White Dwarfs as Astro Particle Physics Laboratories

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WISPs*

From J. Jaeckel
6th Patras Workshop on
AXIONS, WIMPS & WISPS 2010

*Weakly interacting sub-eV particles

Coincidences?

- Neutrino masses: $m_\nu \sim \mathrm{meV}$

$m_a \approx 0.6\ \mathrm{meV}\ (10^{10}\ \mathrm{GeV}/f_a)$

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

- Energy density of the Universe:

$$\rho_{\mathrm{today}} \sim (\mathrm{meV})^4$$

+

Some direct(ish) hints for WISP(ish)s
WD energy loss, (hidden) CMB, γ-transparency,
Pamela, DAMA, CoGent…

See Kim & Carosi'10
for a complete review

$$M_{bol} = -2.5\log L + ctn$$

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

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

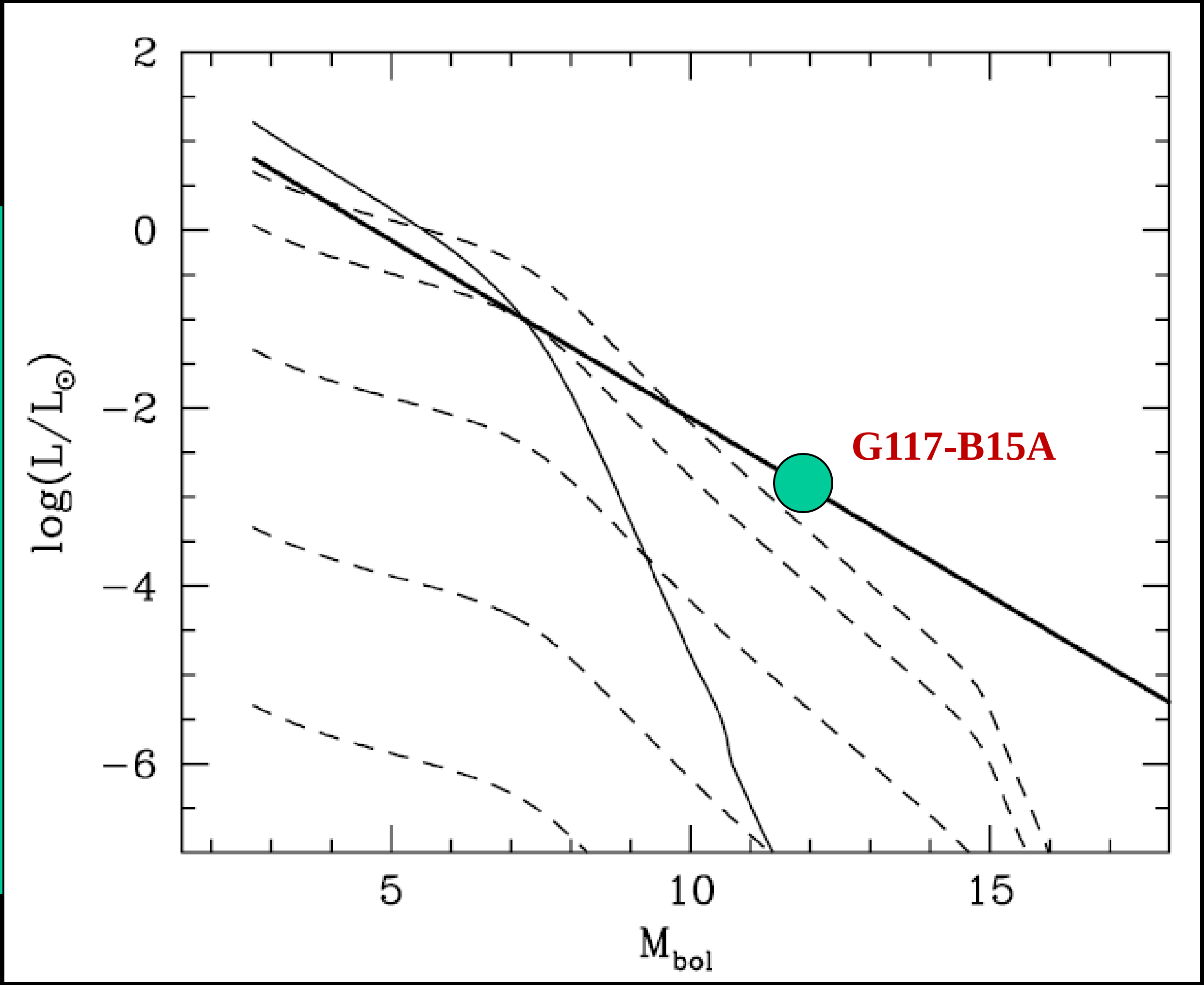
$$g_{ze} = 8.5{\cdot}10^{-11}c_e\left({m_a}/{1eV}\right)$$

$$c_e = \frac{\cos^2\beta}{3}$$

$$\frac{\dot{\Pi}_{obs}}{\dot{\Pi}_{\mathrm{mod}}} \simeq \frac{L_{\mathrm{mod}} + L_x}{L_{\mathrm{mod}}}$$

