

White dwarf cooling: electron-phonon coupling and the metallization of solid helium

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5 June 2013

Outline

White dwarfs overview

Theoretical background

Results

Conclusions

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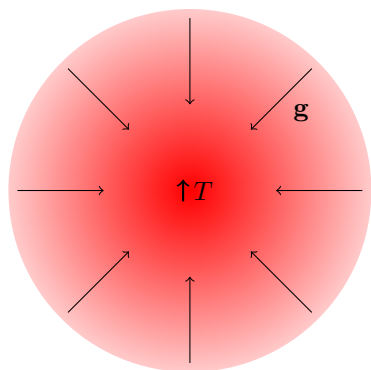
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Star formation

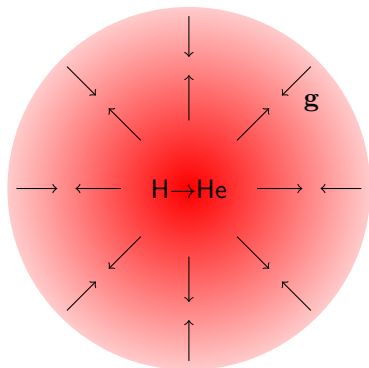


- ▶ Virial theorem: $K = -1/2 V_g$.
- ▶ Energy expressions:

$$K \propto Nk_B T \quad \text{and} \quad V_g \propto -\frac{GM^2}{R}$$

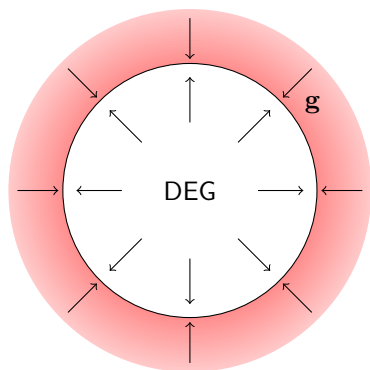
- ▶ Temperature **increases** as the star gravitationally **collapses**.

Main sequence star



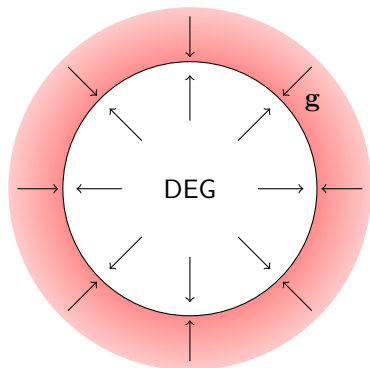
- ▶ Thermonuclear reactions: hydrogen burning.
- ▶ Gravitation balanced by nuclear reactions.
- ▶ Main sequence star (e.g. the Sun).

White dwarf formation



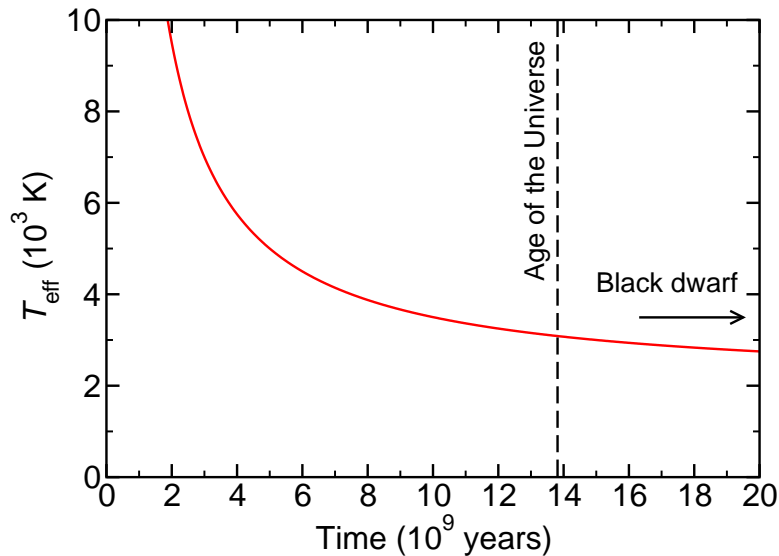
- ▶ Burning material exhausted.
- ▶ Gravitational contraction resumes.
- ▶ High density leads to degenerate electron gas (DEG).
- ▶ White dwarf star balanced by DEG.
- ▶ Complications: mass loss (red giant), further burning cycles, ...

