The Evolution and Pulsation of White Dwarf Stars

MIKE MONTGOMERY, DON WINGET, JJ HERMES,
ROSS FALCON, SAMUEL HARROLD, KEATON BELL

AUGUST 16, 2012

Location of files for talk and problems

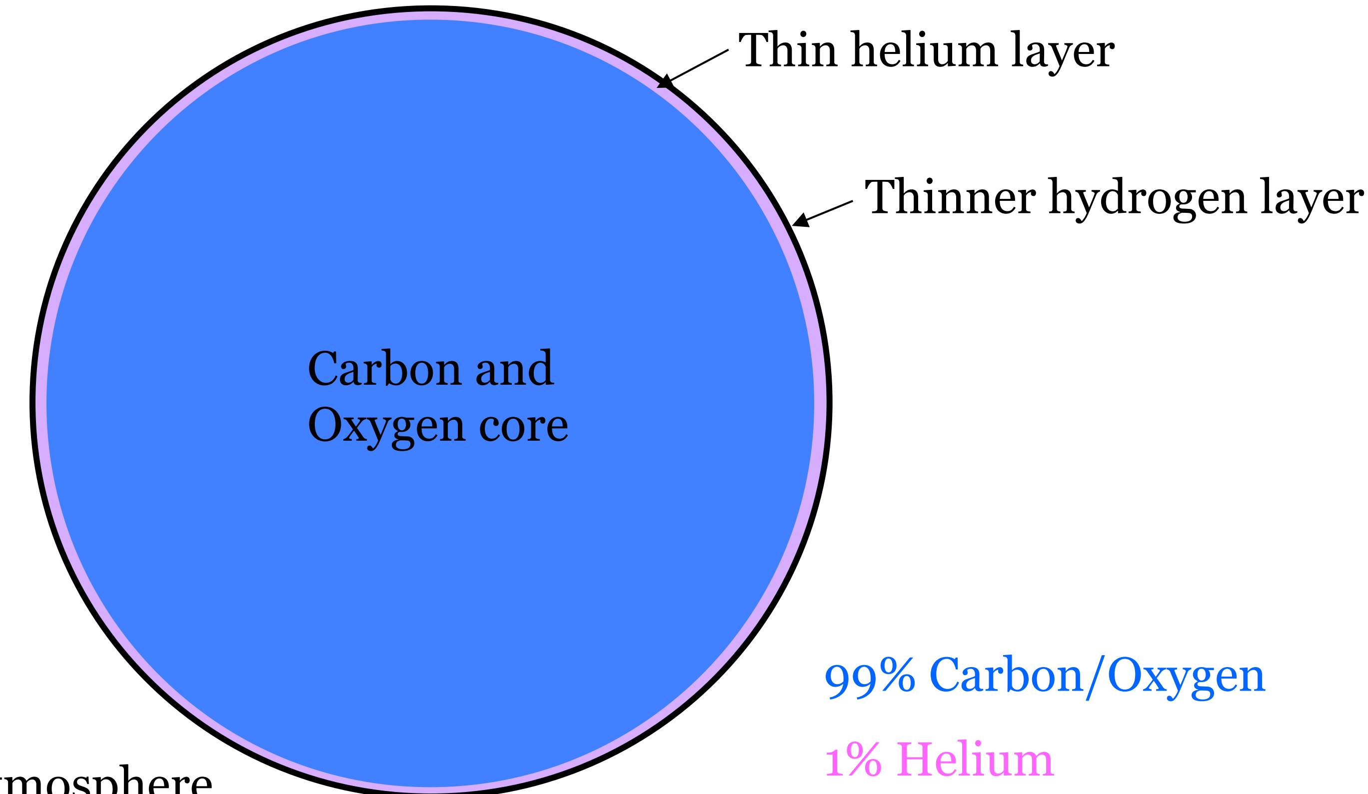
- Download file “wd_problems1.tar” from

mesastar.org -> FAQ -> MESA Summer School 2012 lectures -> Mike Montgomery I

Full web address:

http://mesastar.org/documentation/mesa-summer-school-2012-lectures/mike-montgomery-i/wd_problems1.tar/view

White Dwarfs



99% Carbon/Oxygen

1% Helium

0.01% Hydrogen

DA= hydrogen atmosphere
DB= helium atmosphere
DQ= carbon atmosphere

White Dwarfs

- White dwarfs are supported by electron degeneracy pressure (the Pauli Exclusion Principle)
- Cooling is controlled by the heat capacity of the ions, and the surface temperature
- When hot (> 25,000 K) they emit more energy in neutrinos than in photons
- As they get very cool (about 7000 K), the ions in the core settle into a crystalline lattice, i.e., they "freeze" or crystallize
- Gravity is high ($g \sim 10^8$ cm/s^2), so heavy elements sink, producing nearly pure H and/or He layers
- "Normal" mass ($\sim 0.6\ M_\odot$) white dwarfs have C/O cores

Science with White Dwarfs

- Pulsating white dwarfs allow us to:
  - Constrain their core chemical profiles
  - Constrain the physics of crystallization
  - Probe the physics of convection
  - Test the properties of exotic particles such as plasmon neutrinos and *axions*
  - Look for extra-solar planets
- White dwarf evolution allows us to measure the ages of
  - Thin disk
  - Globular clusters
  - Open clusters
  - Thick disk
  - Halo

White Dwarf Evolution

- Fowler and Chandrasekhar provided the first *mechanical* description of white dwarf structure, with support due to degenerate electrons:

$$\begin{aligned} P &\propto \rho^{5/3}\,(\mathrm{non-relativistic}) \\ P &\propto \rho^{4/3}\,(\mathrm{ultra-relativistic}) \end{aligned}$$