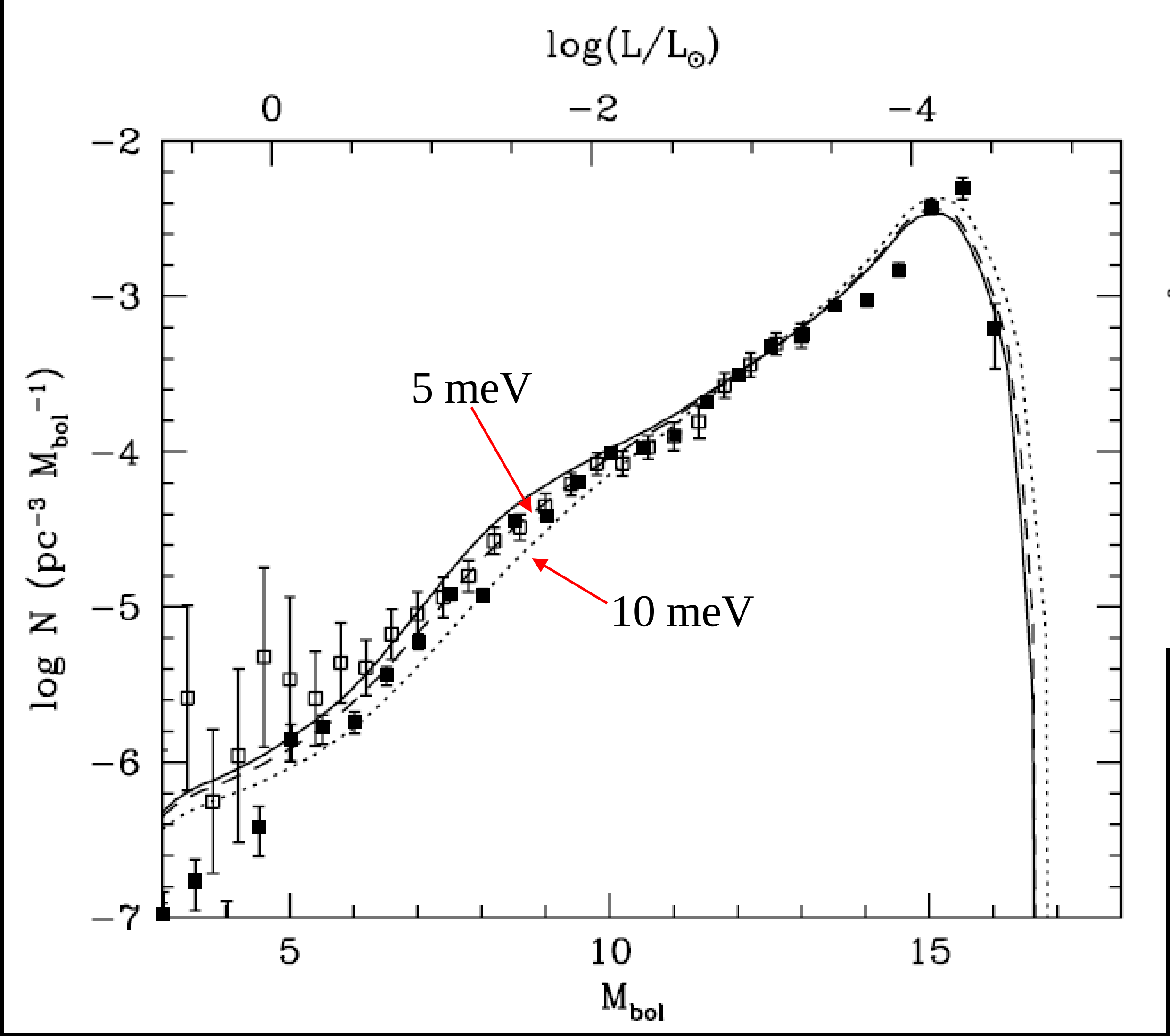
Isern et al 1993

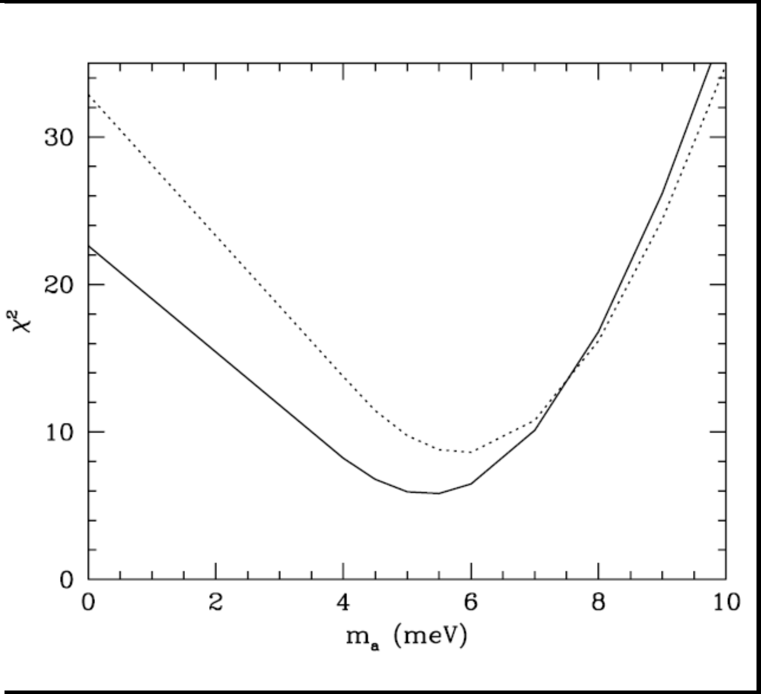
$$m_a\cos^2\beta \simeq 8.5\ \mathrm{meV}$$