White dwarf structure

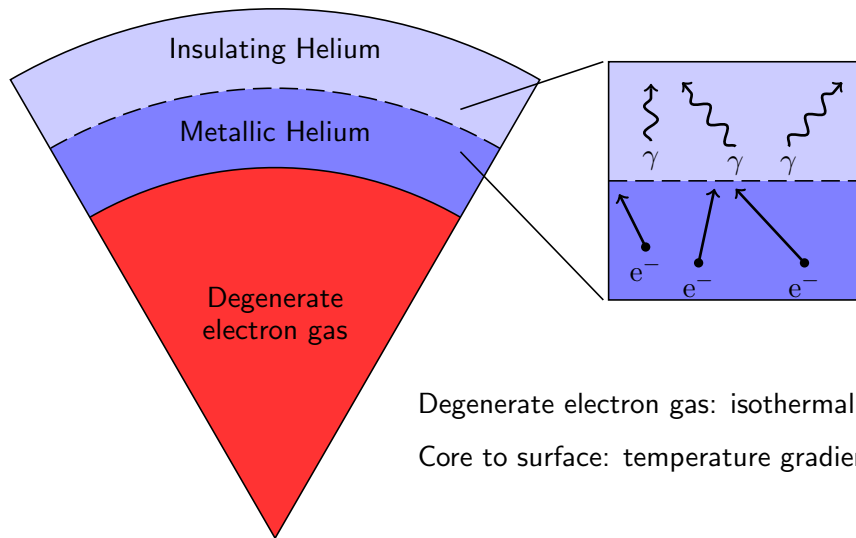


- ▶ Degenerate core: He or C/O.
- ▶ Atmosphere: H, He and traces of other elements.
- ▶ Atmosphere represents $10^{-4} - 10^{-2}$ of the total mass.
- ▶ Weak energy sources: crystallization, ...
- ▶ Energy transport: conduction, radiation and convection.

White dwarf cooling



White dwarf cooling: metallization of solid helium



Degenerate electron gas: isothermal

Core to surface: temperature gradient

Metallization pressure

- ▶ DFT: 17 TPa at all temperatures.
- ▶ DMC and *GW*: 25.7 TPa at all temperatures.
- ▶ Electron-phonon coupling: ?

DMC and *GW* from PRL **101**, 106407 (2008)

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- ▶ Principal axes approximation to the BO energy surface:

$$V(\mathbf{Q}) = V(\mathbf{0}) + \sum_{\mathbf{k},s} V_{\mathbf{k}s}(q_{\mathbf{k}s}) + \frac{1}{2} \sum_{\mathbf{k},s} \sum_{\mathbf{k}',s'}' V_{\mathbf{k}s;\mathbf{k}'s'}(q_{\mathbf{k}s}, q_{\mathbf{k}'s'}) + \dots$$

- ▶ Vibrational self-consistent field method.
- ▶ Phonon expectation values:

$$\langle \hat{O}(\mathbf{Q}) \rangle_{\Phi,\beta} = \frac{1}{Z} \sum_{\mathbf{S}} \langle \Phi^{\mathbf{S}}(\mathbf{Q}) | \hat{O}(\mathbf{Q}) | \Phi^{\mathbf{S}}(\mathbf{Q}) \rangle e^{-\beta E_{\mathbf{S}}}.$$

