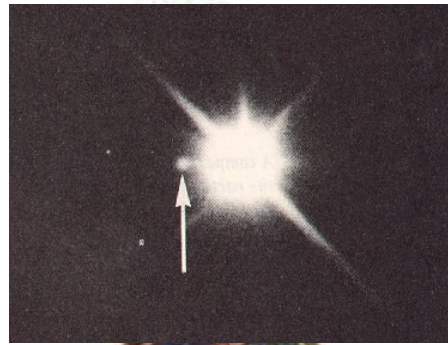


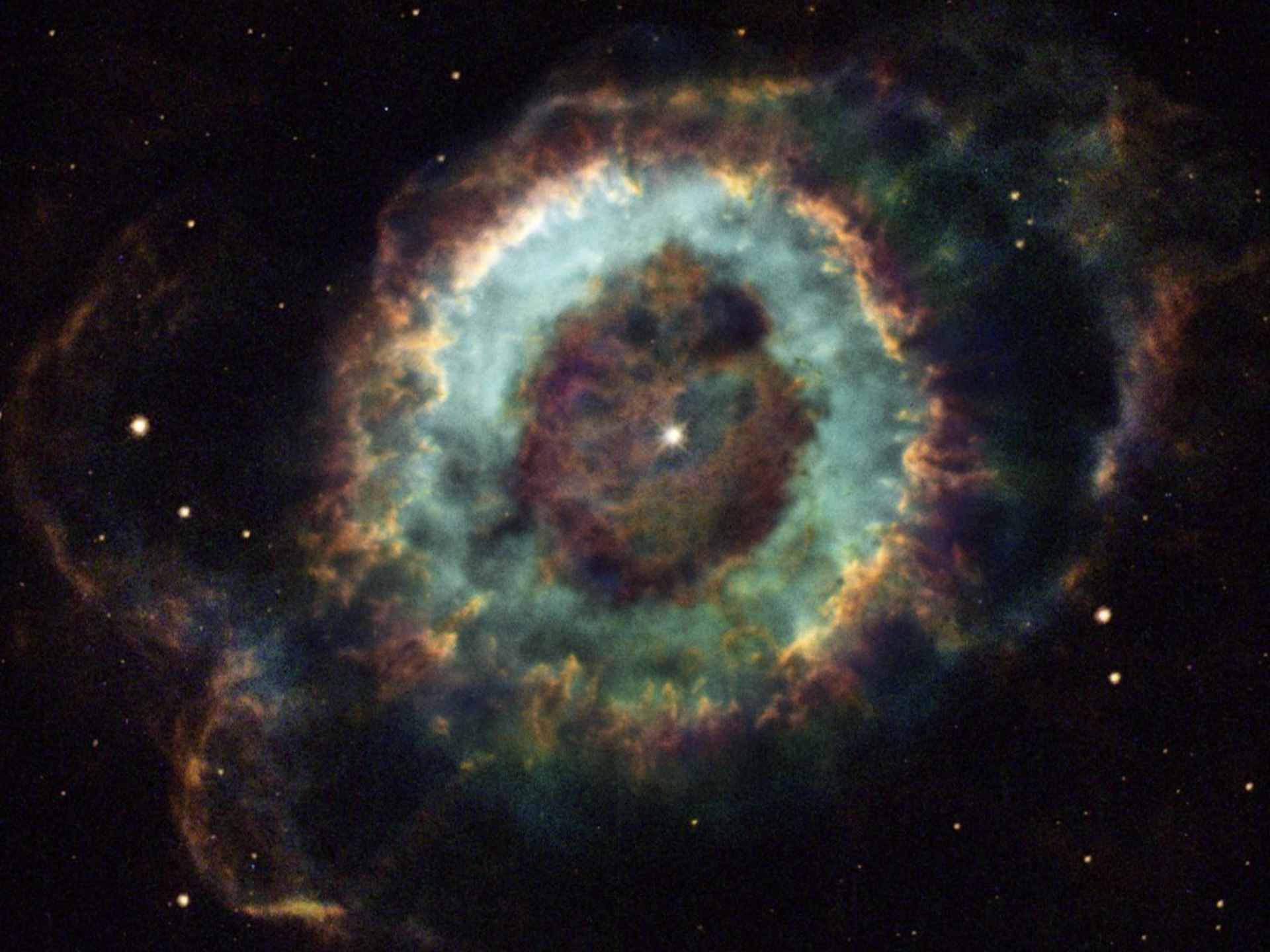
# The Many Faces of White Dwarfs



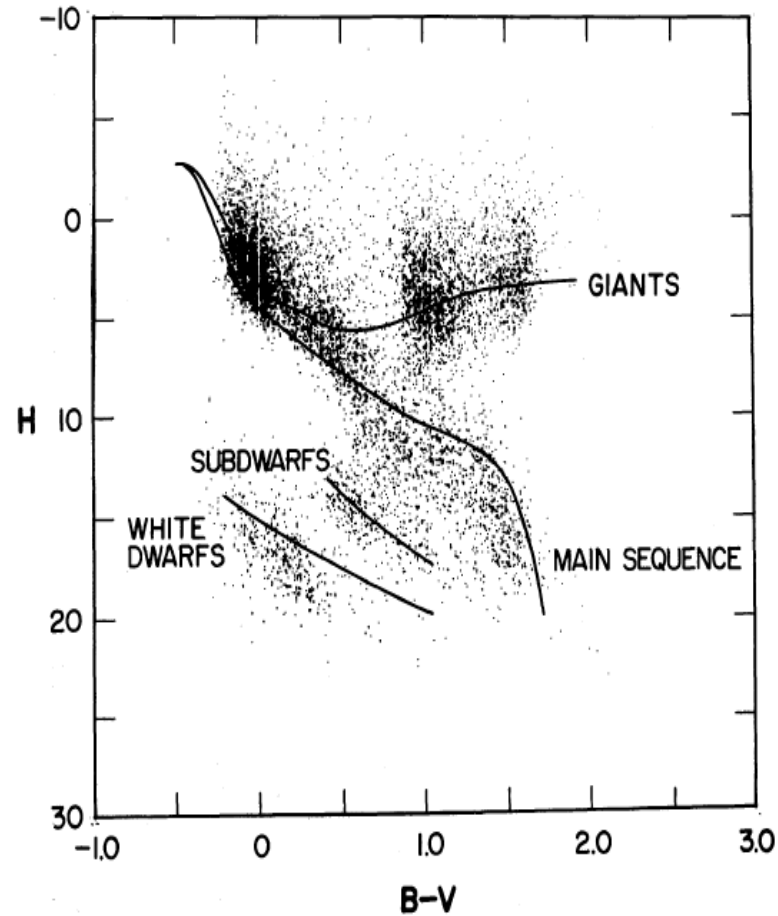
Eugene Yu-Yu Chen  
UCLA Department of Physics and  
Astronomy

# What is a White Dwarf Star?

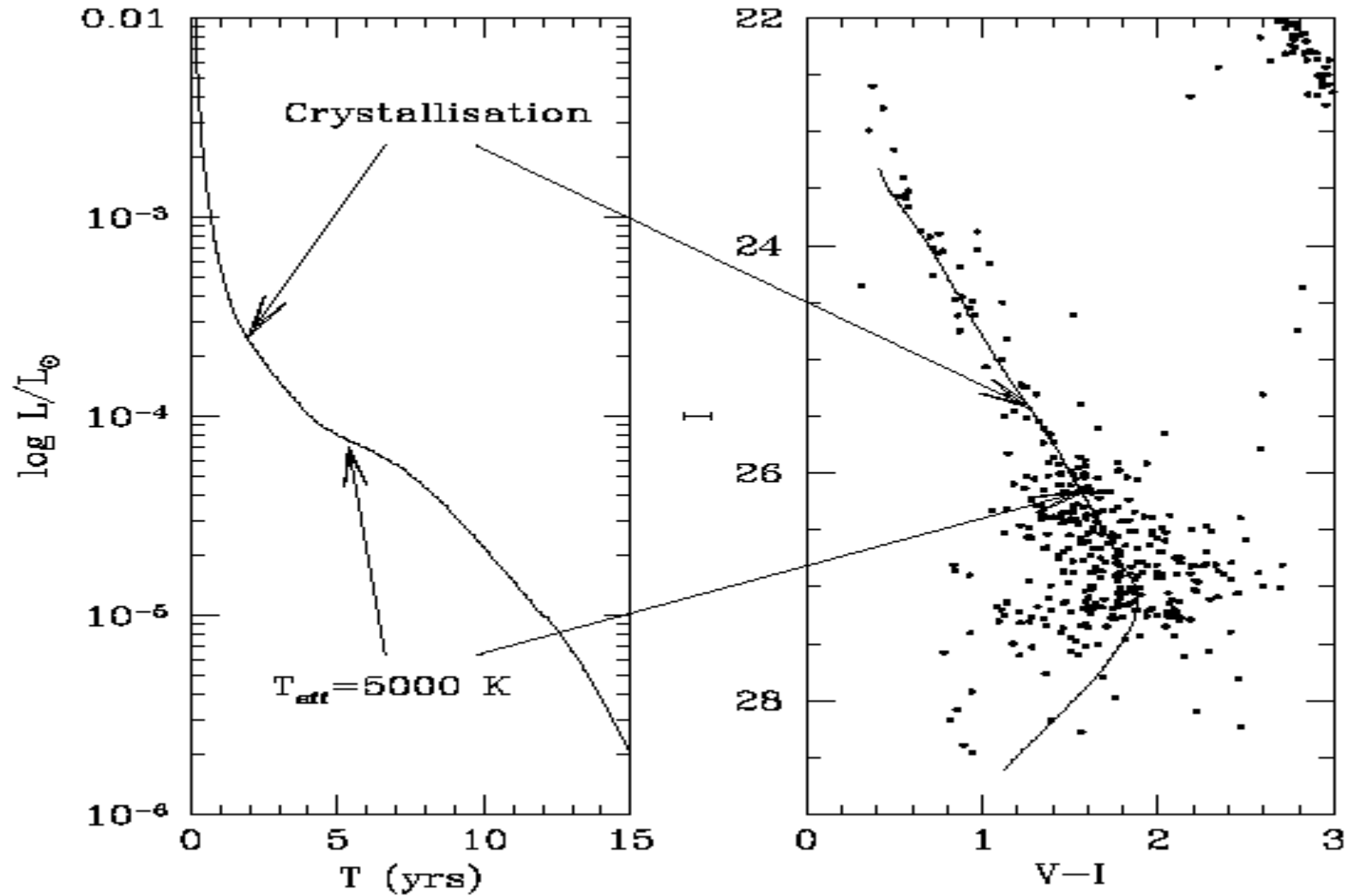
- Endpoint of stellar evolution for low mass stars (  $< 6\sim 8M_{\text{solar}}$  ).
- Degenerate C/O core covered by non-degenerate atmosphere.
- 97% of the stars in our galaxy will end up in this state.