DFSZ axions
Bremmsstrahlung is dominant

Nakagawa et al 1987, 1988

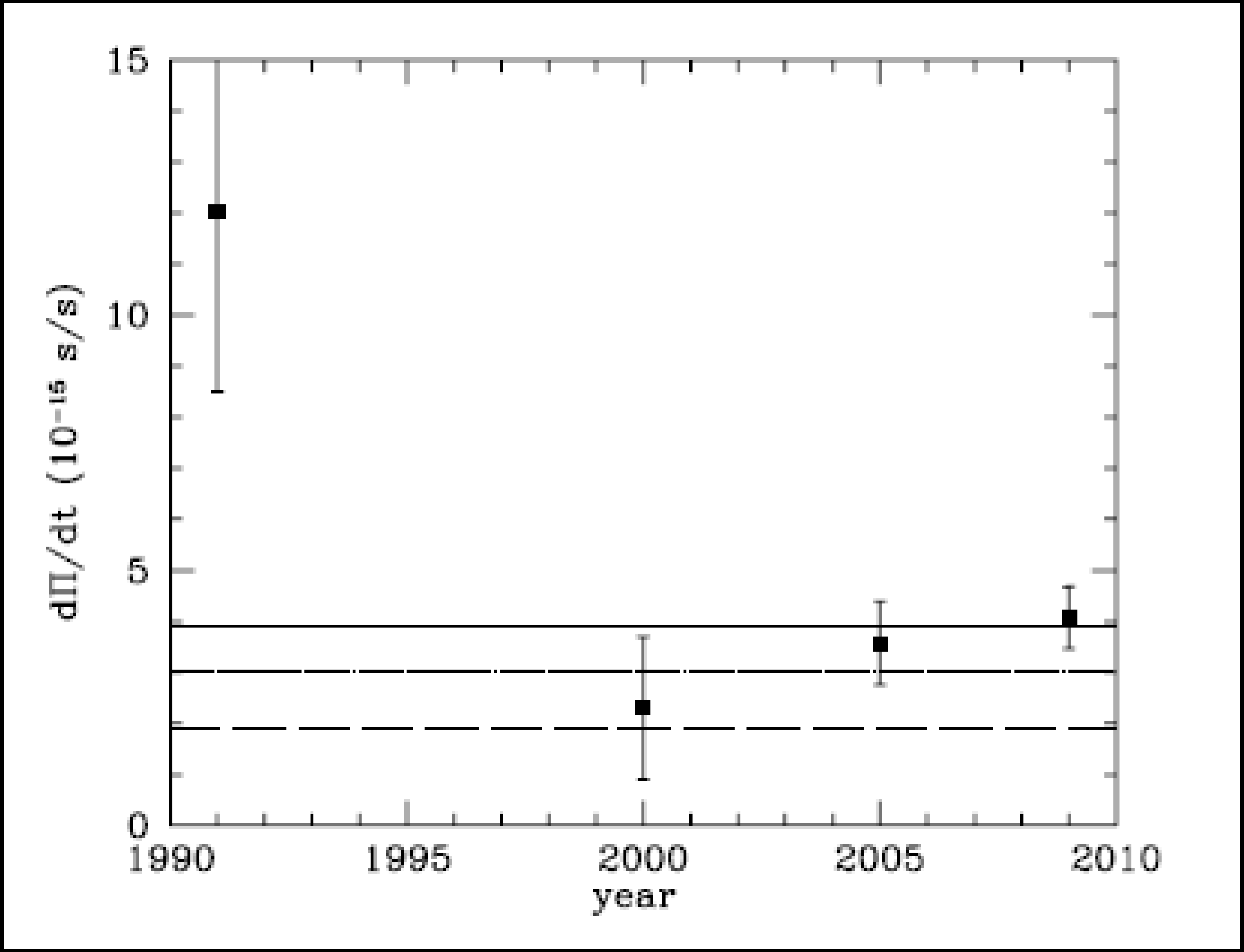




Isern et al'08

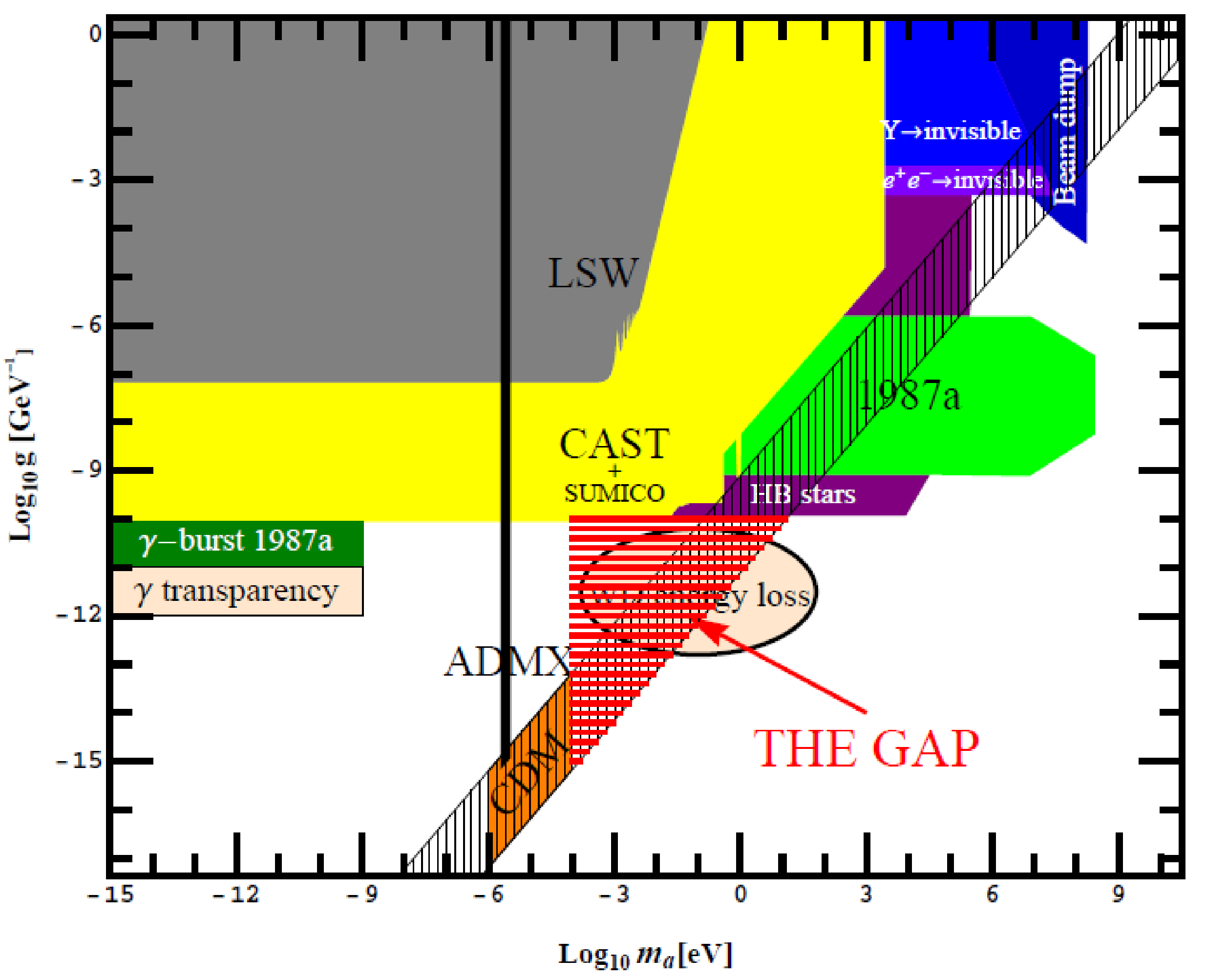
The best fit is obtained for $m_a \cos^2\beta \sim 5$ meV

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



Baker et al'10

$g \sim 1/f_a$

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

Are the WD arguments compelling enough?

White Dwarf Cooling

$$L + L_\nu = -\int_{M_{WD}} c_V \frac{dT_c}{dt}\, dm - \int_{M_{WD}} T \left(\frac{\partial P}{\partial T}\right)_{V, x_0} \frac{dV}{dt}\, dm + (l_s + e_s)\dot{m}_c$$

$+ L_e$

$+ \varepsilon_e$

