PLANETARY MATERIAL IN WHITE DWARF ATMOSPHERES

Simon Blouin

Banting and CITA National Fellow

University of Victoria, Canada

Z User Workshop, SNL

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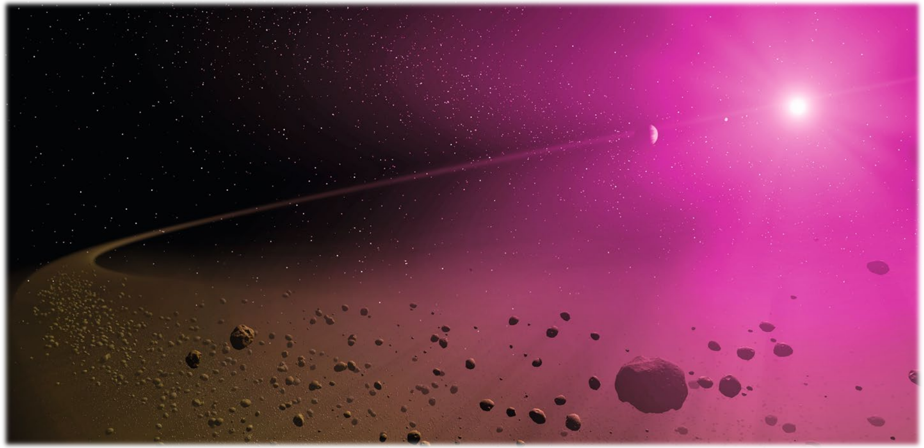


Credits: bild der wissenschaft

University of Victoria

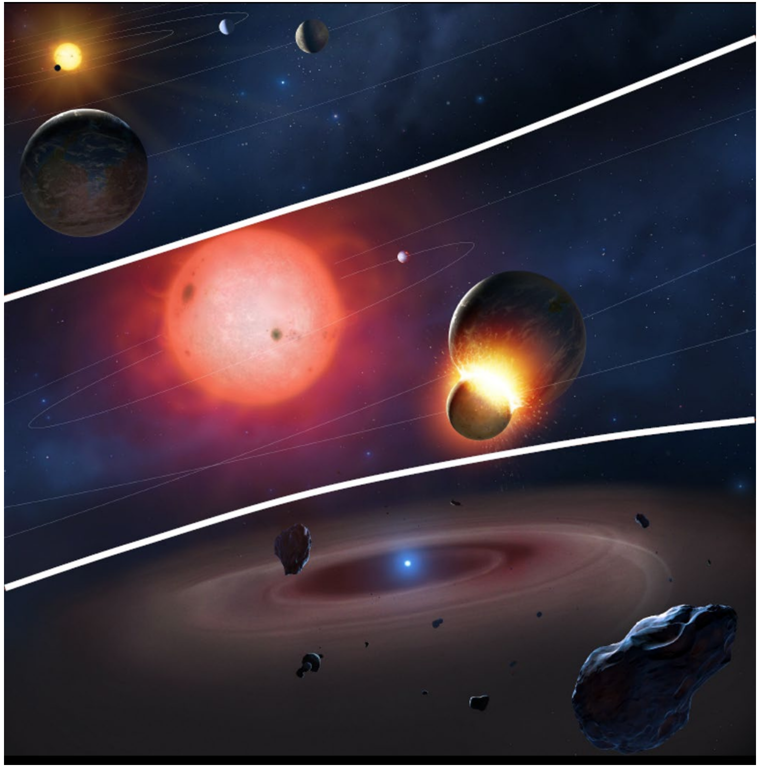
Bourses postdoctorales Banting Postdoctoral Fellowships

CITA | ICAT
Canadian Institute for Theoretical Astrophysics
L'institut Canadien d'astrophysique théorique

THE FATE OF EXOPLANETARY SYSTEMS

Planetary orbits are destabilized by mass-loss episodes during the late stages of stellar evolution

