# Axion and hidden photon constraints from a solar data global fit

(Vinyoles N., Serenelli A., Villante F., Basu S., Redondo J. & Isern J.)

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Núria Vinyoles Vergés

Space Science Institute (CSIC-IEEC)

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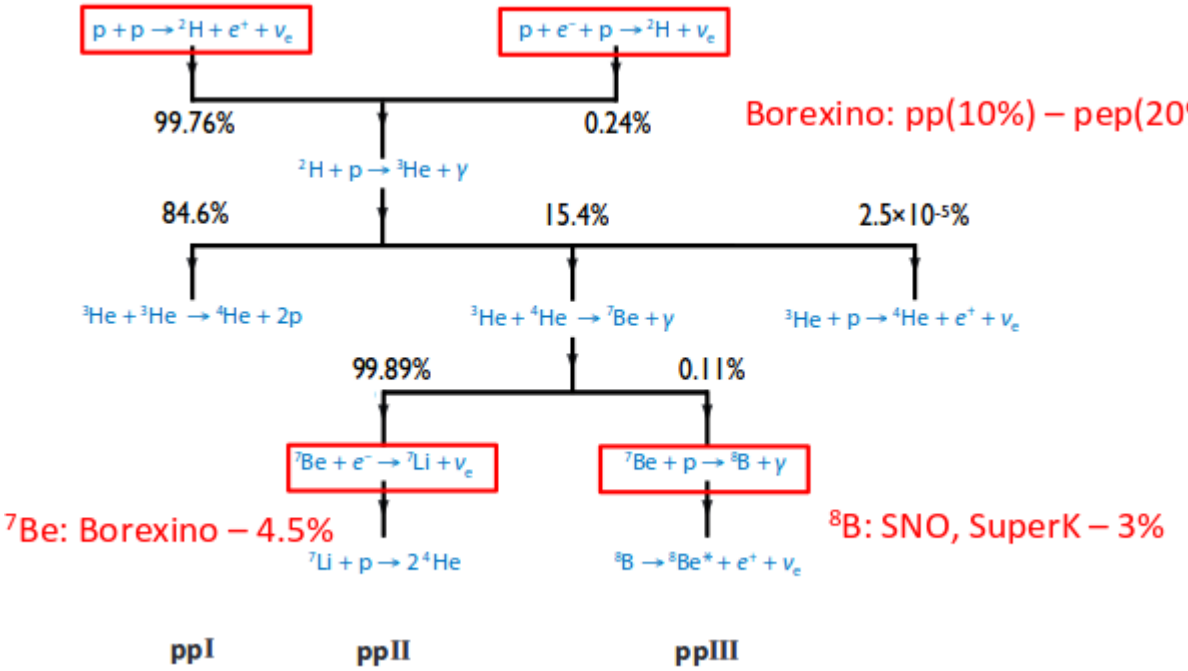
# Objectives

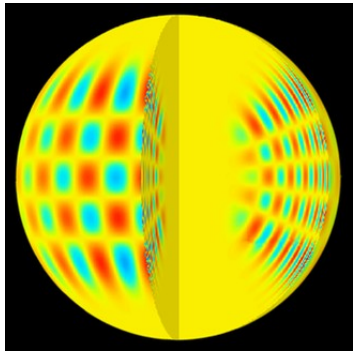
- General statistical approach to constraint properties of particles making use of all the available information of the Sun
  - Sun observations
  - Solar Models
- New solar constraints for axion and hidden photons
- Extended to any kind of particle with relevant effects in the Sun

# The Sun: Observations

- Neutrino fluxes




- Helioseismology



$$c^2 = \frac{\Gamma_1 p}{\rho}$$

# Standard Solar Models (SSM)

- **CONSTRAINTS**
  - Solar luminosity $\longrightarrow L_\odot = 3.8418 \cdot 10^{33}\ \mathrm{erg\ s^{-1}}$
  - Solar Radius $\longrightarrow R_\odot = 6.9598 \cdot 10^{10}\ \mathrm{cm}$
  - Metal-to-hydrogen ratio

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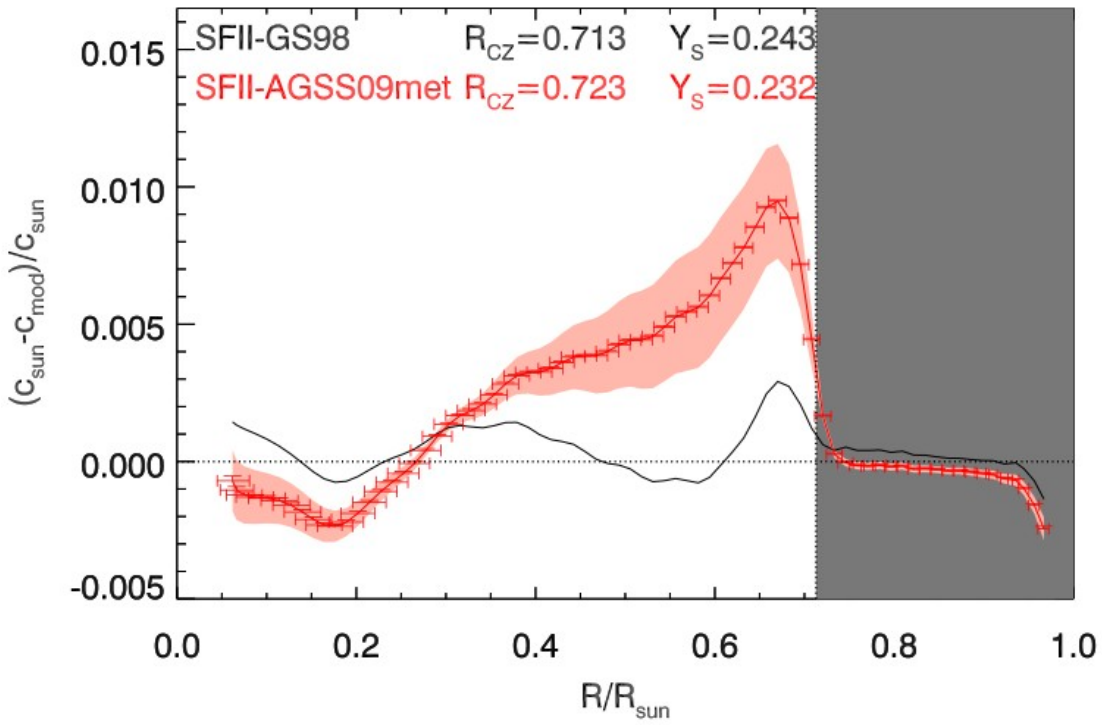
↓

**SOLAR ABUNDANCE PROBLEM!**

# SSM: Solar Abundance Problem

*Grevesse et al. 1998* **(GS98):** 1-D solar atmosphere models

*Asplund et al. 2009* **(AGSS09):** 3-D hydrodynamical models of the solar atmosphere




| Element | GS98 | AGSS09+met |
|---|---|---|
| C | 8.52 | 8.43 |
| N | 7.92 | 7.83 |
| O | 8.83 | 8.69 |
| Ne | 8.08 | 7.93 |
| Mg | 7.58 | 7.53 |
| Si | 7.56 | 7.51 |
| Ar | 6.40 | 6.40 |
| Fe | 7.50 | 7.45 |
| Z/X | 0.0229 | 0.0178 |