To solve this equation it is necessary a $L(T_C)$ relationship that depends on the properties of the envelope

$$n(L) = \int_{M_l}^{M_U} \Phi(M)\Psi(t_{Gal} - t_{cool} - t_{MS})\tau_{cool}\, dM$$

1. n(L) is the observed distribution
2. Φ is the IMF, Ψ is the SFR, t_{Gal} is the age of the Galaxy
3. T_{cool} is the cooling time, t_{MS} lifetime progenitor, τ_{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 exemples:

- Axion [lf, sdp]
- Secular drift of G_N [lf, sdp]
- Magnetic monopoles [lf]
- Neutrino magnetic momentum [lf, sdp]
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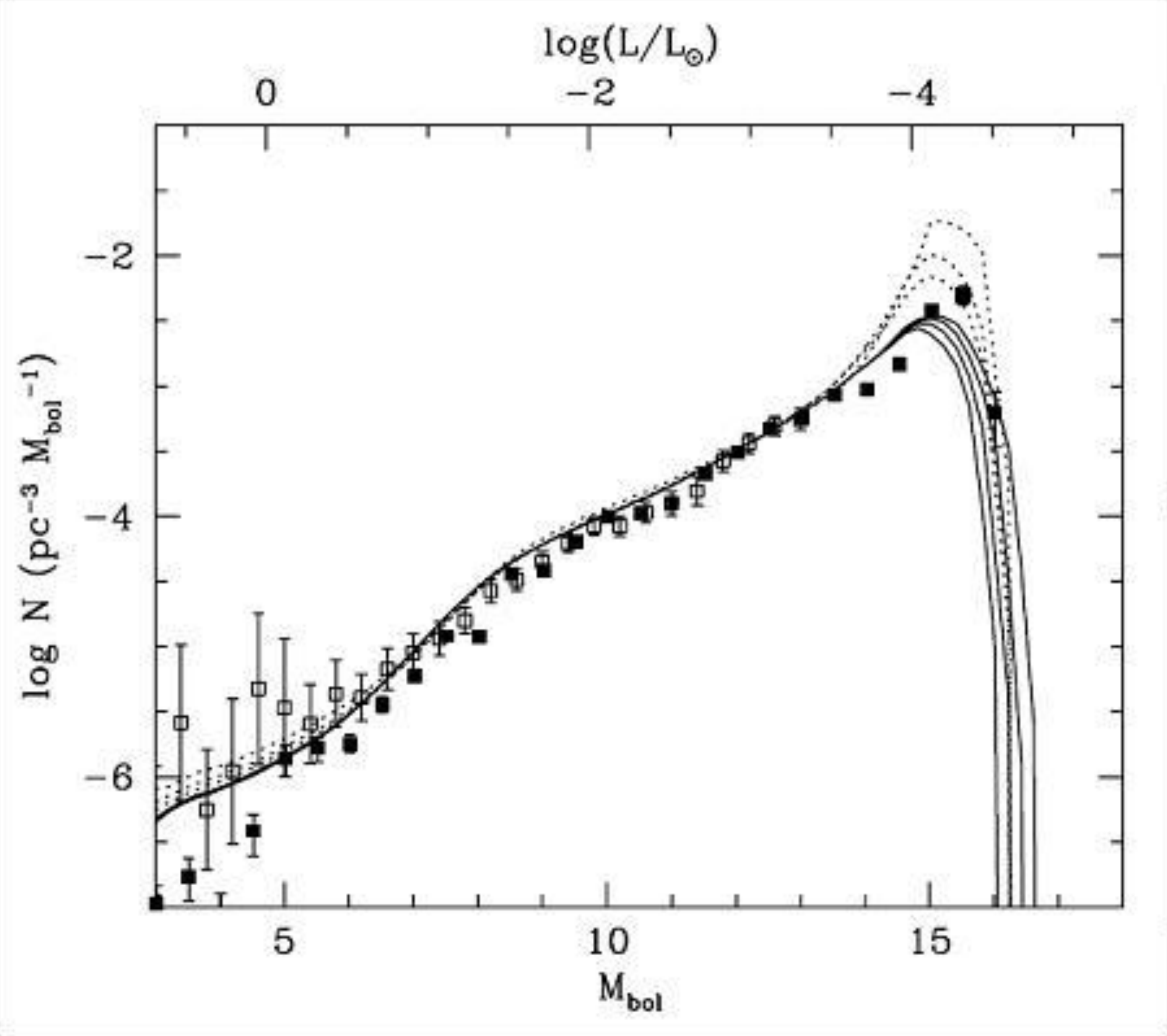
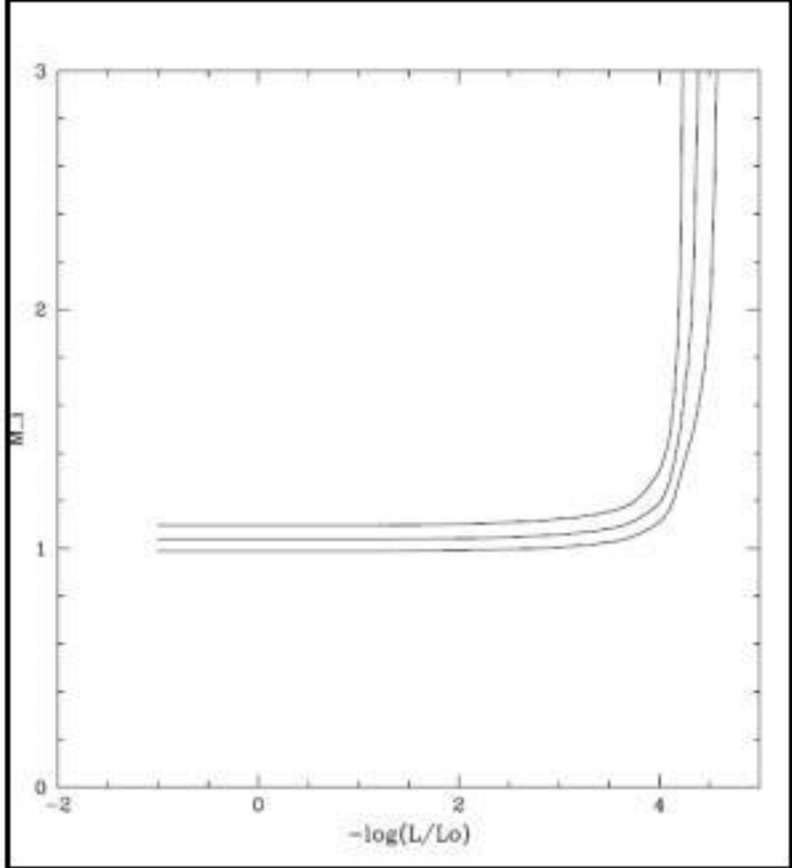
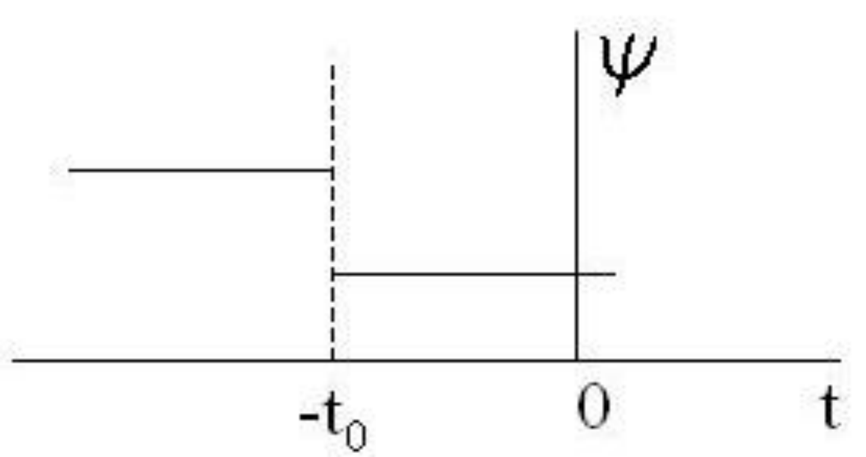




