SAND2022-10565C

WOOTTON CAPP

The White Dwarf Photosphere Experiment

Bart Dunlap, UT Austin

Z Fundamental Science Workshop

August 3, 2022

Collaborators: Mike Montgomery (UT), Patty Cho (UT), Bryce Hobbs (UT), Jackson White (UT), Don Winget (UT), Marc Schaeuble (SNL), Thomas Gomez (SNL), Tai Nagayama (SNL), Jim Bailey (SNL), Sonal Patel (SNL), Georges Jaar (UNR), Patrick Dufour (U Montreal), Ivan Hubeny (UA)

TEXAS
The University of Texas at Austin

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U.S. DEPARTMENT OF ENERGY
Office of Science

NSF

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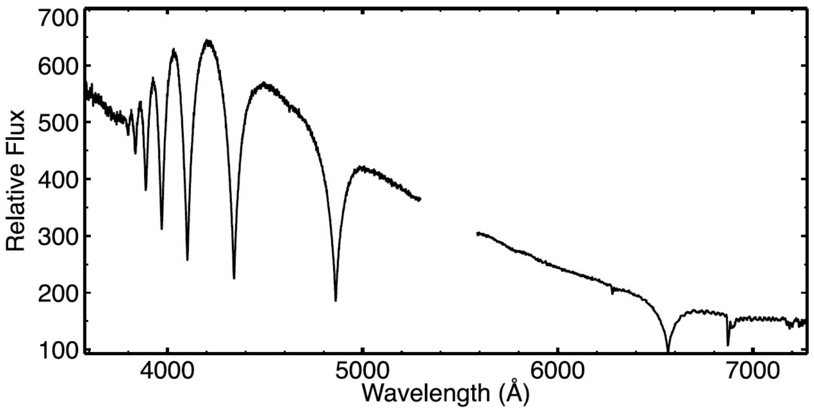
Overview

- What do white dwarf spectra tell us?
  - Mass, Temperature, Atmospheric Composition
- How do white dwarfs help answer broader astrophysical questions?
  - Ages of stellar populations, exoplanets, cosmology
- Why do we think there are problems with spectroscopic mass determinations?
  - Independent mass estimates disagree
- What developments are underway with the white dwarf photosphere experiment?
  - Higher densities in hydrogen
  - Independent electron density diagnostic (PDV)
  - Helium update
  - Theory update: H2 quasi-molecular features, continuum lowering/occupation probability

The Importance of White Dwarf Spectra



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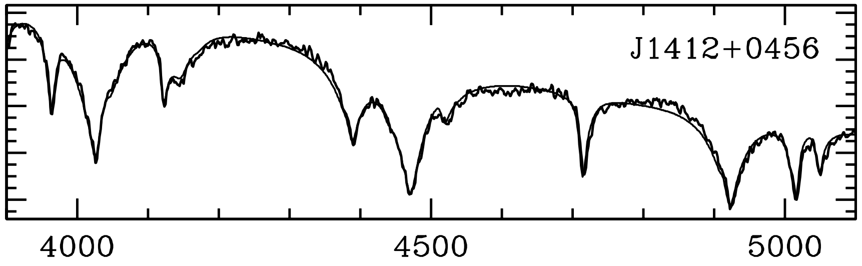

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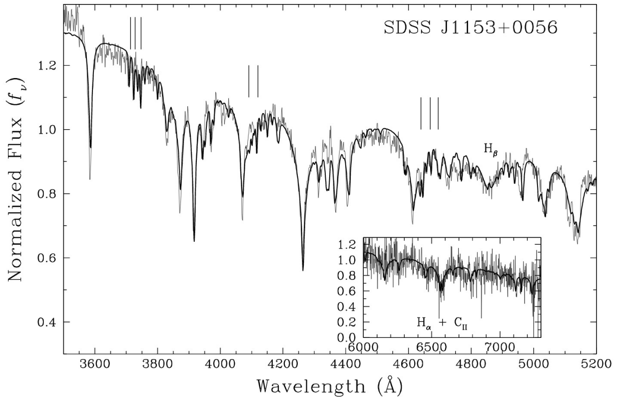

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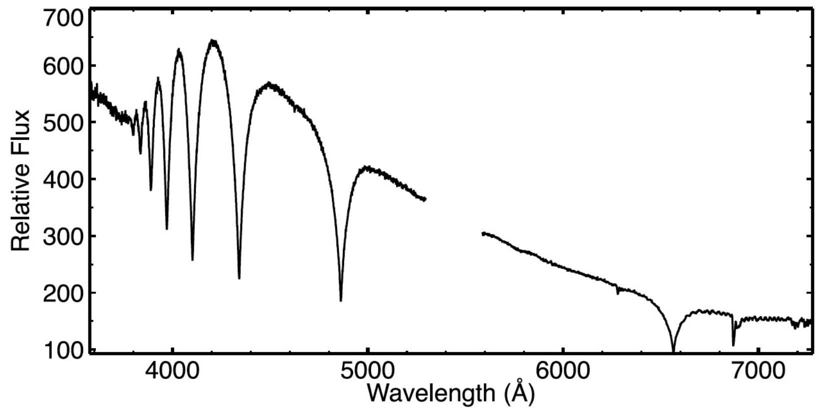
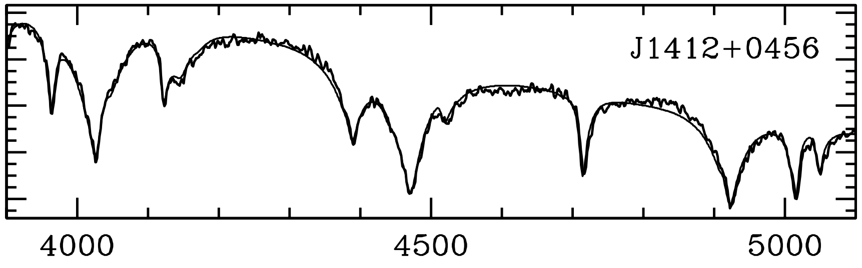
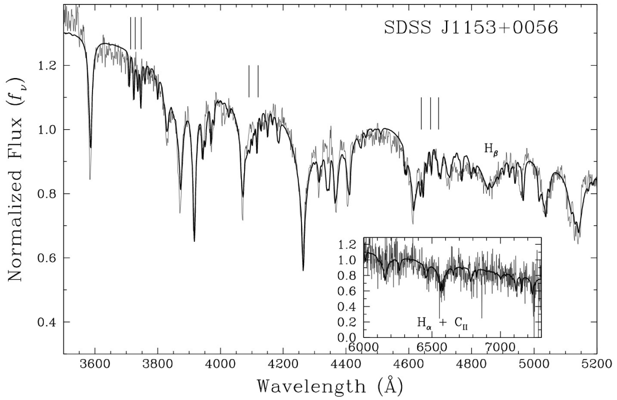
What do they tell us?

White Dwarf Spectra → Composition, Mass, & Temperature







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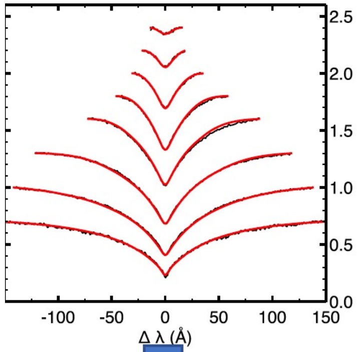


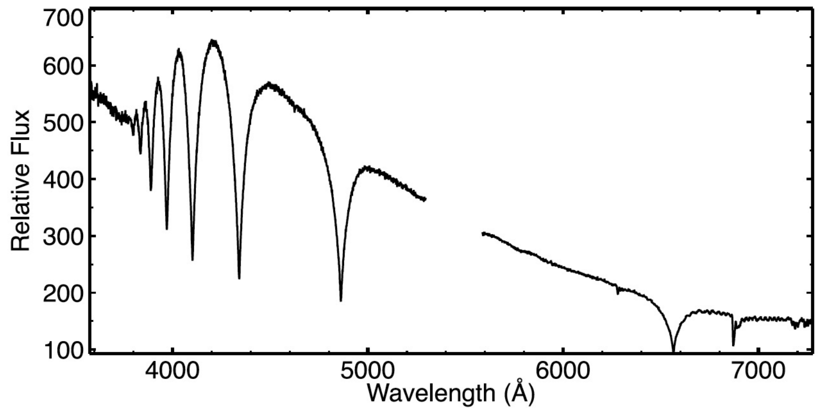
Model Fits to WD **Spectral Lines**

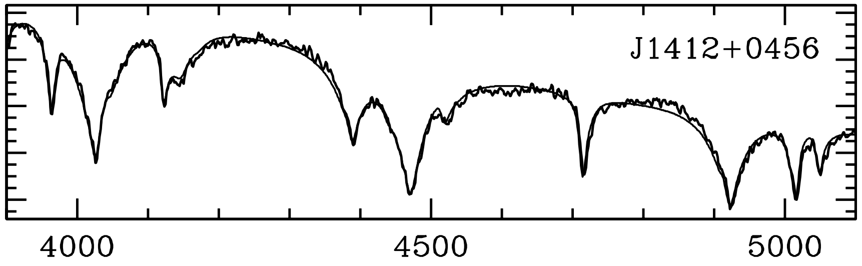
log g => Mass
Temperature
Composition

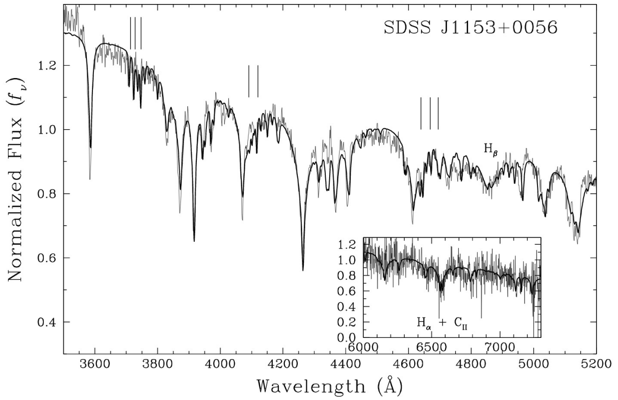
(b/c more massive WDs have smaller radii)

What good are these?

White Dwarf Spectra → Composition, Mass, & Temperature







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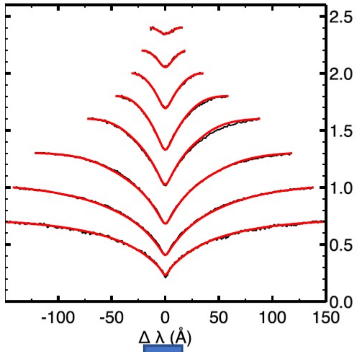

Model Fits to WD **Spectral Lines**

log g => Mass
Temperature
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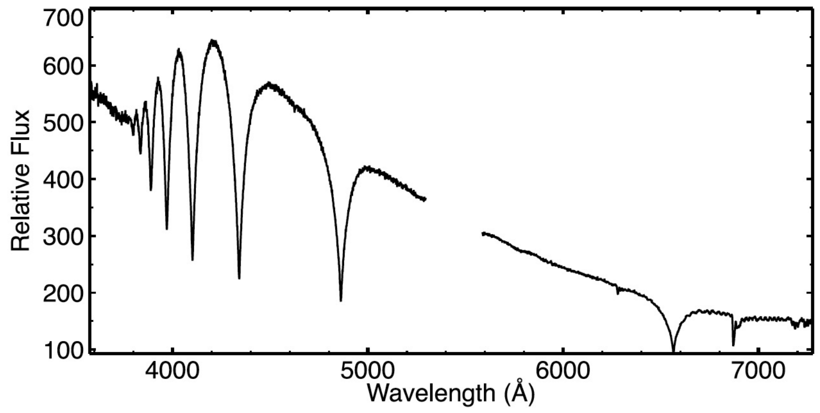
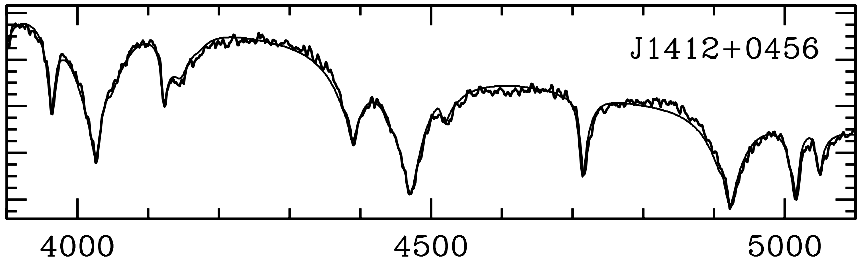
Age & History of the Galaxy

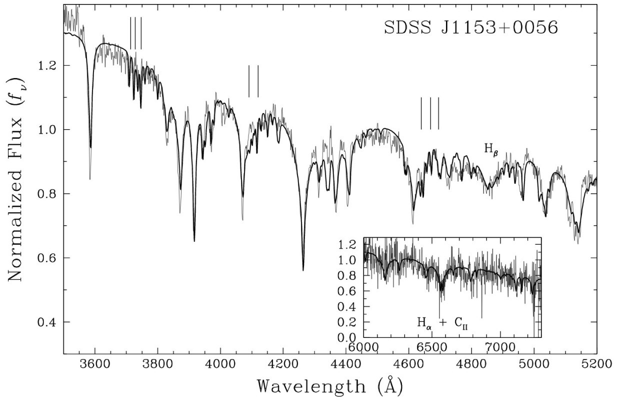
Interior Composition of Exoplanets

Supernova Formation/ Precision Cosmology

White Dwarf Spectra → Composition, Mass, & Temperature







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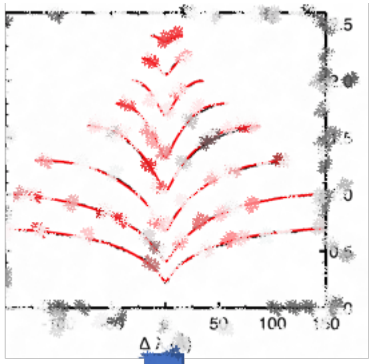

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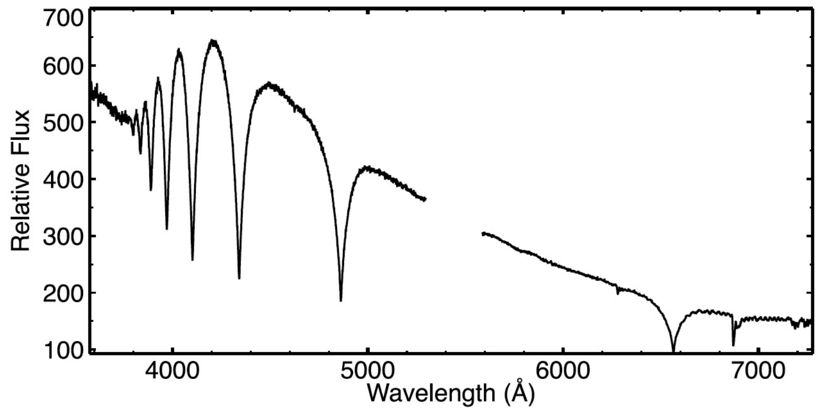

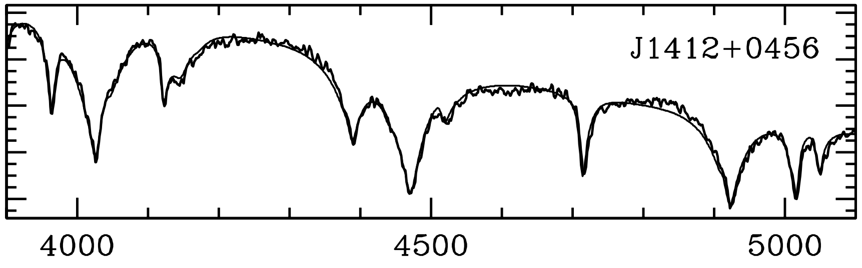

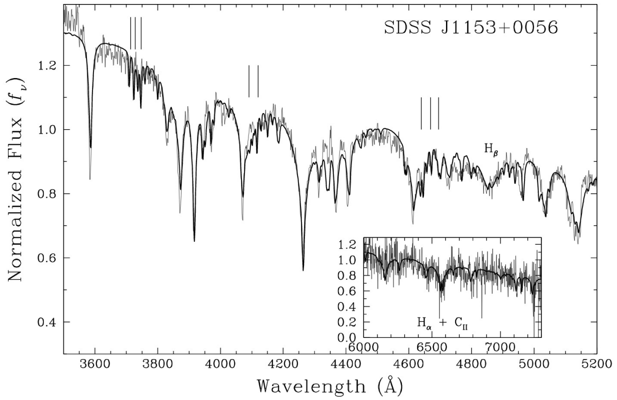

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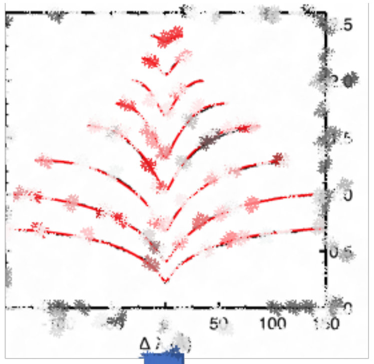
C



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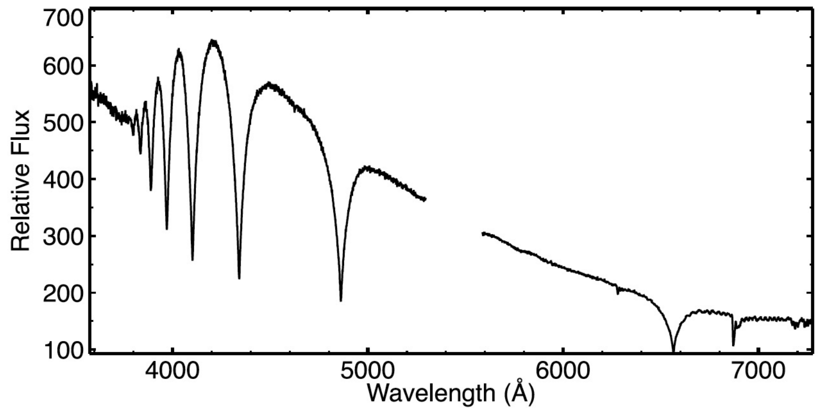
Temperature
Composition

Age & History of the Galaxy

Interior Composition of Exoplanets

Supernova Formation/ Precision Cosmology

Z Measurements focused on 3 main types



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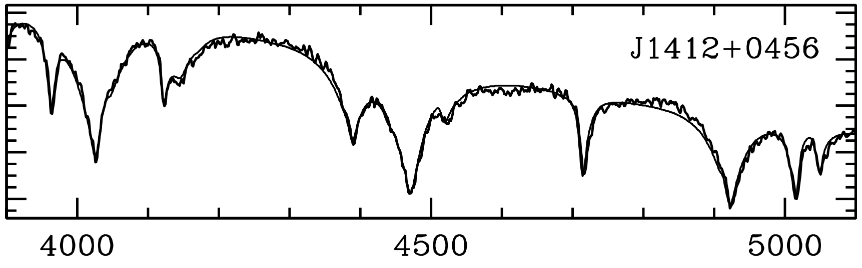

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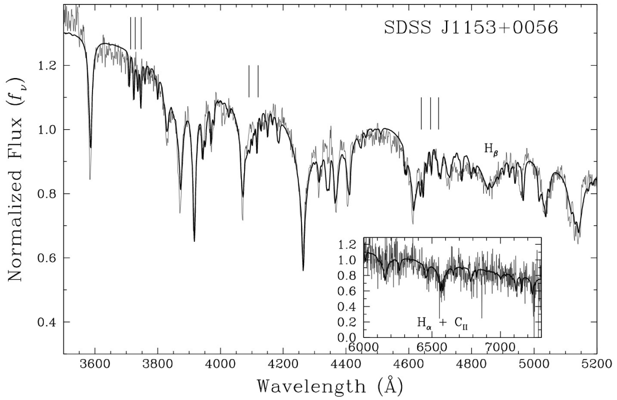

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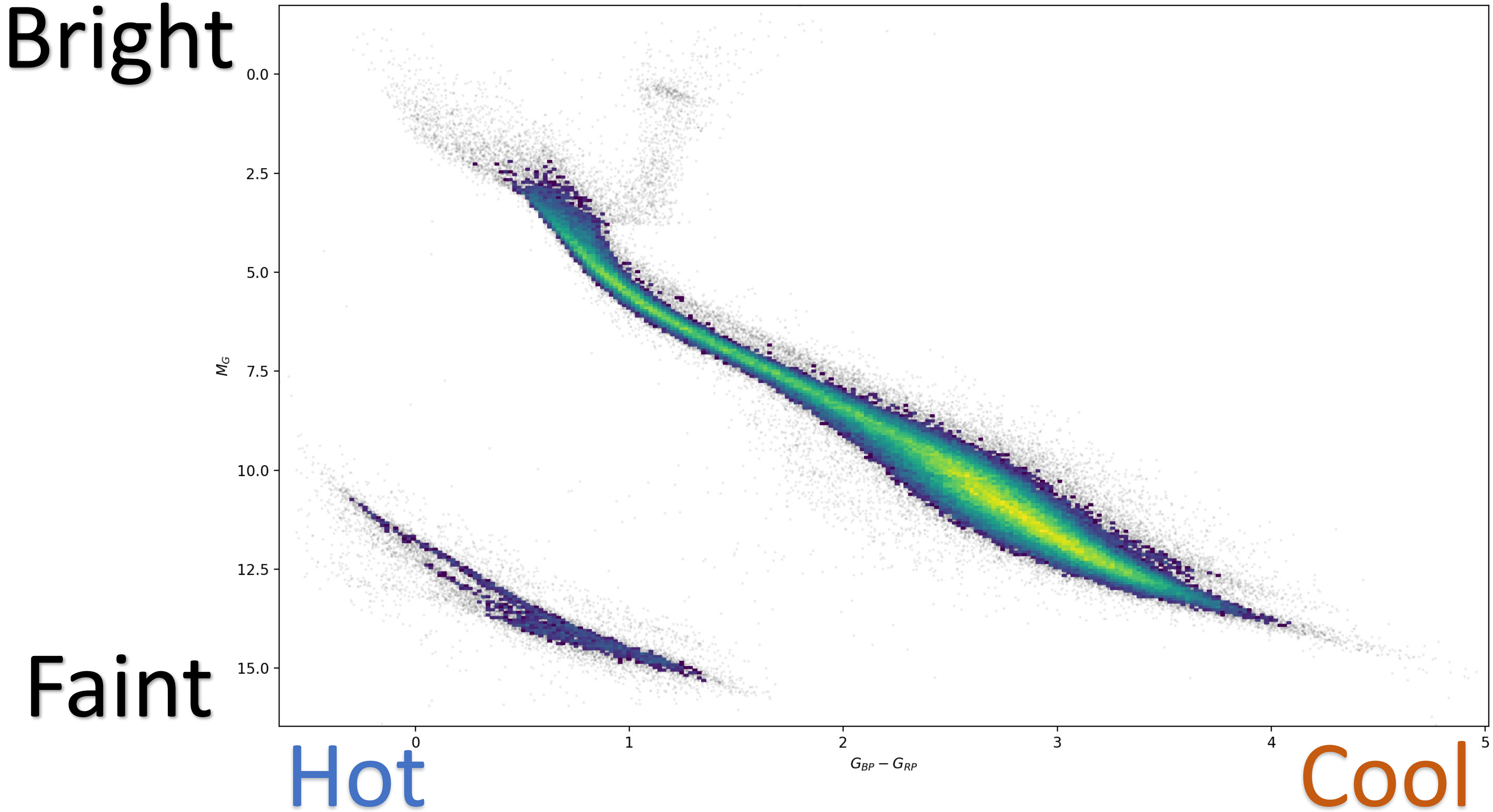
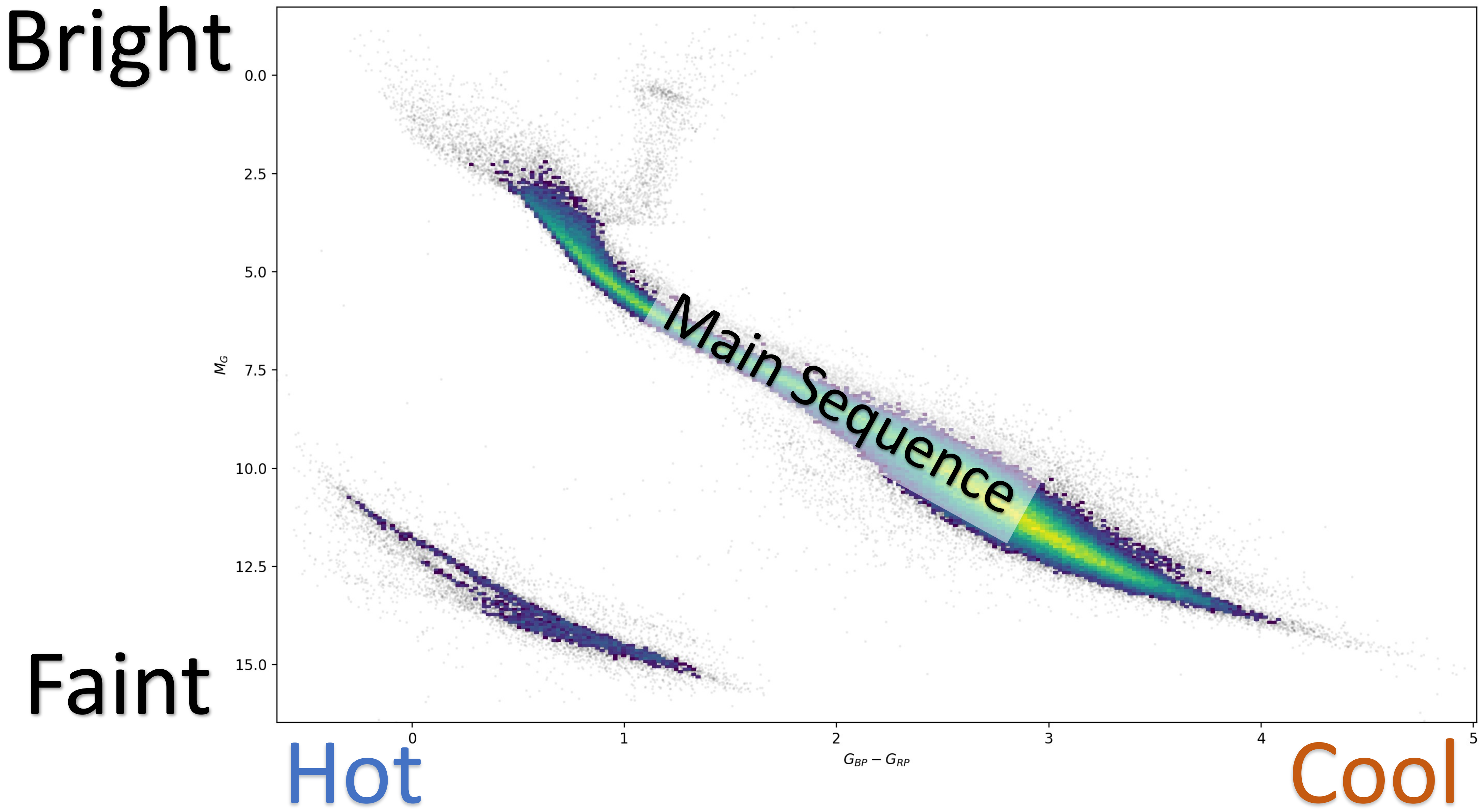
Benchmark measurements of Balmer lines.

Measuring He I Stark/neutral broadening.

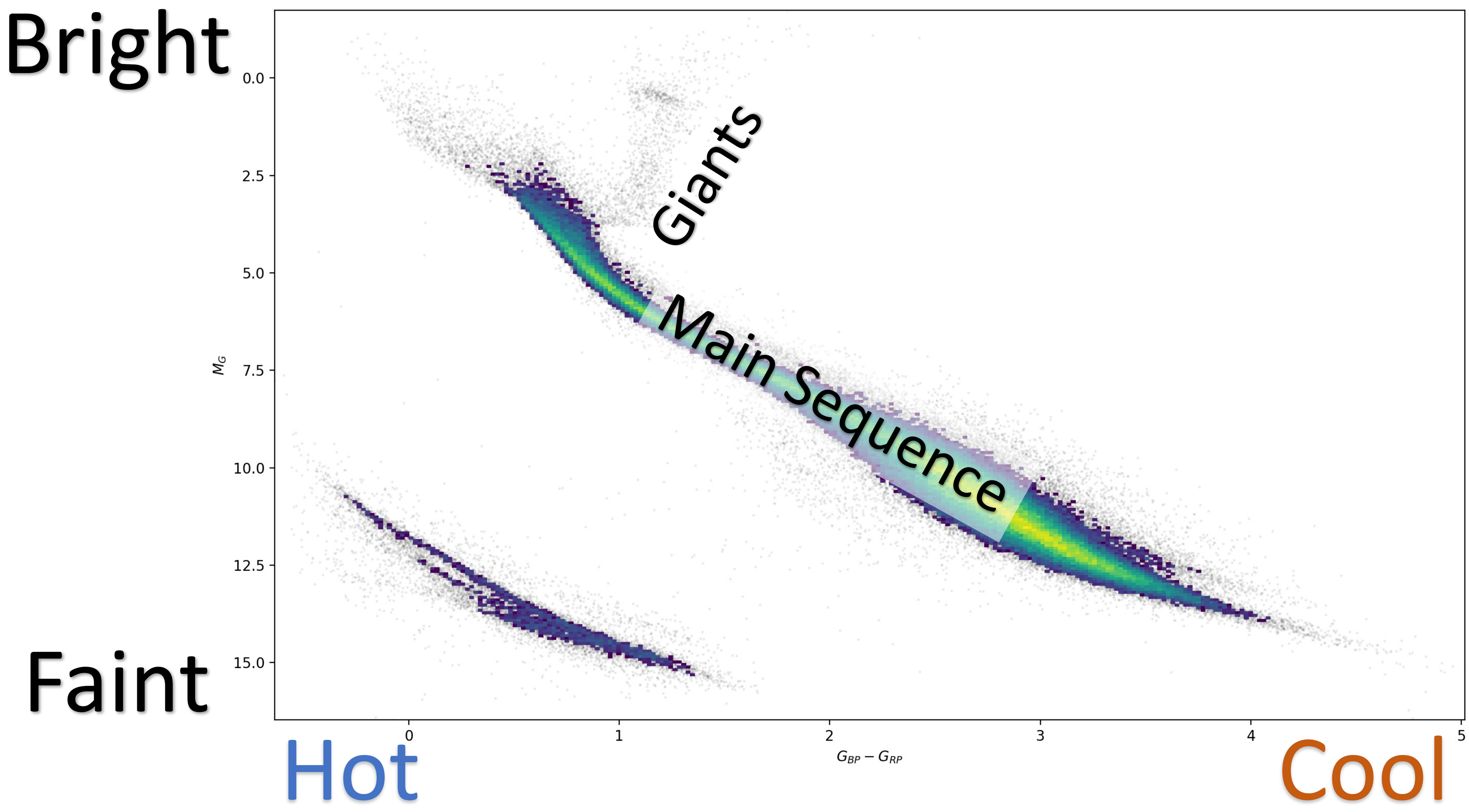
Measuring hotter hot DQ conditions (CII lines)

White Dwarfs and Stellar Evolution

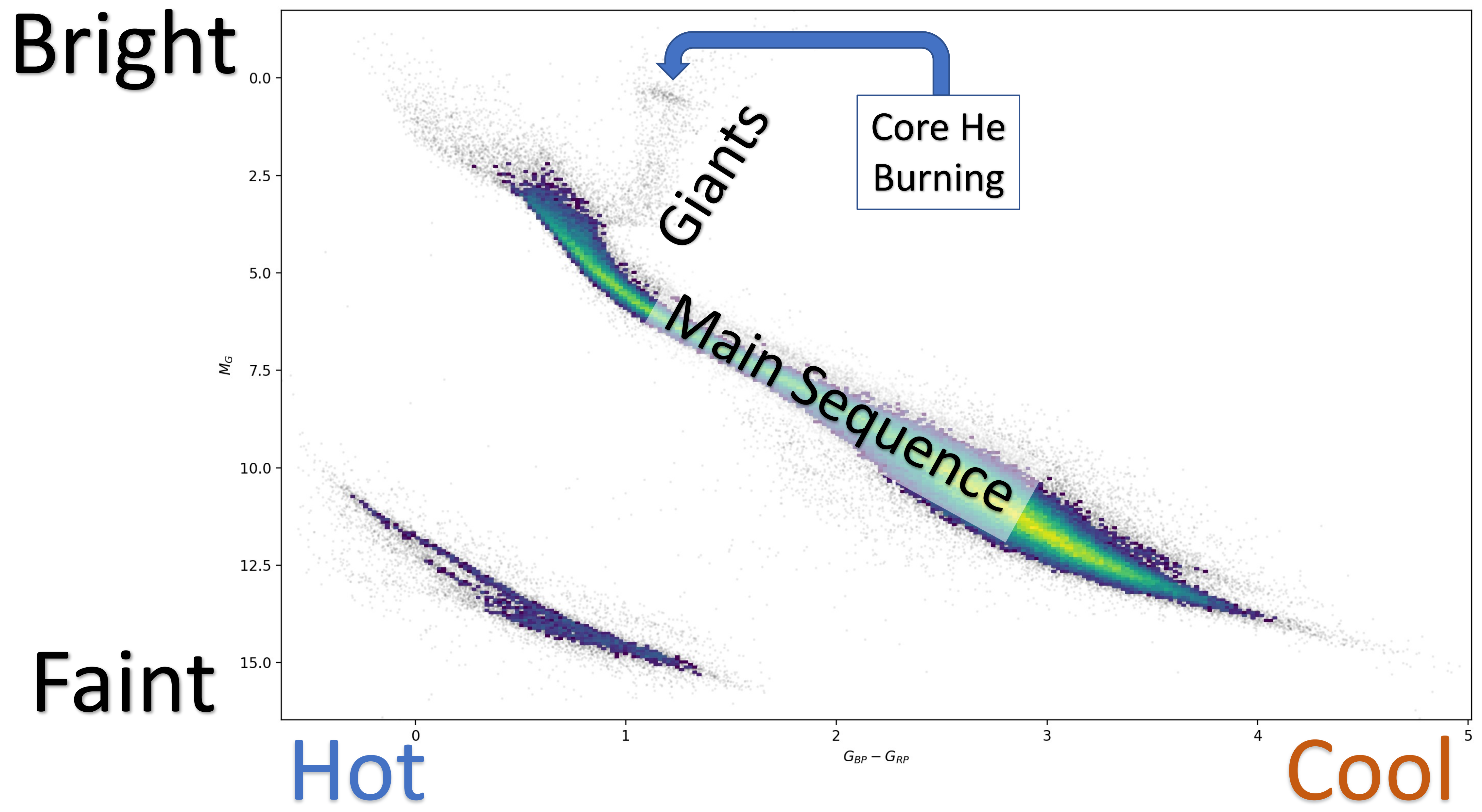




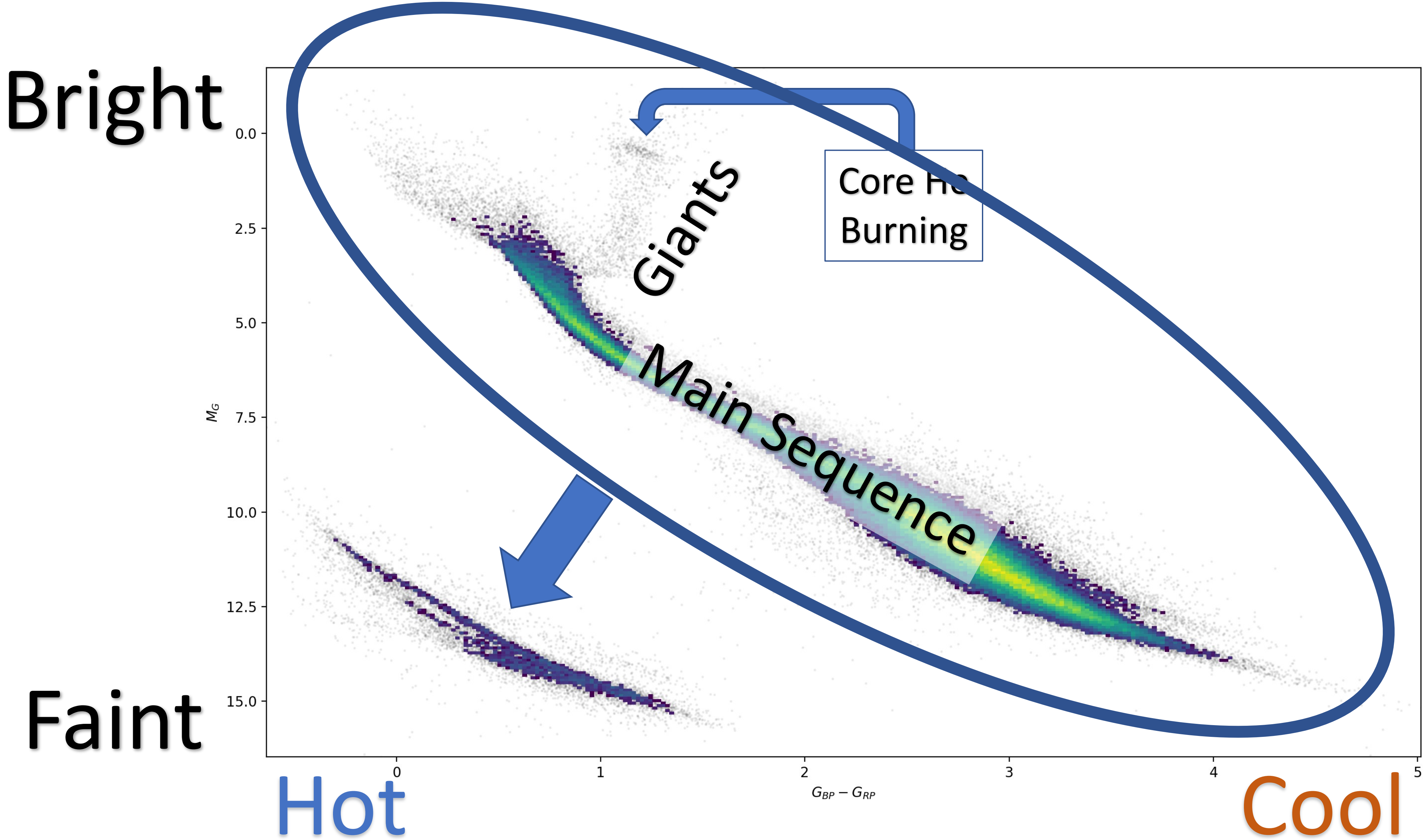
Bright
Faint
Hot
Cool
Main Sequence
M_G
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5
$G_{BP} - G_{RP}$



Bright
Faint
Hot
Cool
Giants
Main Sequence
M_G
$G_{BP} - G_{RP}$
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5



Bright
Faint
Hot
Cool
Core He
Burning
Giants
Main Sequence
M_G
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5
$G_{BP} - G_{RP}$