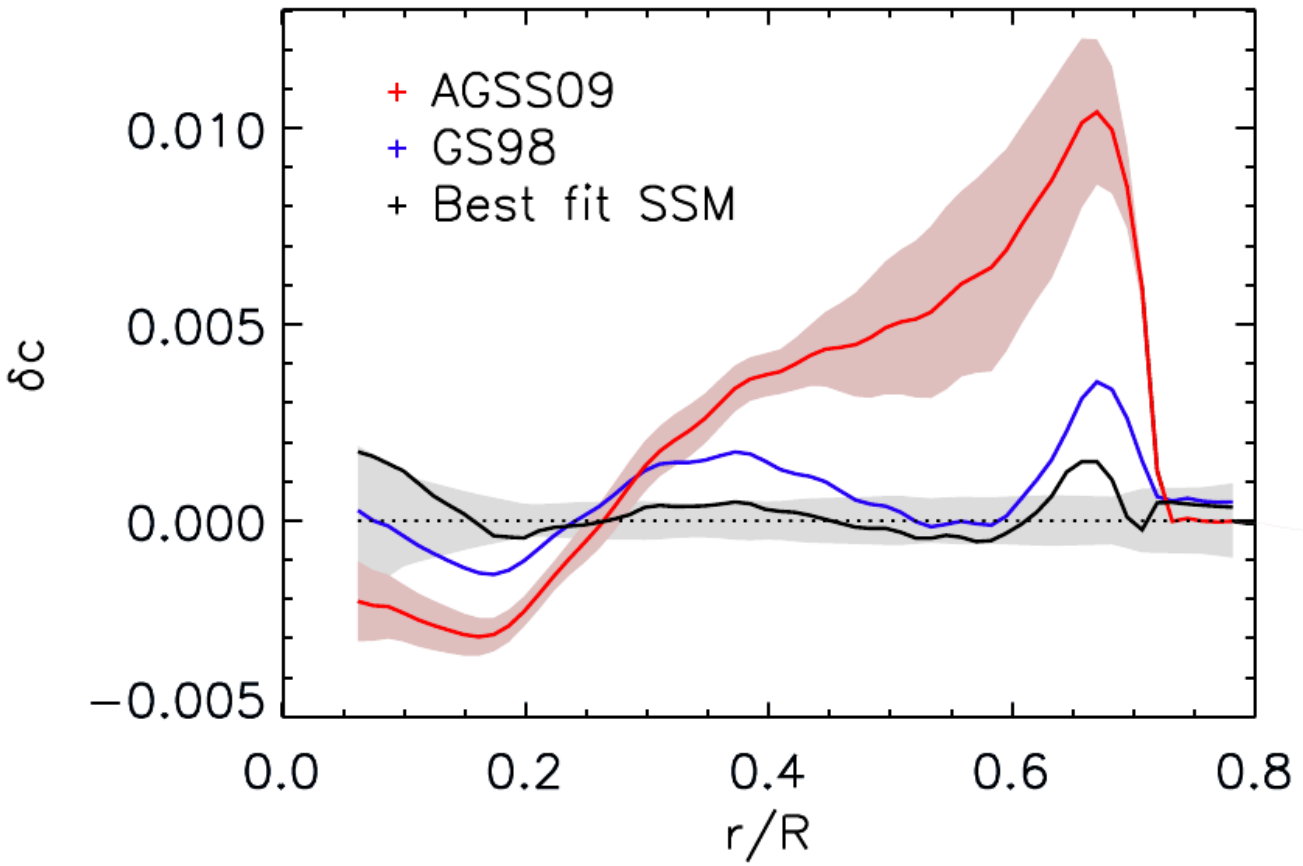
# SSM: Best fit model

*Villante et al 2014:*

Minimize for the composition:

$\delta_{ref}$

$\delta_{vol}$




Best fit model reproduces the thermal stratification of the Sun

# Models with axions and HPs

- Models with axions ⟶ Primakoff effect

$$\epsilon_{a\gamma} = \frac{g_{a\gamma}^2}{4\pi}\frac{T^7}{\rho}F(\kappa^2)$$

- Longitudinal hidden photons ⟶ $\gamma \to \gamma'$ oscillations

$$\epsilon_{hp} = \frac{\chi^2 m^2}{e^{\omega_P/T}-1}\frac{\omega_P^3}{4\pi}\frac{1}{\rho}$$

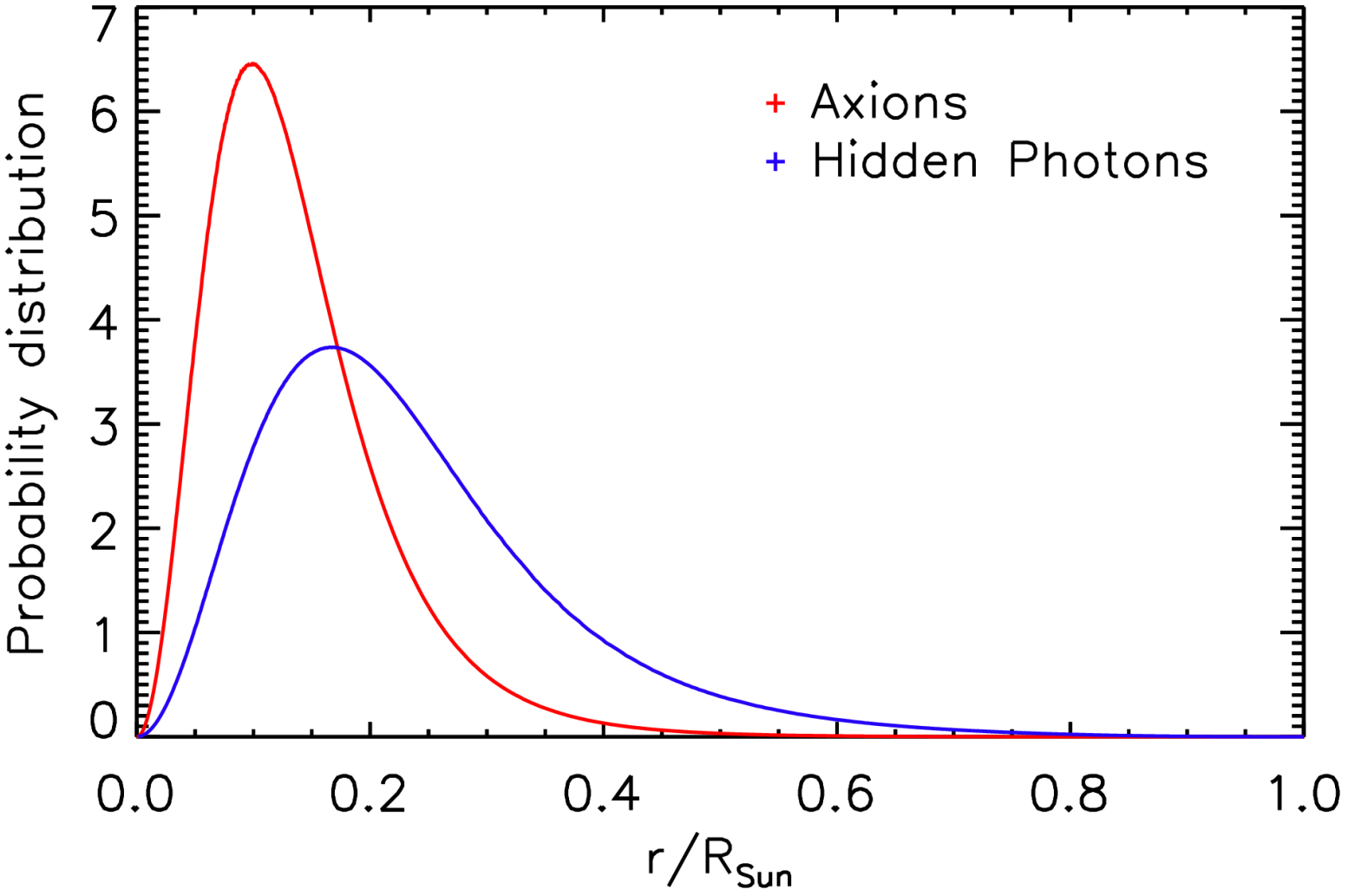
For the Sun:

$$\omega_p < 0.3\,\mathrm{keV}$$

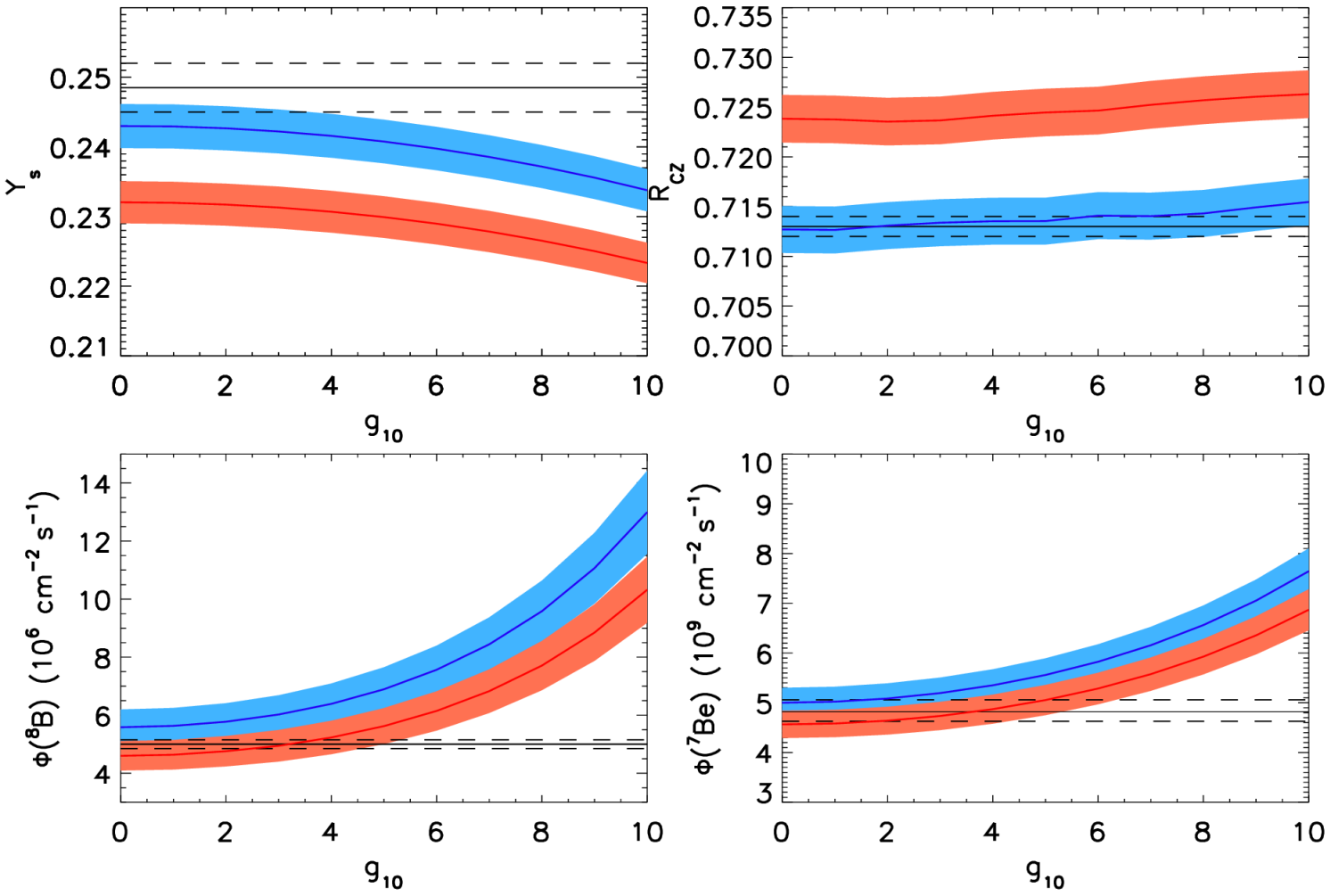
Then:

$$m_{HP} < 0.3\,\mathrm{keV}$$

# Results: Energy loss distribution

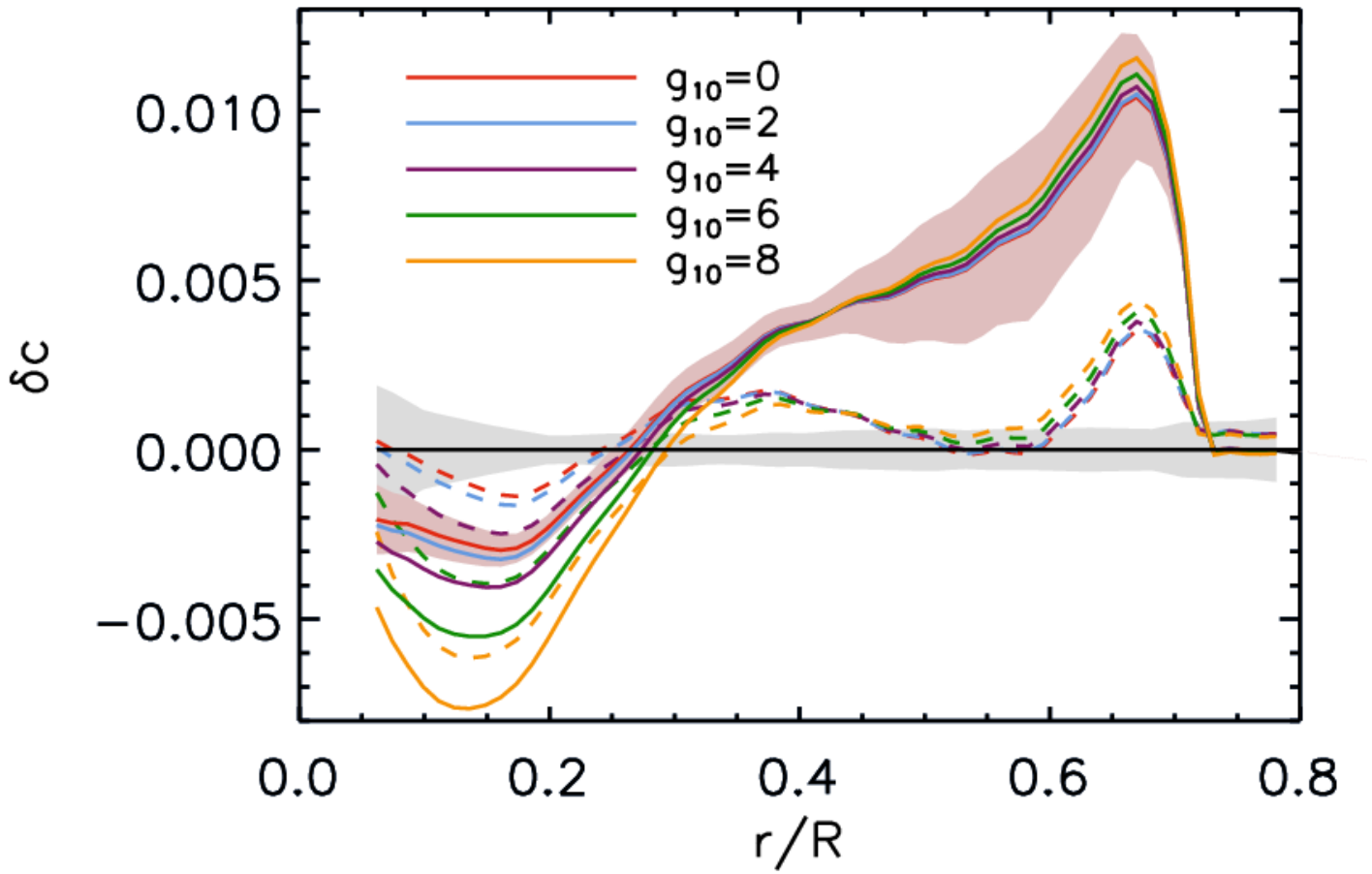


# Results: Axions – Neutrino and convective envelope



# Results: Axions – sound speed profile

Observables: 30 points of the sound speed profile



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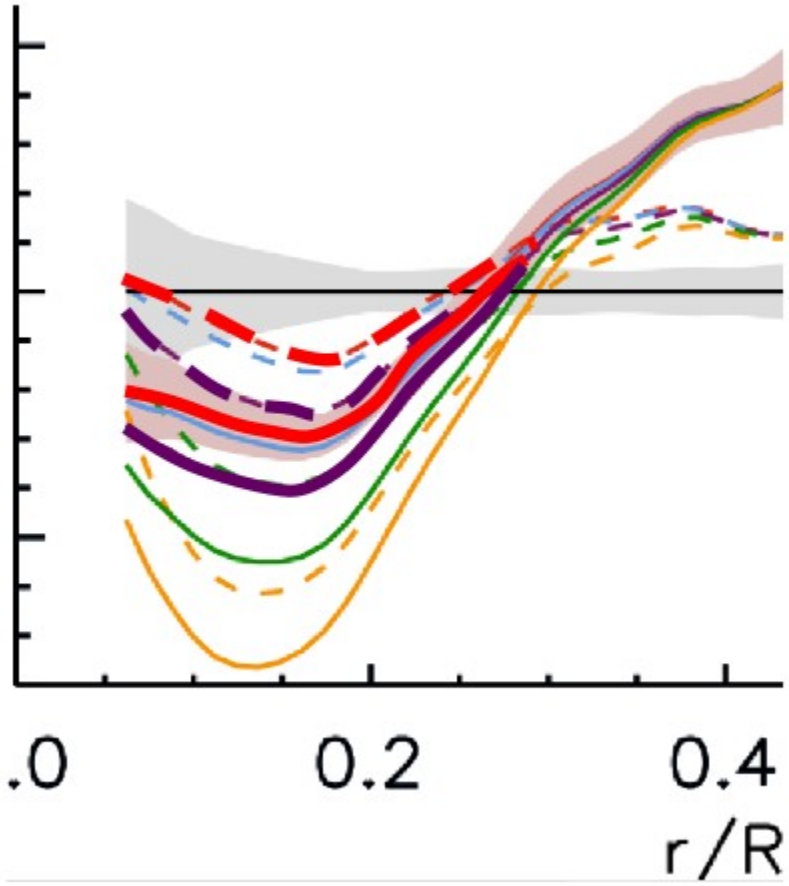


# Statistical procedure

*Villante et al. 2014*

*Seismic and neutrino observables*

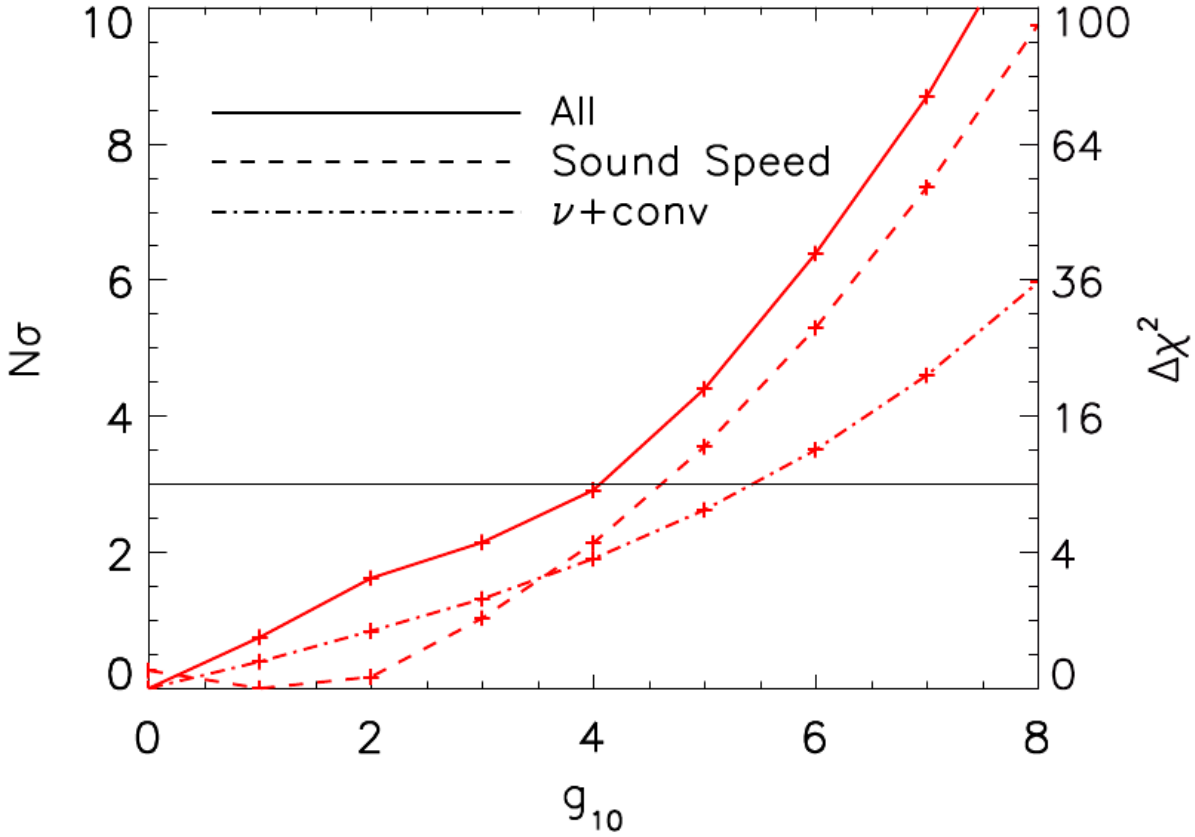
Model correlations

$$\chi^2 = \min_{\{\xi_I\}} \left[ \sum_Q \left( \frac{\delta Q - \sum_I \xi_I C_{Q,I}}{U_Q} \right)^2 + \sum_I \xi_I^2 \right]$$

