The Impact of ^{22}Ne on White Dwarf Cooling

Outline

1. ^{22}Ne Diffusion in Liquid C/O WD Interiors.
2. Evolutionary Model.
3. ^{22}Ne and WD Cooling.
4. Observational Tests.

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Macroscopic Fields in C/O WD Interiors—Why ^{22}Ne Sinks

- ^{22}Ne Production and Abundance in C/O WDs:
  - CNO catalysts end up as ^{14}N when H burning ends.
  - During ^{4}He burning stage: $^{14}\mathrm{N}(\alpha,\gamma)^{18}\mathrm{F}(\beta^+)^{18}\mathrm{O}(\alpha,\gamma)^{22}\mathrm{Ne}$.
  - $X_{22} \approx Z_{init} = 0.02$ (for solar metallicity progenitors).
- Macroscopic Fields in WD interior:
  - Gravitational: $F_g = -Am_pg$
  - Electrostatic Field to Maintain Charge Neutrality:

$$\frac{dP}{dr} \approx \frac{dP_e}{dr} = -m_pAn_ig = -m_en_eg - n_eeE$$
$$\Rightarrow eE \approx \frac{A}{Z}m_pg = 2m_pg$$

- ^{12}C /^{16}O : Both have $A/Z \approx 2$, thus $F \approx 0$ on these species in hydrostatic balance.
- Trace species ^{22}Ne : $A/Z > 2$. $F \approx -2m_pg$ on ^{22}Ne ions
  $\Rightarrow$ ^{22}Ne ions sink! (Bravo 1992, Bildsten & Hall 2001).

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Evolution of WD Temperature and ^{22}Ne Abundance

- Time evolution of ^{22}Ne profile:

$$\frac{\partial \rho_{22}}{\partial t} + \nabla \cdot \mathbf{J}_{22} = 0$$

where

$$\mathbf{J}_{22} = -D\nabla\rho_{22} + \mathbf{v}\rho_{22} \qquad \text{and} \qquad \mathbf{v} = -v\hat{\mathbf{r}} \ .$$

  - If D is known, v can be determined by comparison of diffusive equilibrium and hydrostatic balance: $v = 2Dm_p g/kT$
  - Following Bildsten & Hall (2001), use the OCP Self-Diffusion Coefficient (Hansen, McDonald, & Pollock 1975): $D_s \approx 3\omega_p a^2\Gamma^{-4/3}$ where

$$a^3 = 3Am_p/4\pi\rho \qquad \omega_p = 4\pi n_i (Ze)^2/Am_p \qquad \Gamma = (Ze)^2/akT$$

  - ^{22}Ne profile evolved in a singly composed, static background WD model.
  - Once a region crystallizes, we *halt* ^{22}Ne sedimentation there.

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Evolution of WD Temperature and ^{22}Ne Abundance (cont.)

- Thermal evolution:

$$\frac{dT_c}{dt}\int_0^M \frac{C_v}{Am_p}dm = -L + L_g + \frac{l}{Am_p}\frac{dM_{crys}}{dt} \ .$$

  - C_v: liquid, Potekhin & Chabrier(2000); solid, Chabrier(1993).
  - L obtained from existing $L - T_c$ relations (Althaus & Benvenuto 1998).
  - Displacing a ^{22}Ne ion downward releases:

$$\Delta U = \int 2m_p g dr \ .$$

Power generated by ^{22}Ne settling:

$$L_g = \int_0^R 2m_p g \frac{j_{22}}{\rho_{22}} n_{22} 4\pi r^2 dr \ .$$

  - Latent heat per ion: $l = 0.77kT_c$.

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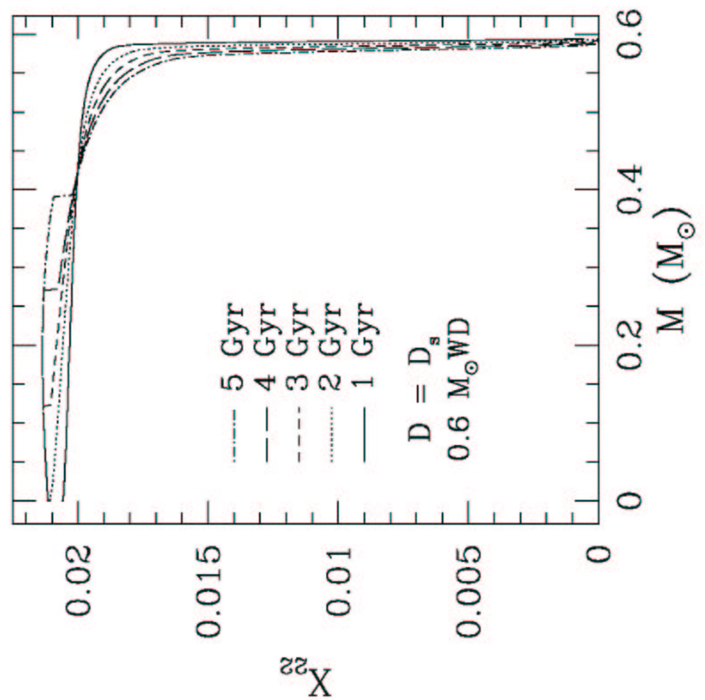
Results: Evolution of ^{22}Ne Profile