$$n(l) \propto \langle \tau_{cool} \rangle \int_{M_i}^{M_{\max}} \Phi(M)\Psi(\tau)dM$$

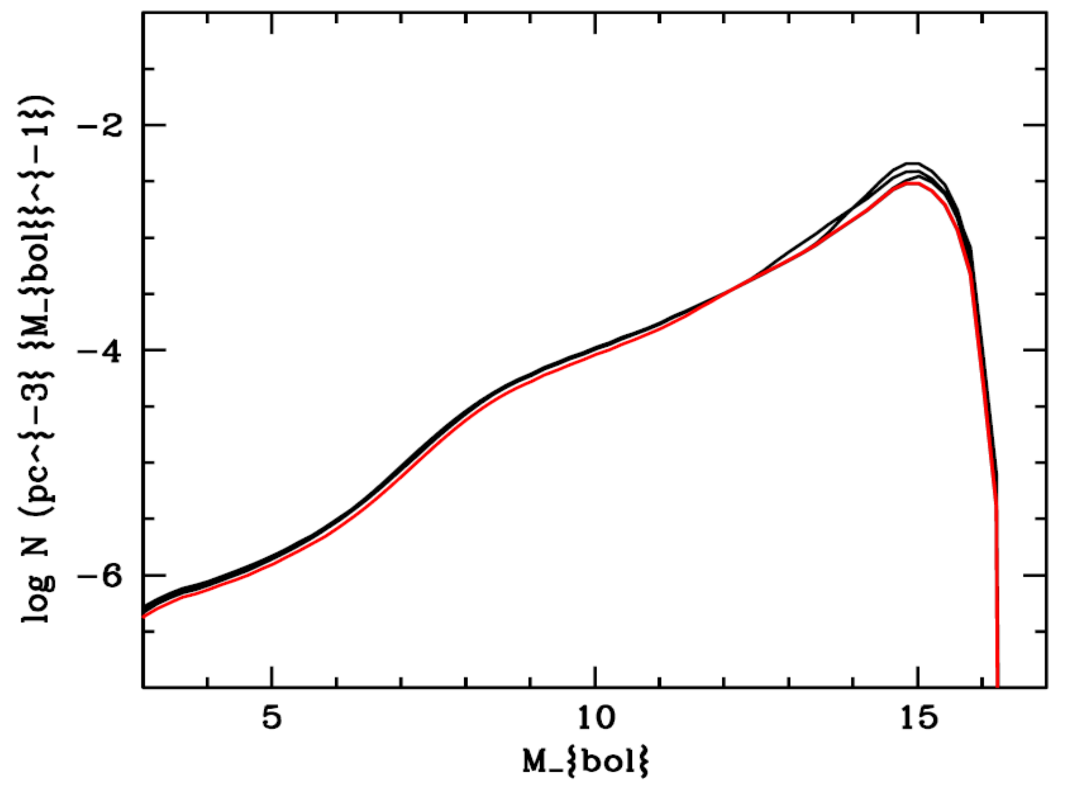
Influence of the SFR



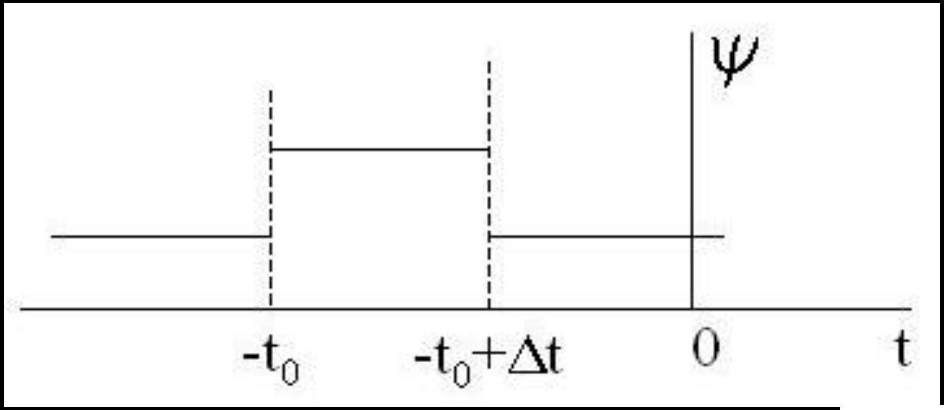
ψ = 2, if t < t_0

ψ = 1, if t > t_0

t_0 = -10, -4, -2, -1, 0



Small diferences appear in case t_0 = -1

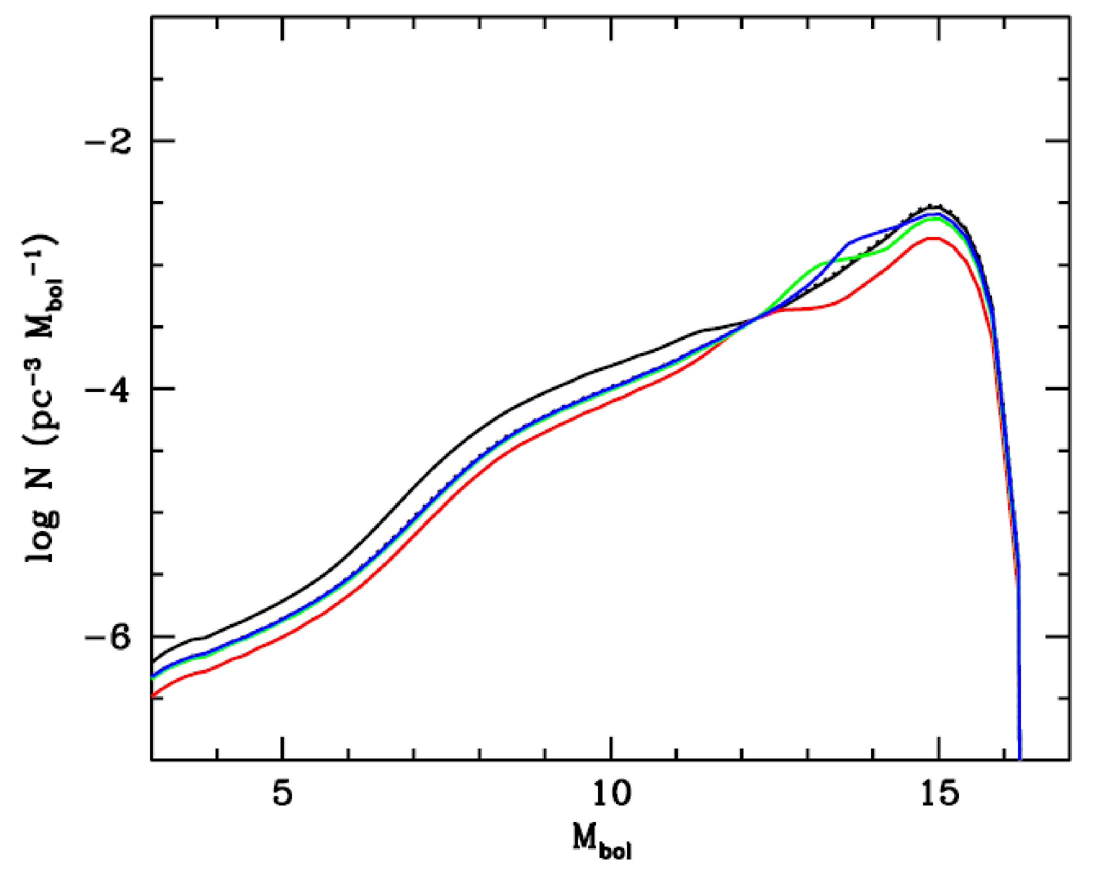


If the peak coincides with the normalization (red line) the bright branch falls below the standard

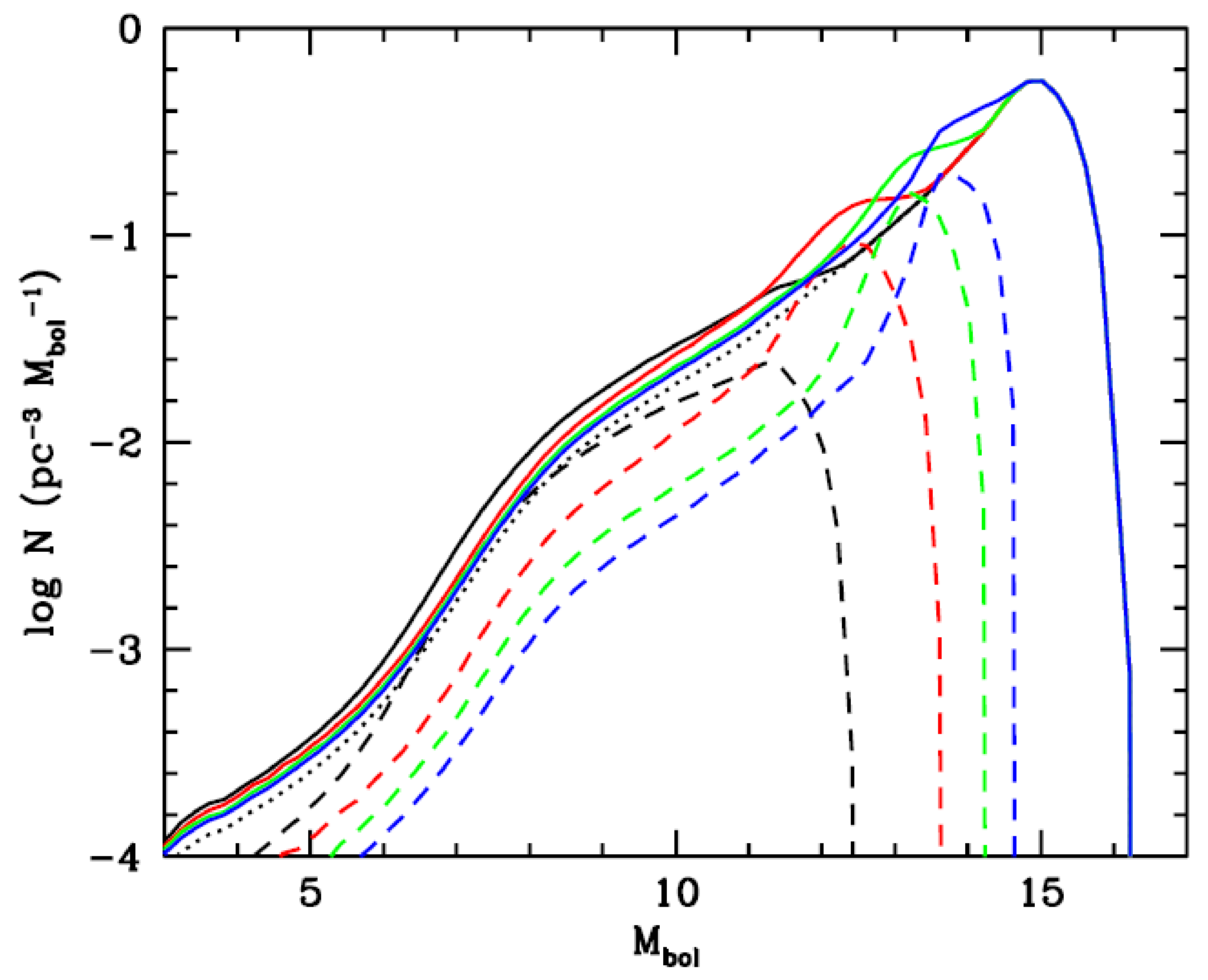
T_0	**Color**
0 (no bump)	Black dotted
-1	Black
-2	red
-3	Green
-4	Blue

