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The White Dwarf Photosphere Experiment: Current status and future directions

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Z Fundamental Science Workshop

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TEXAS
The University of Texas at Austin

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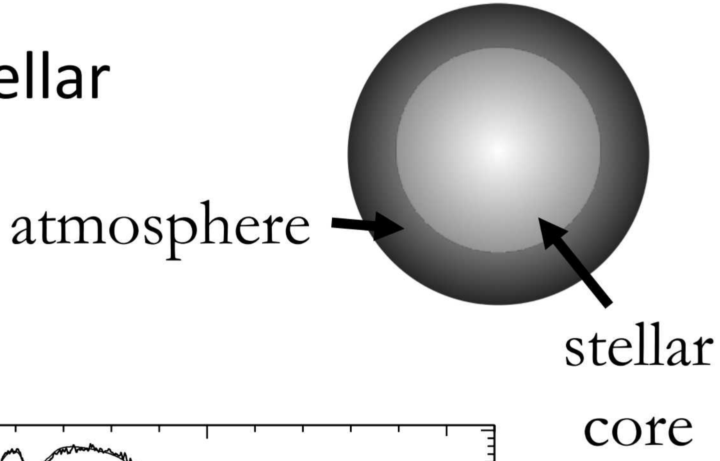
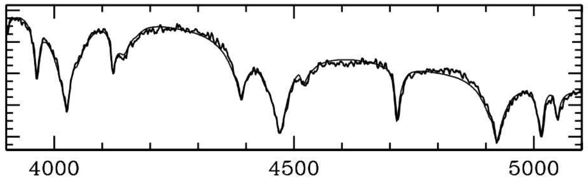
Stellar evolution and the age of the universe can be constrained using WD stars

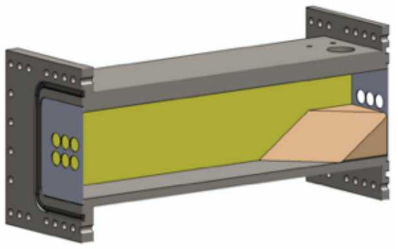
- Applying WD to astrophysical problems requires accurate stellar masses



- The main mass determination methods have deficiencies

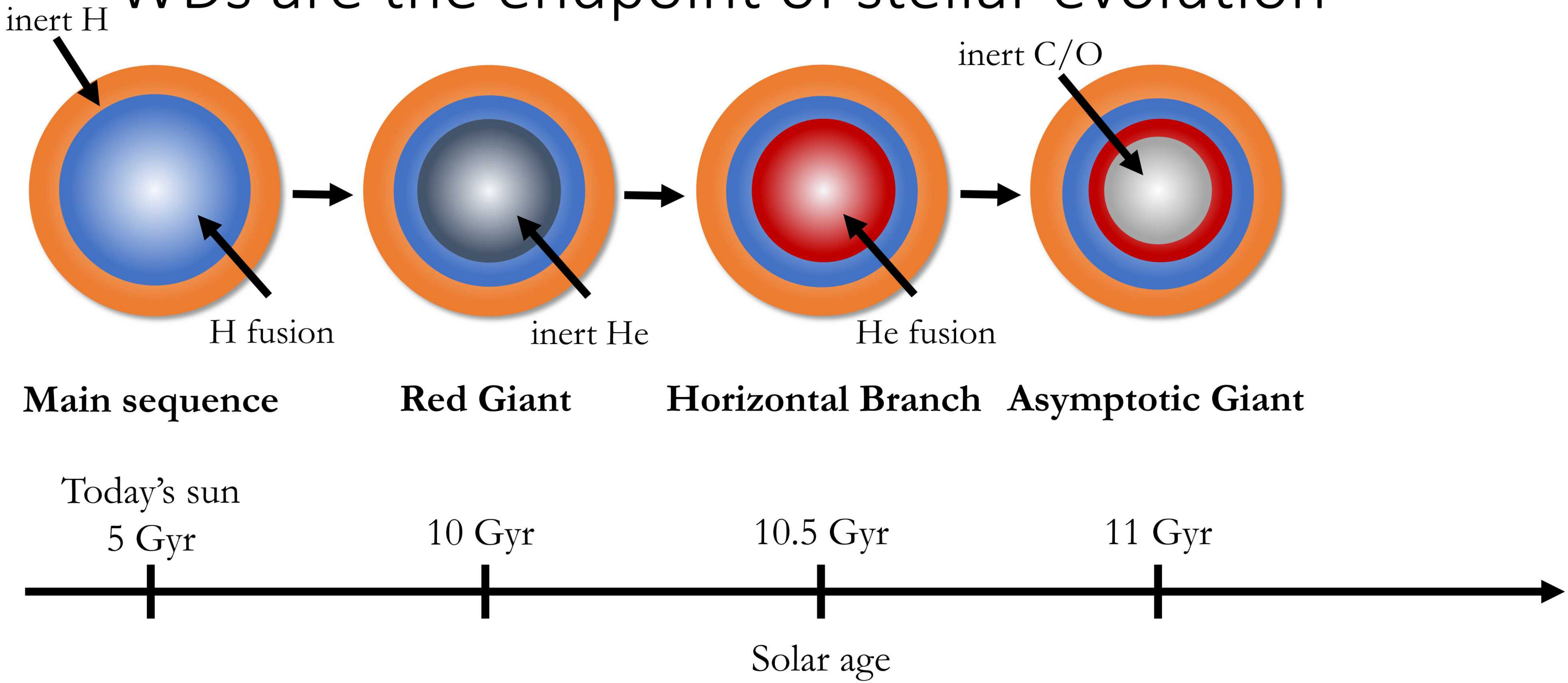


- Z-machine experiments enable scrutiny of constituent atomic physics in WD mass determination methods

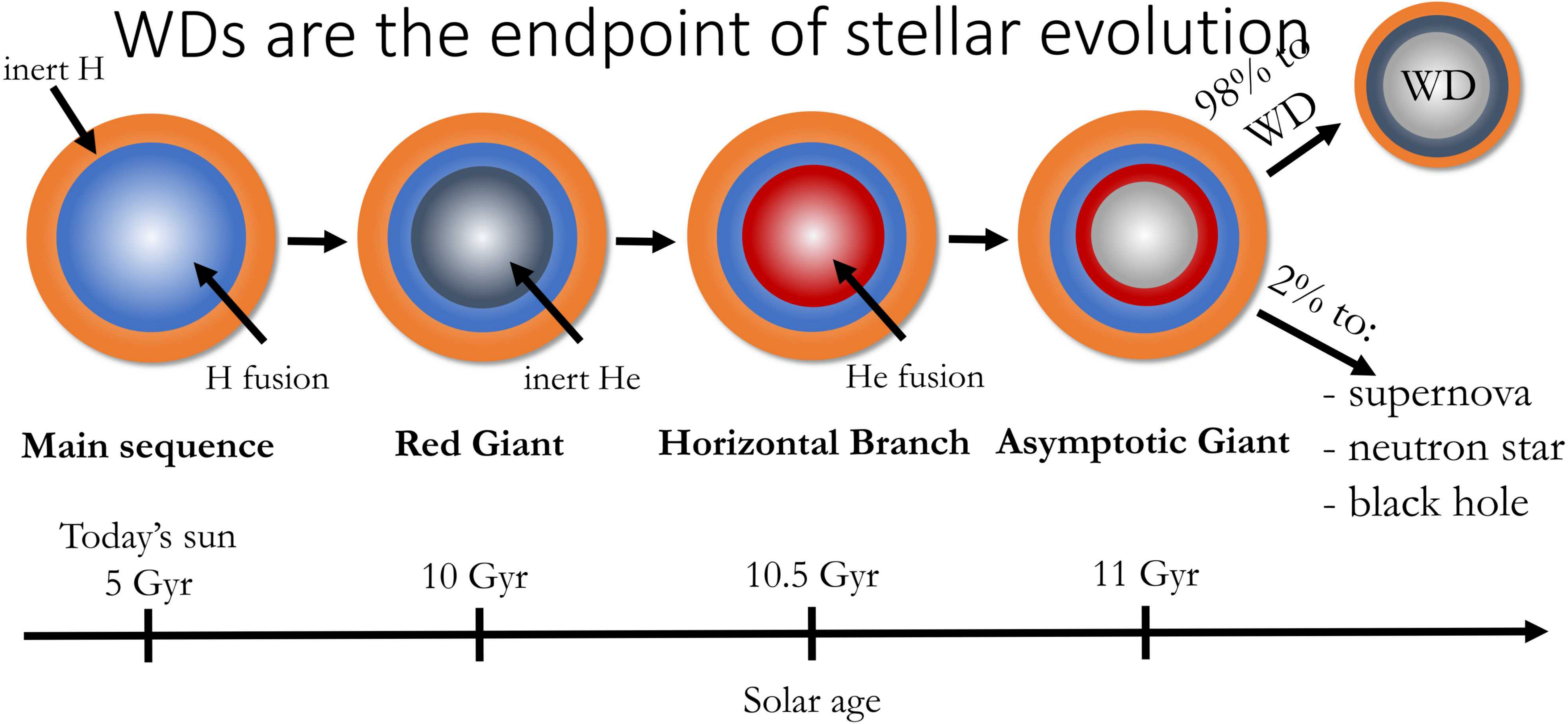


Z-machine data have highlighted deficiencies in the atomic data used for WD mass determination methods.

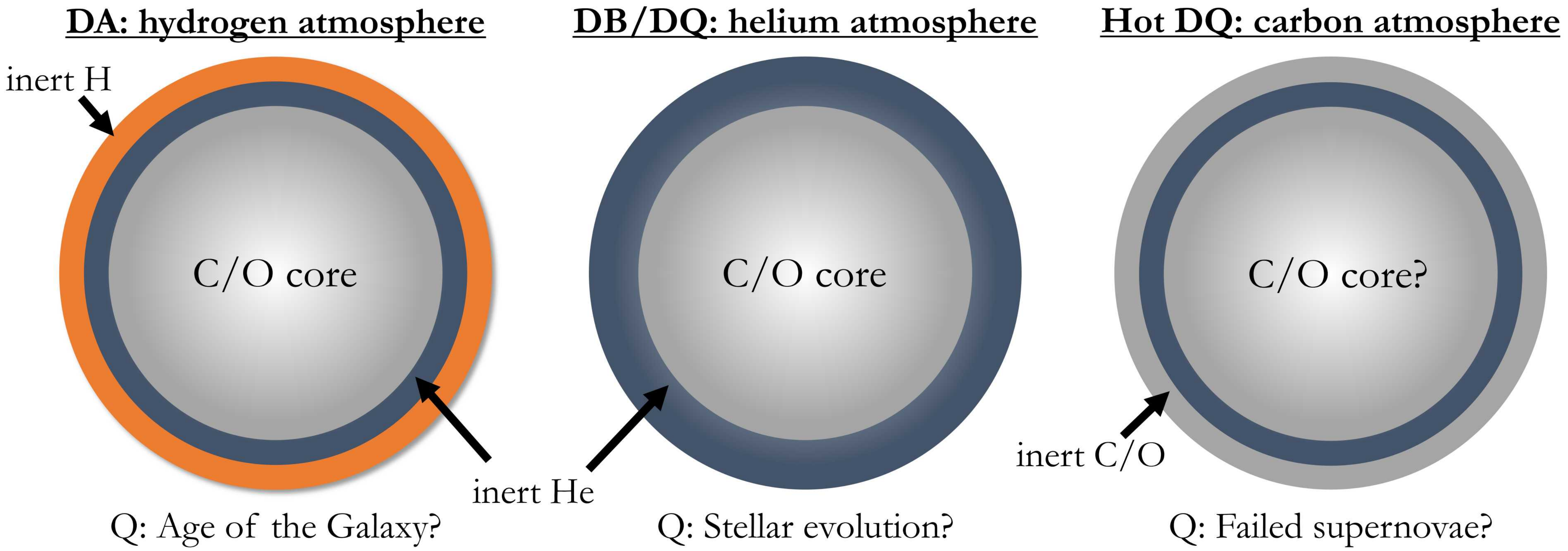
WDs are the endpoint of stellar evolution



WDs are the endpoint of stellar evolution



Several different 'flavors' of WDs can develop from the previous evolutionary scenarios



Accurate WD masses are needed to answer these questions!

WDs are earth-sized objects with masses comparable to the sun

DA: hydrogen atmosphere | DB/DQ: helium atmosphere | Hot DQ: carbon atmosphere

inert H

Typical WD parameters:

Surface temperature (T_{eff}): 10,000 K (~1 eV)

Surface gravity (log g): 10^8 cm/s^2 ($n_e \sim 10^{17}$ cm^{-3})

Radius: r_{earth}

Mass: ~2/3 M_{sun}

C/O core | C/O core | C/O core?

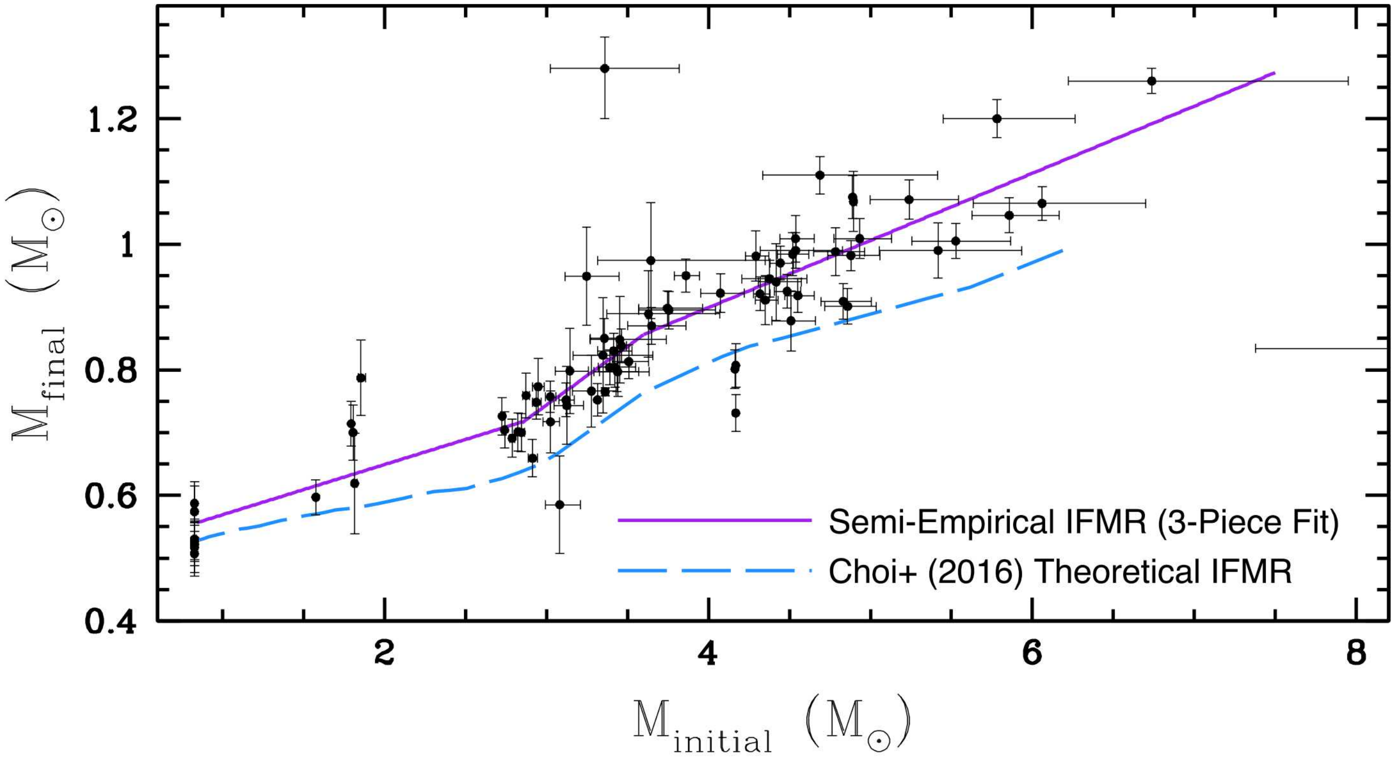
inert He | inert C/O

Q: Age of the Galaxy? | Q: Stellar evolution? | Q: Failed supernovae?

Accurate WD masses are needed to answer these questions!

Initial-Final Mass Relation

M_{WD}

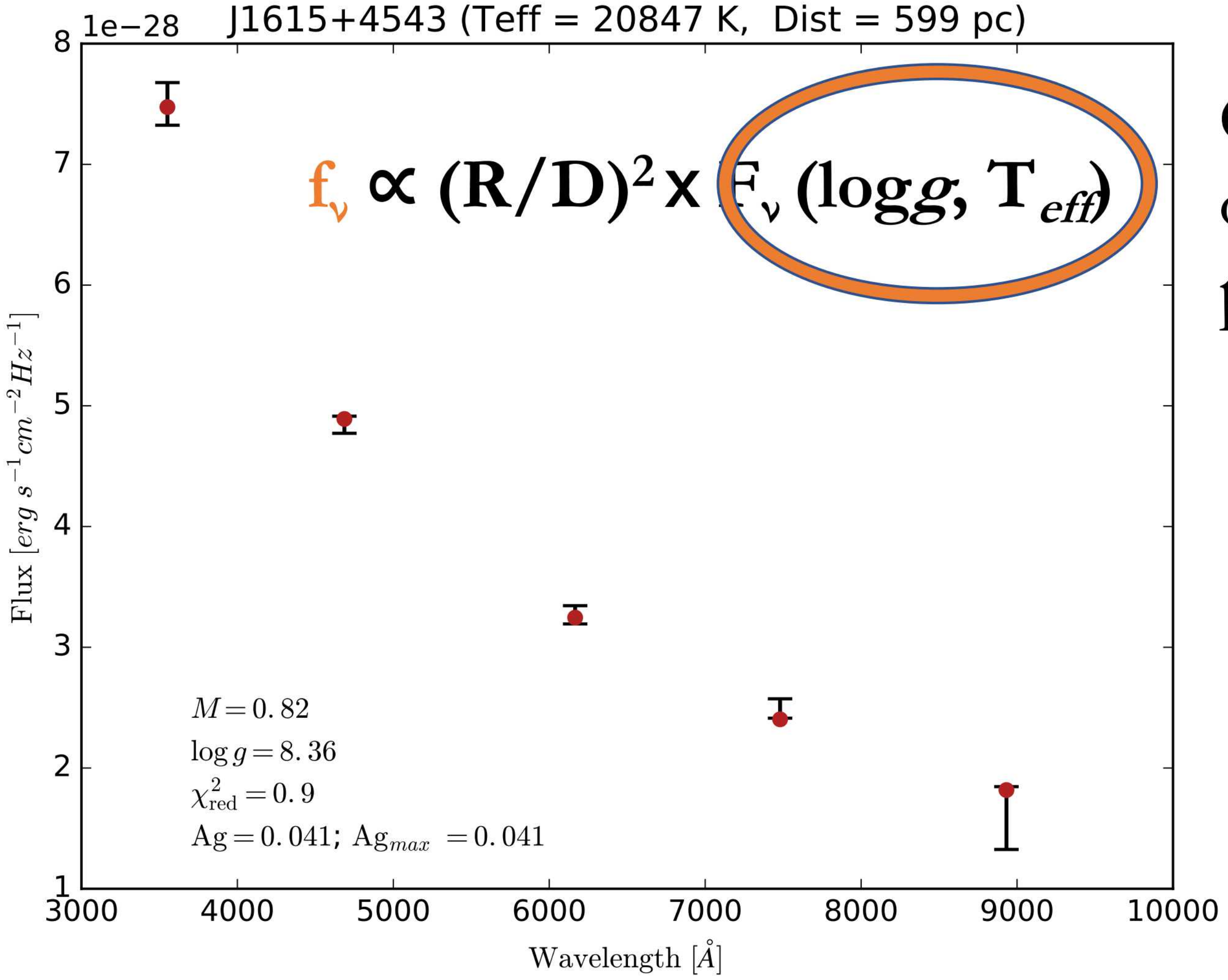


Cummings et al. (2018)

M_{MS}

(And $\tau_{MS} \propto M^{-2.8}$)

Determining Parameters with Parallax + Broad-band photometry

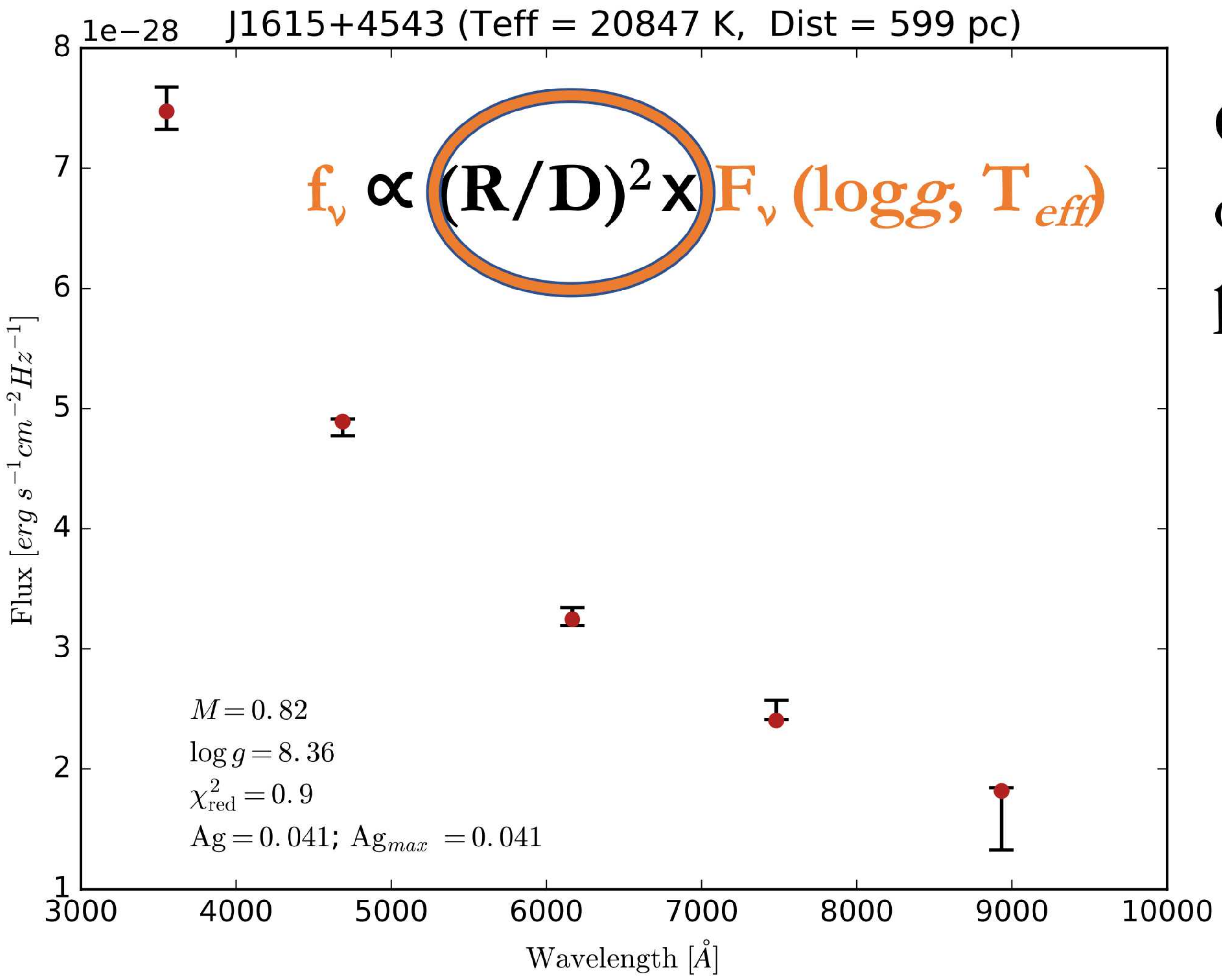


Constrained by *shape* of the broadband photometry.