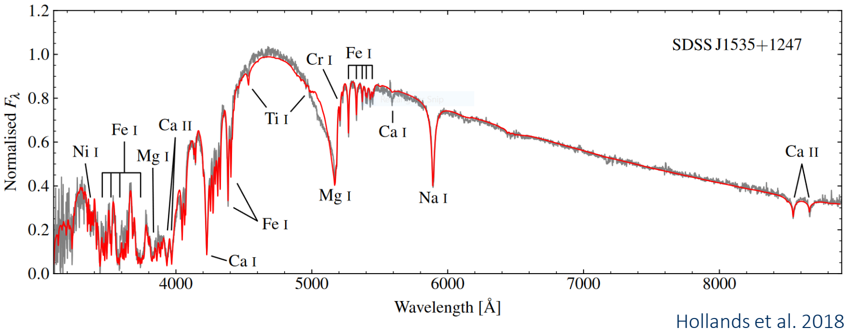
Comets, asteroids, and planets can venture close to their host WD, get torn apart by tidal forces, and accreted onto the WD



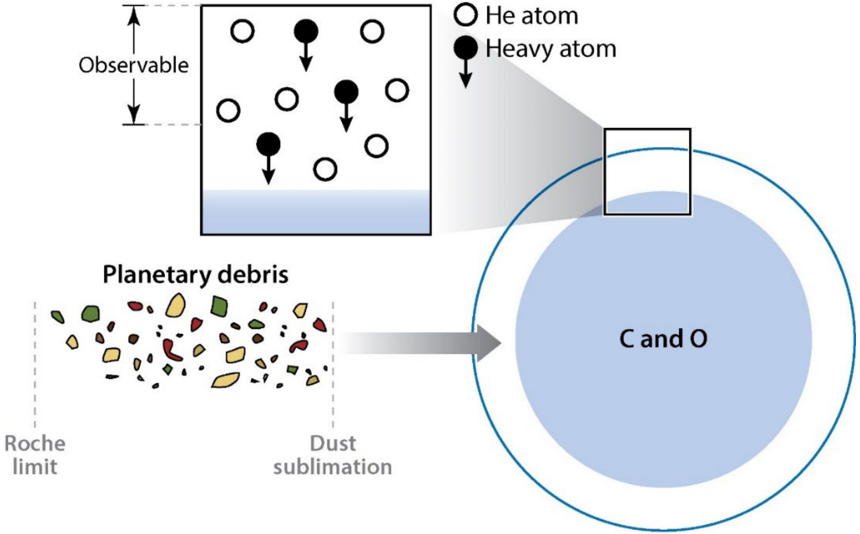
Credits: Warwick / Mark A. Garlick

25-50% OF WDs HAVE RECENTLY ACCRETED PLANETARY DEBRIS

This accretion “pollutes” the WD’s atmosphere and leaves a clear imprint on its spectrum