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

$$\psi = 1, \text{ if } t < t_0 \;;\; t > t_0 + \Delta t$$



Non normalized LF

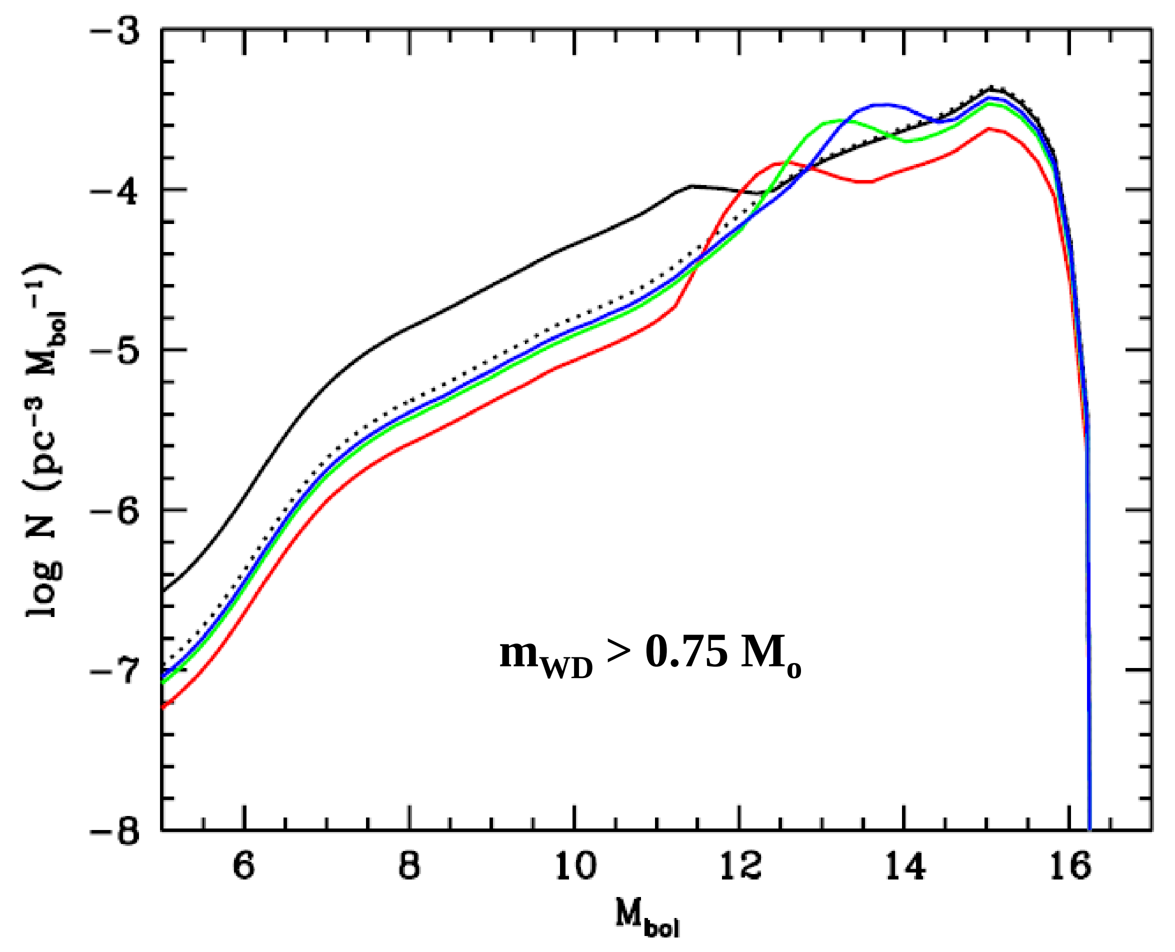


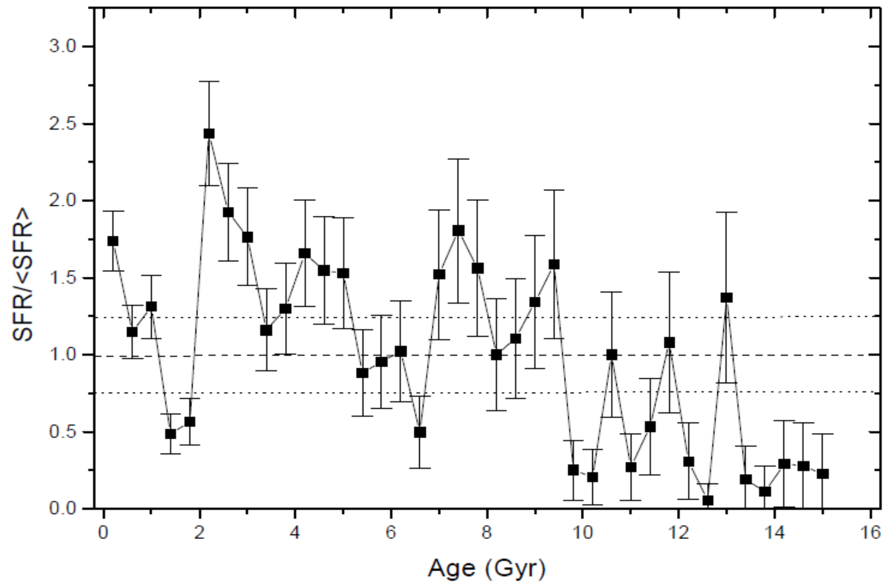
SFR, Ψ = 1
Burst , ΔΨ=2, Δt=1 Gyr
t_0 = -1, -2, -3, -4
(black, red, green,blue)

Dotted line : Ψ = 1

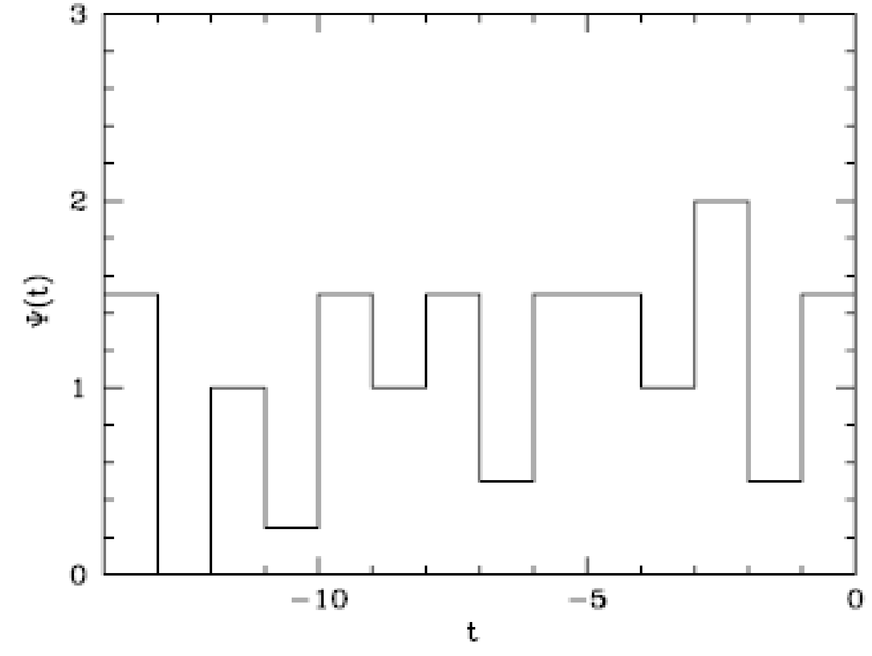
Dashed line represents the contribution of the burst (Ψ = 3, Δt=1 at t_0)