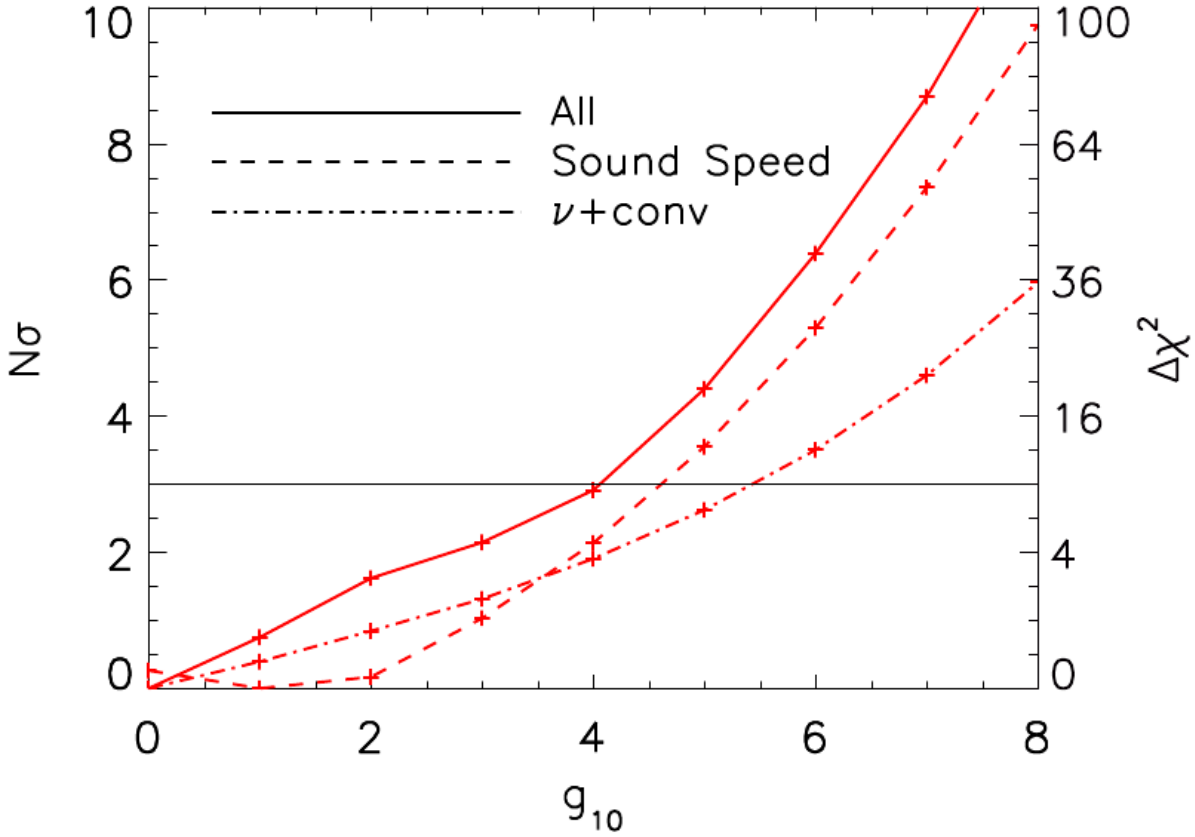
Observables uncertainties

Pulls of input parameters

# Results: Axions

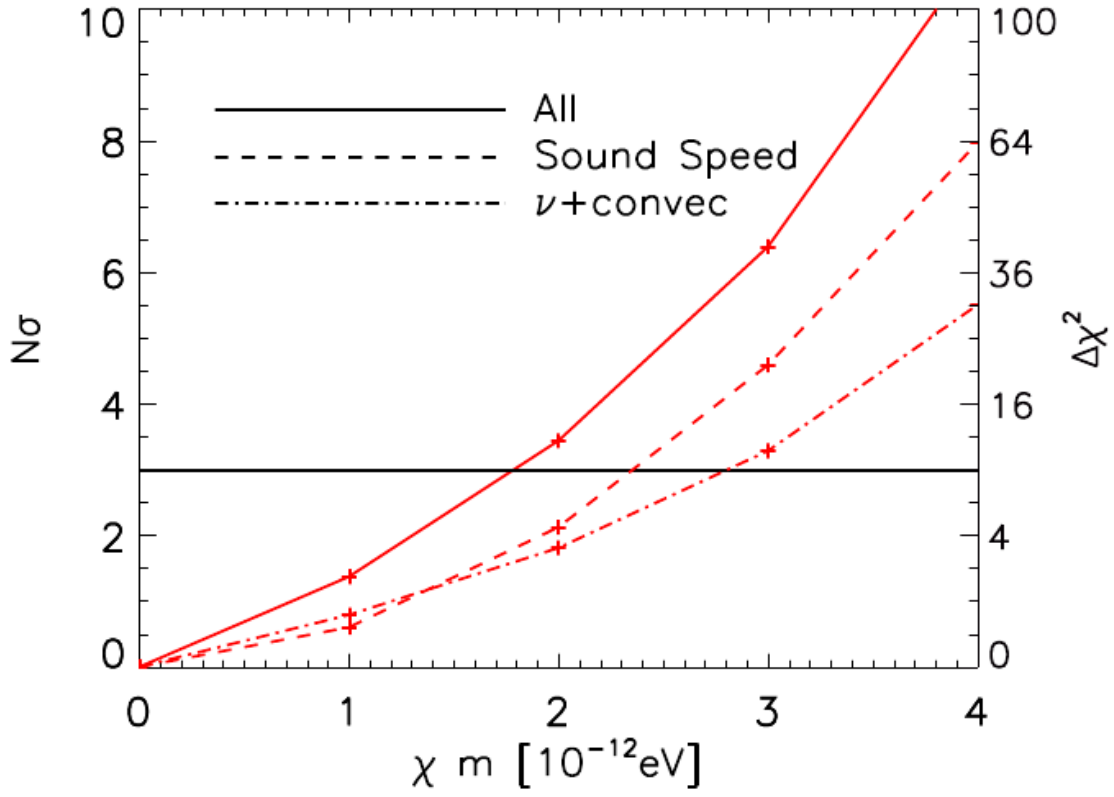


# Results: Axions



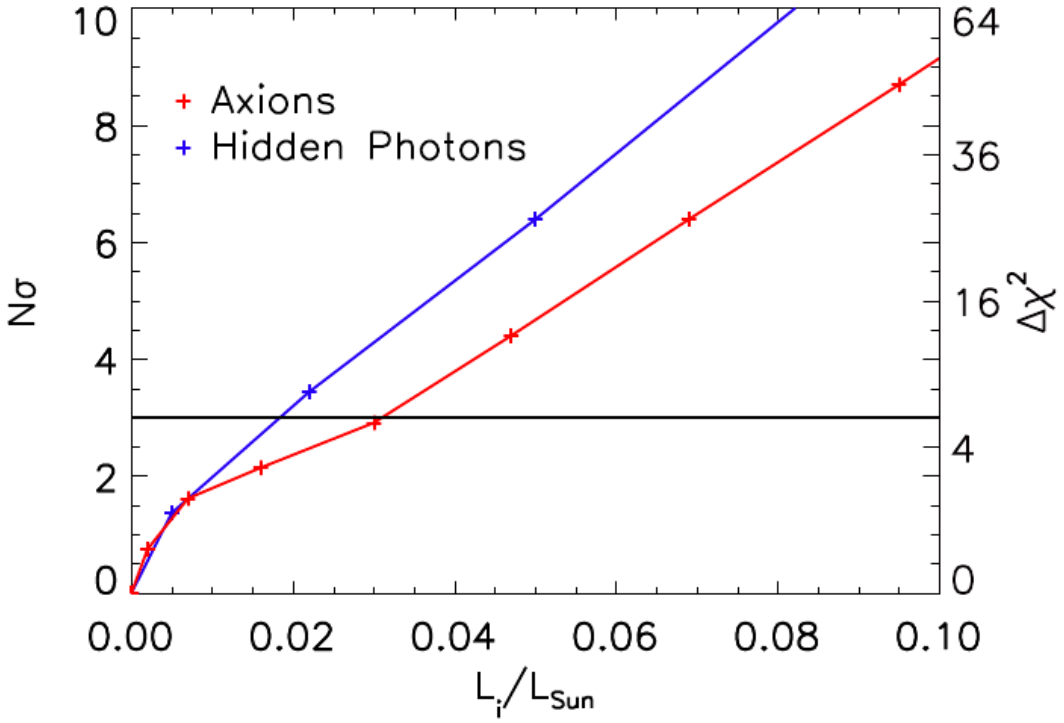

At $3\sigma$ $\longrightarrow$ $g_{a\gamma} < 4.1 \cdot 10^{-10}\,\mathrm{GeV}^{-1}$