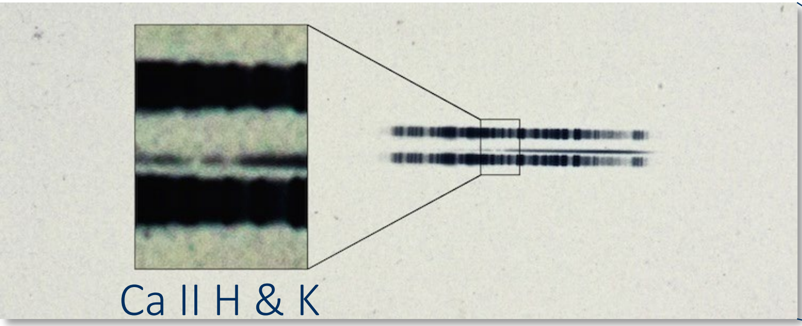


Hollands et al. 2018

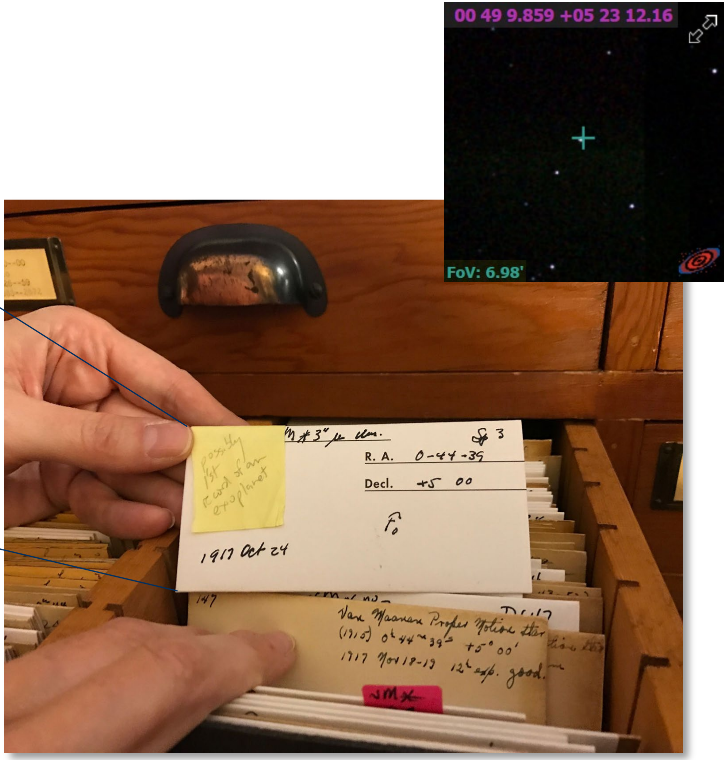


Jura & Young 2014

POLLUTED WDs = FIRST-EVER (OVERLOOKED) EVIDENCE OF THE EXISTENCE OF EXOPLANETS

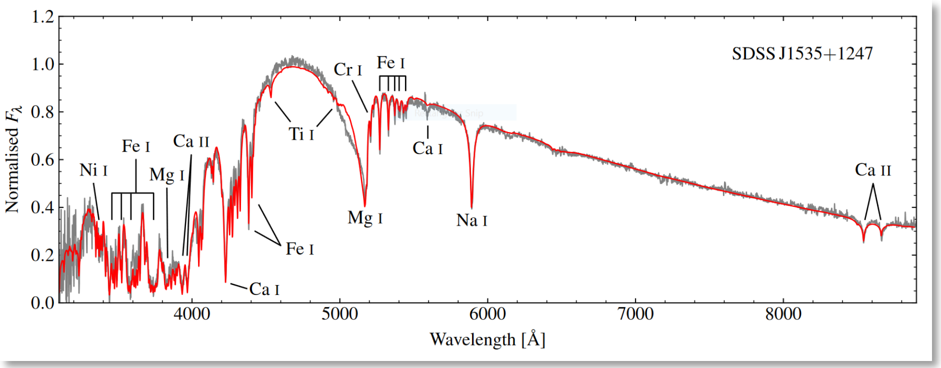


NASA/JPL-Caltech



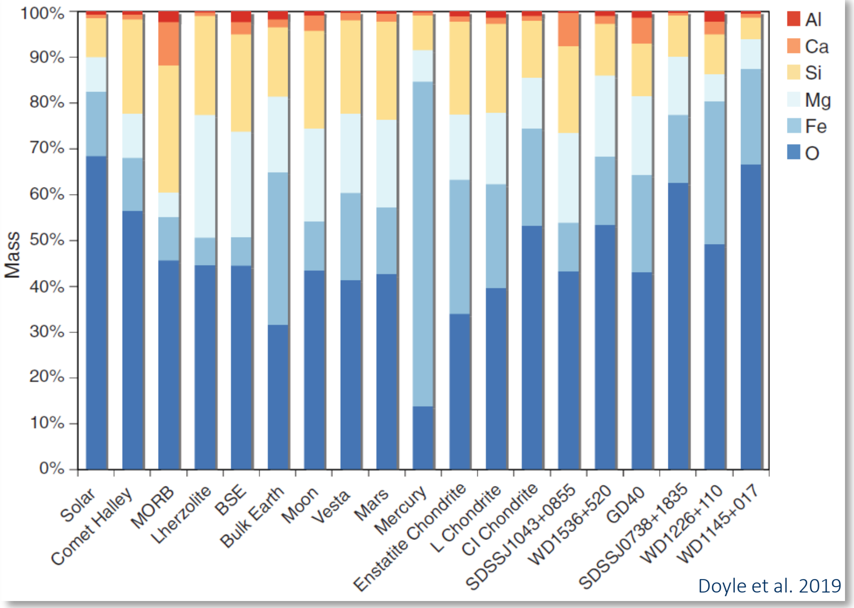
Carnegie

POLLUTED WDs REVEAL THE BULK COMPOSITION OF EXOPLANETESIMALS



Photospheric abundances

Planetesimal composition

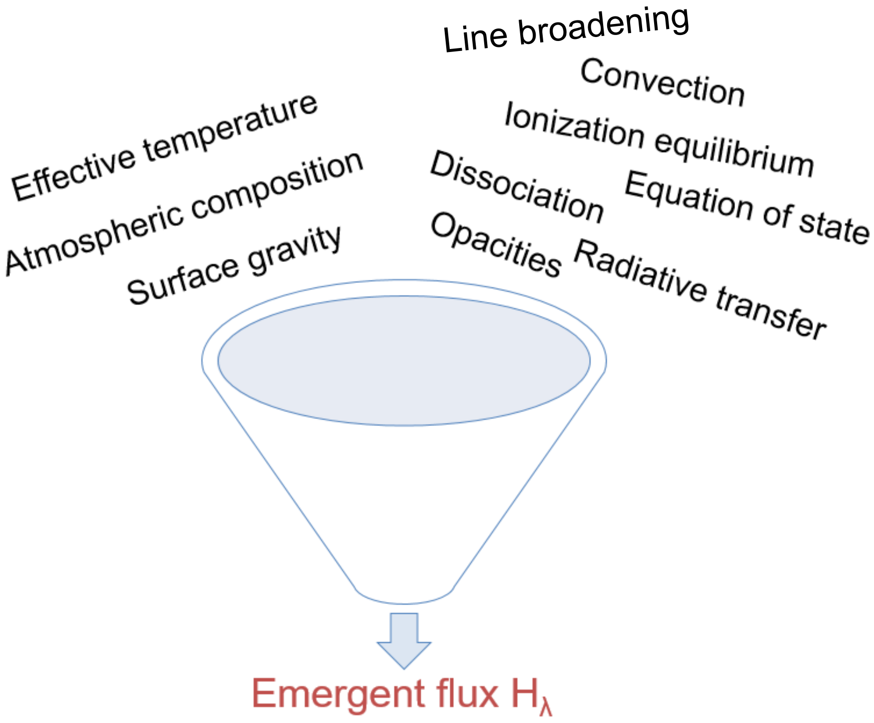


Doyle et al. 2019

THIS ANALYSIS REQUIRES RELIABLE PHYSICS MODELS OF WD ATMOSPHERES