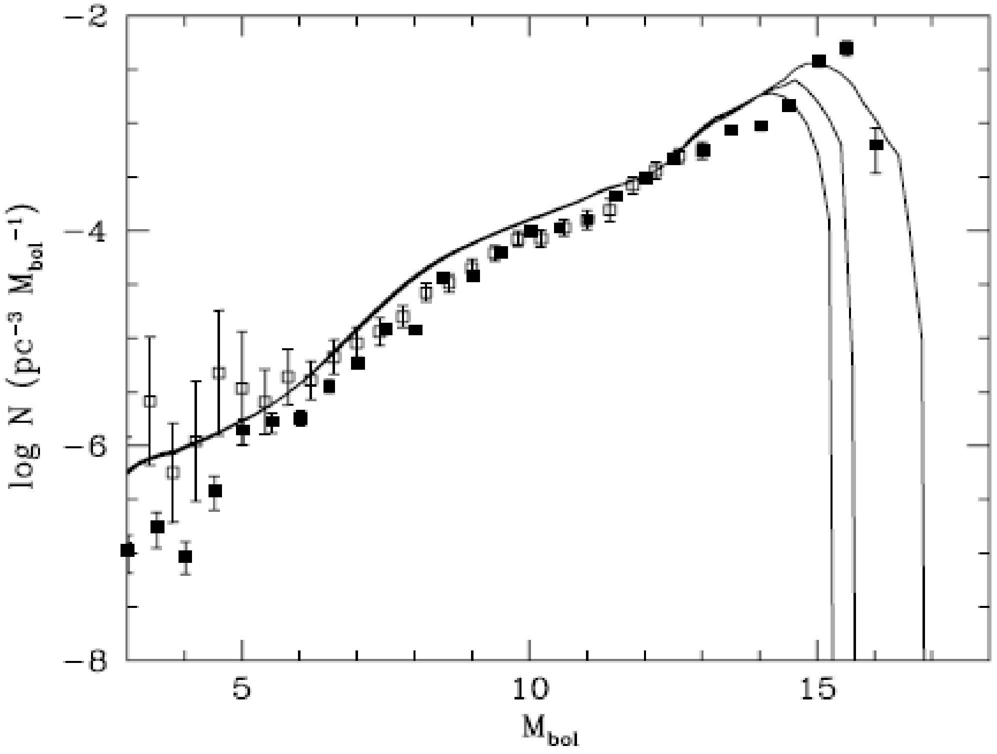
The luminosity function of massive WD closely follows the LF Irregularities are detectable!