# WD as a sequence in HR diagram



WDs trace out the sequence as time pass...



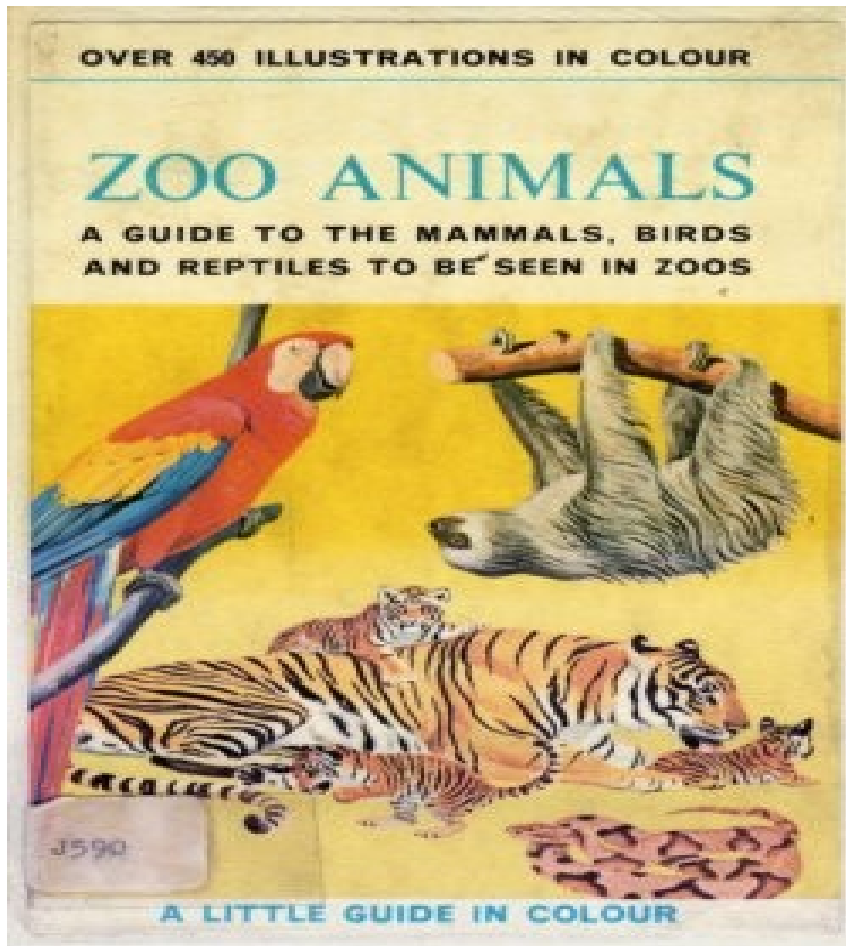
# What do I mean by “The Face” of a White Dwarf Star

## DEFINITION OF PRIMARY SYMBOLS: PRIMARY SPECTRAL

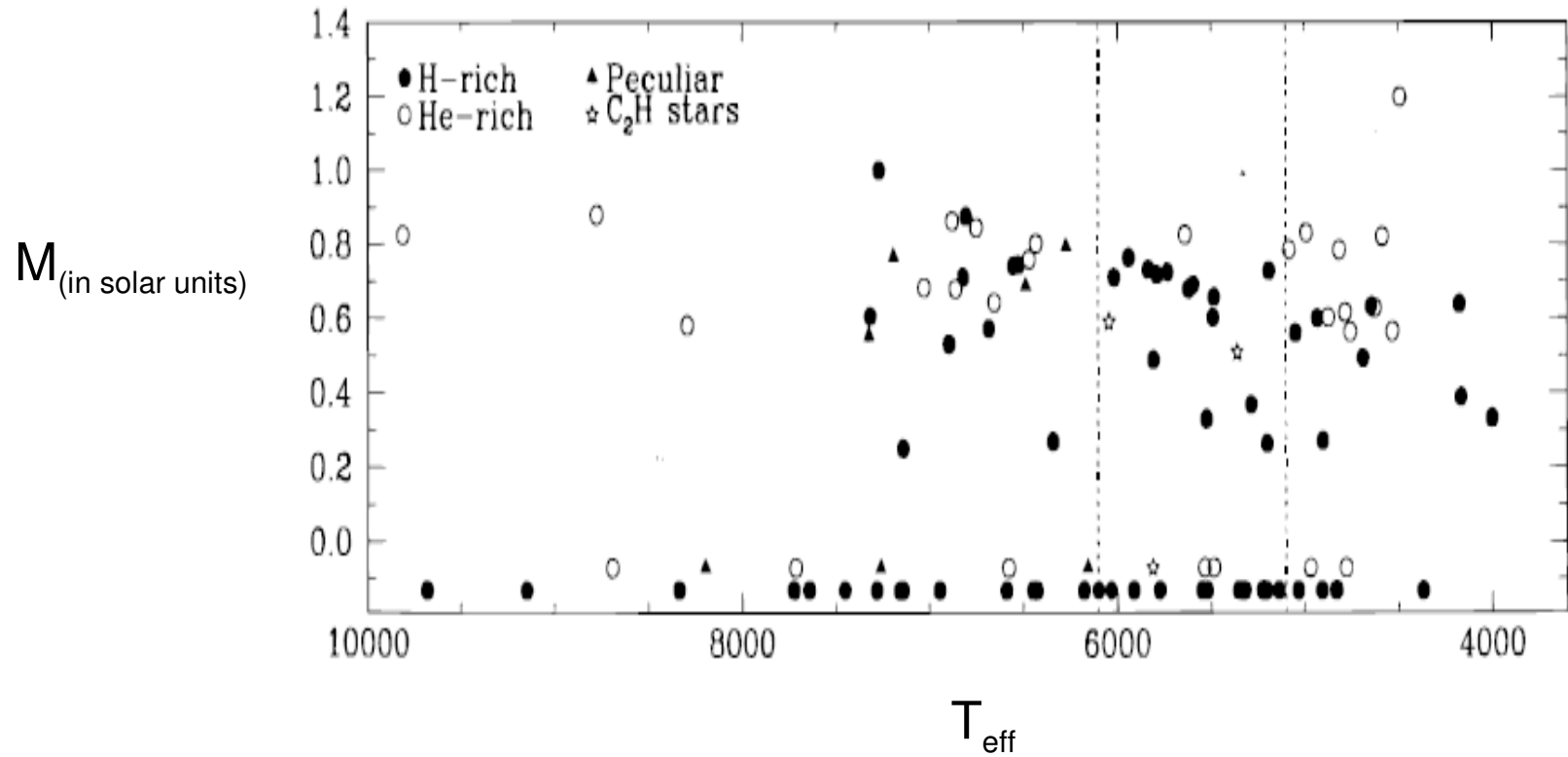
Spectral Type	Characteristics
75% DA .....	Only Balmer lines; no He I or metals present
20% DB .....	He I lines; no H or metals present
DC .....	Continuous spectrum, no lines deeper than 5% in any part of the electromagnetic spectrum
DO .....	He II strong; He I or H present
DZ .....	Metal lines only; no H or He
DQ .....	Carbon features, either atomic or molecular, in any part of the electromagnetic spectrum

White Dwarf has many faces—Does this imply a diverse origin of WD or a complicated spectral evolution?

