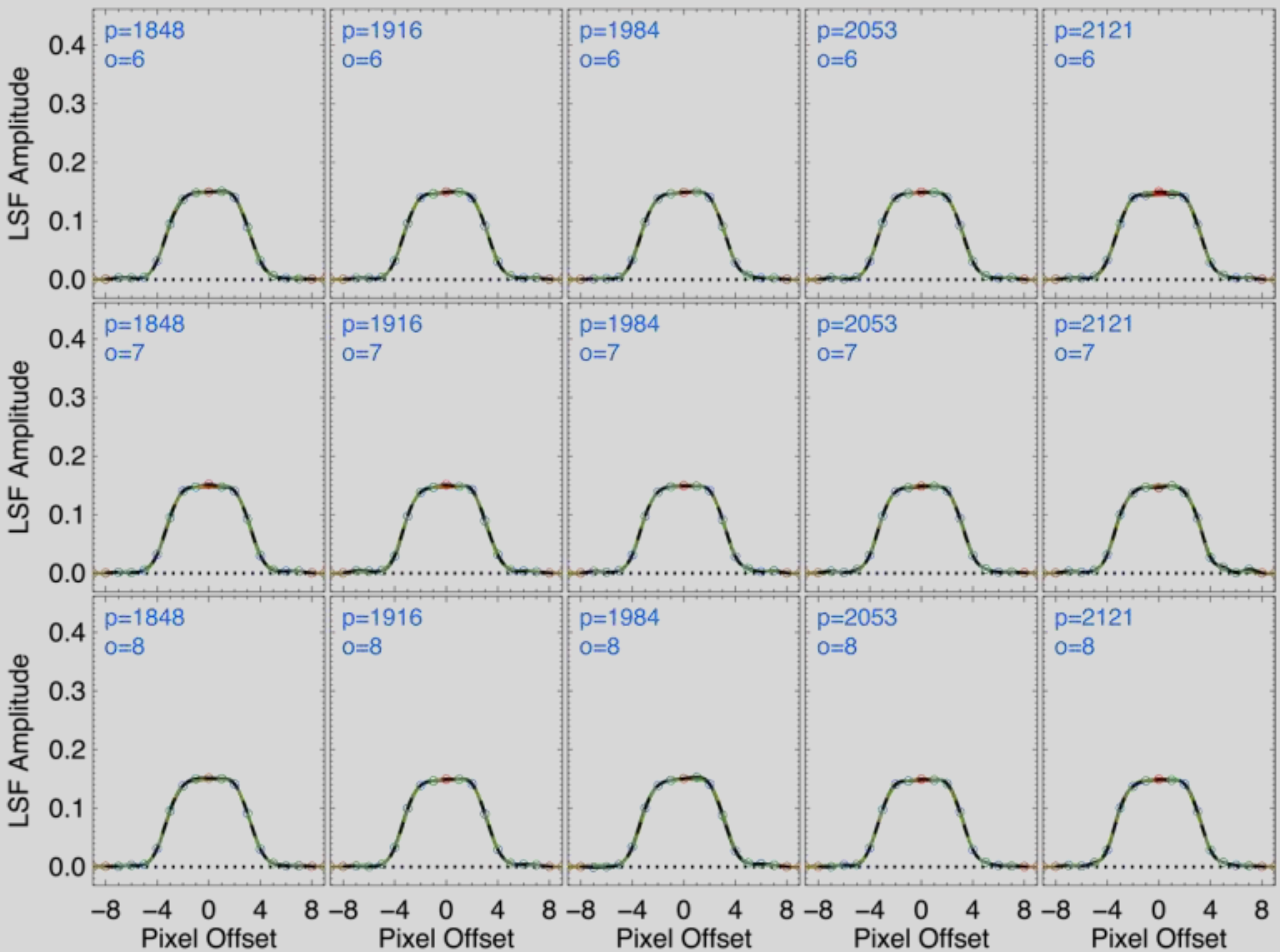
- Spectrograph is stable on short time scales
- Slit illumination may vary
  - Misguiding
  - Seeing changes
- Pupil illumination may vary
  - Misguiding with telescope out of focus
  - Particular concern for mosaic gratings
- Reduce effects with spectrograph design
  - Fiber feed
  - Precise guiding

