Institute of Space Sciences

EXCELENCIA MARÍA DE MAEZTU

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WP8.1: Report progress on solar modeling

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Institute of Space Sciences (ICE, CSIC)
Institut d'Estudis Espacials de Catalunya (IEEC)

(Y. Herrera, ChETEC-INFRA postdoc & F. Villante)

ChETEC-INFRA General Assembly Meeting
Padova, 31st May-1st June 2022

Sun as a standard for stellar physics

WP8.1

-- provide standards for H-burning nuclear reaction rates

-- provide updated solar models (structures, ν-fluxes) as benchmarks for astrophysics and particle physics

Sun as a standard for stellar physics

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Standards for H-burning nuclear reaction rates: more precise and accurate

Solar Fusion III workshop – Berkeley, USA, July 26th-29th 2022

INSTITUTE for NUCLEAR THEORY

ABOUT PEOPLE PUBLICATIONS EVENTS JOBS VISITORS

Workshop Overview

INT WORKSHOP INT-22-82W

Solar Fusion Cross Sections III

July 26, 2022 - July 29, 2022

ORGANIZERS

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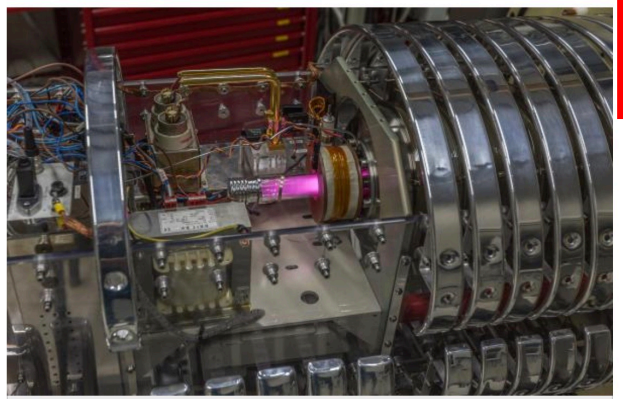

credit: Yuri Suvorov

APPLICATION FORM - FOR FULL CONSIDERATION, APPLY BY JUNE 4, 2022

WORKING GROUP AND PRESENTATIONS WEBSITE

Note to applicants: This workshop will be held in the David Brower Center near the UC Berkeley campus, Berkeley, CA.

June 4th
for full consideration

Solar abundances

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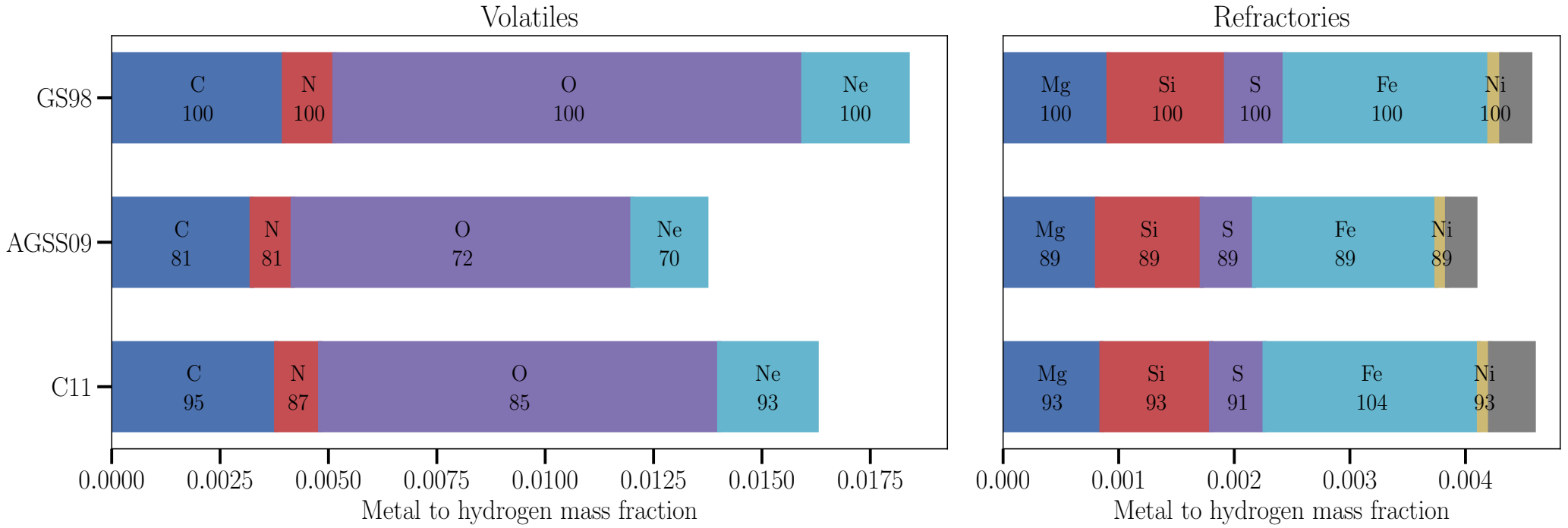
1998
1D - LTE