# Zoo theory V.S. MJ theory



# The non-DA gap (BRL1997)

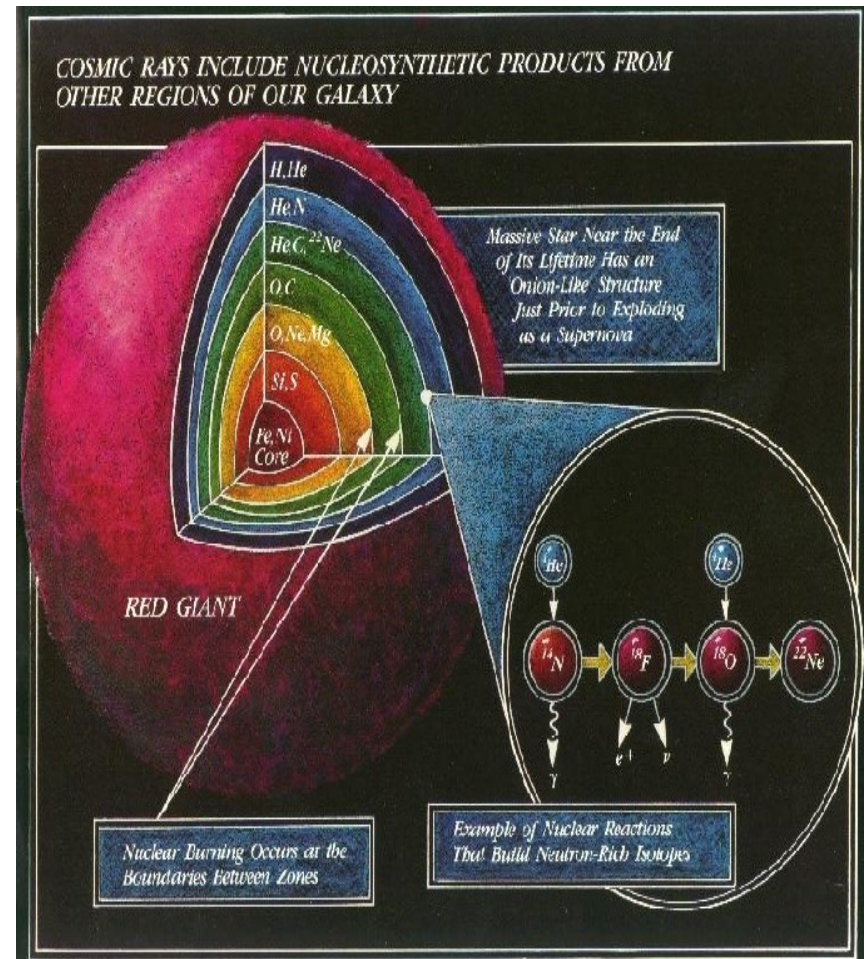


Evidence of spectral evolution!

# The “natural” configuration of a white dwarf

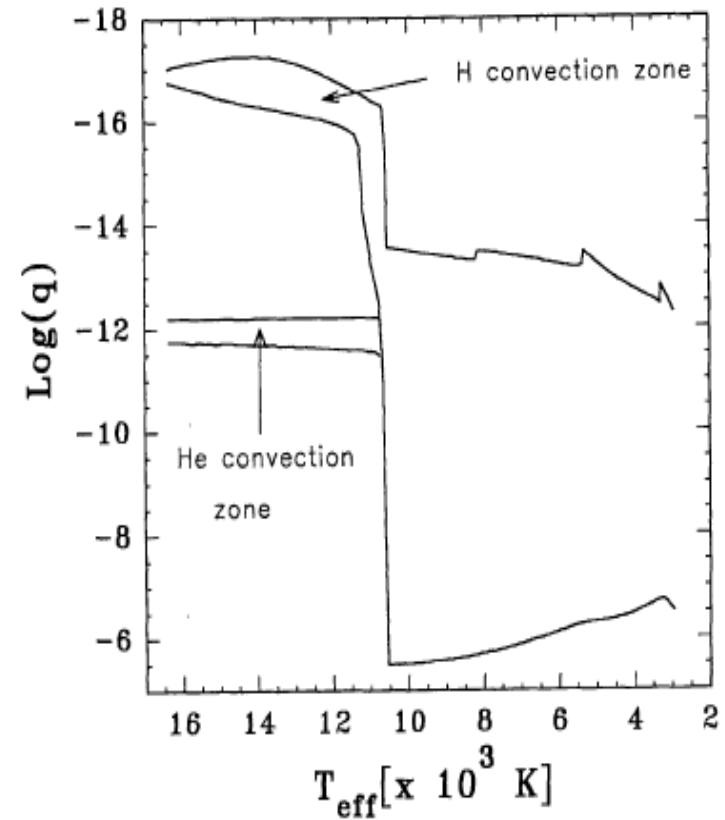
$$w_1 - w_2 = -D_{12} \left[ \frac{1}{c_1 c_2} \frac{\partial c_1}{\partial r} + \frac{m_2 - m_1}{c_1 m_1 + c_2 m_2} \frac{1}{\rho} \frac{\partial \rho}{\partial r} - \frac{m_1 m_2 (F_1 - F_2)}{kT (c_1 m_1 + c_2 m_2)} + \frac{a_{12}}{T} \frac{\partial T}{\partial r} \right]$$

- Reducing the chemical inhomogeneity
- Lighter species tend to diffuse towards region of lower pressure
- Occurs when acceleration is different for different particles. (say, in an E-field)



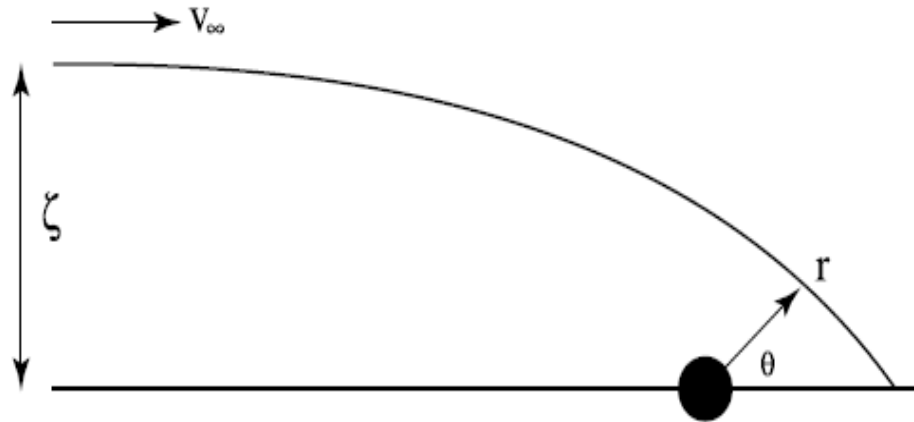
# Convection and Spectral Evolution

- Convective dredge up
- Convective engulfing
- Sudden dilution



# Accretion from ISM

- Bondi solved the problem of spherical accretion of fluid by a gravitating mass.
- Hoyle and Lyttleton extend the problem to the case where there is a relative speed between the mass and the fluid.



# Bondi-Hoyle-Lyttleton

- Thus, rate of accretion is a function of ISM density, sound speed and the velocity of the star.

