Axion effect on the minimum stellar mass that experiences central carbon burning, Mup

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Why axions ?

- Axions are:
  (1) **predicted (BSM)** to solve the strong CP problem
  (2) **dark matter candidates** (in general, ALP-Axion Like Particles)

- **Stars are good Laboratories for particle physics**: Axions may be produce at stellar temperatures carrying energy out

- Astrophysical **observational evidences of extra-energy sink in stars**... by axions/ALPs (?)

- Next generation of ALP experimental searches, **ALPSII & IAXO**, will look in the range relevant for astrophysical constraints

Why Mup ?

Initial Stellar Mass

Mup $\sim 8\ M_{\odot}$

M_{CCSNe} $\sim 10\ M_{\odot}$

$\sim 1.5\ M_{\odot}$

Low & Intermediate Mass stars

- CO WDs
- SNIa

$\sim$ 8–10 $M_{\odot}$

- ONe WDs
- ECSNe

Massive stars

- CCSNe

(SNIIP, IIL, Ib, Ic...)

Axions processes & rates

DFSZ (*Dine-Fischler-Srednicki-Zhitnitsk*) axion model
(GUT) → **axions couple to photons & fermions**

Coupling constants: $g_{a\gamma}$ g_{ae}

Energy loss rates

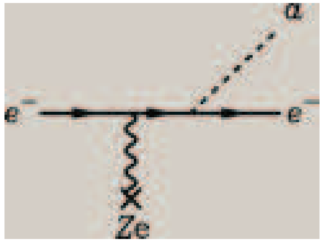
$\varepsilon_{a\gamma} \propto g_{a\gamma}^2$

$\varepsilon_{ae} \propto g_{ae}^2$

Electrons:

Compton

Bremsstrahlung



Photons:

Primakoff

Our approach

- **Assume that axions (DFSZ) exist**, with values of the coupling constants to photons and electrons close to current upper limits/hints :

  $g_{a\gamma} \leq 0.66\ 10^{-10}$ **GeV^{-1}** $g_{ae} \leq 4.3\ 10^{-13}$

  $g\gamma_{10} \leq 0.66$ **GeV^{-1}** $ge_{13} \leq 4.3$

  Ayala+ 2014, Straniero+ 2016 **Isern+ 2018**, 2008, Miller Bertolami+2014,

  CAST collaboration 2017 Viaux+2013

- **Stellar evolution** with **Primakoff, Compton & Bremsstrahlung axion processes** →

  FUNS stellar evolution code Straniero+ 06, Cristallo+09,11

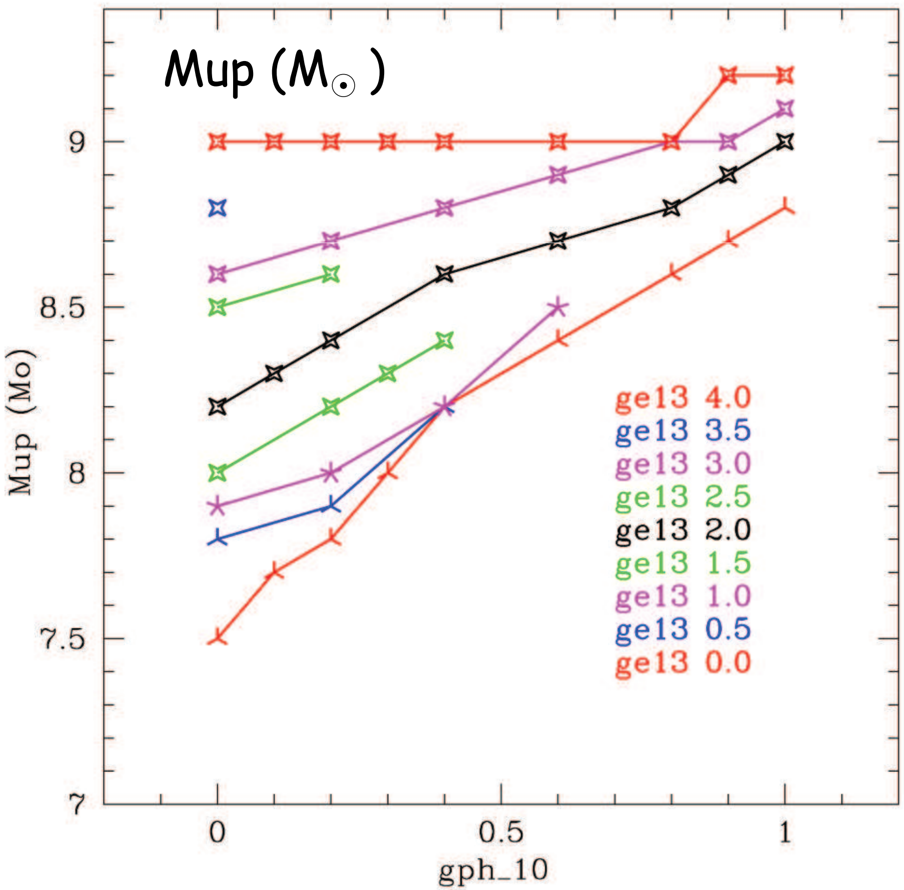
  Axion rates from Nakawaga+ 1987, 1988; Raffelt & Dearborn 1987, Raffelt & Weiss, 1995, Raffelt 1996 **Updated by us !!**