2009
3D – LTE/NLTE

2011
3D – LTE/NLTE



Orebi Gann et al. 2021/2022

GS98: Grevesse & Sauval 1998 – AGSS09: Asplund, Grevesse et al. 2009 – C11: Caffau et al. 2011

Updates in solar abundances

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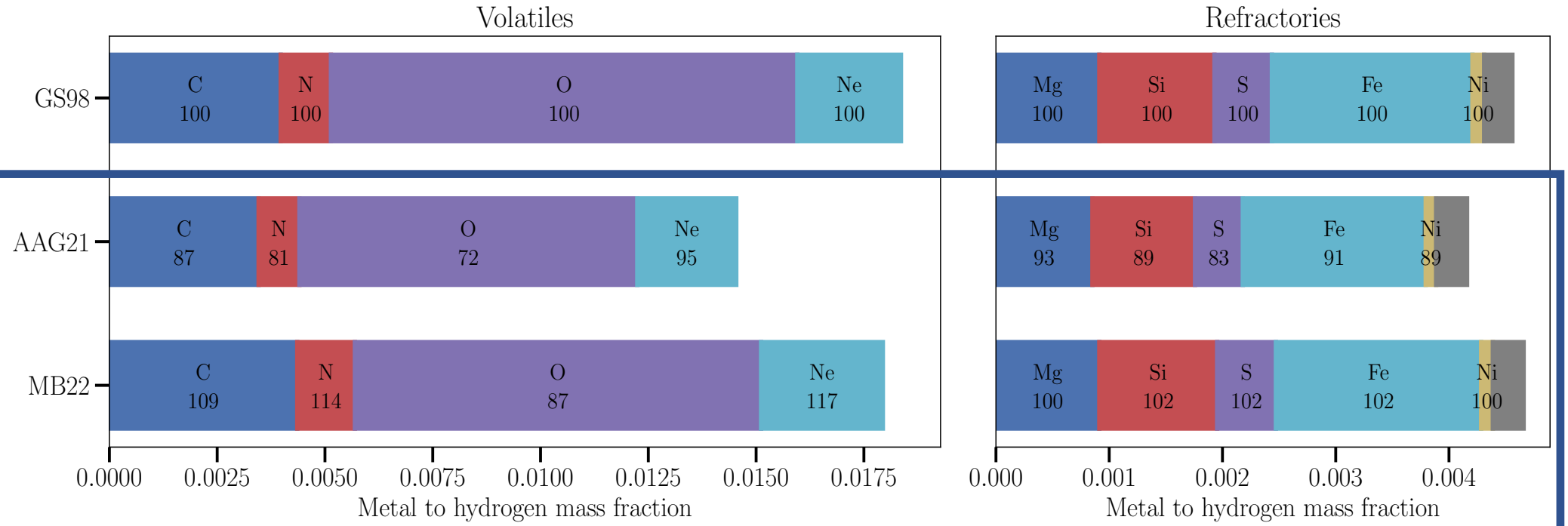
1998
1D - LTE