Spline Nodes Describe Narrow LSF Core



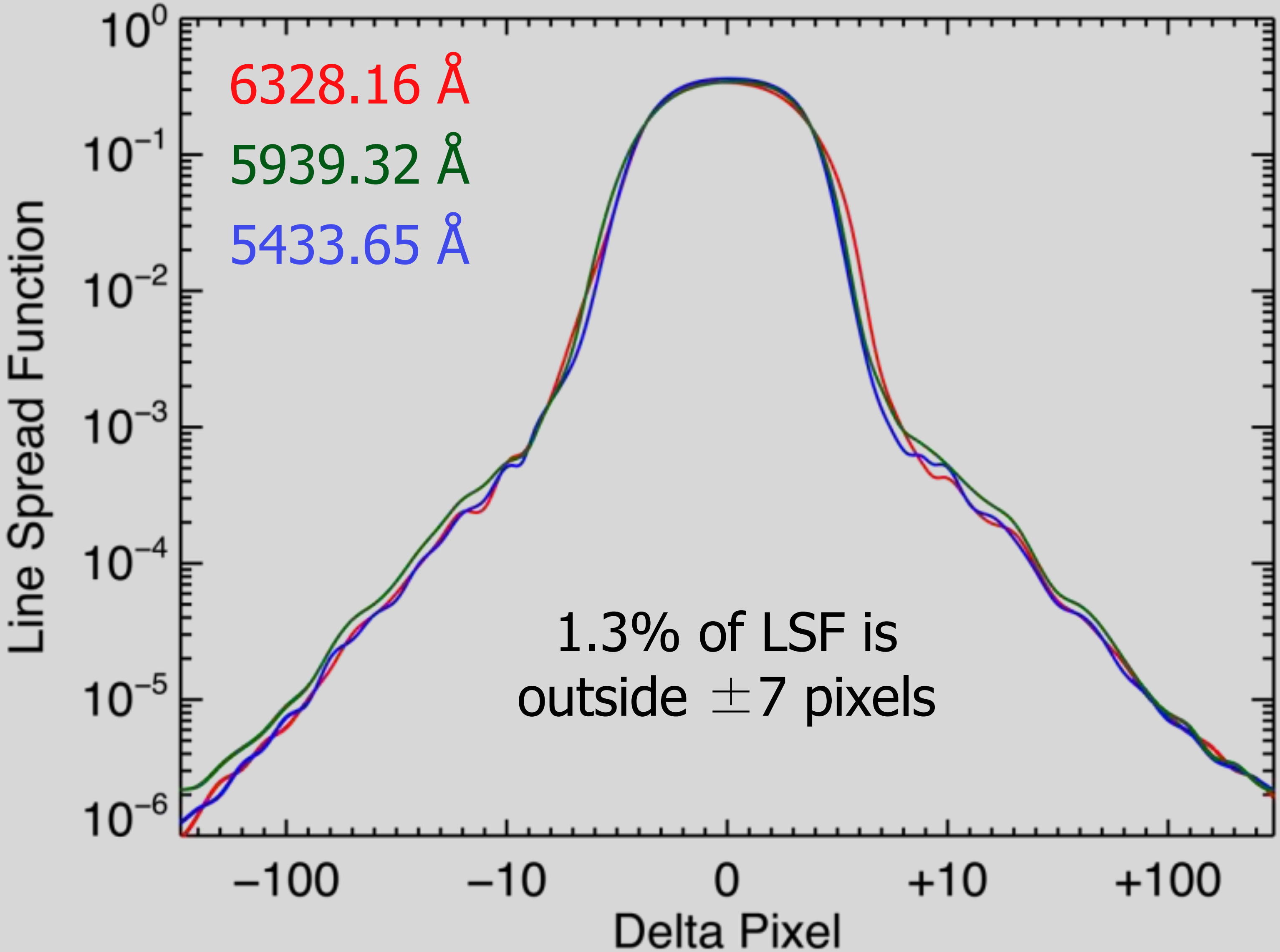
New Code

Works Equally Well for Broader LSF Core



New Code

Broad LSF Wings Seen in Laser Exposures