Determining Parameters with Parallax + Broad-band photometry

Constrained by absolute flux level

Depends on angular size of the star on the sky



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Determining Parameters with Parallax + Broad-band photometry

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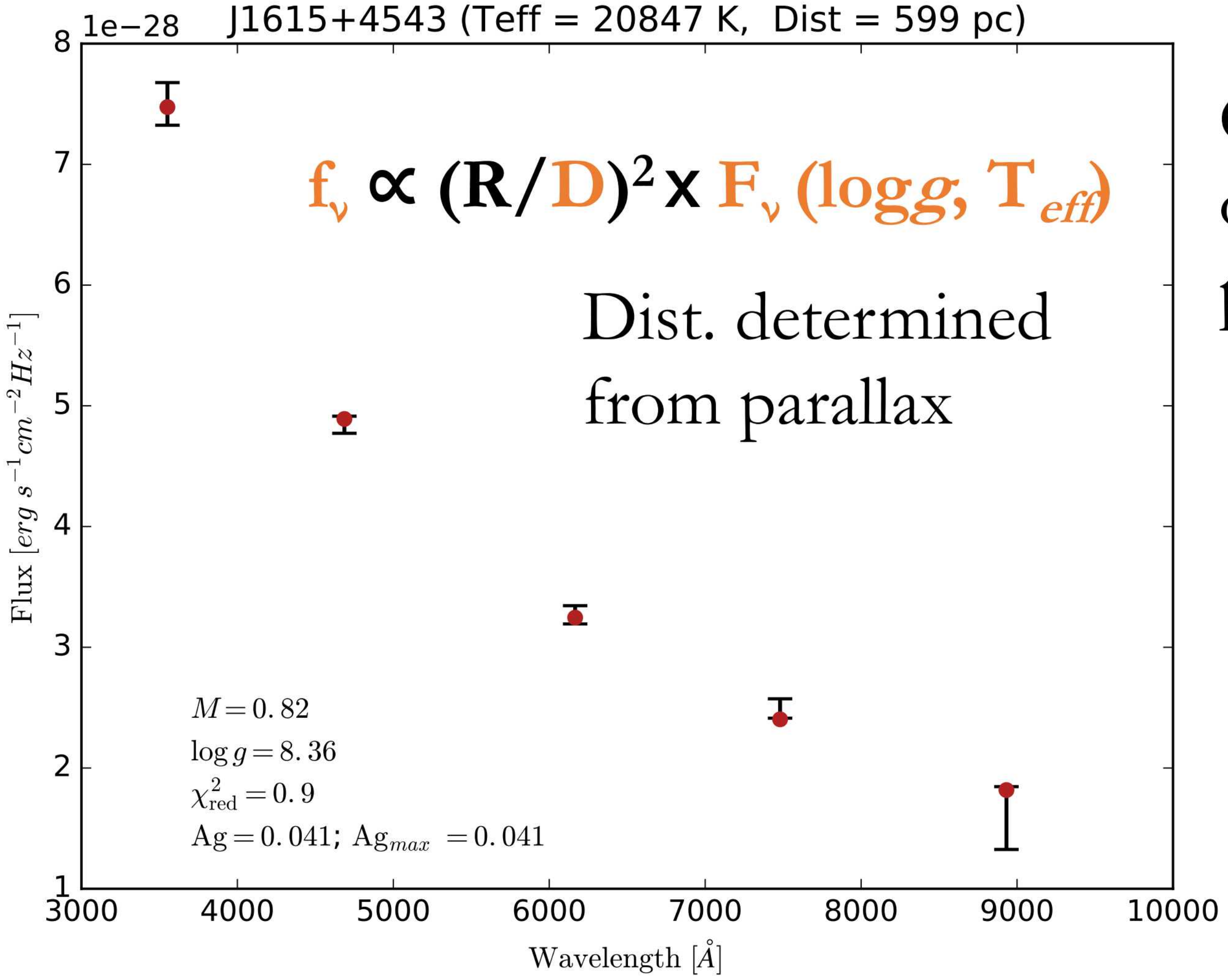
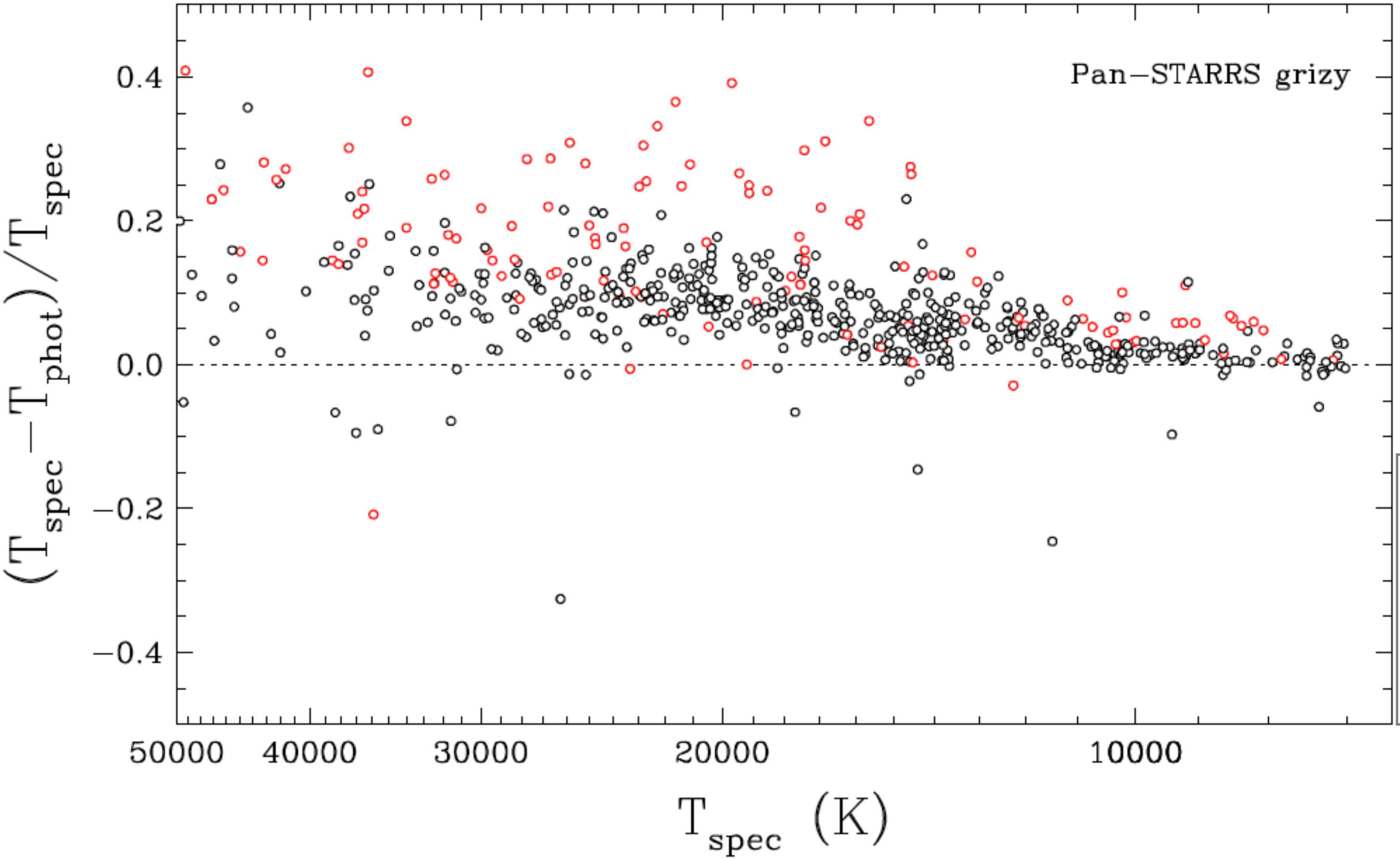


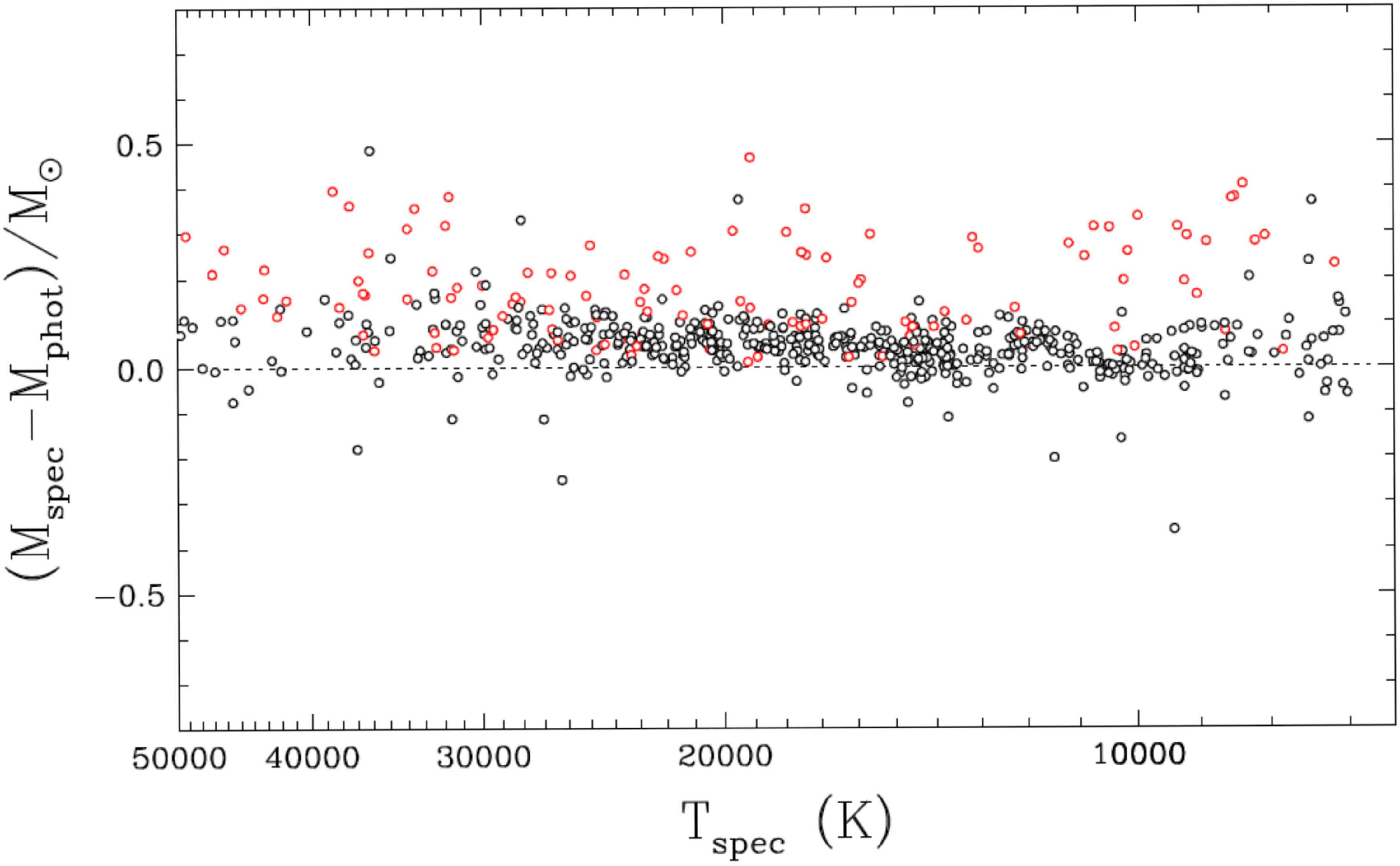
$f_\nu \propto (R/D)^2 \times F_\nu(\log g, T_{eff})$

Dist. determined from parallax

Constrained by *shape* of the broadband photometry.



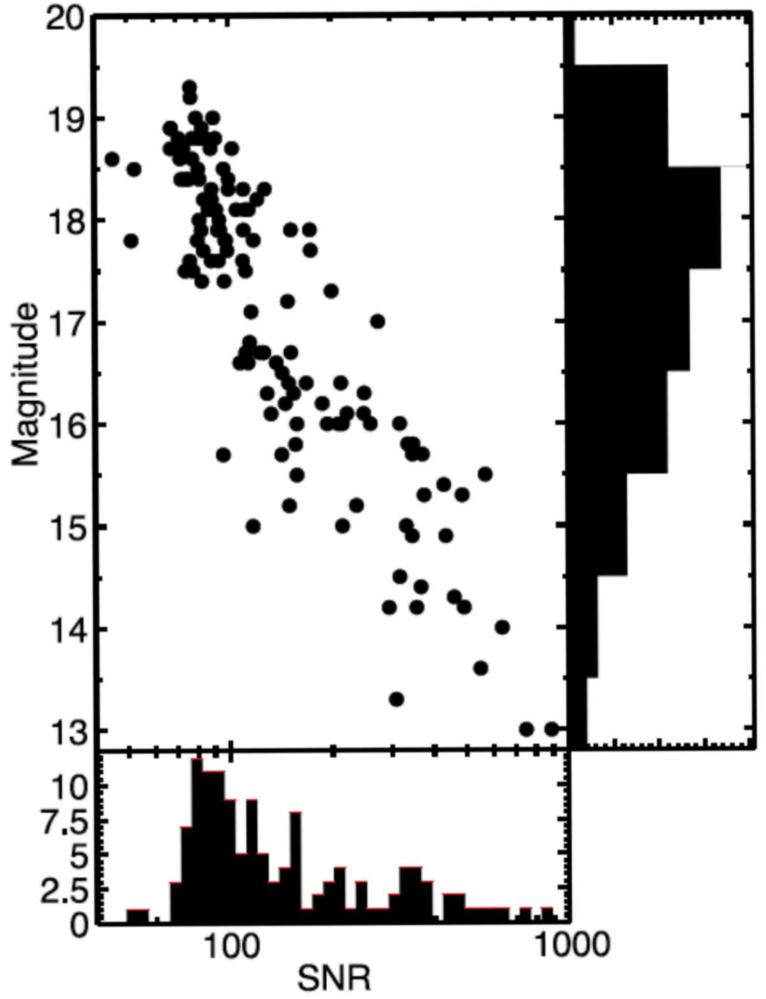
Bergeron et al. 2019

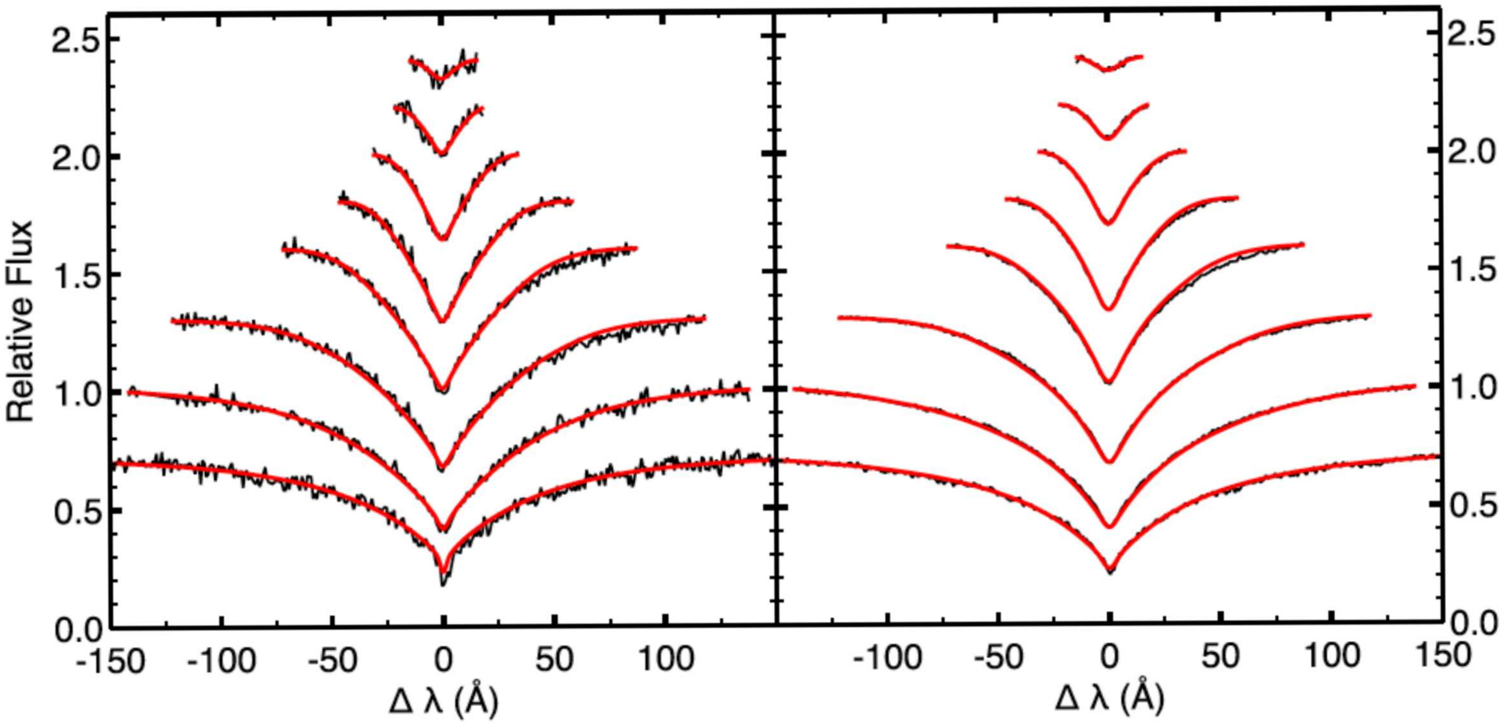


Bergeron et al. 2019

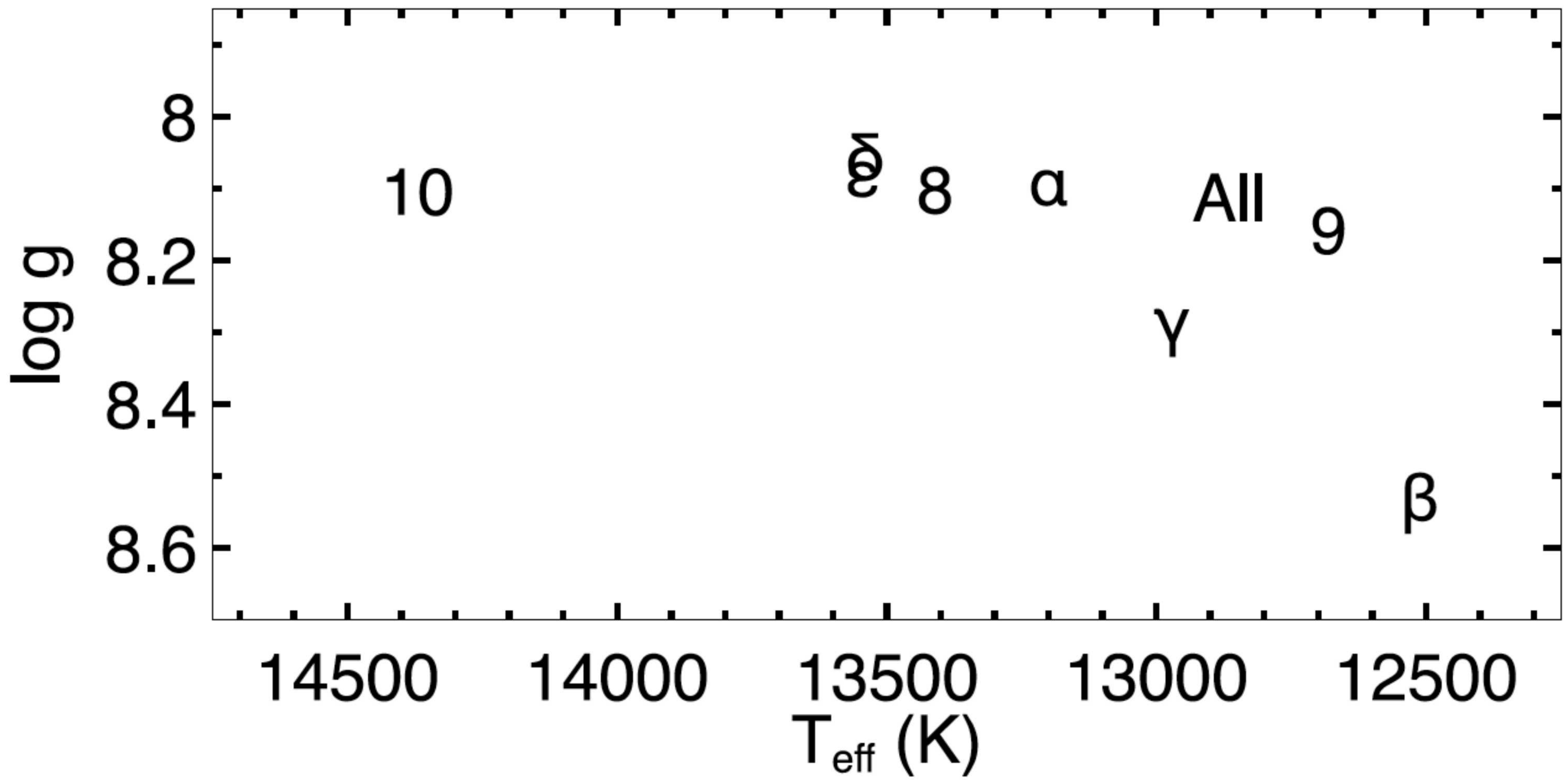
SOAR ZZ Ceti Survey

Spectroscopy of 129 DAs in and around the DAV instability strip (Fuchs, Dunlap et al. in prep)