2021
3D – NLTE

2022
3D – NLTE



AAG21: Asplund, Amarsi & Grevesse 2021 – MB22: Magg, Bergemann et al. 2022

Helioseismic results

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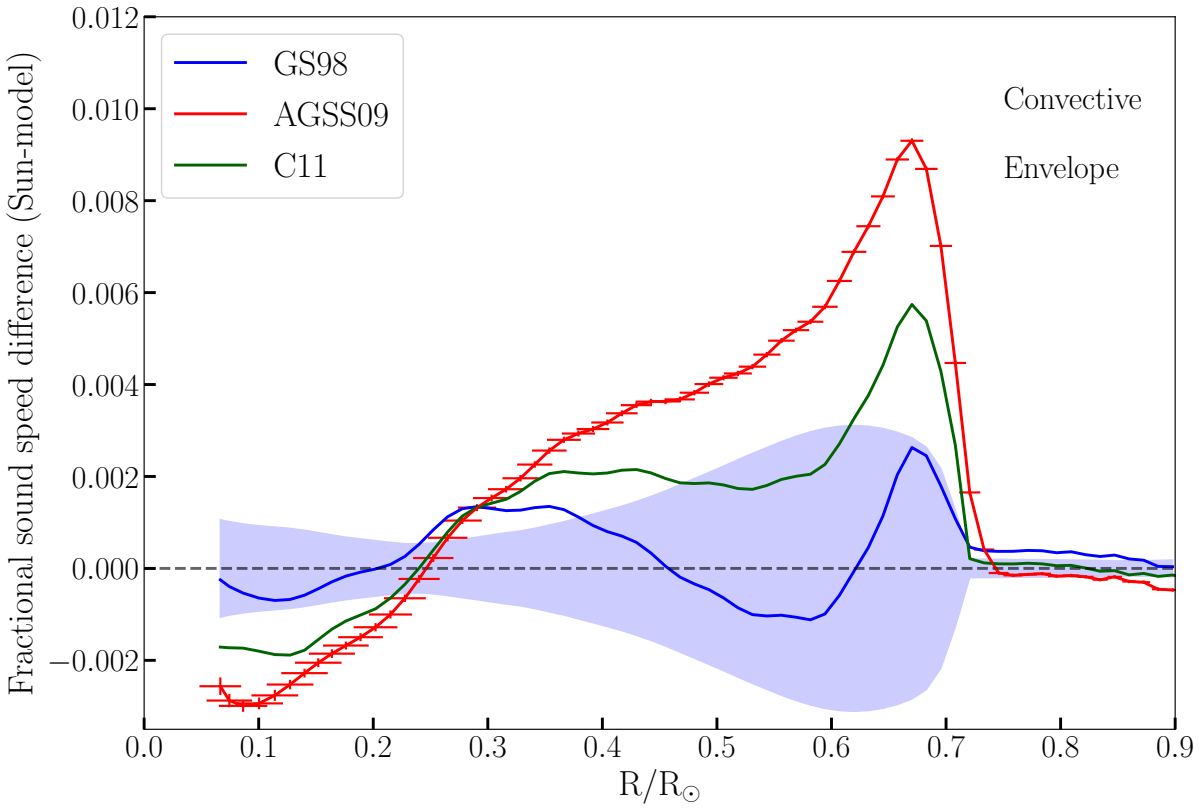
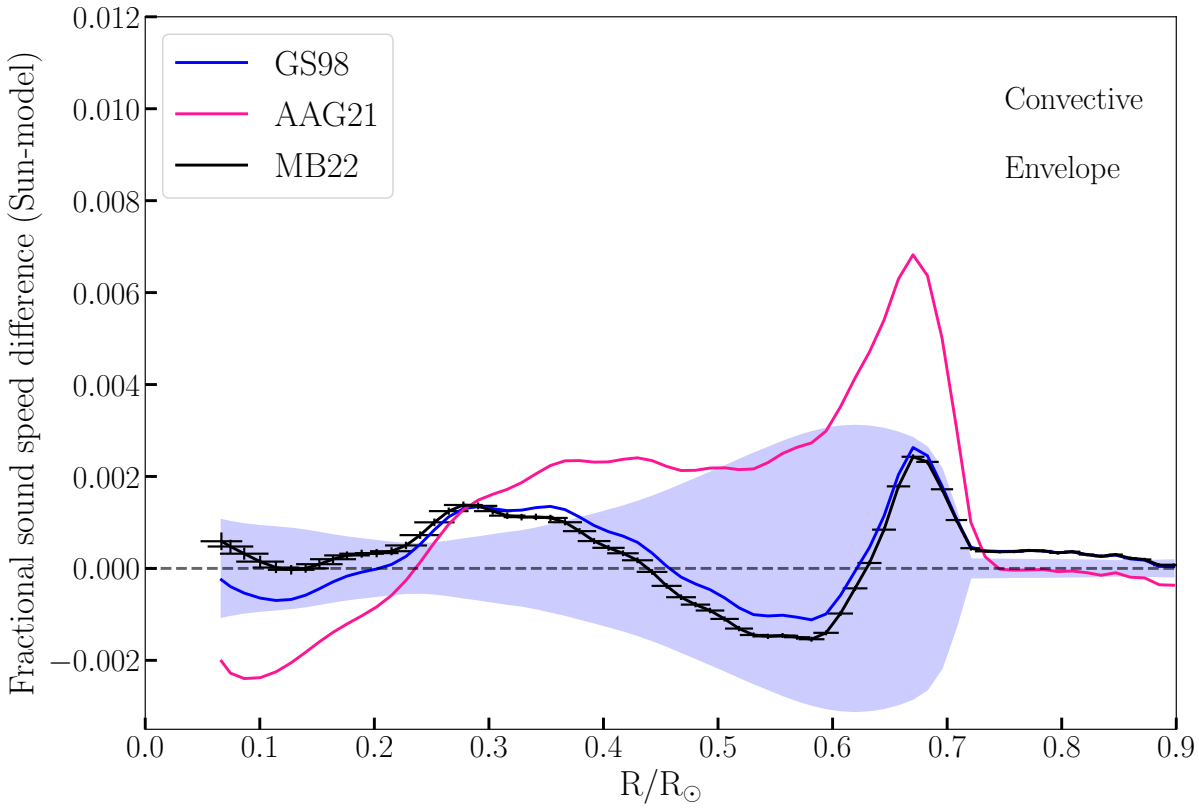
2019 – Dresden ChETEC-INFRA prep meeting