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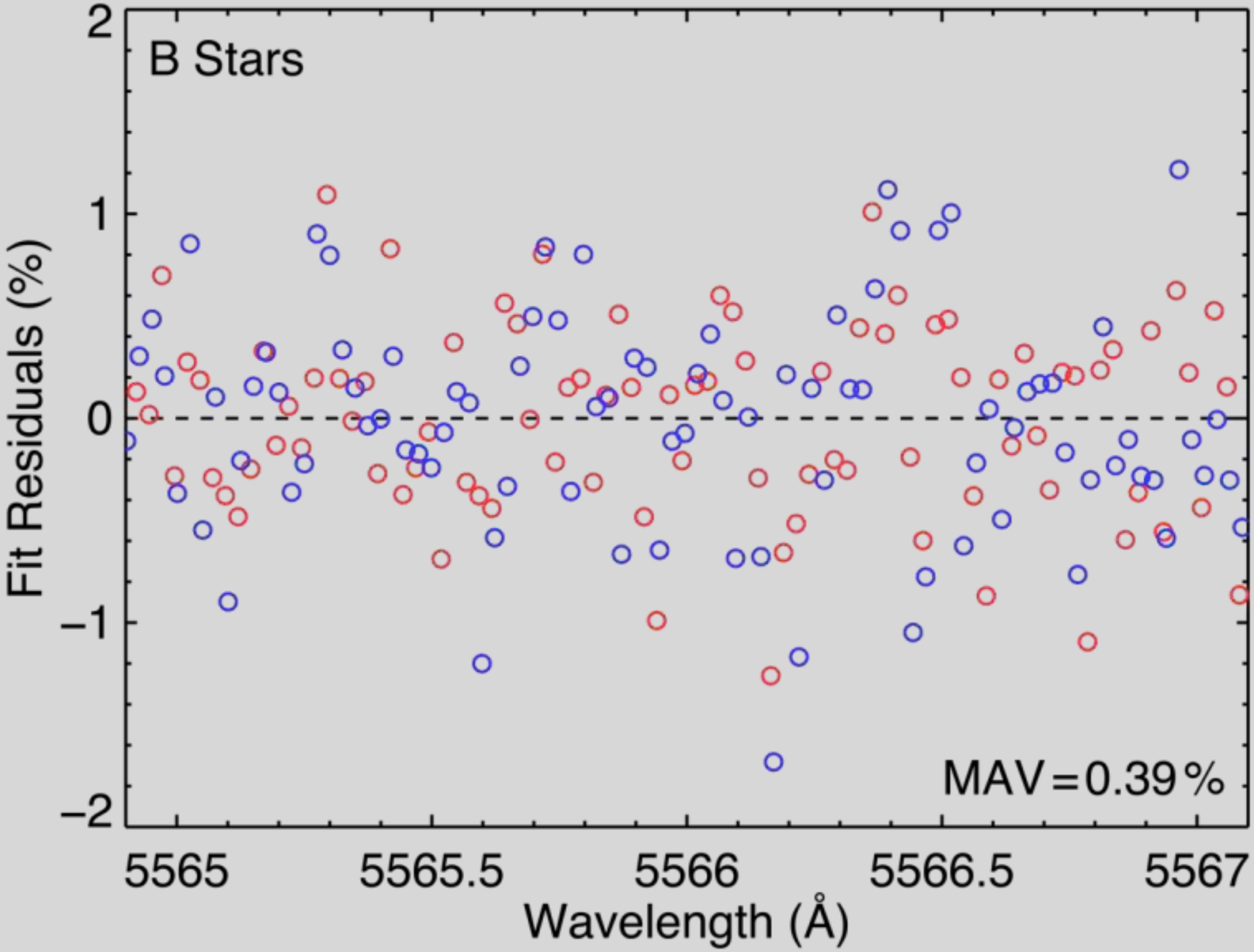
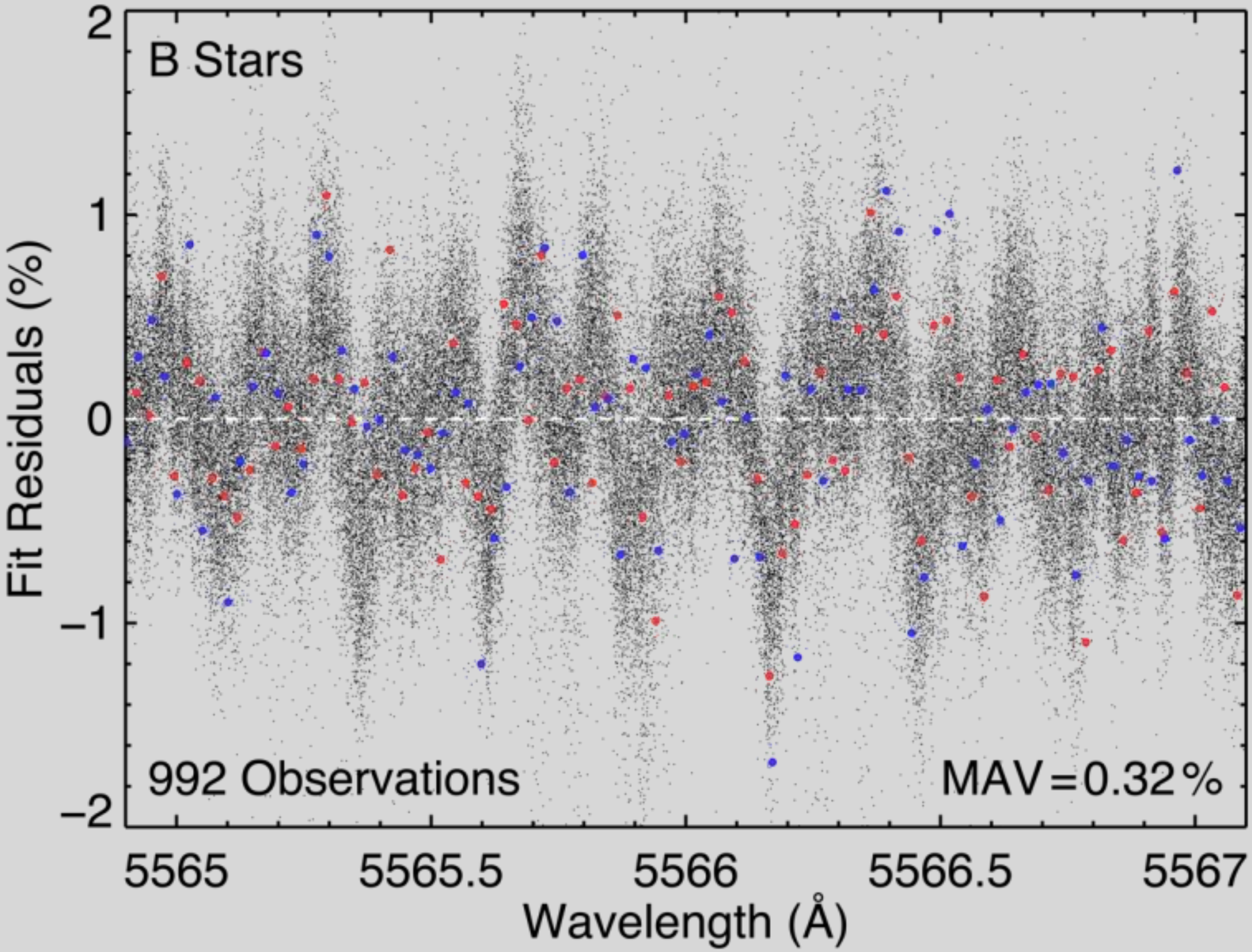
Fit Residuals for B Star Spectra