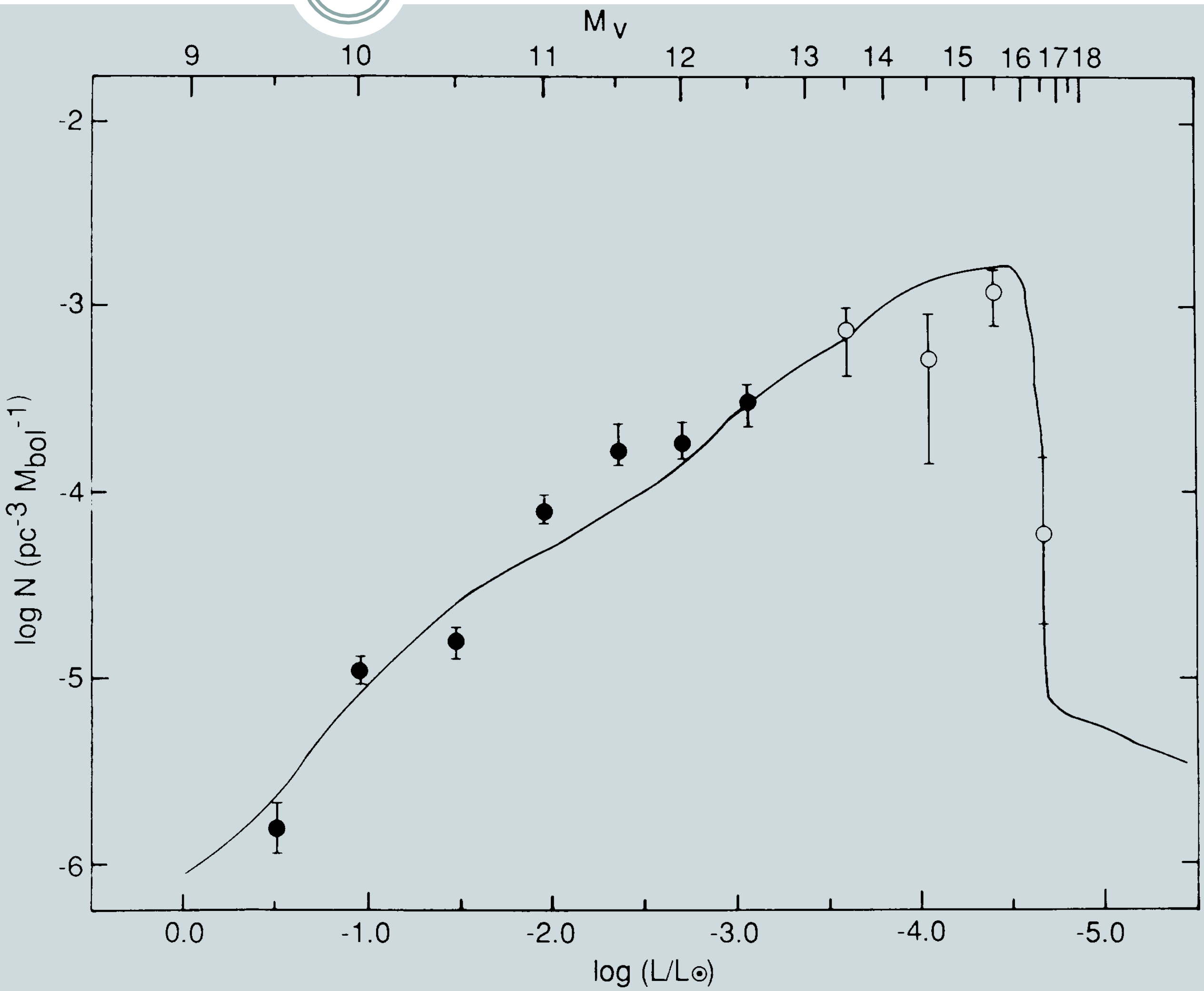
- Mestel (1952) provided first the *thermal* description of white dwarf evolution:

$$t_{\mathrm{cool}} \approx \frac{10^8}{A}\left(\frac{M/M_\odot}{L/L_\odot}\right)^{5/7}\ \mathrm{yrs}$$

The White Dwarf Luminosity Function (WDLF)

Winget et al. (1987)

The downturn is due to the finite Galactic age: 9 ± 2 Gyr



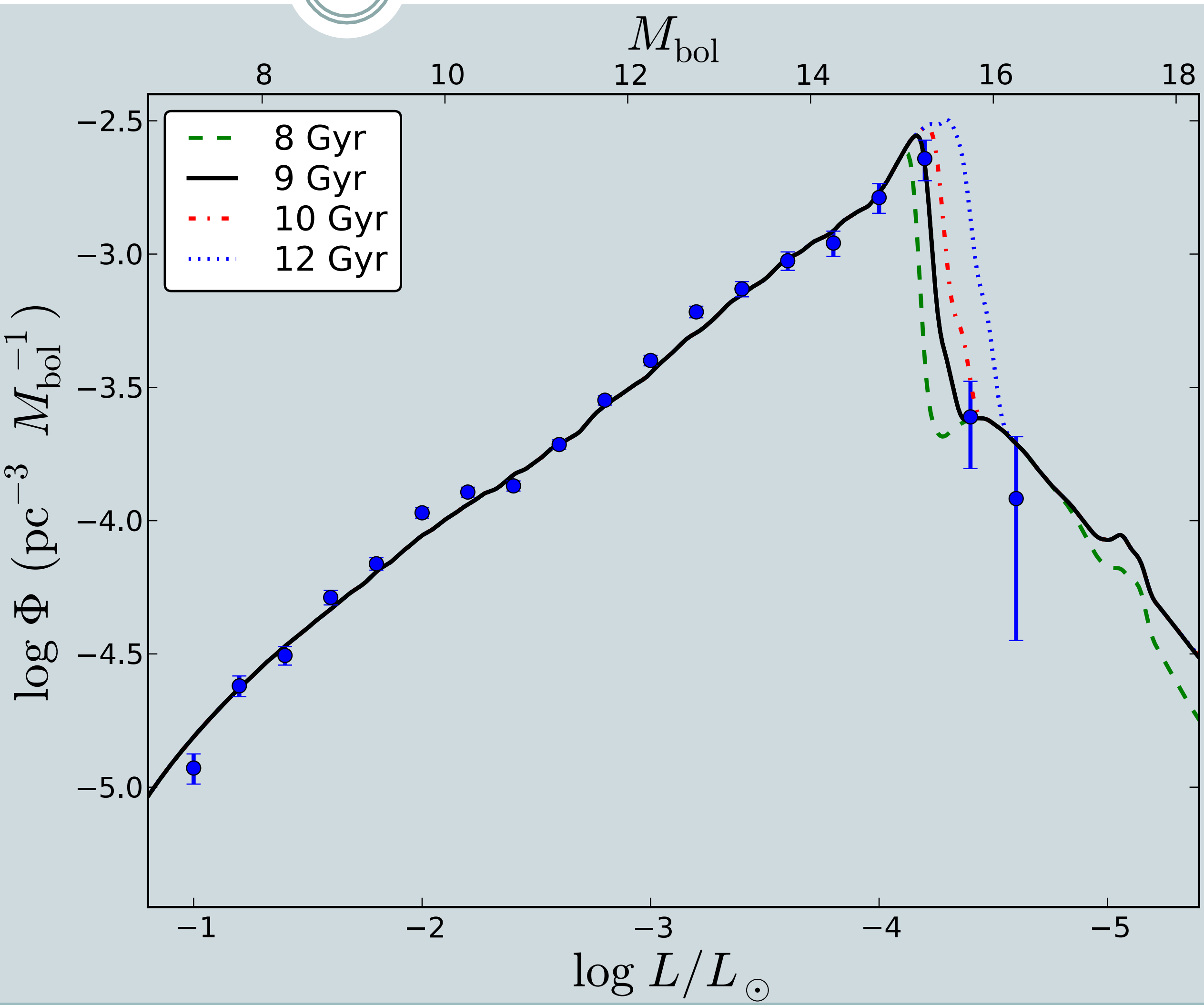
The WDLF (motivation for using MESA)

Data of Harris et al. (2006)

Low-mass C/O models of Salaris et al. (2010)

High-mass O/Ne models of Althaus et al. (2007)