2022 –ChETEC-INFRA GA meeting



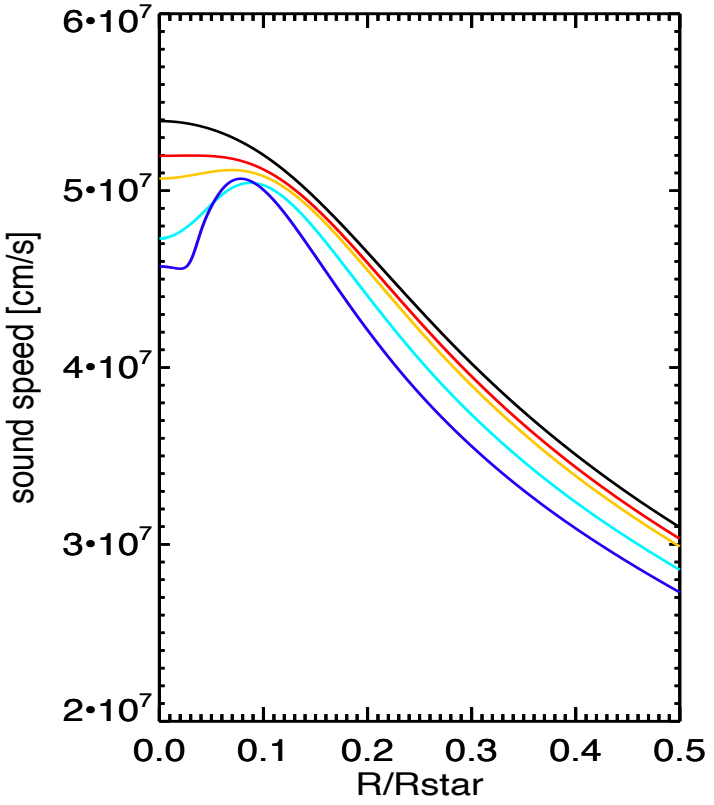
Magg et al. 2022

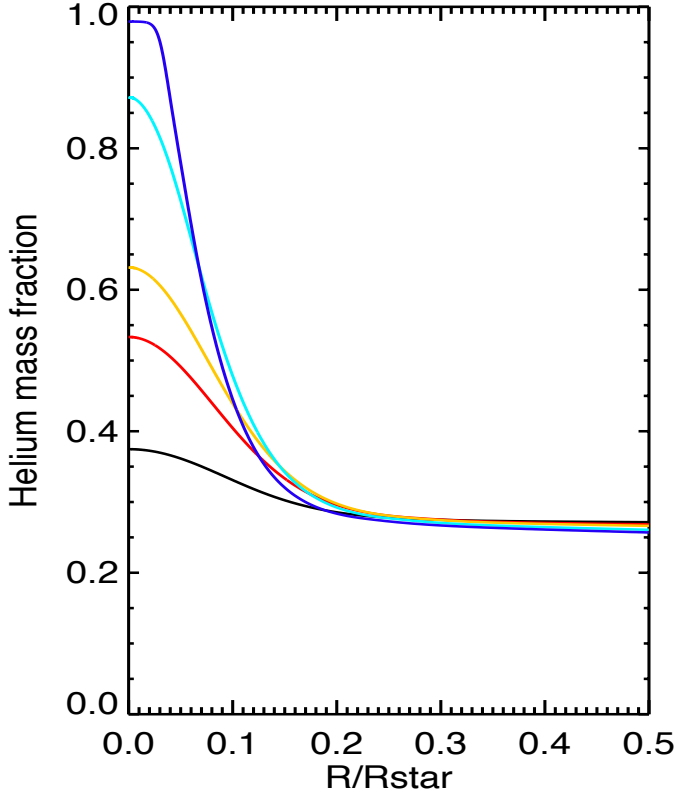
The Sun as a star

Use low-degree solar oscillations (as observed for other stars – Kepler, TESS, PLATO)
l = 0, 1, 2, 3

$$\nu_{n,\ell} - \nu_{n-1,\ell+2} \propto \frac{1}{4\pi\nu_{n,\ell}} \int_0^R \frac{dc}{dr}\frac{dr}{r}$$