# Results: Hidden photons




At $3\sigma$ $\longrightarrow$ $\chi m < 1.8 \cdot 10^{-12}\,\mathrm{eV}$

# Results: Luminosity constraints

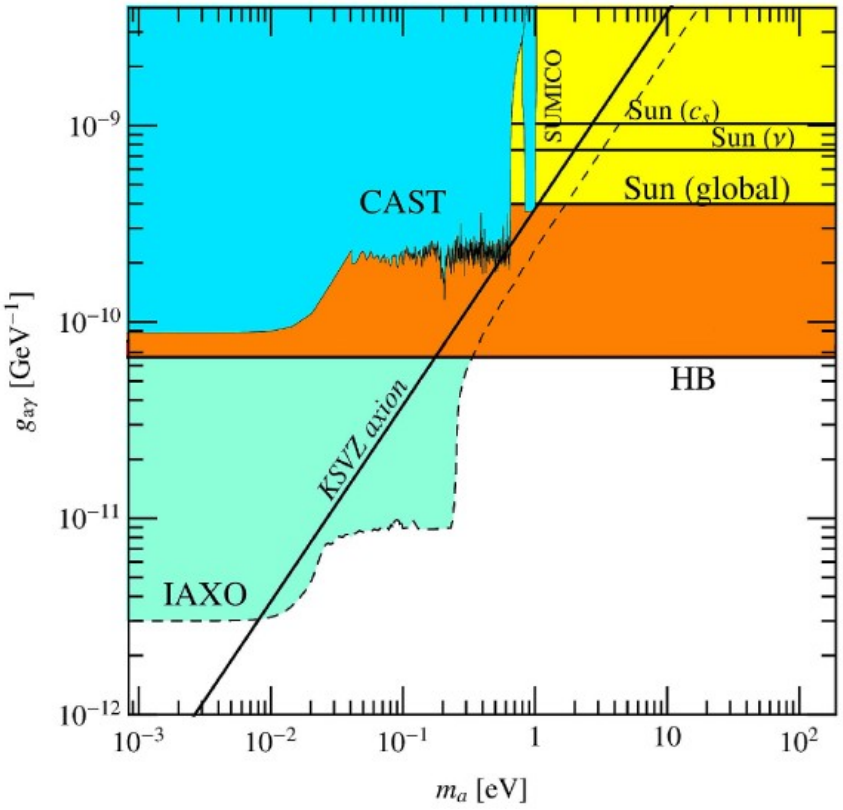



Luminosity constraint is not universal and depend on the type of particle

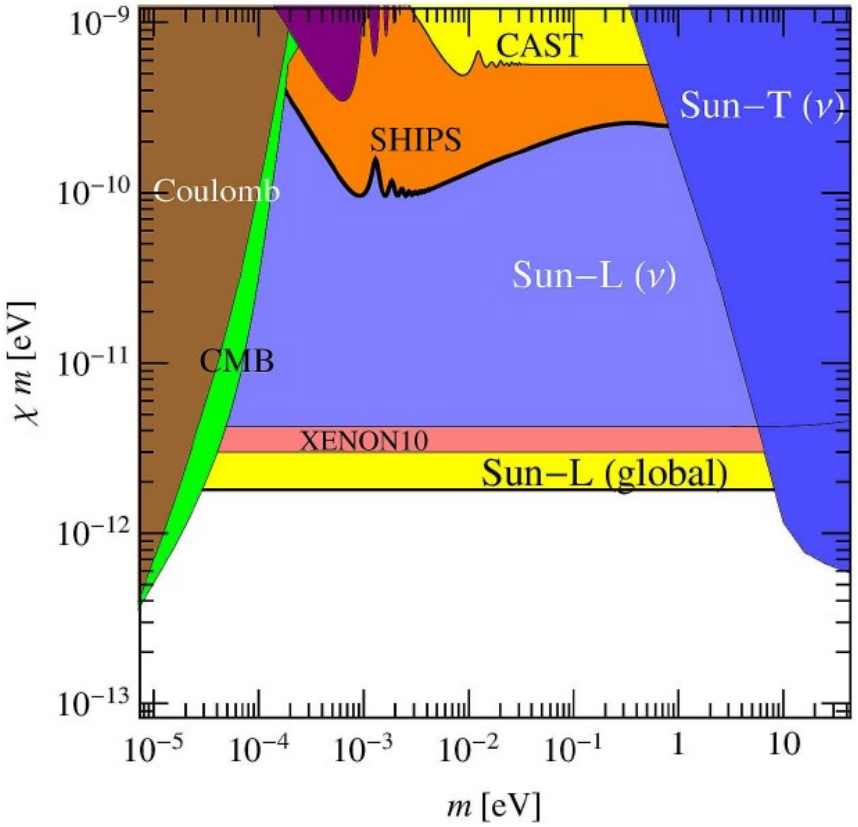
$$L_{ax} < 3\% L_{\odot} \qquad L_{HP} < 2\% L_{\odot}$$