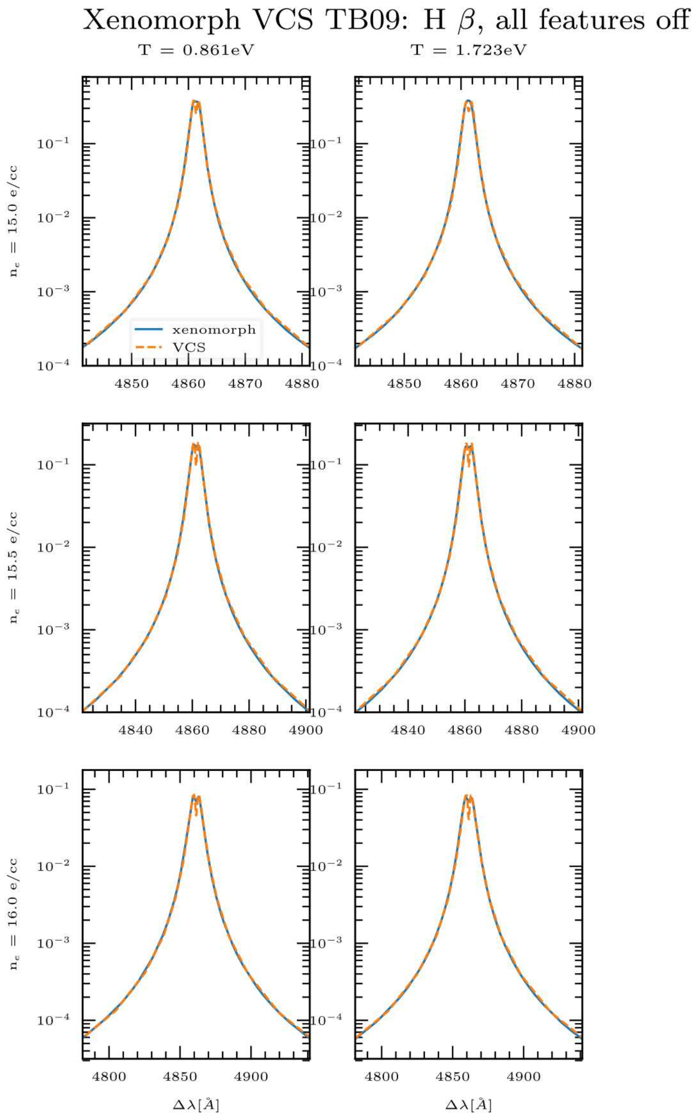


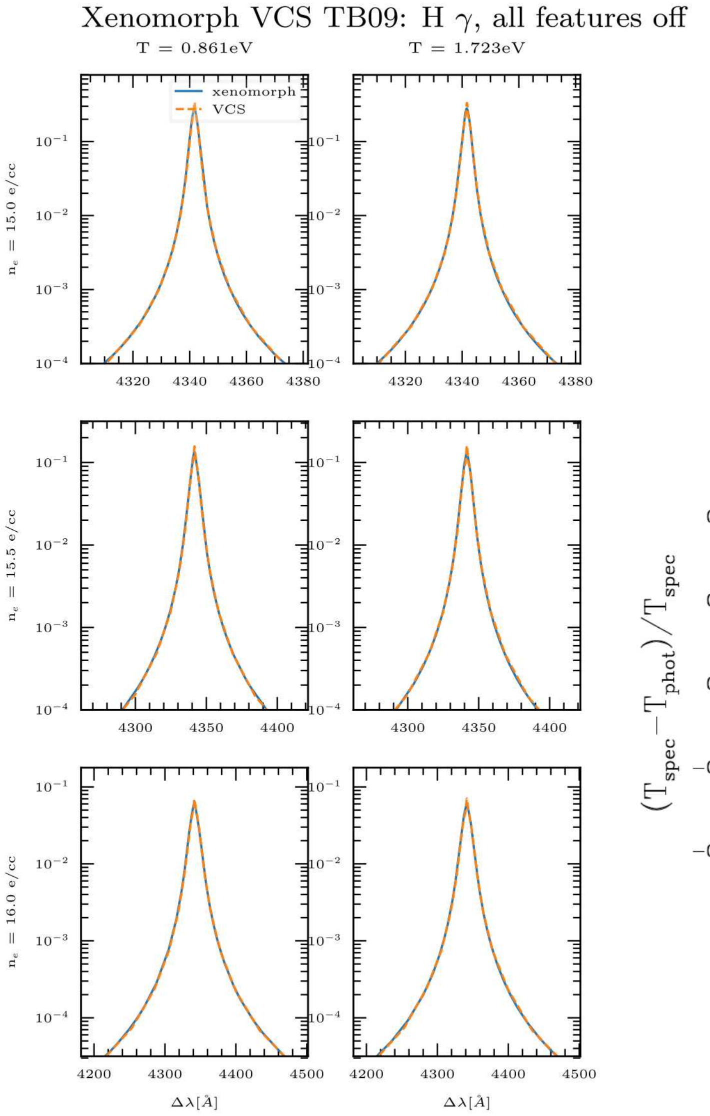
Solutions for individual Balmer lines (L19-2)



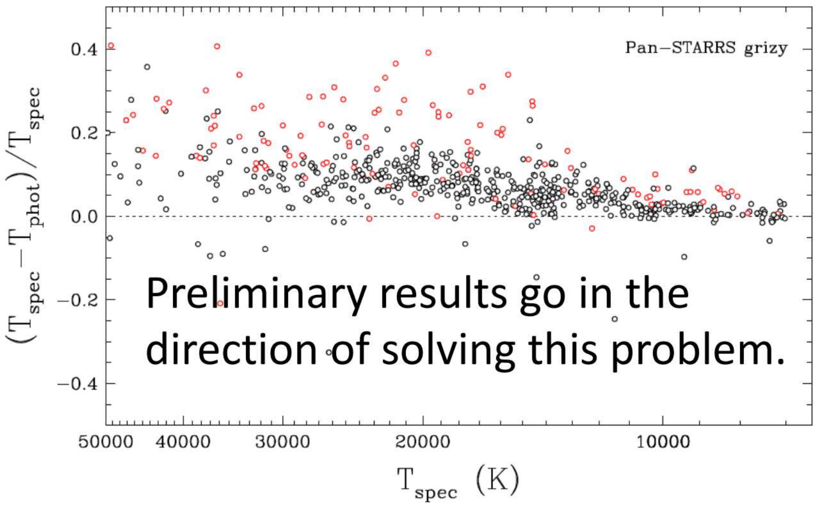
Fuchs et al. in prep

New WD Model Atmospheres



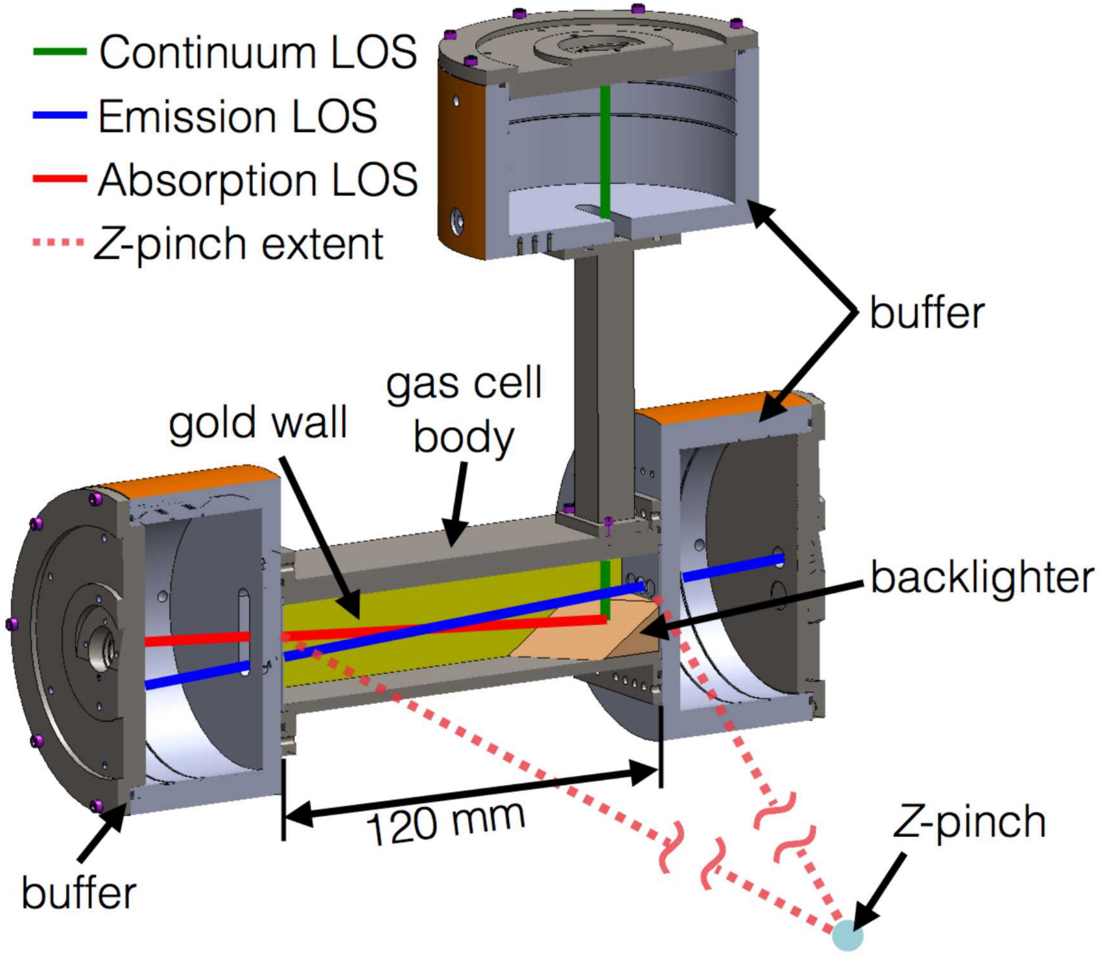


Work led by Patty Cho to incorporate state of the art Balmer line profiles into TLUSTY.



Preliminary results go in the direction of solving this problem.

The White Dwarf Photosphere Experiment on the Z-machine

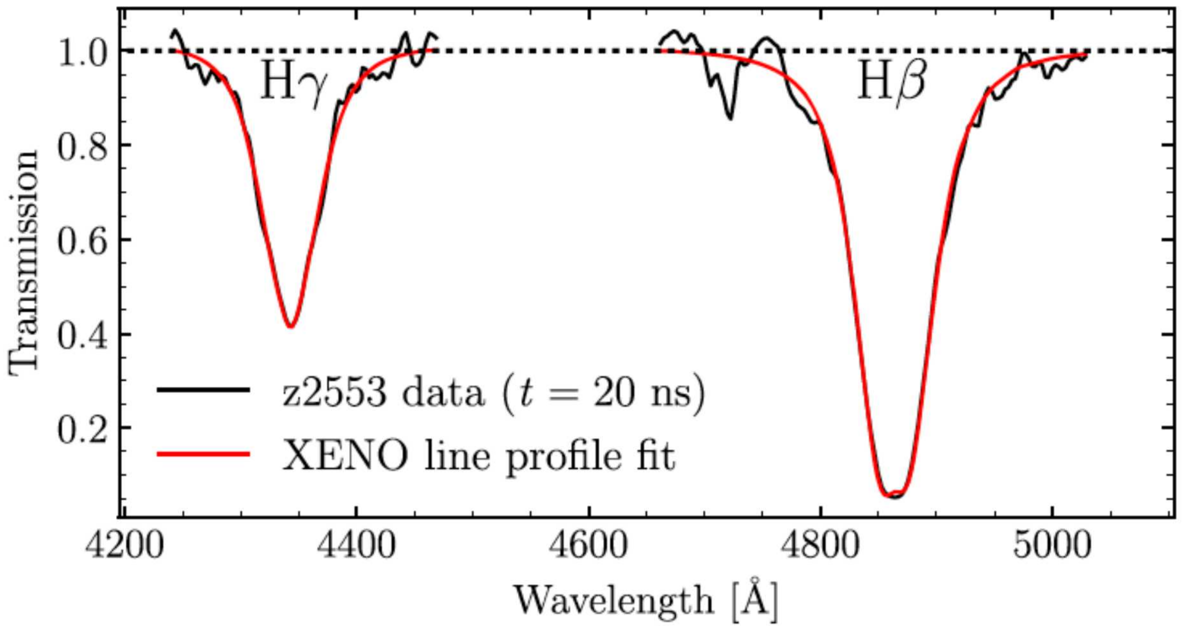


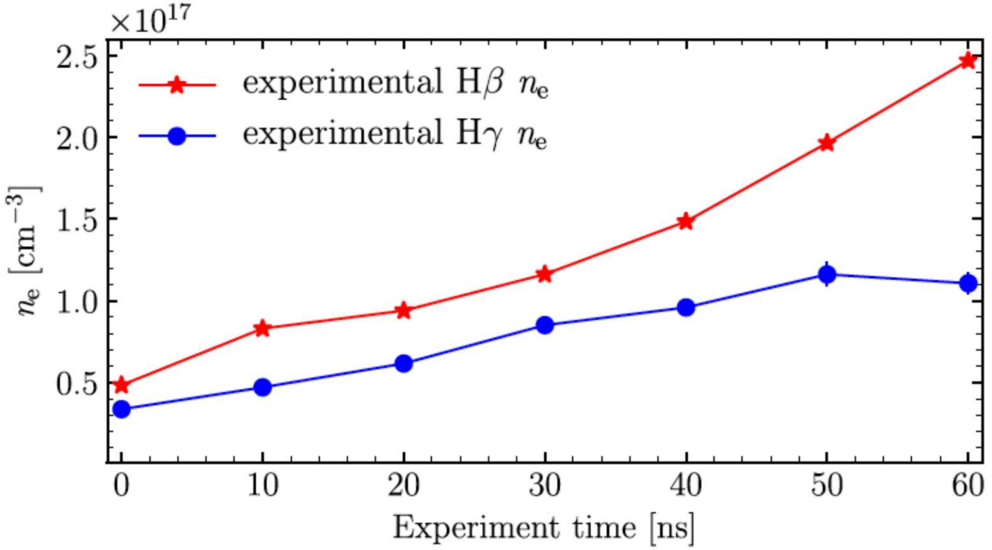
Schaeuble et al. (2019)

- The White Dwarf Photosphere Experiment platform is ~324 mm away from the Z-pinch
- We observe the resulting spectrum using the absorption (red), emission (blue) and continuum line-of-sight (green). This experimental setup allows us to re-create WD absorption observations.

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

Schaeuble et al. (2019)





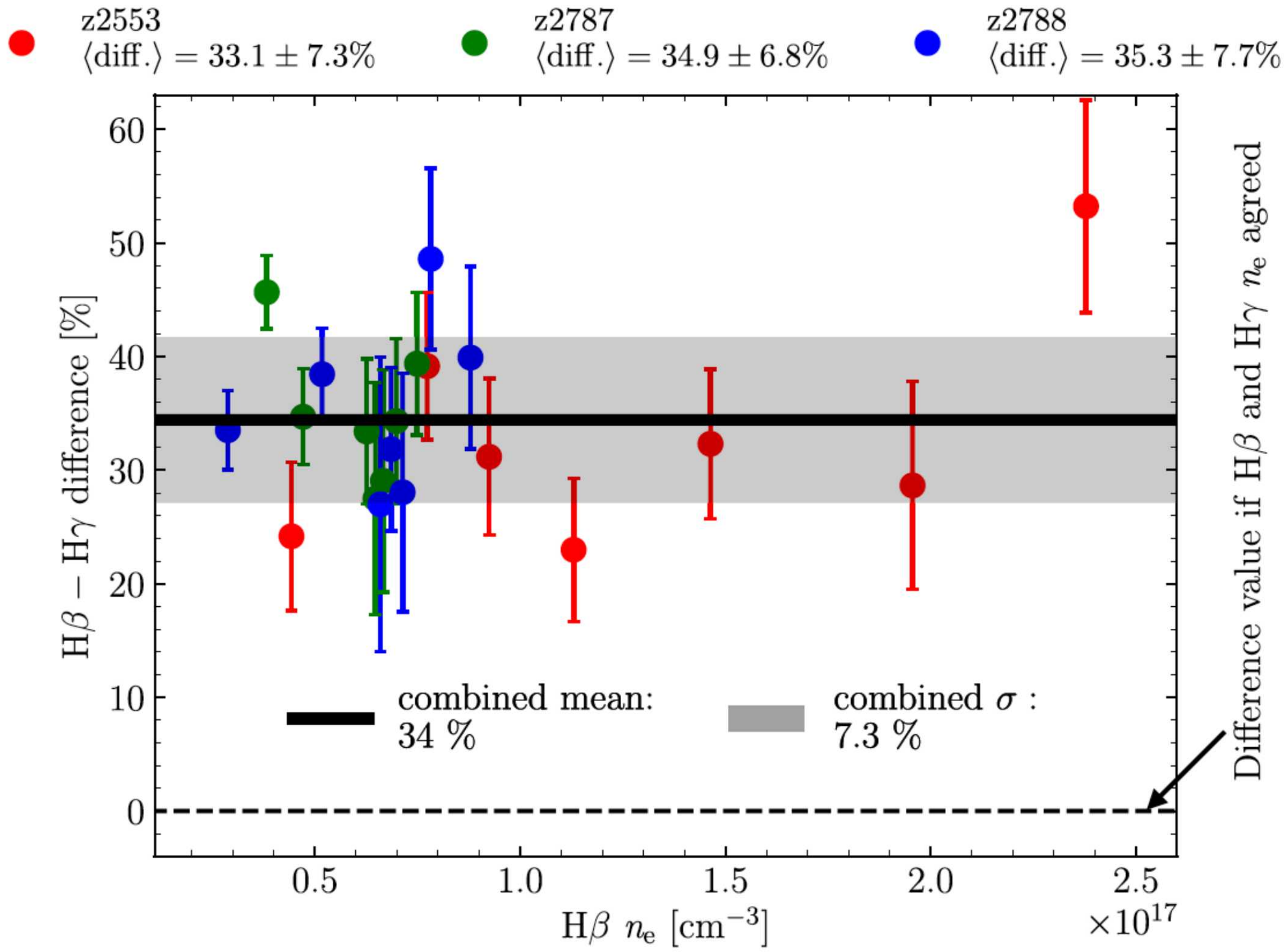
Line fits to absorption spectra.
These are used to extract n_e values.

Hβ and Hɣ n_e values differ by ~30%.

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

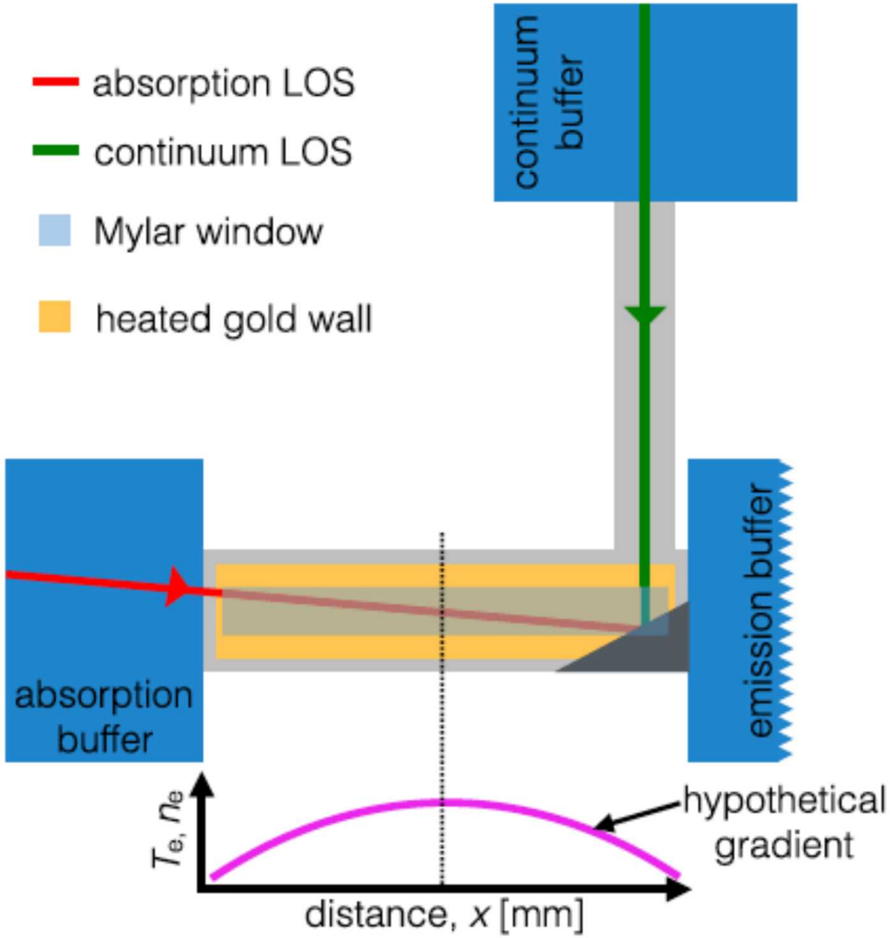
Hβ and Hɣ n_e values differ by ~30%.

This difference is consistent across multiple shots.



Schaeuble et al. (2019)

Is this a result of plasma gradients?