Bright
Faint
Hot
Cool
Giants
Main Sequence
Core He
Burning
M_G
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
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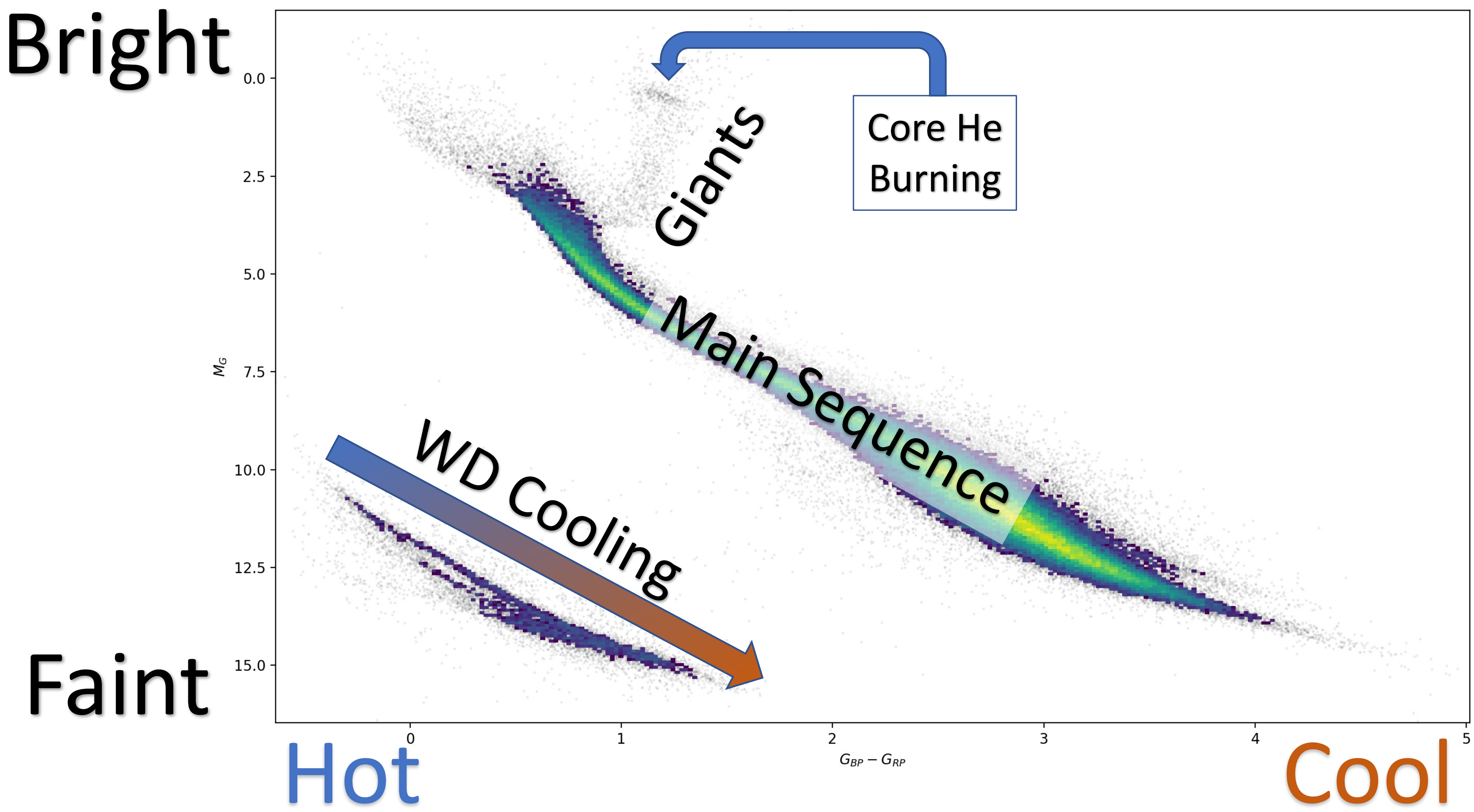
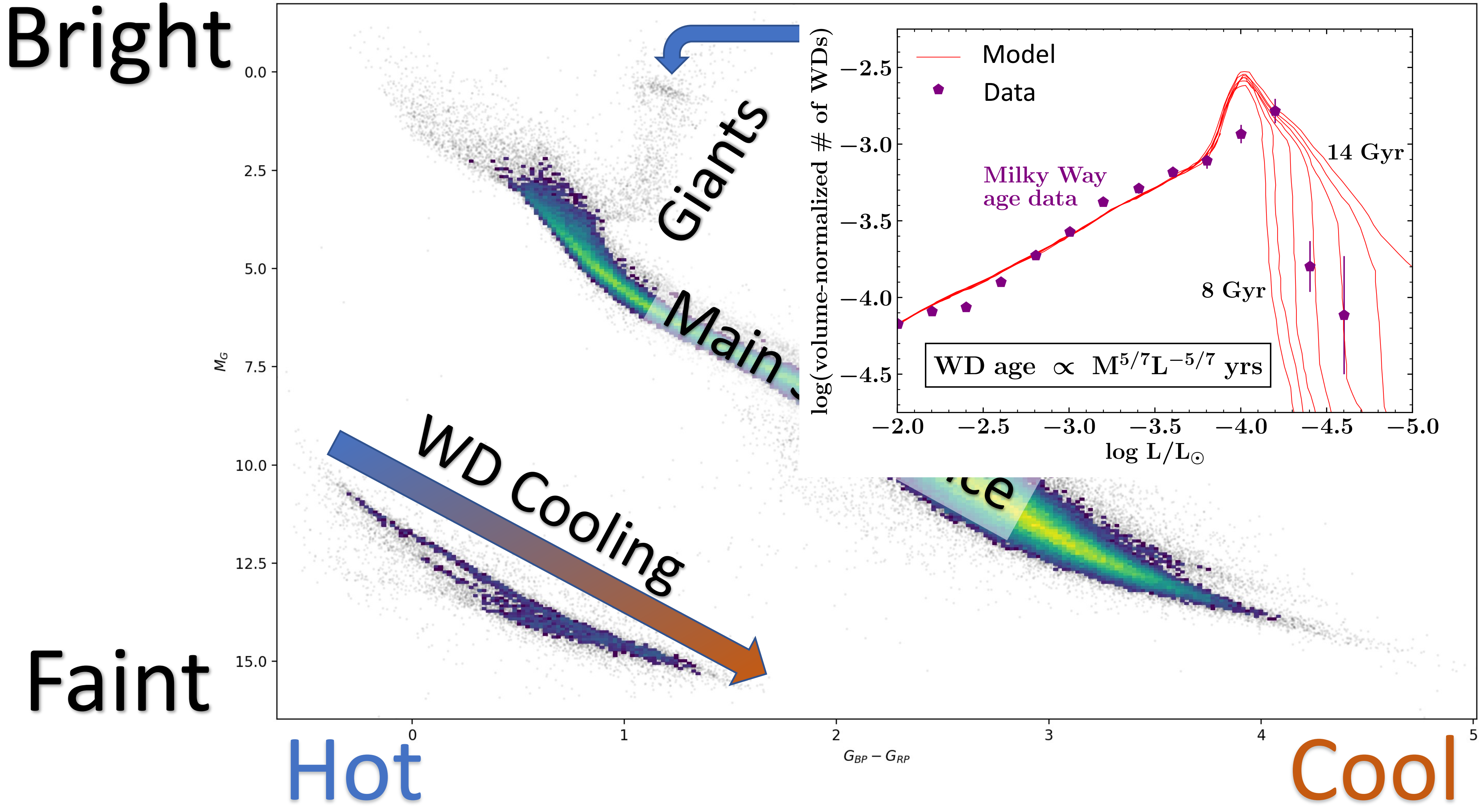


Bright
Faint
Hot
Cool
Core He Burning
Giants
Main Sequence
WD Cooling
M_G
$G_{BP} - G_{RP}$
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5

White Dwarfs Constrain Ages of Stellar Populations



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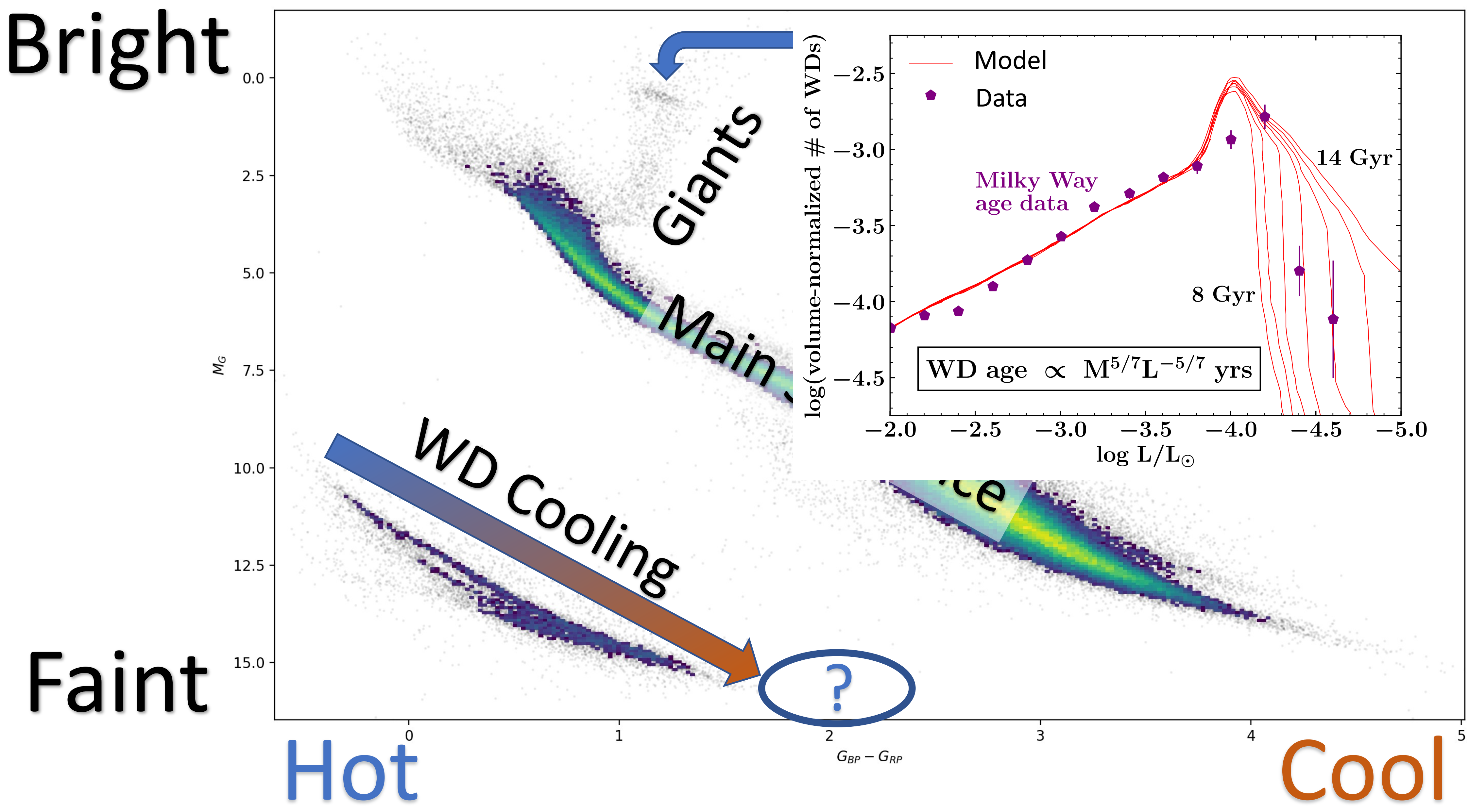
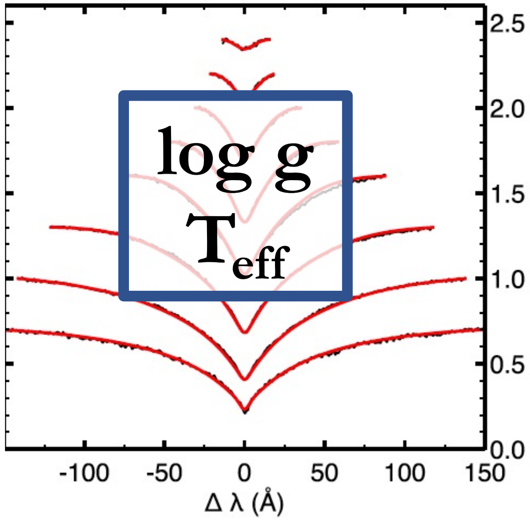
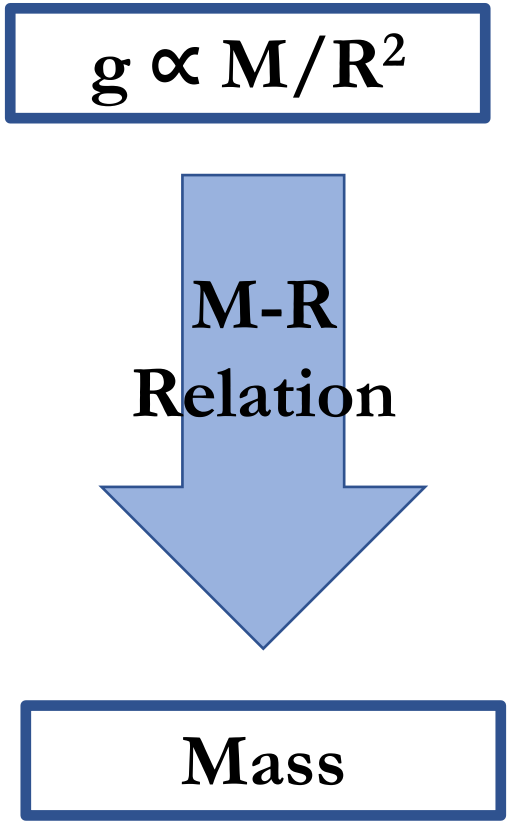
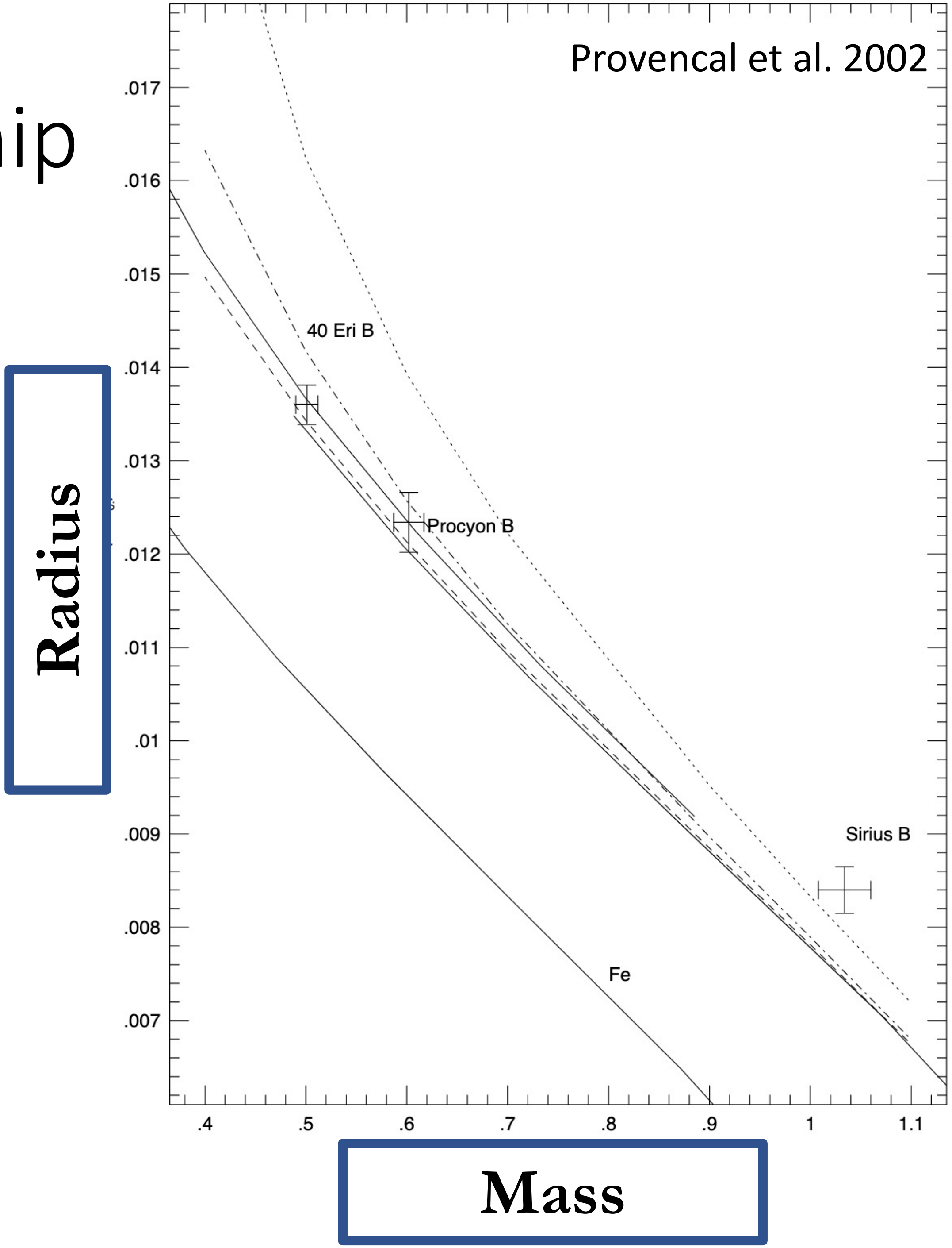
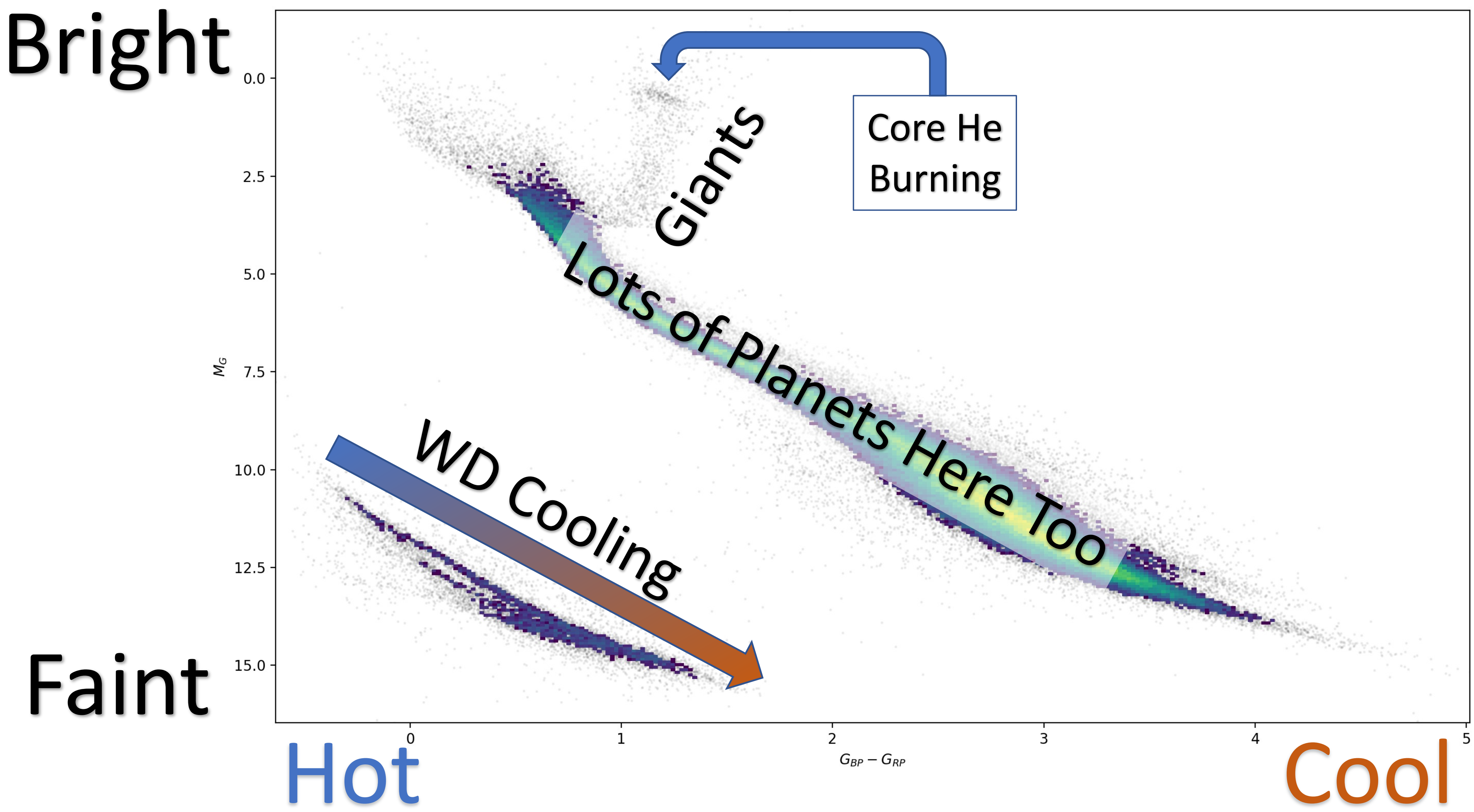


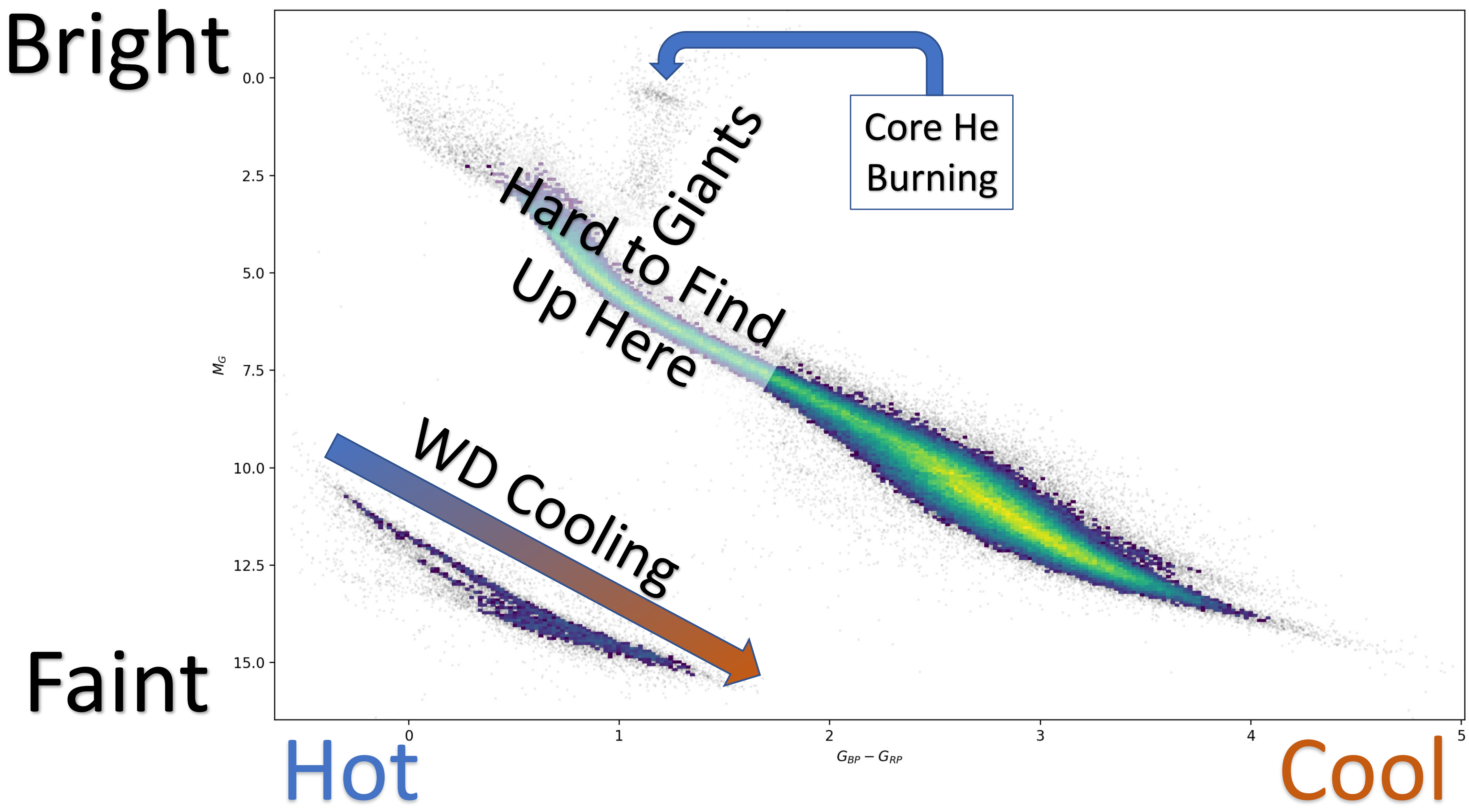
Converting surface gravity to mass via mass-radius relationship





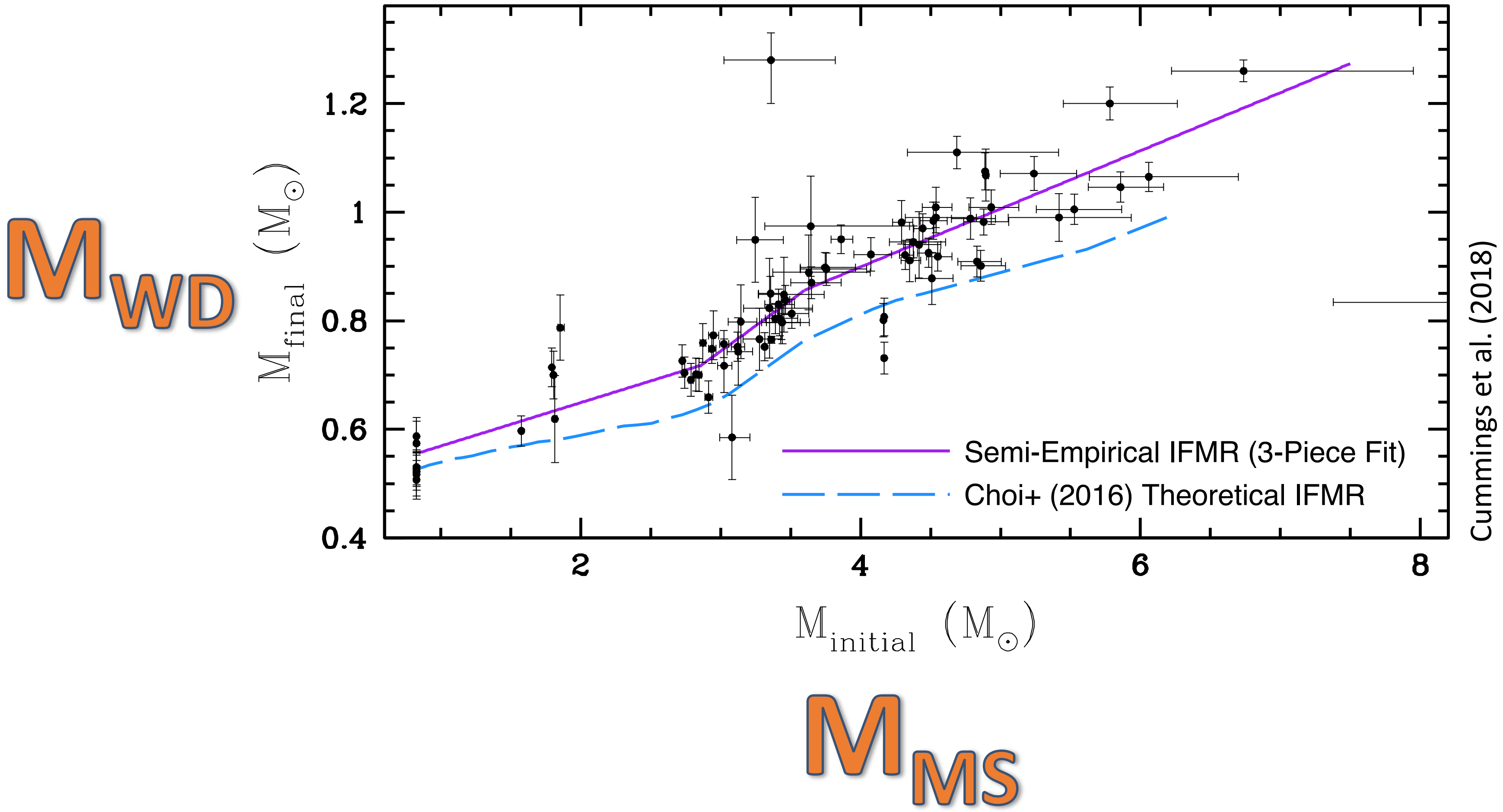


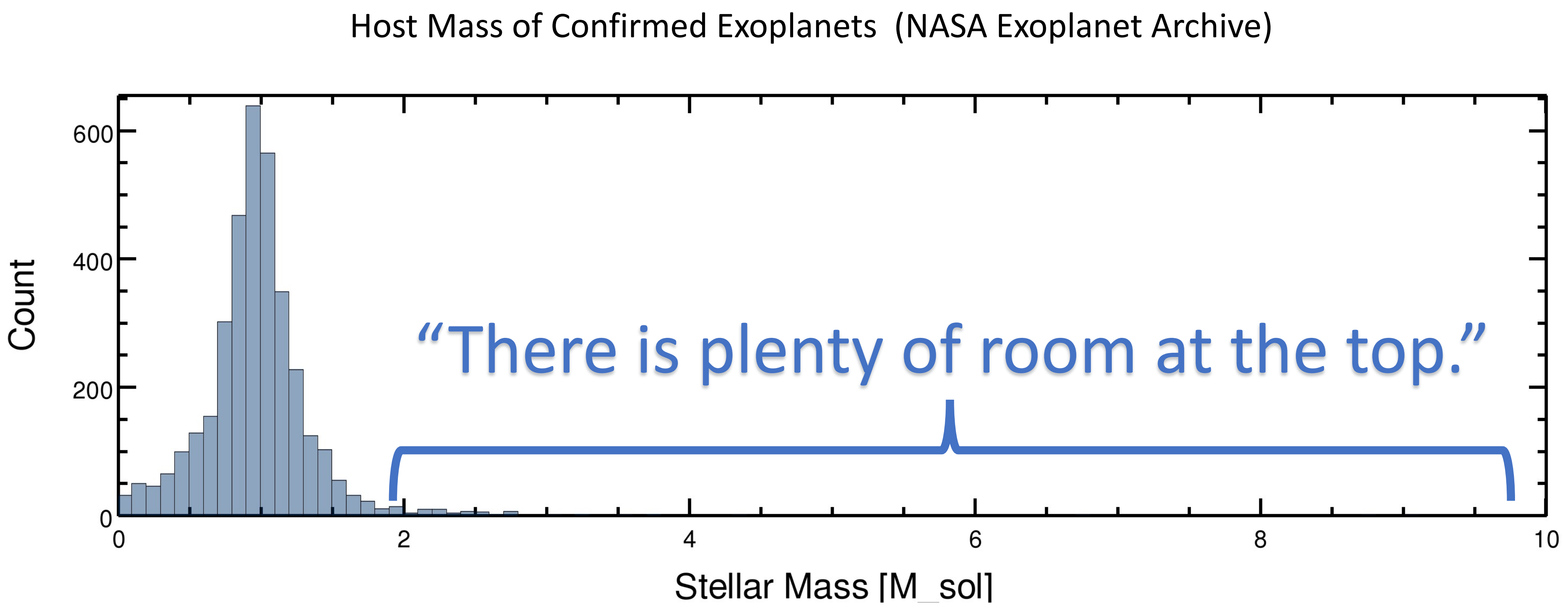

Bright
Faint
Hot
Cool
Core He Burning
Giants
Lots of Planets Here Too
WD Cooling
M_G
$G_{BP} - G_{RP}$
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5



Bright
Faint
Hot
Cool
Core He Burning
Giants
Hard to Find Up Here
WD Cooling
M_G
$G_{BP} - G_{RP}$
0.0
2.5
5.0
7.5
10.0
12.5
15.0
0
1
2
3
4
5

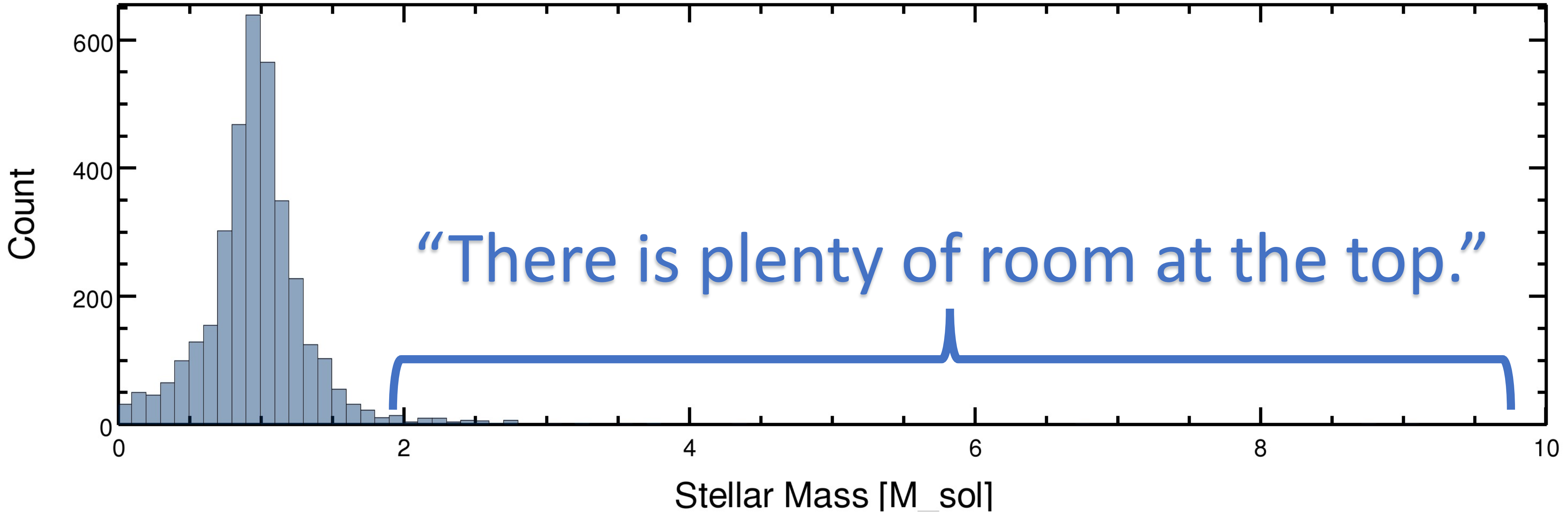
Initial-Final Mass Relation allows us to infer progenitor mass from white dwarf mass



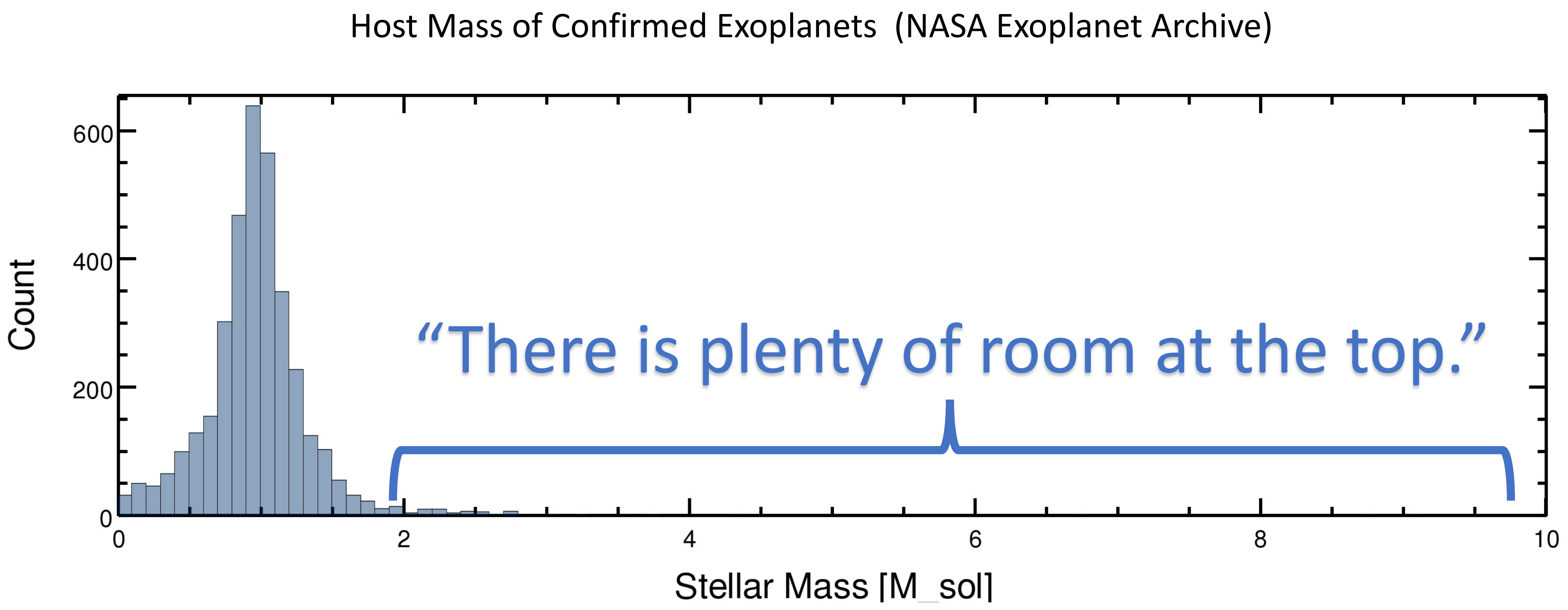


Planetary detection on the main sequence is particularly hard at high mass.

Host Mass of Confirmed Exoplanets (NASA Exoplanet Archive)

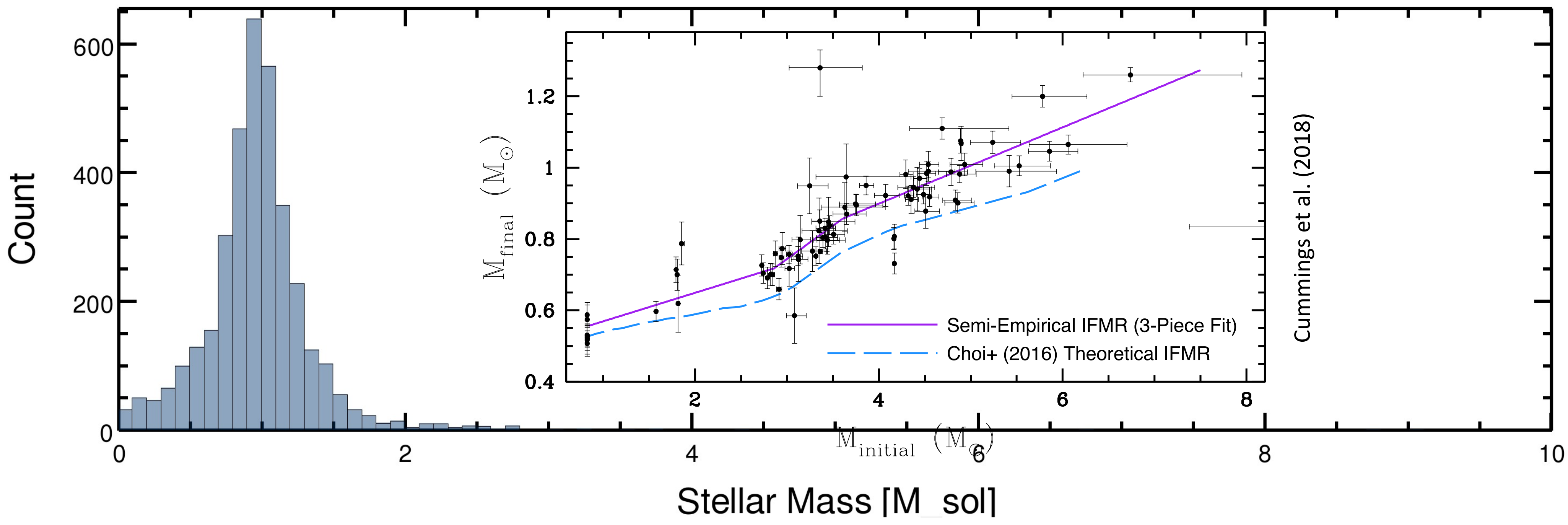


White Dwarfs allow us to probe this regime much more easily.