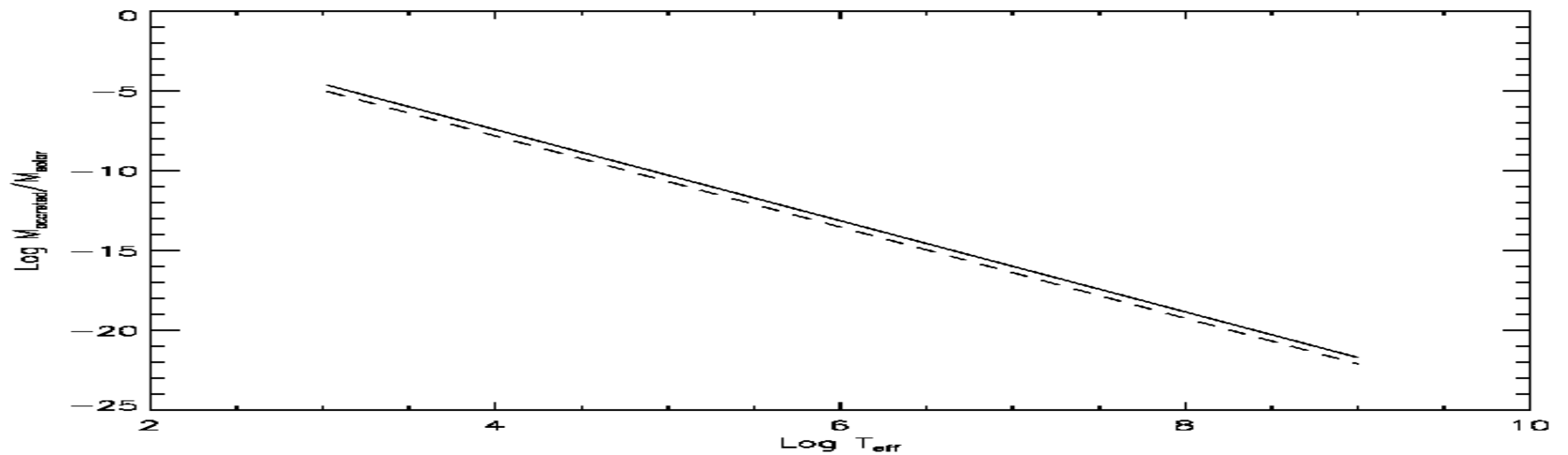
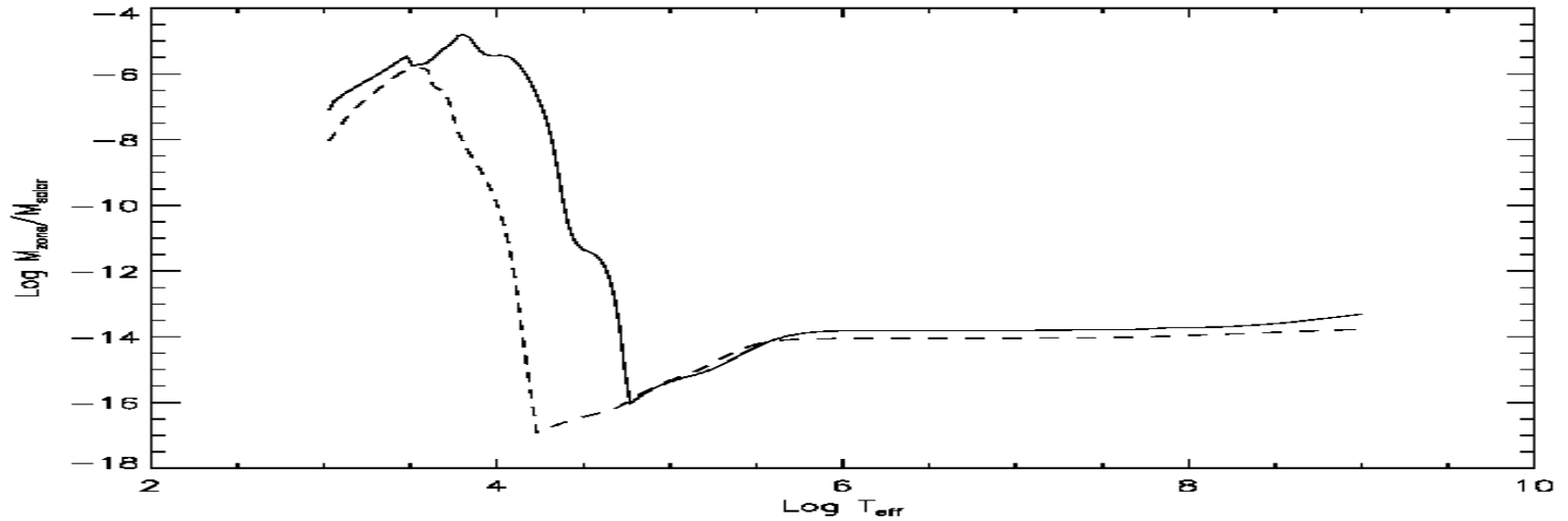
$$\dot{M} = \frac{4\pi G^2 M^2 \rho_\infty}{(c_\infty^2 + v_\infty^2)^{\frac{3}{2}}}$$

- Accretion rate for disk WD, halo WD and WDs in globular clusters are *different*.
- Using our local ISM condition and the typical velocity of a disk star, we found  $\dot{M} = 5 \times 10^{-17} M_{solar} / yr$

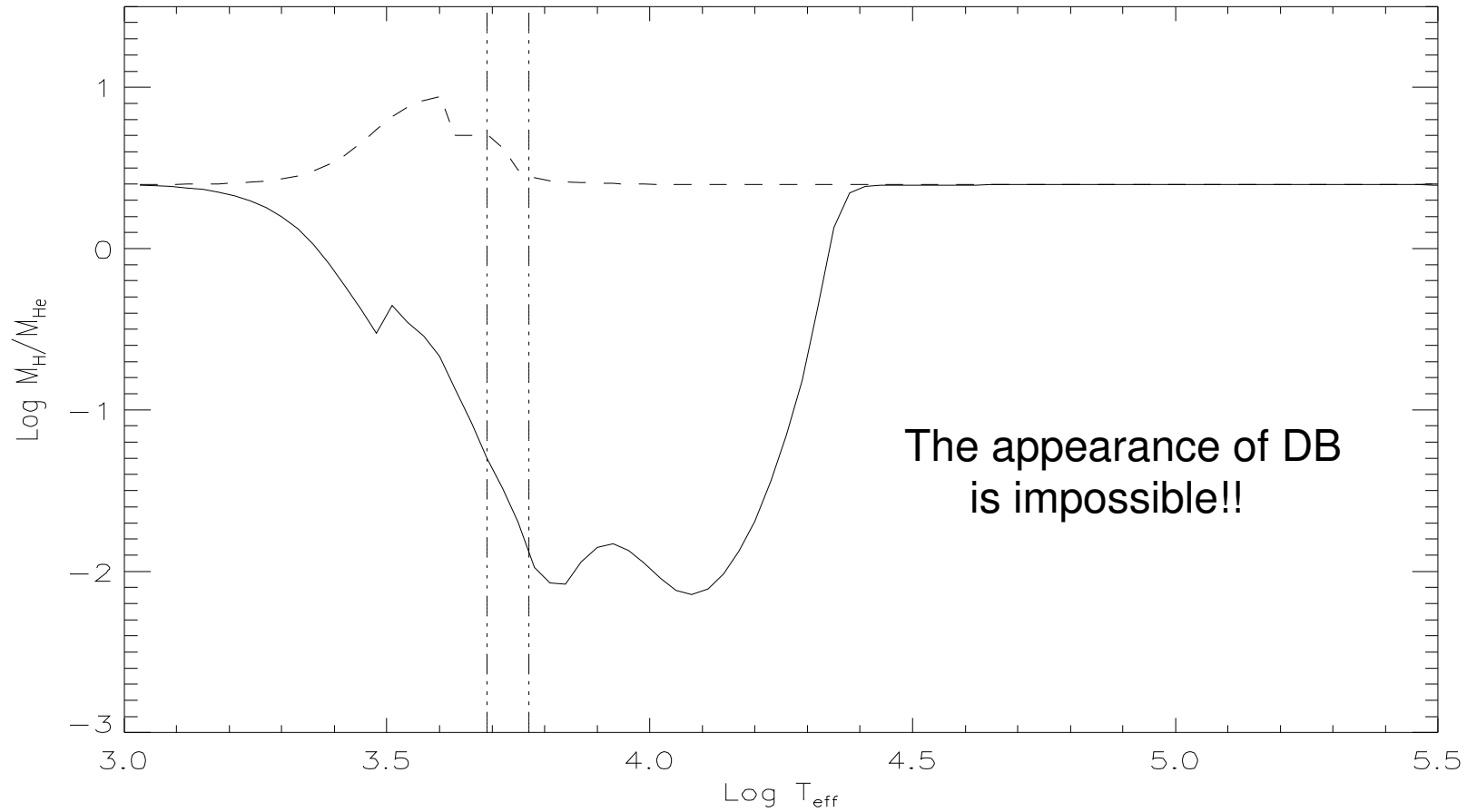
# The Interplay Between Convection and Accretion—First attempt

- D'Antona & Mazzitelli (1974)
- Consider H-He mixture accreting on a pure He atmosphere.
- Spectral type DB→DA if  $N_{\text{H}}/N_{\text{He}} \geq 10^{-3}$  in the photosphere.
- Assume the size of convection zone is independent of chemical composition.