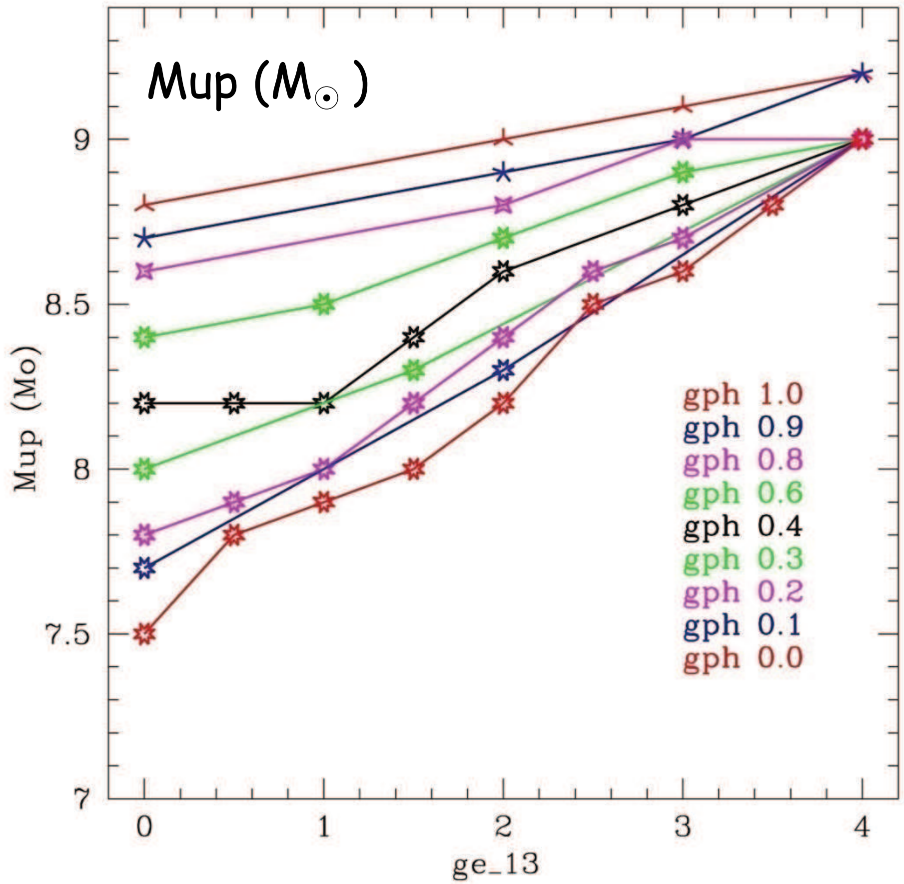
- **Explore axion impact on Mup** (the minimum mass that experiences carbon burning)