Evolutionary state of the solar(stellar) core





The Sun as a star

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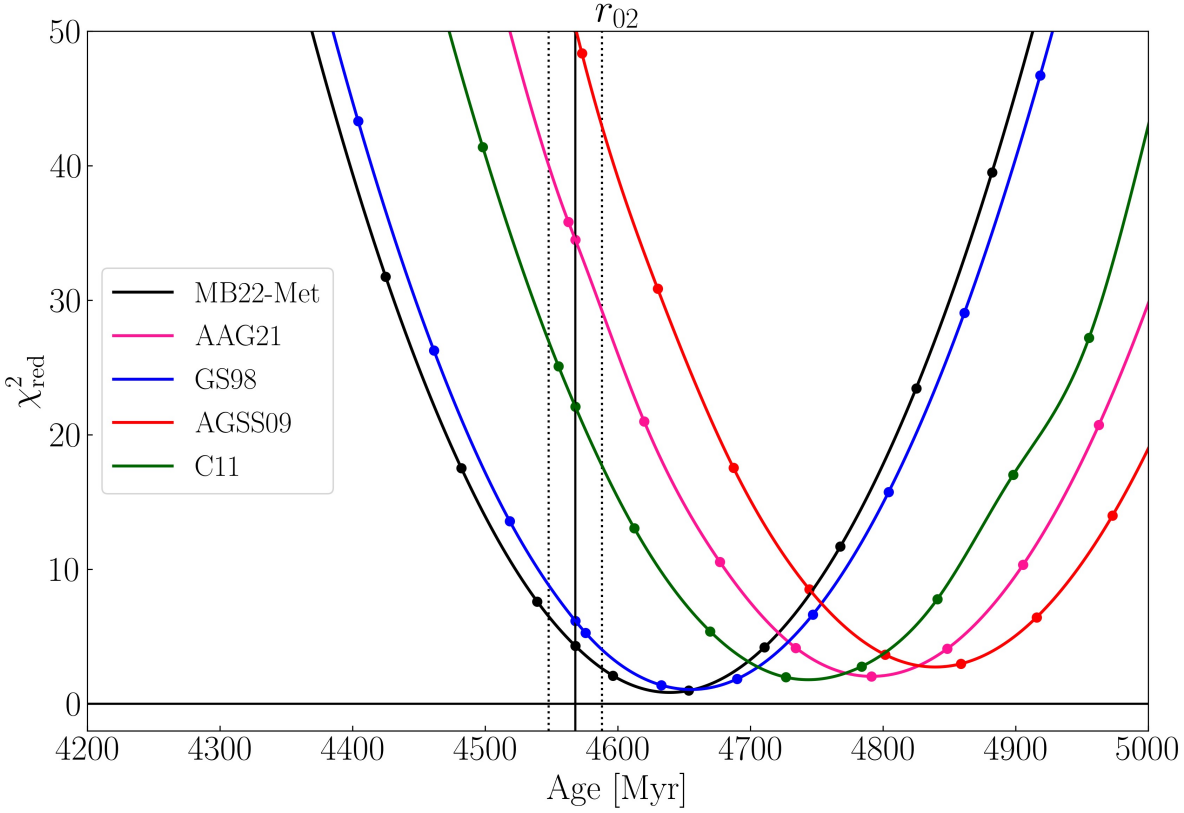