# Constraints on ALPs and HPs

**ALPs**




**HPs**



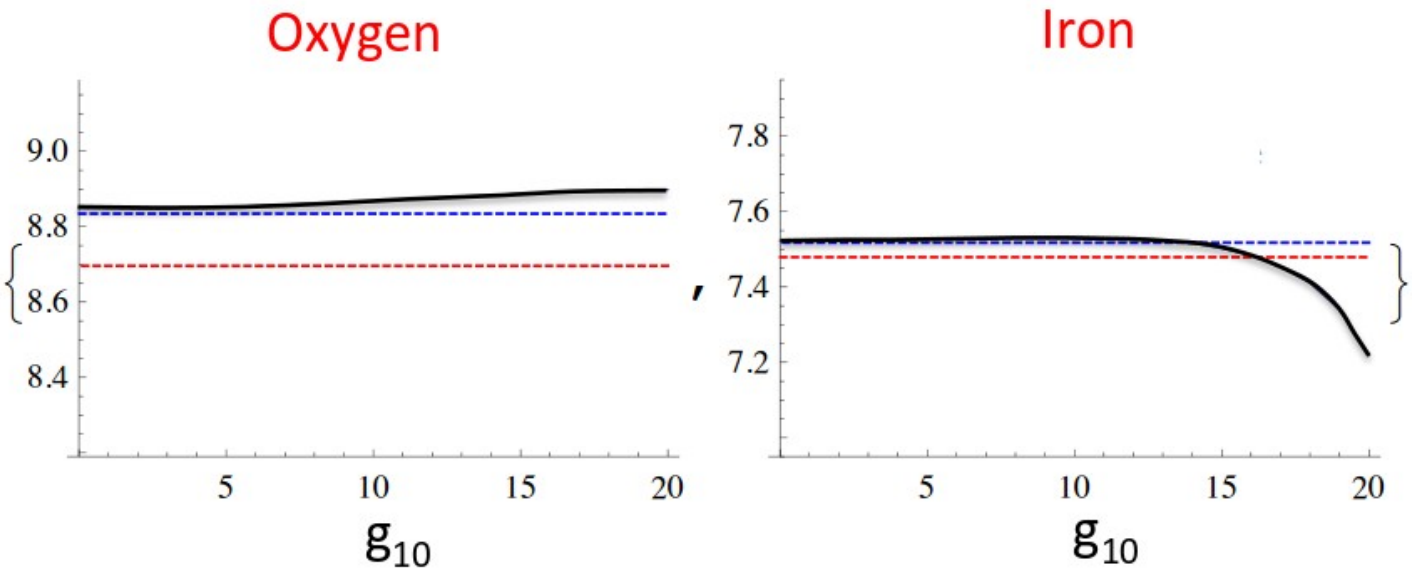
# Summary

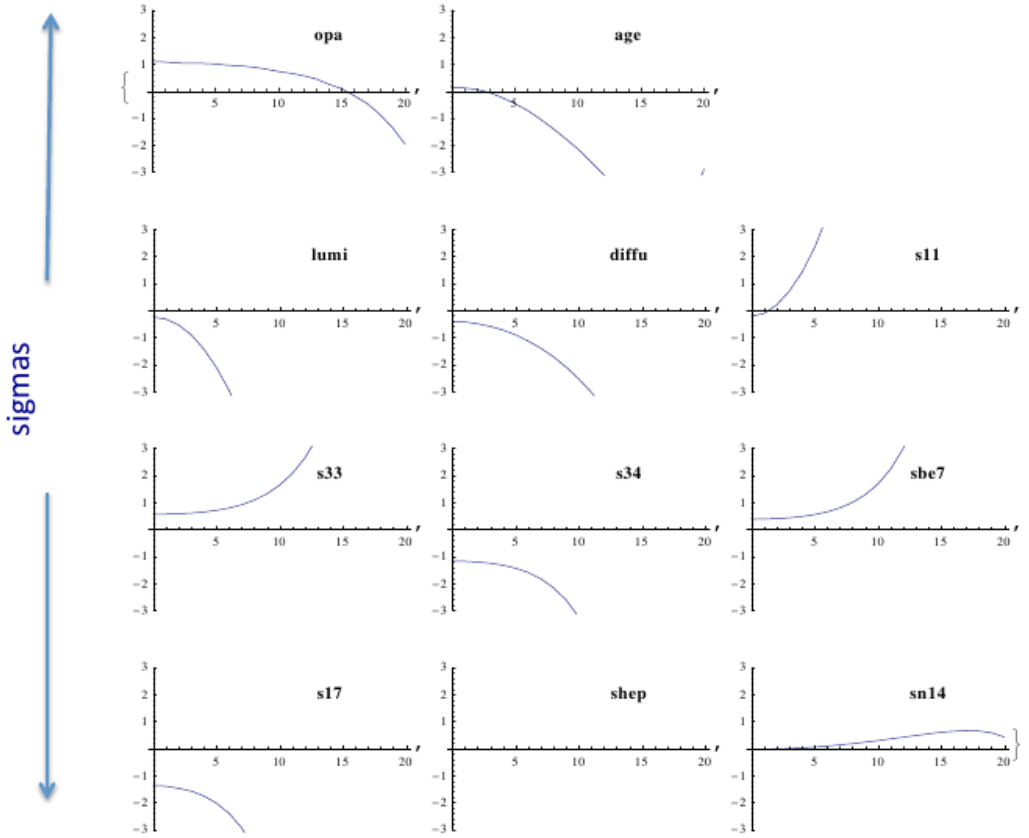
- Global fit using all available observables of the Sun
- Improvement on the previous results based on the Sun
  - Axions: $g_{a\gamma} < 4.1 \cdot 10^{-10}\,\mathrm{GeV}^{-1}$
  - HPs: $\chi m < 1.8 \cdot 10^{-12}\,\mathrm{eV}$
- Importance of self-consistent solar models
- Work in progress: Extended it to other cases.