The Initial Final Mass relation lets us translate knowledge of white dwarf planetary systems to previous stages of stellar evolution.

Host Mass of Confirmed Exoplanets (NASA Exoplanet Archive)



The Initial Final Mass relation lets us translate knowledge of white dwarf planetary systems to previous stages of stellar evolution.

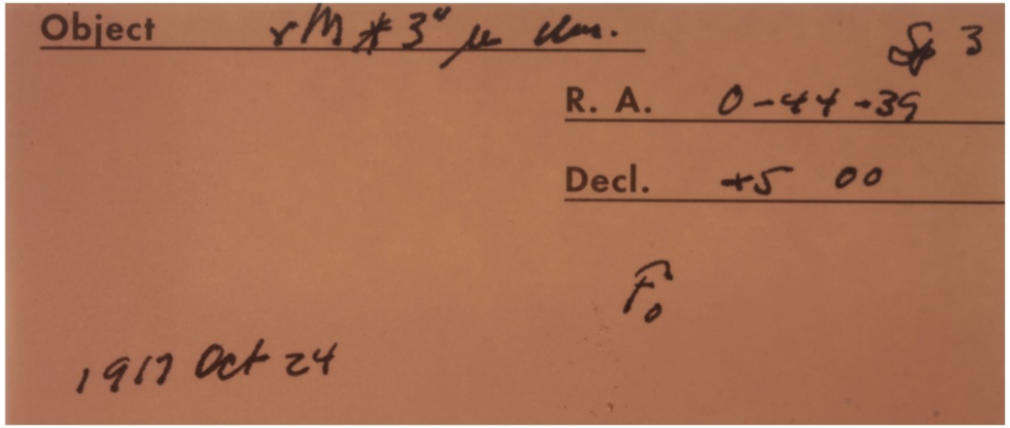
White Dwarfs Reveal Planetary Interiors

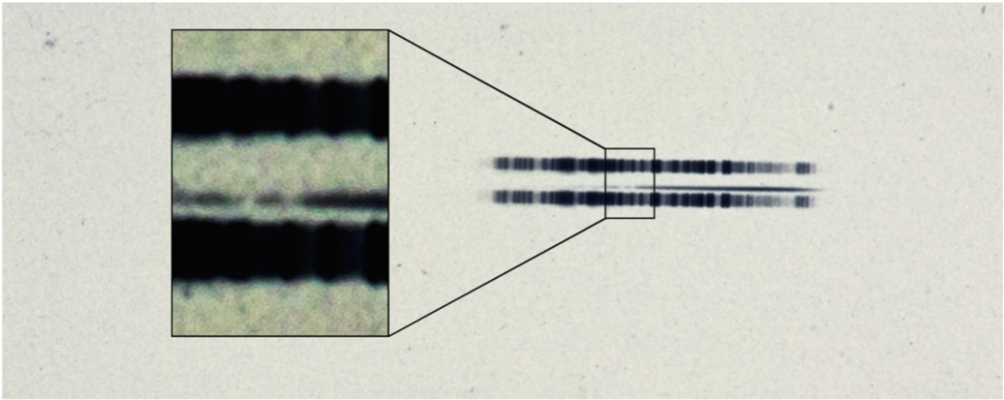
They Crush Exoplanetary Rocky Debris & Accrete It

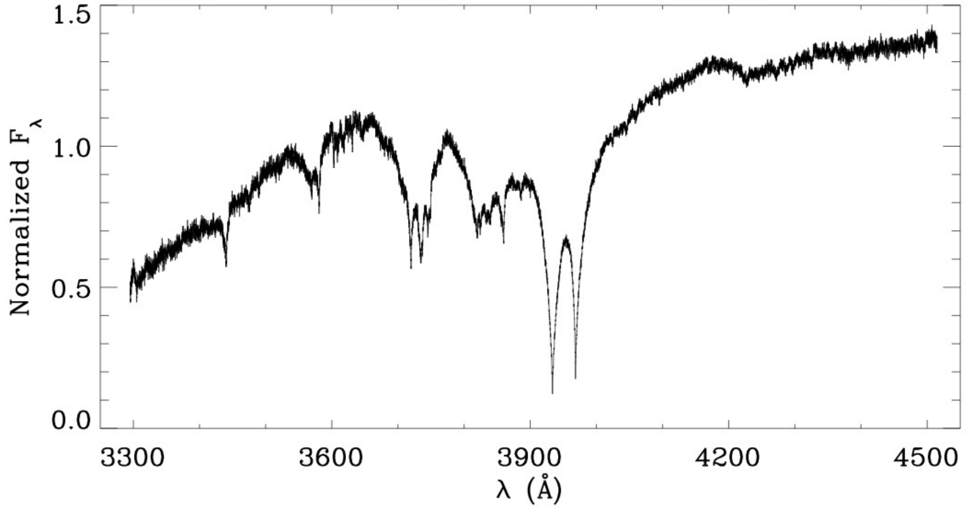
Spectra Give Abundances

Accurate log g Necessary to Infer Composition

For more on planetary material in white dwarf atmospheres, see the breakout session talk by Simon Blouin this afternoon.







Farihi 2016

White Dwarfs Reveal Planetary Interiors and the long-term evolution of exoplanetary systems

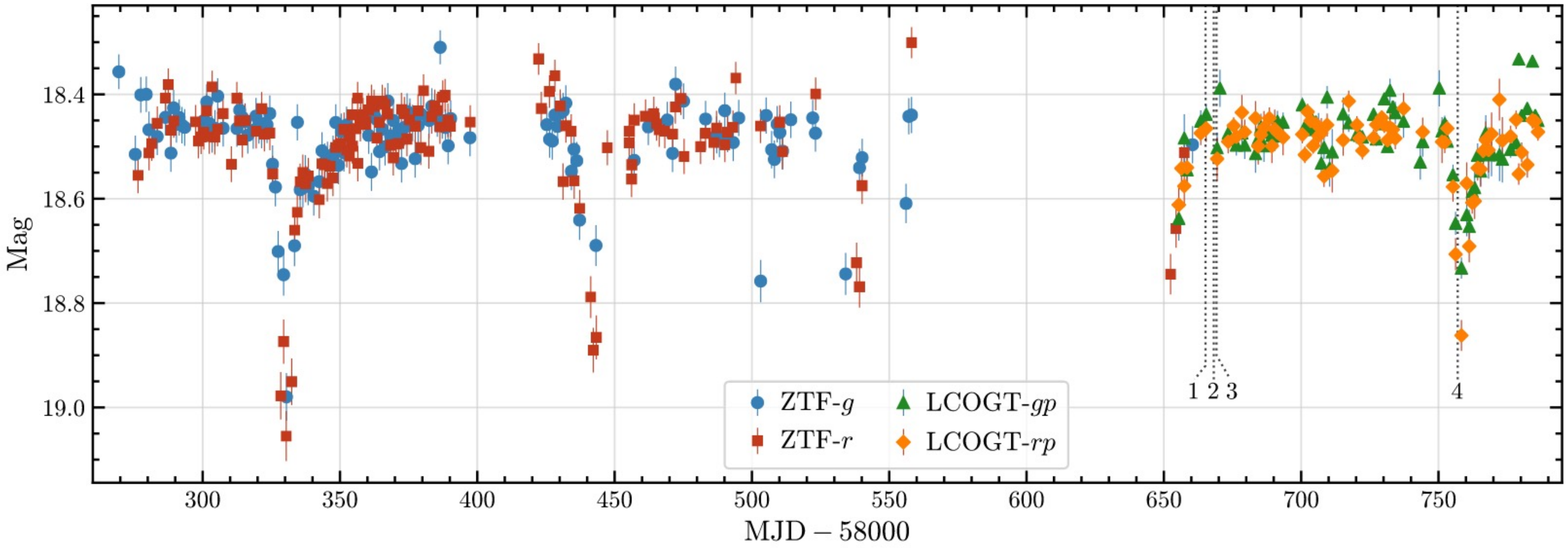
THE ASTROPHYSICAL JOURNAL, 897:171 (9pp), 2020 July 10 https://doi.org/10.3847/1538-4357/ab9649

CrossMark

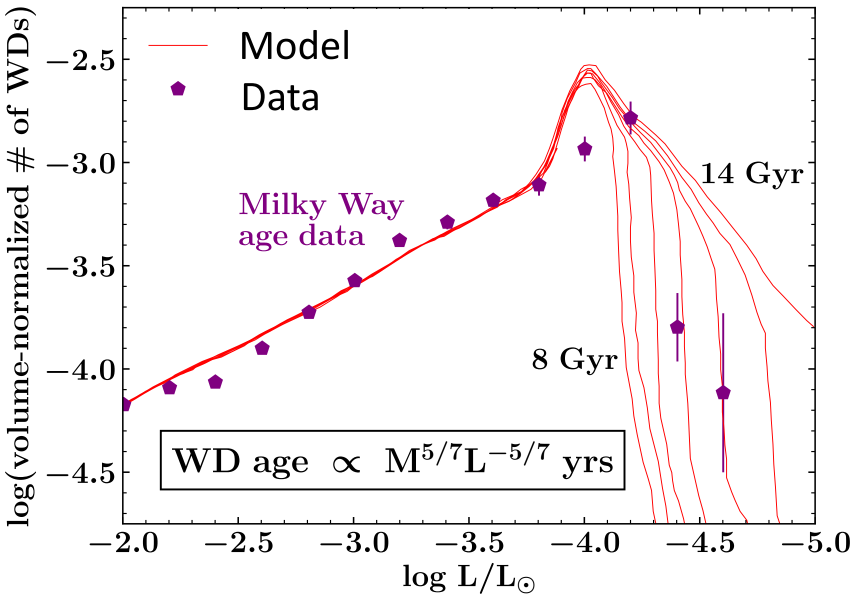
A White Dwarf with Transiting Circumstellar Material Far outside the Roche Limit

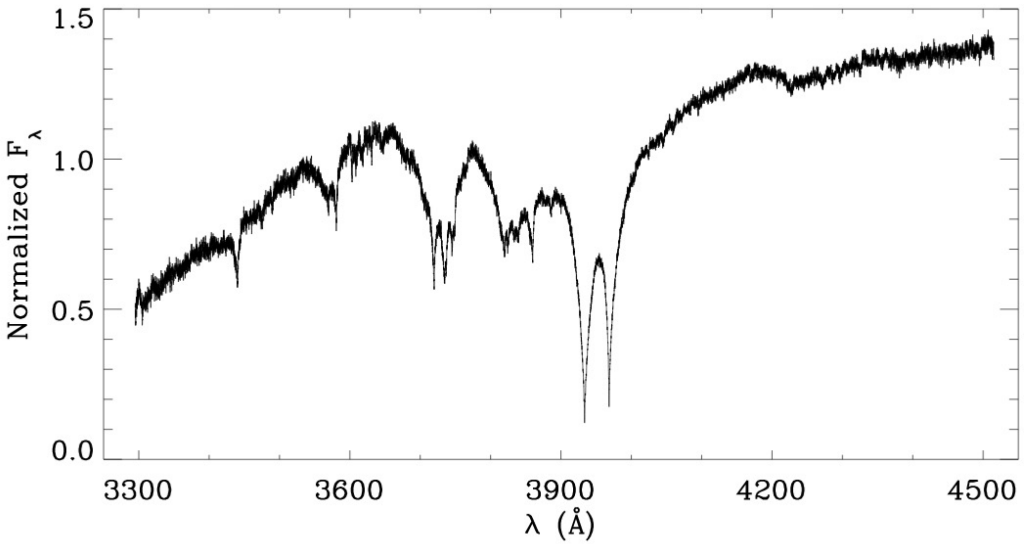
Z. Vanderbosch[1,2], J. J. Hermes[3], E. Dennihy[4], B. H. Dunlap[1], P. Izquierdo[5,6], P.-E. Tremblay[7], P. B. Cho[1,2], B. T. Gänsicke[7], O. Toloza[7], K. J. Bell[8,9], M. H. Montgomery[1,2], and D. E. Winget[1,2]
[1] Department of Astronomy, University of Texas at Austin, Austin, TX 78712, USA; zvanderbosch@astro.as.utexas.edu
[2] McDonald Observatory, Fort Davis, TX 79734, USA

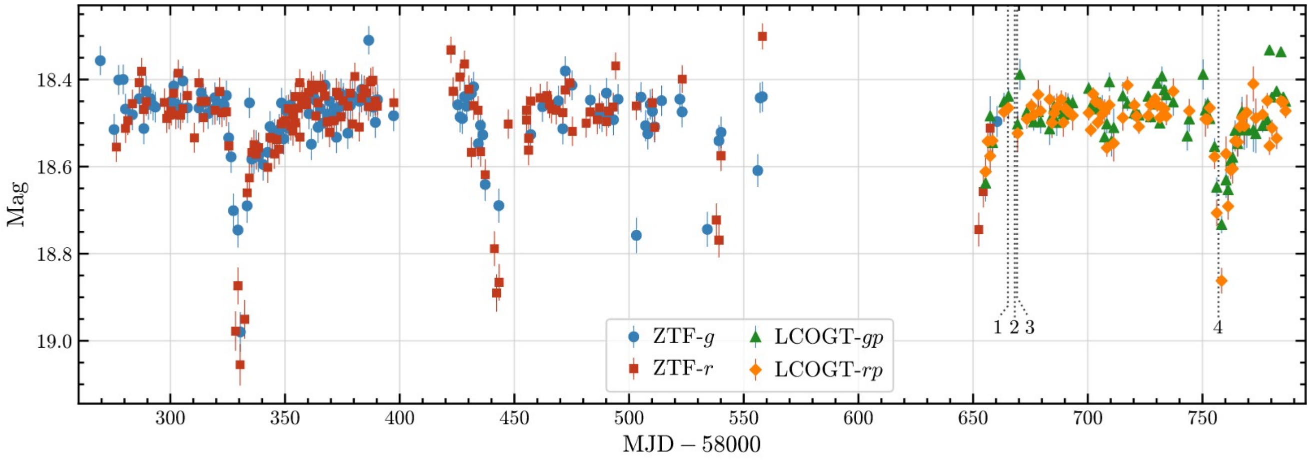
See also
Guidry et al. 2021



Accurate White Dwarf Masses & log g Are Important







Evidence of Inaccurate Mass & Temperature Determinations

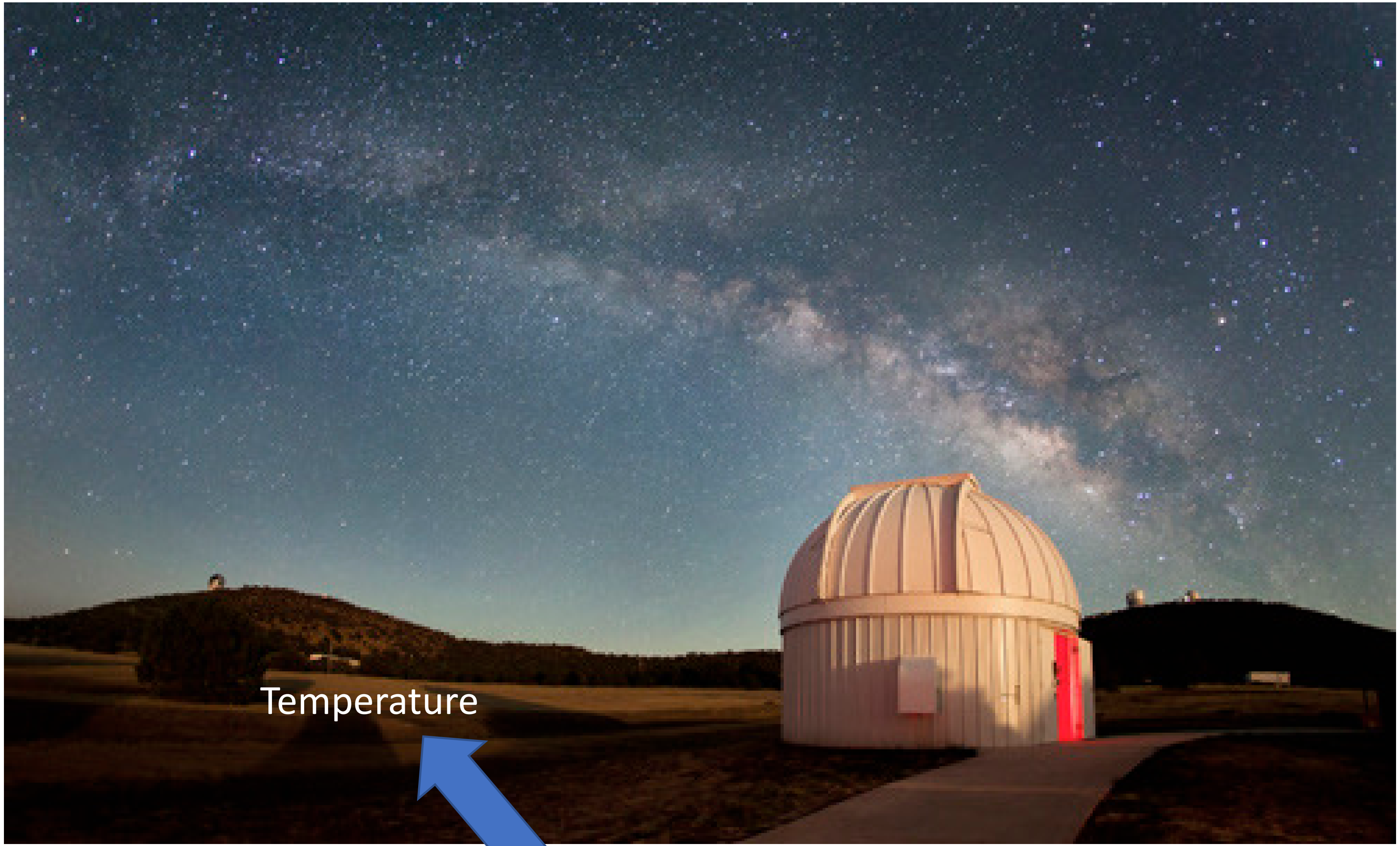
A view from McDonald Observatory

Why are some of these brighter than others?

Why are some of these brighter than others?

$$f_{Earth} \propto F_{star} \times (Radius/Dist)^2$$

Why are some of these brighter than others?



$$f_{Earth} \propto F_{star} \text{ x } (Radius/Dist)^2$$

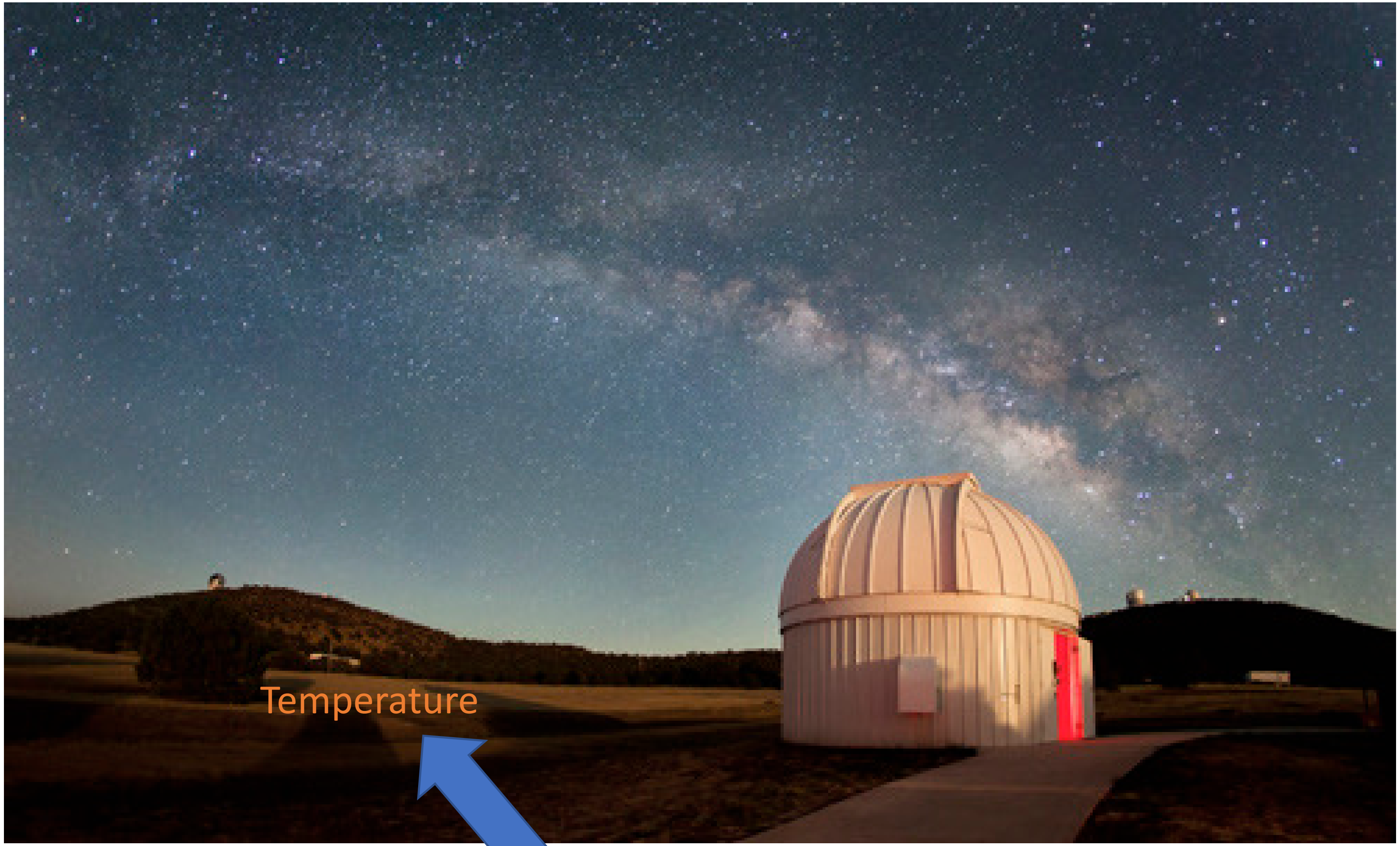
Why are some of these brighter than others?

$$f_{Earth} \propto F_{star} \times (Radius/Dist)^2$$

Why are some of these brighter than others?

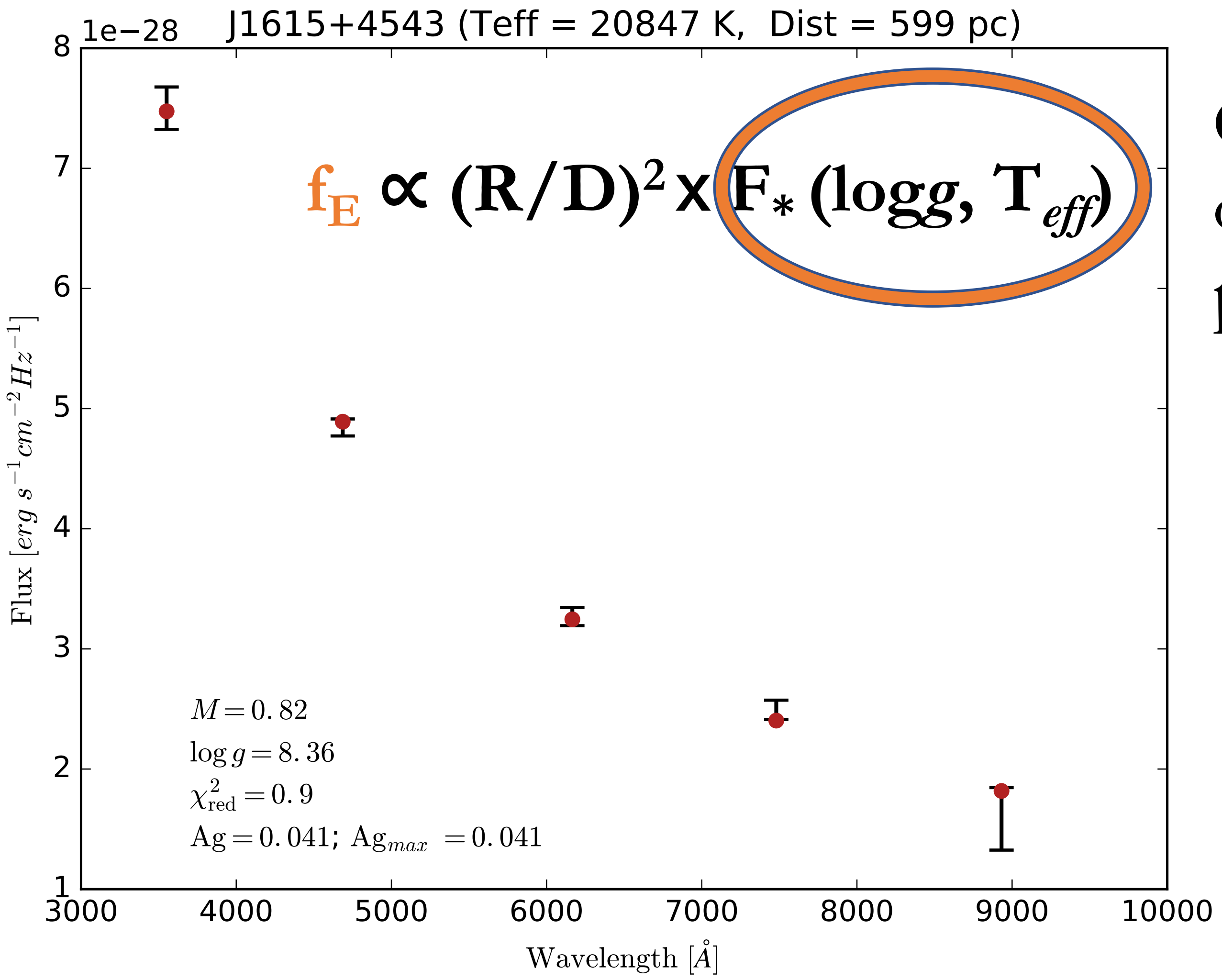
$$f_{Earth} \propto F_{star} \times (Radius/Dist)^2$$

If we measure all of these, we can determine radius



$$f_{Earth} \propto F_{star} \times (\text{Radius}/\text{Dist})^2$$

Mass & T_{eff} from Broadband Photometry + Gaia Distances

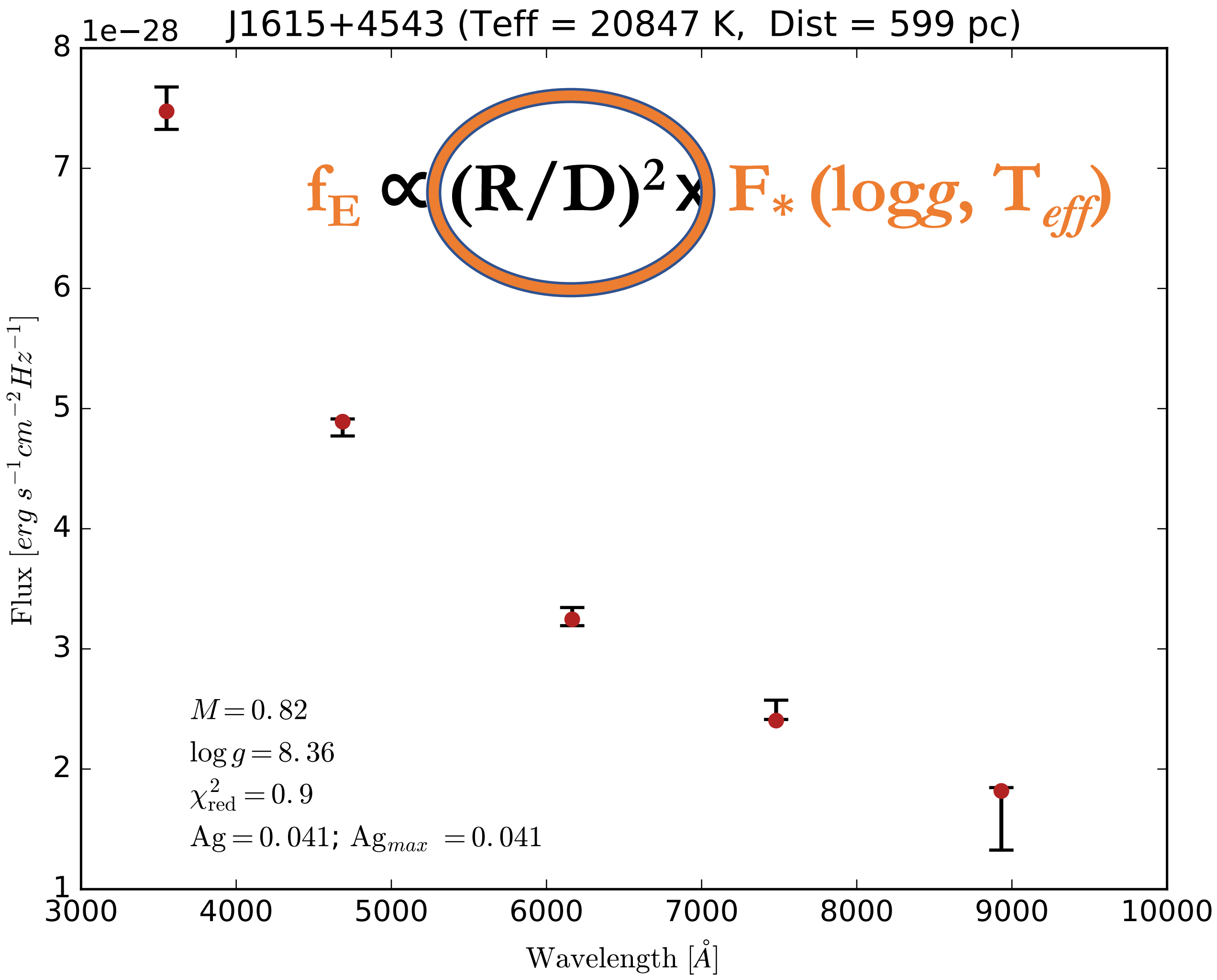


Constrained by *shape* of the broadband photometry.

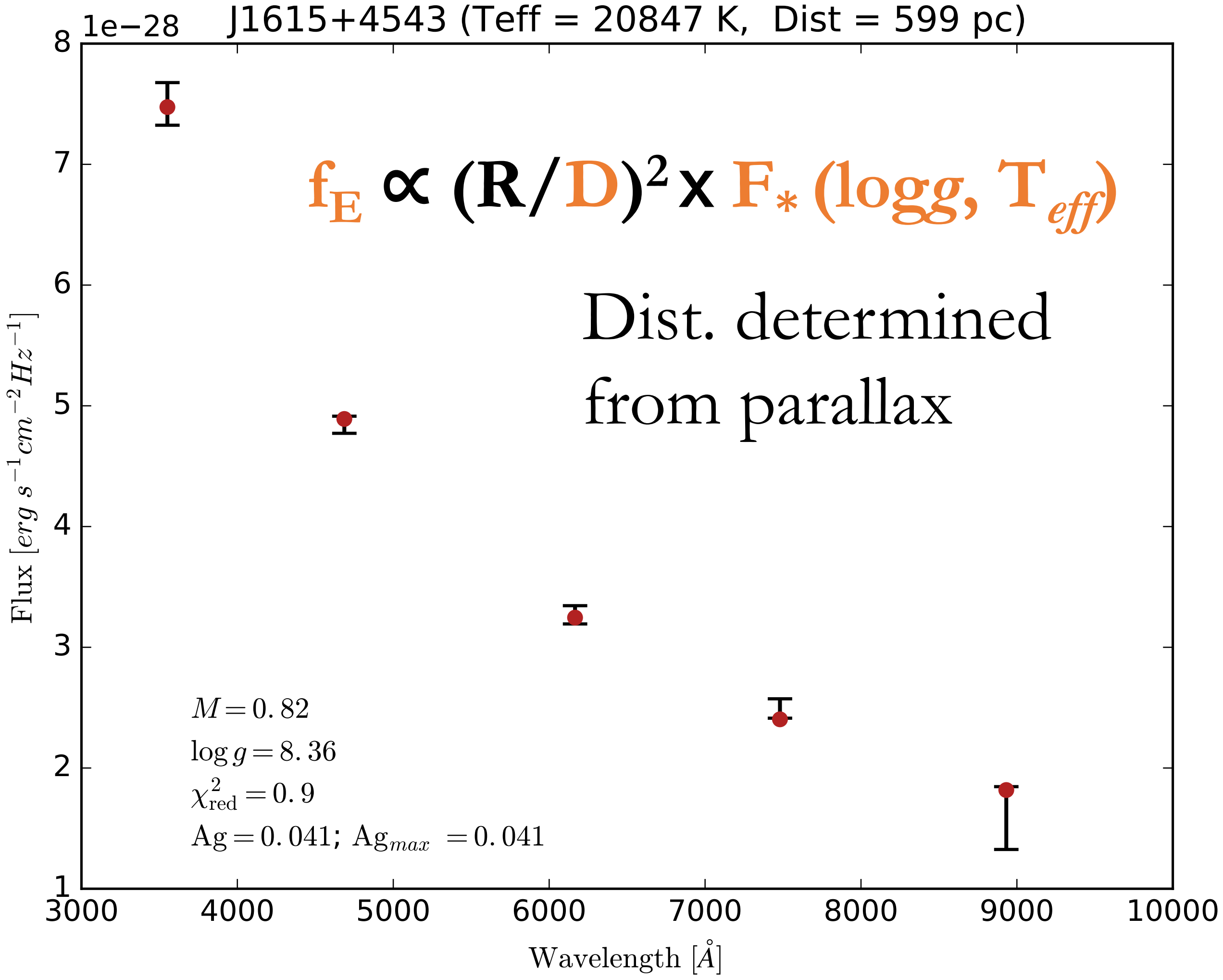
Mass & T_{eff} from Broadband Photometry + Gaia Distances

Constrained by absolute flux level

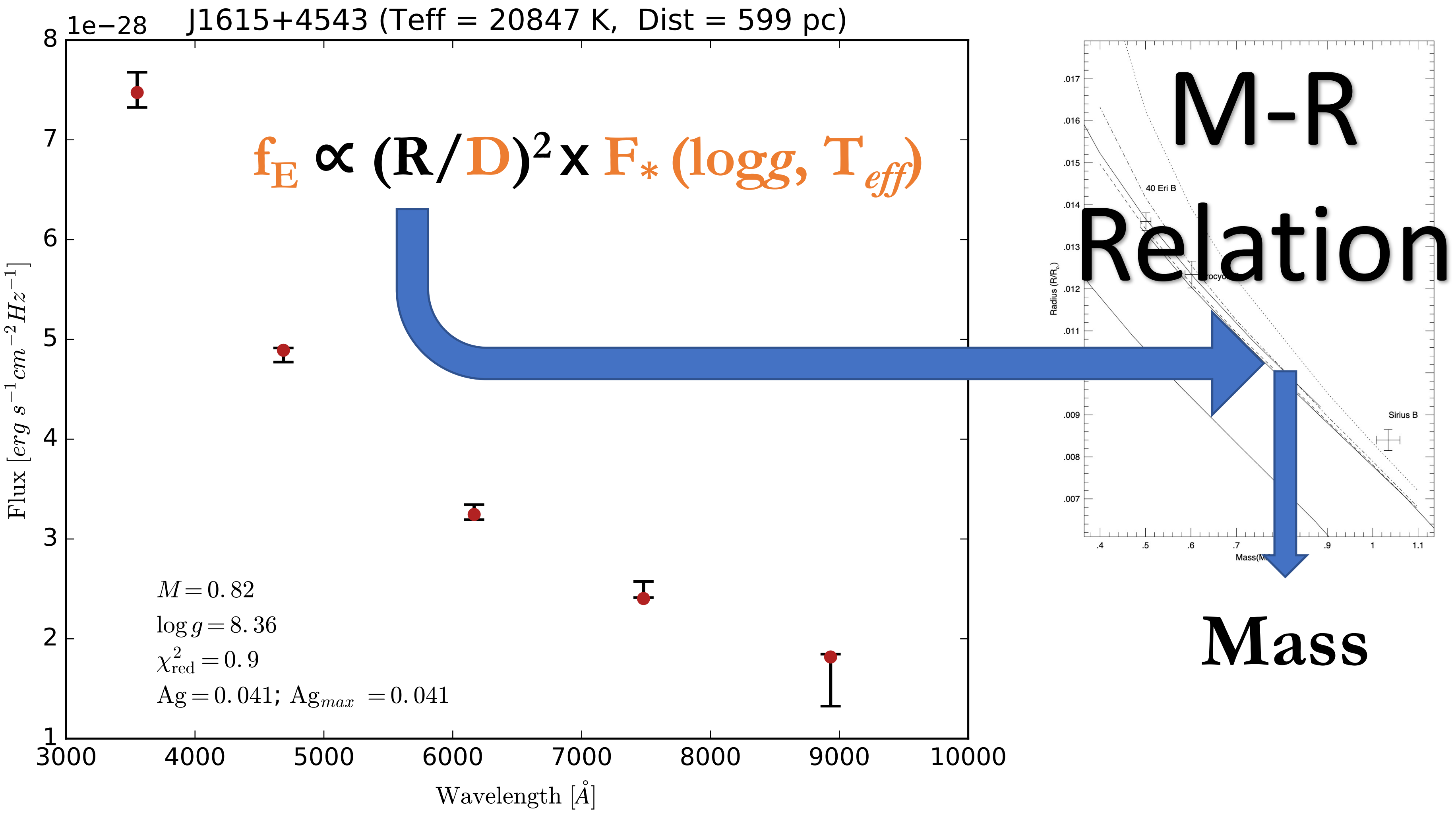
Depends on angular size of the star on the sky