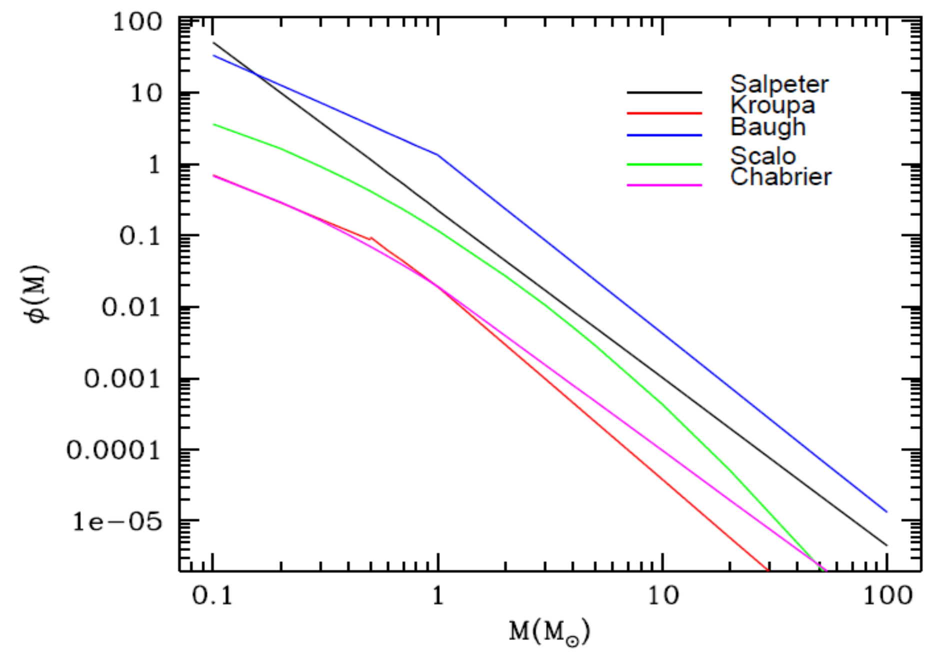


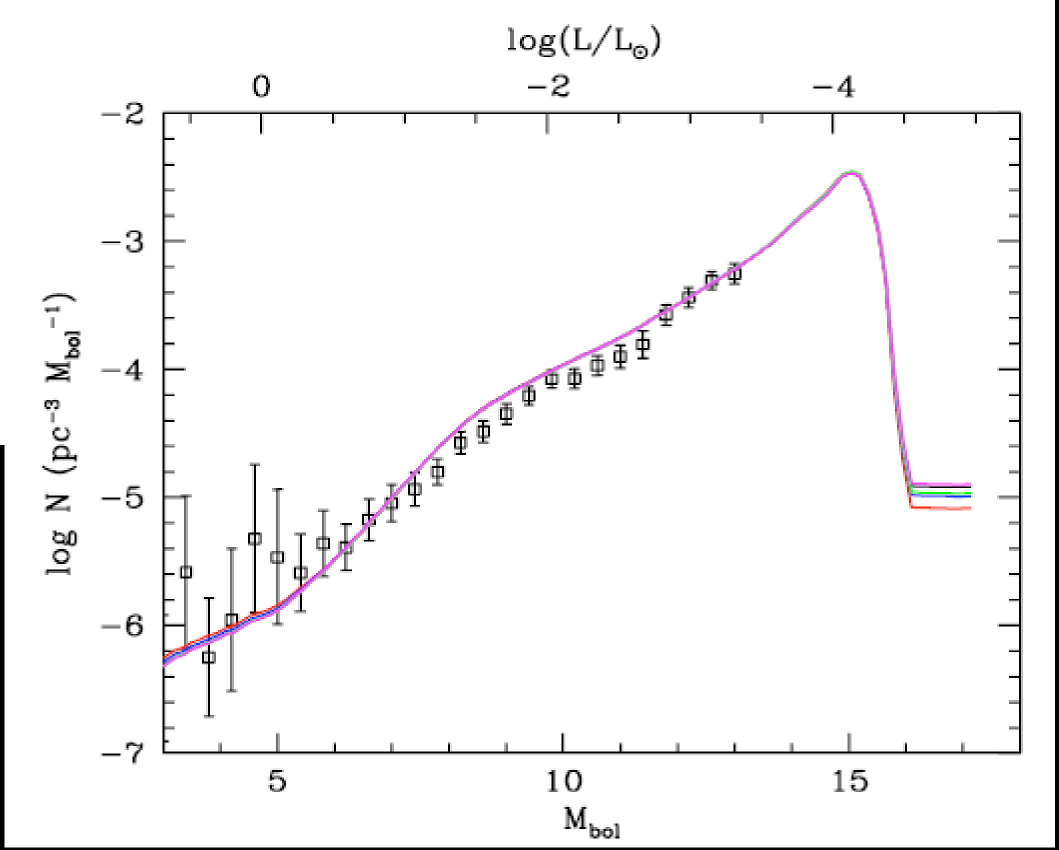
Rocha-Pinto et al'00



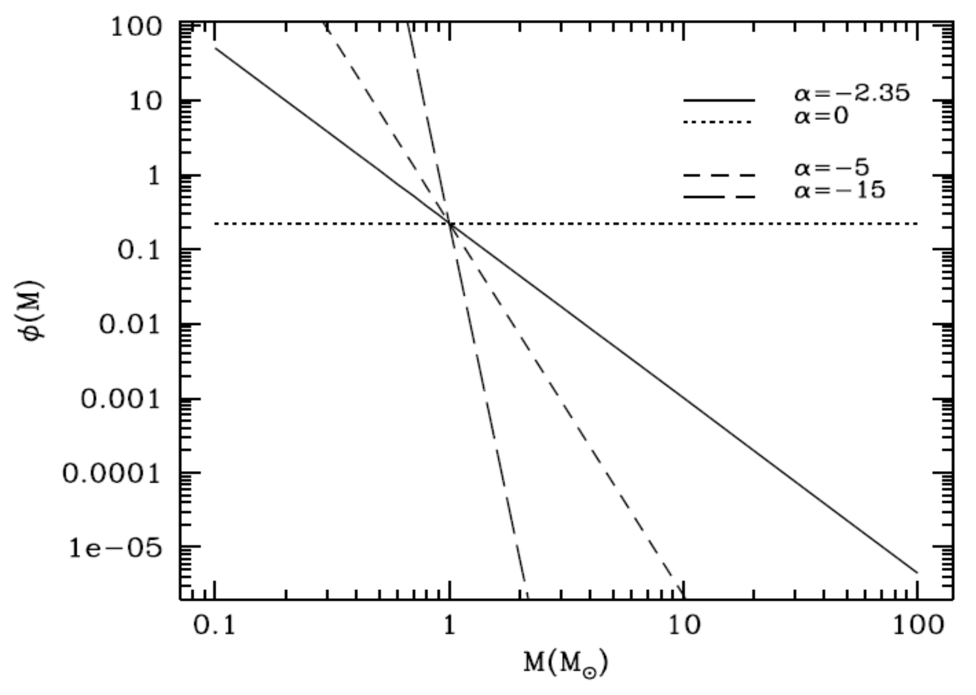


Dependence on the IMF

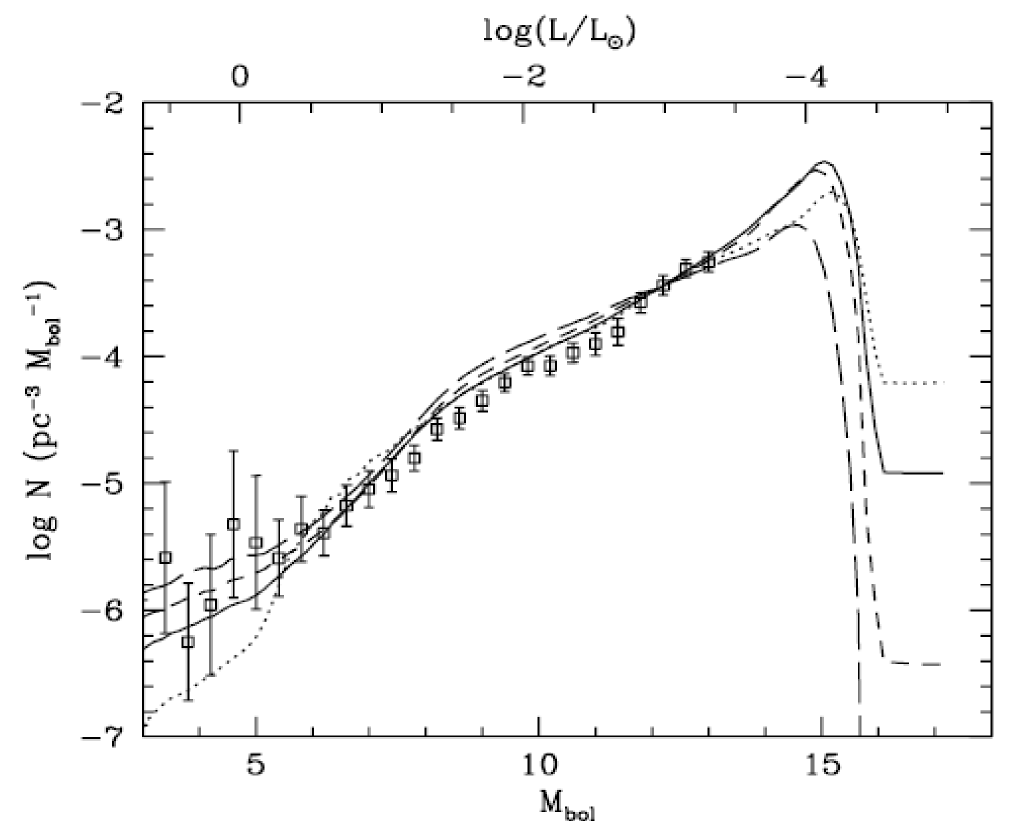




SFR=1 and the age=11 Gyr

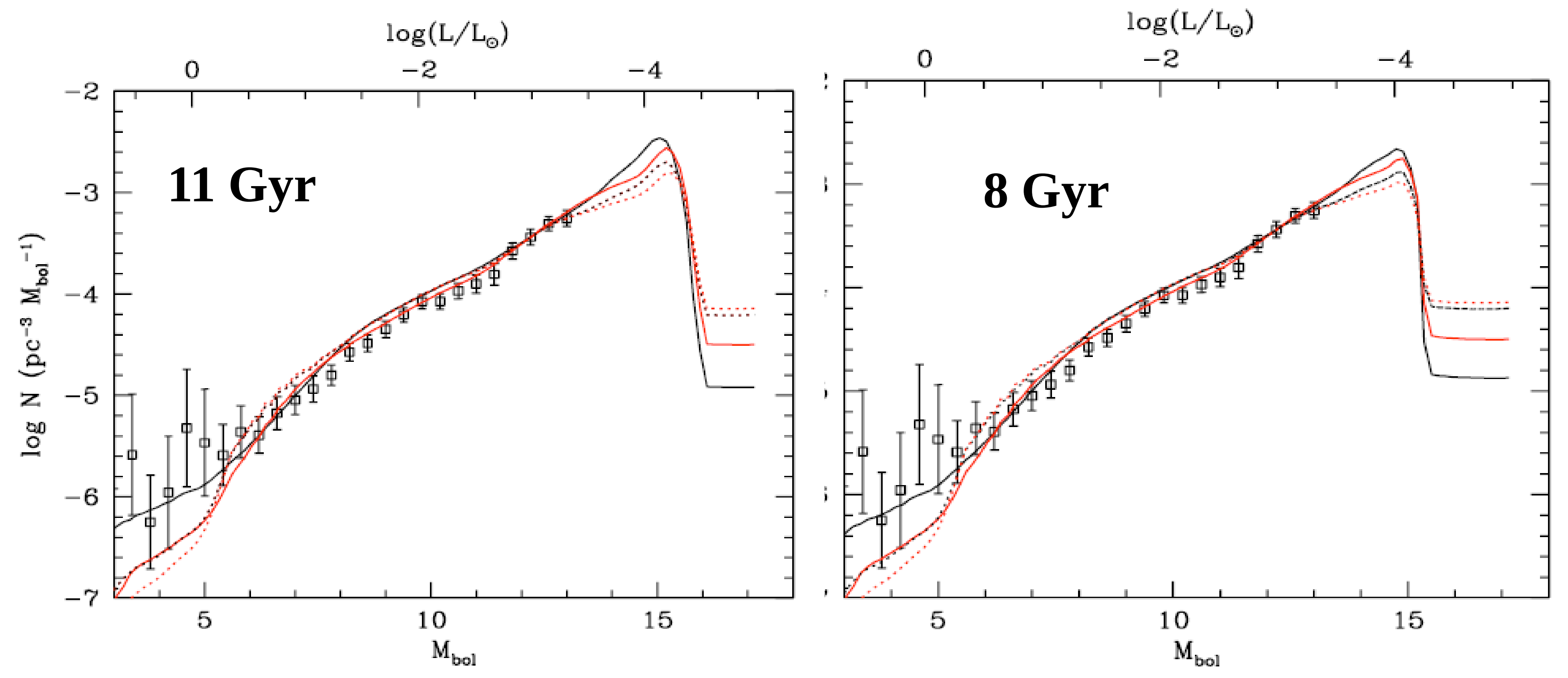


Power—law IMFs. The Salpeter one corresponds to –2.35



WDLFs obtained with the different IMFs

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_{inf} =0.1; red M_{inf} = 1

We need M_{inf} > 1 M_o 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 DAV 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
* …