White Dwarfs as Astro Particle Physics Laboratories

J. Isern
Institut de Ciències de l’Espai (CSIC-IEEC)
Institut d’Estudis Espacials de Catalunya (IEEC)

Collaborators:
S. Catalán (U. Hertfordshire)
E. García - Berro (UPC-IEEC)
M. Salaris (John Mores Liverpool U.)
S. Torres (UPC-IEEC)

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**WISPs**

*Weakly interacting sub-eV particles*

**Coincidences?**

- Neutrino masses: \( m_\nu \sim \text{meV} \)

- Dark Energy scale: \( \rho_\Lambda \sim (\text{meV})^4 \)

- Energy density of the Universe: \( \rho_{\text{today}} \sim (\text{meV})^4 \)

Some direct(ish) hints for WISP(ish)s

WD energy loss, (hidden) CMB, \( \gamma \)-transparency, Pamela, DAMA, CoGent...

See Kim & Carosi’10 for a complete review
\[ M_{bol} = -2.5 \log L + ctn \]

\[ \varepsilon_a = 1.08 \times 10^{23} \alpha \frac{Z^2}{A} T_7^4 F(\Gamma) \]

\[ \alpha = \frac{\frac{g_{ae}^2}{4\pi}}{4\pi} \]

\[ g_{ze} = 8.5 \times 10^{-11} c_e \left( \frac{m_a}{1eV} \right) \]

\[ c_e = \frac{\cos^2 \beta}{3} \]

\[ \frac{\dot{\Pi}_{obs}}{\dot{\Pi}_{mod}} \approx \frac{L_{mod} + L_x}{L_{mod}} \]

Isern et al 1993

\[ m_a \cos^2 \beta \approx 8.5 \text{ meV} \]

DFSZ axions
Bremmsstrahlung is dominant

Nakagawa et al 1987, 1988
The best fit is obtained for $m_a \cos^2 \beta \sim 5$ meV

Isern et al'08
Observed and predicted secular drift of G117-B15A

Corsico et al’01 (_______)
Bishkof-Kim et al’08
thick envelope (-----)
thin envelope (___)

Isern et al’10
Future experiments will be aimed to fill the gap (Baker et al’10)

Are the WD arguments compelling enough?

\[ g \sim \frac{1}{f_a} \]
White Dwarf Cooling

\[ L + L_v = - \int_{M_{WD}} c_v \frac{dT_c}{dt} \, dm - \int_{M_{WD}} T \left( \frac{\partial P}{\partial T} \right)_{V,x_0} \frac{dV}{dt} \, dm + (l_s + e_s) \dot{m}_c + L_e \]

1. \( n(L) \) is the observed distribution
2. \( \Phi \) is the IMF, \( \Psi \) is the SFR, \( t_{Gal} \) is the age of the Galaxy
3. \( T_{cool} \) is the cooling time, \( t_{MS} \) lifetime progenitor, \( \tau_{cool} \) characteristic cooling time, and hidden there is the IFMR

If the 3 ingredients are reasonably well known, it is possible to use the WDLF to test new physics.
Uncertainties:
• Internal structure
• Emission rates
• Transparency of the envelope
• Initial-final mass relationship
• IMF
• Pathological SFR
• Ages of MS progenitors
• Metallicities
• Observational systematics

Some examples:
• Axion [lf, sdp]
• Secular drift of $G_N$ [lf, sdp]
• Magnetic monopoles [lf]
• Neutrino magnetic momentum [lf, sdp]
\[ n(l) \propto \langle \tau_{cool} \rangle \int_{M_i}^{M_{\text{max}}} \Phi(M) \Psi(\tau) dM \]
Influence of the SFR

\[ \psi = 2, \text{ if } t < t_0 \]
\[ \psi = 1, \text{ if } t > t_0 \]

\[ t_0 = -10, -4, -2, -1, 0 \]

Small differences appear in case \( t_0 = -1 \).
If the peak coincides with the normalization (red line) the bright branch falls below the standard.

<table>
<thead>
<tr>
<th>$T_0$</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 (no bump)</td>
<td>Black dotted</td>
</tr>
<tr>
<td>-1</td>
<td>Black</td>
</tr>
<tr>
<td>-2</td>
<td>red</td>
</tr>
<tr>
<td>-3</td>
<td>Green</td>
</tr>
<tr>
<td>-4</td>
<td>Blue</td>
</tr>
</tbody>
</table>

$\psi = 3$, if $t_0 < t < t_0 + \Delta t$

$\psi = 1$, if $t < t_0$ ; $t > t_0 + \Delta t$
Non normalized LF

SFR, $\Psi = 1$
Burst, $\Delta \Psi = 2$, $\Delta t = 1$ Gyr
$t_0 = -1, -2, -3, -4$
(black, red, green, blue)

Dotted line: $\Psi = 1$

Dashed line represents the contribution of the burst
($\Psi = 3$, $\Delta t = 1$ at $t_0$)
The luminosity function of massive WD closely follows the LF. Irregularities are detectable!

\[ m_{\text{WD}} > 0.75 \, M_\odot \]
Dependence on the IMF

\[ \text{SFR}=1 \quad \text{and the age}=11 \ \text{Gyr} \]
Power-law IMFs. The Salpeter one corresponds to $-2.35$.

The WDLF is not very dependent on the IMF as far as low mass stars are effectively produced.
Solid: Salpeter; dotted: $\alpha = 0$

Black: $M_{\text{inf}} = 0.1$; red $M_{\text{inf}} = 1$

We need $M_{\text{inf}} > 1 \, M_\odot$ to introduce changes
Conclusions:

- Because of their simplicity, WDs are excellent complementary laboratories for testing new physics.
- The recent luminosity functions and the measurement of the secular drift of the pulsation period of DA V suggest that WDs cool down more quickly than expected. Axions or light bosons able to couple to electrons could account for this discrepancy.
- The results seem robust (for the moment) but more refinements are needed:
  * Observational LF independent from the SDSS (GAIA will be fundamental)
  * Improvement of the cooling models. Envelope is crucial
  * …