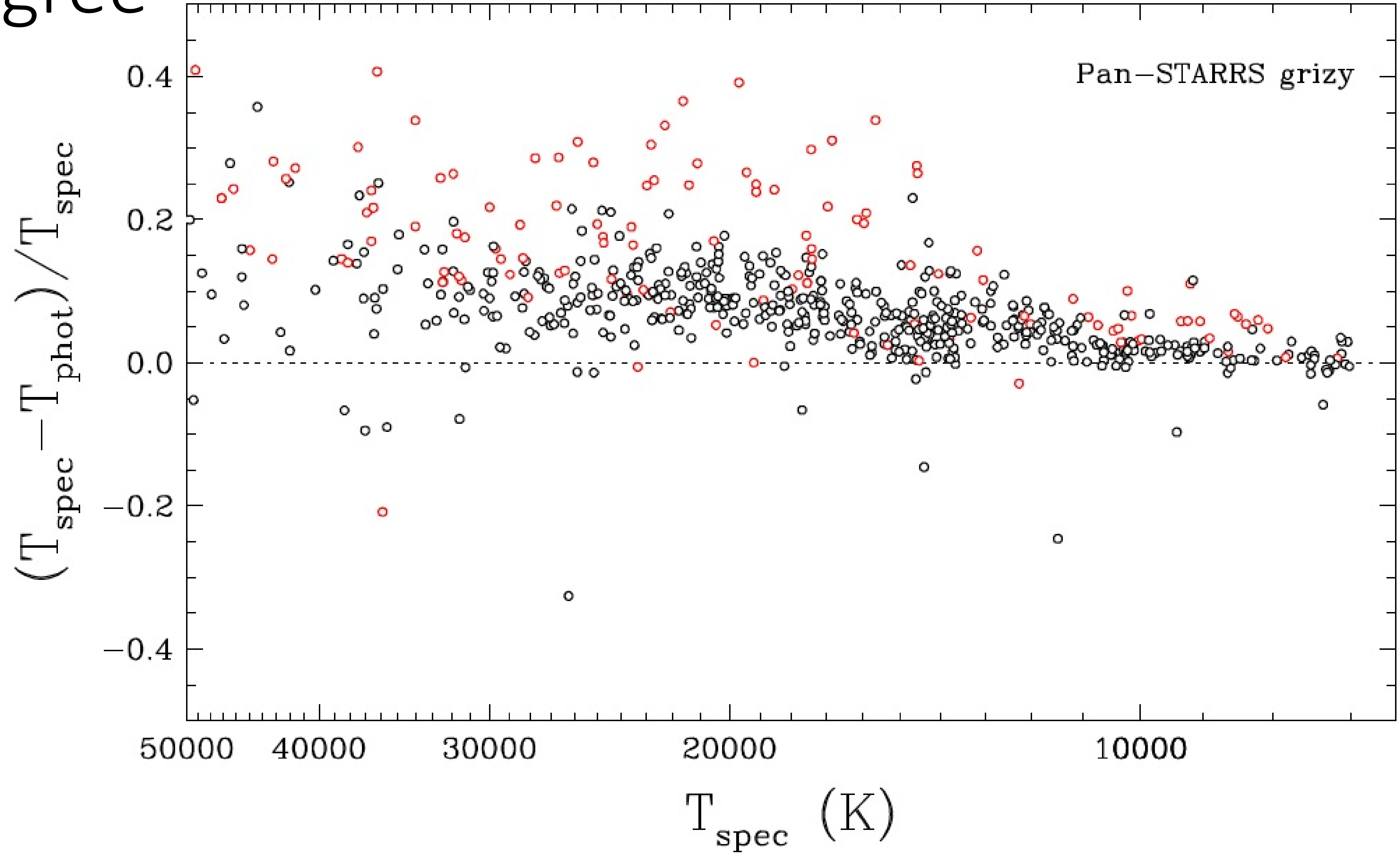
Mass & T_{eff} from Broadband Photometry + Gaia Distances



Mass & T_{eff} from Broadband Photometry + Gaia Distances

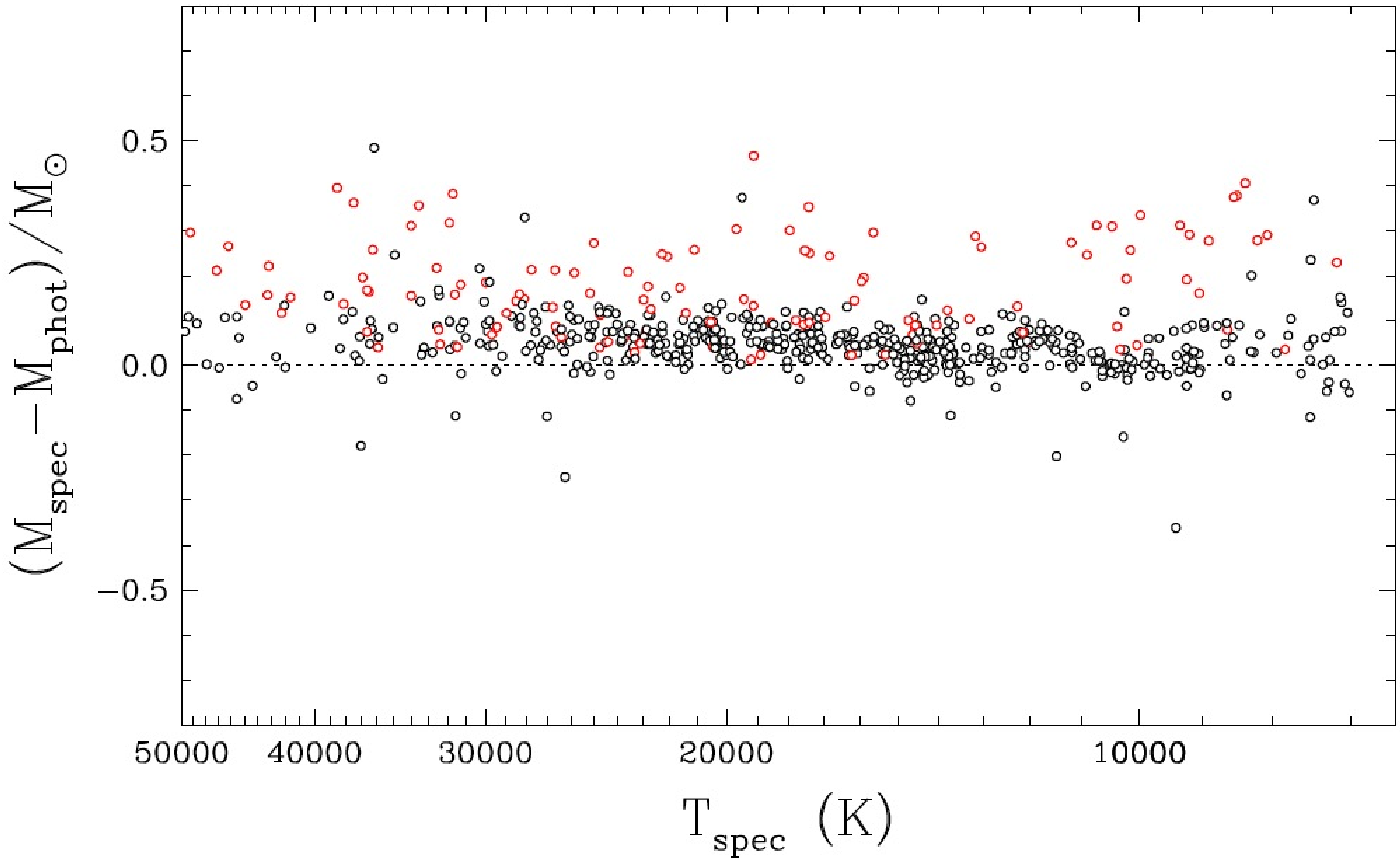


Photometric and Spectroscopic Temperatures Disagree



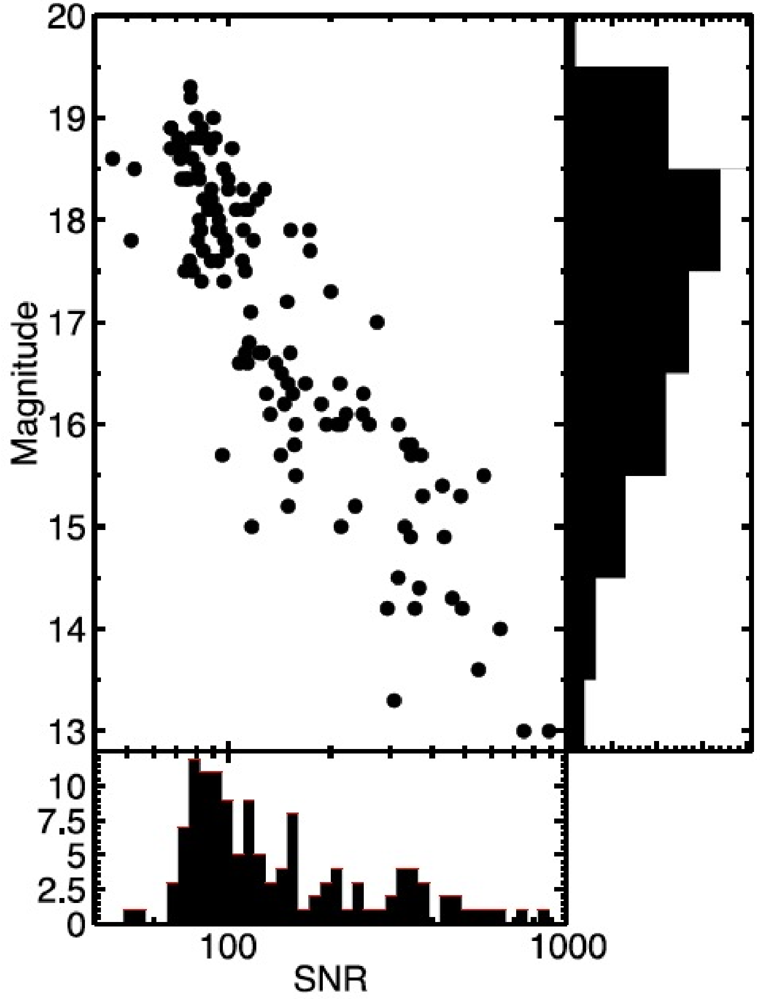
Bergeron et al. 2019

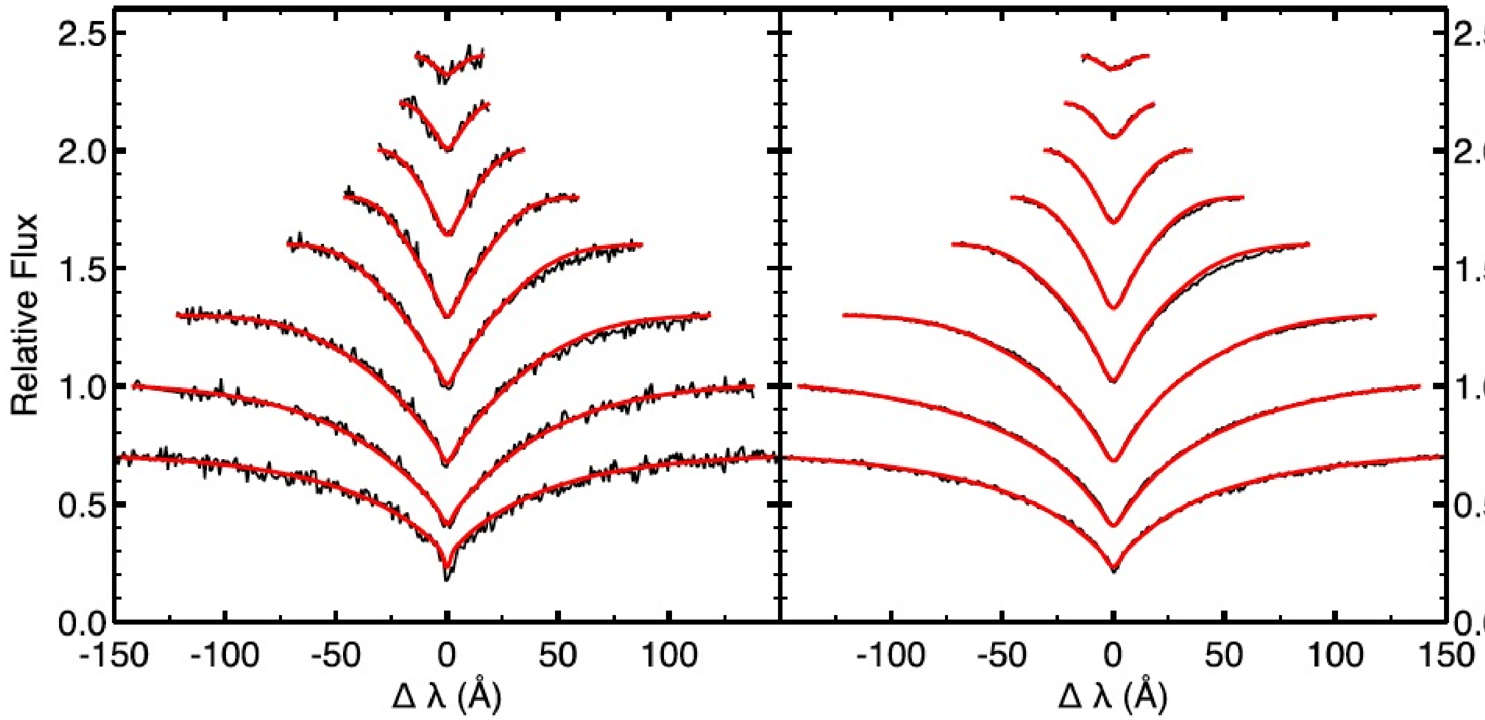
Photometric and Spectroscopic Masses Disagree



Bergeron et al. 2019

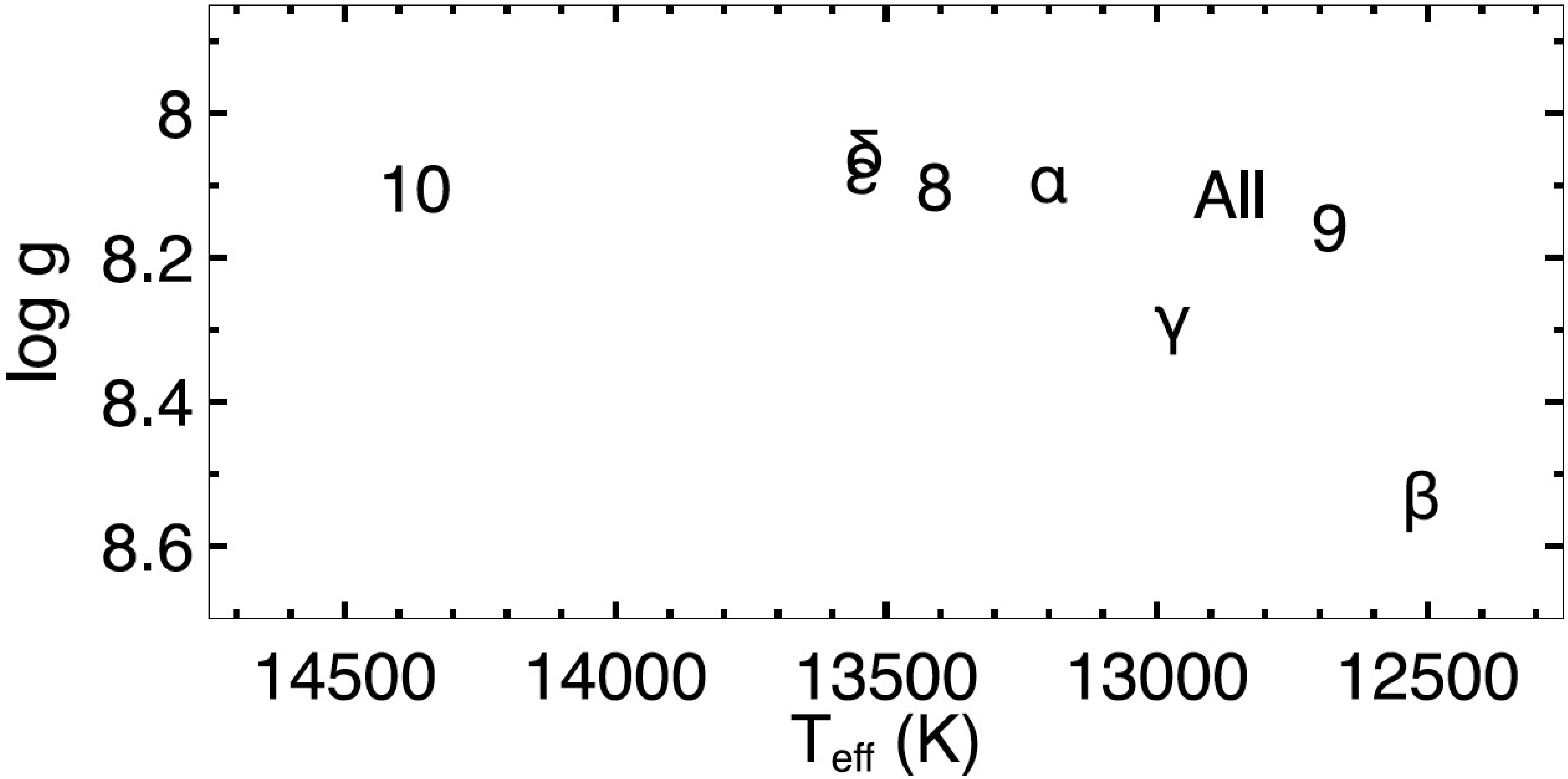
Fits to white dwarf spectral lines look pretty good, but…





High S/N spectroscopy of 129 DAs in and around the DAV pulsational instability strip (Fuchs et al. in prep)

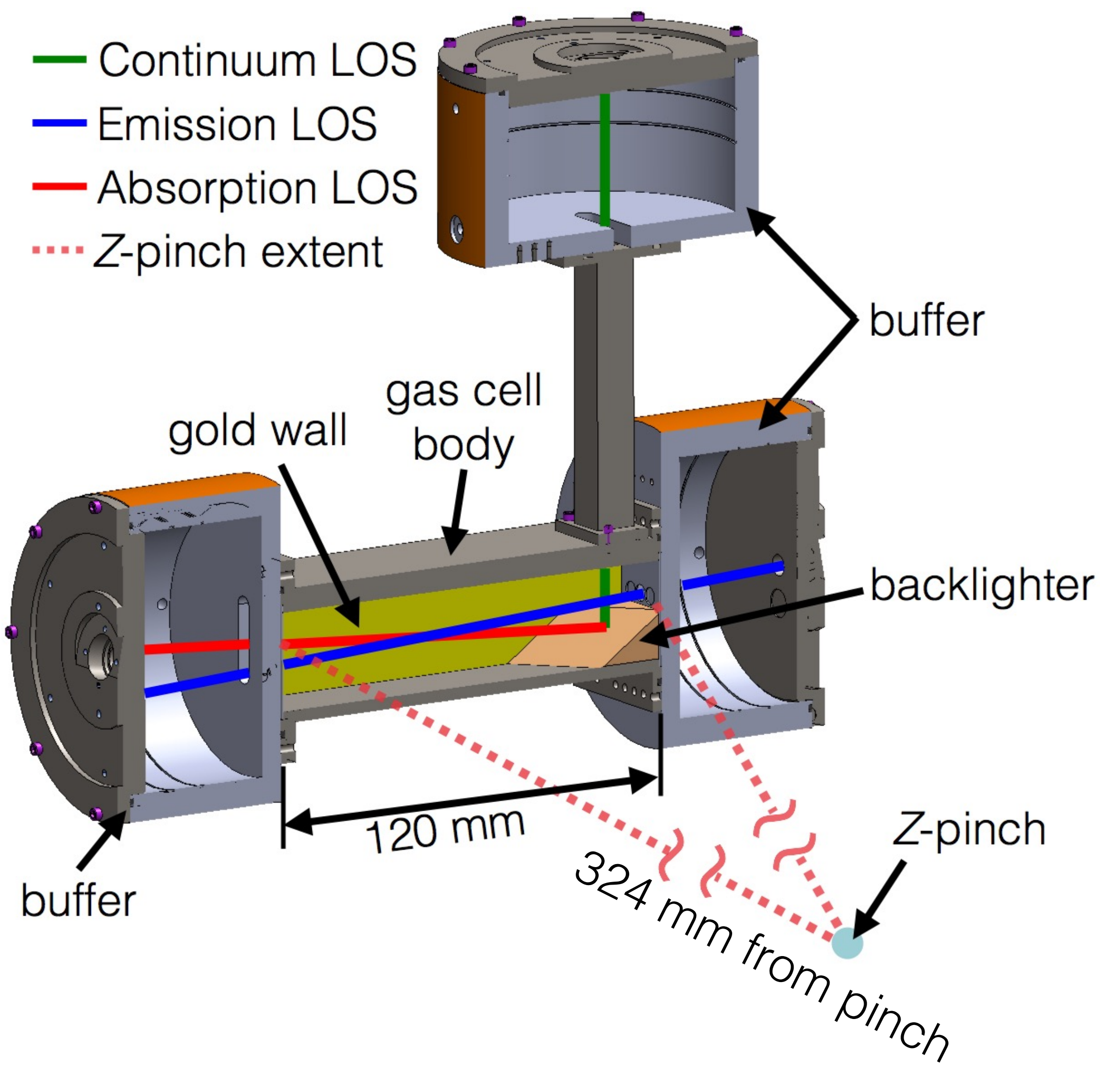
Individual Balmer lines give different results

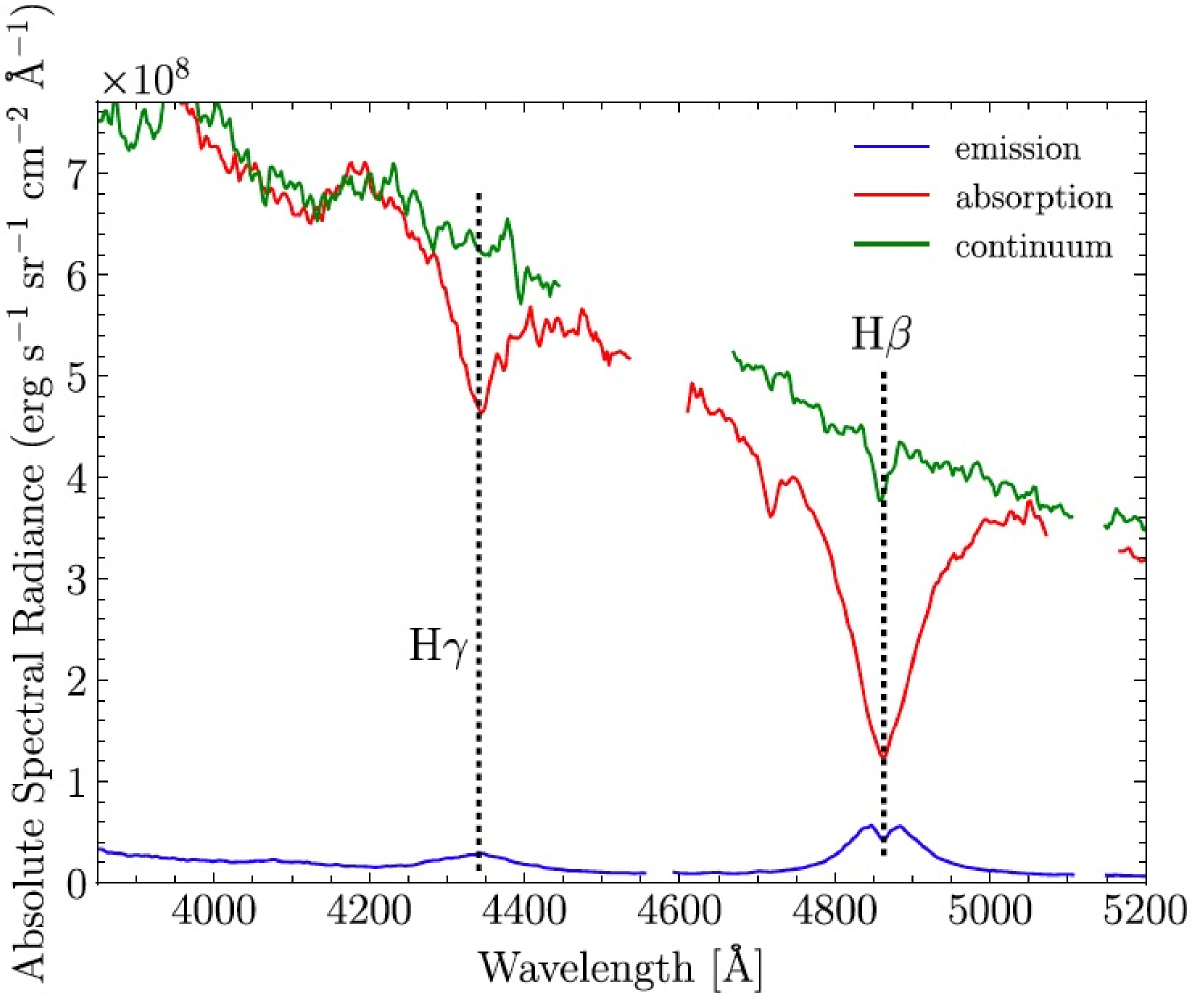


Fuchs et al.

The White Dwarf Photosphere Experiment on the Z-machine

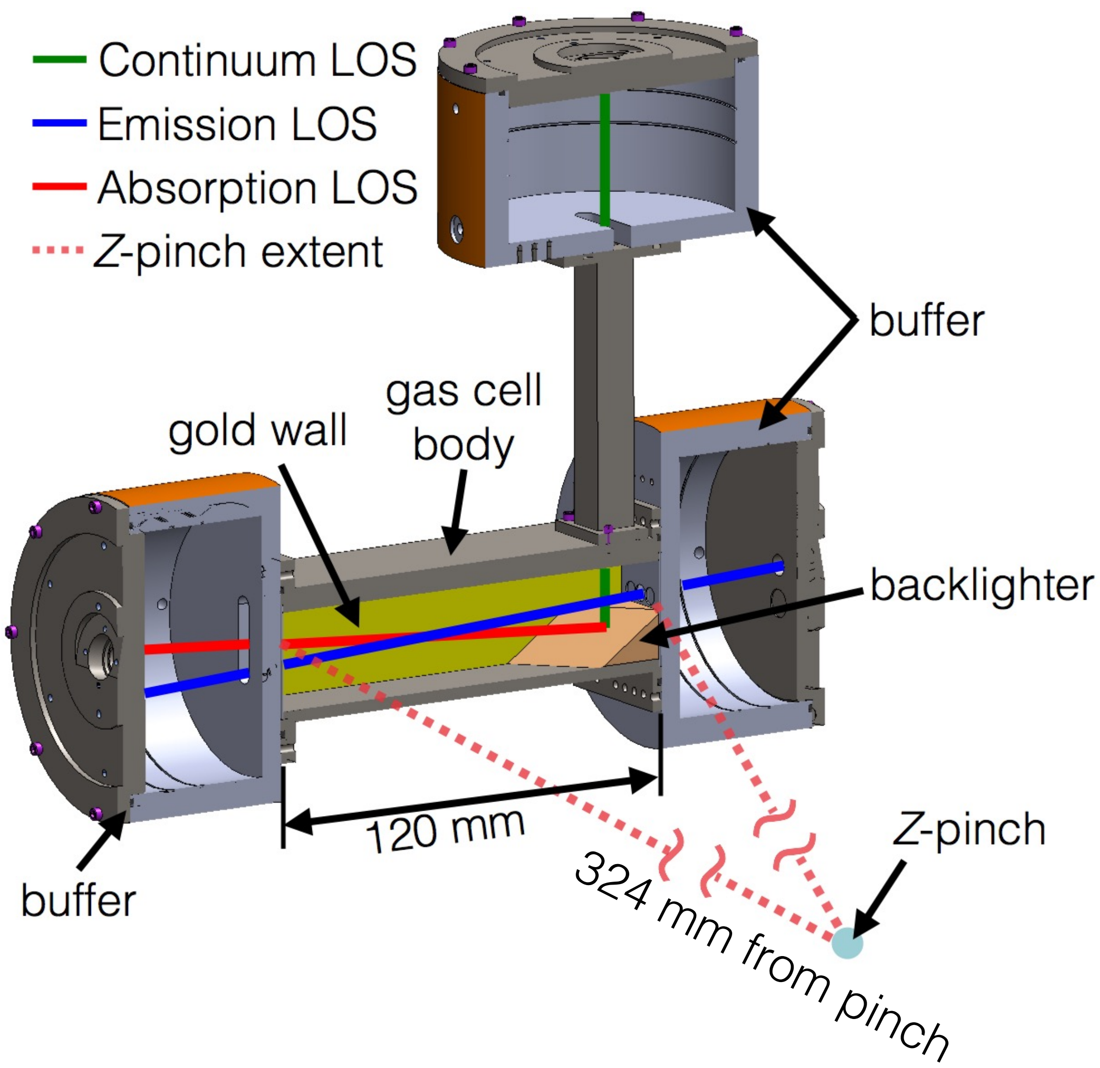
Schaeuble et al. (2019)





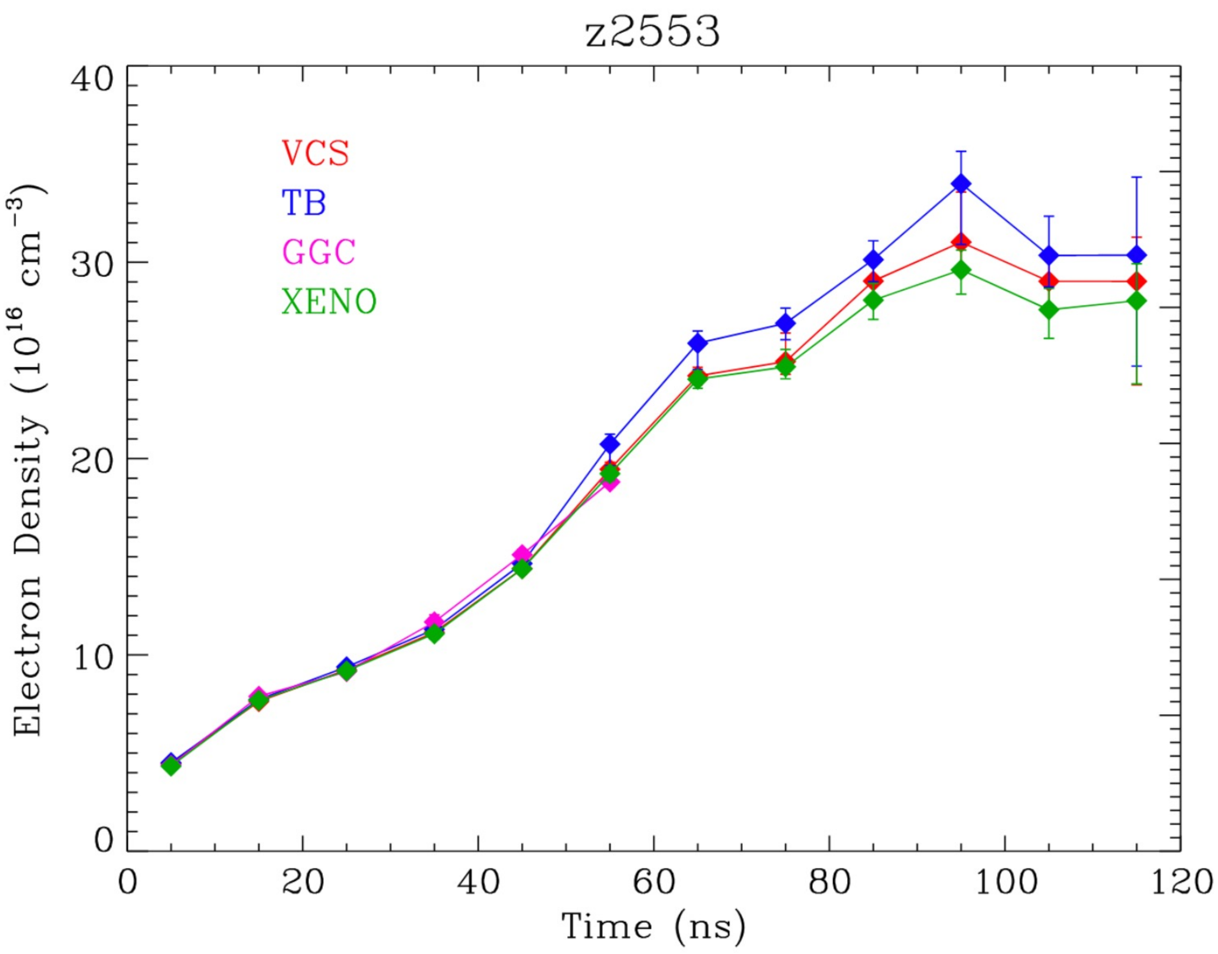
Schaeuble et al. (2019)

The White Dwarf Photosphere Experiment on the Z-machine



Schaeuble et al. (2019)

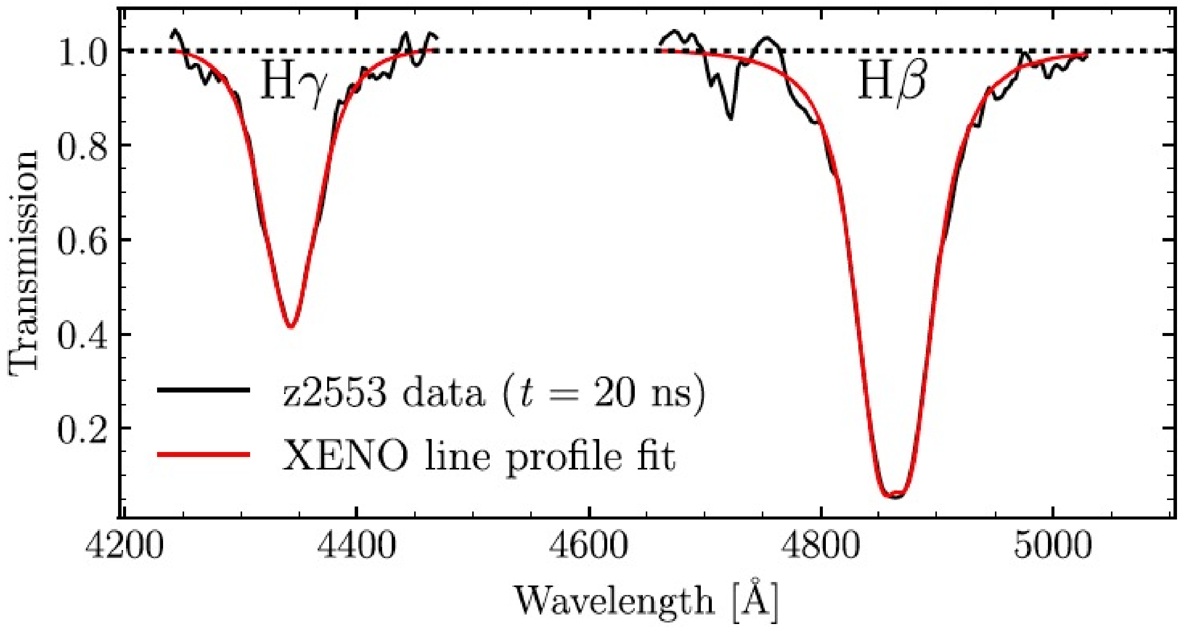
Across a range of n_e during each experiment.



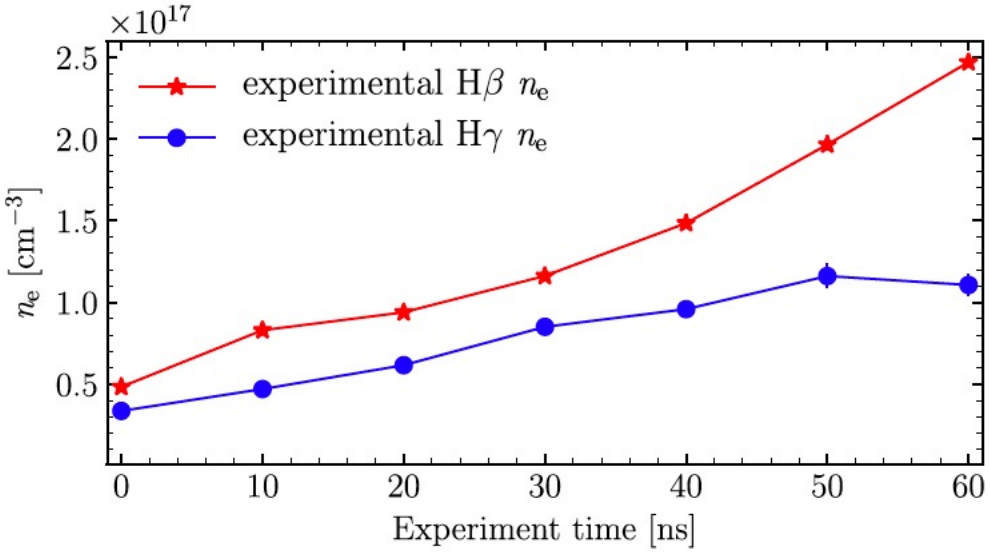
Falcon et al. ApJ (2015)

Analysis of the WDPE absorption spectra reveal trends similar to those observed in stellar spectra

Schaeuble et al. (2019)



Line fits to absorption spectra.
These are used to extract n_e values.

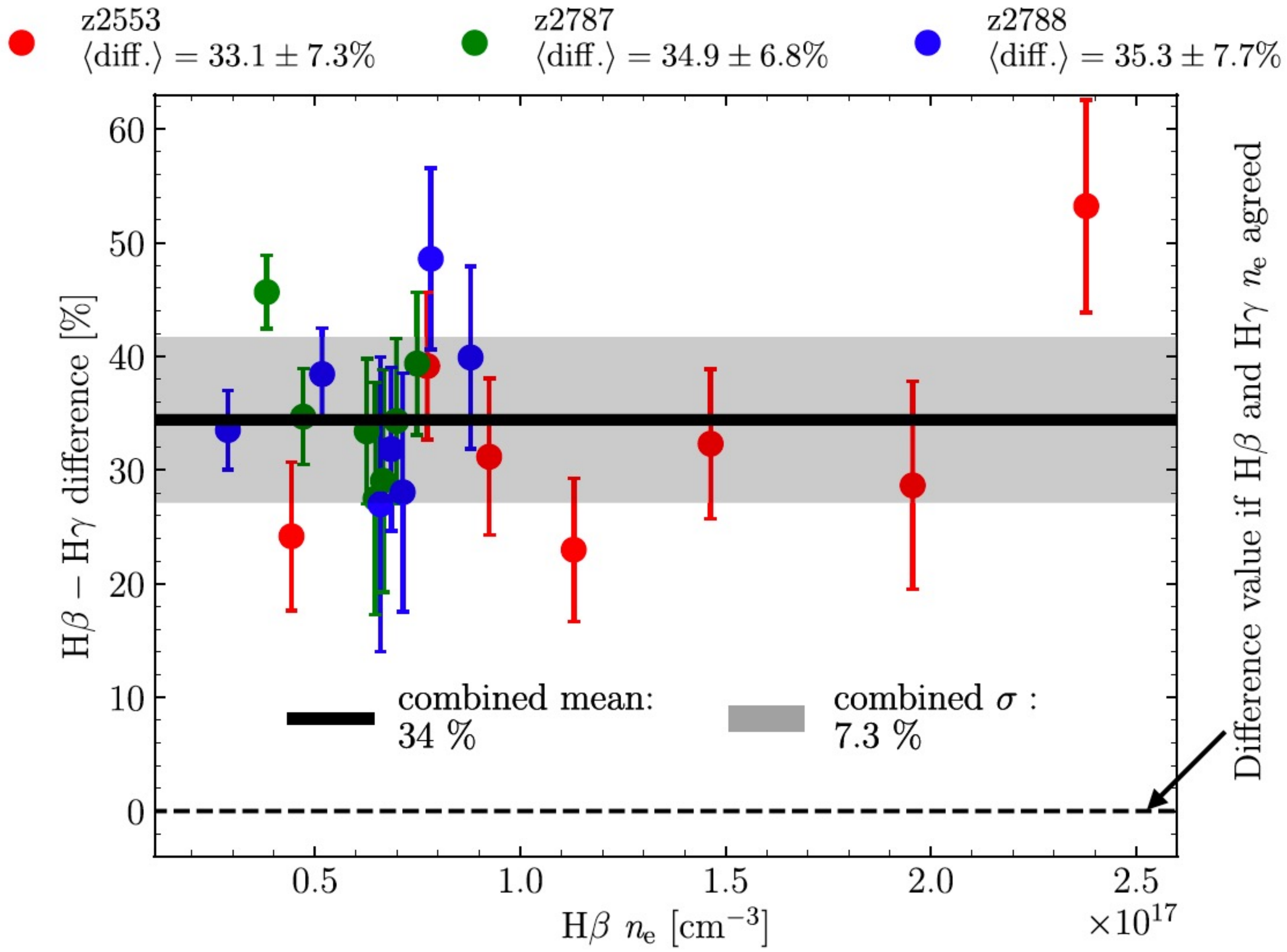


Hβ and Hγ n_e values differ by ~30%.