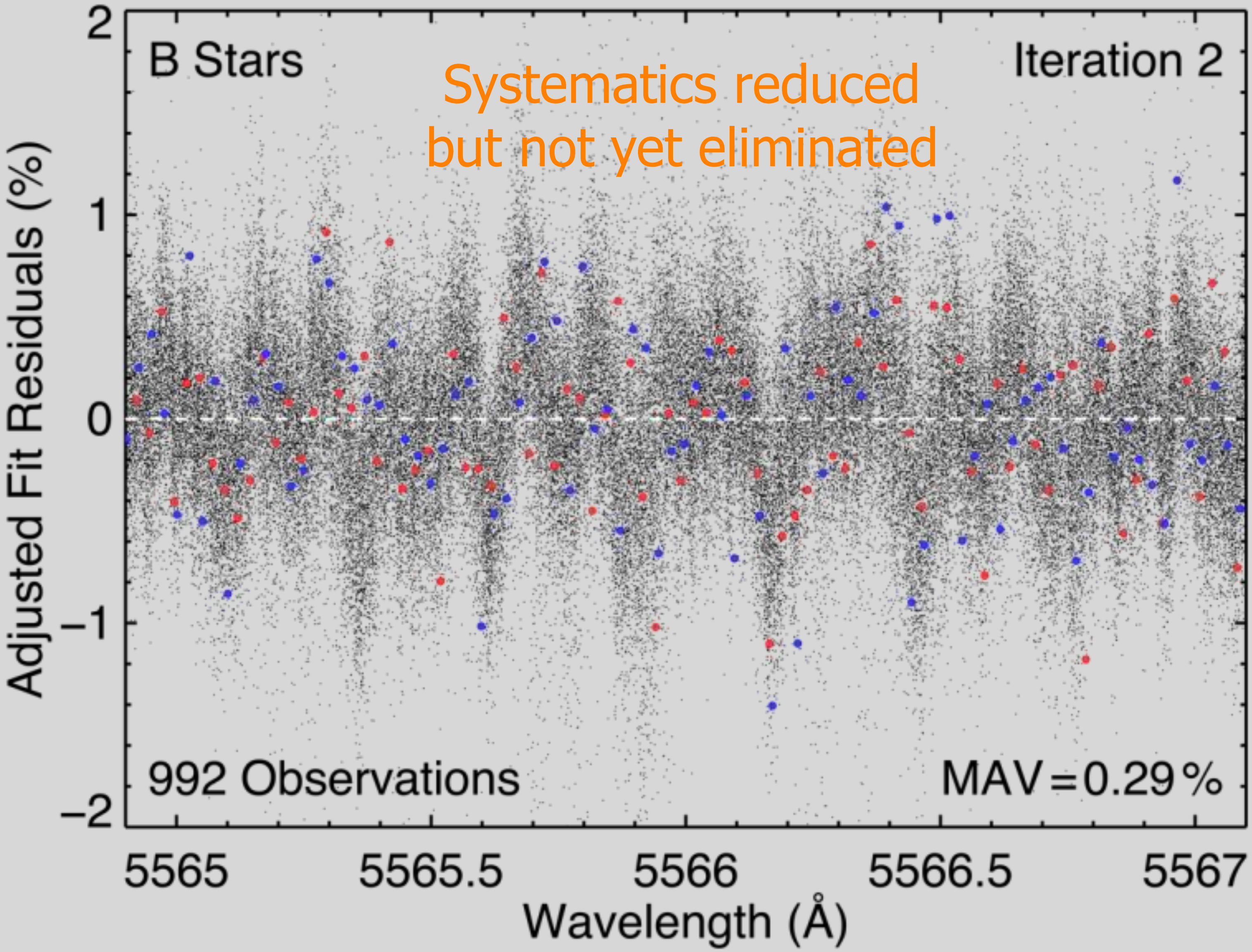
New Code

Fit Residuals for 992 B Star Spectra



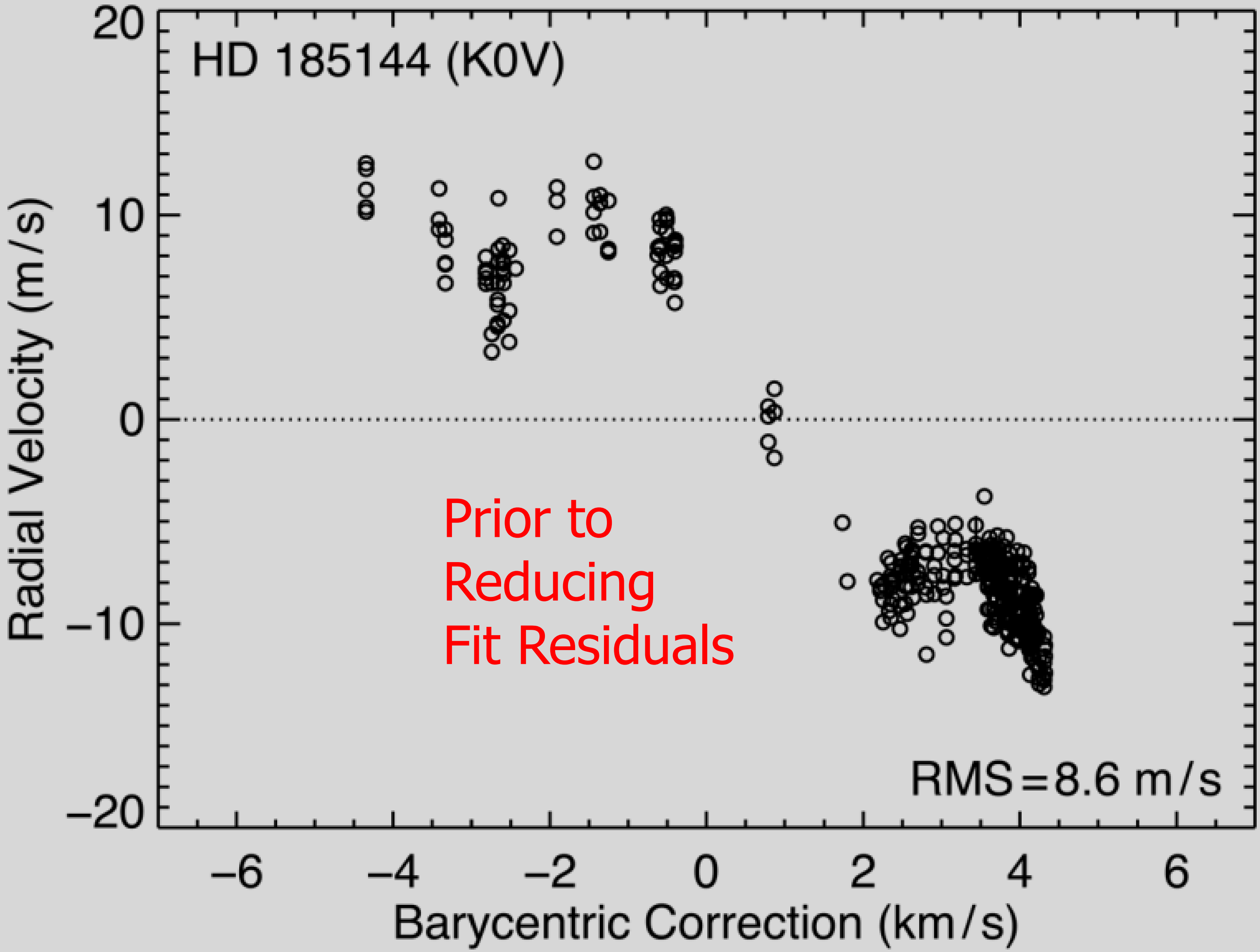