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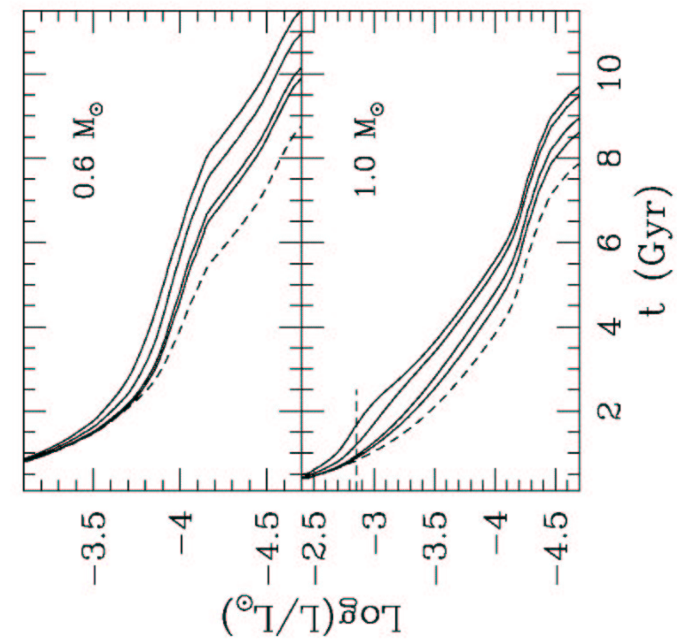
Results: WD Cooling Curves



Dashed: $D = 0$ and $l = 0$; Solid: $D = 0, D_s, 5D_s, \& 10D_s$ (bottom to top).

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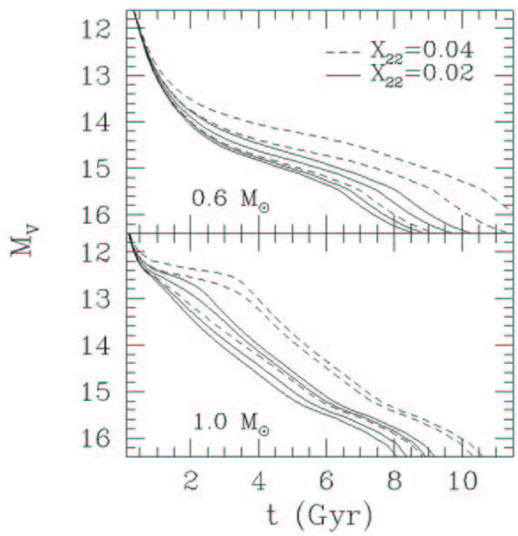
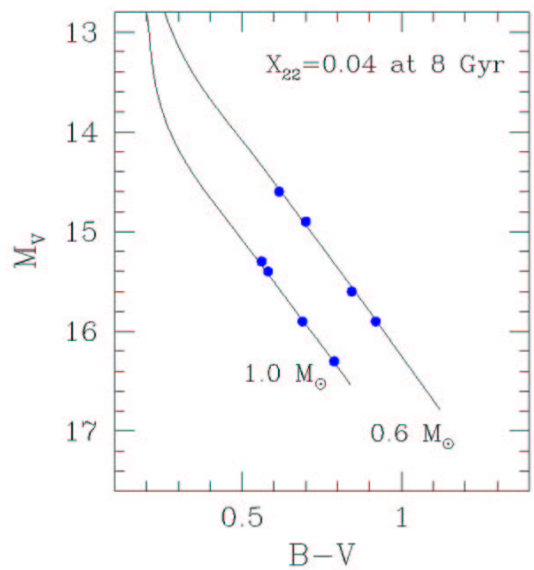
Observational Consequences in High Z Clusters



Cooling of WDs with high Z progenitors. $X_{22} = 0.04$ curves are representative of WDs in NGC 6791 (Chaboyer et al., 1999).



Changes in WD colors and magnitudes due to differing values of D for WDs in NGC 6791. Magnitudes and colors determined using Bergeron et al (1995) envelopes.

Full Details: astro-ph/0207623, to appear in ApJ, Dec. 1, 2002

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