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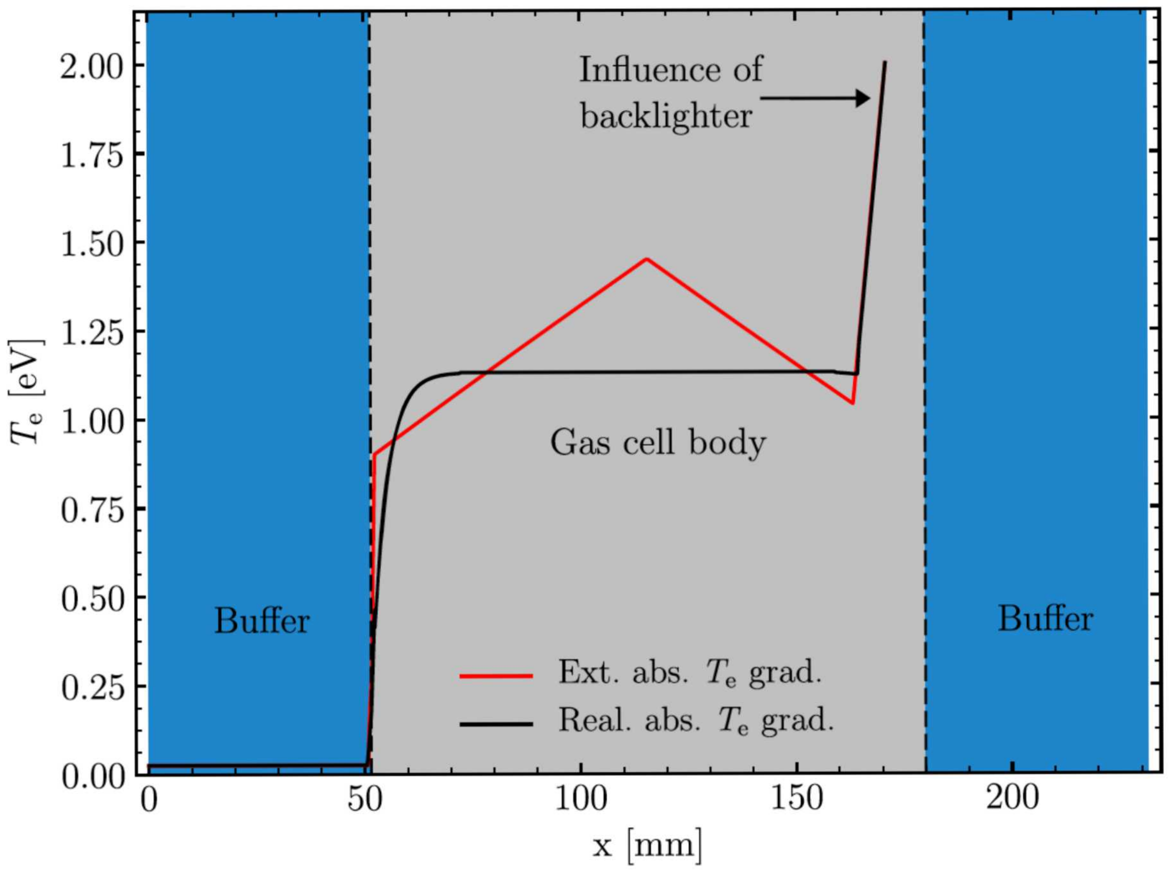
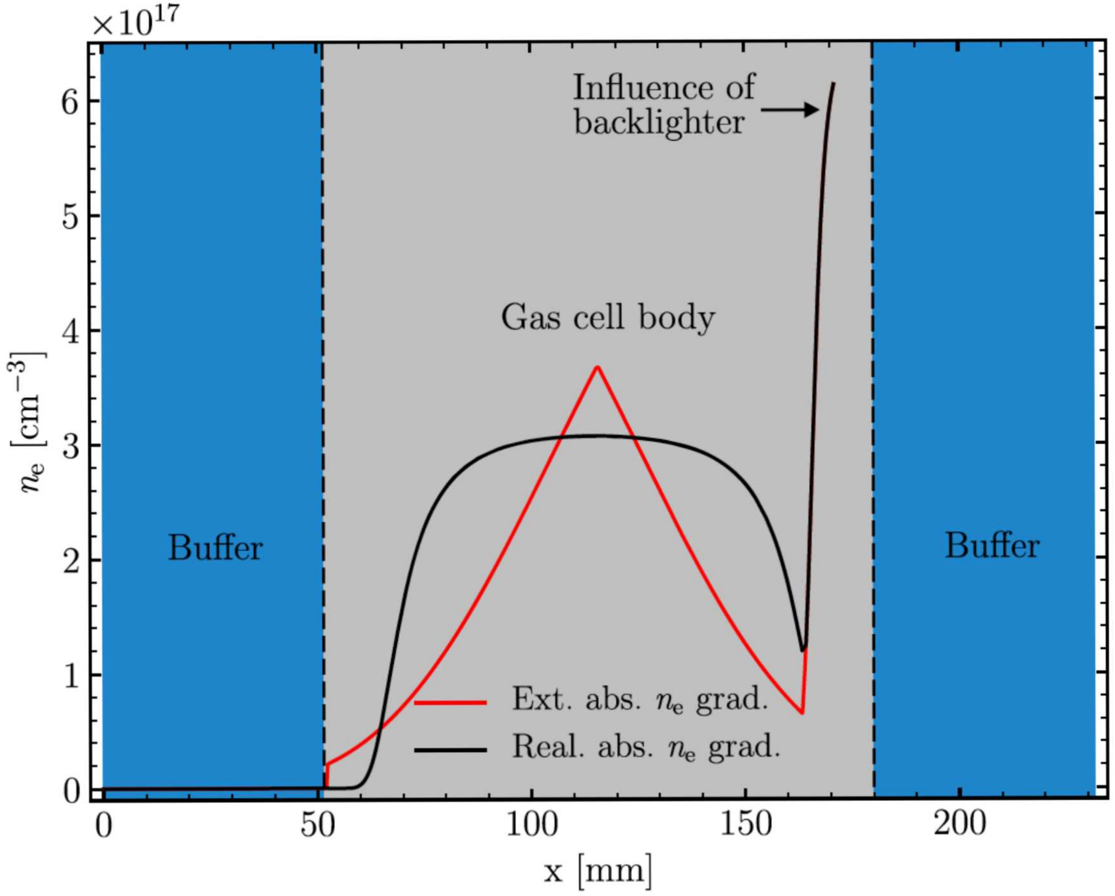
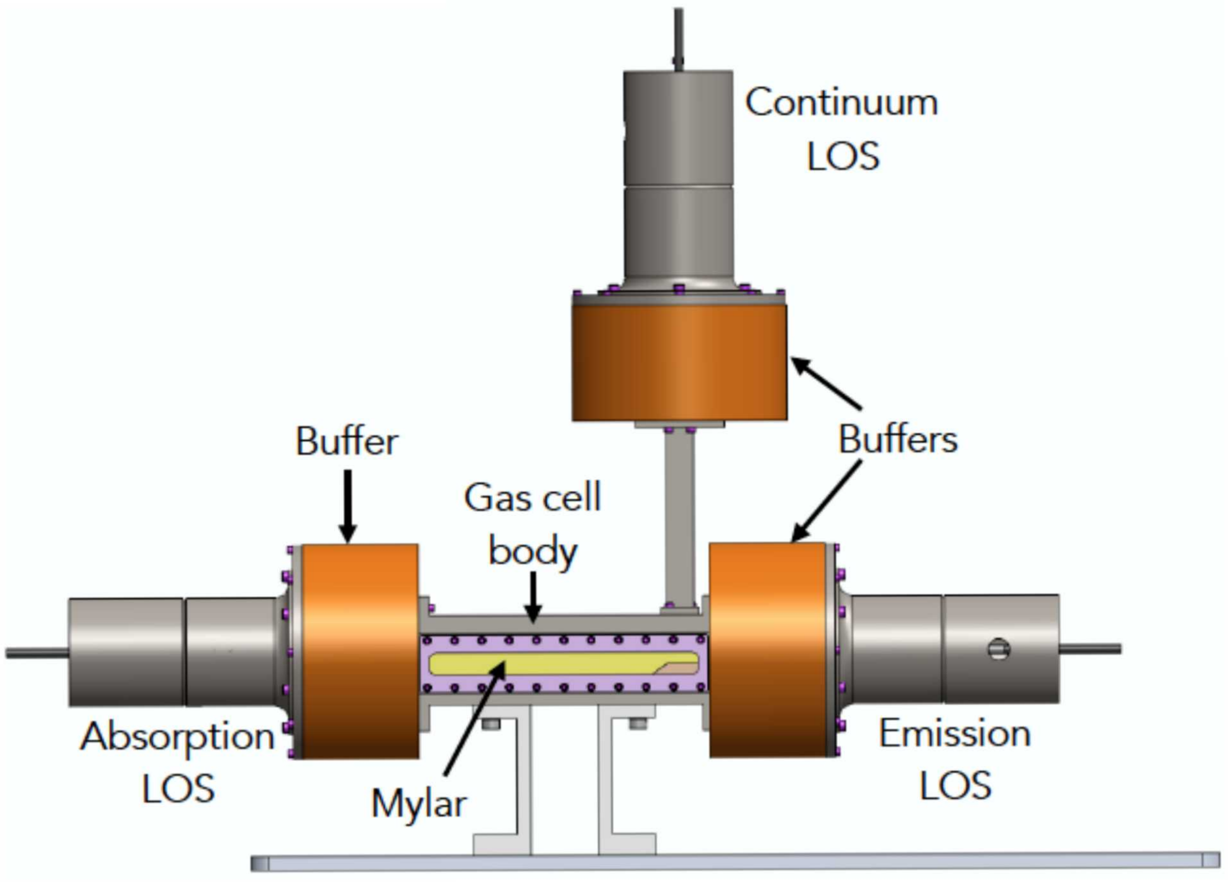




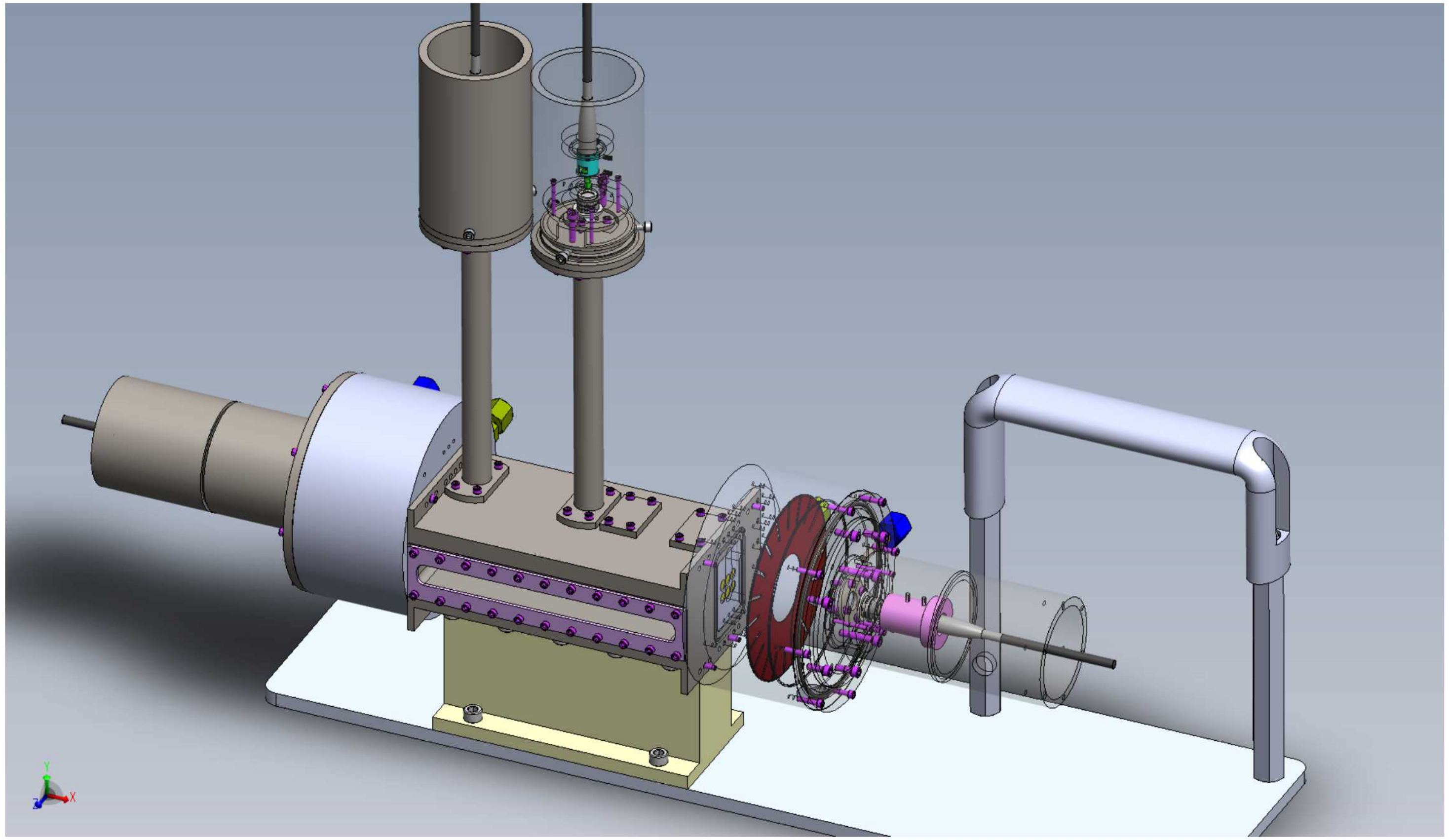
Better constraints on gradients experimentally



Plans to better-constrain gradients experimentally

Use Hβ to probe gradients along the absorption/emission LOS.

New lower buffer allows us to avoid scattered light from gas cell floor.



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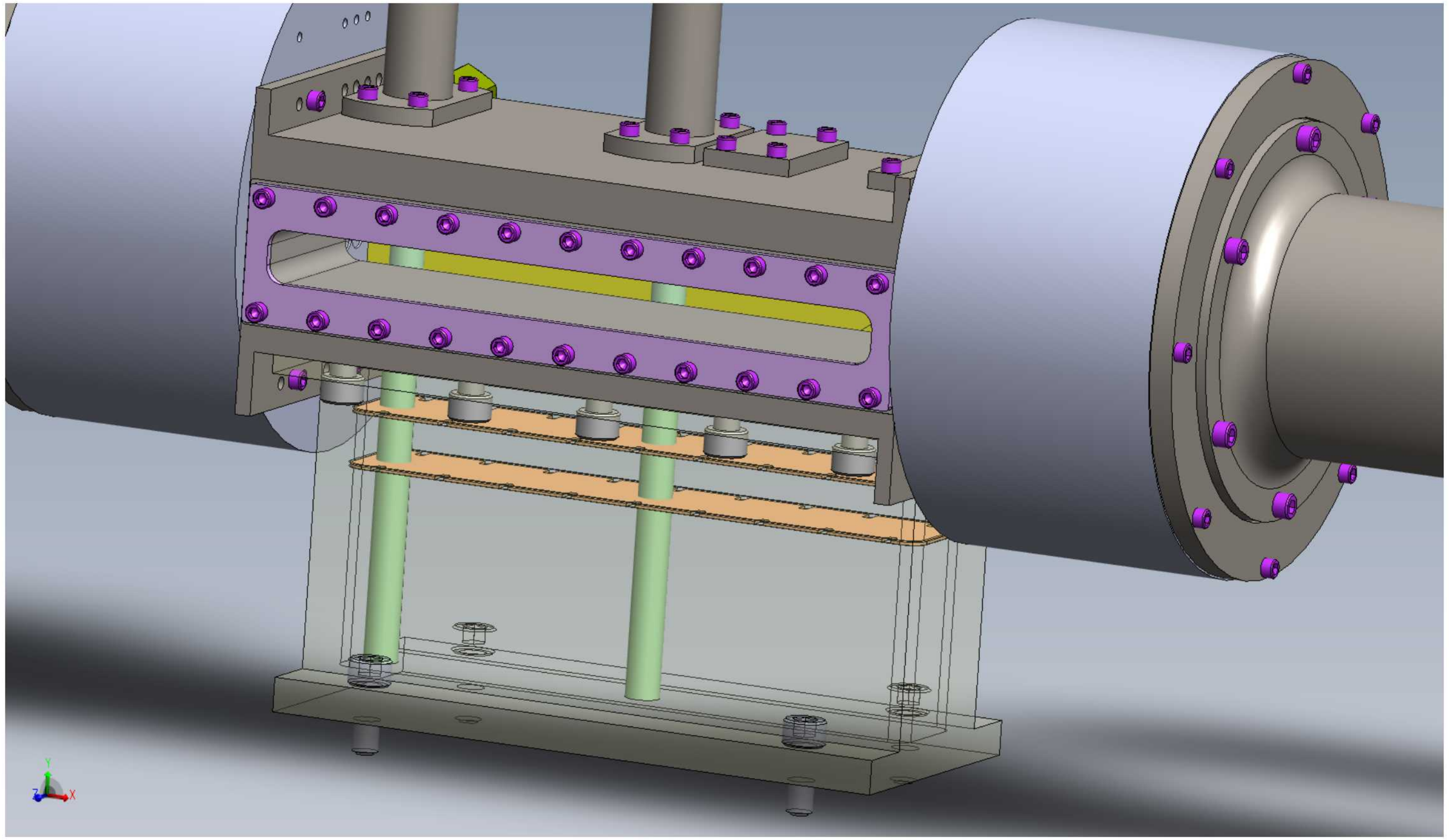
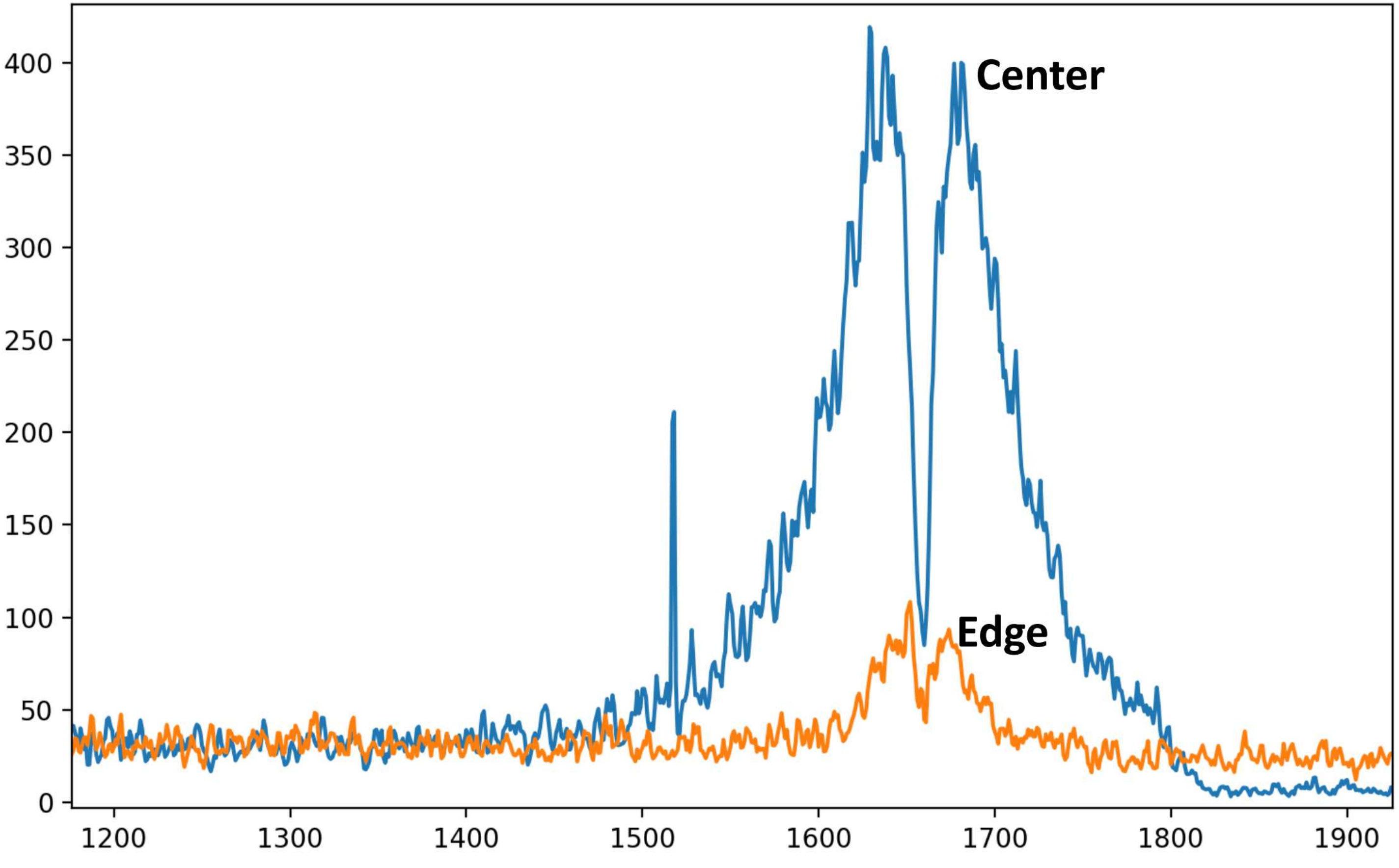
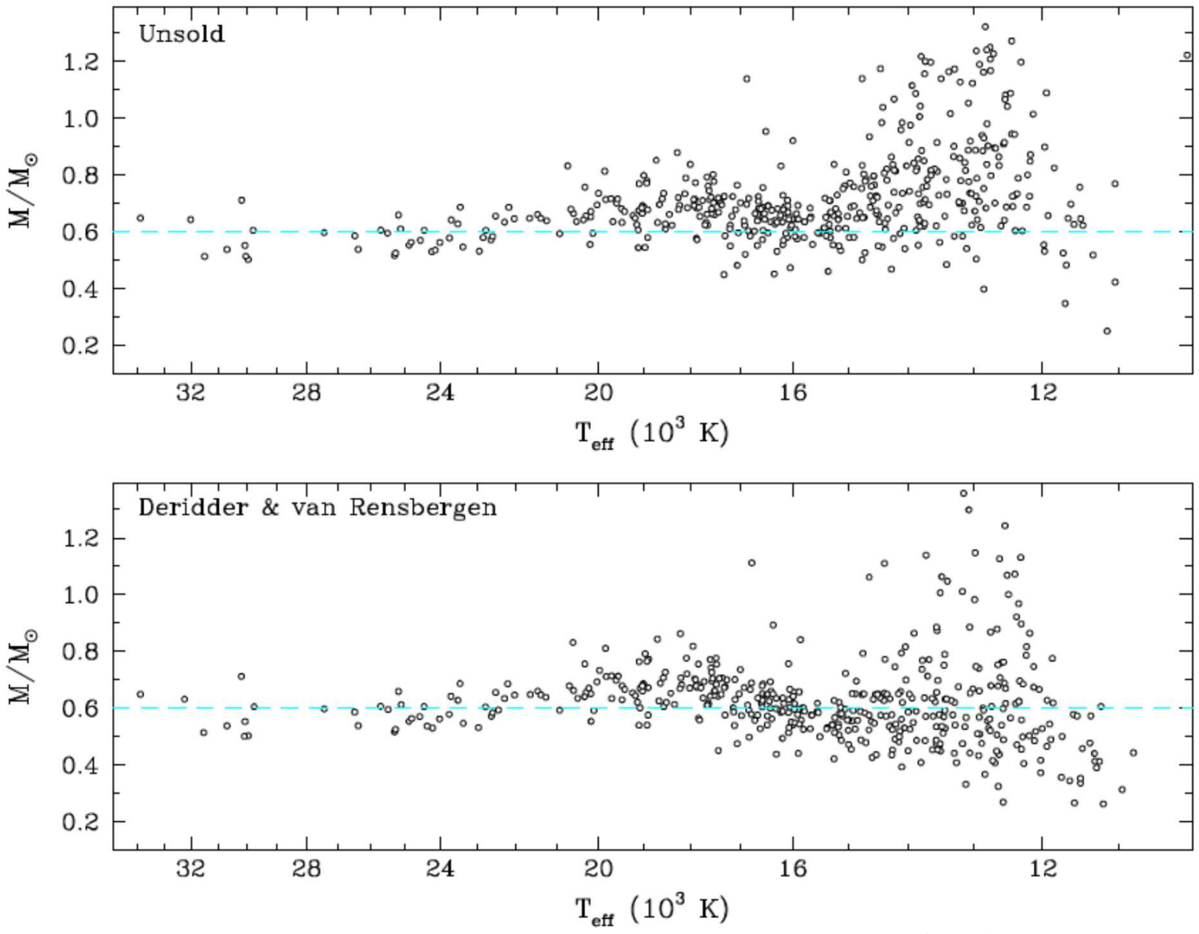


Proof of concept (z3460)



Problems with helium model atmospheres

At low temperatures, where neutral broadening becomes important, the surface gravities of He-atmosphere white dwarfs derived from spectral line fits show large scatter.

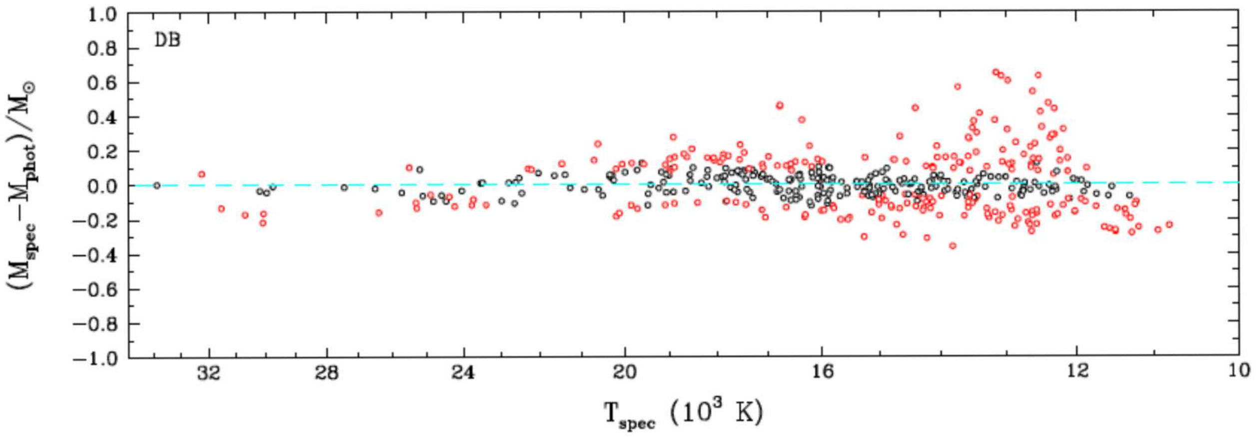


Genest-Beaulieu & Bergeron 2019

Problems with helium model atmospheres

At low temperatures, where neutral broadening becomes important, the surface gravities of He-atmosphere white dwarfs derived from spectral line fits show large scatter.