Main sequence lifetimes from Dartmouth database



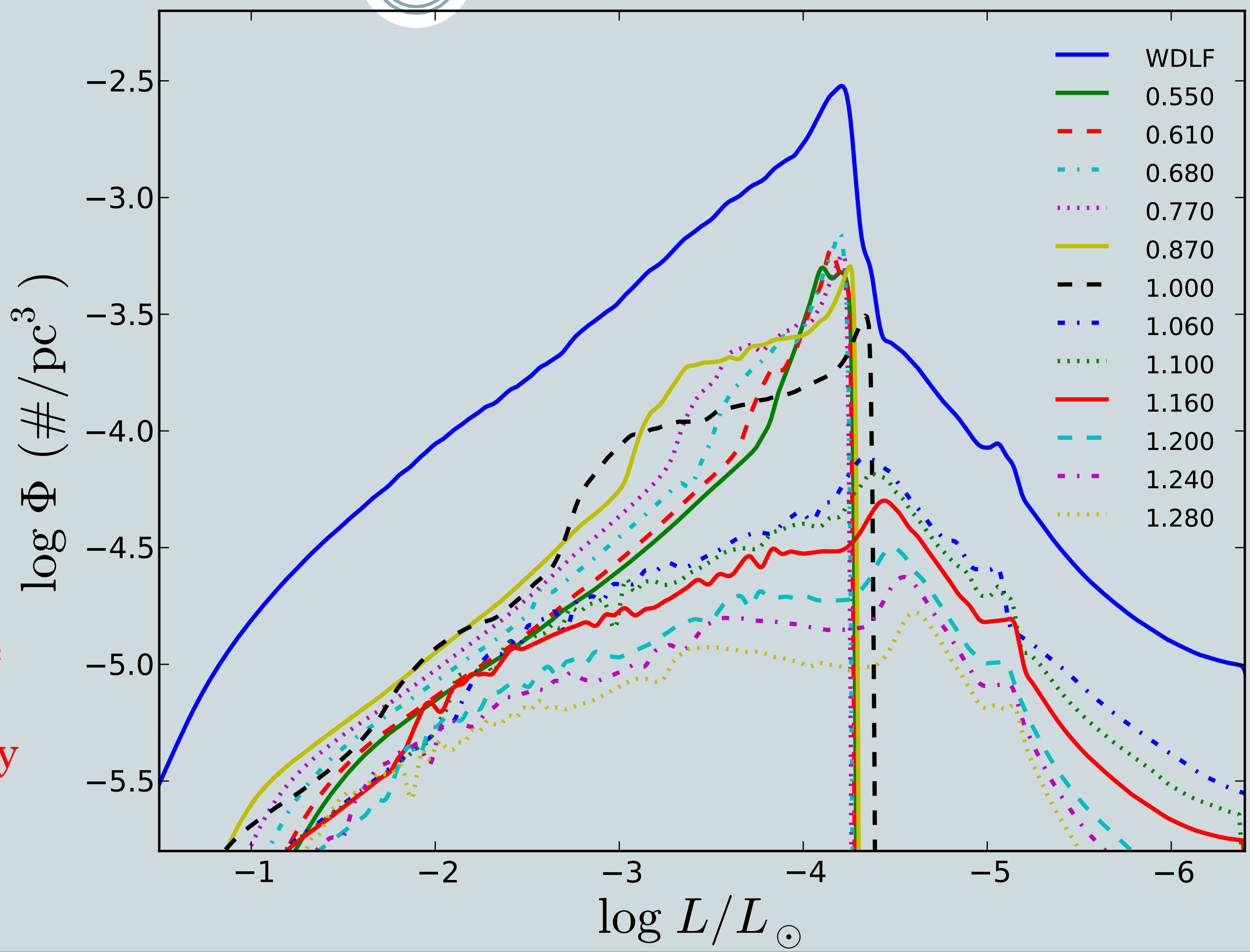
The WDLF (motivation for using MESA)

Data of Harris et al. (2006)

Low-mass C/O models of Salaris et al. (2010)

High-mass O/Ne models of Althaus et al. (2007)

The O/Ne models are entirely responsible for the low-luminosity tail of the WDLF



MESA Rapid Problem #1

- Download file “wd_problems1.tar” from

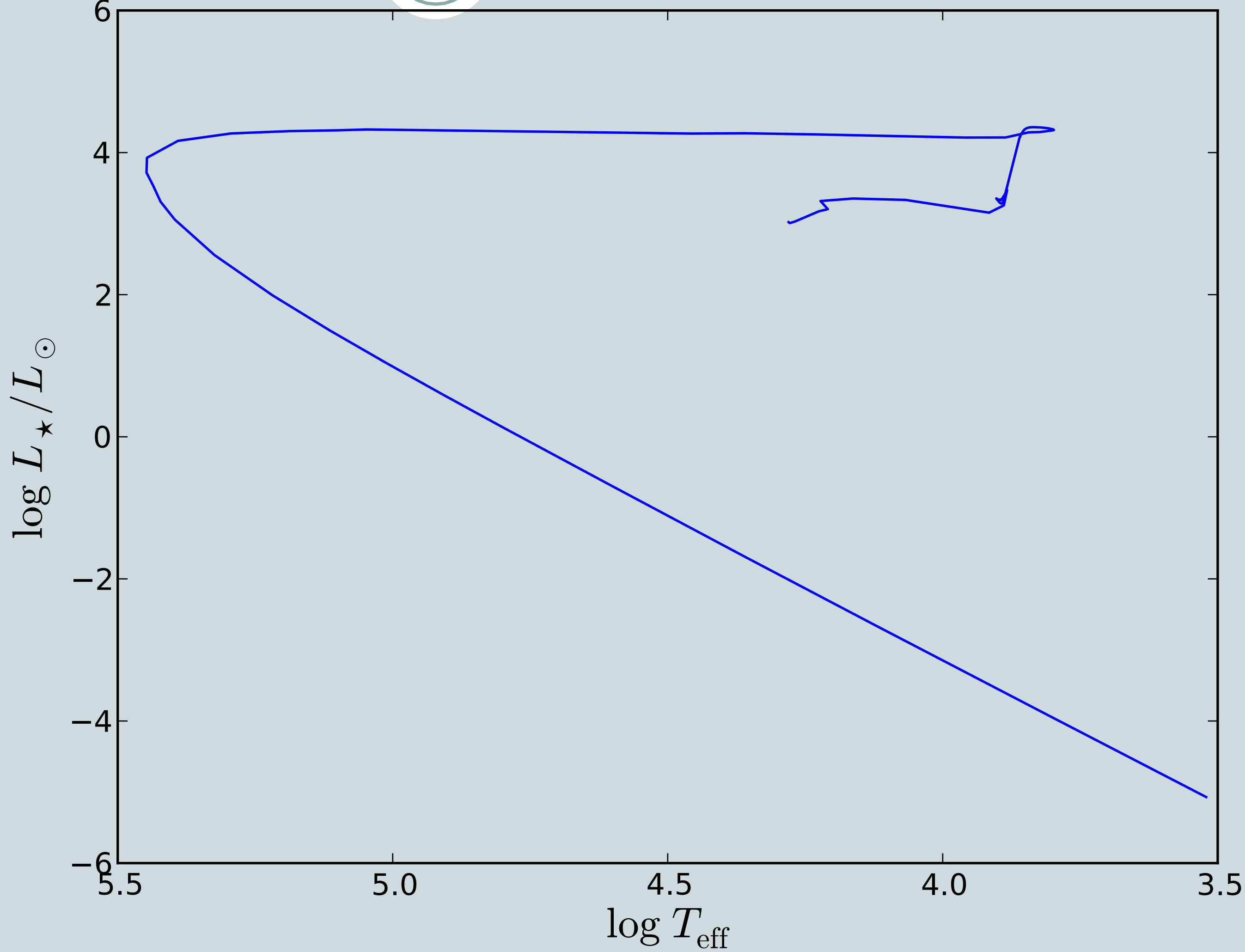
mesastar.org -> FAQ -> MESA Summer School 2012 lectures -> Mike Montgomery I