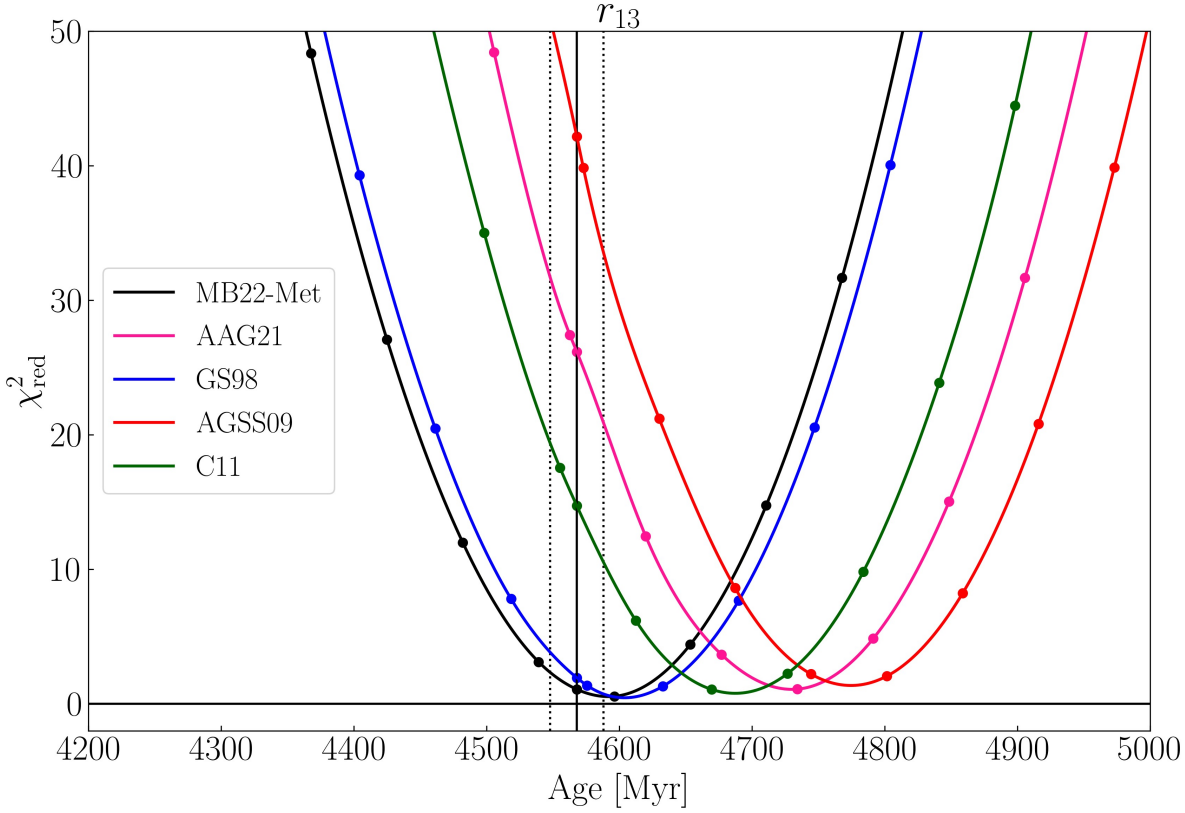
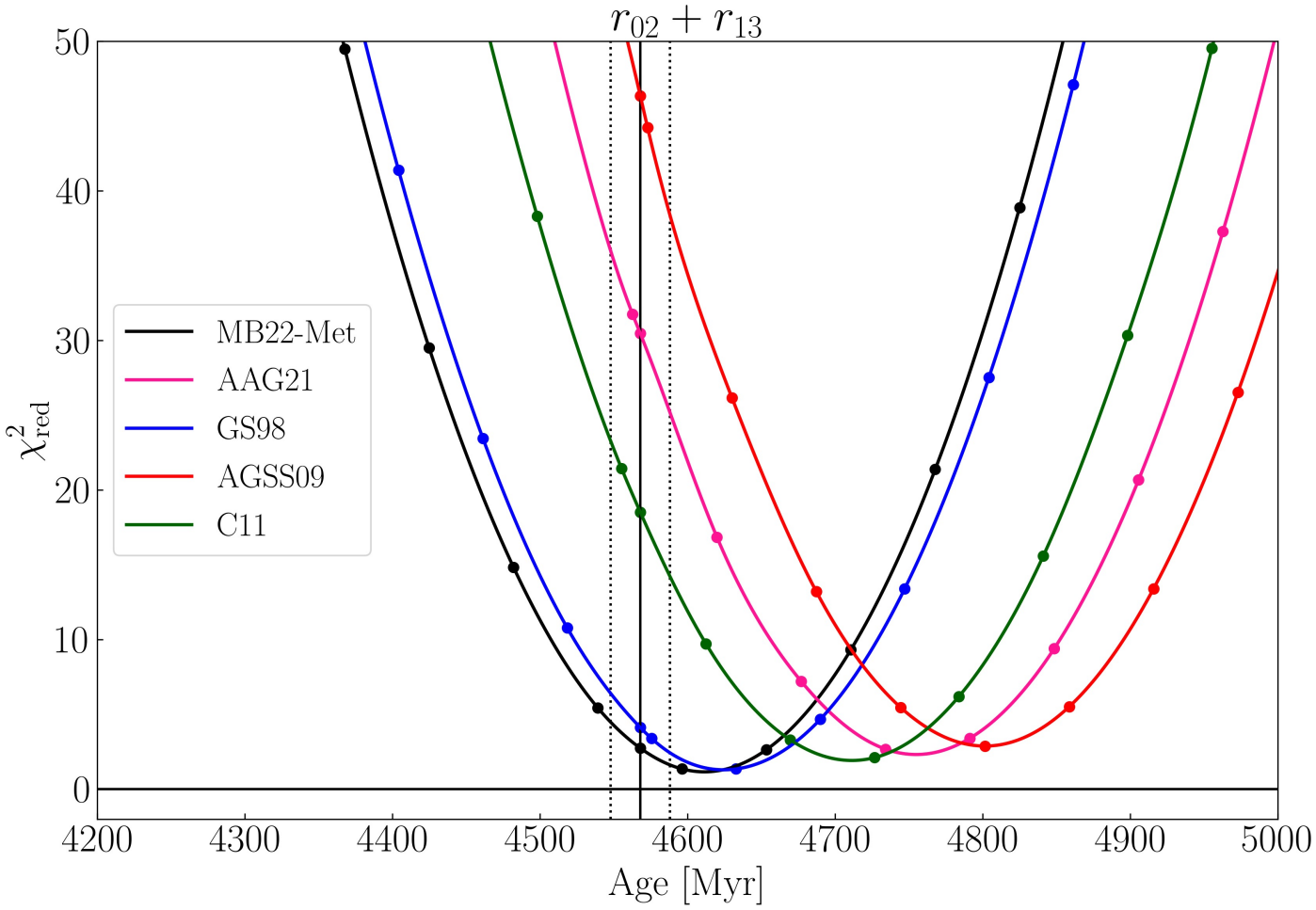
Using BiSON data: +25 years of solar observations