WD atmosphere models depend on a lot of input physics

Abundance determinations are particularly sensitive to the spectral line shapes

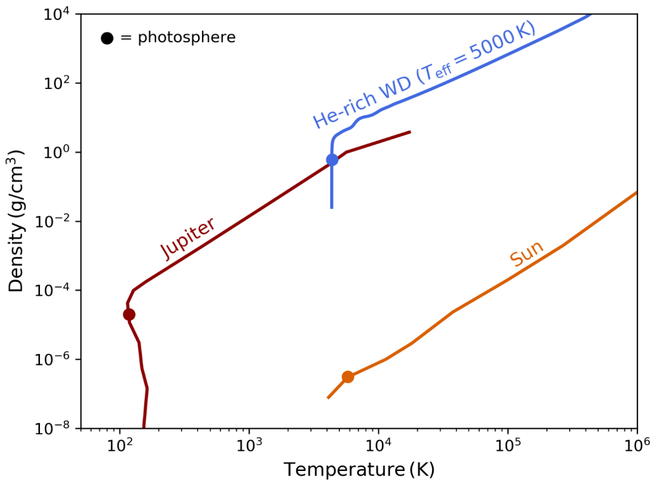


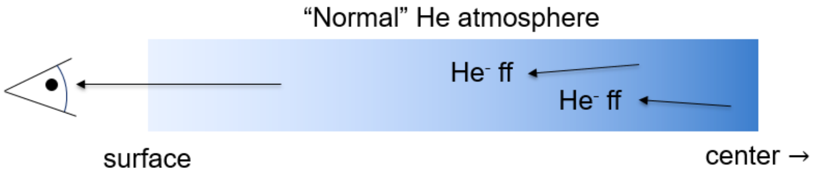
THE PECULIAR CONDITIONS OF COOL HELIUM-RICH WD ATMOSPHERES

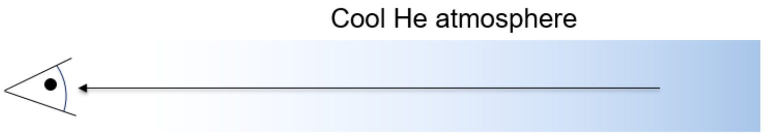
Cool He-rich atmospheres are interesting because

1. They belong to very old WDs and allow to probe the composition of planetary material much older than our Solar System
2. They are transparent and easily reveal metal pollution