# A calculation a la D'Antona



$$M_{\text{H}}/M_{\text{He}}$$



# So...what's wrong?

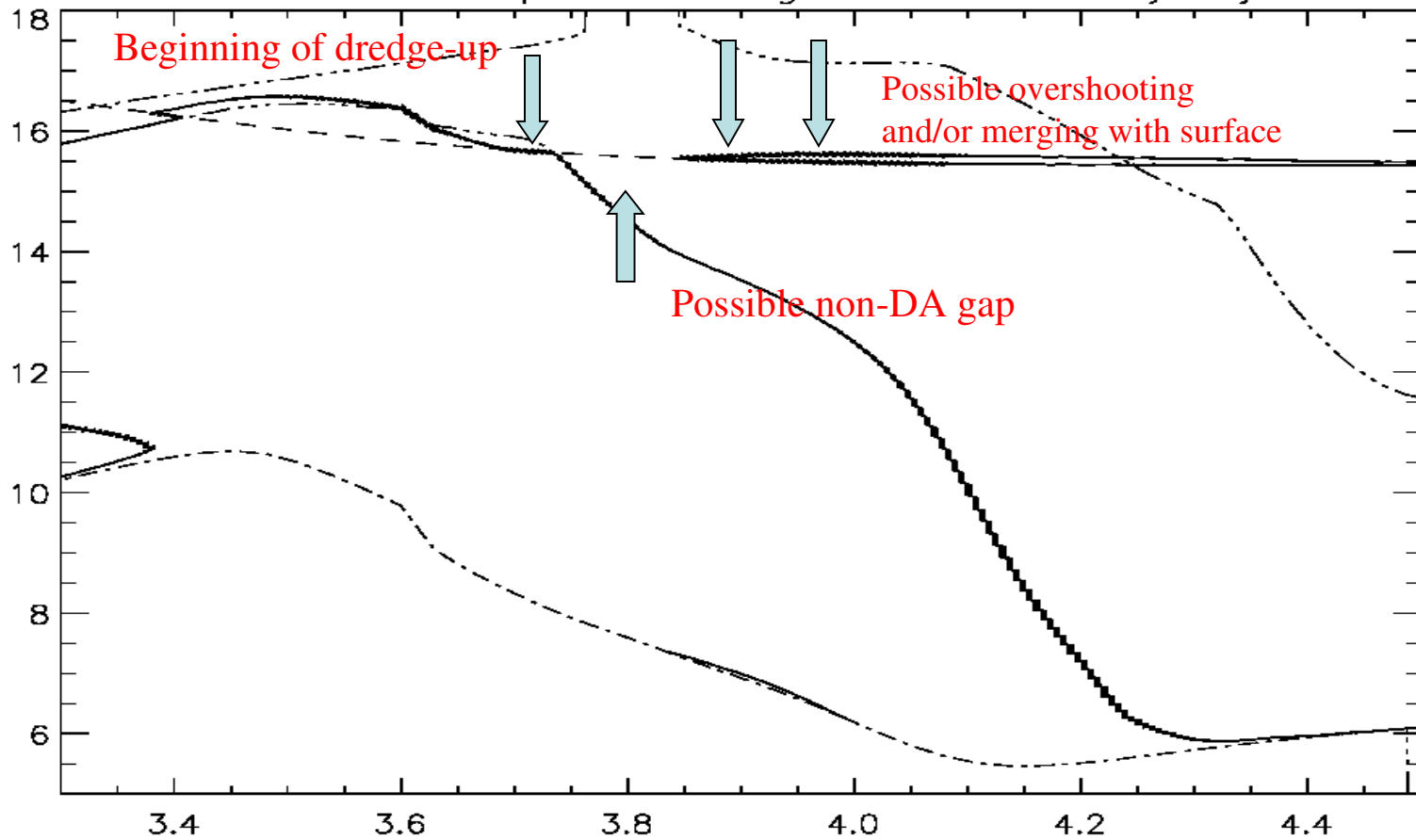
- The size of convection zone is sensitive to chemical composition – the calculation is good only when  $N_H \ll N_{HE}$ , which is far from the case.
- However, the size of convection zone of an arbitrary mixture is hard to estimate because plasma simulation is computationally expansive.

# Our approach to the same problem

- We attack the same problem through two different means.
- First we calculate the structure of strictly layered atmospheres with thickening hydrogen layers.

# Spectral Evolution – a first look

Convection Zone in Pressure Space V.S.  $\log T_{\text{eff}}$  in A Strictly Layered Atmosphere



mHini =  $5.00000\text{e}-008$  Msolar, Accretion rate =  $5.00000\text{e}-018$  Msolar/yr.

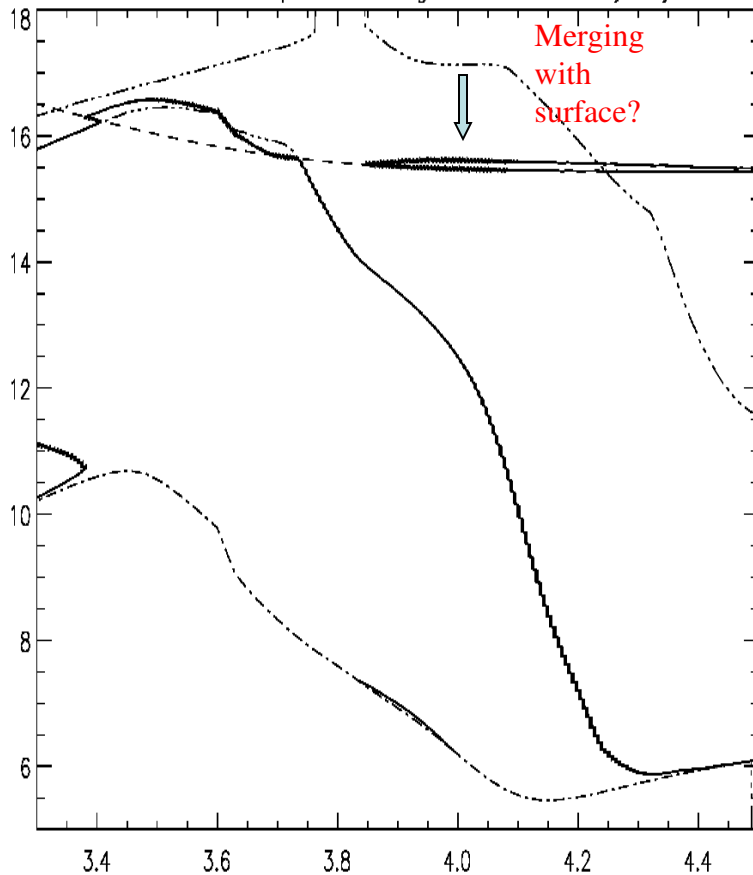
# Examining the possibilities...

- If engulfing or dilution is ever happening, the surface convection zone must be homogeneous.
- Instead of calculating  $N_{\text{H}}/N_{\text{He}}$  from the size of convection zone, we calculate the amount of hydrogen in convection zone from all kinds of atmosphere with different  $Y$  (another representation of  $N_{\text{H}}/N_{\text{He}}$ ).
- We compare the amount of hydrogen in the candidates with that calculated from accretion theory.

# Testing our hypothesis

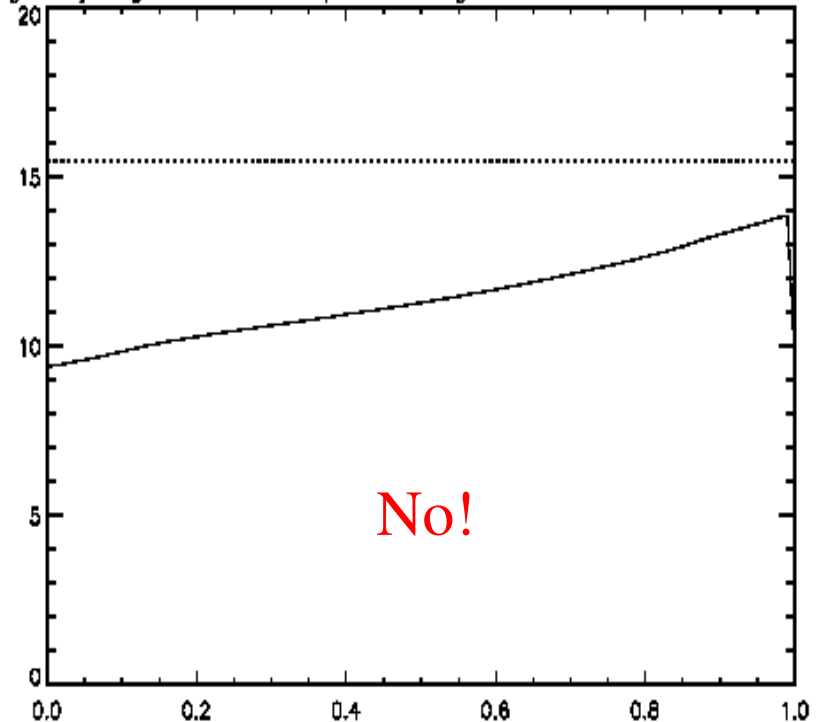
$$Y \equiv \frac{M_{HE}}{M_{TOTAL}}$$

Convection Zone in Pressure Space V.S. logTeff in A Strictly Layered Atmosphere



mHini = 5.00000e-008 Msolar, Accretion rate = 5.00000e-018 Msolar/yr.

log M<sub>H</sub>Hydragen in an atmosphere at logTeff =4.020 as a function of Y.