New Code

Adjusted Fit Residuals for 992 B Stars



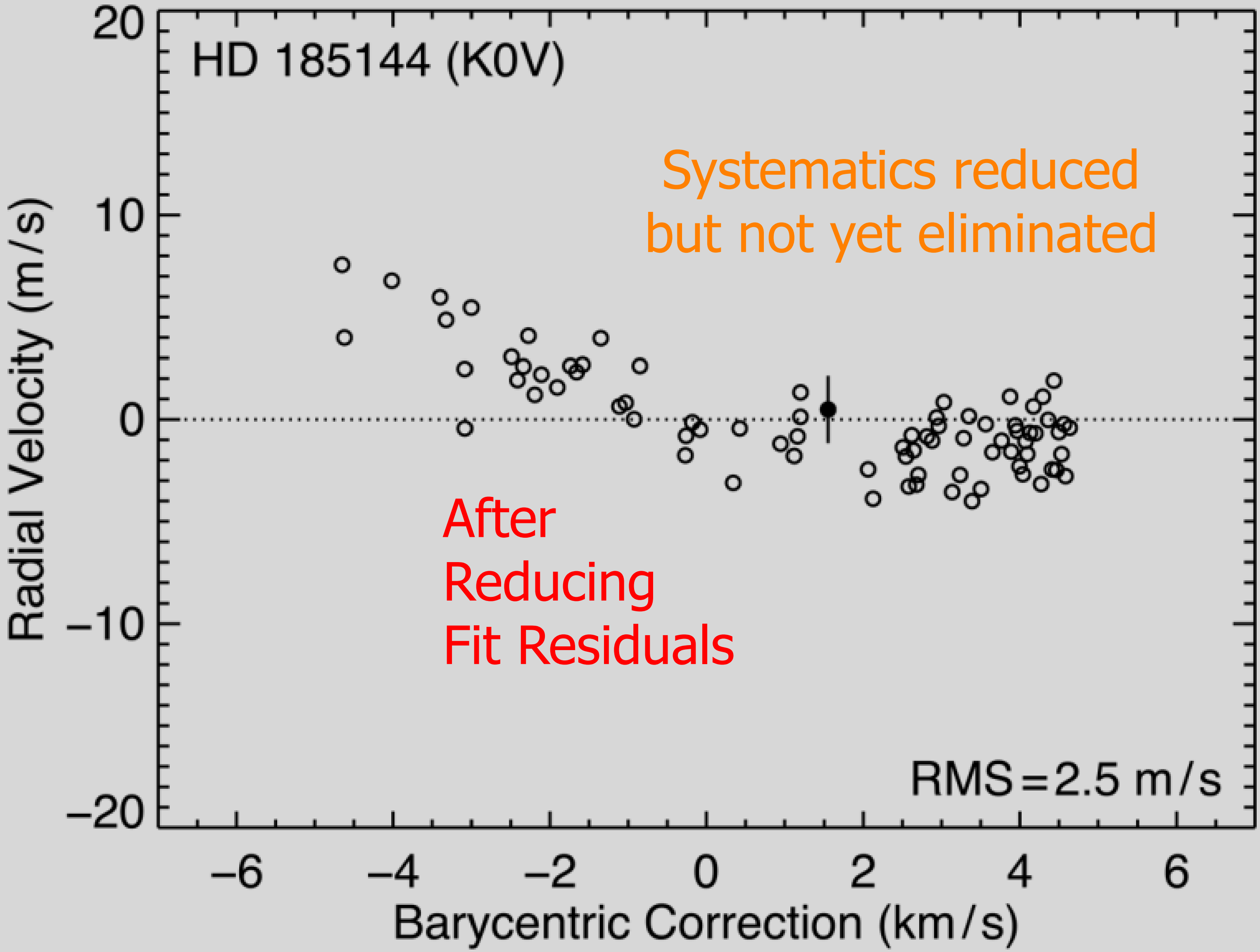
New Code