Analysis of the WDPE absorption spectra reveal trends similar to those observed in stellar spectra

Hβ and Hγ n_e values differ by ~30%.

This difference is consistent across multiple shots.



Schaeuble et al. (2019)

Hydrogen data at higher densities can more easily test theories of line shapes and occupation probability

Previous data at higher densities showed larger disagreement among theories.

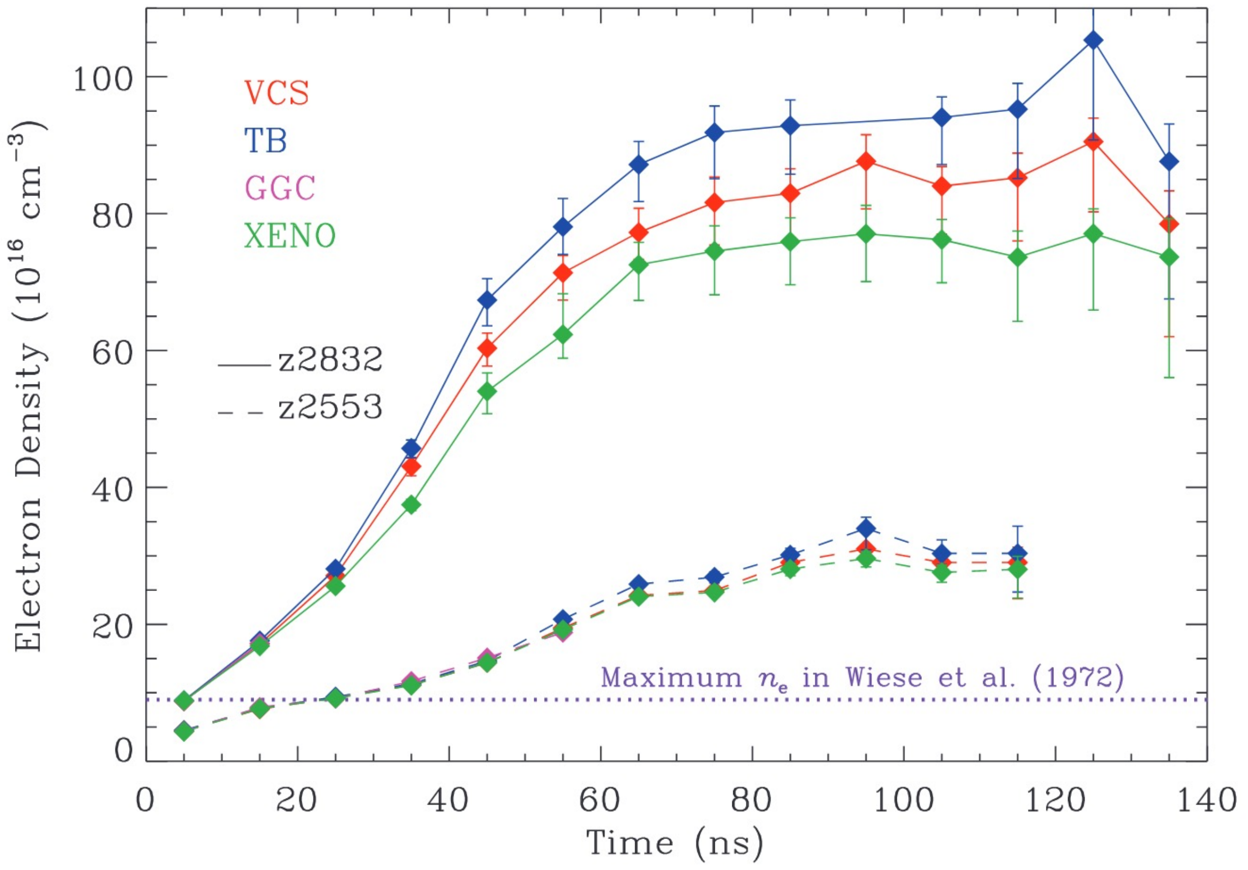


Figure 1. Electron density, n_e, as a function of time throughout our experiments z2553 and z2832. We infer n_e using different theoretical line-profile calculations.

Falcon et al. 2017

Hydrogen data at higher densities can more easily test theories of line shapes and occupation probability

Previous data at higher densities showed larger disagreement among theories.

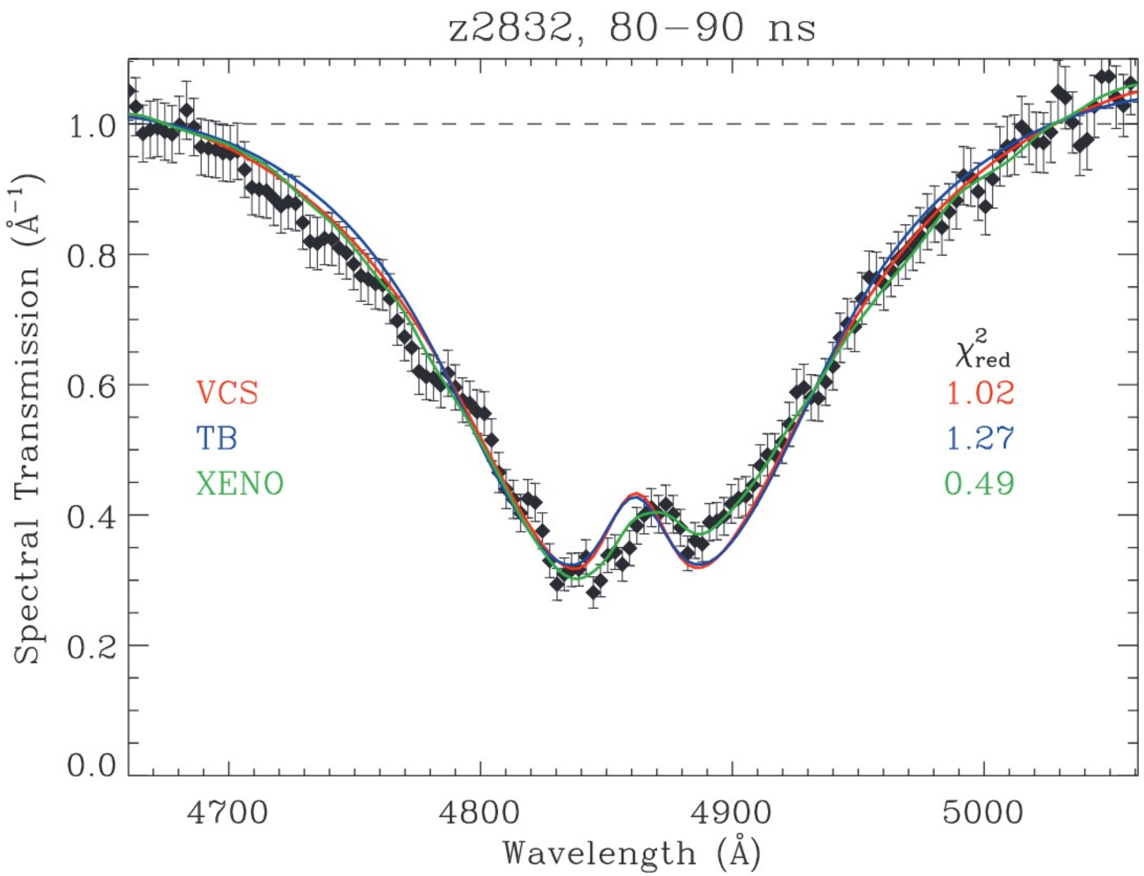


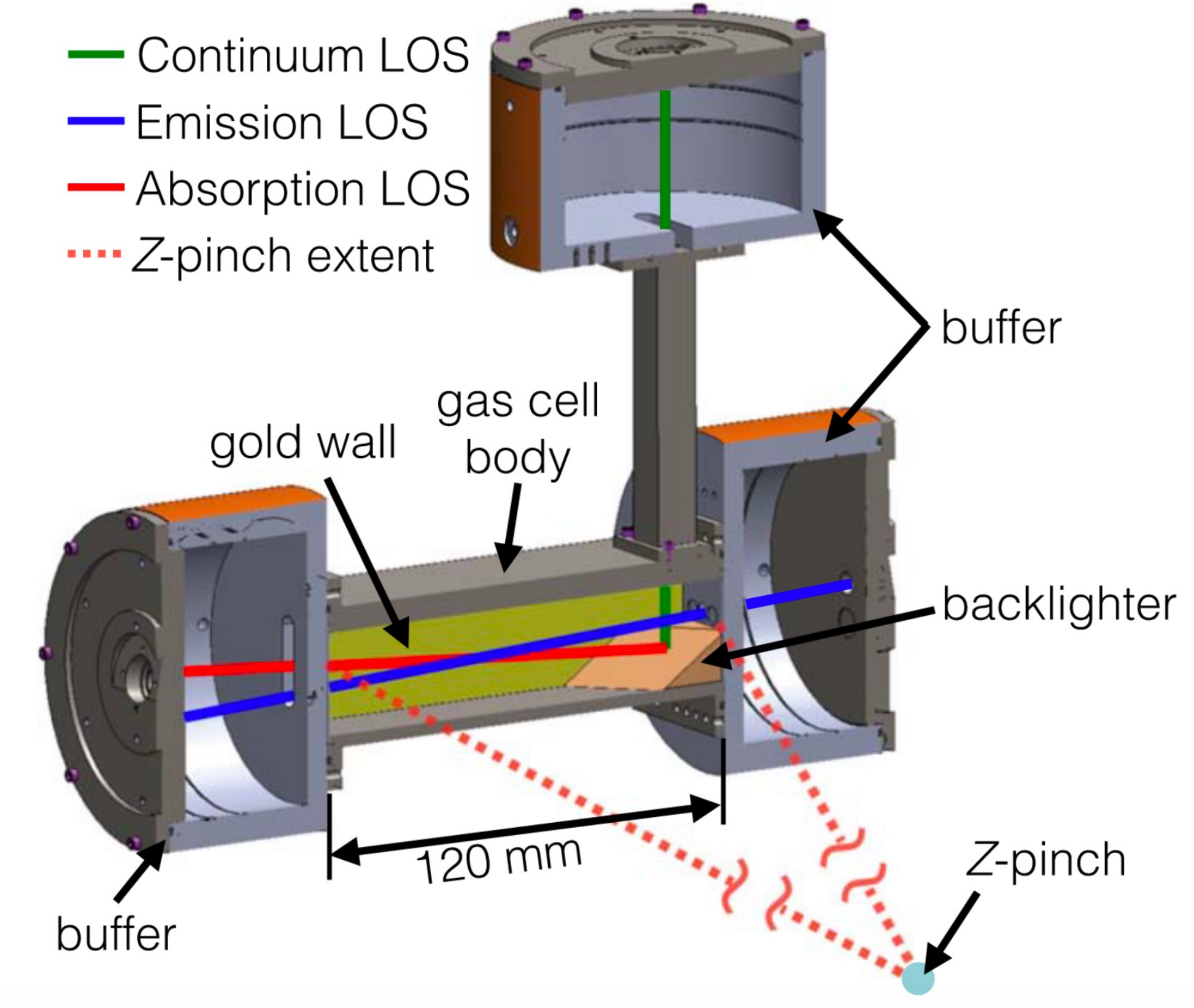
Figure 2. Measured Hβ spectral transmission at 80–90 ns during experiment z2832. We fit using different theoretical line-profile calculations (n_e ~ 83, ~ 93, and ~ 76 × 10^{16} cm^{-3} for VCS, TB, and XENO, respectively) and show the goodness of fit (reduced χ^2).

Falcon et al. 2017

Hydrogen data at higher densities can more easily test theories of line shapes and occupation probability

Previous data at higher densities showed larger disagreement among theories.

Data had to be taken at the 5 mm line of sight, where gradients across the beam are larger.



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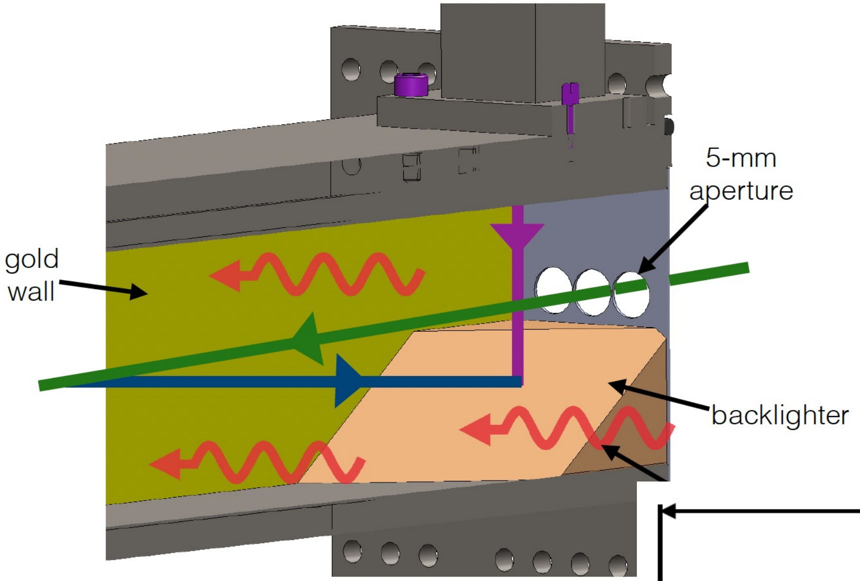
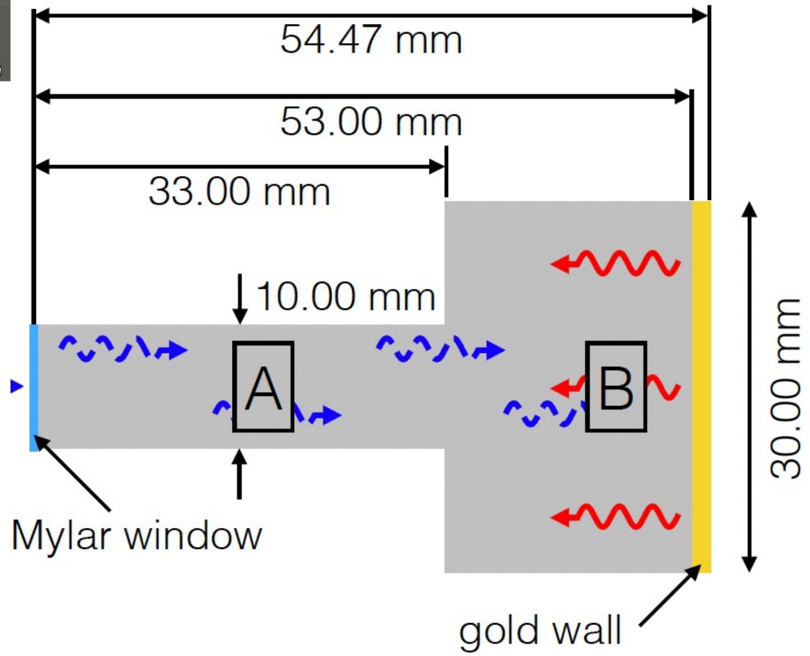


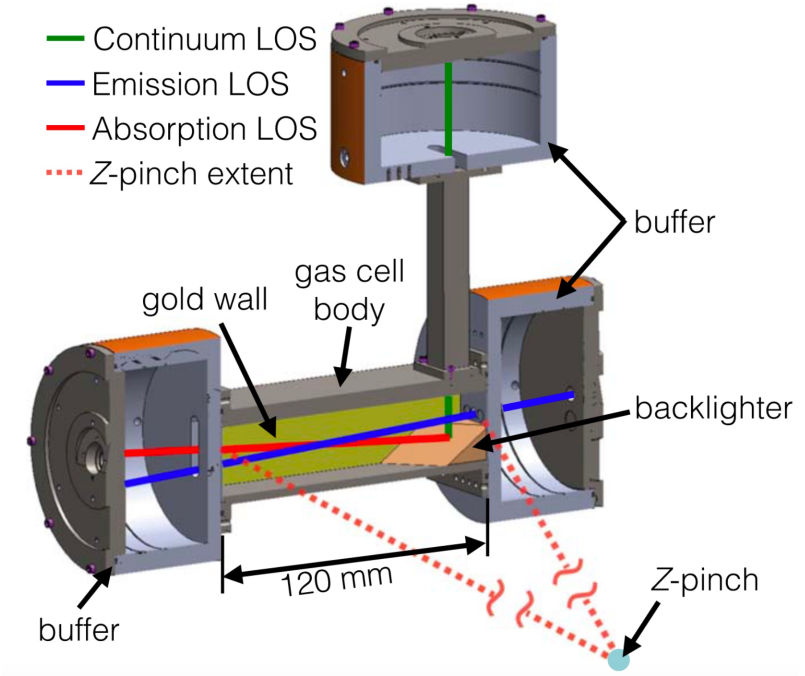


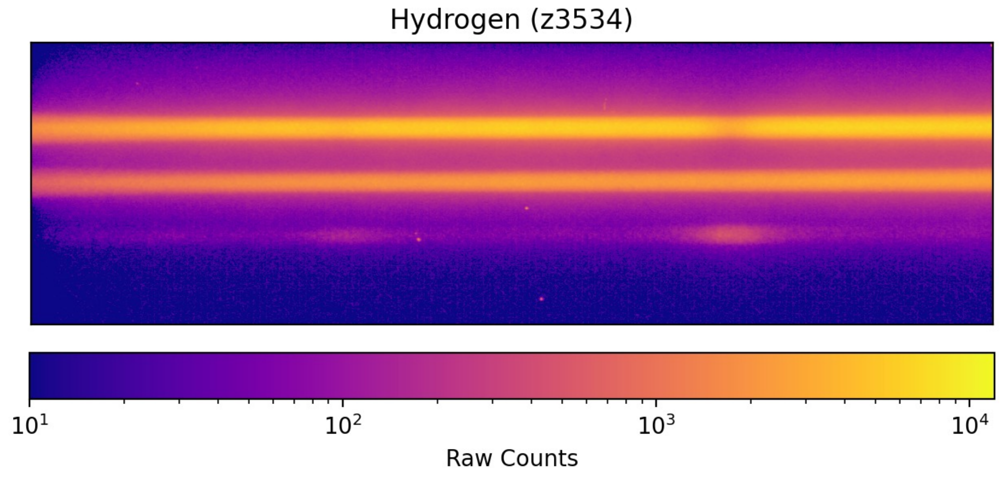
Hydrogen data at higher densities can more easily test theories of line shapes and occupation probability

Previous data at higher densities showed larger disagreement among theories.

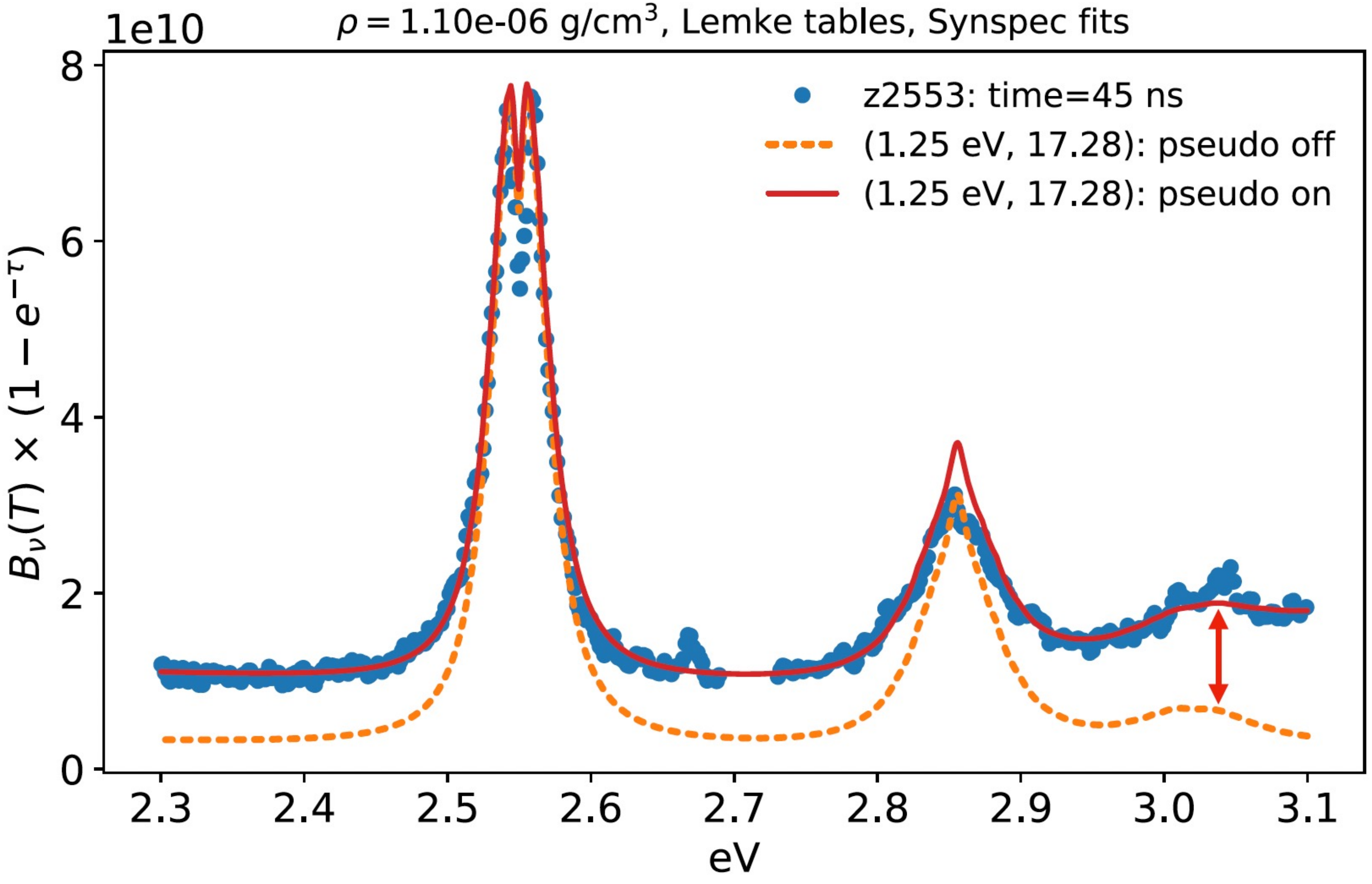
Data had to be taken at the 5 mm line of sight, where gradients across the beam are larger.

Continuum data not collected simultaneously, which limits the ability to test theories of occupation probability.





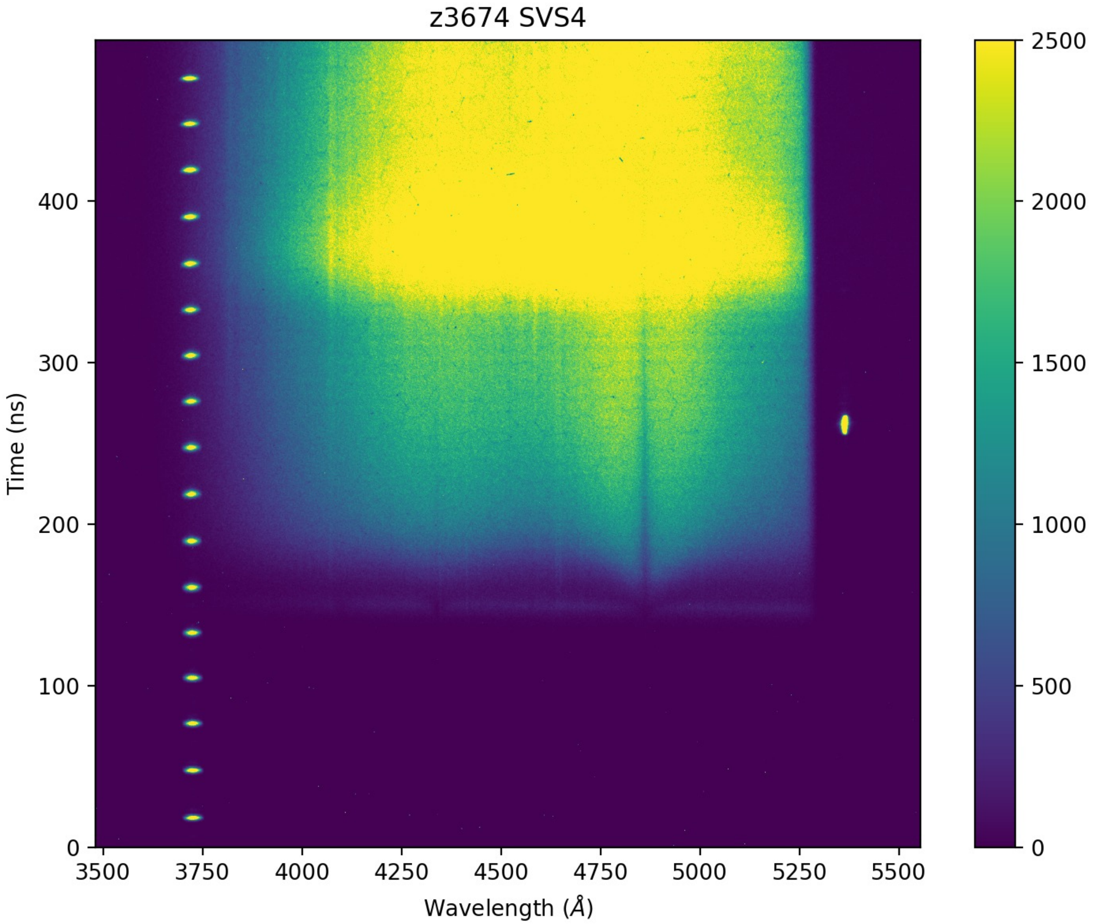
Effect of the Pseudo-continuum

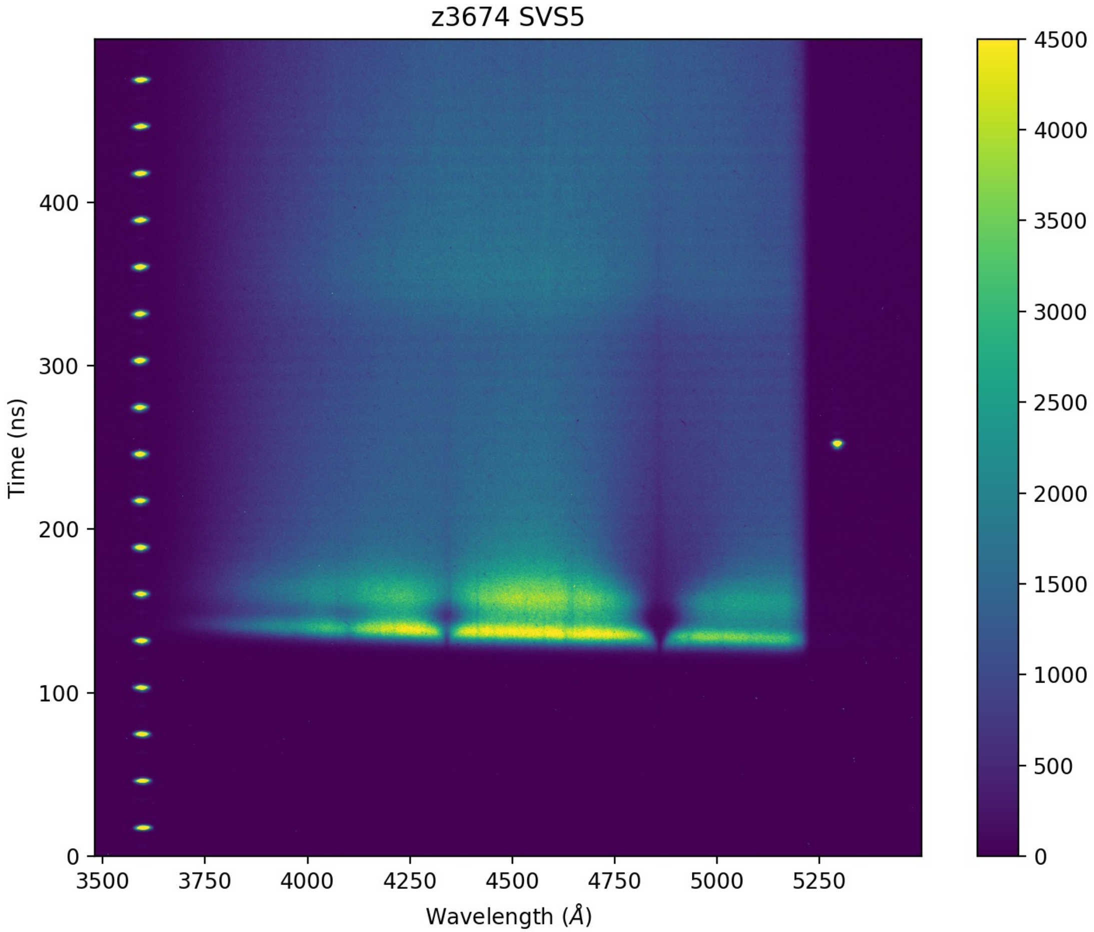


These calculations use the code *Synspec*, part of the *Tlusty* suite (Ivan Hubeny), which is used to fit the observed spectra of white dwarf stars.

Achieved higher n_e in H at 10 mm line of sight

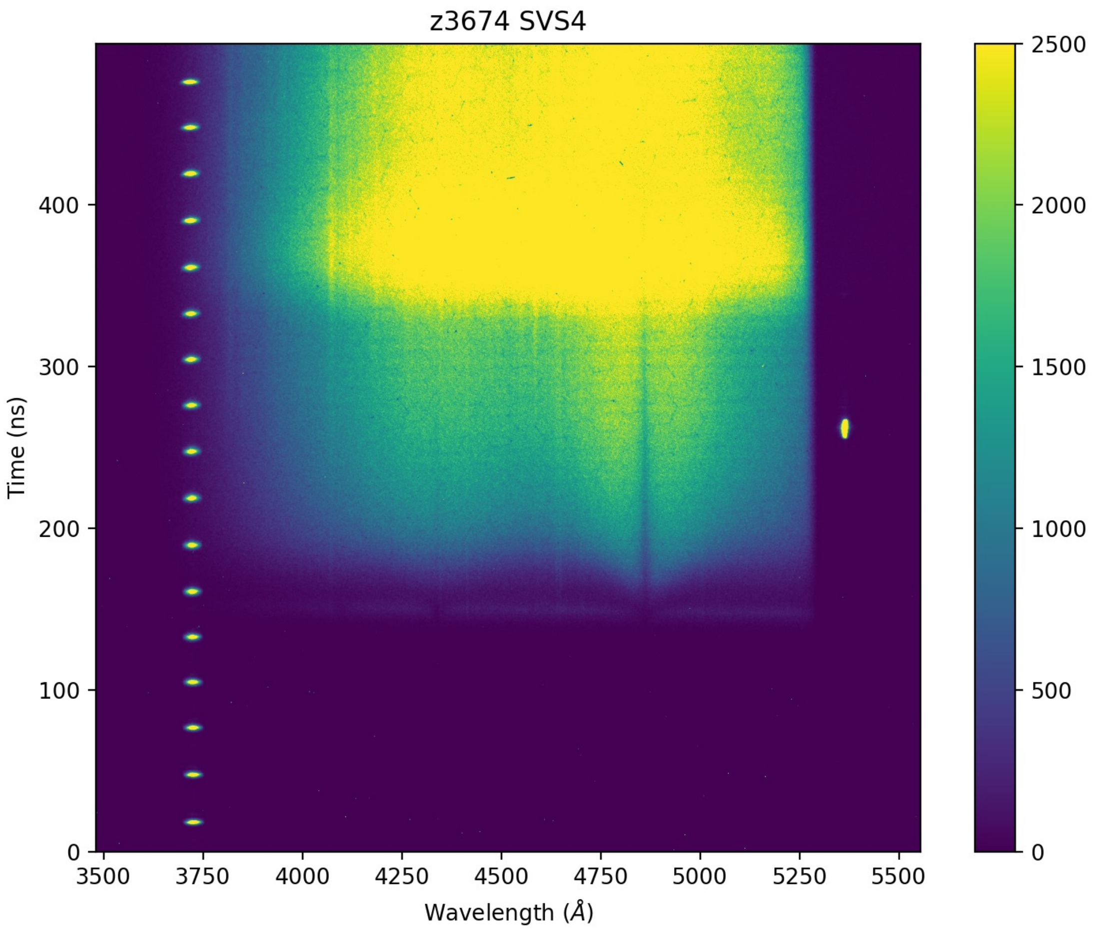
- Previous attempts at higher fill pressure did not lead to increased n_e at the 10 mm LOS, possibly because of self-shielding.
- Increased pressure (from 10 Torr to 25 Torr) **and** decreased window thickness (from 1.4 μm to 0.7 μm)

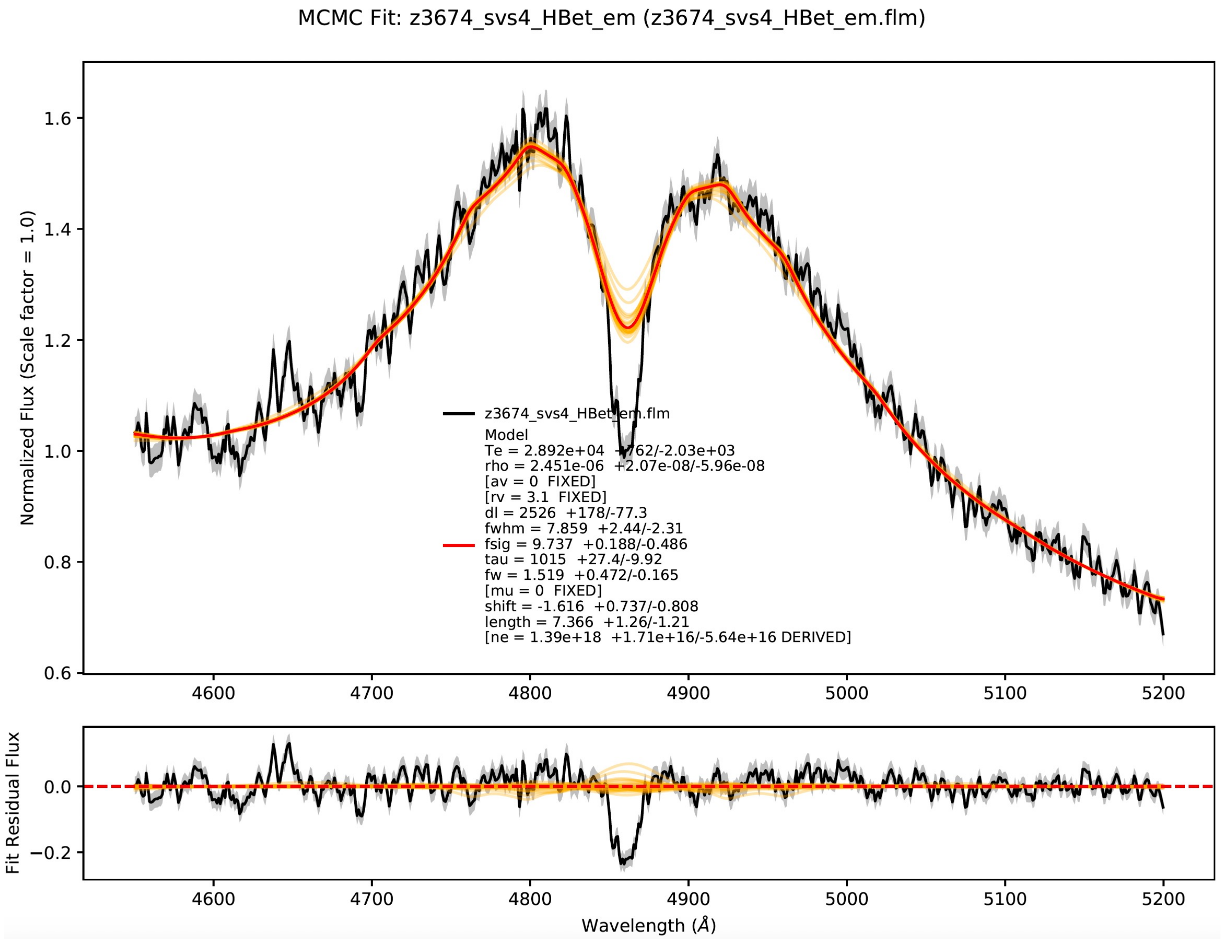




Fits to emission data suggest $n_e > 10^{18}\ cm^{-3}$

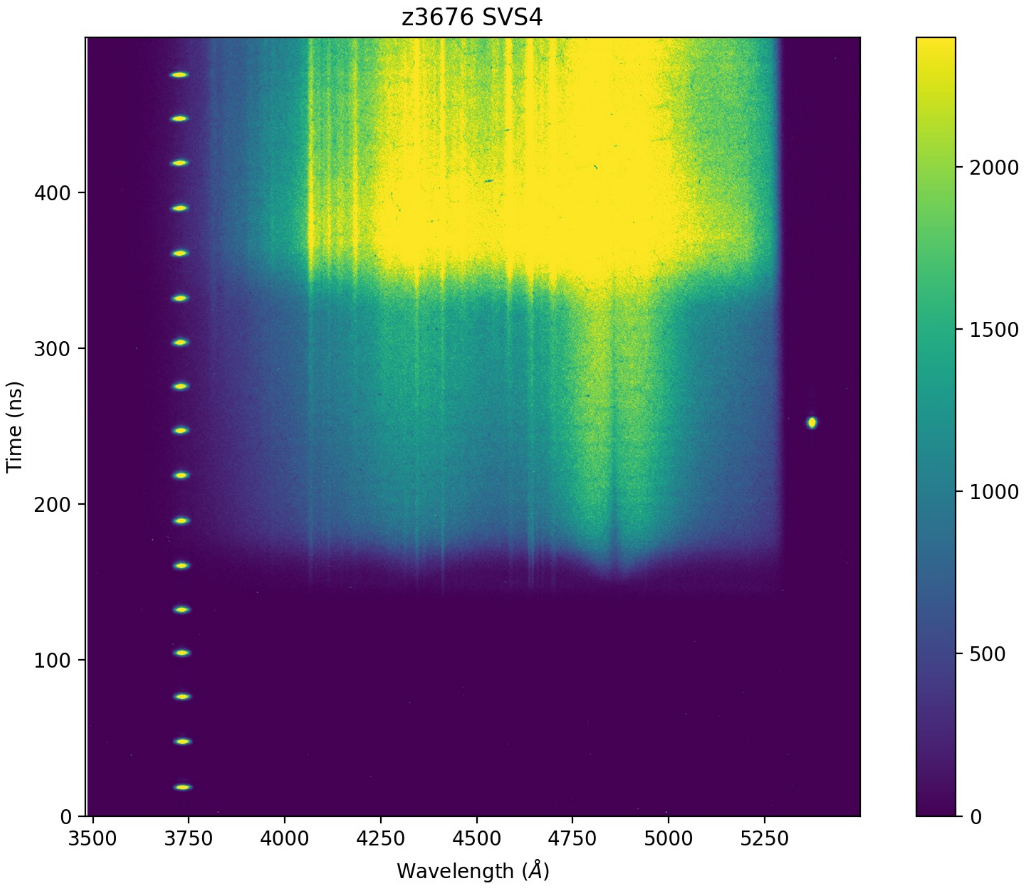
Hitting upper bounds of my current model grid…
Typical $n_e \sim 5 \times 10^{16} - 3 \times 10^{17}$.