Stellar evolution from pre-MS to CO core cooling or C-burning

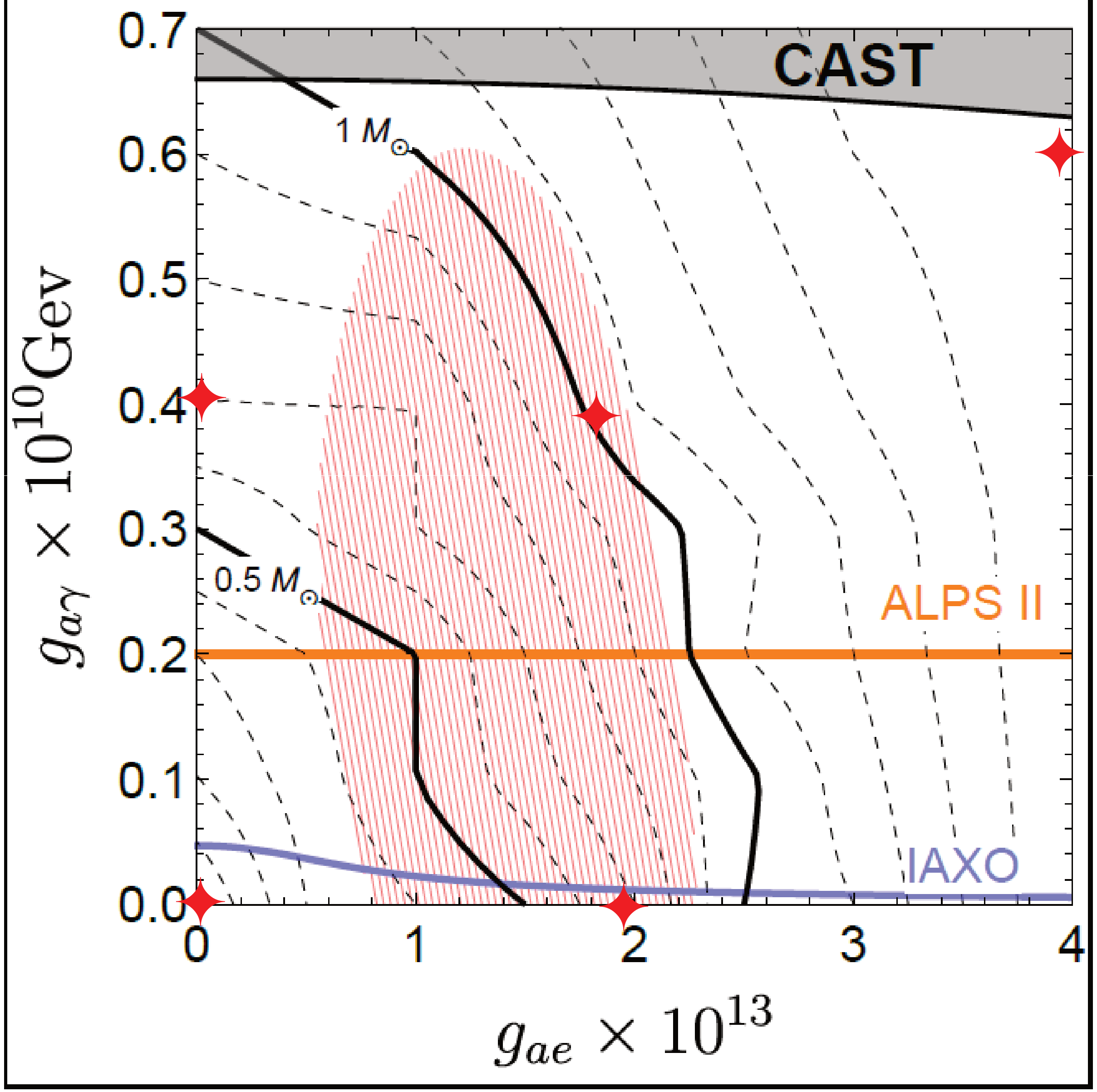
M_{ini}: 7.0 - 11 $M_\odot$ ge_{13}: 0 - 4 Δge_{13} = 0.5

Y=0.26 Z=0.014 $g\gamma_{10}$: 0 - 1 GeV^{-1} $\Delta g\gamma_{10}$ = 0.1 GeV^{-1}





ΔMup contours (ΔMup=0.1$M_\odot$)



Impact of axions on Mup

In red 2σ region of astrophysical hints (WDs + HB + RGB)

ΔMup ≥ 0.5 $M_\odot$ expected to be significant

Why axions increase Mup ?

- 2nd Dup is anticipated (due to faster evolution) → stop the growth of the CO core mass for a given M_{ini}

ge_{13}	$g\gamma_{10}$ GeV^{-1}	Mup ($M_{\odot}$)	M_{WD} ($M_{\odot}$)	Age (Myr)
0.0	0.0	7.5	1.05	39.5
2.0	0.0	8.2	1.08	34.3
0.0	0.4	8.2	1.09	32.5
2.0	0.4	8.6 (+1.1)	1.11 (+0.06)	29.5 (-25%)
4.0	0.6	9.0 (+1.5)	1.12 (+0.07)	25.6 (-35%)

- The mass of the CO core needed to reach C-ignition conditions increases (due to CO core cooling):

ge_{13}	$g\gamma_{10}$ GeV^{-1}	M_{CO} ($M_{\odot}$)
0.0	0.0	1.07
0.0	0.4	1.10 (+0.03)
2.0	0.4	1.13 (+0.06)
4.0	0.6	1.15 (+0.08)