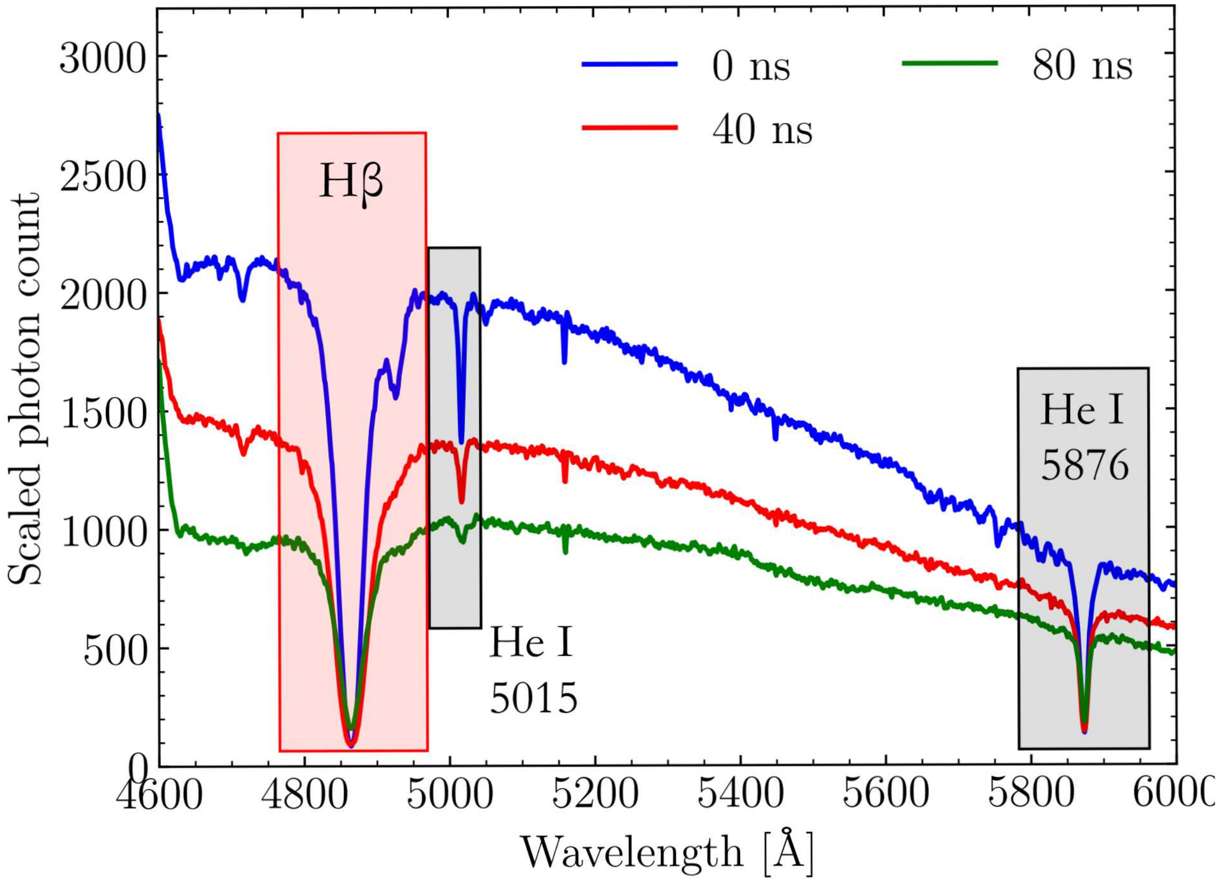
And they diverge from the masses inferred by parallax+photometry



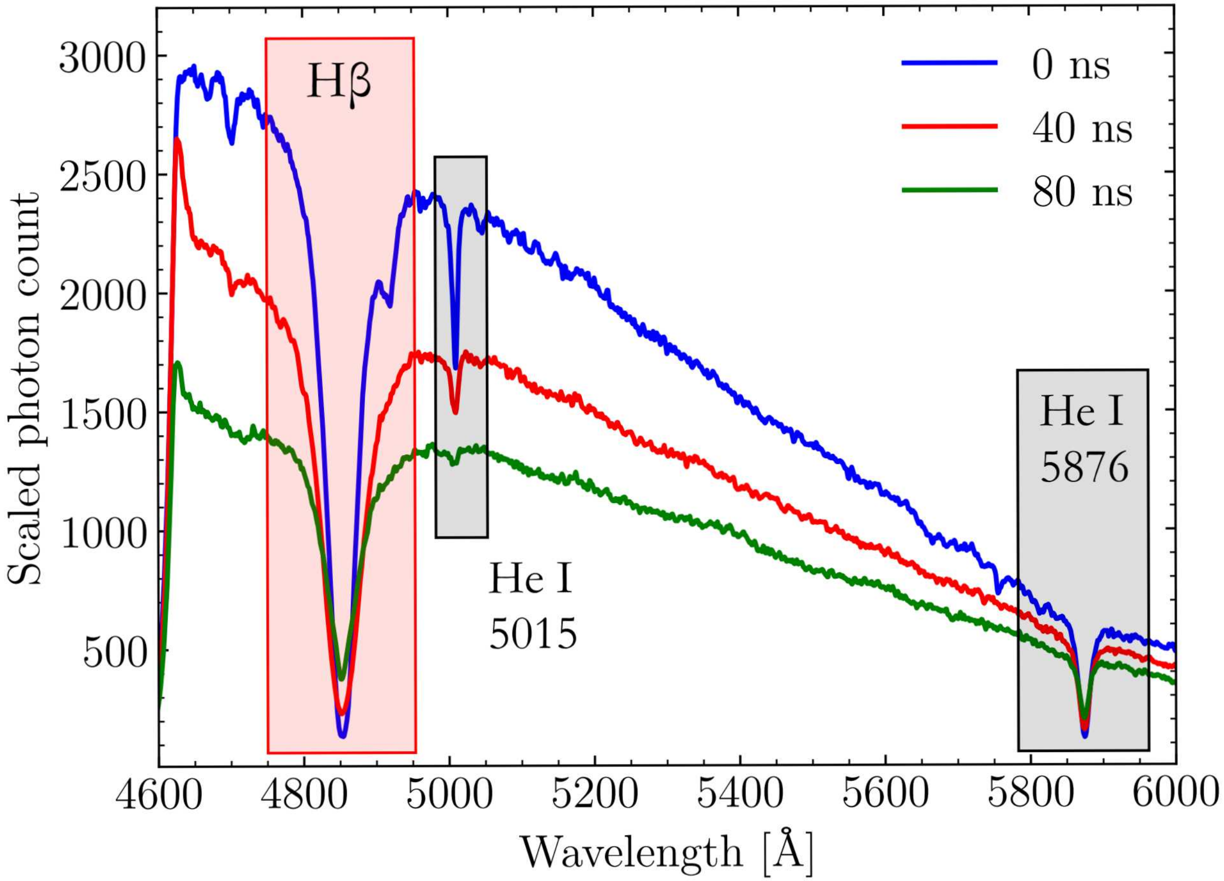
Genest-Beaulieu & Bergeron 2019

Helium line widths from Z

SVS4



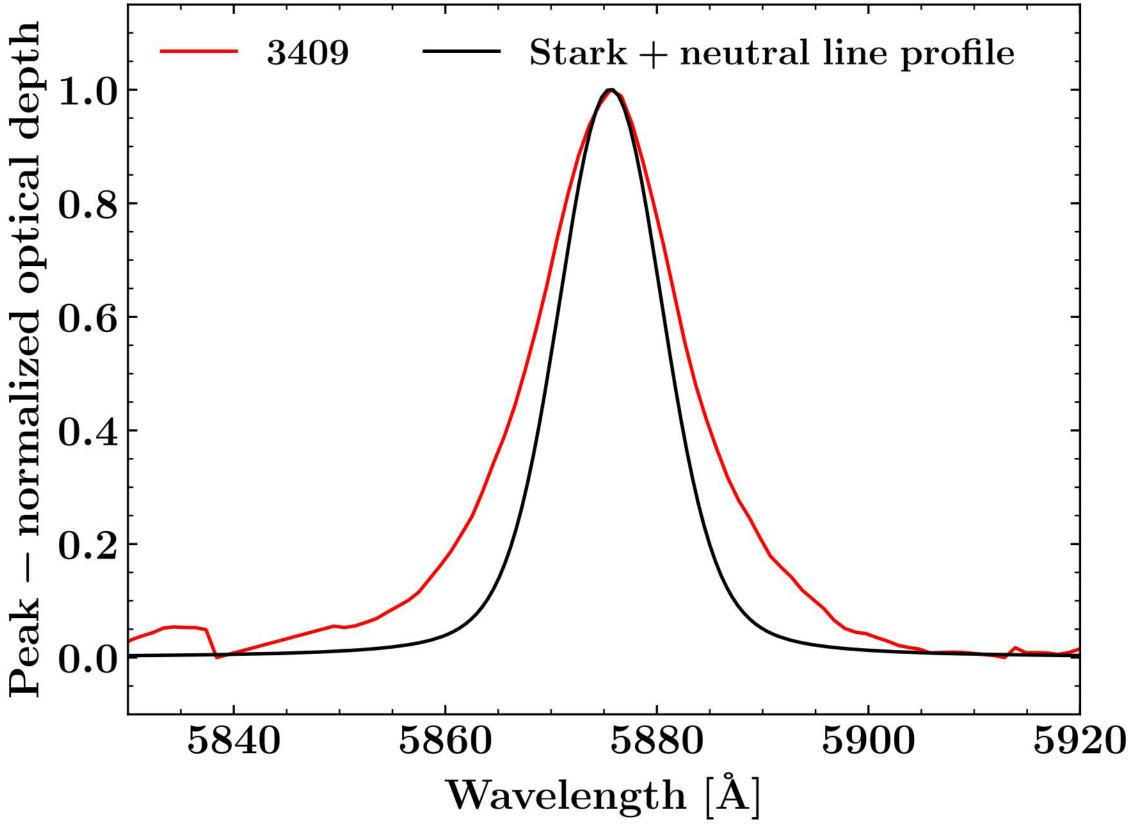
SVS5



A detailed analysis of all these data will follow soon!

Helium line widths from Z

The width of the measured profile (red) is a combination of Stark and neutral broadening.



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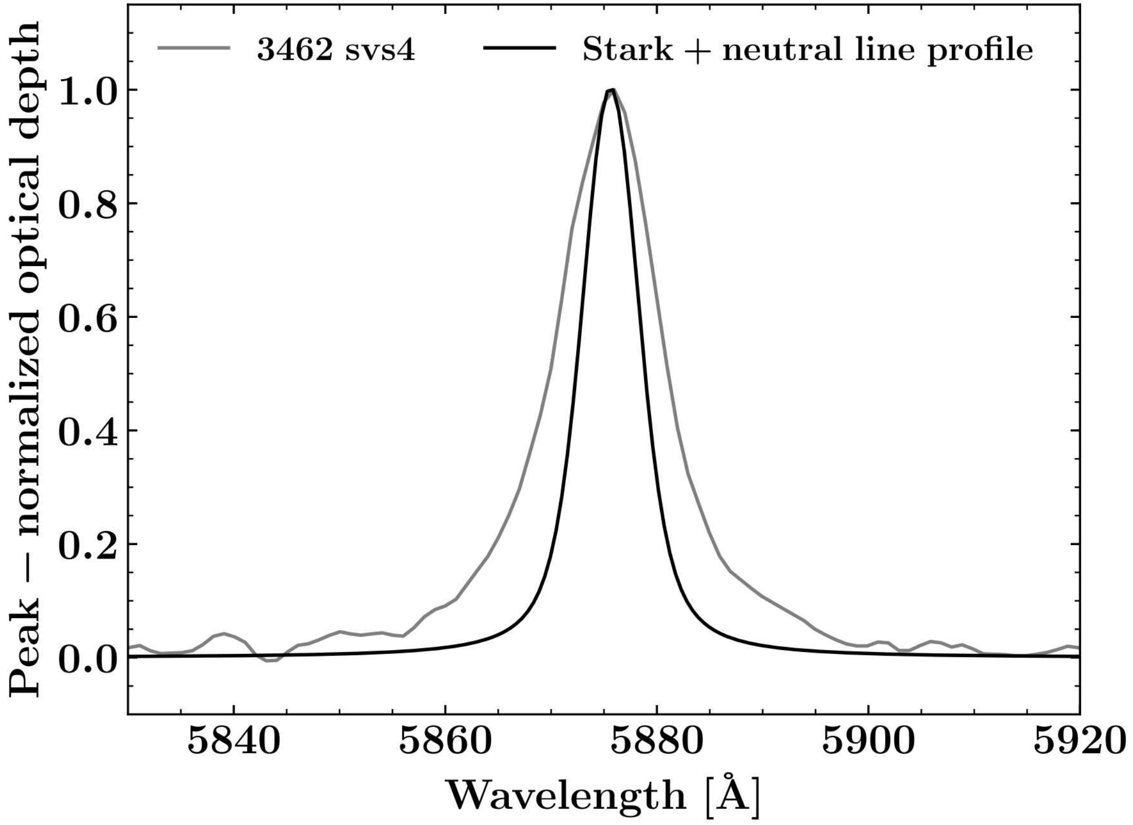
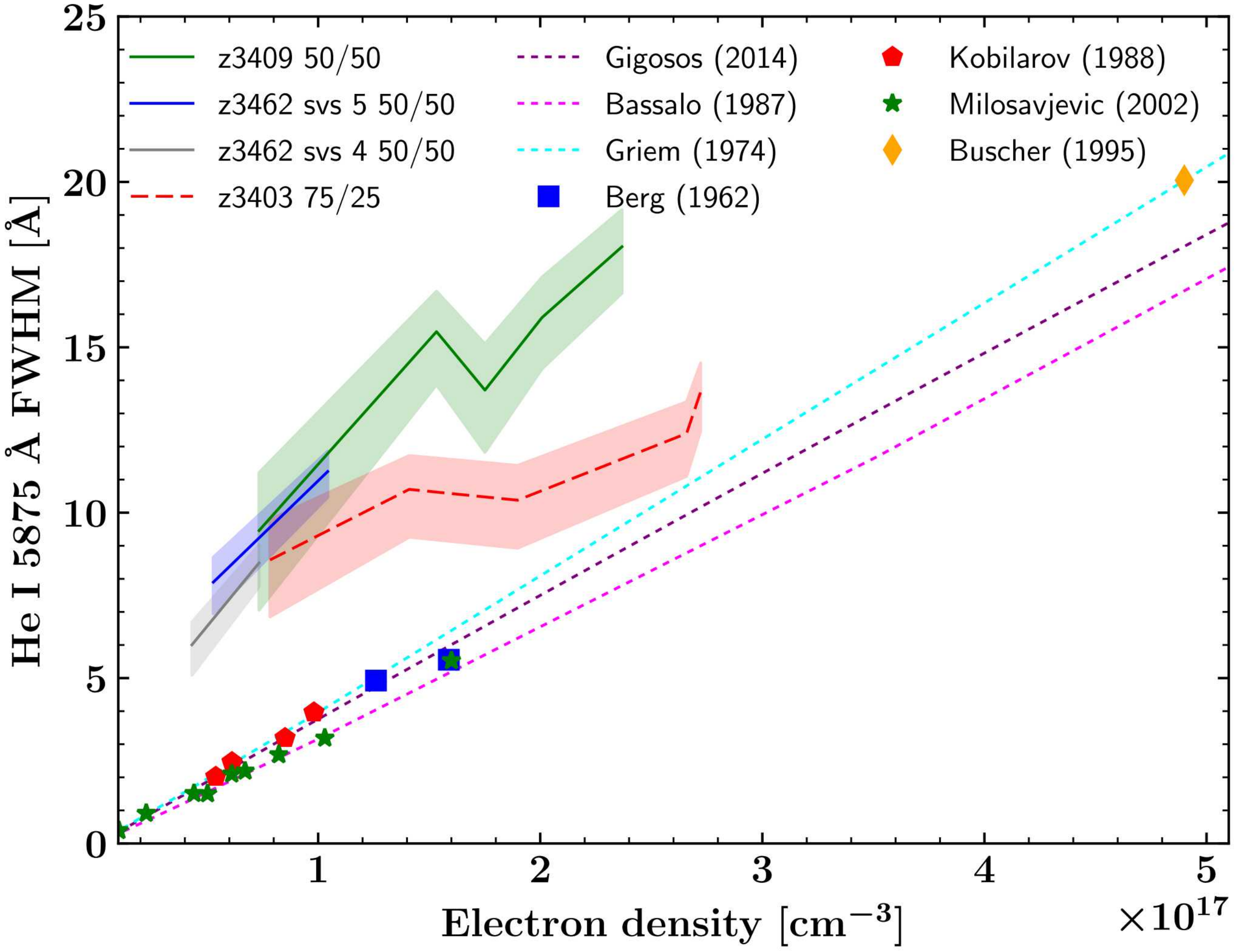
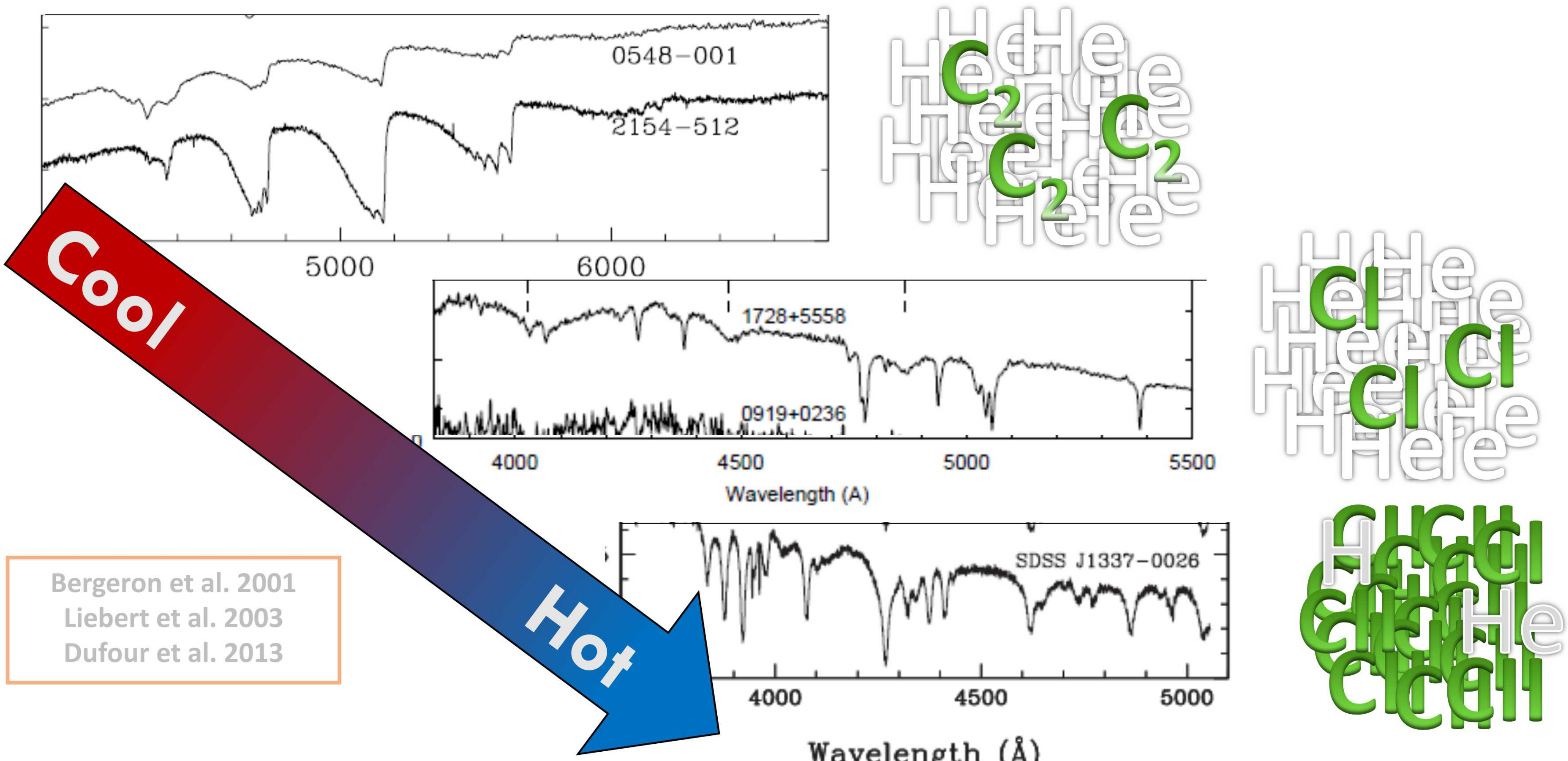


Helium line widths from Z

Comparison of line widths from Z (3 shots) with experimental & theoretical Stark widths.