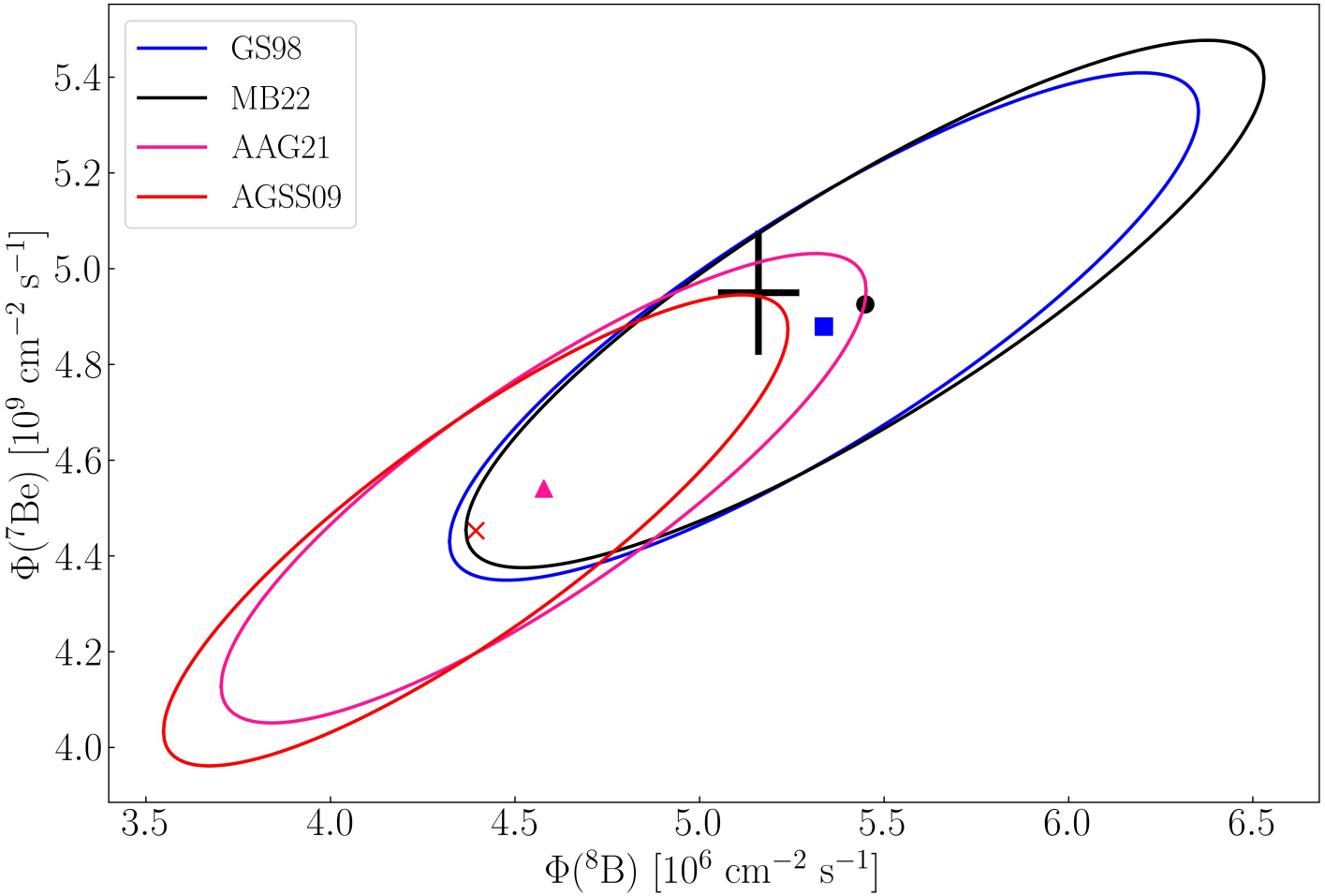
Serenelli et al. in prep

The Sun as a star

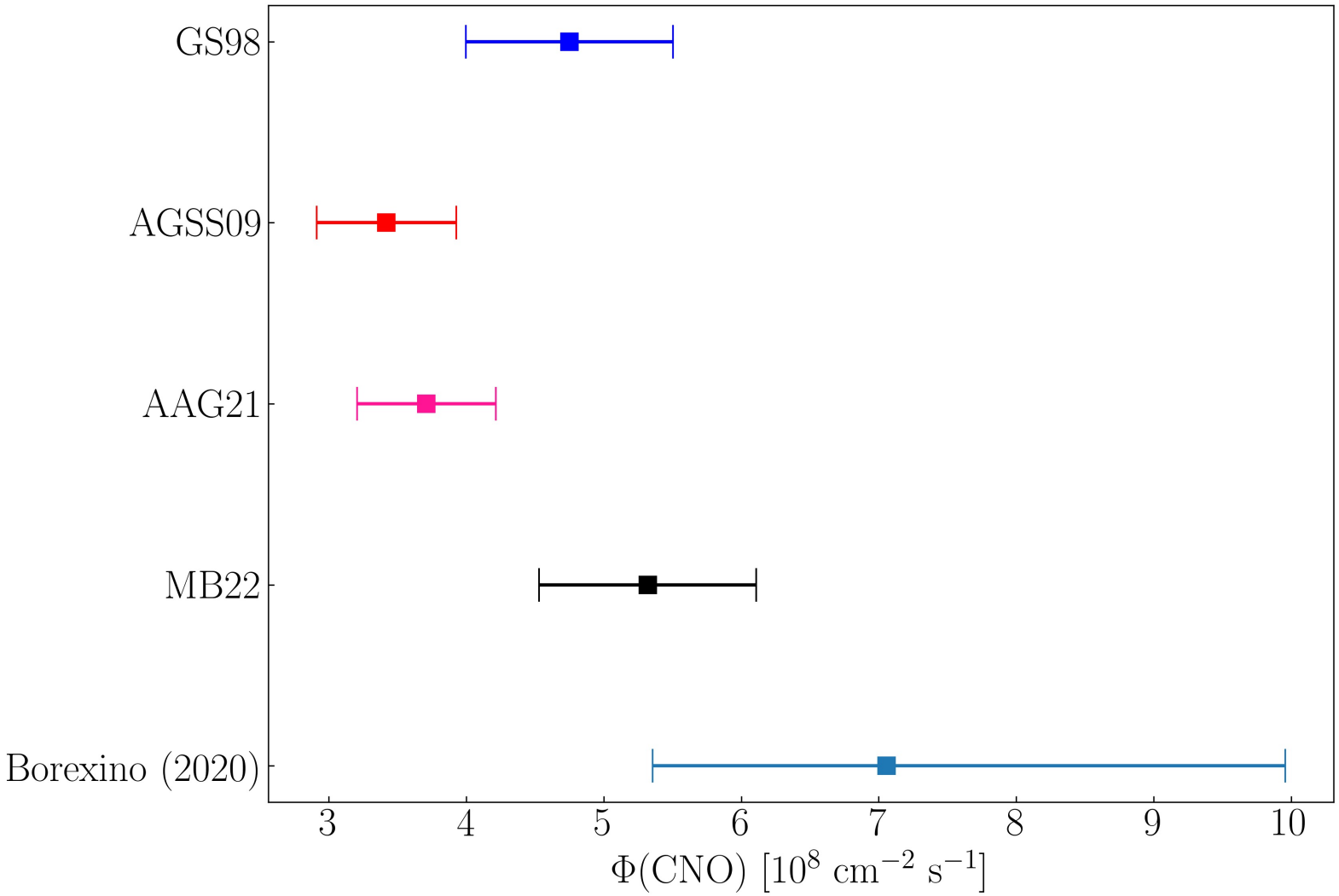


	Solar age (Gyr)	χ^2 (33 dofs)
Sun	**4.568 ± 0.020**	---
GS98	4.625 ± 0.034	42.9
AGSS09	4.802 ± 0.035	95.3
C11	4.711 ± 0.035	63.5
AAG21	4.755 ± 0.034	76.6
MB22	4.611 ± 0.032	38.4