σ Dra without Residual Correction



New Code

σ Dra with Residual Correction and Uniform BC



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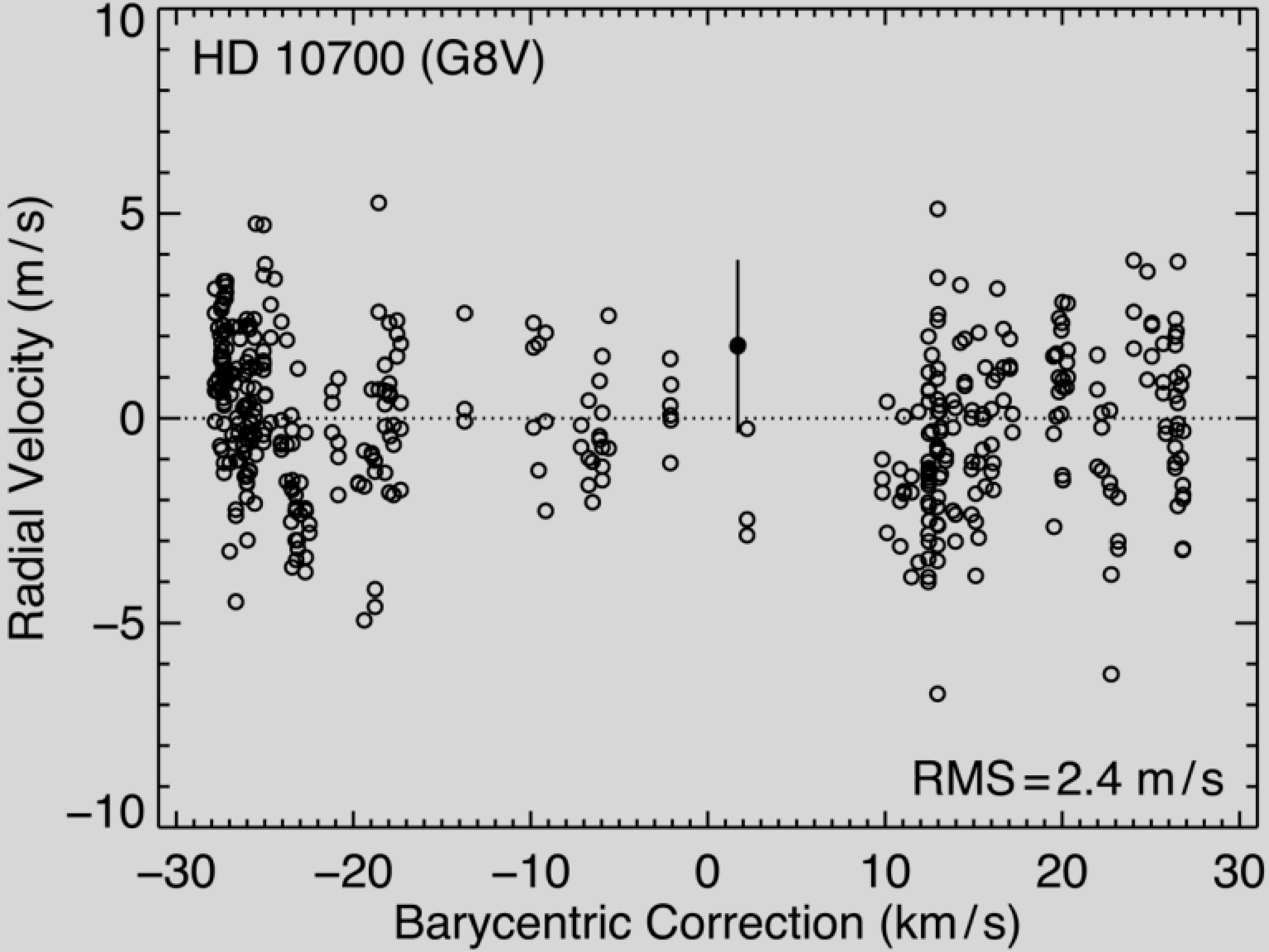
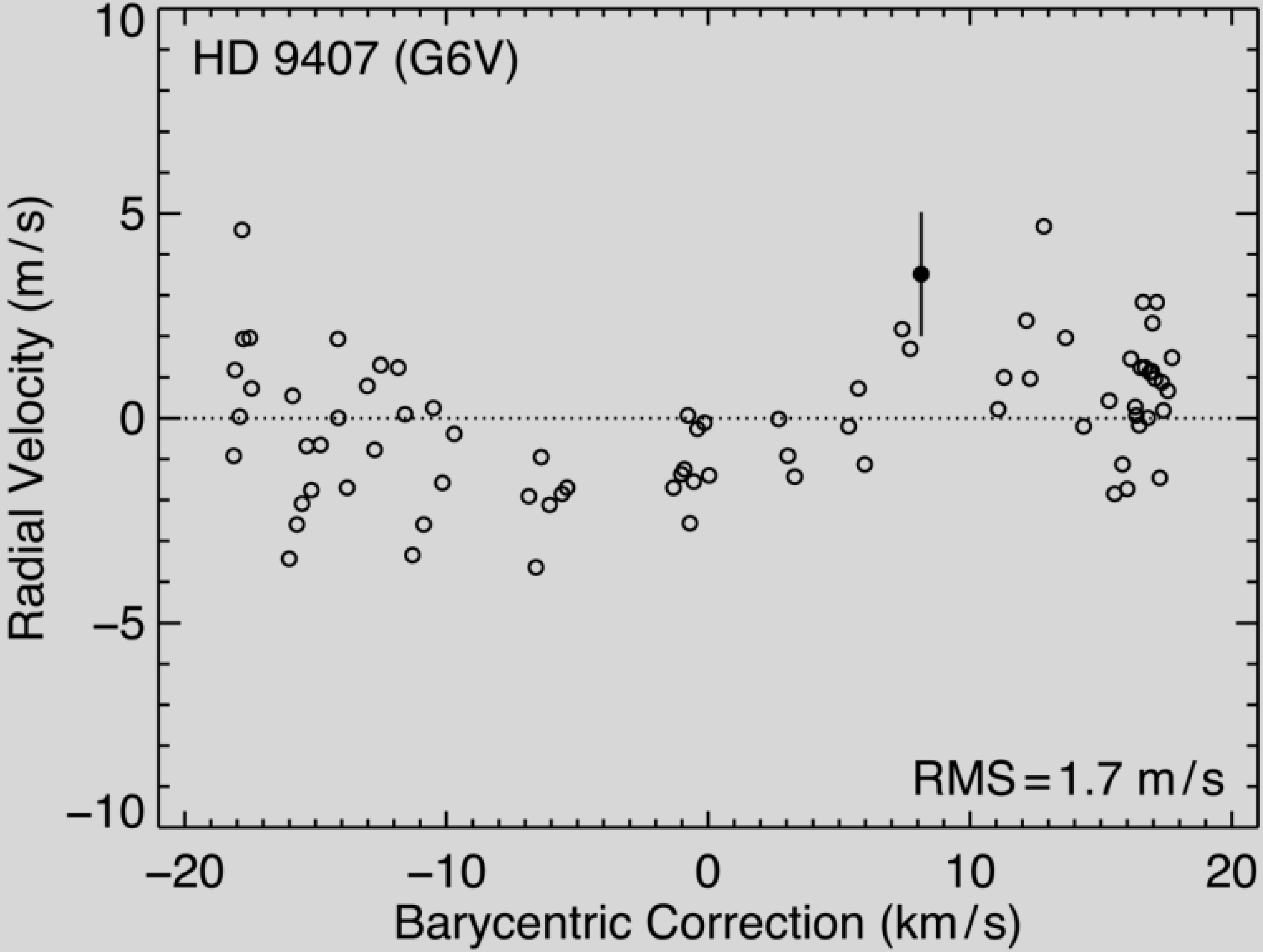
Radial Velocities for τ Cet