Full web address:

http://mesastar.org/documentation/mesa-summer-school-2012-lectures/mike-montgomery-i/wd_problems1.tar/view

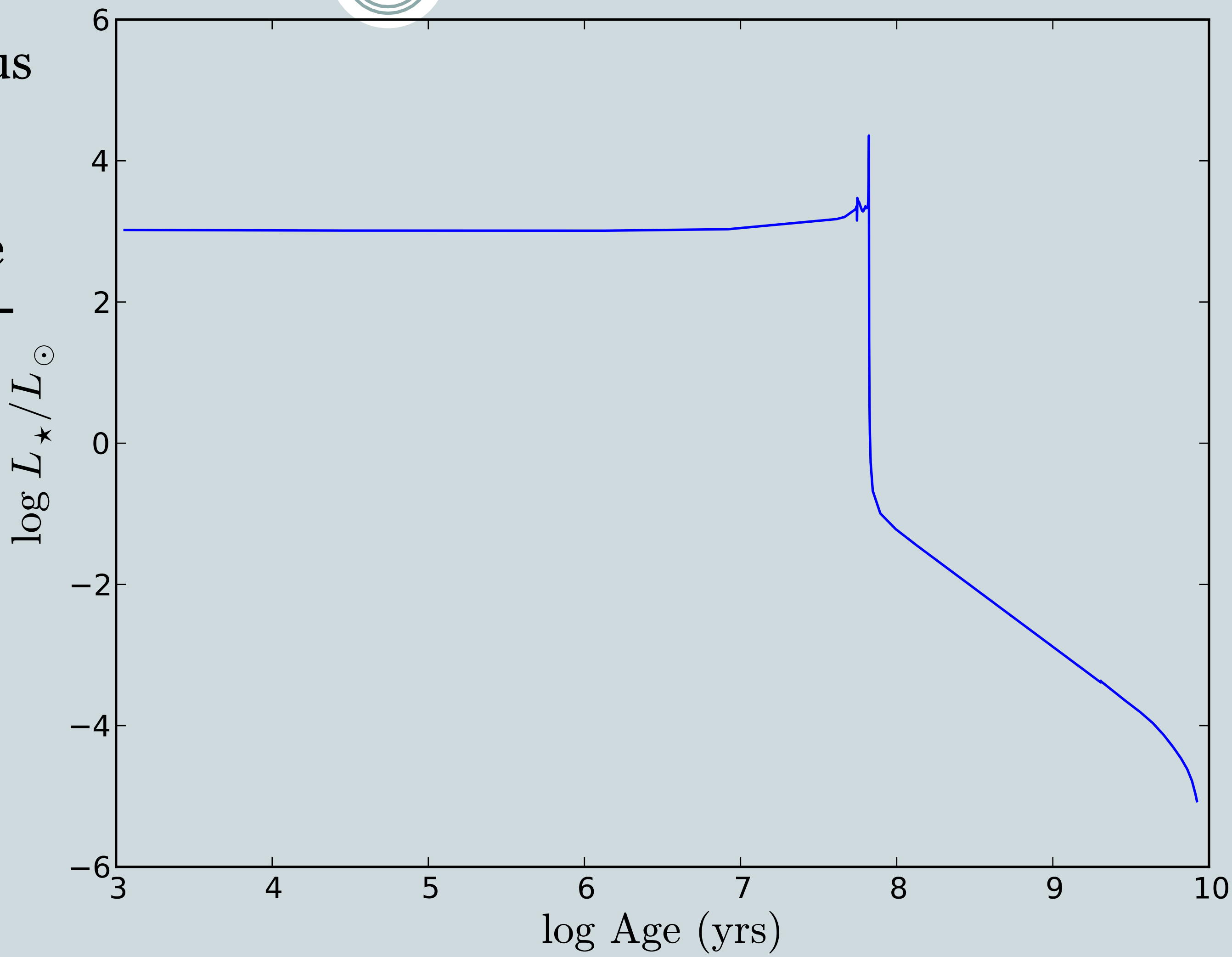
MESA Rapid Problem #1

- HRD diagram



MESA Rapid Problem #1

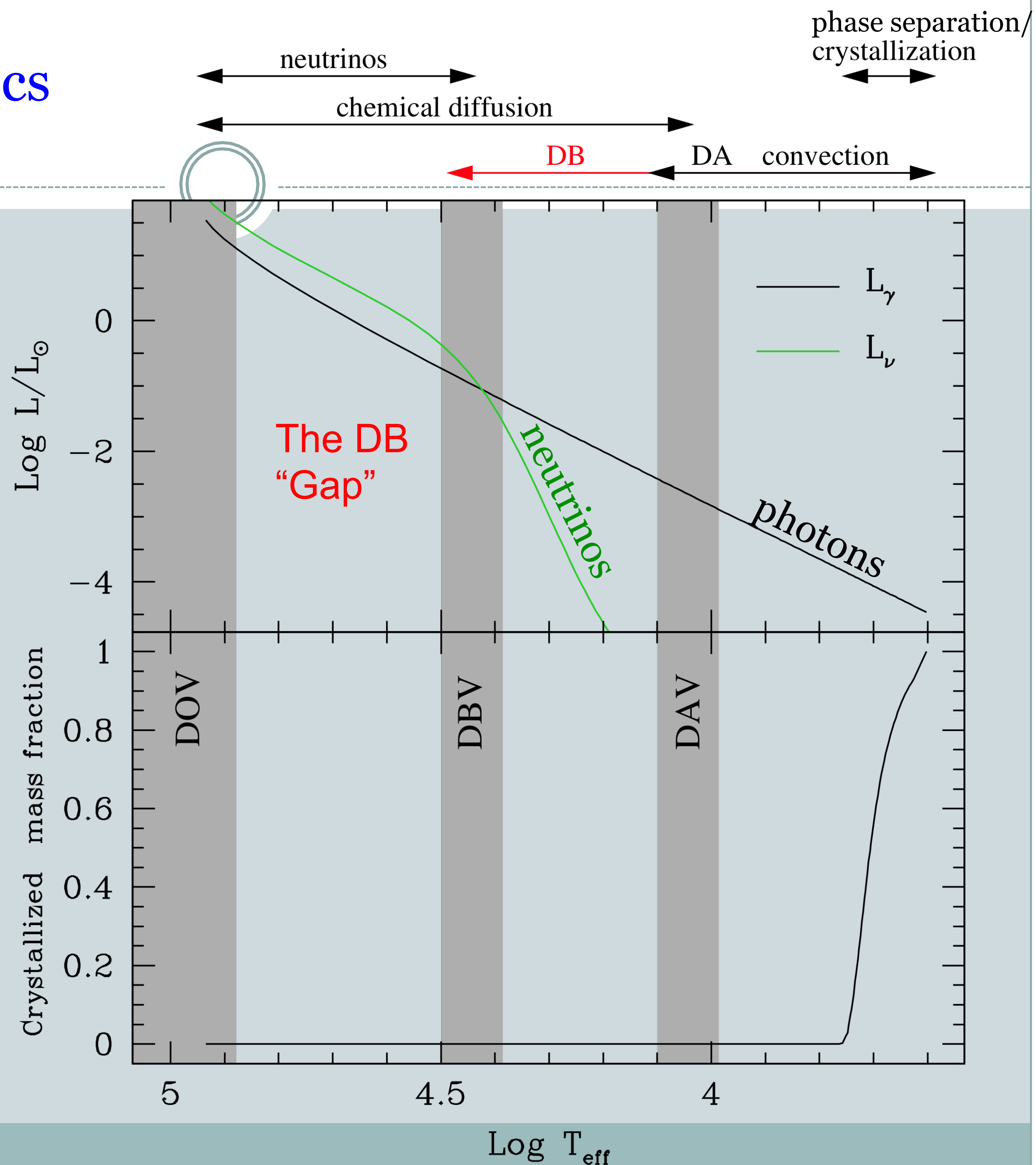
- Luminosity versus age
- What percent of the time does the star spend in pre-WD evolution?
- Where is all the "funny stuff" in this plot? (RGB, AGB,…)