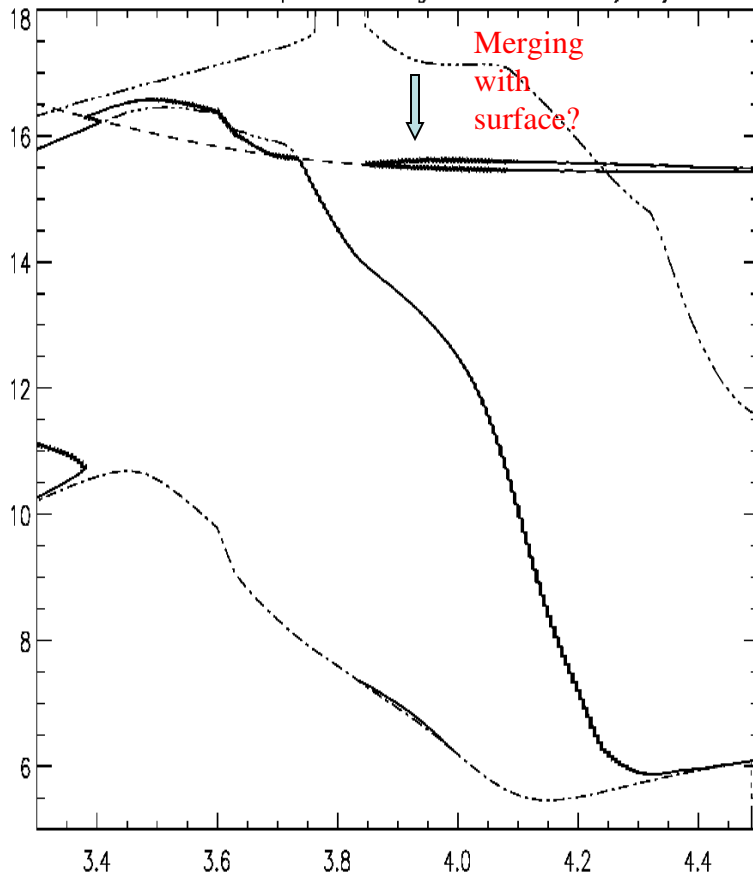


dotted line: log M<sub>H</sub> predicted by Mestel cooling model. (mass measured in equivalent pressure)

# Testing our hypothesis

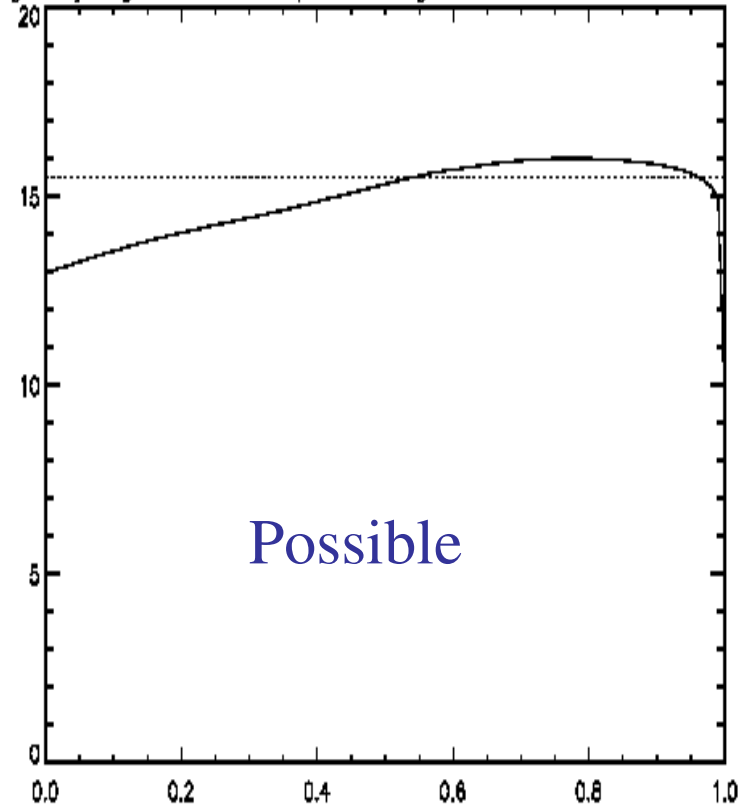
$$Y \equiv \frac{M_{HE}}{M_{TOTAL}}$$

Convection Zone in Pressure Space V.S. logTeff in A Strictly Layered Atmosph



mHini = 5.00000e-008 Msolar, Accretion rate = 5.00000e-018 Msolar/yr.

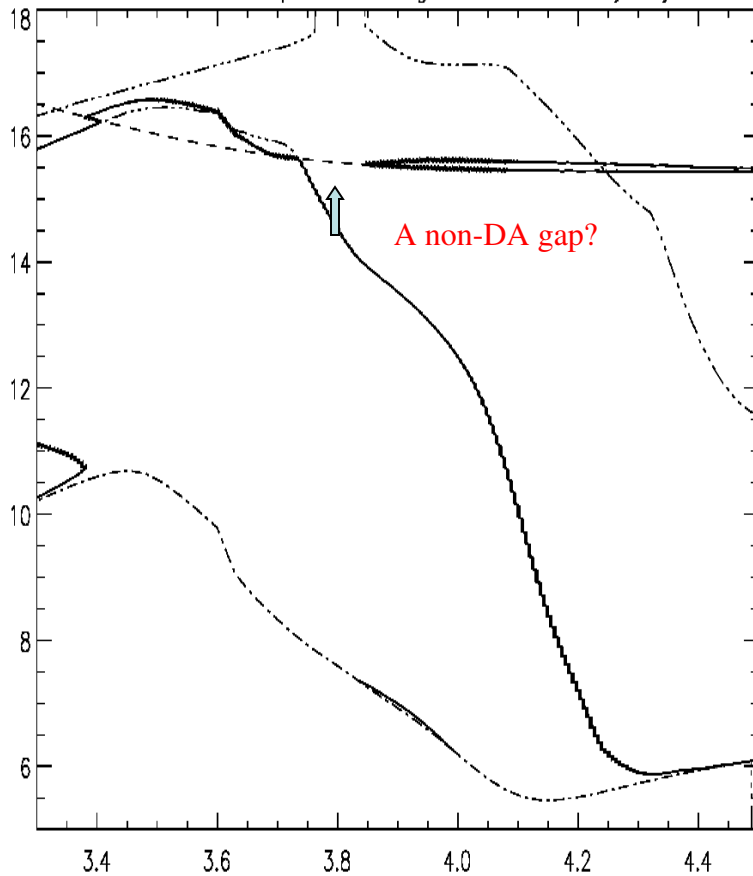
log M\_Hydrogen in an atmosphere at logTeff =3.918 as a function of Y.



dotted line: log M<sub>H</sub> predicted by Mestel cooling model. (mass measured in equivalent pressure)

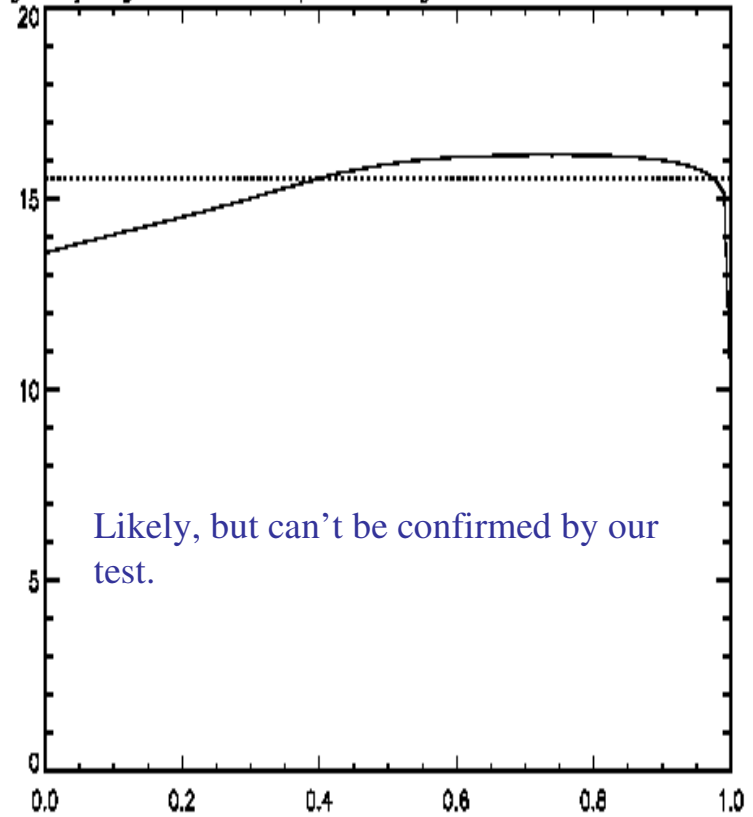
# Testing our hypothesis

Convection Zone in Pressure Space V.S. logTeff in A Strictly Layered Atmosph



$m_{\text{Hini}} = 5.00000e-008$  Msolar, Accretion rate =  $5.00000e-018$  Msolar/yr.

log M\_Hydrogen in an atmosphere at logTeff =3.870 as a function of Y.