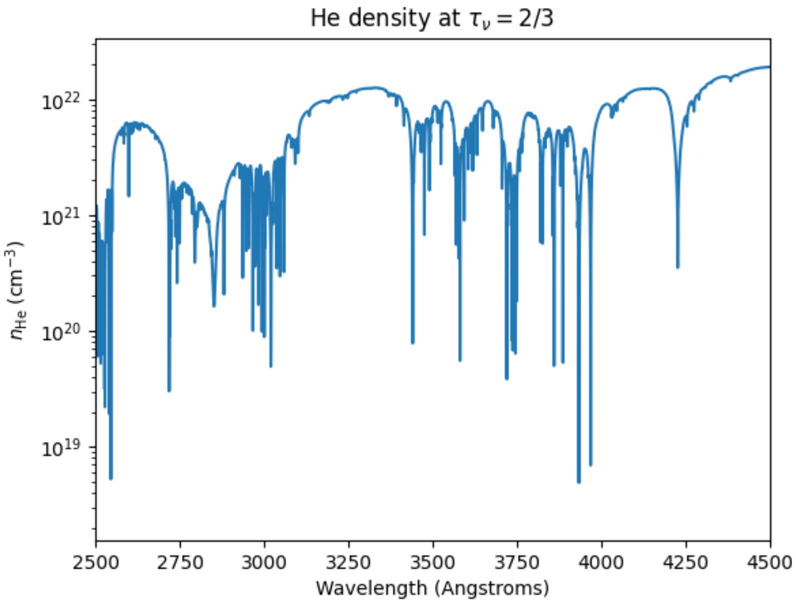
But they are challenging to model!



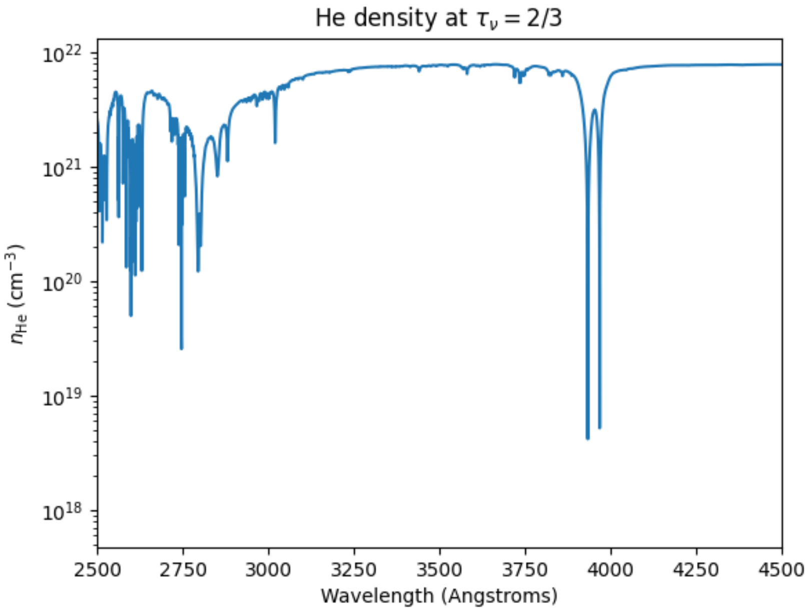




LINE-FORMING REGIONS IN COOL POLLUTED WDs



T_{eff} = 5000K, log g = 8, log Ca/He = -9.5, log H/He = -5



T_{eff} = 7000K, log g = 8, log Ca/He = -9.5, log H/He = -5

LINE BROADENING IN COOL WD ATMOSPHERES

Broadening dominated by neutral interactions with He atoms, with n_{He} above ~10^{20} cm^{-3}