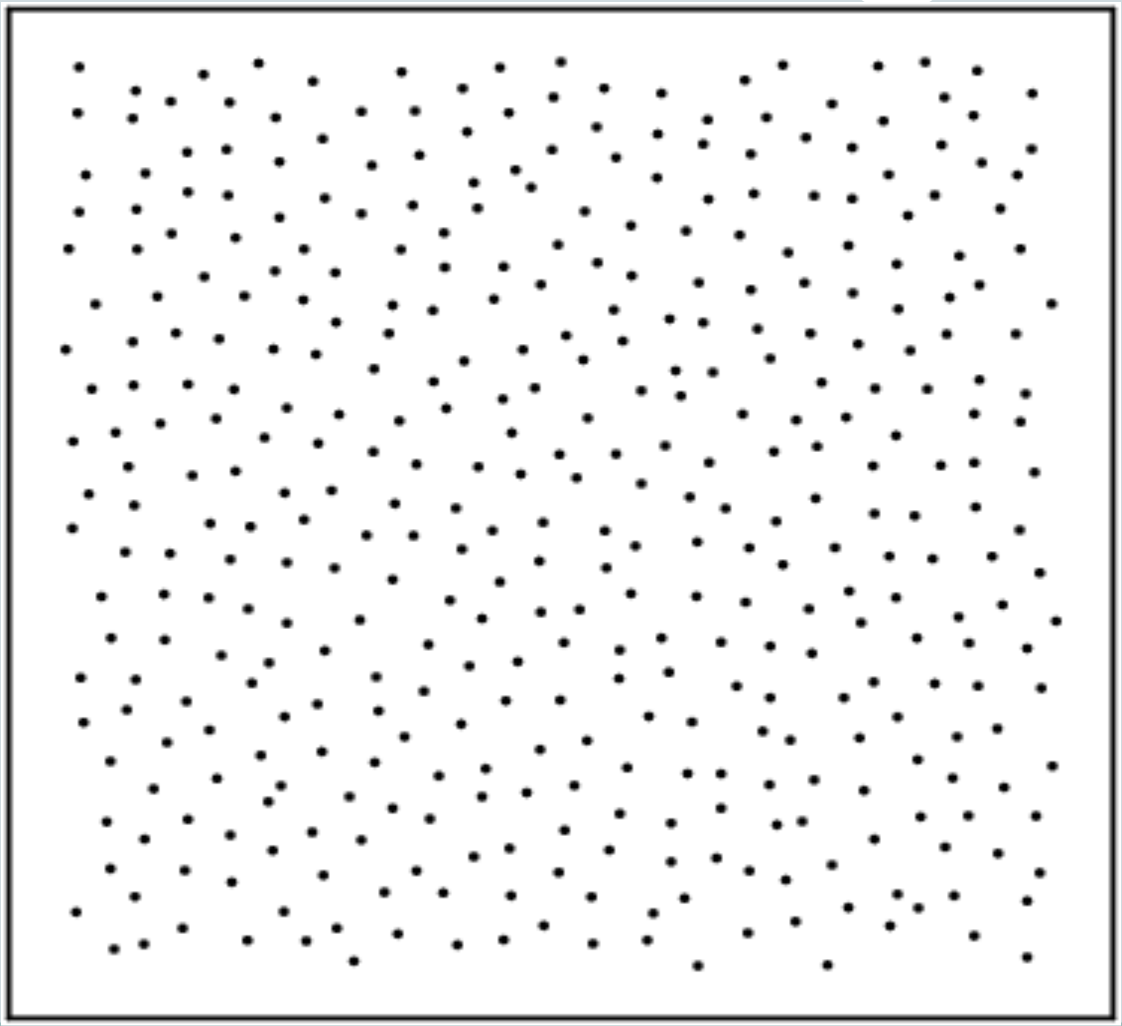
Summary of WD physics

Various physical processes thought to be important in WD evolution:

- neutrino emission
- chemical diffusion
- crystallization
- convection
- C/O phase separation
- CIA opacities
- exotic physics? (axion emission, dark matter heating)



Crystallization and Atmospheres



- A one-component plasma (OCP) -- all the particles are identical
- $\Rightarrow$ regular lattice structure
- in 3D, $\Gamma_{\mathbf{Crys}} = 178$

THE PHYSICS OF CRYSTALLIZATION FROM GLOBULAR CLUSTER WHITE DWARF STARS IN NGC 6397

D. E. Winget[1,2], S. O. Kepler[2], Fabíola Campos[2], M. H. Montgomery[1,3], Leo Girardi[4], P. Bergeron[5], and Kurtis Williams[1,6]
[1] Department of Astronomy, University of Texas at Austin, Austin, TX, USA; dew@astro.as.utexas.edu
[2] Instituto de Física, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brazil
[3] Delaware Asteroseismic Research Center, Mt. Cuba Observatory, Greenville, DE, USA
[4] INAF-Padova Astronomical Observatory, Padova, Italy
[5] Département de Physique, Université de Montréal, C. P. 6128, Succ. Centre-Ville, Montréal, Québec H3C 3J7, Canada
Received 2008 August 18; accepted 2009 January 16; published 2009 February 11

ABSTRACT

We explore the physics of crystallization in the deep interiors of white dwarf (WD) stars using the color–magnitude diagram and luminosity function constructed from proper-motion cleaned *Hubble Space Telescope* photometry of the globular cluster NGC 6397. We demonstrate that the data are consistent with the theory of crystallization of the ions in the interior of WD stars and provide the first empirical evidence that the phase transition is first order: latent heat is released in the process of crystallization as predicted by van Horn. We outline how these data can be used to observationally constrain the value of $\Gamma \equiv E_{\text{Coulomb}}/E_{\text{thermal}}$ near the onset of crystallization, the central carbon/oxygen abundance, and the importance of phase separation.