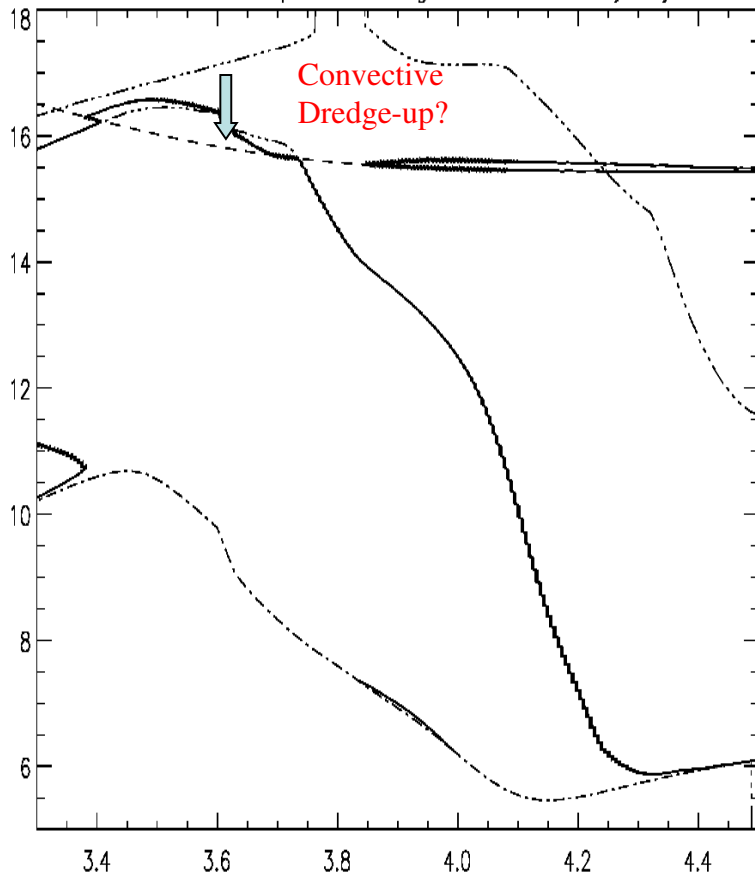


Likely, but can't be confirmed by our test.

dotted line: log M<sub>H</sub> predicted by Mestel cooling model. (mass measured in equivalent pressure)

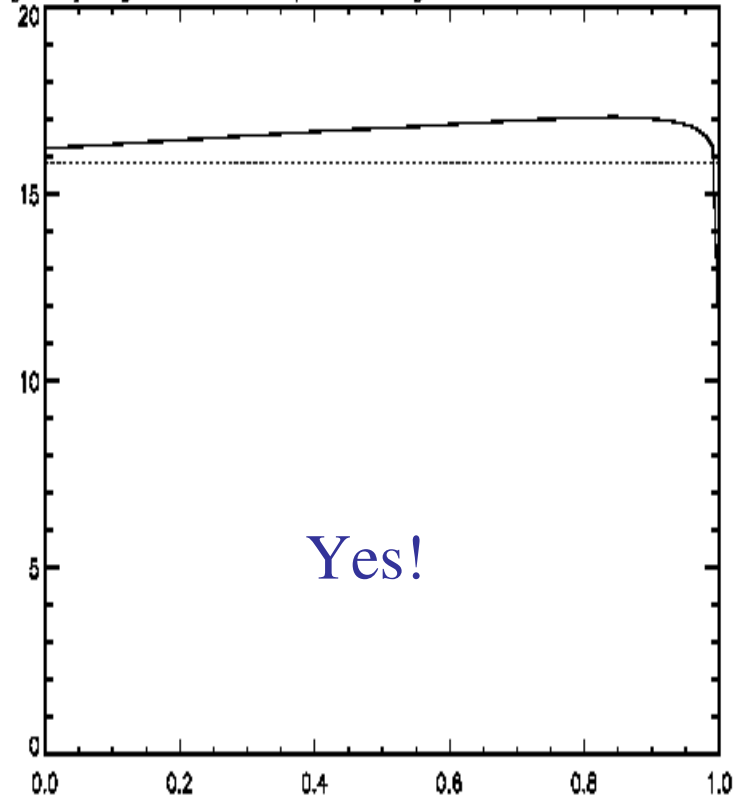
# Testing our hypothesis

Convection Zone in Pressure Space V.S. logTeff in A Strictly Layered Atmosph



$m_{\text{Hini}} = 5.00000\text{e-}008$  Msolar, Accretion rate =  $5.00000\text{e-}018$  Msolar/yr.

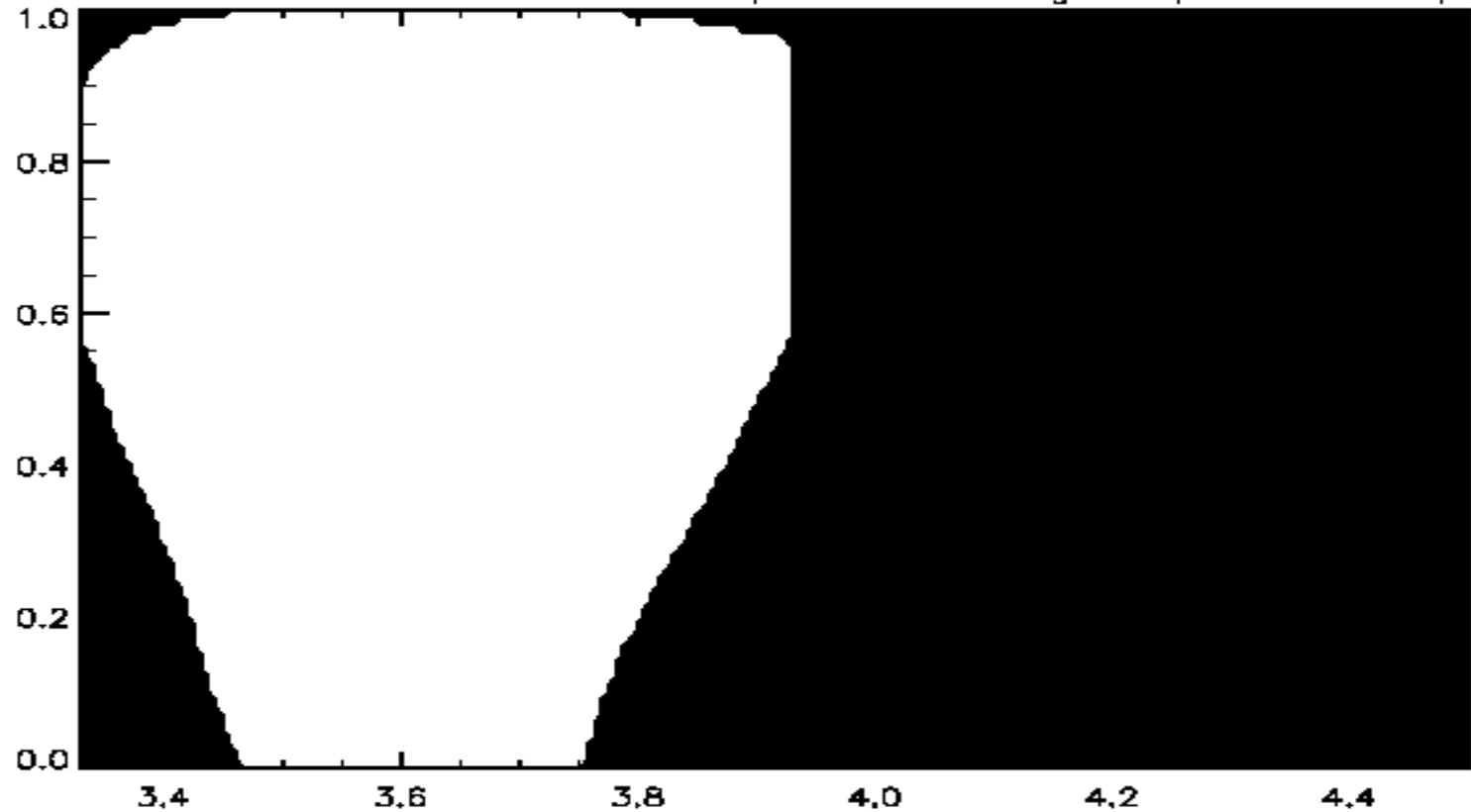
log M\_Hydrogen in an atmosphere at logTeff =3.600 as a function of Y.



dotted line:  $\log M_{\text{H}}$  predicted by Mestel cooling model. (mass measured in equivalent pressure)