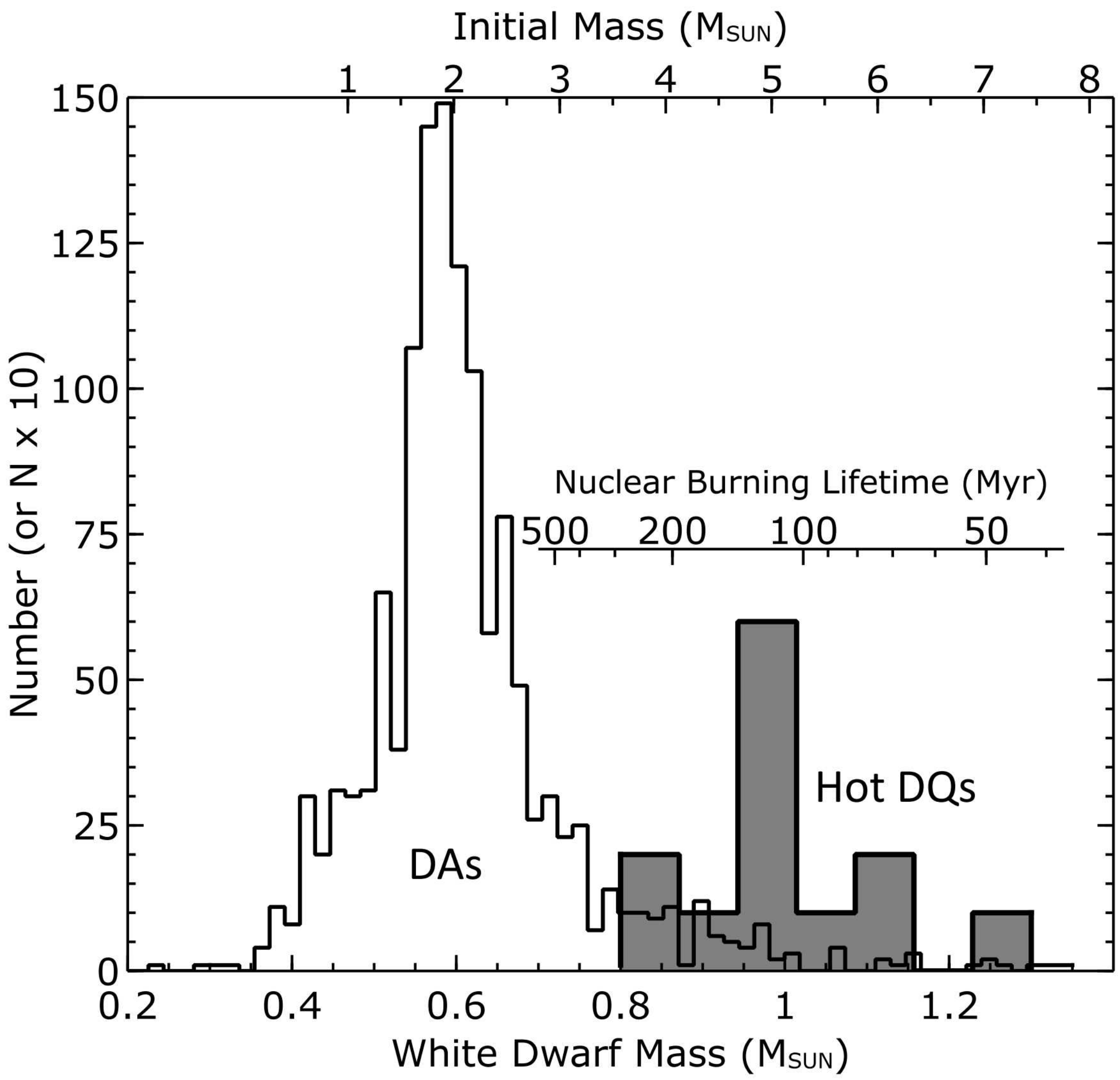


White Dwarfs with Carbon Lines



Bergeron et al. 2001
Liebert et al. 2003
Dufour et al. 2013

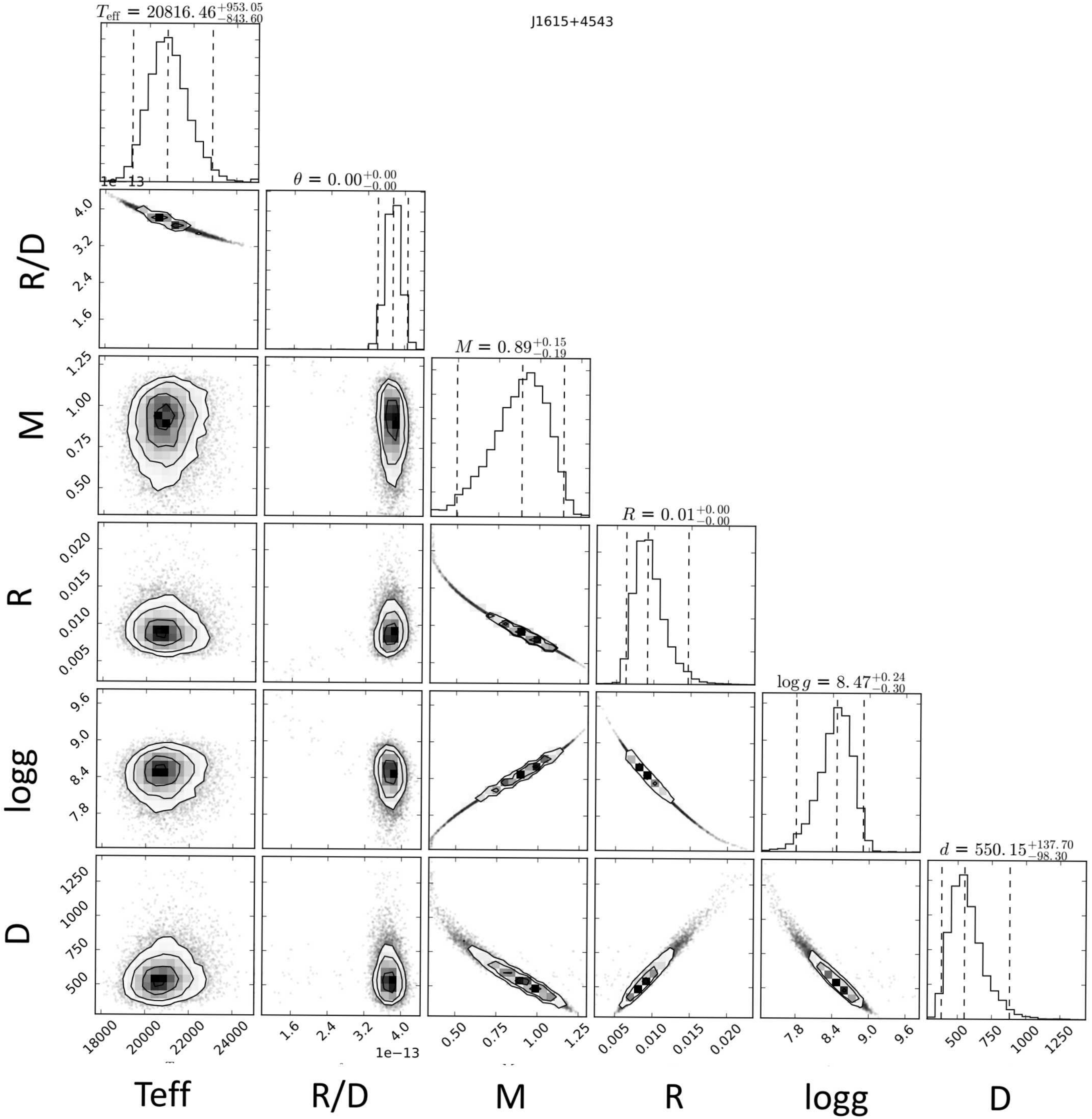
Carbon: Hot DQ White Dwarfs



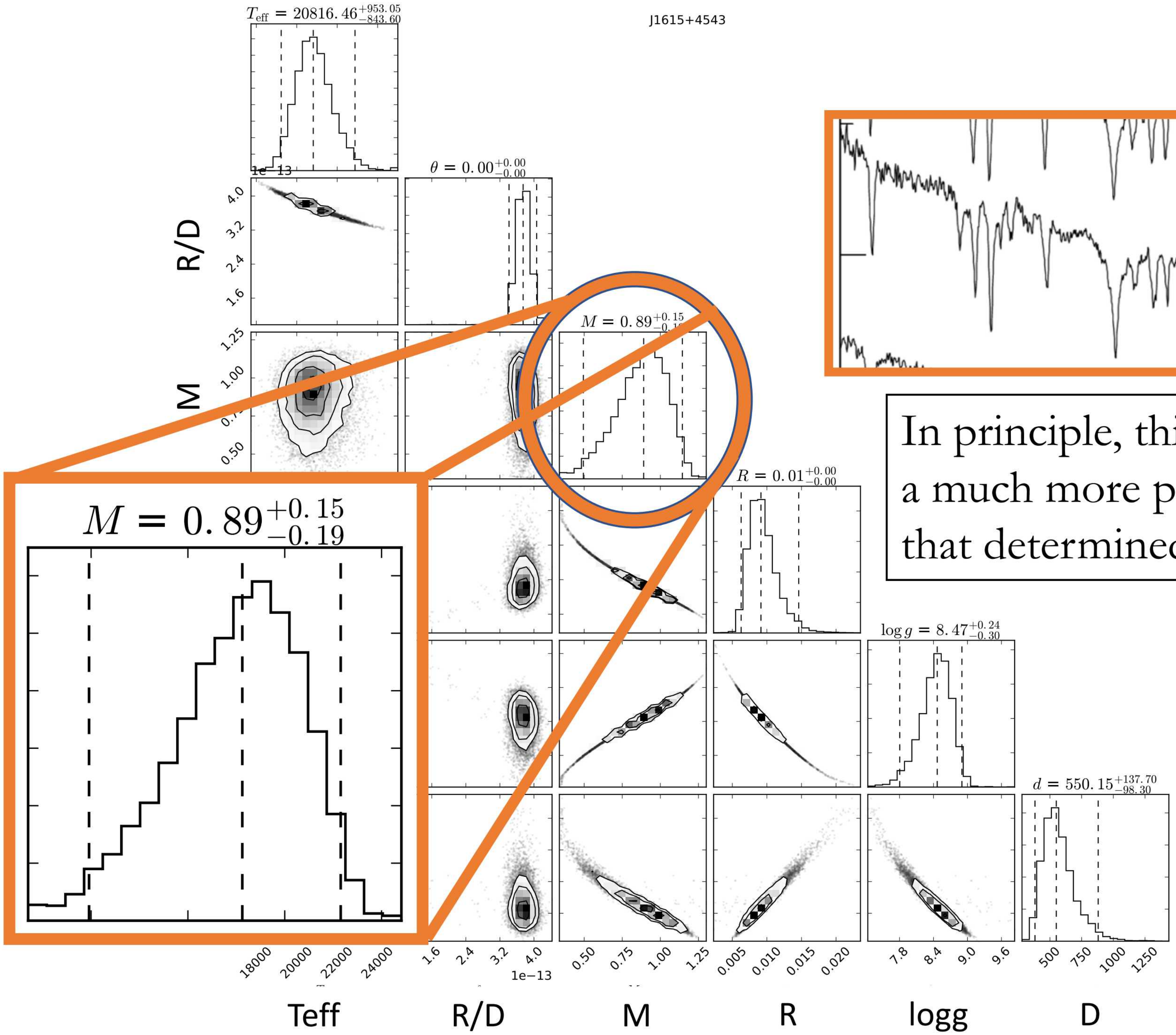
The hot DQ white dwarfs (~18,000 – 25,000 K) have C-dominated atmospheres. Little experimental data exists on the Stark broadening of the CII lines (Dufour et al. 2011) seen in the spectra.

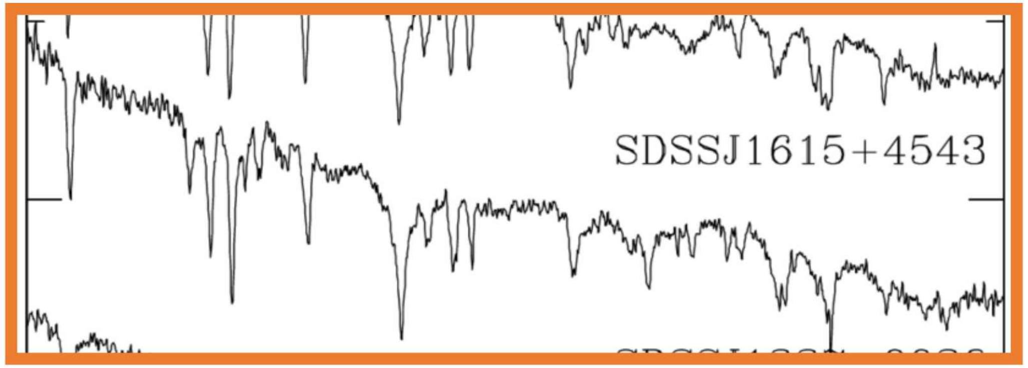
Our Gaia/SDSS fits show they are all massive WDs, and we find evidence that they are WD-WD mergers.

The mass distribution may tell us the lower limit for mergers resulting in type Ia supernovae. But we need a more precise mass distribution.



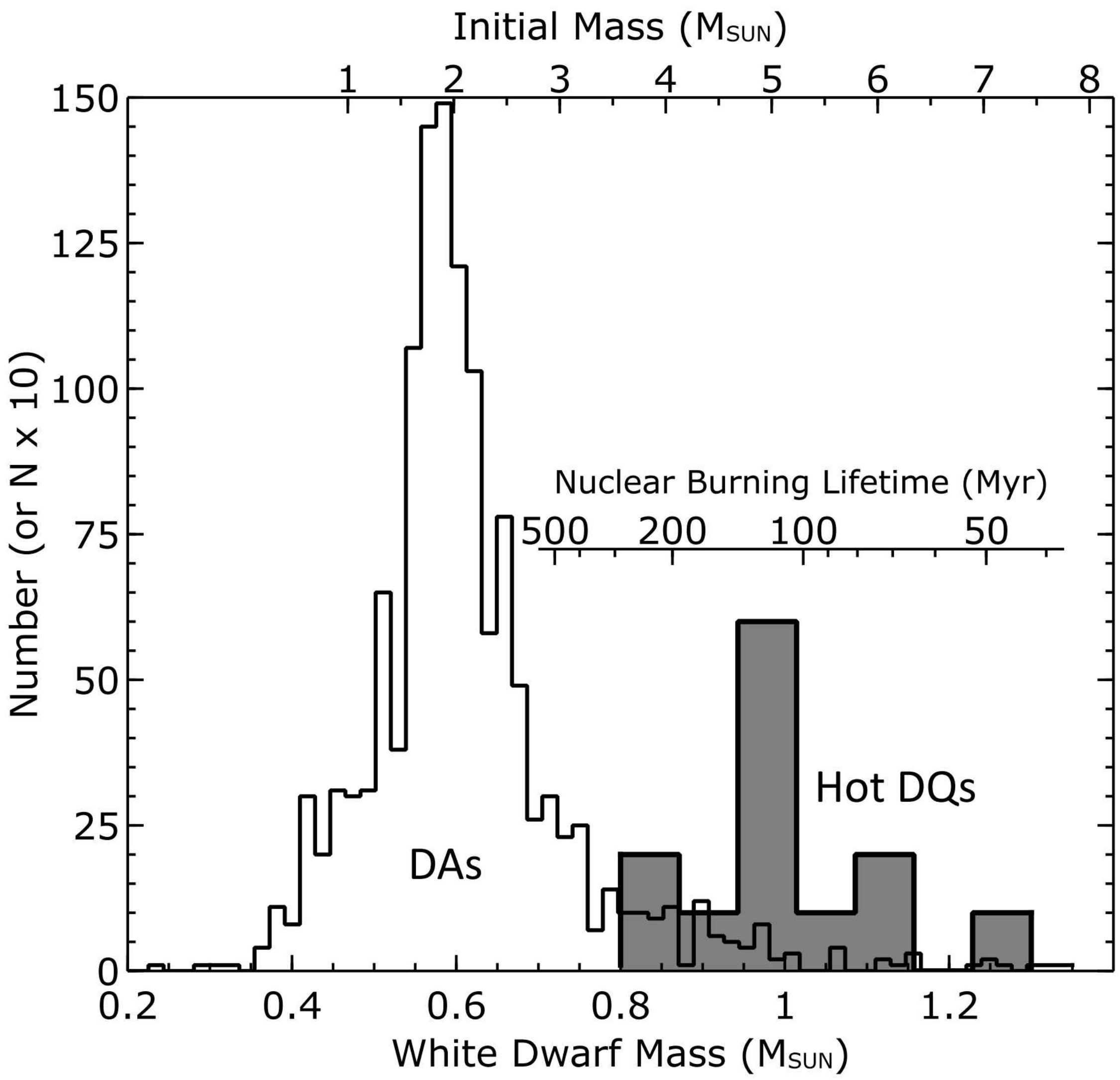
J1615+4543
$T_{\rm eff} = 20816.46^{+953.05}_{-843.60}$
$\theta = 0.00^{+0.00}_{-0.00}$
$M = 0.89^{+0.15}_{-0.19}$
$R = 0.01^{+0.00}_{-0.00}$
$\log g = 8.47^{+0.24}_{-0.30}$
$d = 550.15^{+137.70}_{-98.30}$
Teff
R/D
M
R
logg
D





In principle, this spectrum can give a much more precise mass than that determined from parallax.

The value of precise spectroscopic log*g*

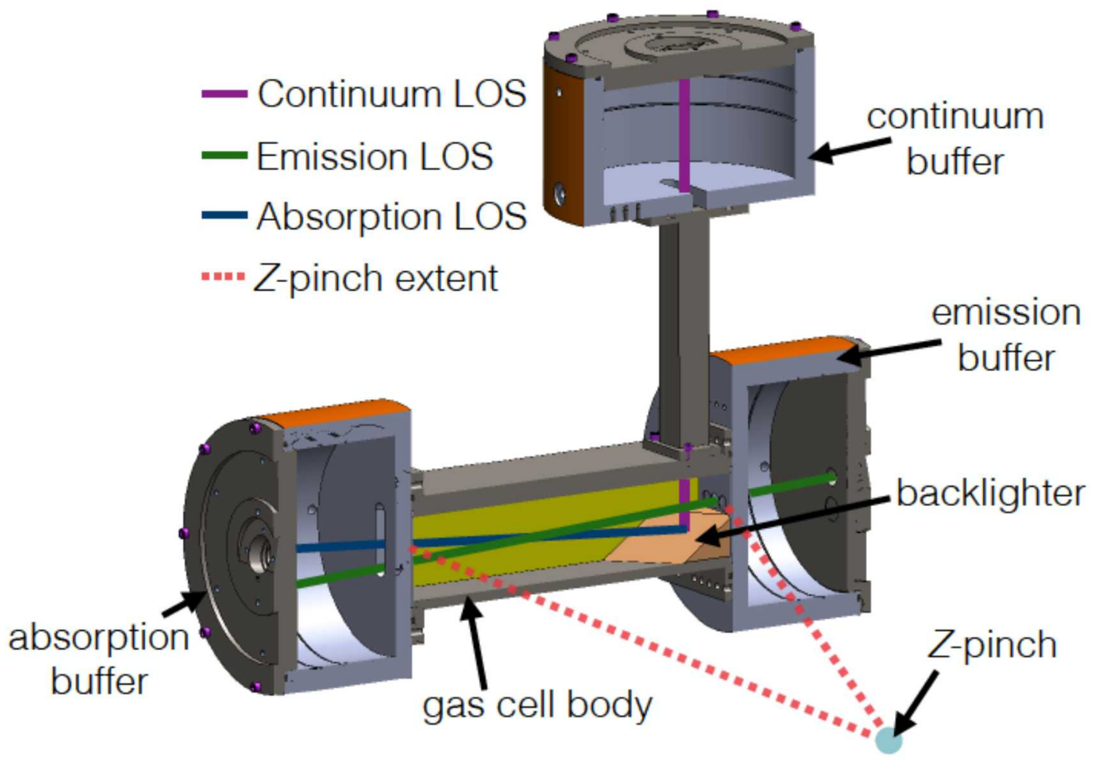


How narrow is the hot DQ mass distribution?
Constraint on formation channels

Is there a cutoff mass? This could be the lower mass of WD+WD mergers that produce type Ia supernovae.

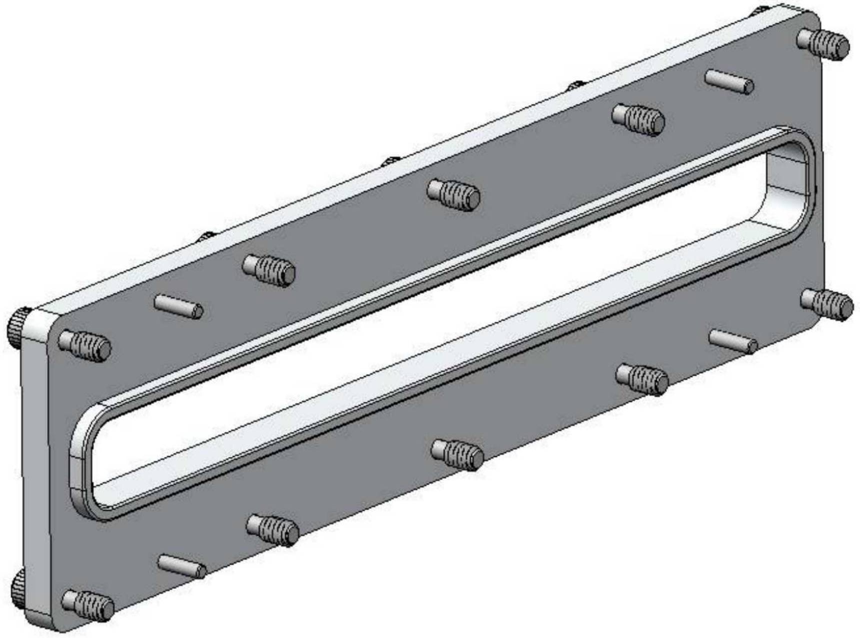
Is there evidence for Fe-cores?
Radius from parallax;
log*g* from spectroscopy