From our paper...

$$\Gamma = \frac{1}{kT}\frac{(Ze)^2}{R}$$

only to the interior composition. Therefore, we conclude that the onset of crystallization is determined by the particular mixture and the value of Γ for that mixture. Comparison of the theoretical models and the data promises to provide important measures of the onset and development of crystallization.

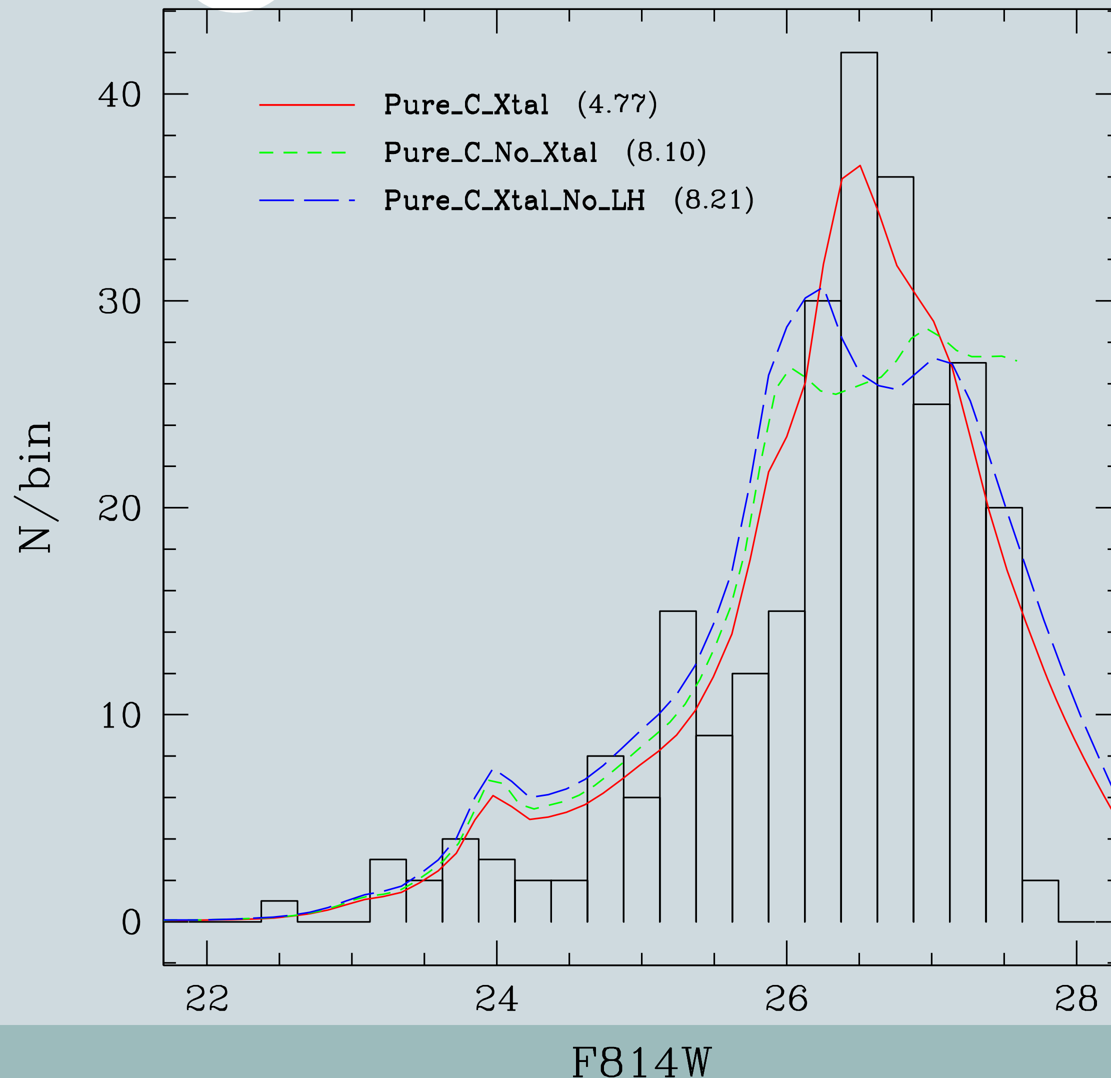
summary: either these WDs have no significant Oxygen or $\Gamma_{\mathbf{Crys}}$ of a C/O mixture ~ 220

WDs in Globular Cluster NGC 6397

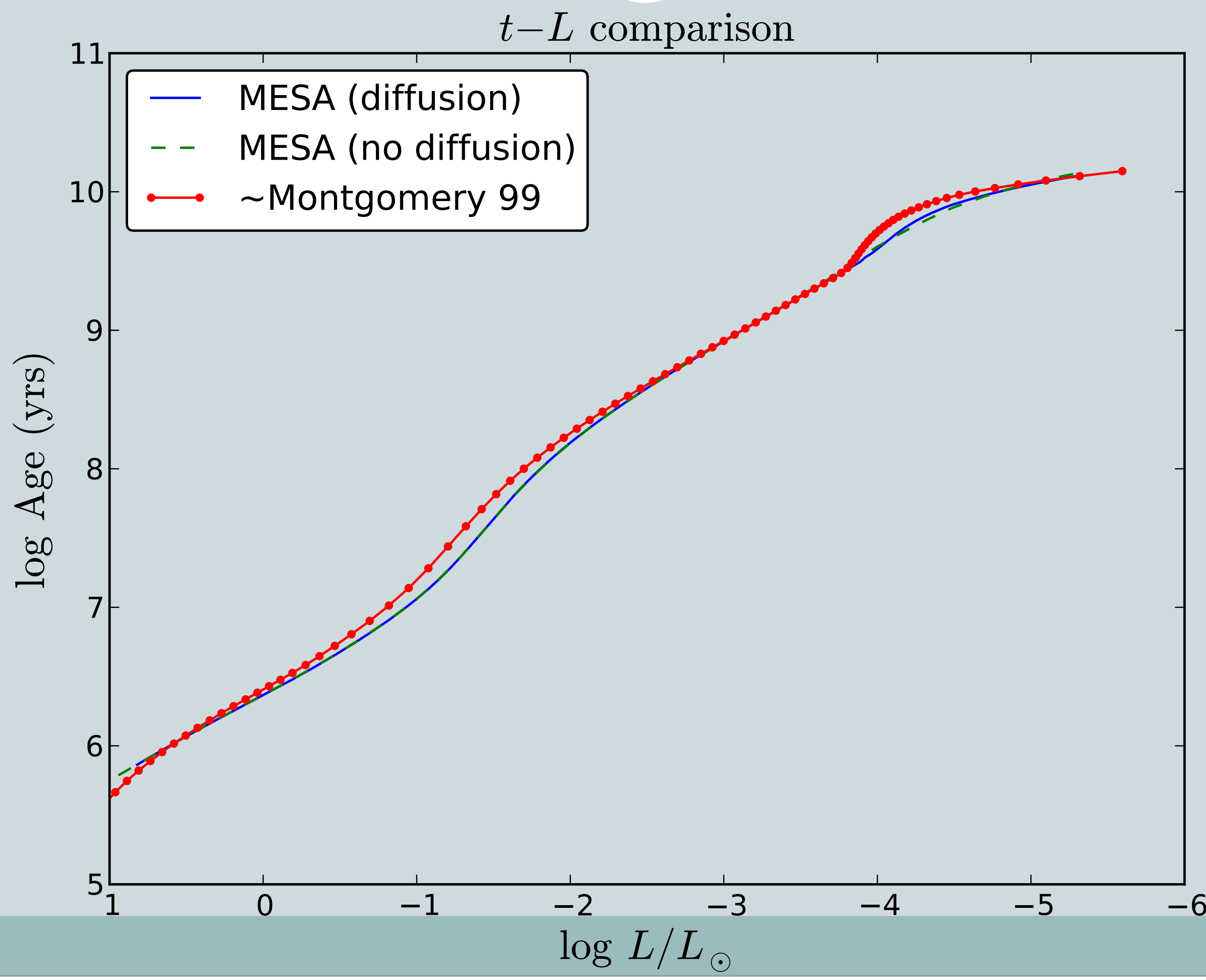
Winget et al. (2009)