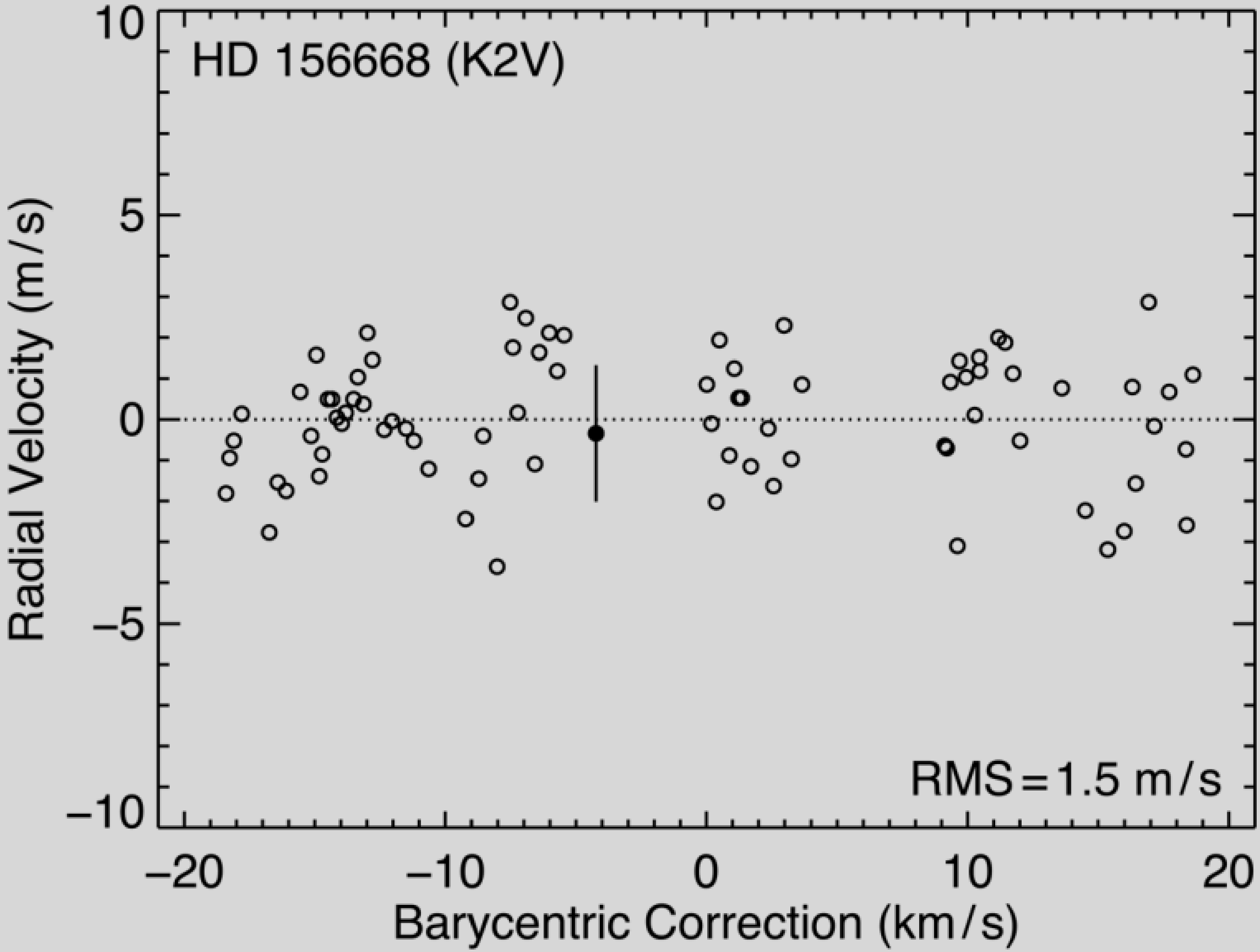
New Code

Radial Velocities for HD 9407



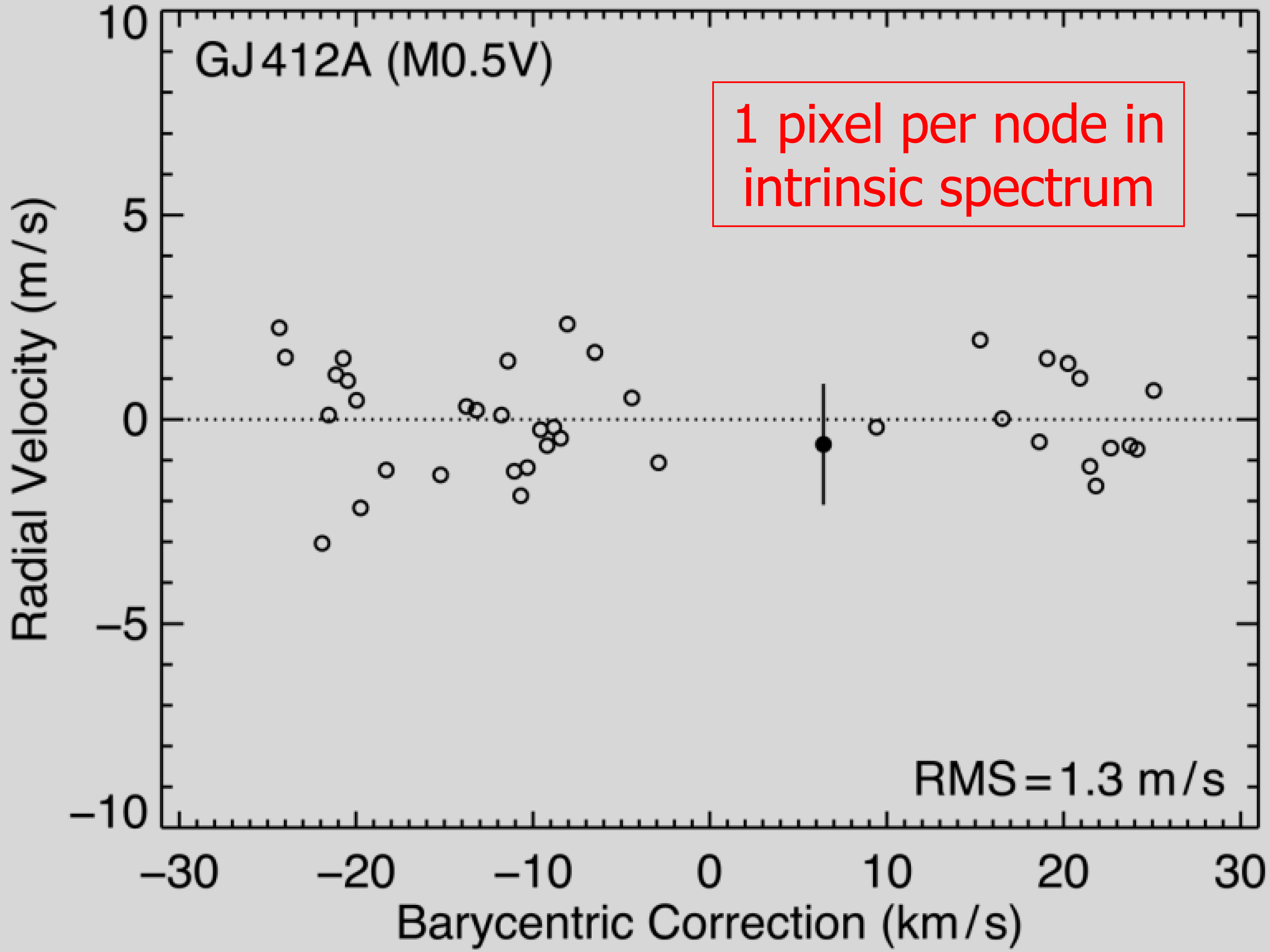
New Code

Radial Velocities for HD 156668



New Code

Radial Velocities for GJ 412a



New Code

Main Points

- Gas cell compensates for spectrograph instabilities
- Need Instrinsic stellar spectrum
  - Obtain directly with R ~ 300 000 spectrograph
  - Deconvolve using contemporaneous LSF
  - Deconvolve using simultaneous LSF (“grand solution”)
- Iodine cell temperature depends on environment
- Describe LSF by spline curve
  - Centroid at zero breaks degeneracy with wavelengths
  - Need to accommodate extended wings seen in laser
- Diagnostics of systematic errors
  - Fit residuals of many stars in iodine reference frame
  - Radial velocity versus barycentric correction
- Grand solution is starting to yield precise velocities