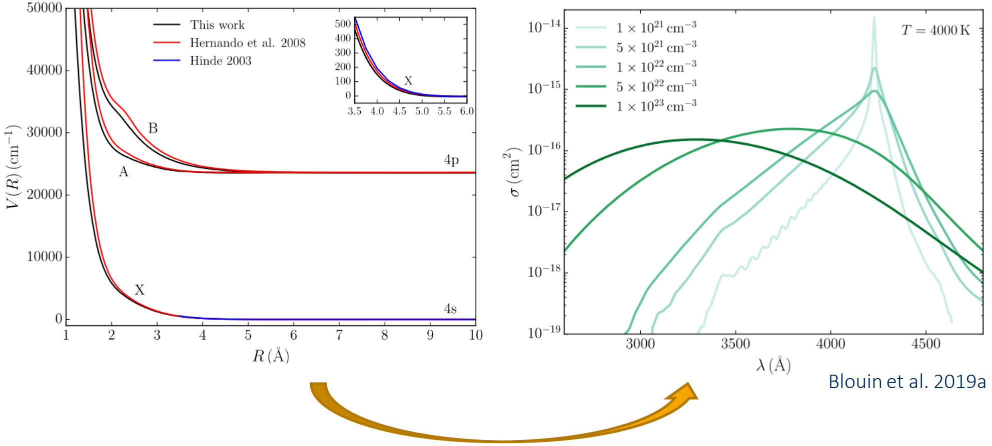
Impact approximation not applicable

A “unified theory” (Allard et al. 1999) is used to calculate line shapes given the interaction and the radiative transition moments of relevant states of the radiating atom with other atoms in its environment

$$I(\omega) = \frac{1}{\pi} Re \int_0^{+\infty} \Phi(s) e^{-i\omega s} ds \qquad \Phi(s) = e^{-n_p g(s)}$$

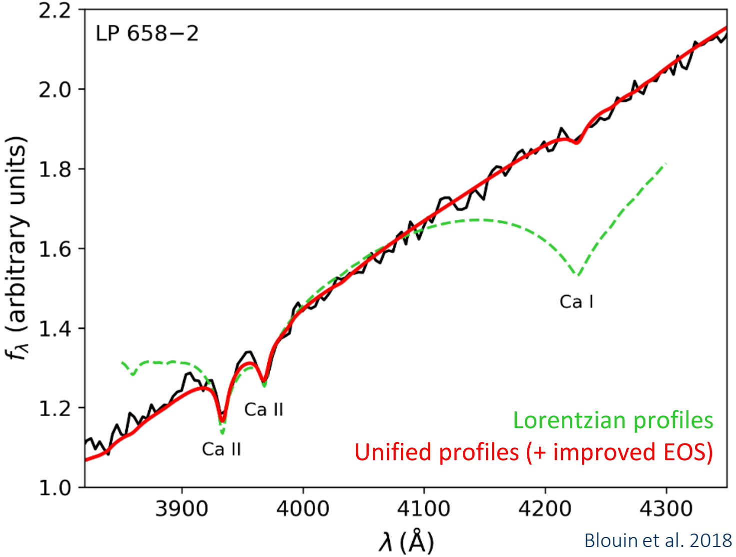
$$g_\alpha(s) = \frac{1}{\sum_{e,e'}^{(\alpha)} |d_{ee'}|^2} \sum_{e,e'}^{(\alpha)} \int_0^{+\infty} 2\pi\rho d\rho \qquad R(t) = \left[\rho^2 + (x+\bar{v}t)^2\right]^{1/2}$$

$$\times \int_{-\infty}^{+\infty} dx\, \tilde{d}_{ee'}[R(0)] \left[e^{\frac{i}{\hbar}\int_0^s dt\, V_{e'e}[R(t)]}\, \tilde{d}^*{}_{ee'}[R(s)] - \tilde{d}_{ee'}[R(0)]\right].$$