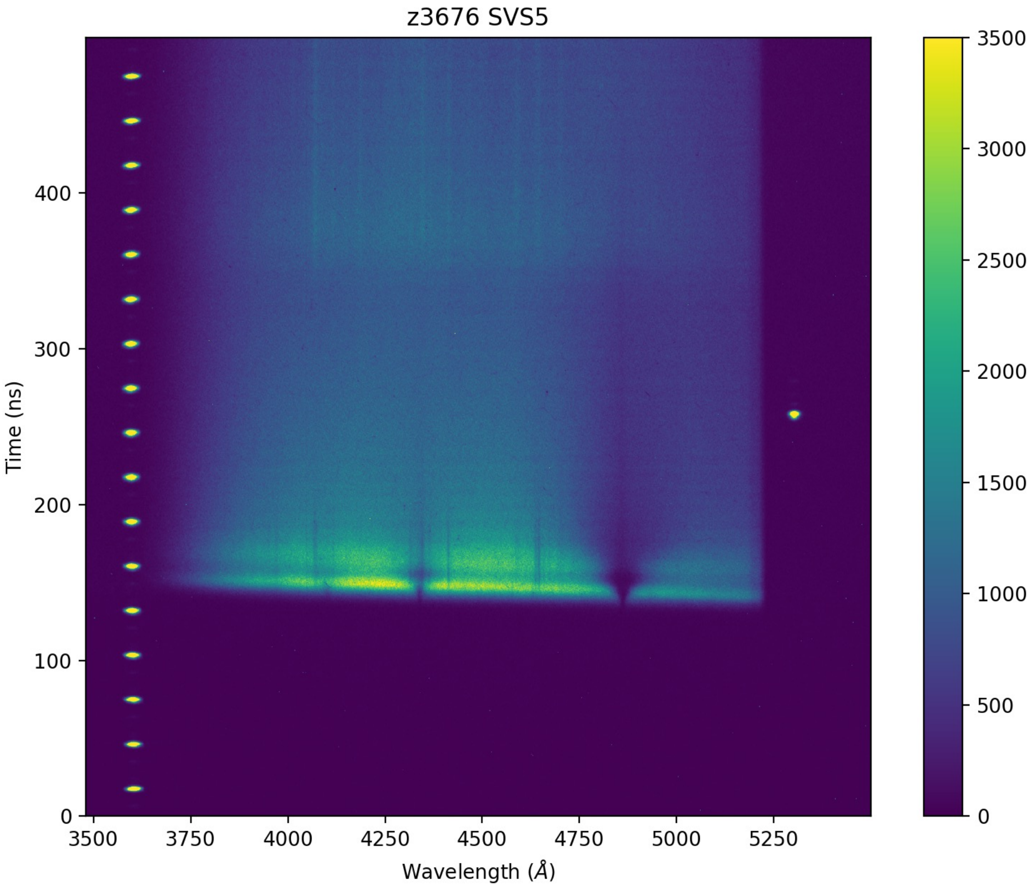




Achieved higher n_e in H at 10 mm line of sight

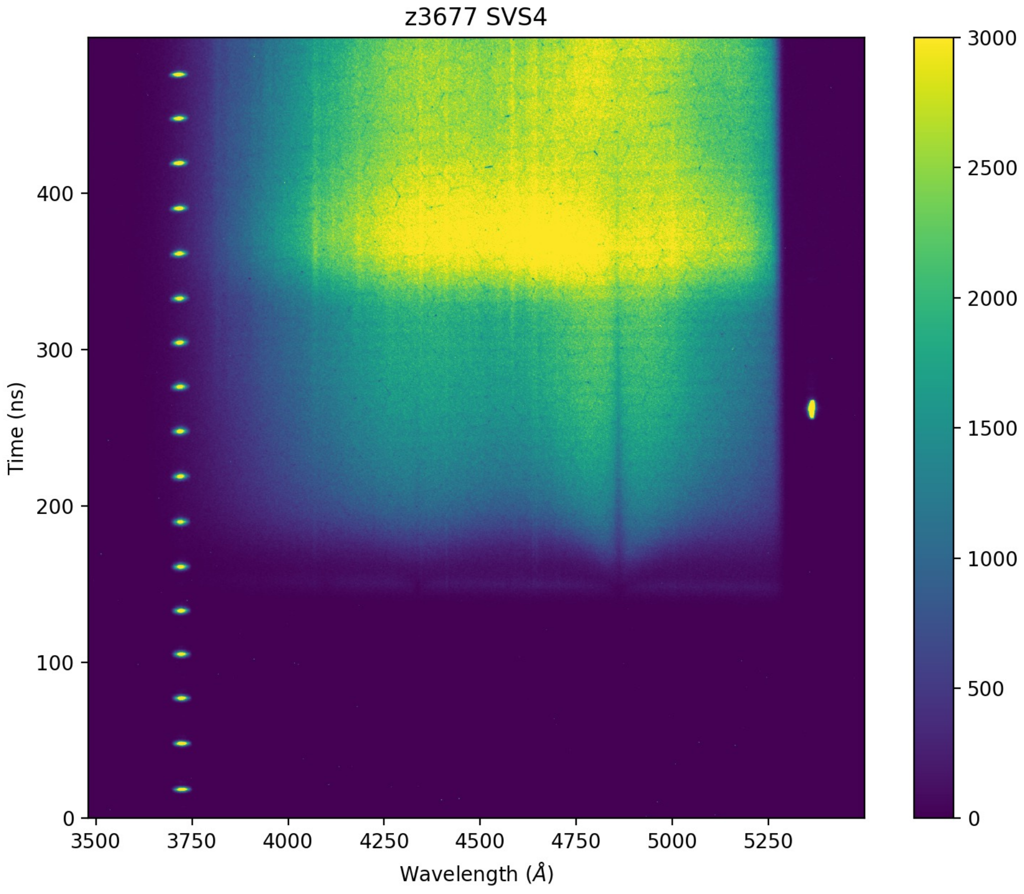
- Fill pressure = 18 Torr.
- More contamination visible.
- Cell sensor indicated increase in pressure after lockup; gas cabinet sensor did not show increase.

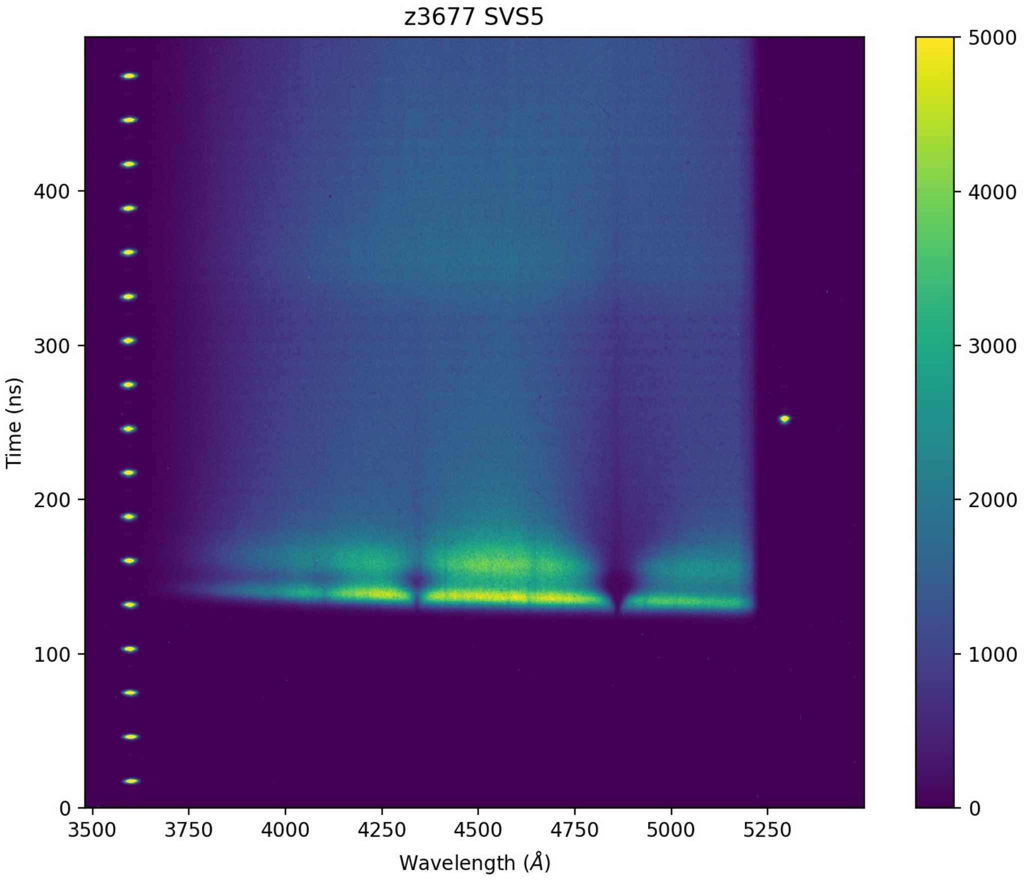




Achieved higher n_e in H at 10 mm line of sight

- Fill pressure = 35 Torr

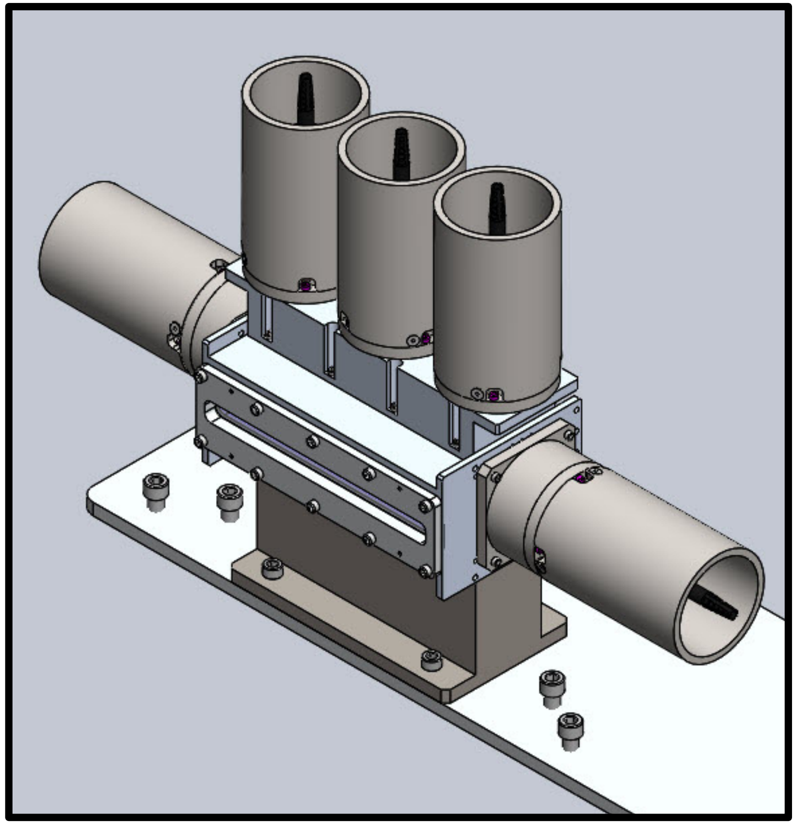


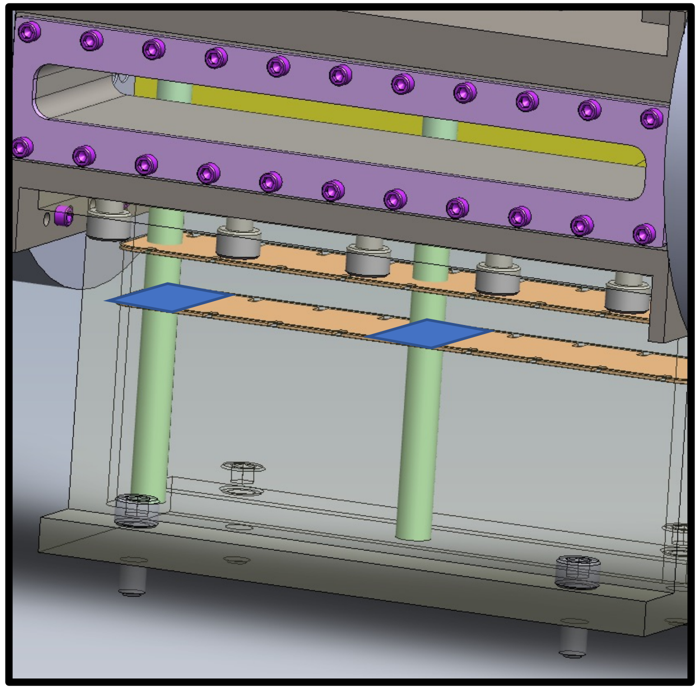


Importance of independent ne diagnostic

- We don’t want to have to rely on theoretical Hbeta lineshapes
- This is especially important at higher densities
- In our carbon experiments, we don’t have Hbeta
- Pure He experiments would be useful

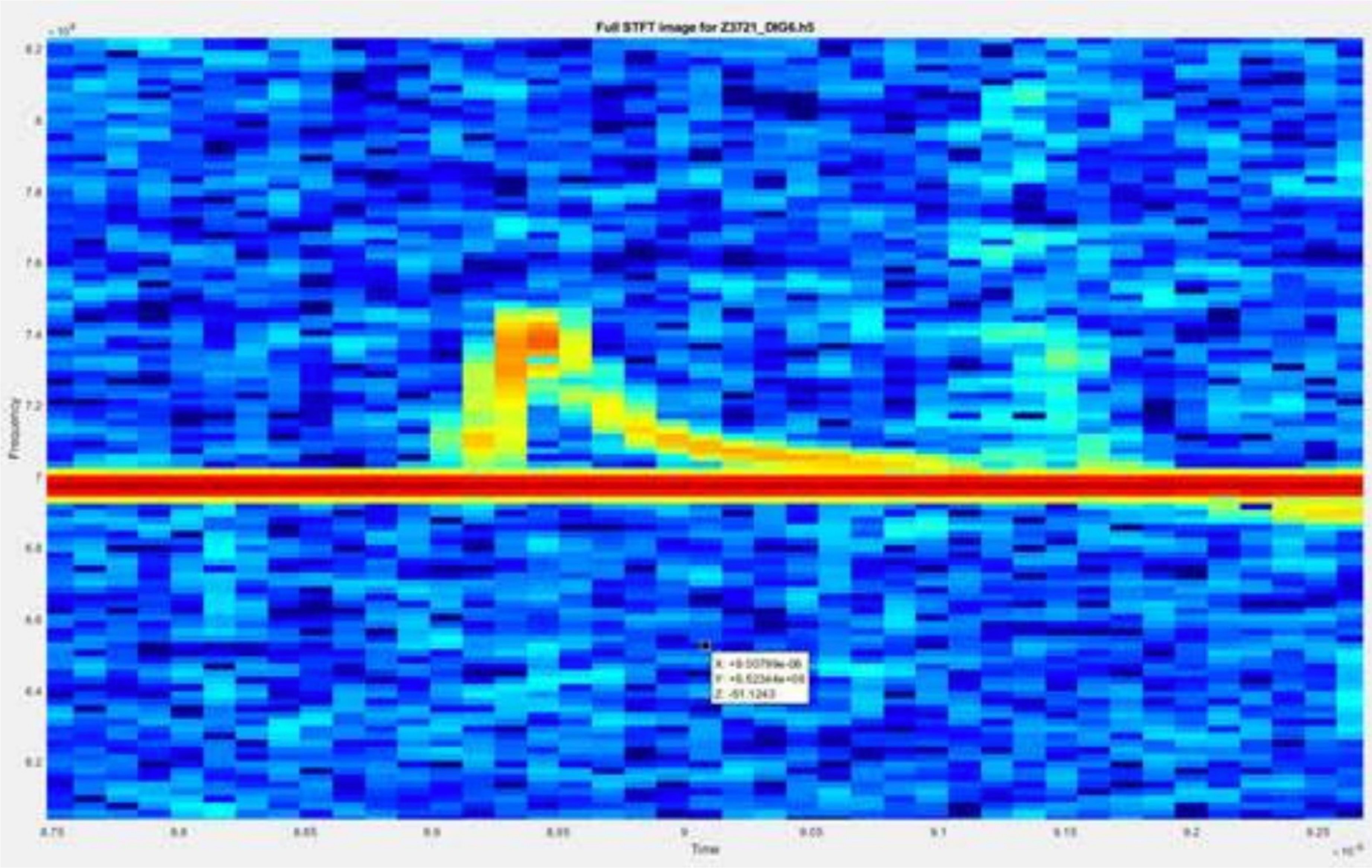
Fielding PDV on the WDPE



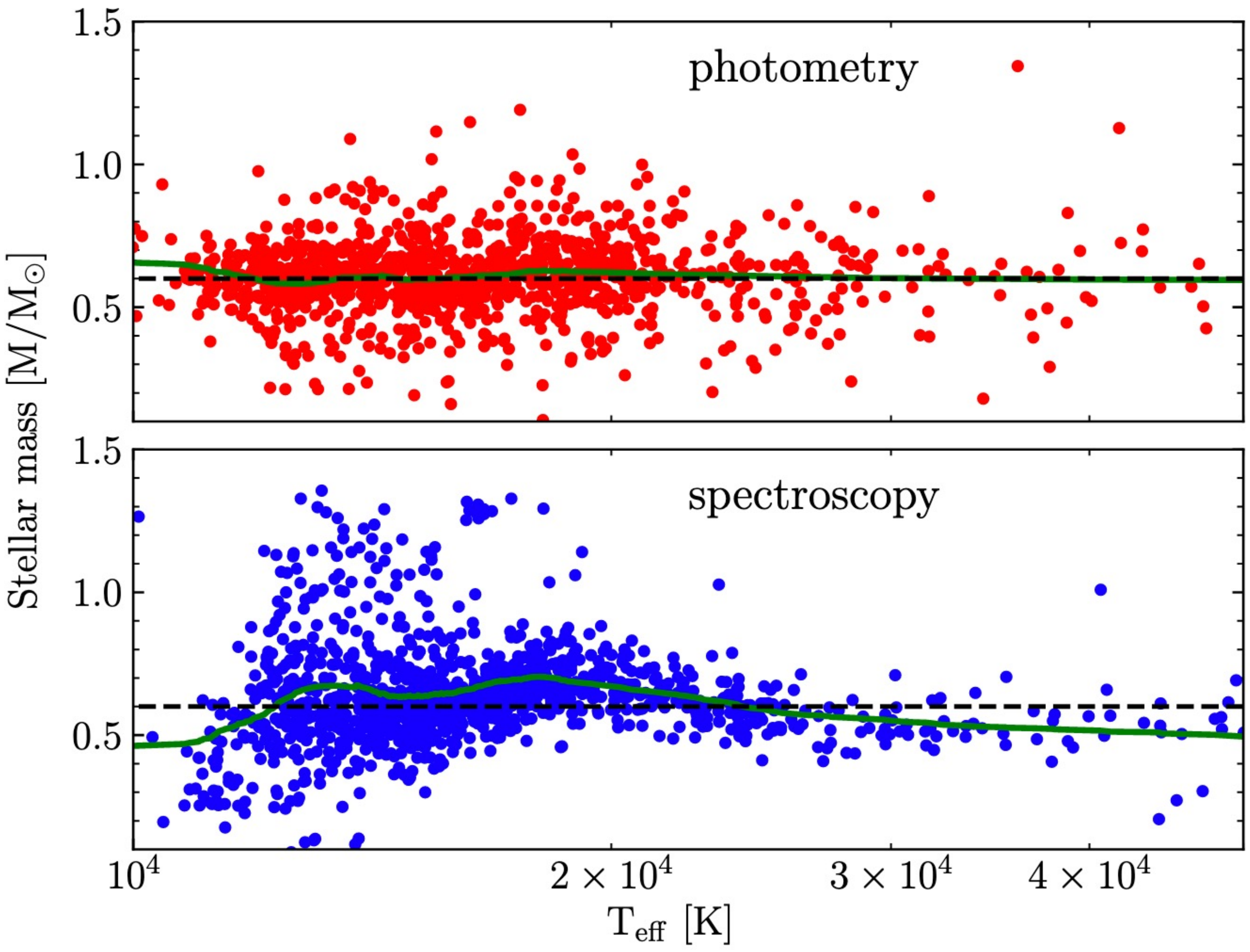


Replaced baffle with rigid piece to mount reflective tape.

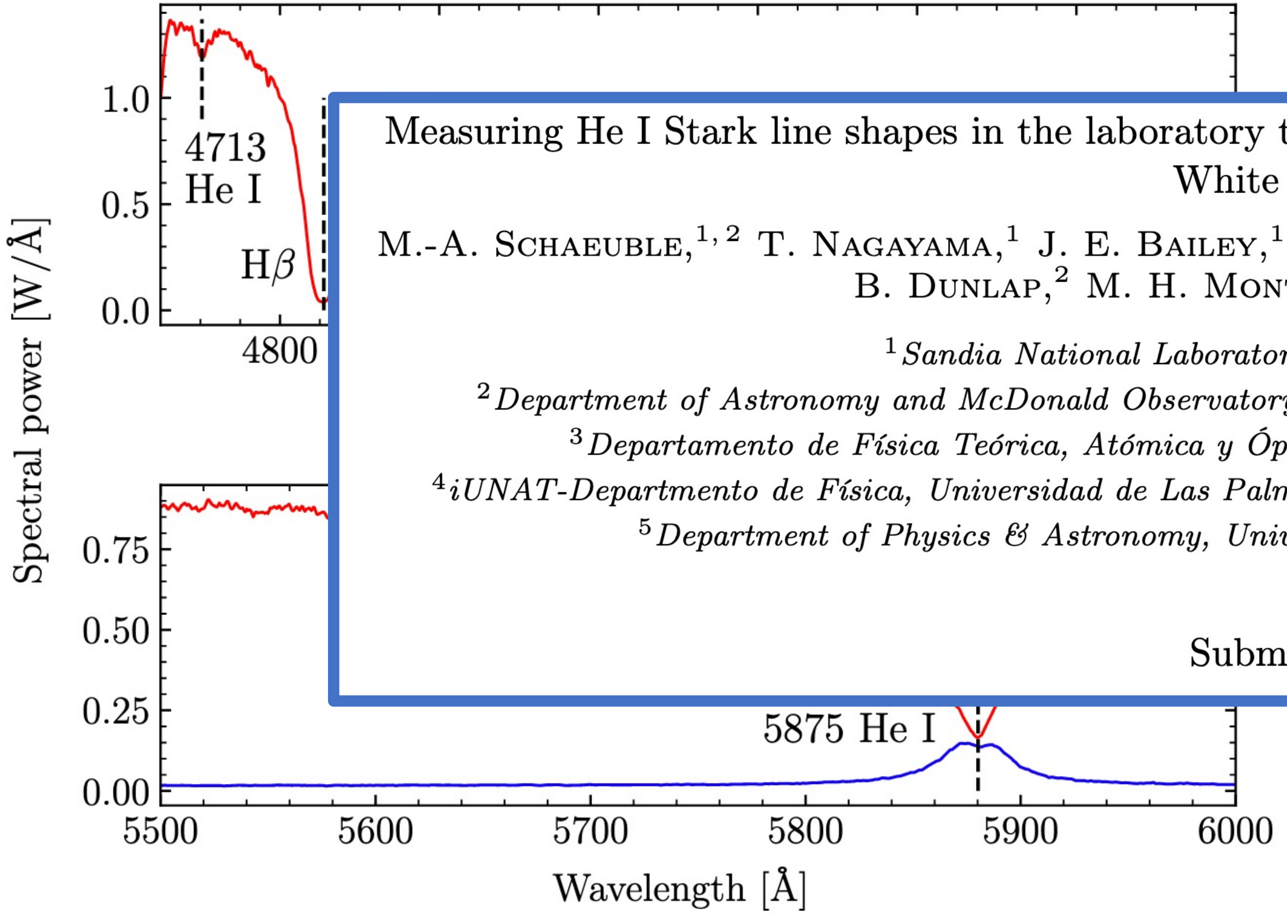
First PDV results (z3721)

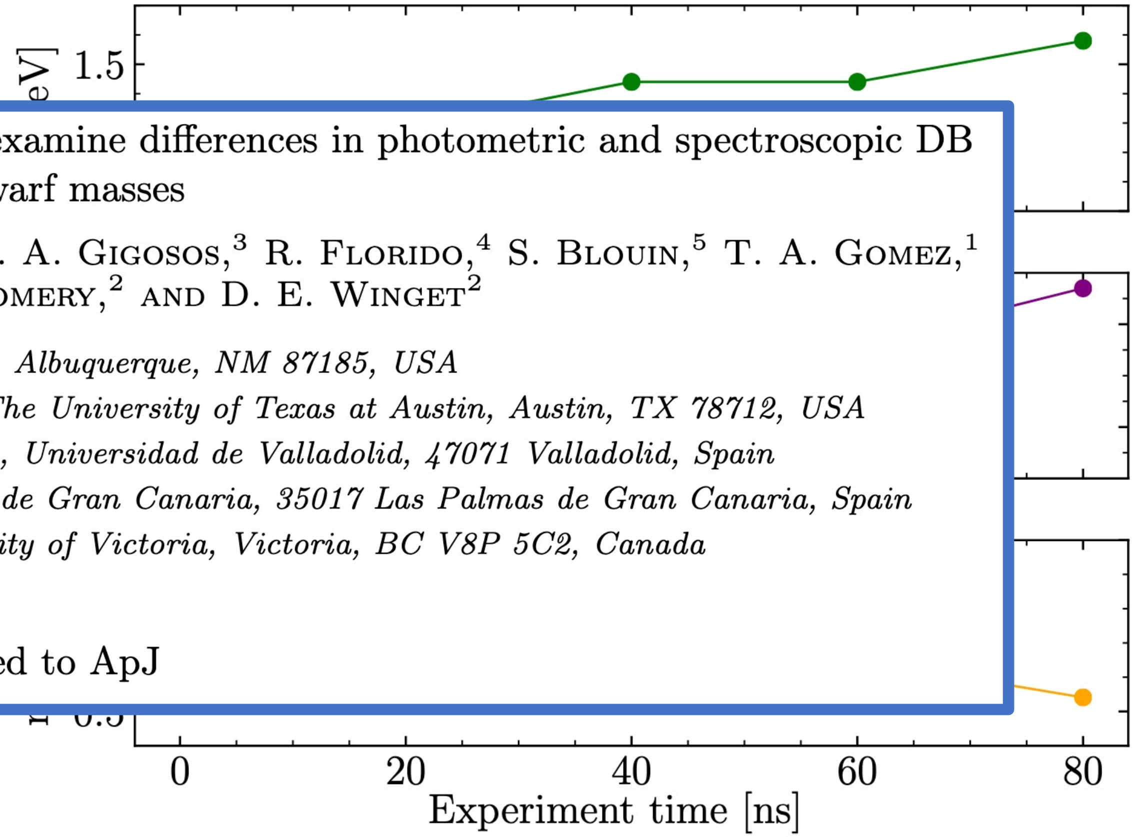


Helium atmosphere (DB) white dwarfs also indicate problems with spectroscopic mass



Measuring Helium lines with the WDPE on Z





Measuring He I Stark line shapes in the laboratory to examine differences in photometric and spectroscopic DB White Dwarf masses

M.-A. Schaeuble,[1,2] T. Nagayama,[1] J. E. Bailey,[1] M. A. Gigosos,[3] R. Florido,[4] S. Blouin,[5] T. A. Gomez,[1] B. Dunlap,[2] M. H. Montgomery,[2] and D. E. Winget[2]

[1] *Sandia National Laboratories, Albuquerque, NM 87185, USA*

[2] *Department of Astronomy and McDonald Observatory, The University of Texas at Austin, Austin, TX 78712, USA*

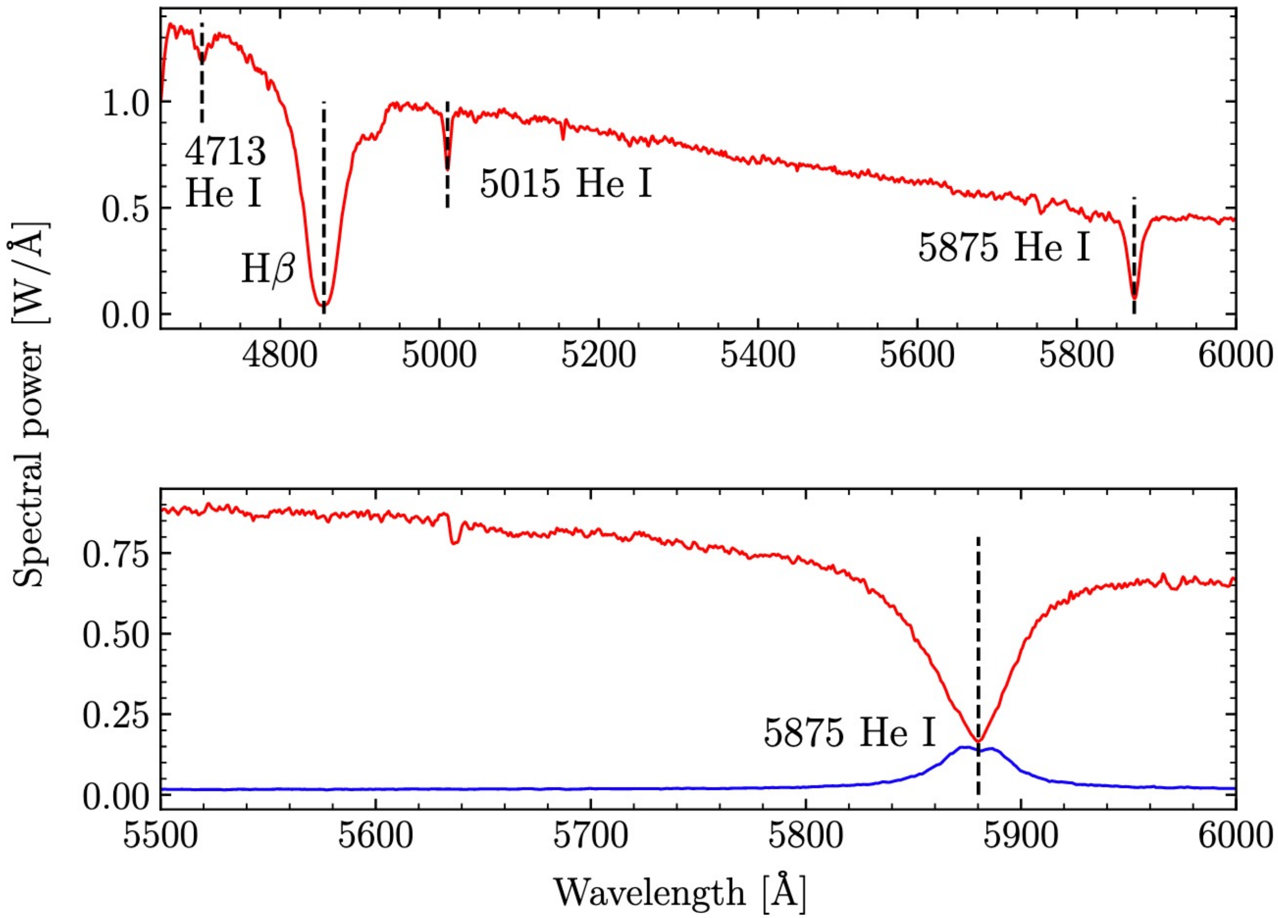
[3] *Departamento de Física Teórica, Atómica y Óptica, Universidad de Valladolid, 47071 Valladolid, Spain*

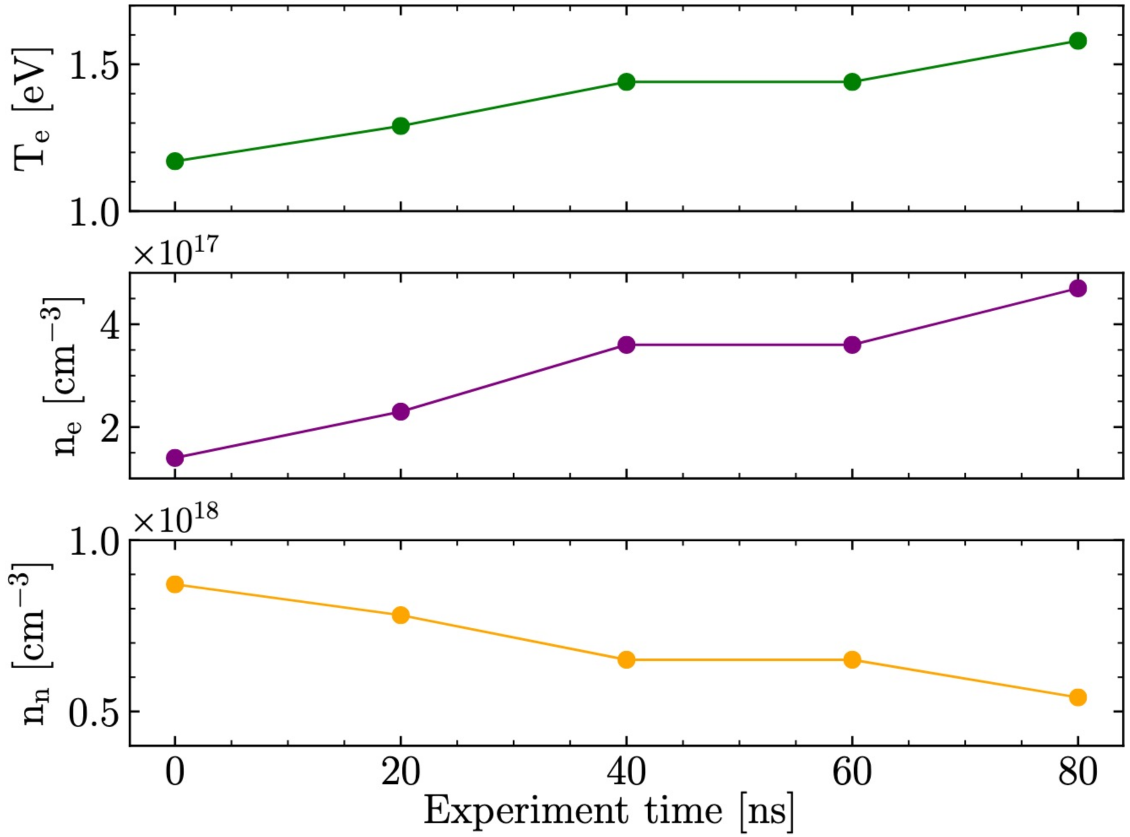
[4] *iUNAT-Departmento de Física, Universidad de Las Palmas de Gran Canaria, 35017 Las Palmas de Gran Canaria, Spain*

[5] *Department of Physics & Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada*