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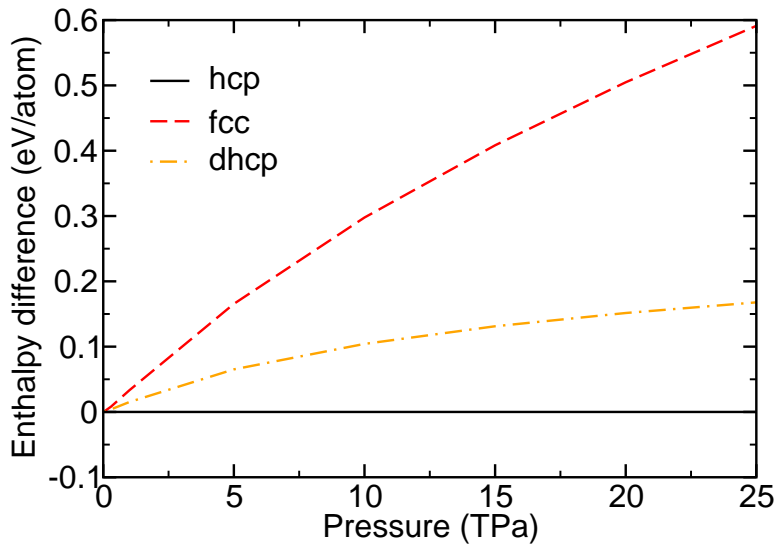
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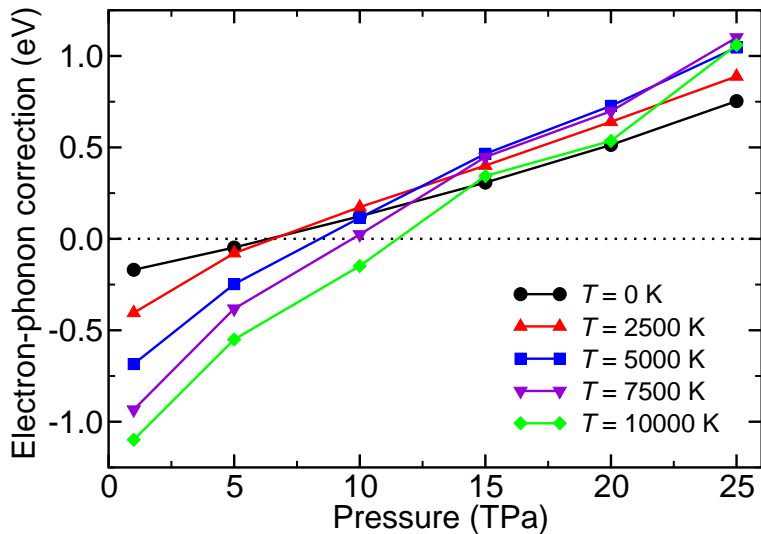
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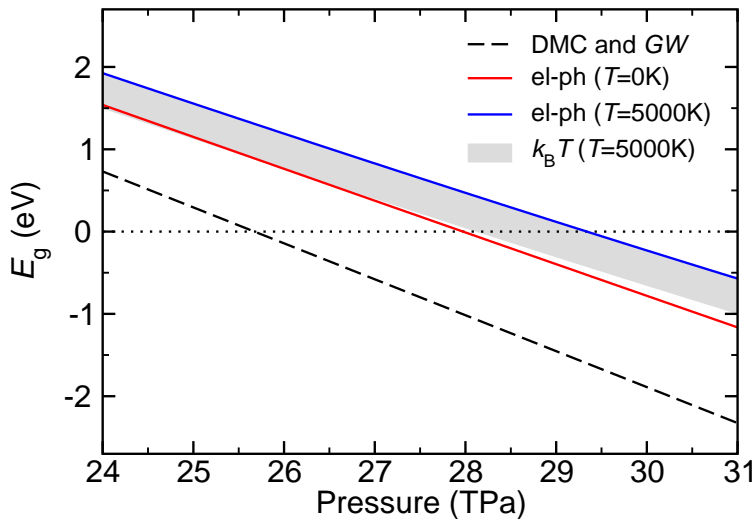
Solid helium stable phase



Solid helium electron-phonon gap correction

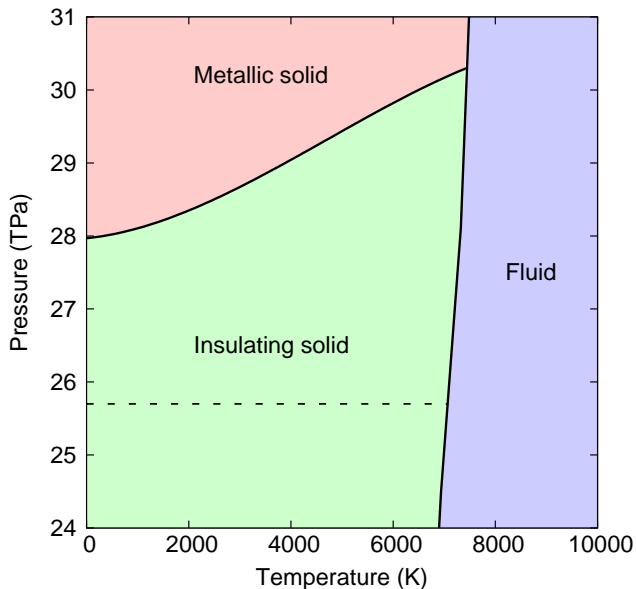


Solid helium metallization pressure



DMC and GW from PRL **101**, 106407 (2008)

Helium phase diagram revisited



White dwarf cooling revisited: metallization of solid helium

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- ▶ Summary:
 - ▶ Theory for anharmonic vibrational energy of solids.
 - ▶ General framework for phonon-dependent expectation values.
 - ▶ Metallization of solid helium.
 - ▶ White dwarf energy transport and cooling.

- ▶ Outlook:
 - ▶ Low pressure solid helium.

▶ Acknowledgements:

- ▶ Prof Richard J. Needs
- ▶ Dr Neil D. Drummond
- ▶ TCM group
- ▶ EPSRC

▶ References:

- ▶ B. Monserrat, N.D. Drummond, R.J. Needs
Physical Review B **87**, 144302 (2013)