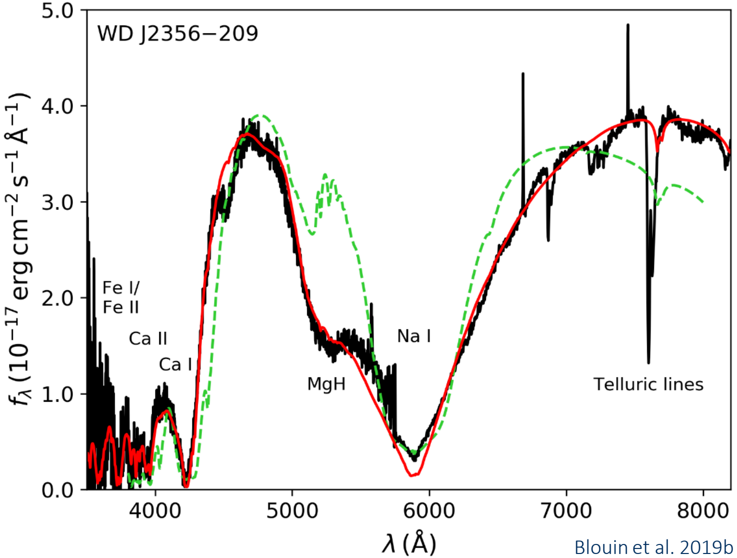


Blouin et al. 2019a

RECENT SUCCESSES



Blouin et al. 2018



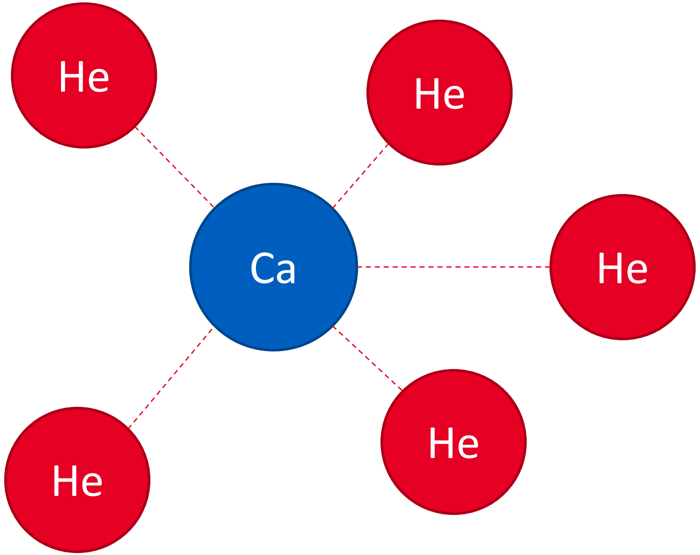
Blouin et al. 2019b

CURRENT CHALLENGES AND OPPORTUNITIES

1. No “at-parameter” experimental validation: experiments typically conducted at much lower temperatures

CURRENT CHALLENGES AND OPPORTUNITIES

2. Unified theory not applicable when higher-order correlations between the perturbers are important (assumes "infinite-dilution" pair potentials)



CURRENT CHALLENGES AND OPPORTUNITIES

3. “Fudge factors” are sometimes used to get a good match to the observed line shape. This is dangerous! This may reflect inaccuracies with the line profiles, or not.

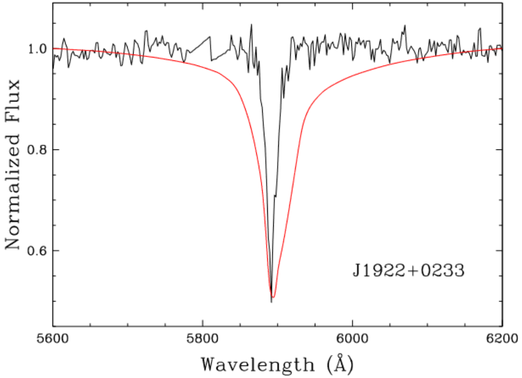
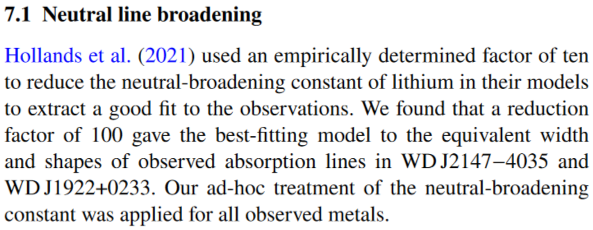


Figure 11. Na D region of J1922+0233. The atmospheric parameters are set to the values given in Figure 10, and the Na abundance of the synthetic spectrum is adjusted ($\log\ \mathrm{Na/He} = -9.7$) to match the depth of the observed Na D doublet. We find that the inferred He-rich composition leads to too much broadening of the Na D doublet.

Bergeron et al. 2022



7.1 Neutral line broadening

Hollands et al. (2021) used an empirically determined factor of ten to reduce the neutral-broadening constant of lithium in their models to extract a good fit to the observations. We found that a reduction factor of 100 gave the best-fitting model to the equivalent width and shapes of observed absorption lines in WD J2147−4035 and WD J1922+0233. Our ad-hoc treatment of the neutral-broadening constant was applied for all observed metals.

Elms et al. 2022

SUMMARY

Accurate mid-Z element line profiles at n_{He} above ~10^{20} cm^{-3} and T around 5000 K are needed to reliably measure the bulk composition of ancient planetary bodies accreted by old white dwarfs

The current theoretical framework generally works well, but not always

Experimental anchors would be extremely beneficial, but the densities we need to reach are fairly high

CfA/Mark A. Garlick

SUPPLEMENTARY MATERIAL: T-RHO PROFILES