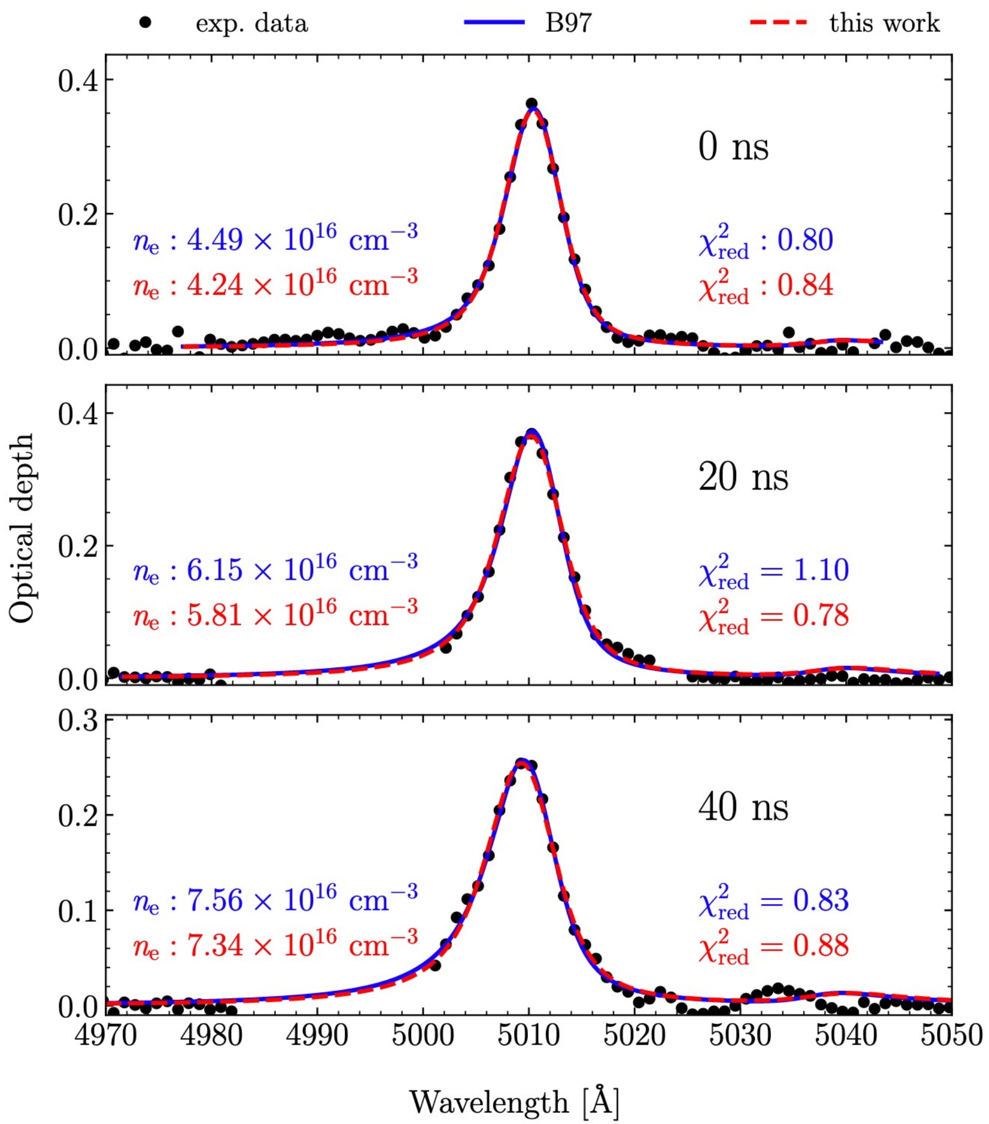
Submitted to ApJ

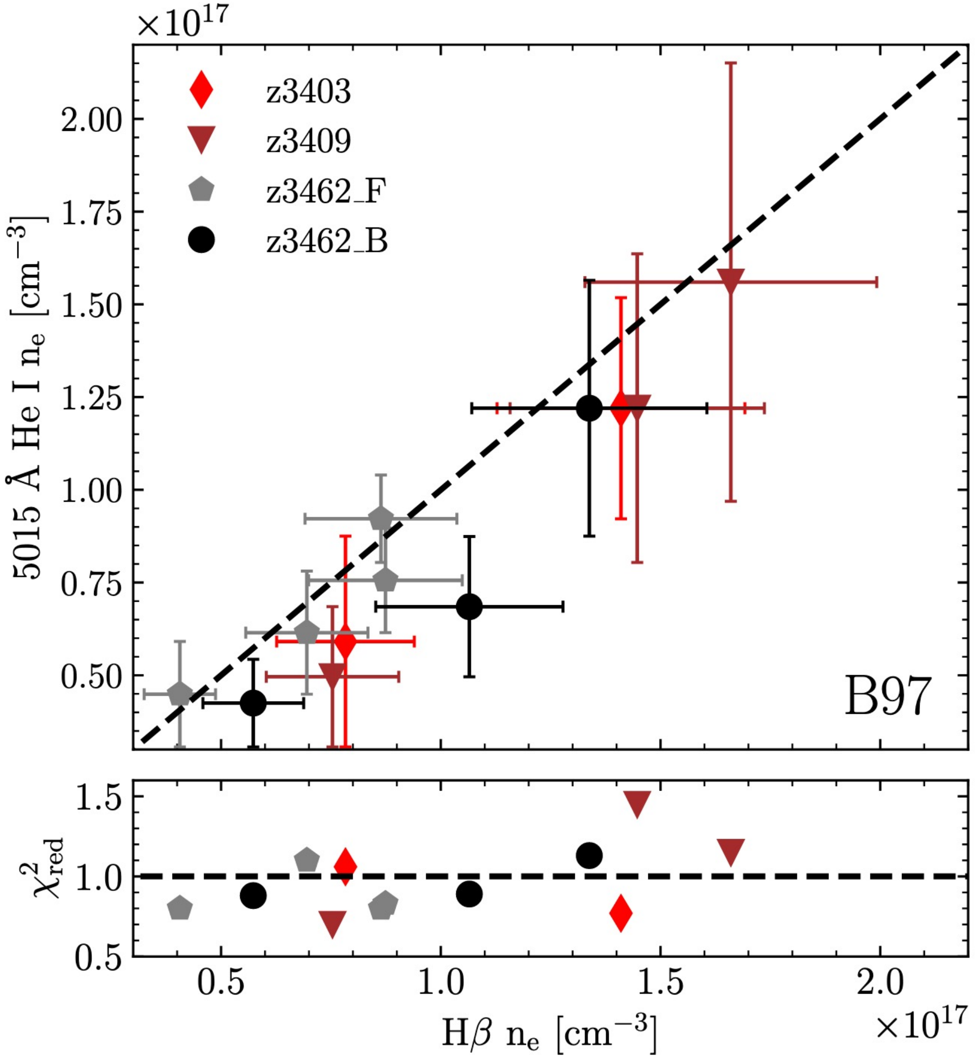
Measuring Helium lines with the WDPE on Z



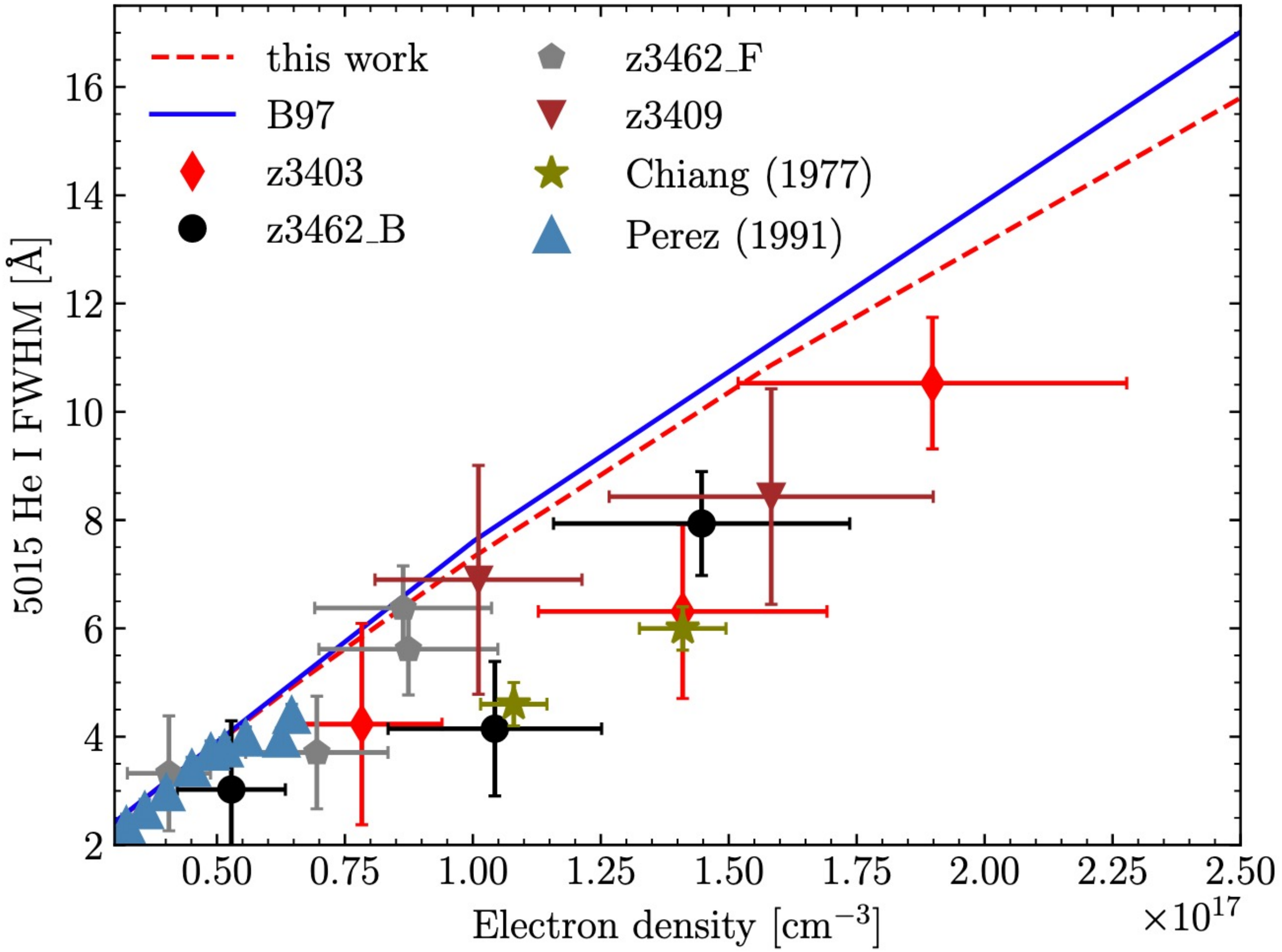


Fits to He I 5015 compared with Hbeta

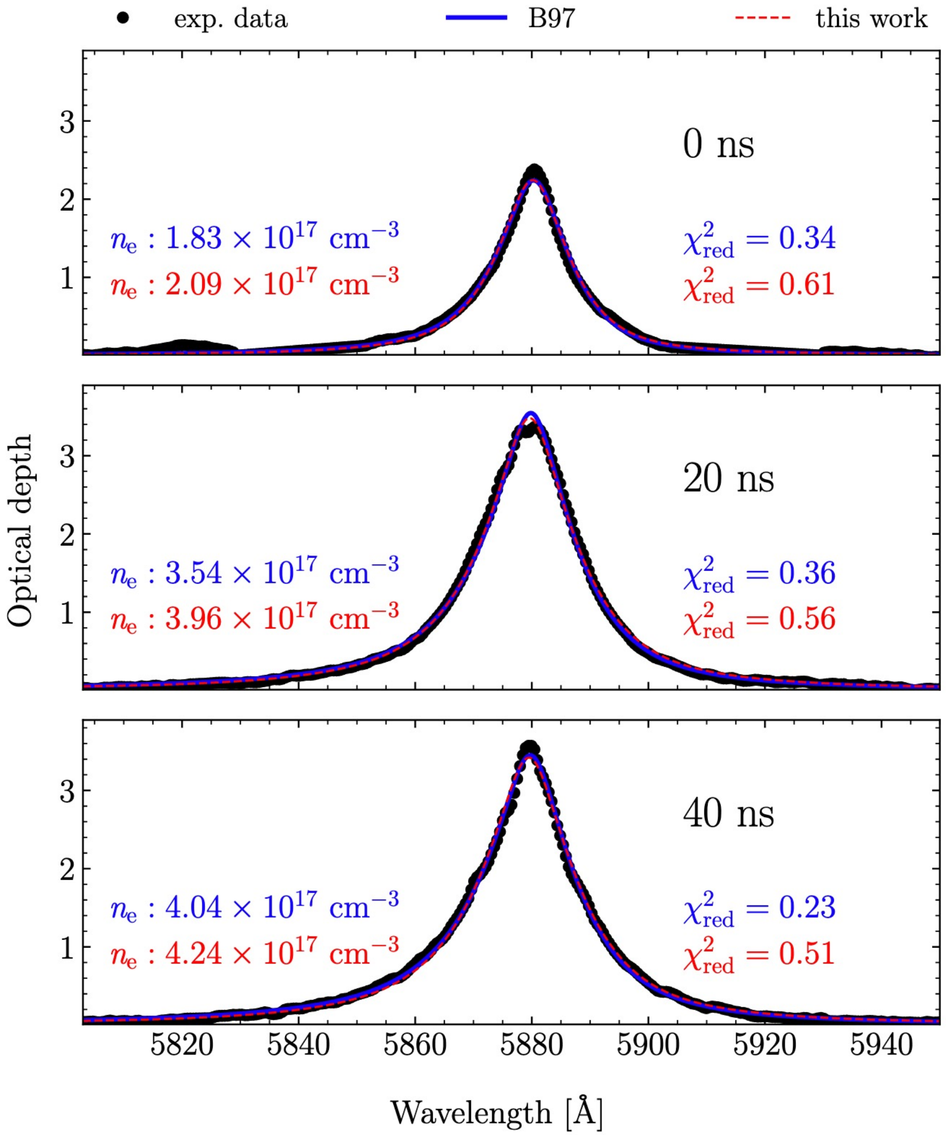


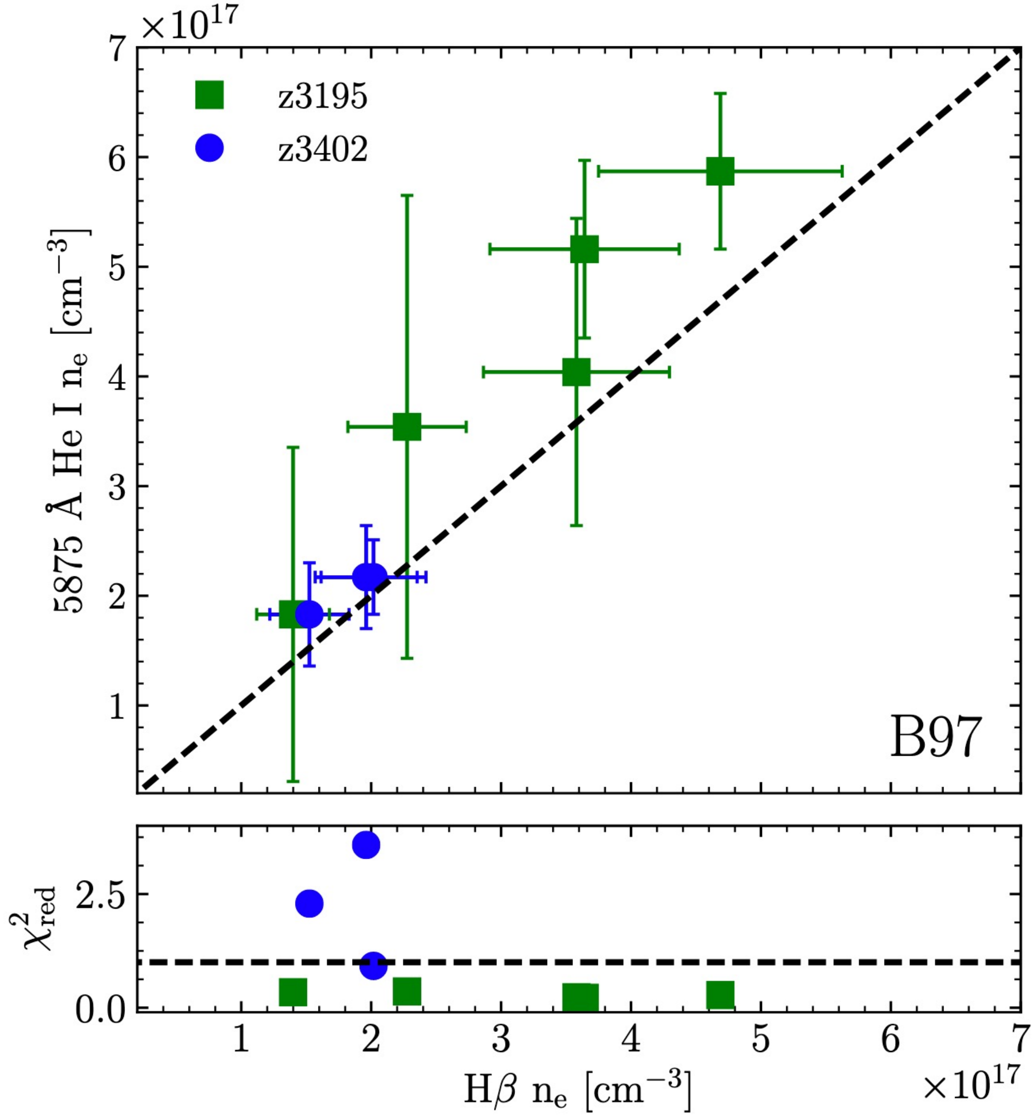


He I 5015 line widths compared to theory

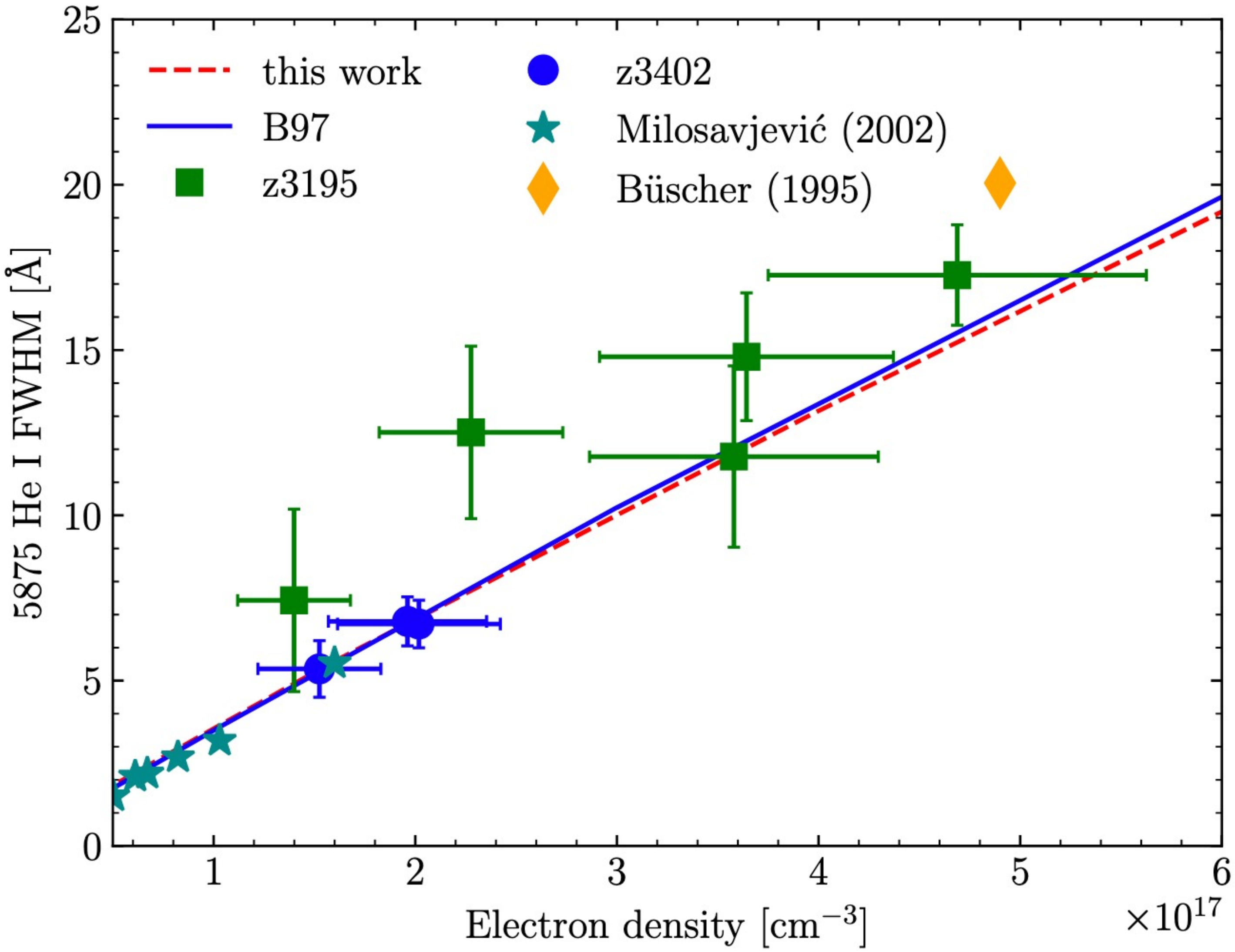


Fits to He I 5875 compared with Hbeta

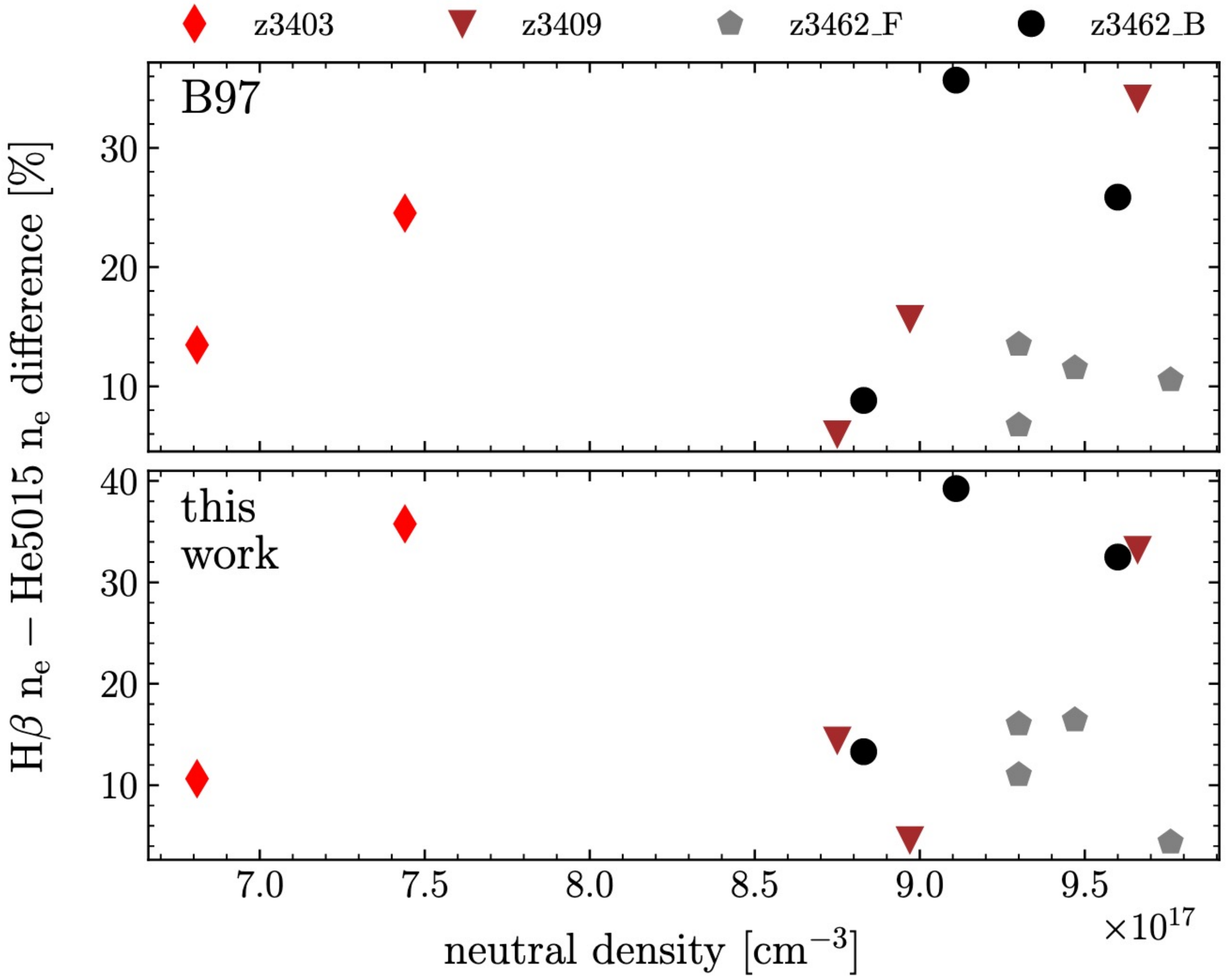




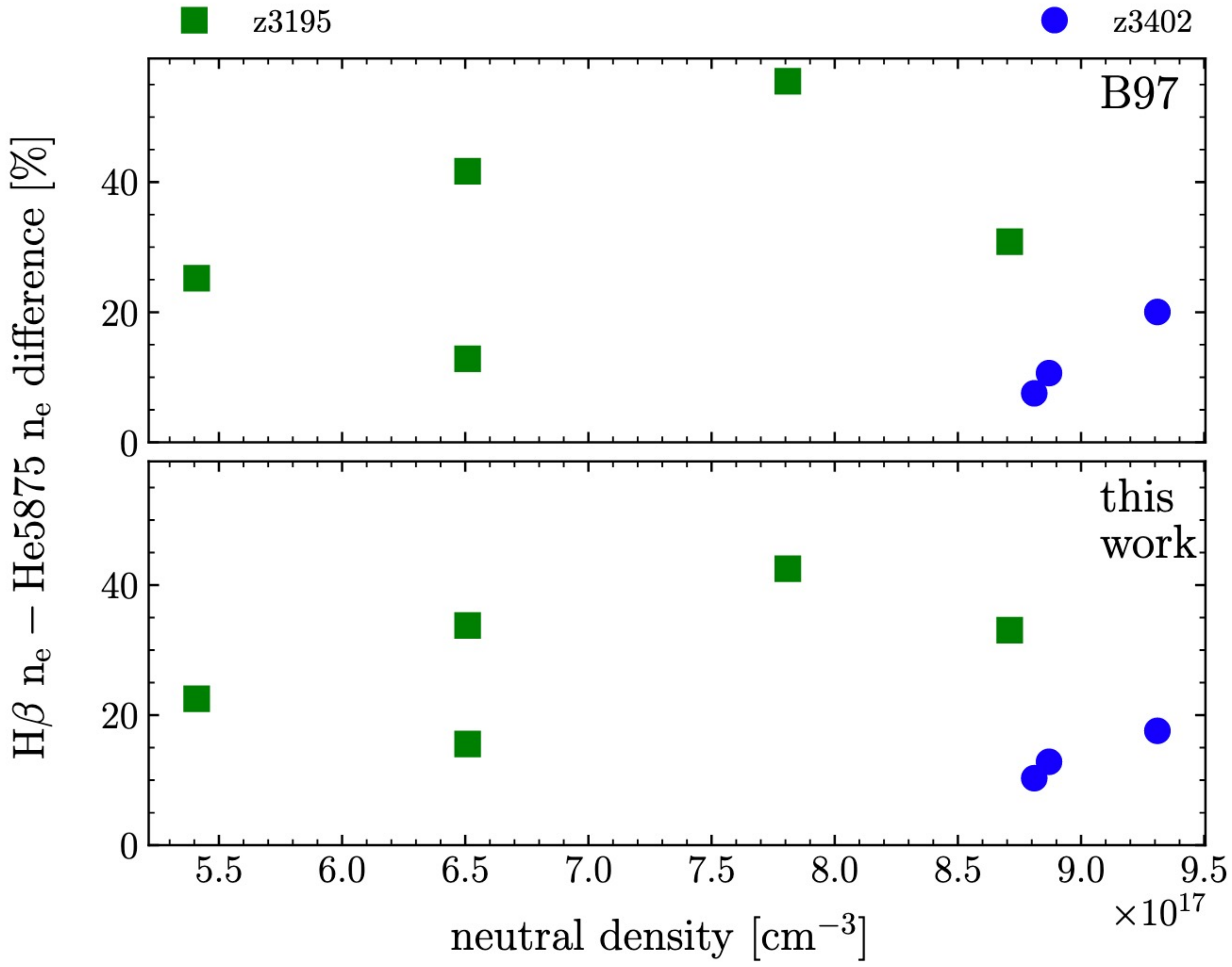
He I 5875 line widths compared to theory



Effect of neutral density



Effect of neutral density



Theoretical Developments

The effect of screening on line shapes

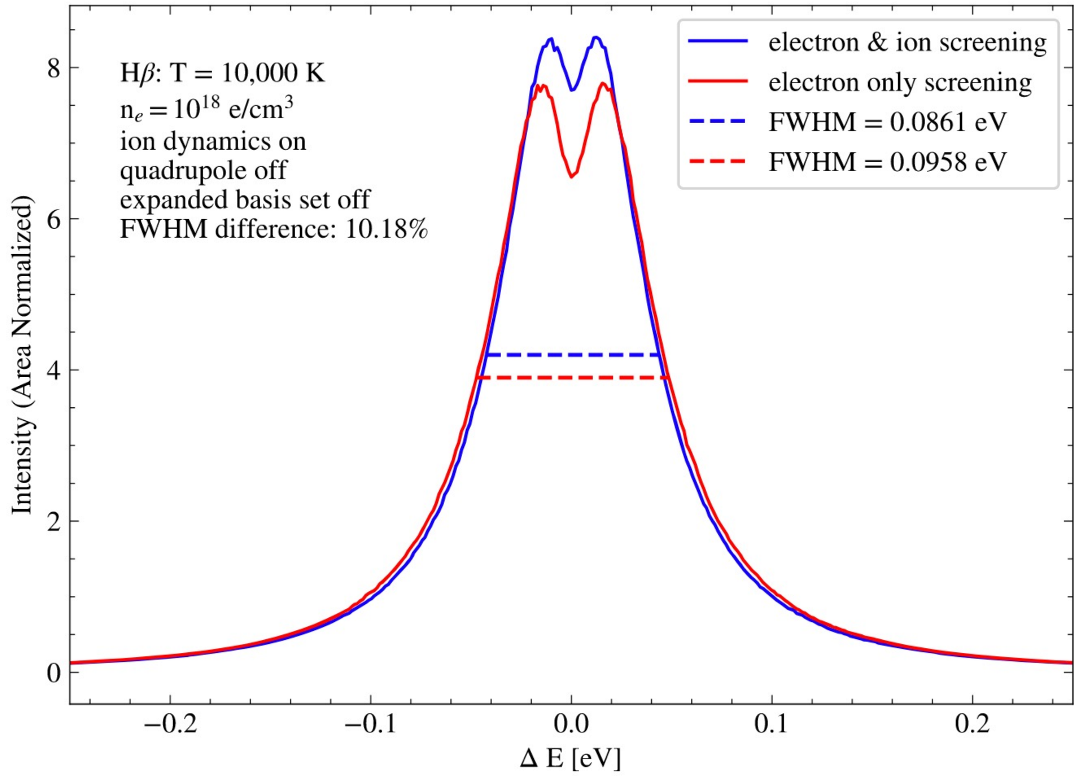
The Astrophysical Journal, 927:70 (20pp), 2022 March 1
https://doi.org/10.3847/1538-4357/ac4df3

Simulation of Stark-broadened Hydrogen Balmer-line Shapes for DA White Dwarf Synthetic Spectra

P. B. Cho[1,2,3], T. A. Gomez[3], M. H. Montgomery[1,2], B. H. Dunlap[1,2], M. Fitz Axen[1,2], B. Hobbs[1,2], I. Hubeny[4], and D. E. Winget[1,2]

[1] Department of Astronomy, University of Texas at Austin, Austin, TX-78712, USA; patricia.cho@utexas.edu
[2] McDonald Observatory, Fort Davis, TX-79734, USA
[3] Sandia National Laboratories, Albuquerque, NM-87123, USA
[4] Department of Astronomy and Steward Observatory, University of Arizona, Tucson, AZ-85721, USA

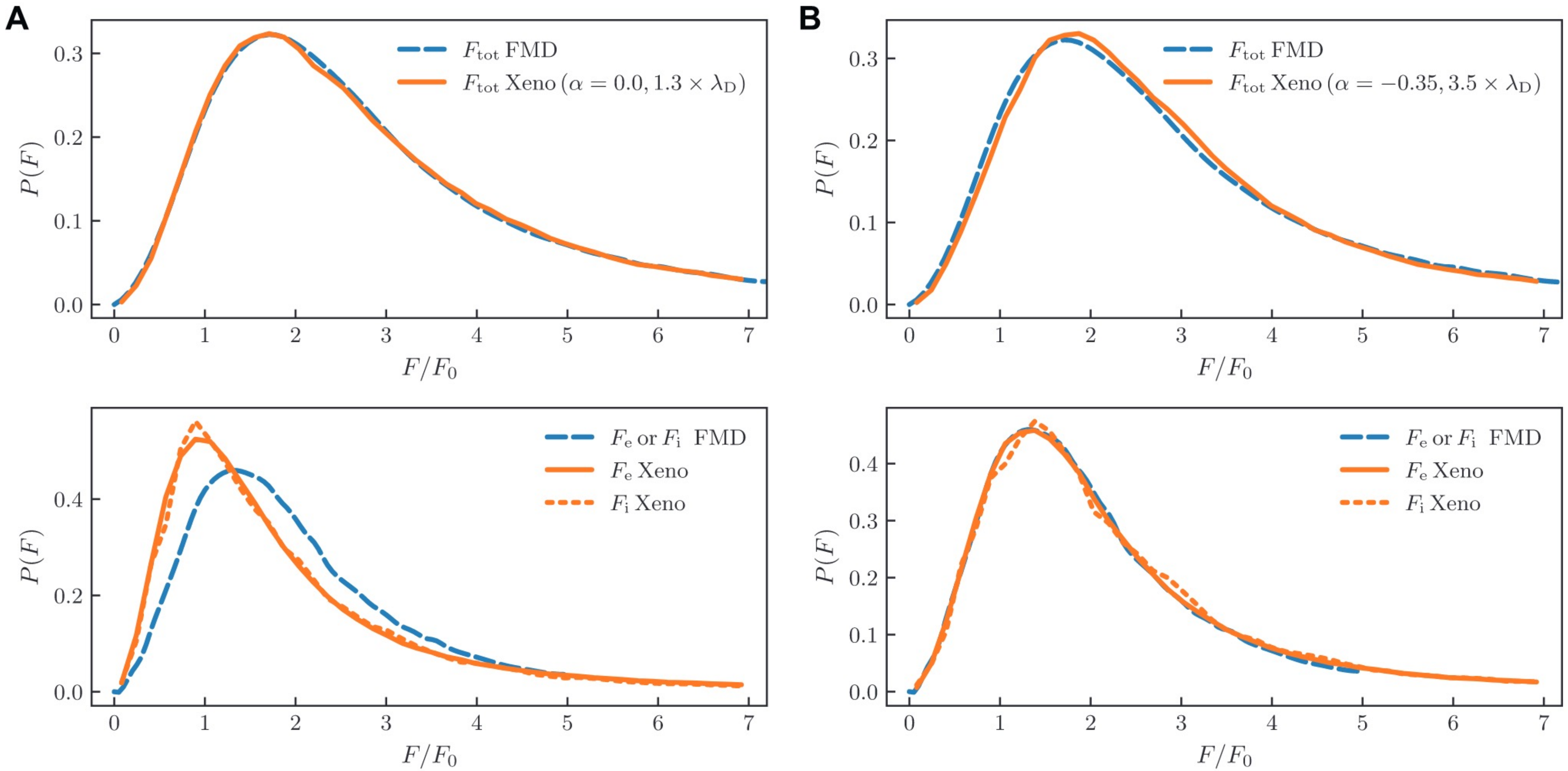
Received 2021 August 27; revised 2022 January 13; accepted 2022 January 20; published 2022 March 7



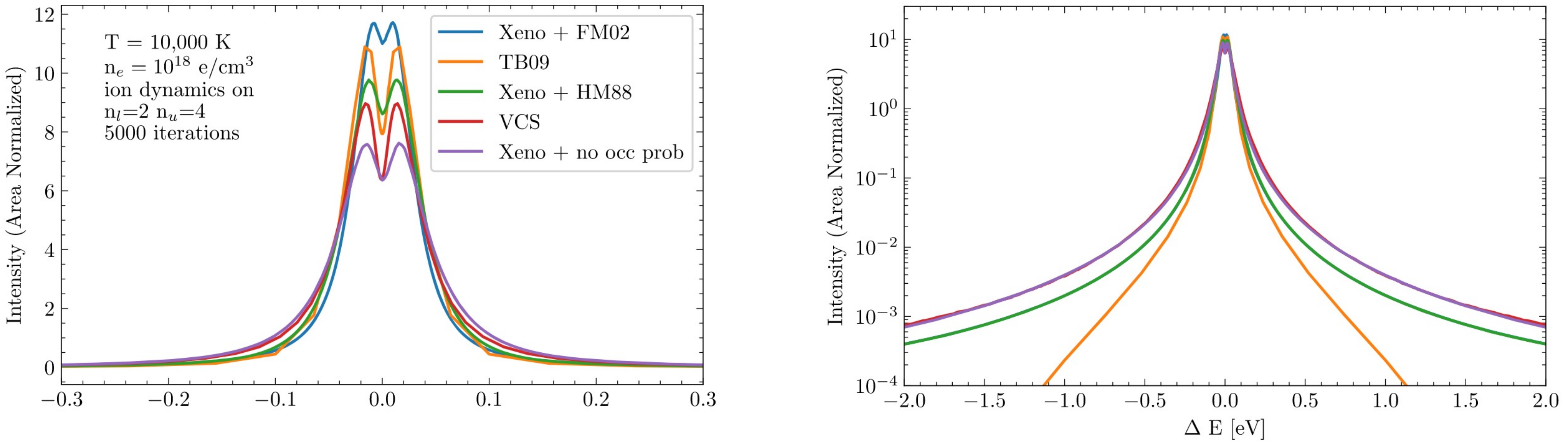
Hydrogen Line Shape Uncertainties in White Dwarf Model Atmospheres

M. H. Montgomery[1], B. H. Dunlap[1], P. B. Cho[1] and T. A. Gomez[2]*

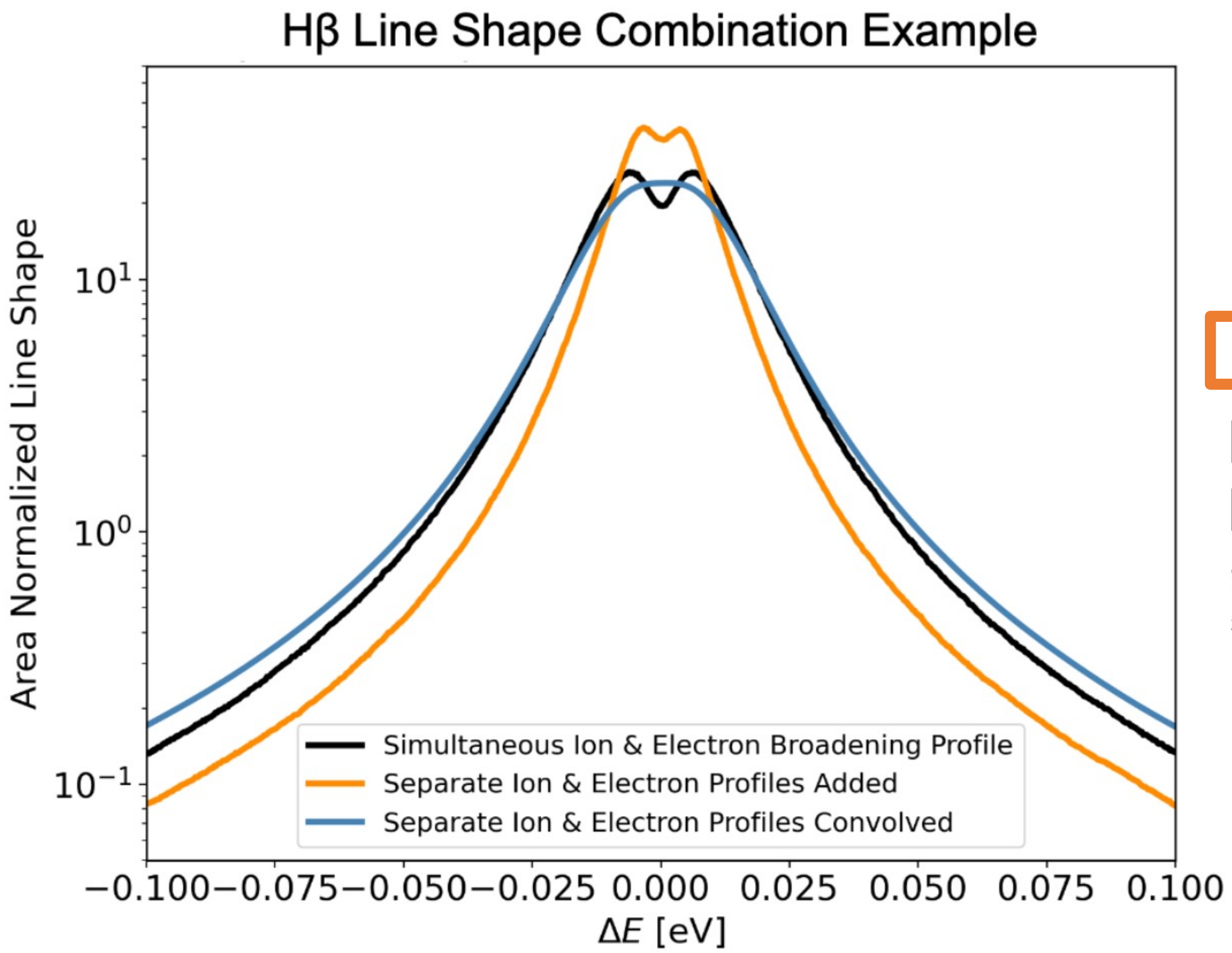
[1]Department of Astronomy, University of Texas at Austin, Austin, TX, United States, [2]Sandia National Laboratories, Albuquerque, NM, United States



The effect of occupation probability on line shapes



H2 quasi-molecular features



See poster by Jackson White!