Observational constraints related to Mup

- Minimum progenitor mass of CCSNe

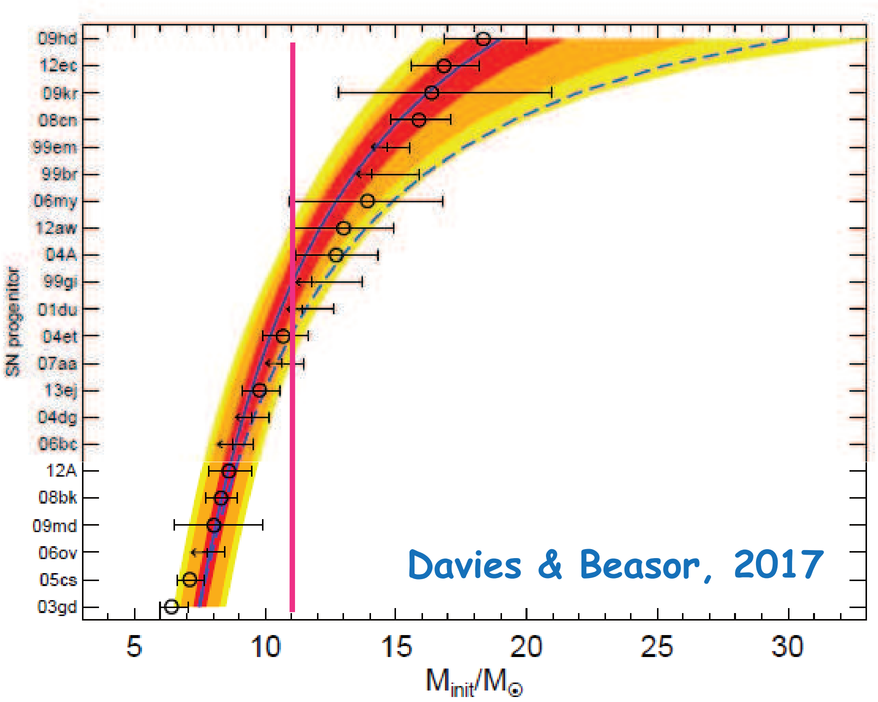
- High mass end of the Initial-Final Mass Relation
  (i.e. maximum mass of an isolated CO WD)

- CCSN rates/SNIa rates △ ΔMup ~ 1.0 - 1.5 $M_\odot$
  (ECSN, NS, BH)

- DTD (Delayed Time Distribution) SNe Ia
  young population observed < 180Myr (< 30Myr)
  Aubourg+ 2008, Brandt + 2010

CO WD of 0.8 $M_\odot$ ← No axions ~ 4.0 $M_\odot$ ~ 194.8 Myr
← g_{e13}4 $g_{\gamma10}$ 1GeV^{-1} ~ 6.0 $M_\odot$ ~63.8 Myr