Achieving hot DQ conditions on Z



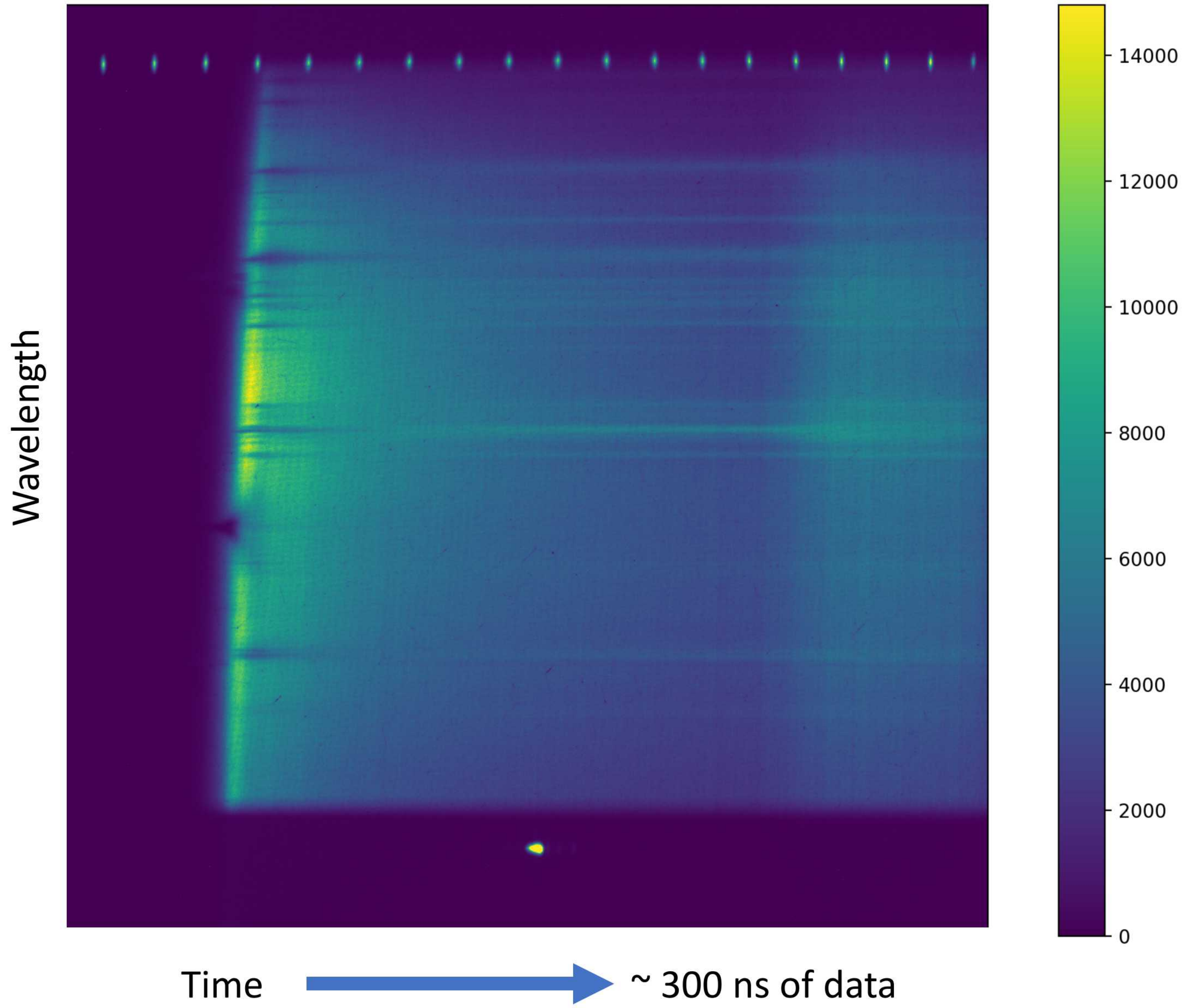
Standard Design

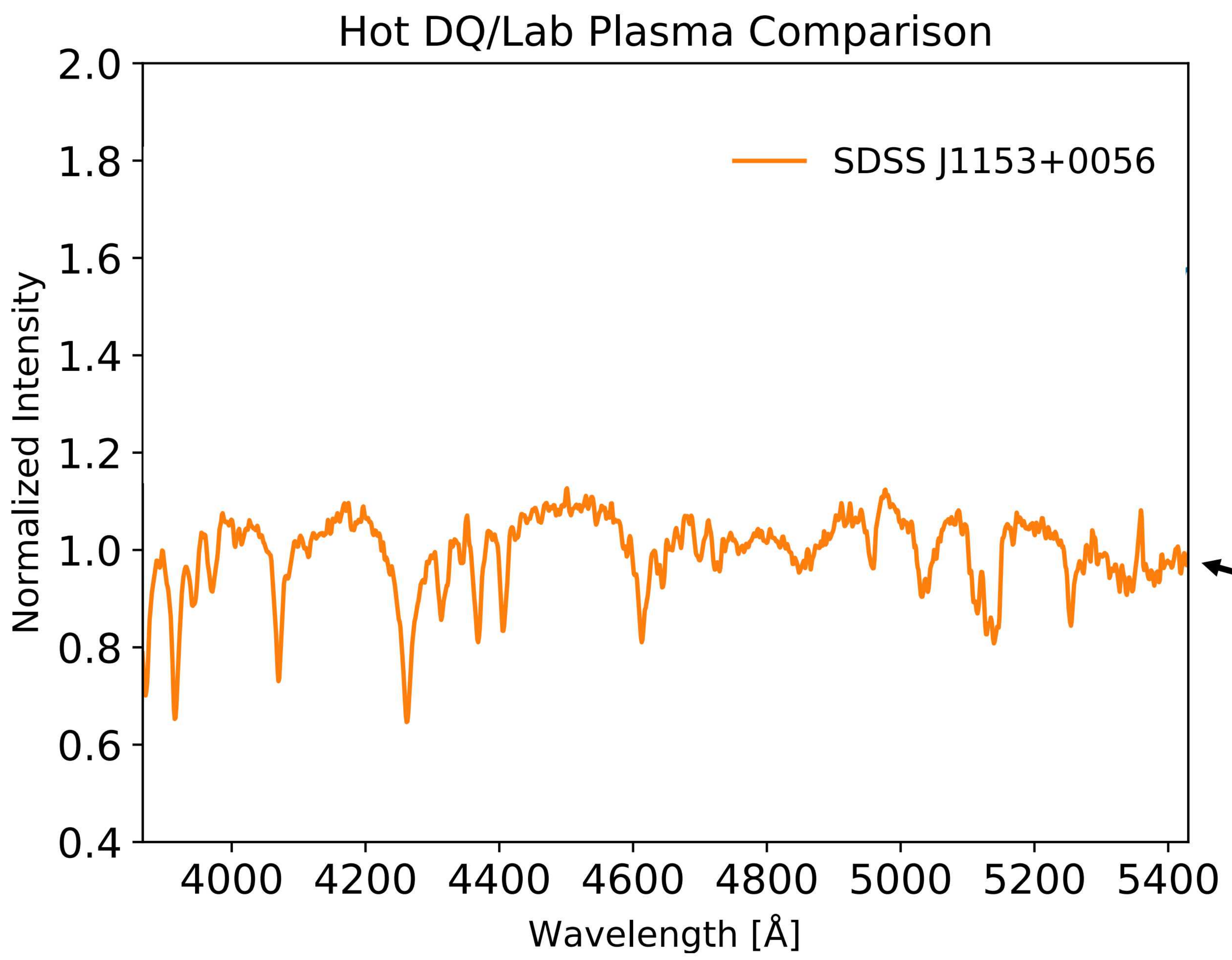
+



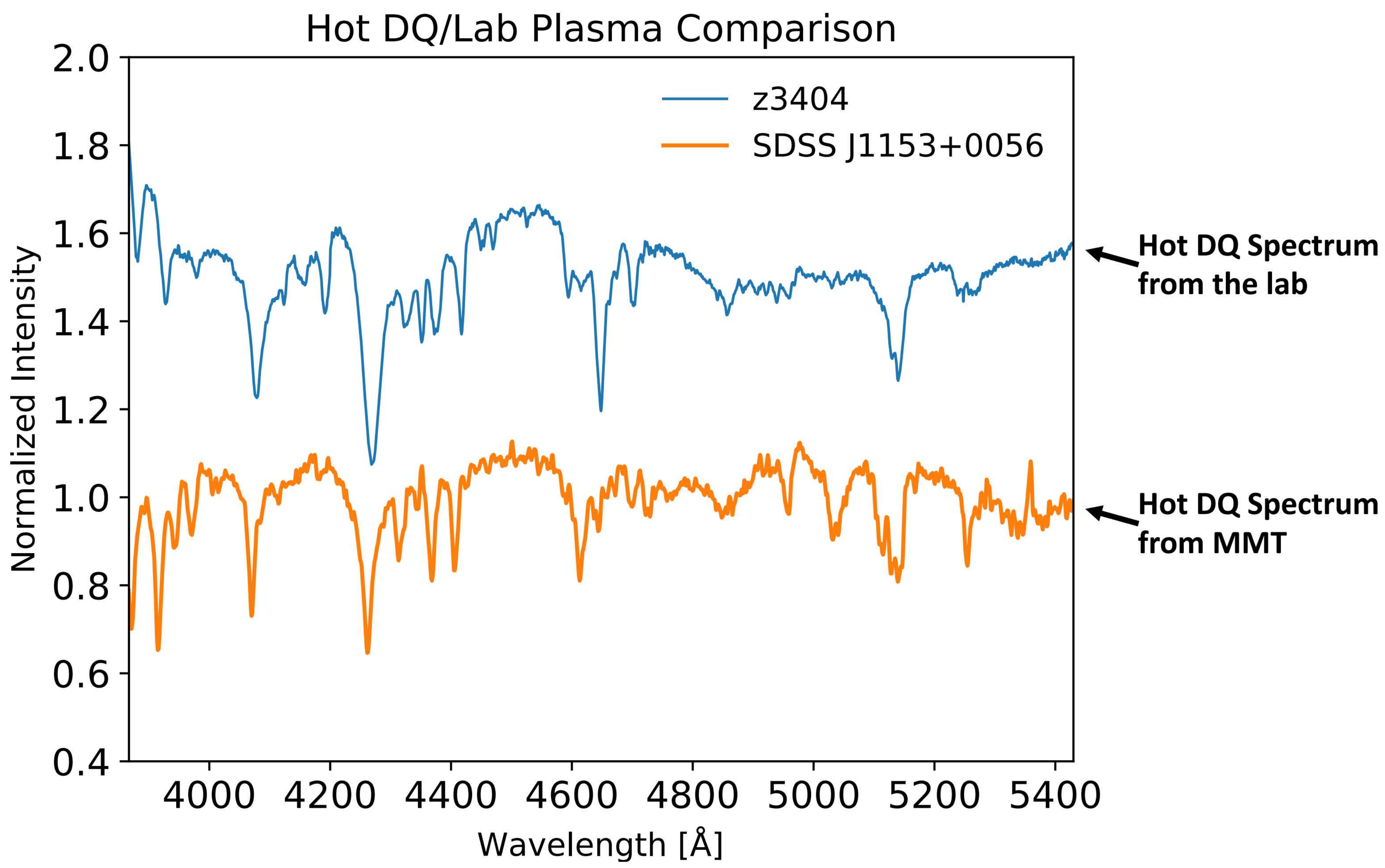
Modified window frame with thin polyimide window from Luxel

Z3404 Carbon Data





Hot DQ Spectrum from MMT (Dufour et al.)

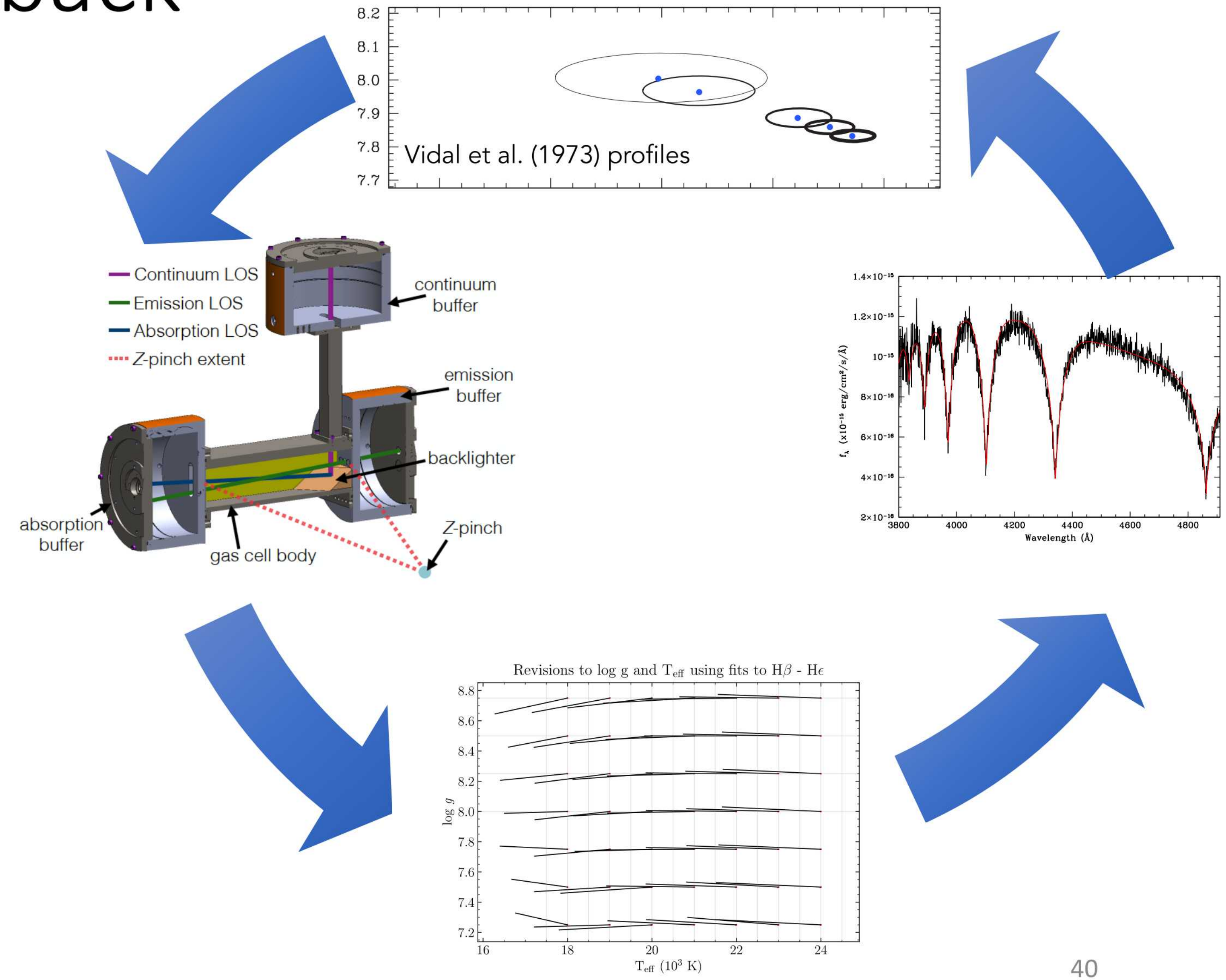


Hot DQ/Lab Plasma Comparison
z3404
SDSS J1153+0056
Normalized Intensity
Wavelength [Å]
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
4000
4200
4400
4600
4800
5000
5200
5400
Hot DQ Spectrum from the lab
Hot DQ Spectrum from MMT

Astrophysical Feedback

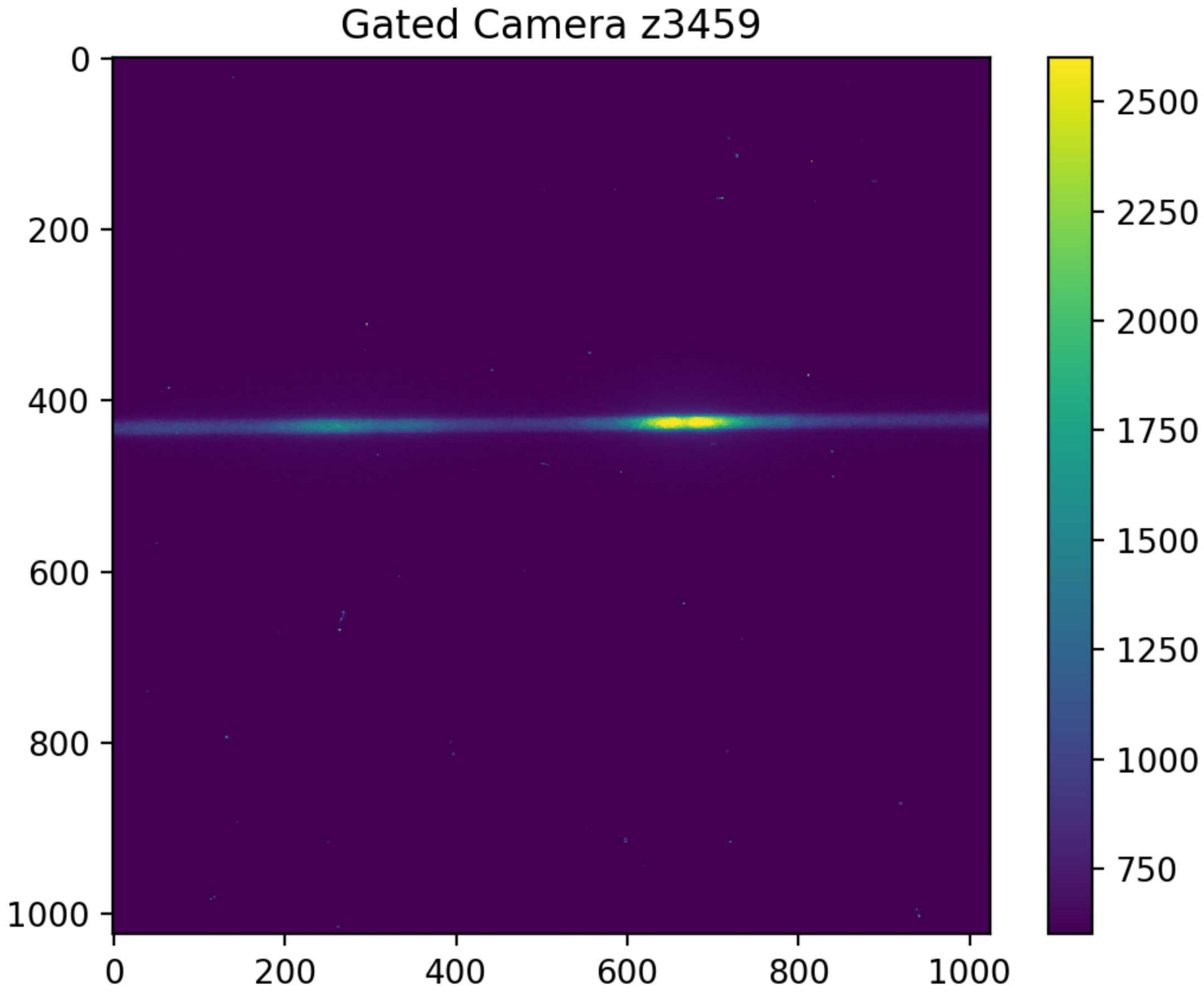
For our work to have quantitative implications for astrophysics, we have to take what we learn about single Te, ne plasmas on Z and incorporate this into a model white dwarf atmosphere.

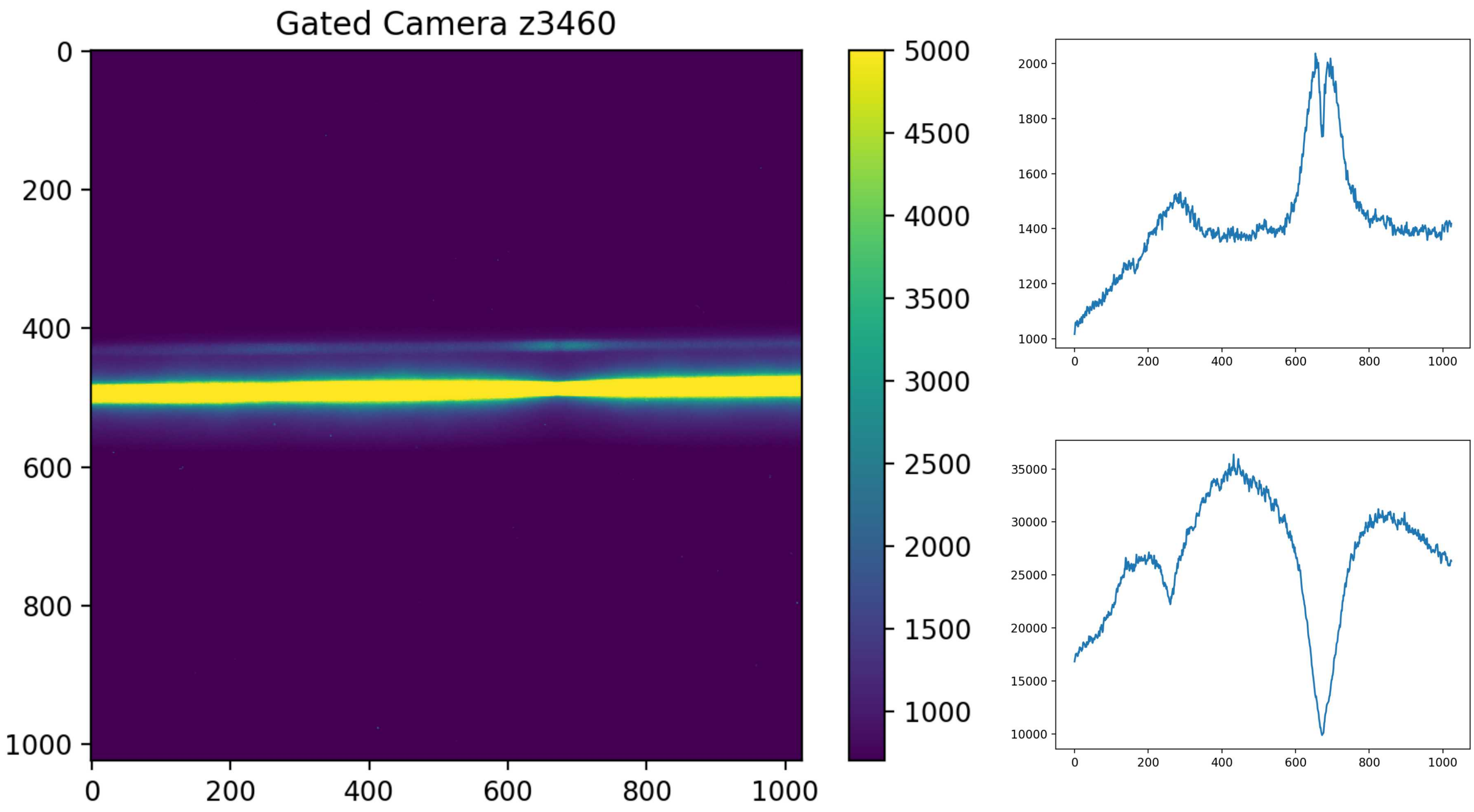
Patty Cho is leading an effort to insert new H Lyman and Balmer line profiles (from Xenomorph) into the model atmosphere code TLUSTY (I. Hubeny), and we're starting to explore the impact of these new model atmospheres on our inferences about white dwarf stars.