# BACK-UP

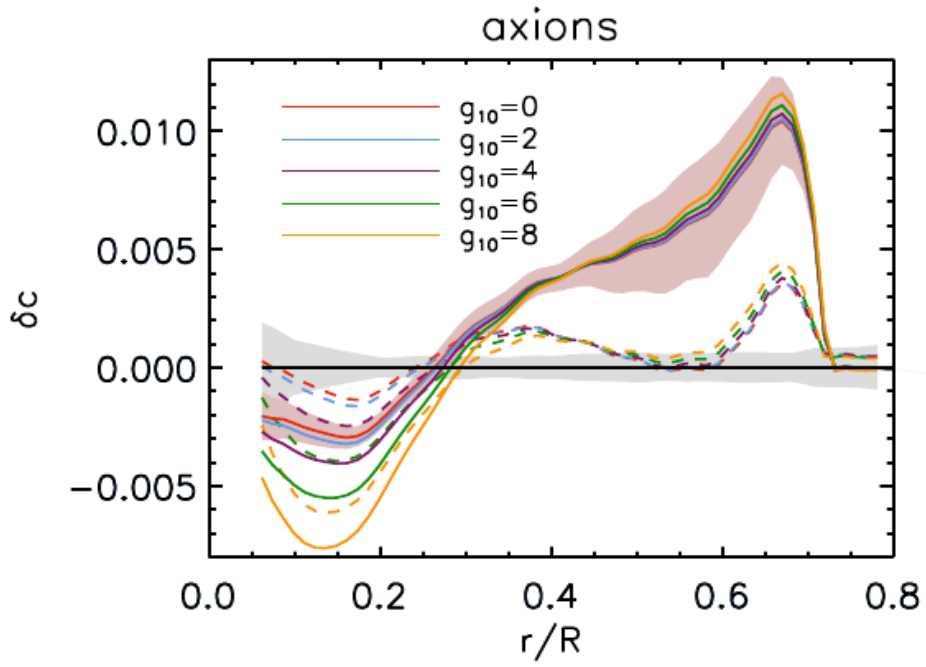
GS98 – high Z

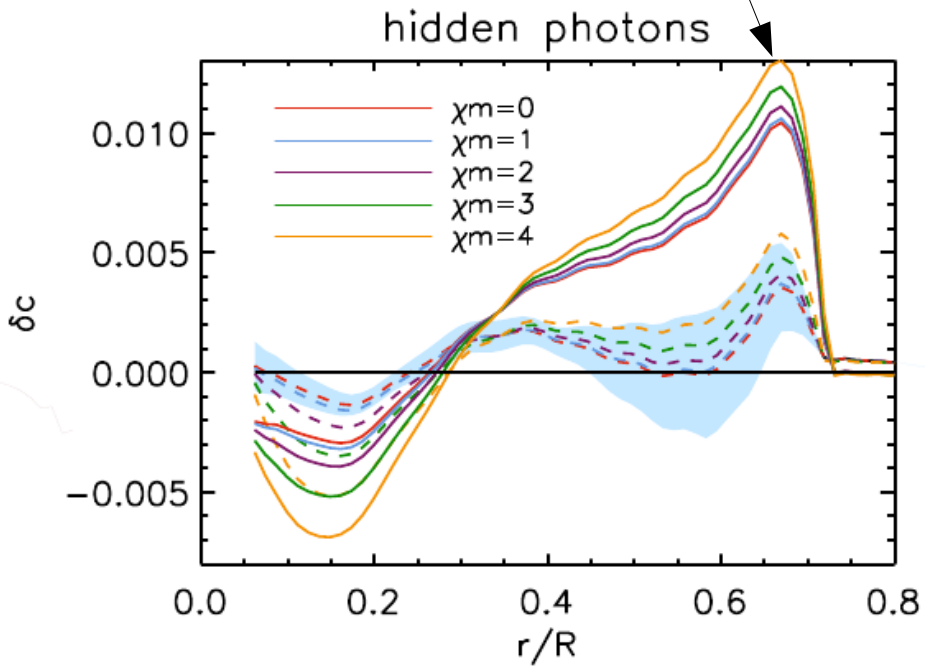
AGSS09 – low Z

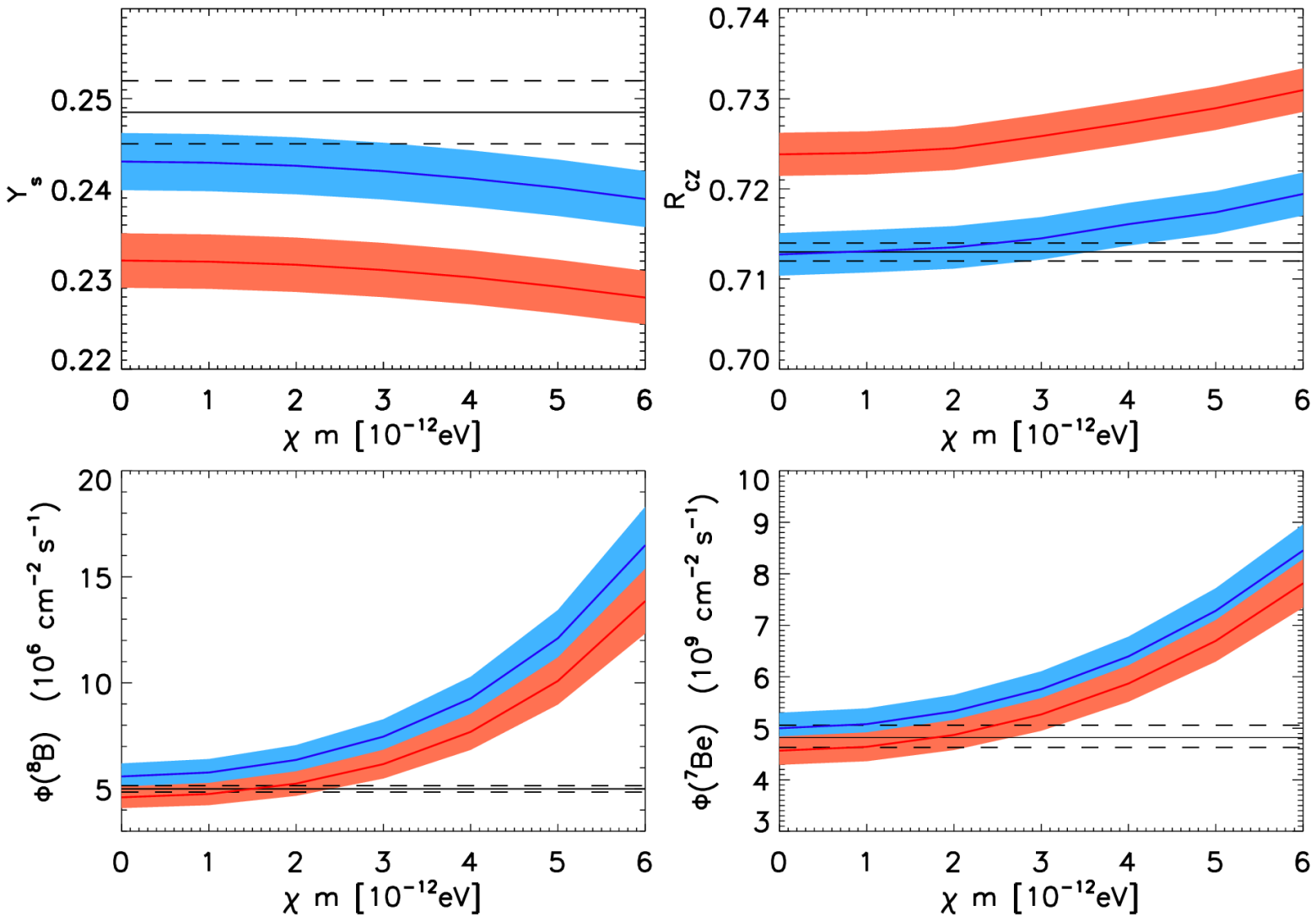



sigmas
opa
age
lumi
diffu
s11
s33
s34
sbe7
s17
shep
sn14

Effects in also in the outer part




0.25
0.24
0.23
0.22
$Y_s$
0
1
2
3
4
5
6
$\chi$ m [$10^{-12}$eV]
0.74
0.73
0.72
0.71
0.70
$R_{cz}$
$\chi$ m [$10^{-12}$eV]
20
15
10
5
$\Phi(^8B)$ ($10^6$ cm$^{-2}$ s$^{-1}$)
$\chi$ m [$10^{-12}$eV]
10
9
8
7
6
5
4
3
$\Phi(^7Be)$ ($10^9$ cm$^{-2}$ s$^{-1}$)
$\chi$ m [$10^{-12}$eV]