➢ Minimum mass of CCSNe (SNIIP) progenitors



Observations: $7.5^{+0.3}_{-0.2}\ M_\odot$

Smartt, 2015, Davies & Beasor, 2018

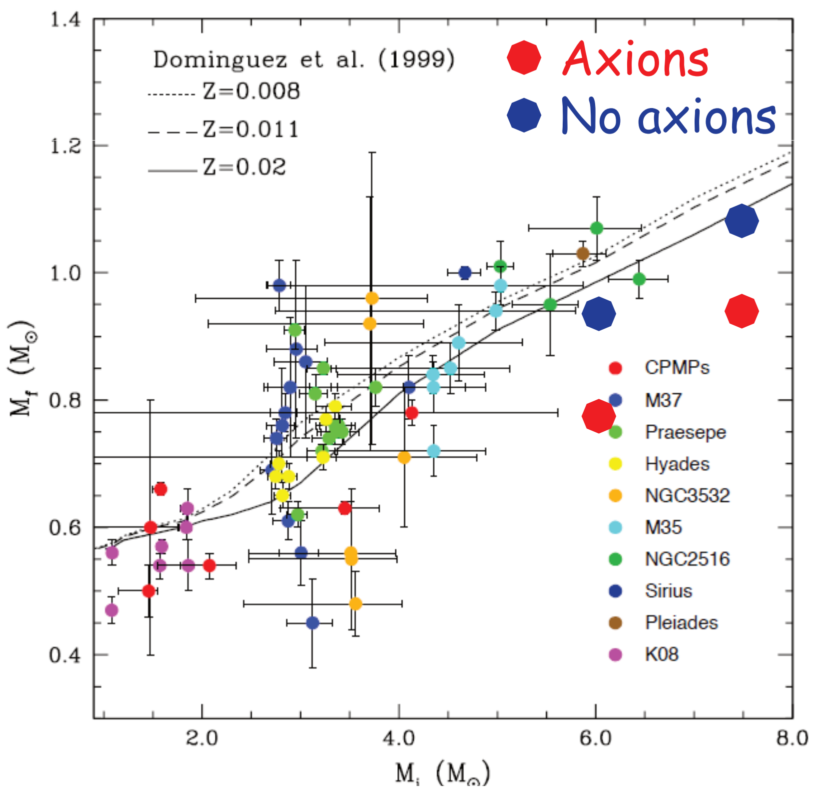
Models > $9\text{-}10\ M_\odot$

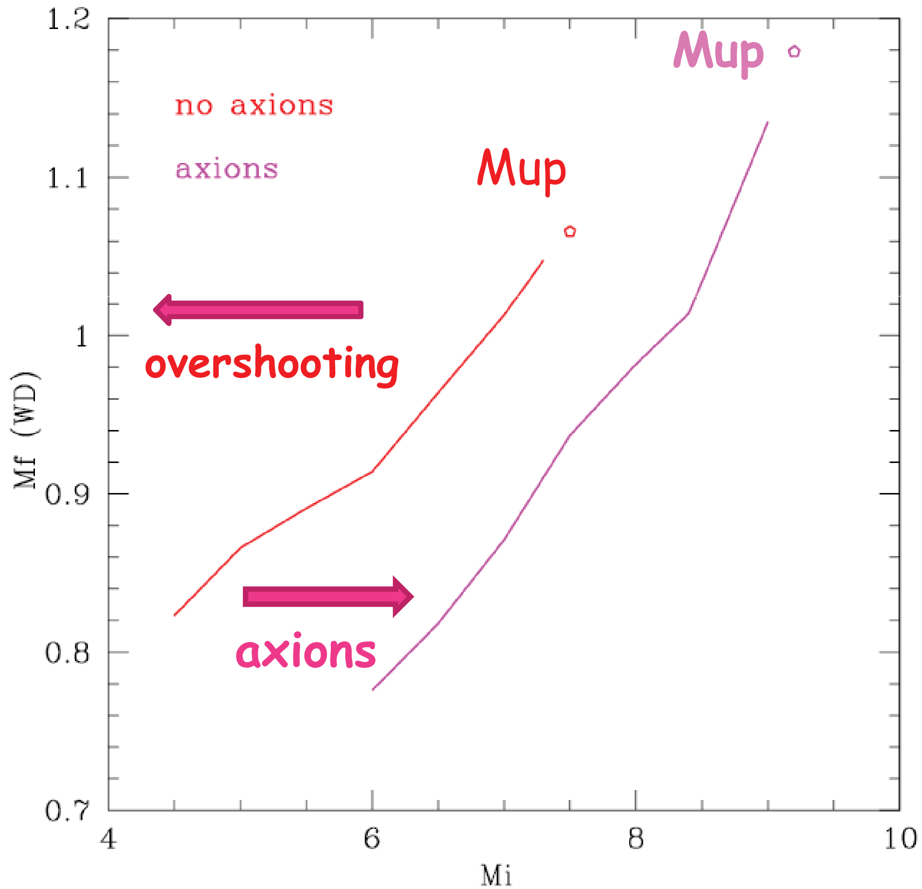
Doherty+ 2015, Heger+ 2003, Poelarends+ 2008

→ *Already in tension ?*

Not much room, if any, to increase Mup →
So, not much room for axions
with $g_{e13} > 2.5$ & $g_{\gamma 10} > 0.6\ \mathrm{GeV}^{-1}$
if $\Delta Mup \geq 1.0\ M_\odot$ is excluded

High mass end of the semi-empirical Initial-Final Mass Relation (IFMR)





Courtesy of Jordi Isern (Catalán, Isern, García-Berro & Ribas, 2008)

Summary

Axions may increase Mup: 7.5 → 8.6 $M_\odot$ (9.2) $M_\odot$
for current constraints (DFSZ) on g_{ae} & $g_{a\gamma}$
also CO core mass needed for C-ignition
M_{CO}: 1.09 → 1.13 (1.16) $M_\odot$

So, **influence:**

→ High mass end of the IFMR →

- **CO WD maximum mass** ↑: 1.11 (1.14) $M_\odot$
- **SNIa rates** ↑ (more stars end as CO WDs)
- **Younger SNIa progenitors (~Age/3)**
- **CCSN rates** ↓

→ **Mup & minimum progenitor mass of CCSNe** ↑
Not leaving much room (if any) for axions with
with $ge_{13} > 2.5$ & $g\gamma_{10} > 0.6$ GeV^{-1}

Main theoretical uncertainties:
treatment of convection & $^{12}C+^{12}C$ rate