H2+ Quasi Molecular Line Shape Profiles in Stellar Atmospheres

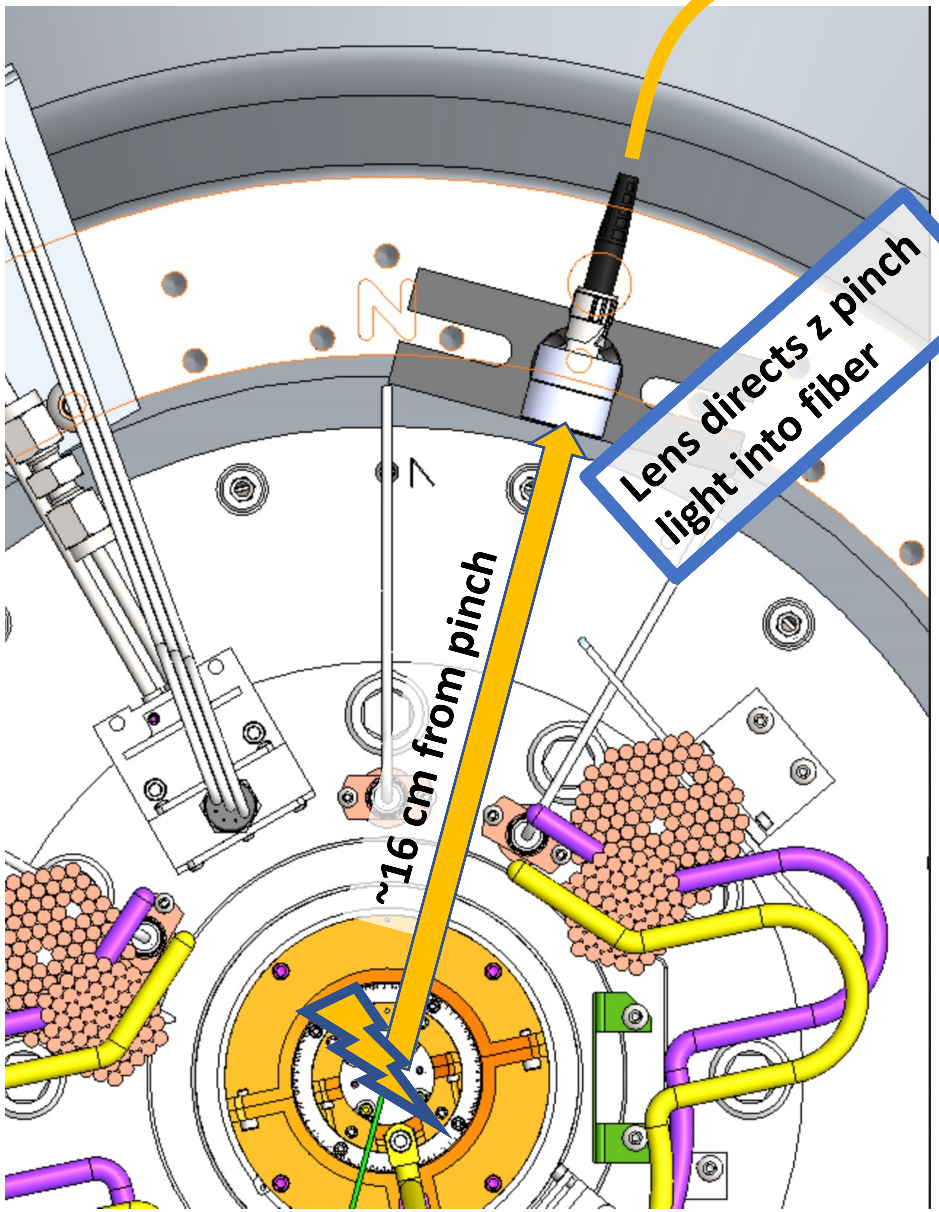
Jackson White[1], Thomas Gomez[1,2], Mike Montgomery[1], Bart Dunlap[1]
[1]Department of Astronomy, University of Texas at Austin
[2]Sandia National Laboratory

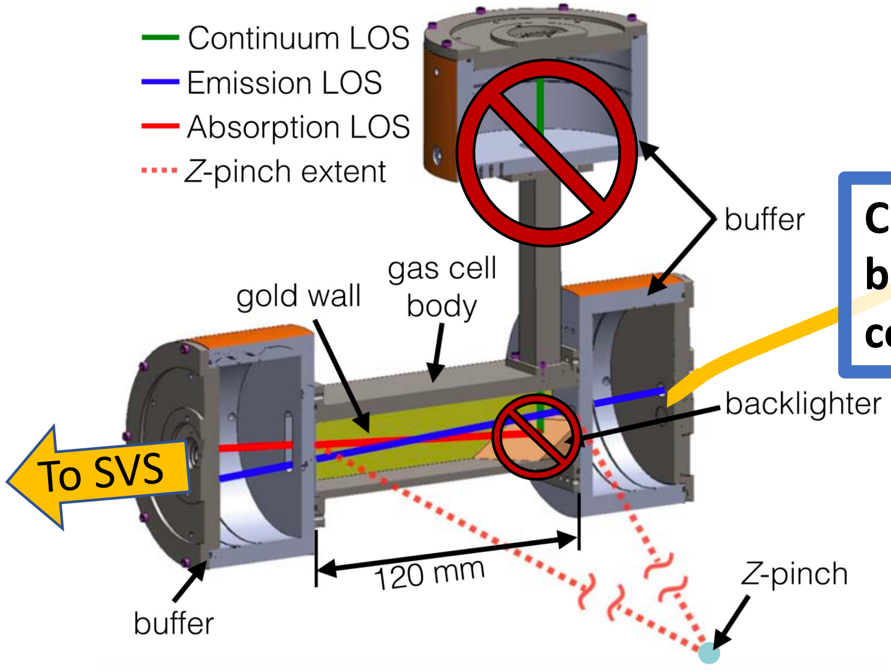
Extra Slides

Light from pinch is used to backlight plasma in cell

Long fiber delays light and directs it into cell

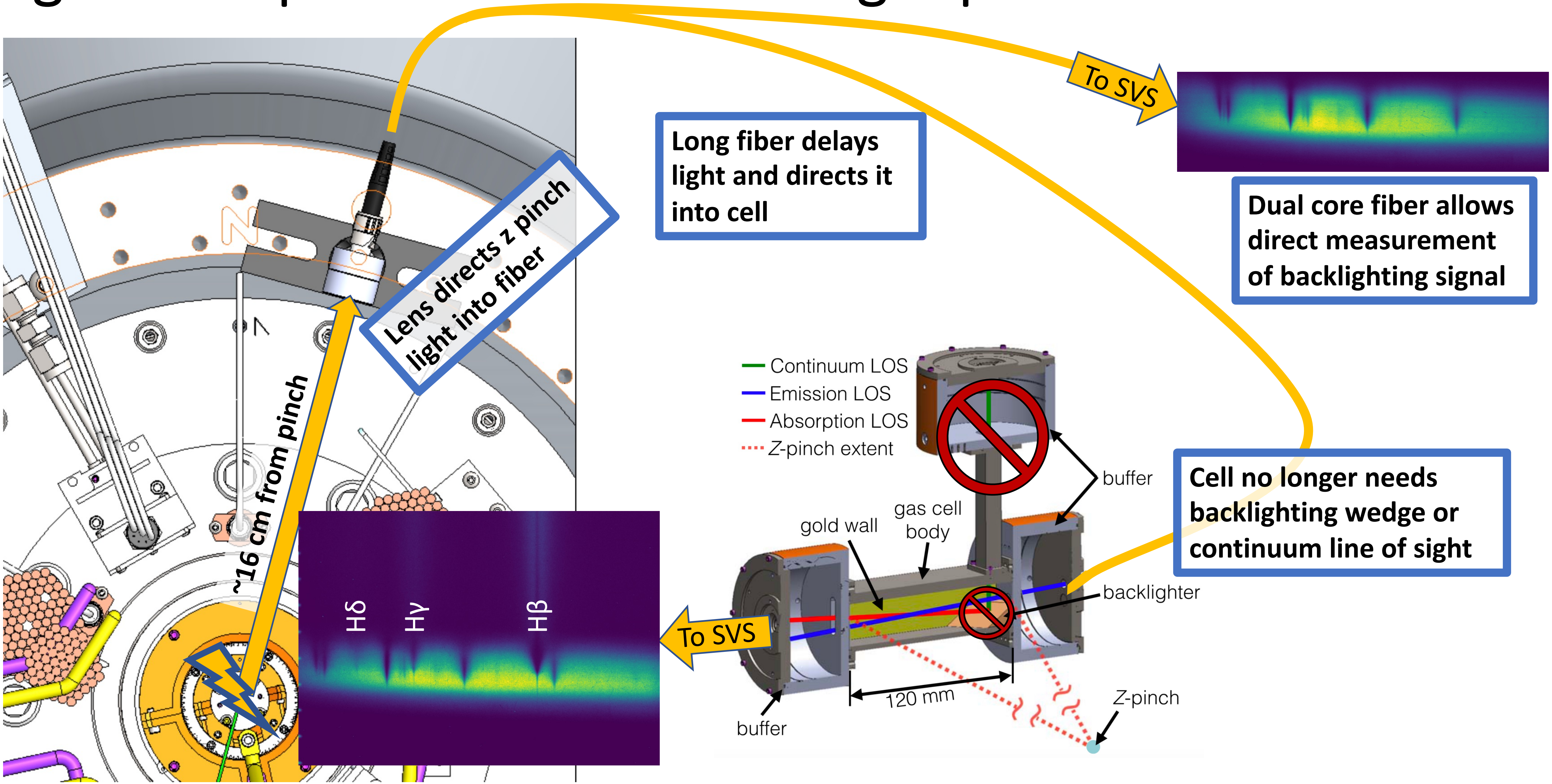
Dual core fiber allows direct measurement of backlighting signal





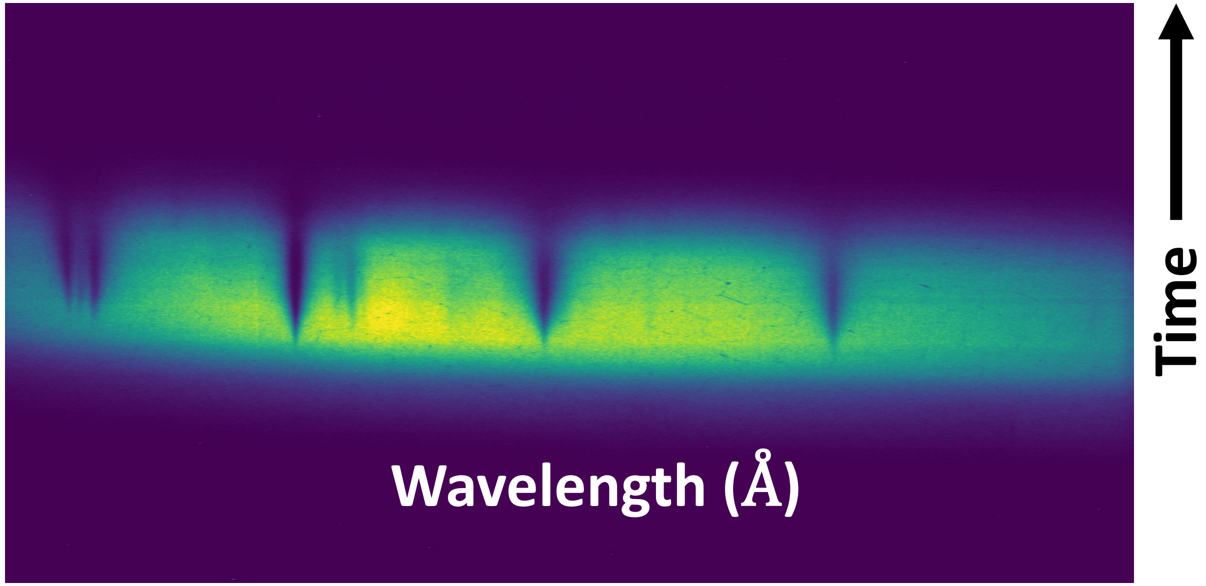
Cell no longer needs backlighting wedge or continuum line of sight

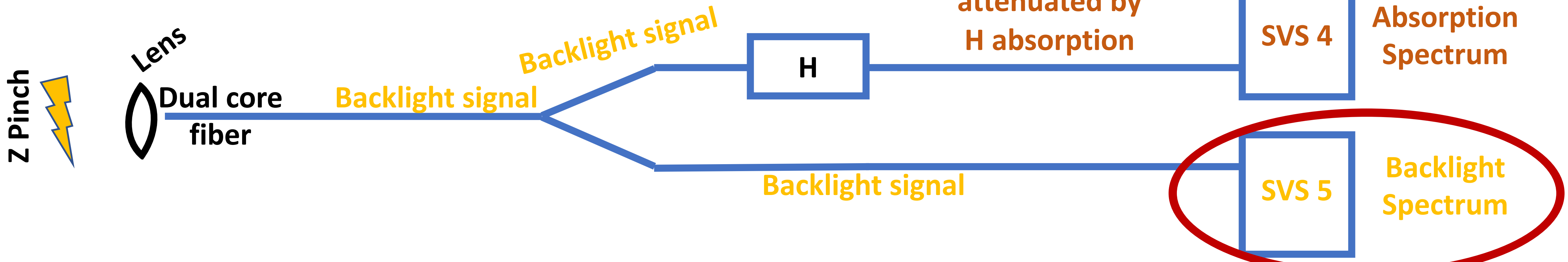
Light from pinch is used to backlight plasma in cell



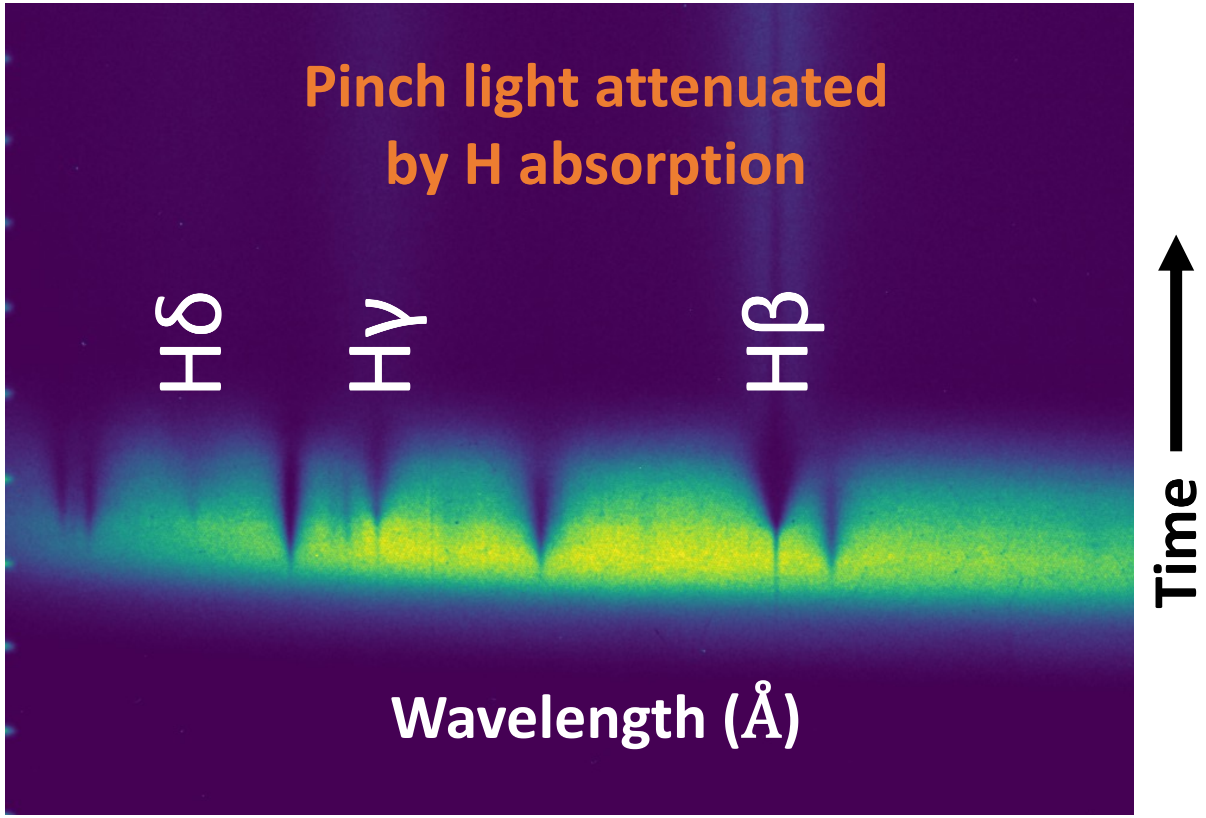
Pinch light successfully fielded as backlight for absorption spectrum

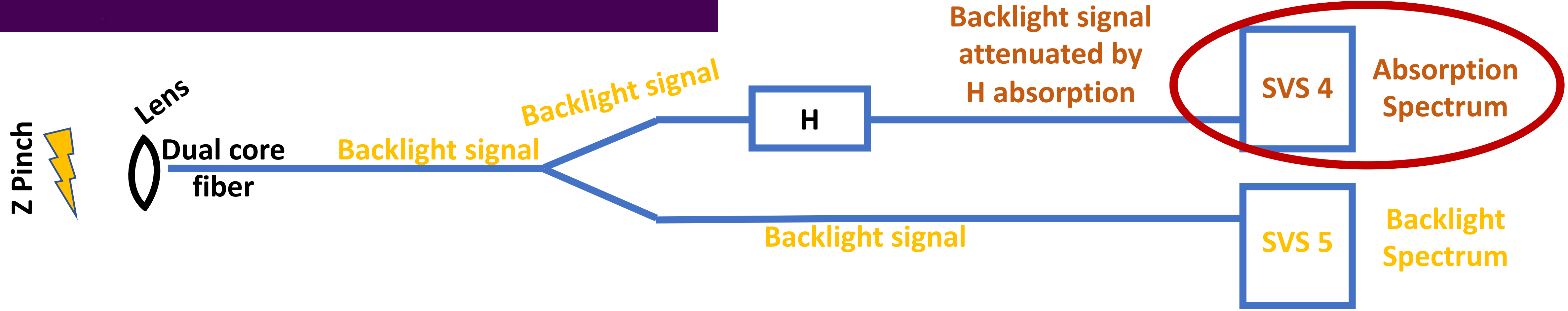
Pinch light direct to SVS





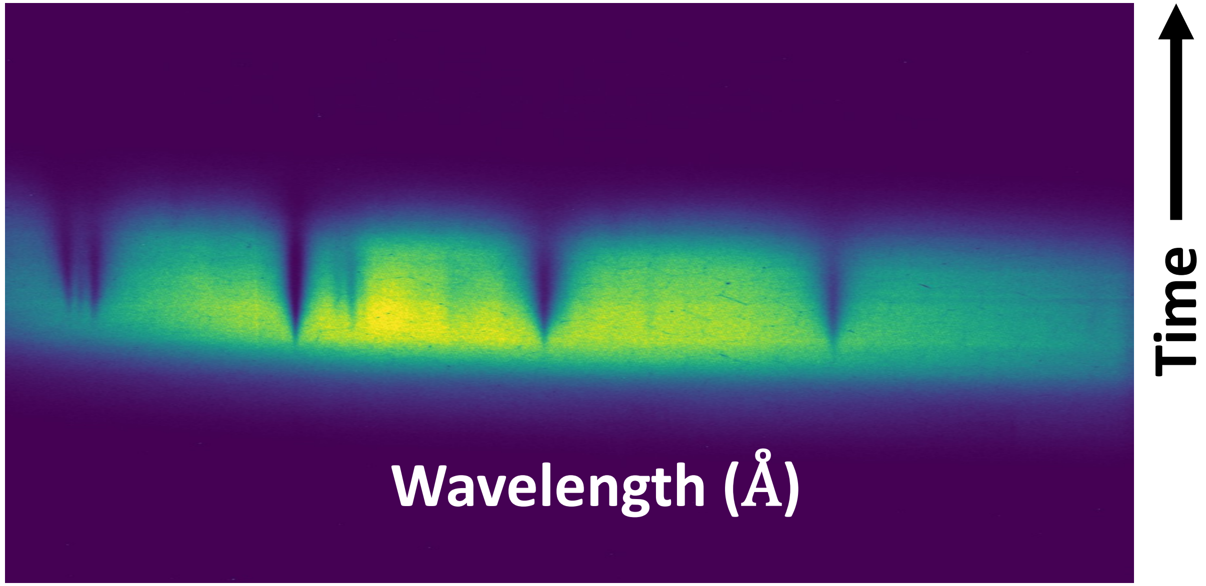
Pinch light successfully fielded as backlight for absorption spectrum

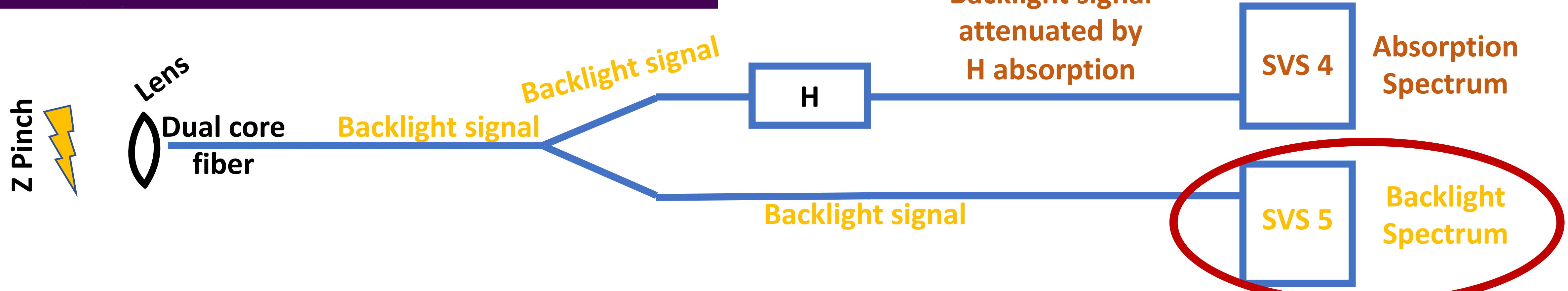




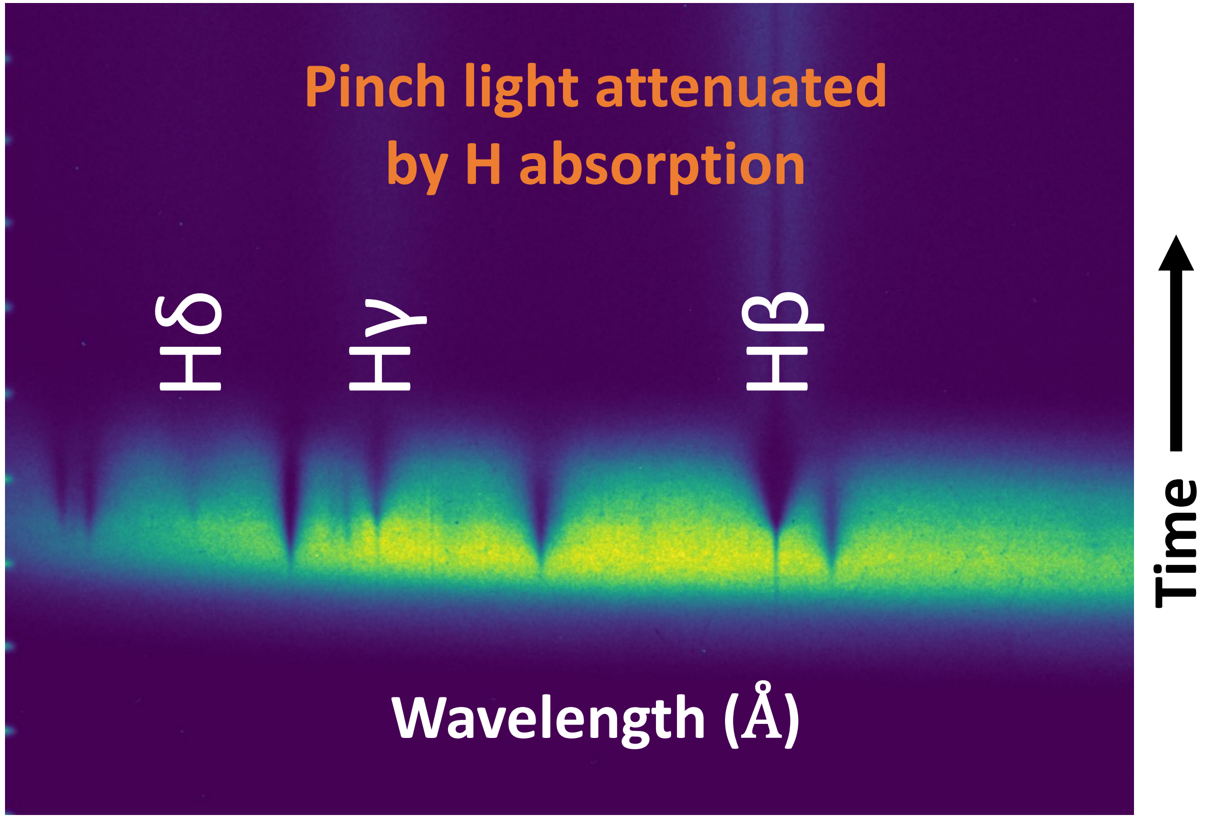
Pinch light successfully fielded as backlight for absorption spectrum

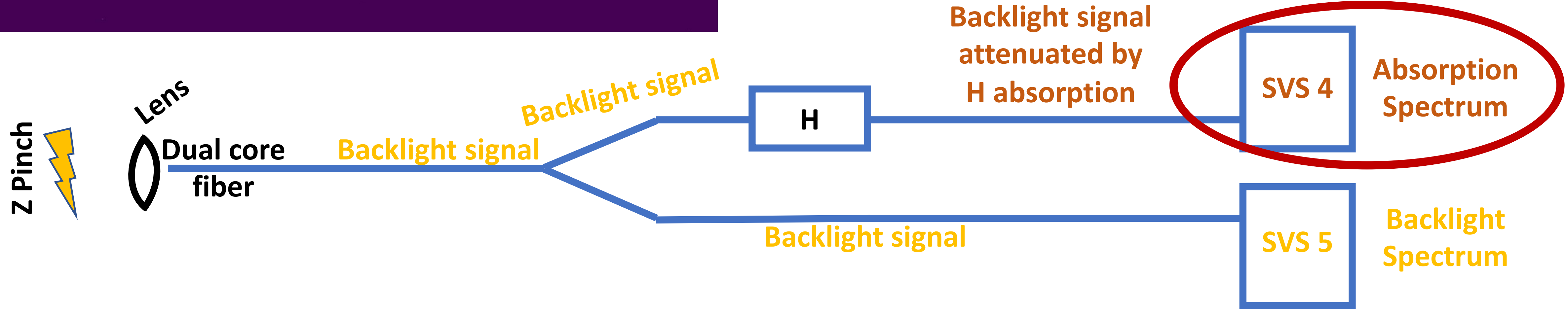
Pinch light direct to SVS



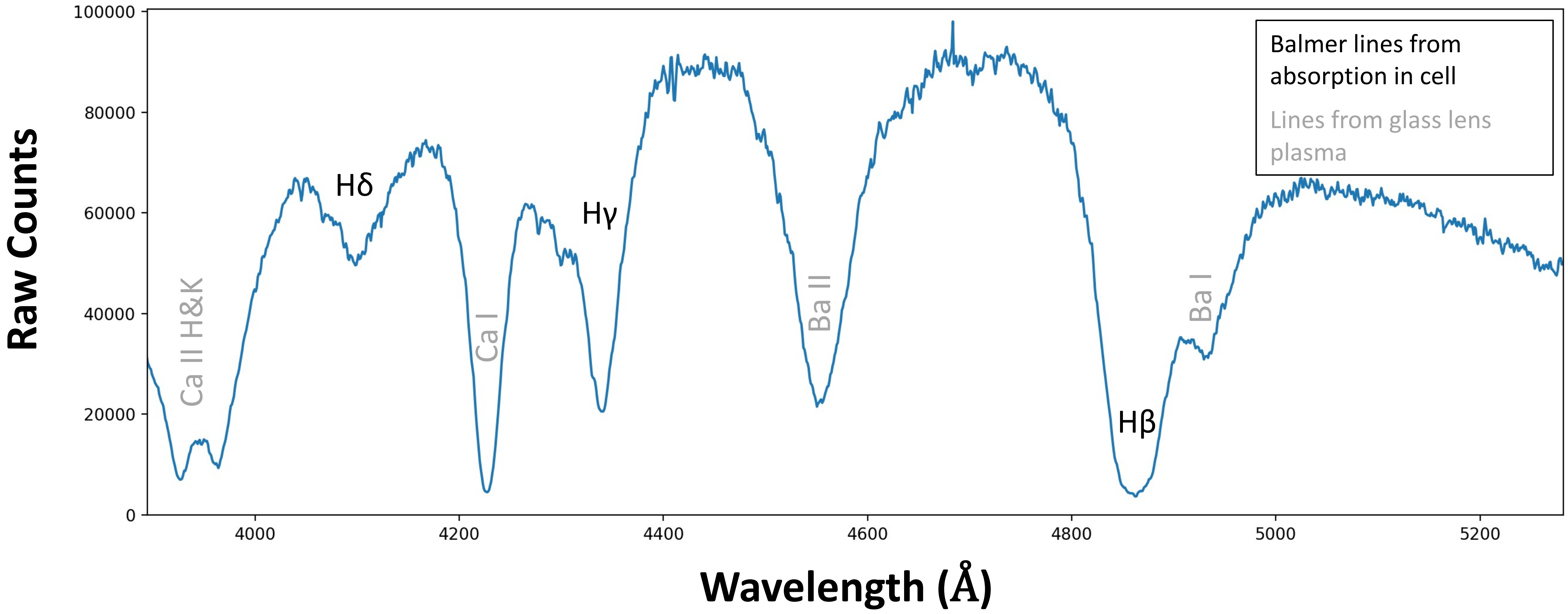


Pinch light successfully fielded as backlight for absorption spectrum





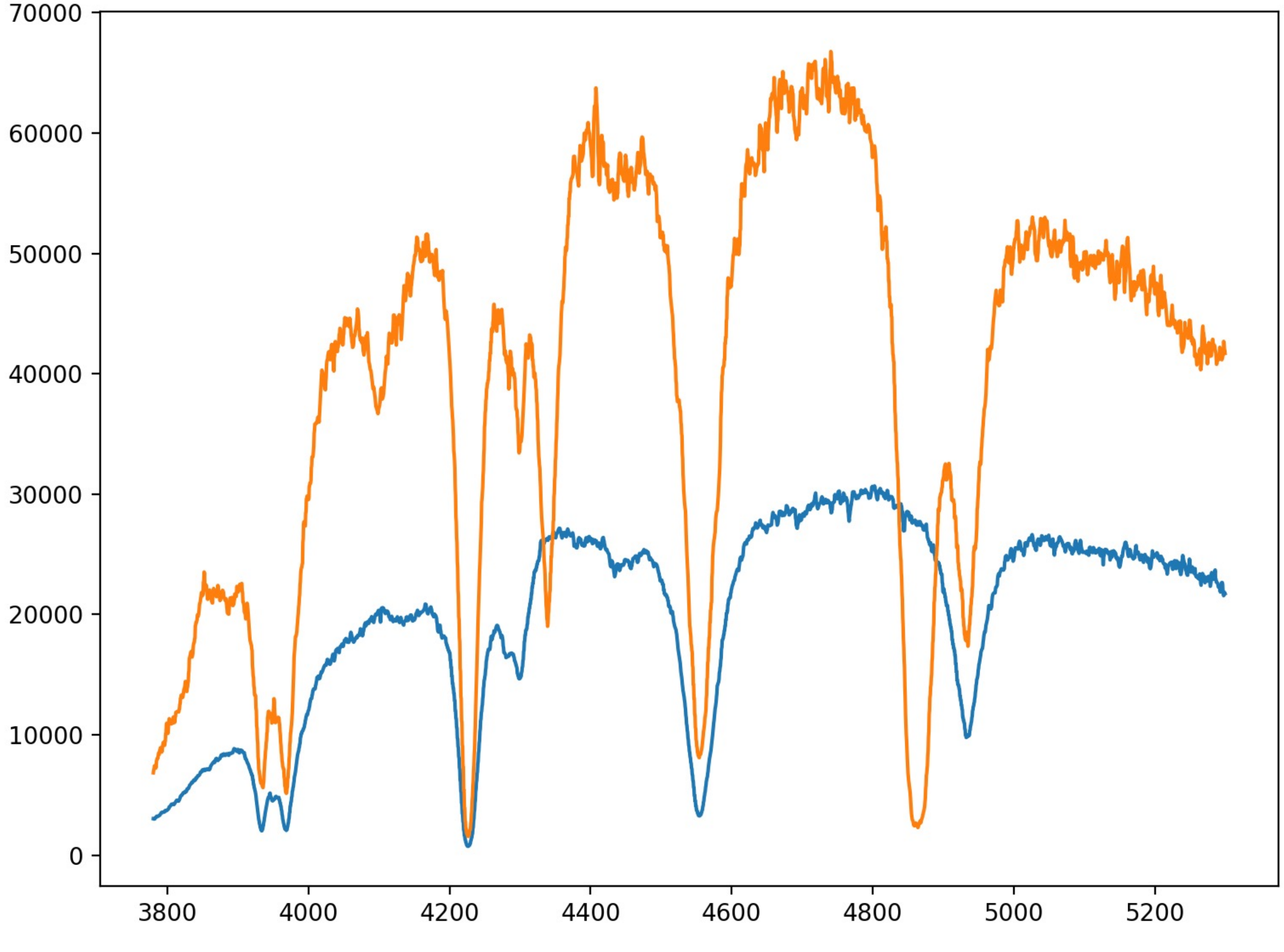
Hydrogen absorption measured with backlight from z pinch



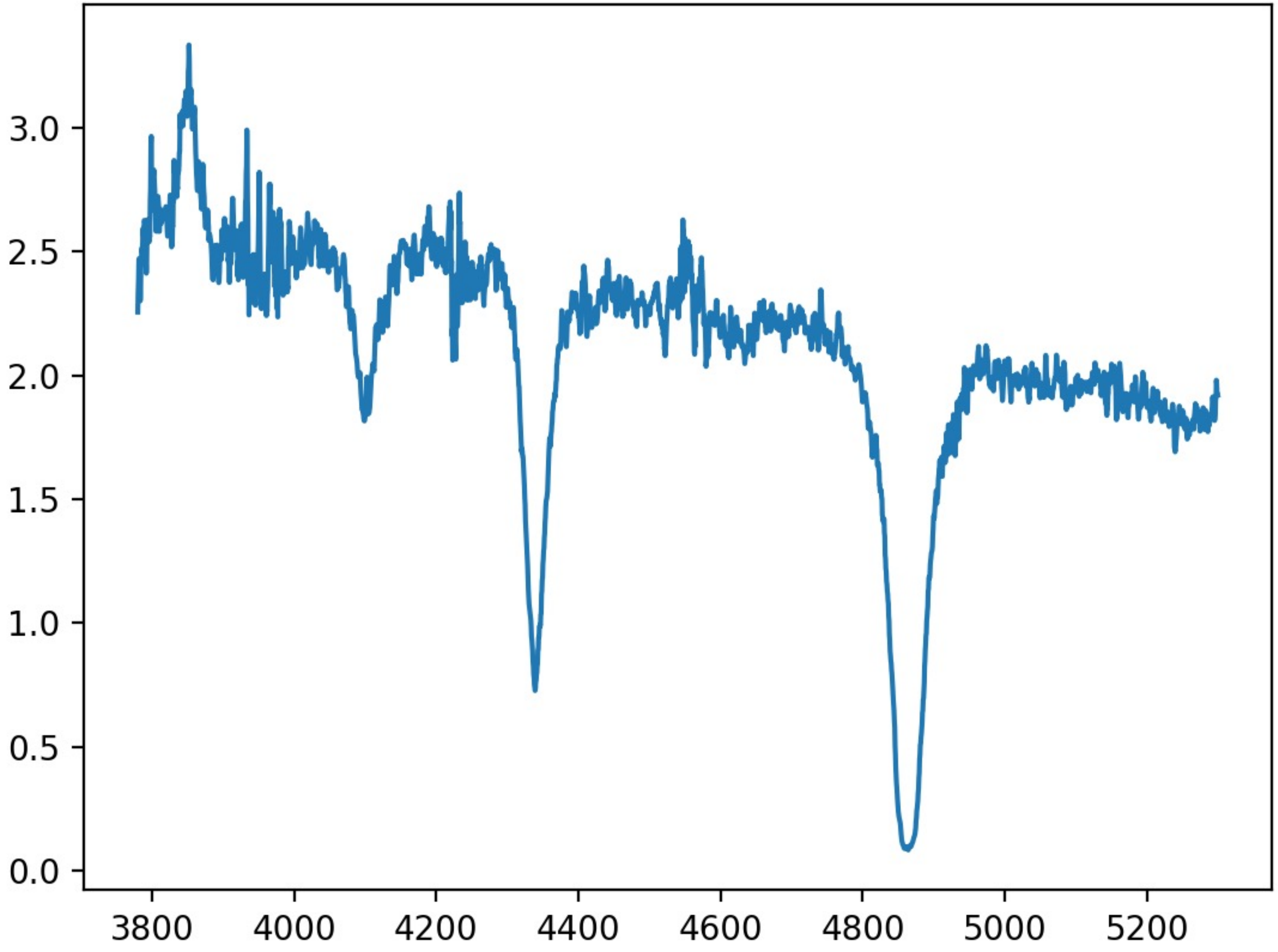
Pinch as backlight enables several possibilities

- It should **increase signal-to-noise** and **remove self-emission uncertainty**
- Allows **absorption measurement at late time** when our standard backlighting wedge has cooled off
- Allows the possibility of **high S/N absorption** measurements along other lines of sight (e.g., downward lines of sight with short plasma lengths)
- With more shielding or distance, we should be able to capture peak brightness for a significant gain in S/N.
- Capturing the peak would also allow for a brief **backlighting pulse,** which could allow **absorption and emission on the same system and LOS**.

Naïve application shows attenuated spectrum brighter than backlight spectrum



Spectral lines from lens are removed ~ well in resulting transmission spectrum



Spectra can be scaled based on early-time data