- Showed that not only does crystallization occur, latent heat is also released
- Γ_{crys} of C/O mixture would have to be $\gtrsim 220$
- This possibility is reinforced by the calculations of Horowitz, Schneider, and Berry
- Weakness in our models was that grey atmospheres were used for low temperature WD evolution

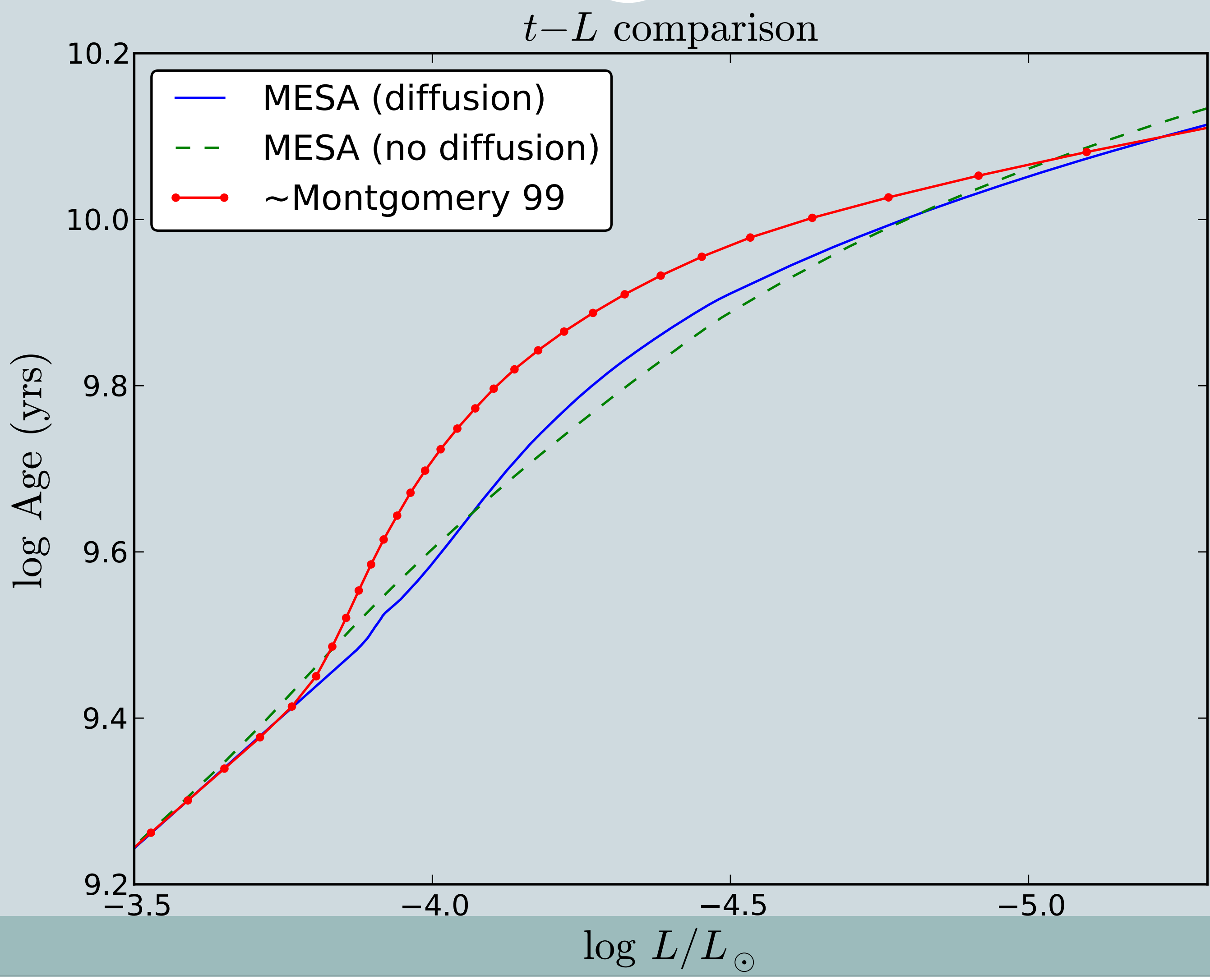
$\Rightarrow$ we will explore this in the upcoming long problem