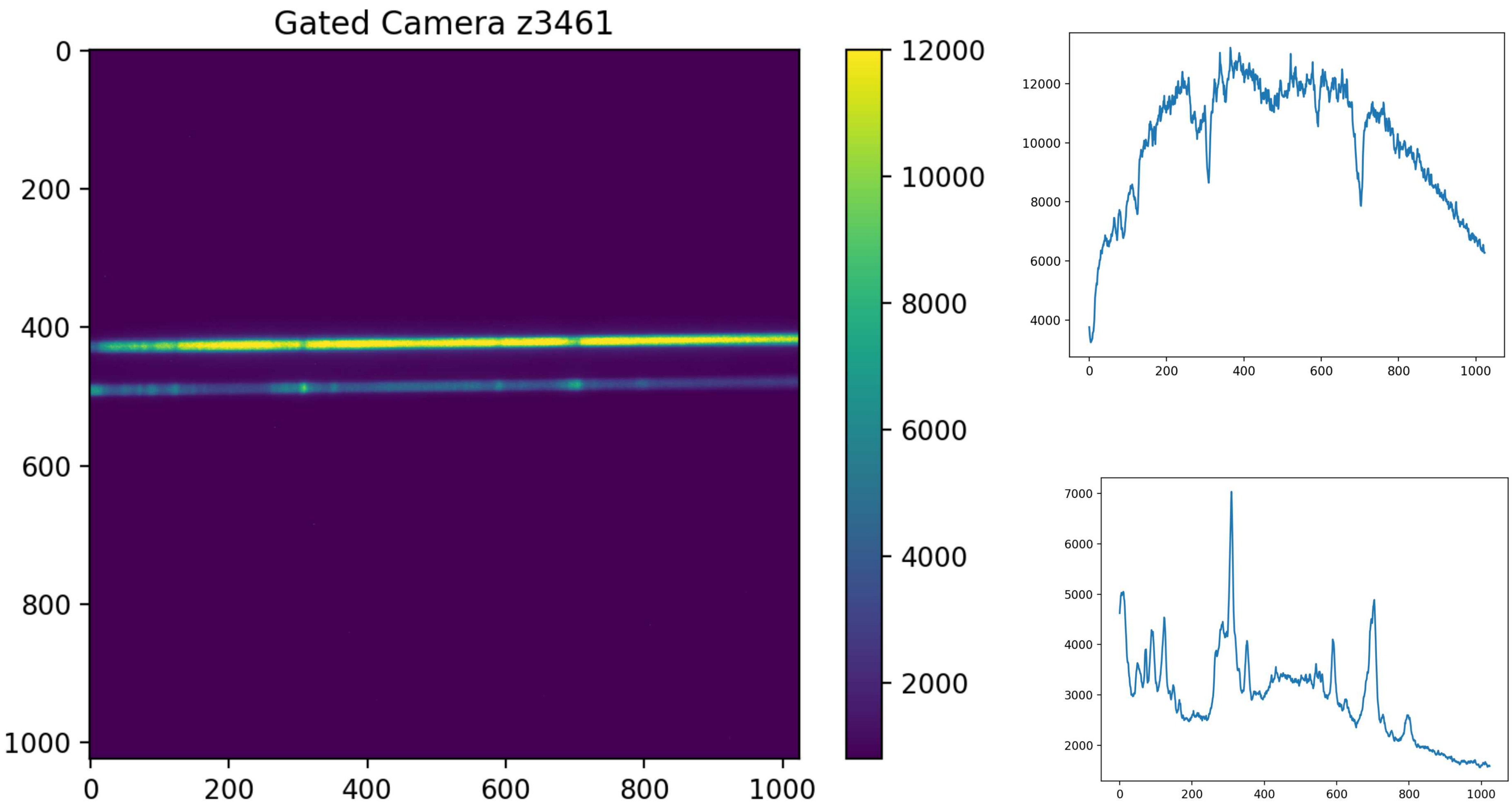


Extra Slides

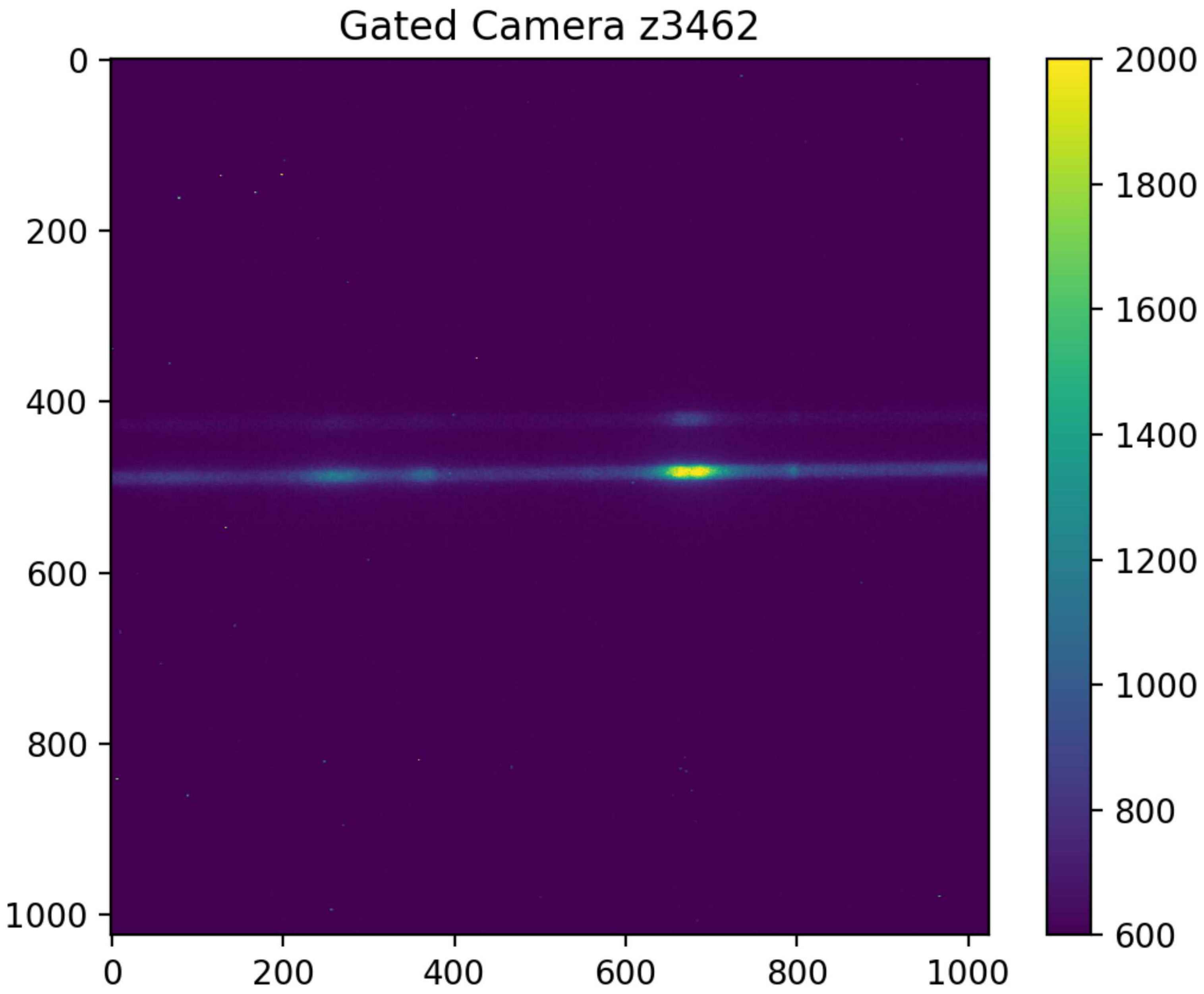
First Series to Field Gated Camera




Gated Camera z3460



Gated Camera z3461


Gated Camera z3462
0
200
400
600
800
1000
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200
400
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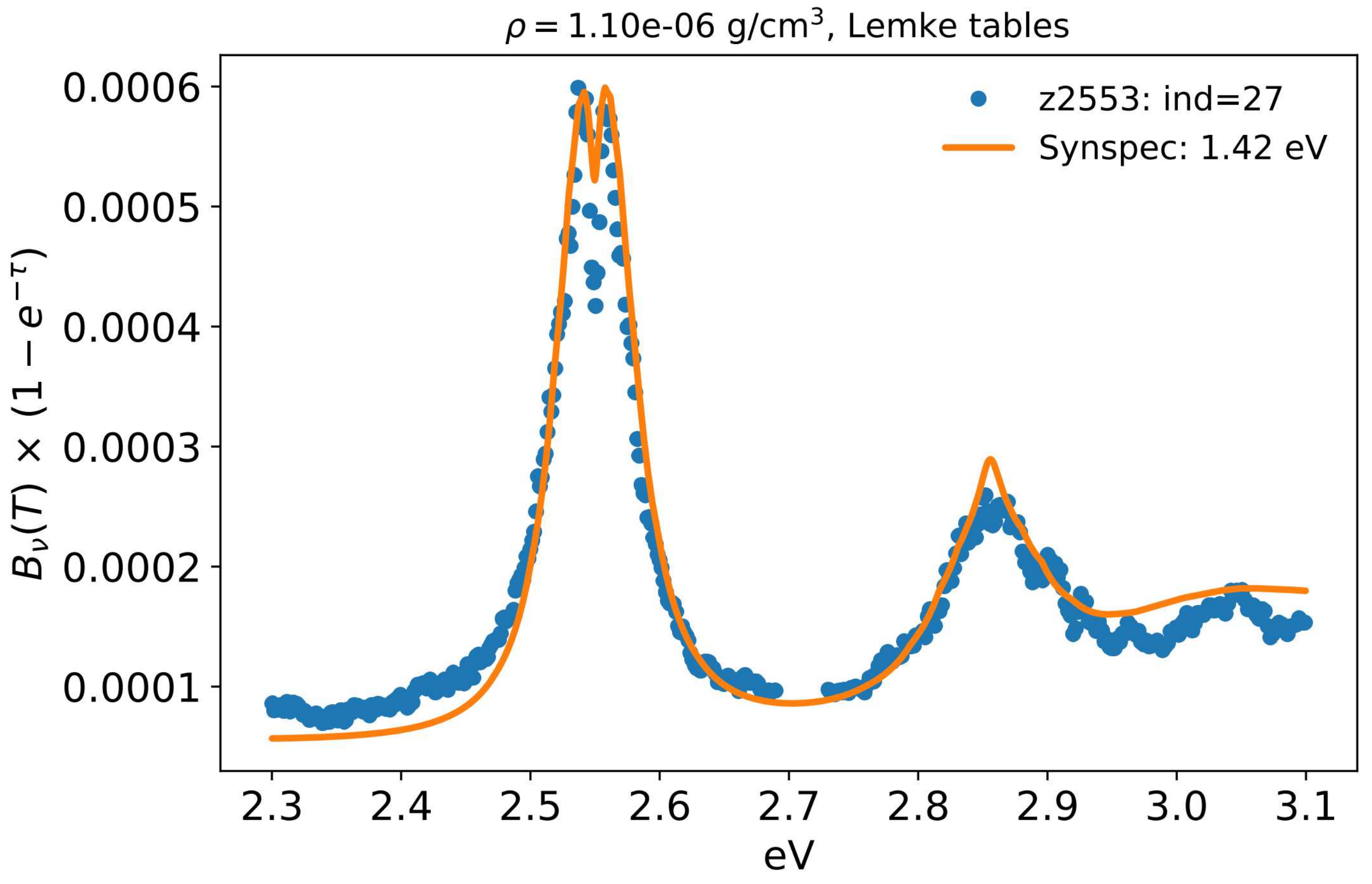
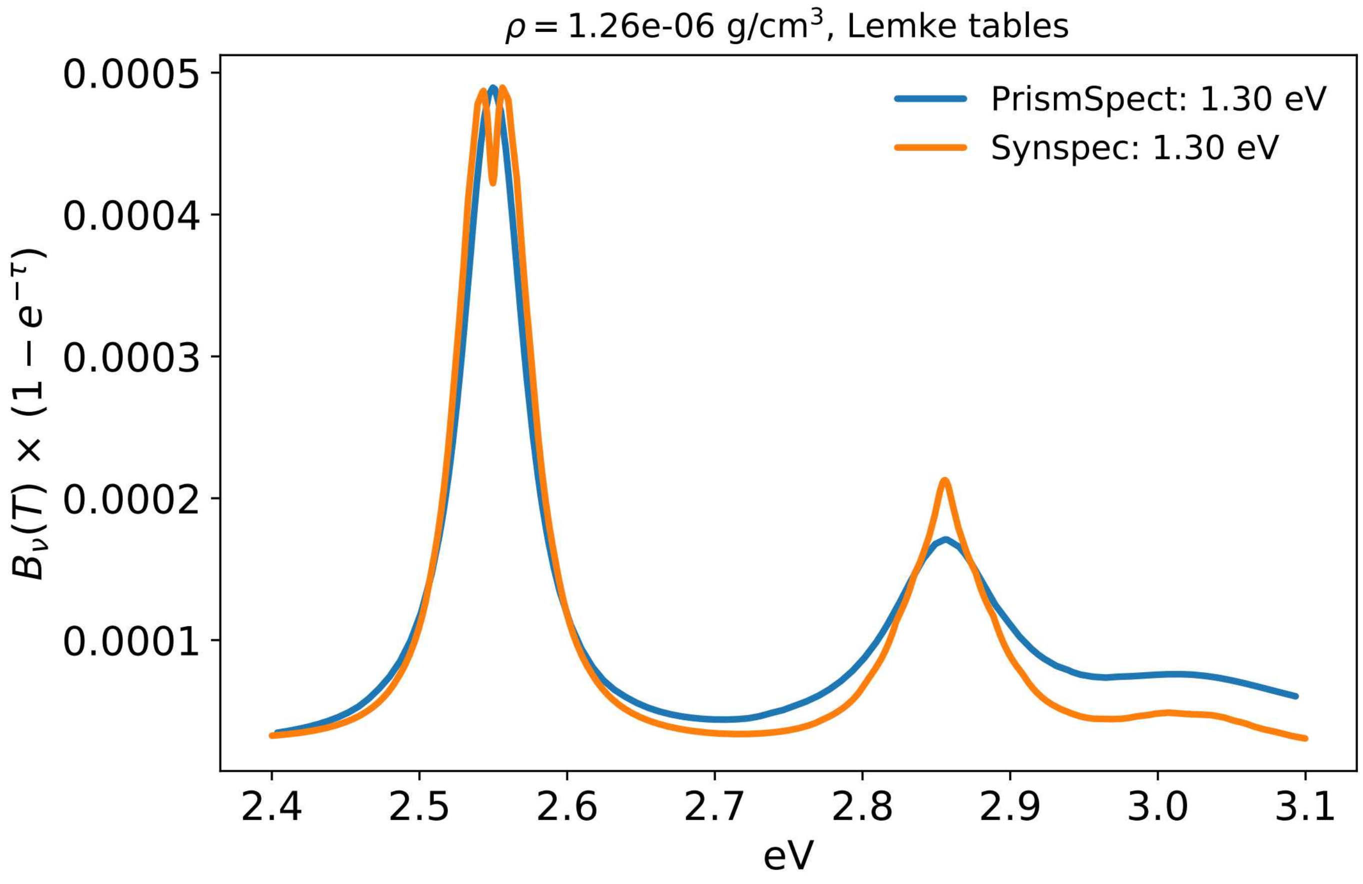
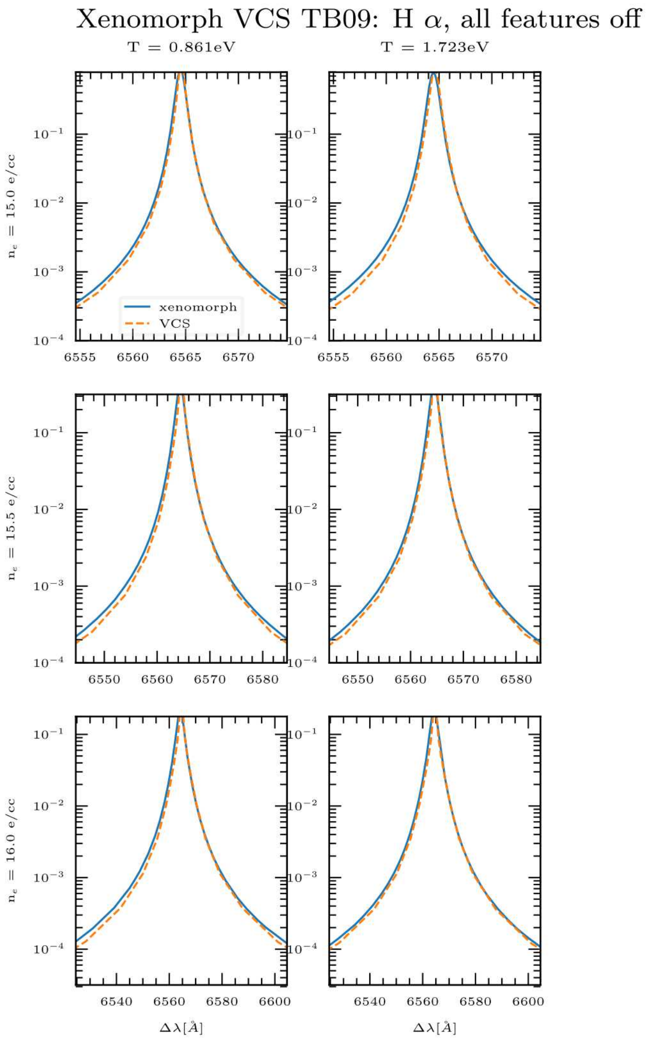
1000
2000
1800
1600
1400
1200
1000
800
600

Z2553 Hydrogen vs Synspec model



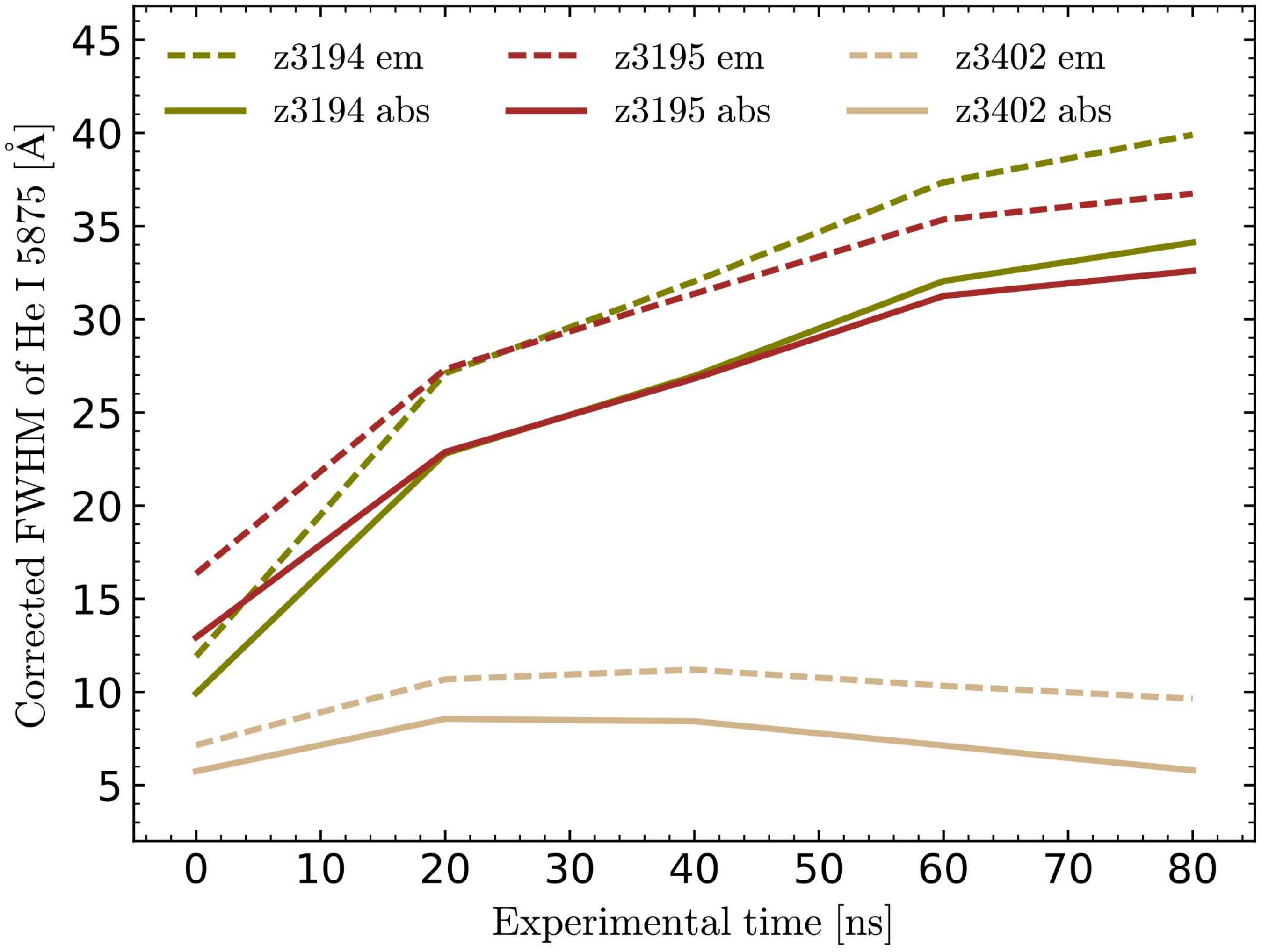
PrismSpect vs. Synspect Hydrogen





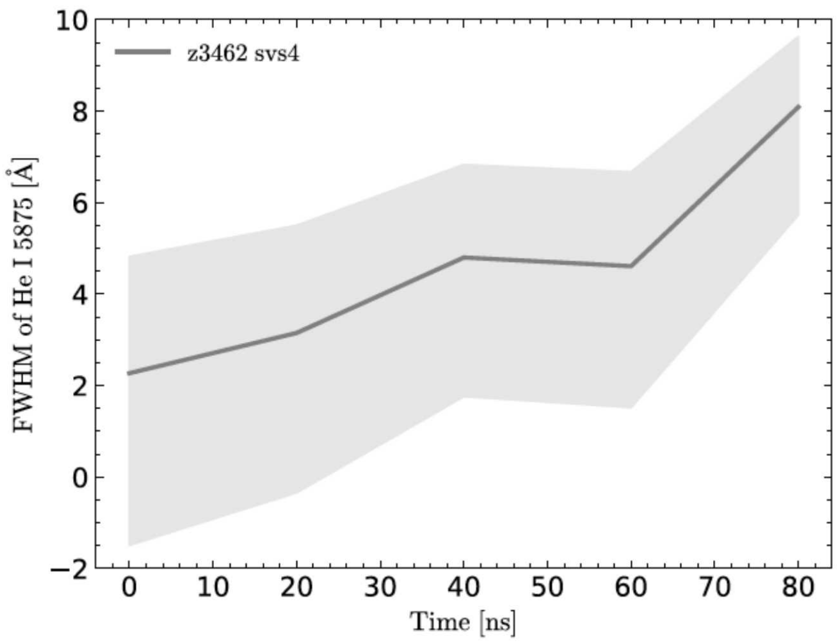
Xenomorph VCS TB09: H α, all features off
T = 0.861eV
T = 1.723eV
n_e = 15.0 e/cc
n_e = 15.5 e/cc
n_e = 16.0 e/cc
xenomorph
VCS
$\Delta\lambda[\mathring{A}]$
$\Delta\lambda[\mathring{A}]$

Lingering concern: what is the FWHM of the emission data?

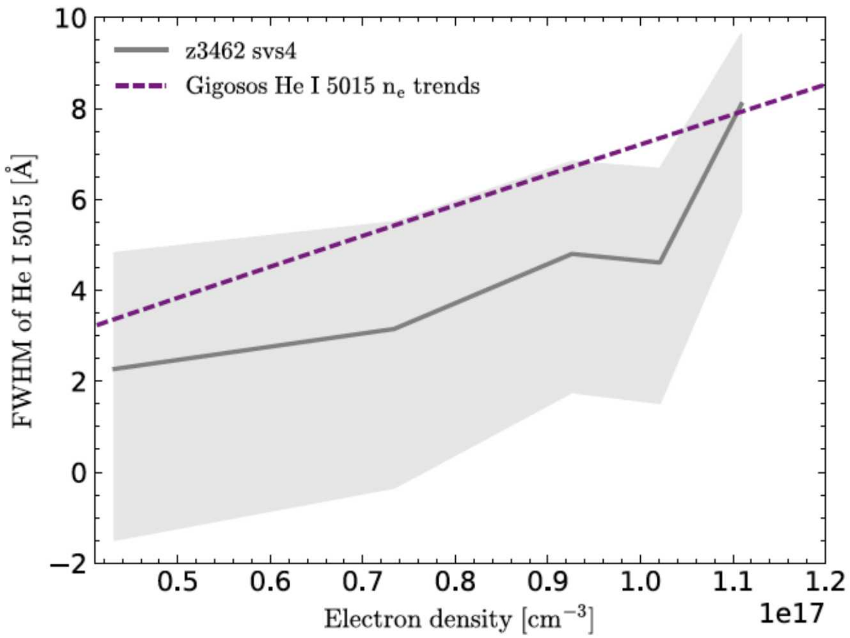


- The emission data has a higher FWHM than the absorption data.
- This is reminiscent of the hydrogen data.
- Further, this probably makes the results from the self-emission correction test even more conservative.

The He I 5015 line in z3462 svs4 – FWHM measurements



Measured FWHM vs experiment time



Measured FWHM vs electron density

The measured widths are ***lower*** than the predicted widths.

Summary of tests performed thus far

Test	Effects/Results
Data calibration	None on line width
Data distortion correction	None on line width
CCD background subtraction	Makes lines **wider**
Scattered light background subtraction	None on line width
Self-emission correction	None on line width
Using 5015/5875 population ratios to constrain plasma conditions	He I 5875/5015 seem to be formed in the same plasma – no evidence for Hβ being formed in a different plasma region
Analysis of pure He shots	Analysis inconclusive
Incorrect accounting for instrumental broadening	No significant effects on line width
Incorrect measurement for instrumental broadening	No significant effects on line widths
Analyze emission data	Emission data shows similar FWHM trends as absorption
Analyze spectra for potential He II signature	Very limited evidence for presence of He II