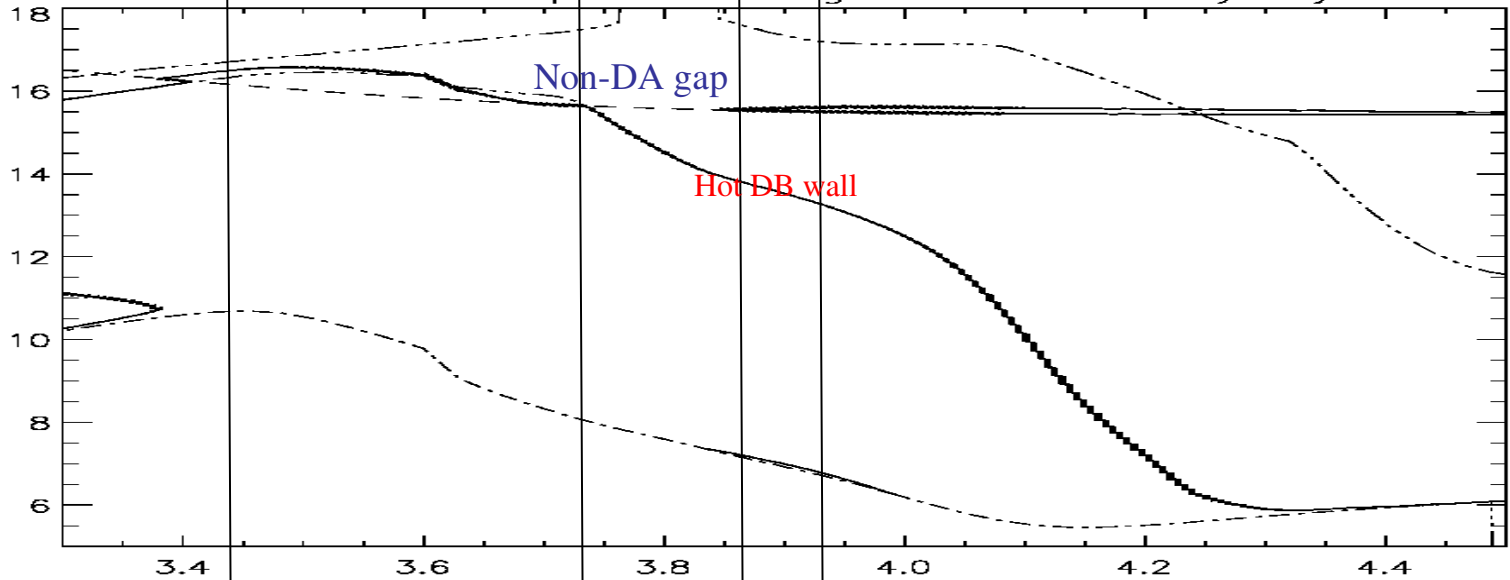
# Glue our plots together and view from top...

Distribution of "Consistent" Atmosphere in  $Y$ - $\log T_{\text{eff}}$  parameter space



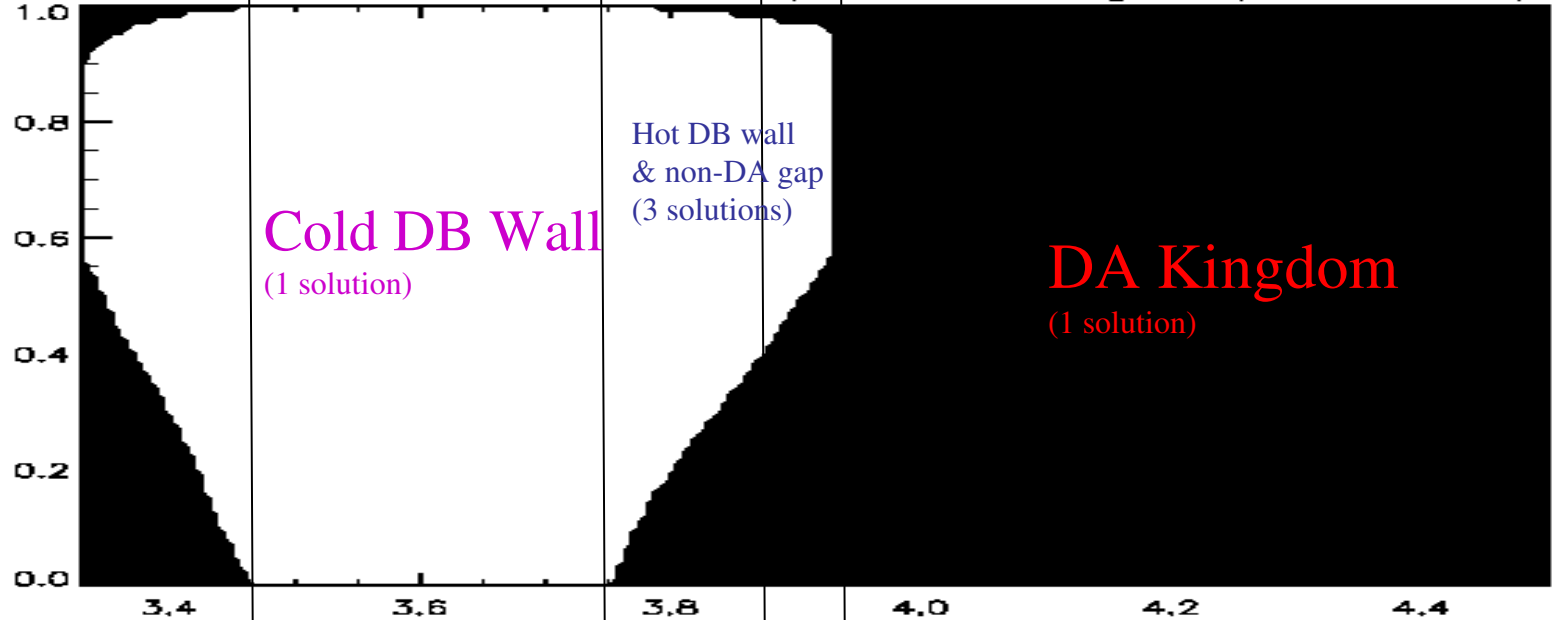
Given Mestel Cooling Model and an Accretion rate of  $5e-18$  Msolar/yr &  $M_{\text{H,ini}} = 5e-8$  Msolar

Convection Zone in Pressure Space V.S.  $\log T_{\text{eff}}$  in A Strictly Layered Atmosphere



$m_{\text{Hini}} = 5.00000\text{e}-008$  Msolar, Accretion rate =  $5.00000\text{e}-018$  Msolar/yr.

Distribution of "Consistent" Atmosphere in  $Y-\log T_{\text{eff}}$  parameter space

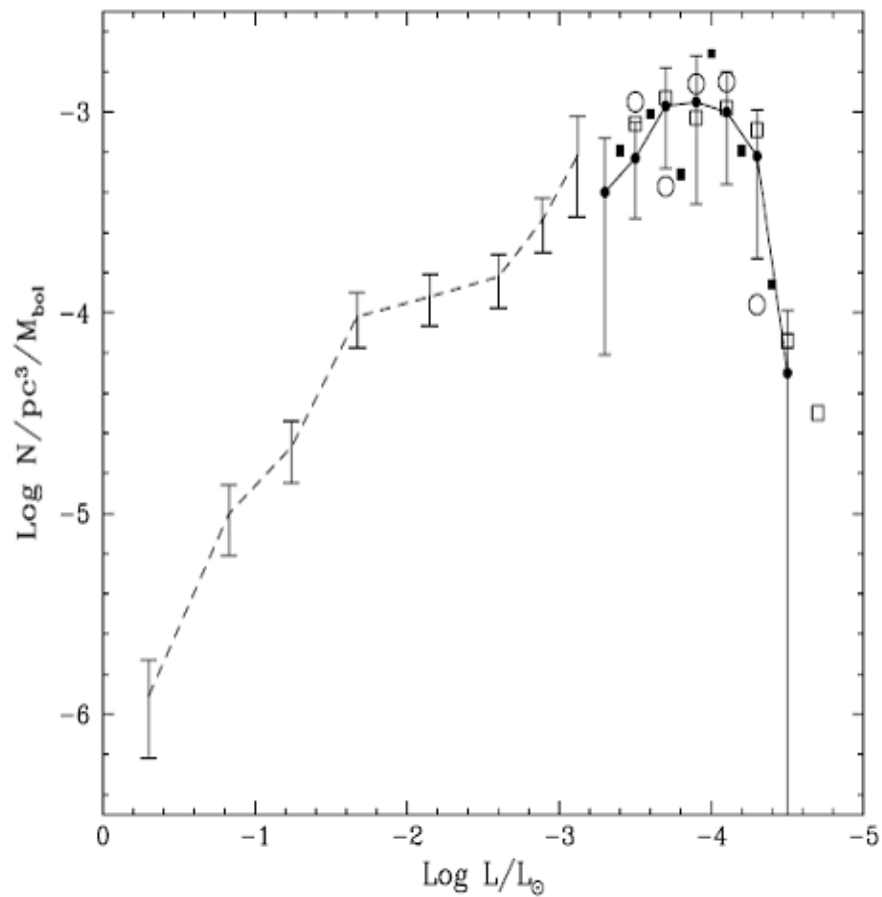


Given Mestel Cooling Model and an Accretion rate of  $5\text{e}-18$  Msolar/yr &  $M_{\text{Hini}}=5\text{e}-8$  Msolar

# Conclusions

- This is a very promising explanation for the non-DA gap mentioned by Bergeron, Ruiz and Leggett (1997).
- Whether a WD in 3-solution regime choose to be a DA or DB requires further investigation.
- More realistic calculation should include cooling model.

# Applications



Ziggy



The End