Comparison of MESA with other Codes



Comparison of MESA with other Codes

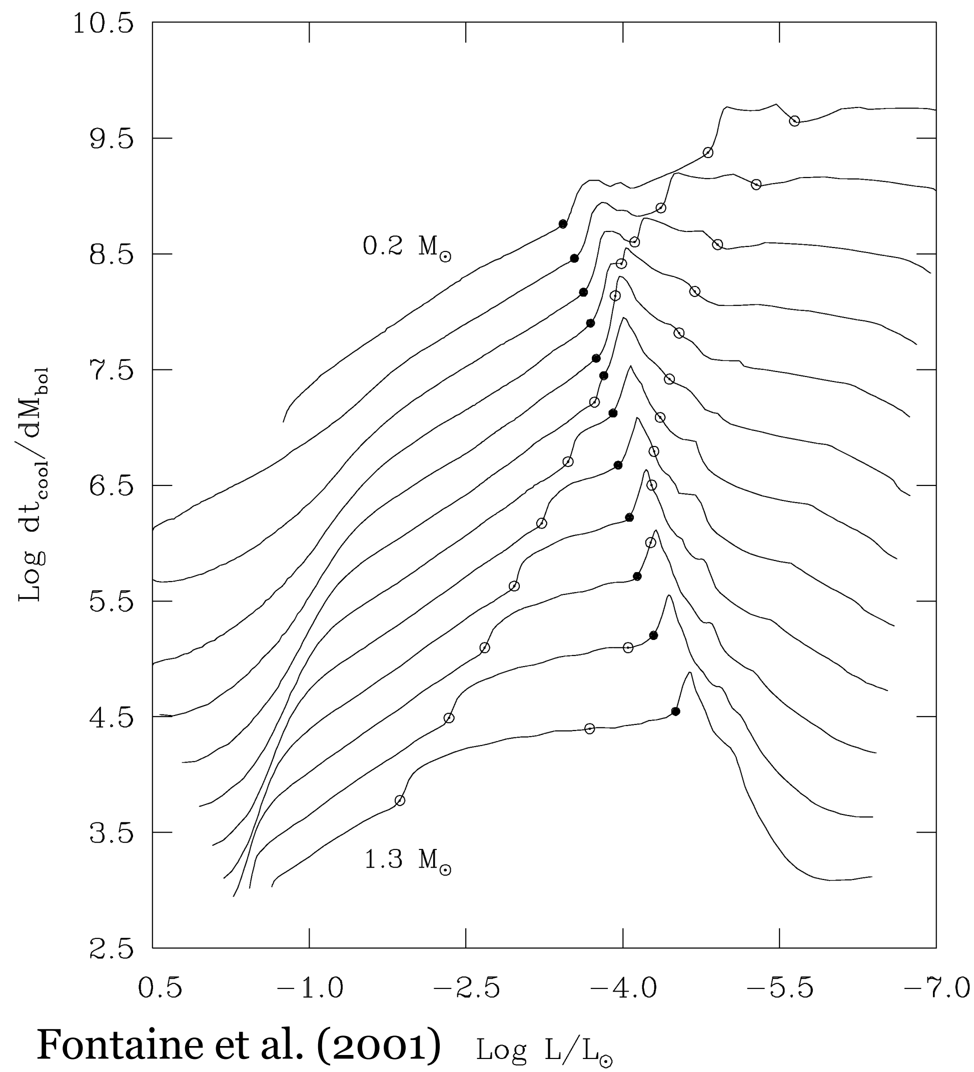


"Cooling Function"

- The "Cooling Function" Φ of a given mass WD is a measure of its "discovery probability"
- $\Rightarrow$ proportional to the time it spends at a given luminosity

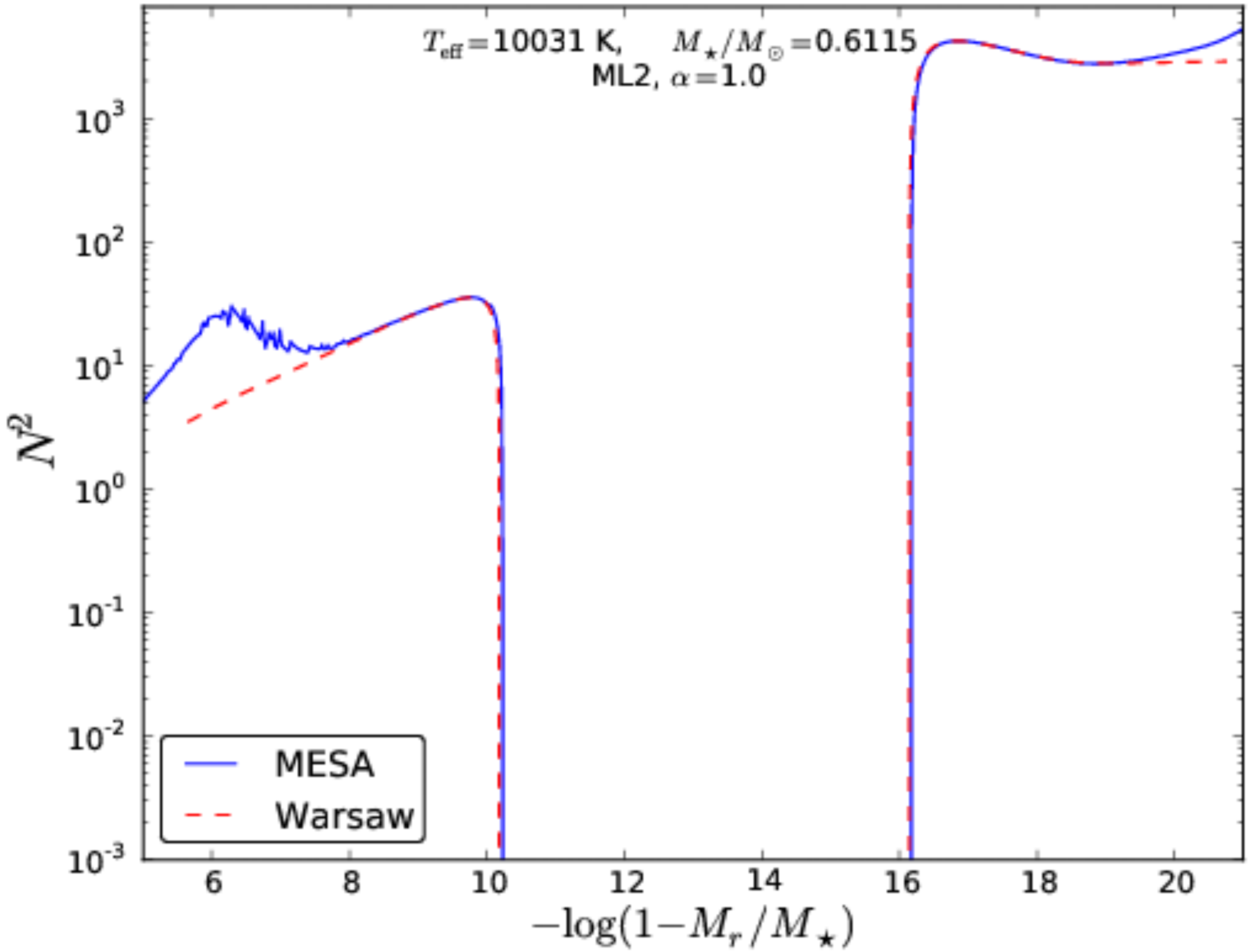
$$\Phi \equiv \left| \frac{L}{dL/dt} \right|$$

- You will use this in the long lab



Fontaine et al. (2001)

Comparison of MESA with other Codes



Useful namelist variables for WD evolution…

- &star_job:
  - relax_tau_factor = .true
  - relax_to_this_tau_factor = 37.5 (or some other number)
- &controls:
  - min_dq = 1d-20
  - mesh_delta_coeff = 0.75
  - which_atm_option = 'grey_and_kap' (or 'Paczynski_grey' or 'WD_tau_25_tables')
  - pulse_info_format = 'OSC'
  - add_atmosphere_to_pulse_info = .true.
  - use_Henyey_MLT = .true.
  - MLT_option = 'ML2'
  - mixing_length_alpha = 1.0
  - do_element_diffusion = .true.
  - calculate_Brunt_N2 = .true.

MESA Long Problem #1

- If you haven't already done this, download the file wd_problems1.tar from

mesastar.org -> FAQ ->

MESA Summer School 2012 lectures -> Mike Montgomery I

After detarring, you'll find the instructions are in mesa_long1.pdf. You will also need the files 0.611_from_2.5_z2m2.mod and inlist_cool

Full web address:

http://mesastar.org/documentation/mesa-summer-school-2012-lectures/mike-montgomery-i/wd_problems1.tar/view

MESA Long Problem #1

After detarring, you'll find the instructions are in mesa$_{l}$ong1.pdf. You will also need the files 0.611from2.5$_{z}$2m2.mod and inlist$_{c}$ool

After running the given model, randomly choose a model from ~/mesa/data/star$_{d}$ata/whitedwarf$_{m}$odels/

Choose from the models with the names matching the pattern *from*mod

Let me know how successful you were with these models, what "compromises" you had to make (i.e., increase meshdelta$_{c}$oeff, turn off diffusion…), and what the coolest T_{eff} you evolved to