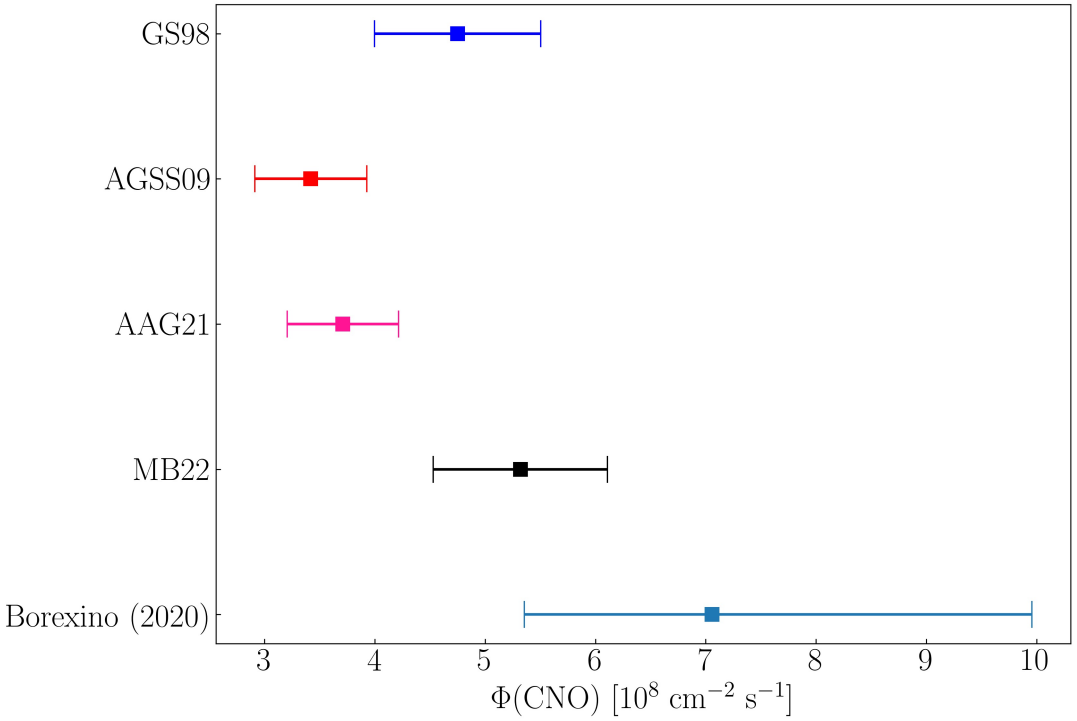
Solar Neutrinos: pp-chains



Solar Neutrinos: CNO



Solar Neutrinos: CNO



New results by Borexino to be announced tomorrow

at Neutrino 2022 and paper submitted to arxiv & PRL

Uncertainties and central values will change

$$\frac{\phi(^{15}\mathrm{O})}{\phi(^{15}\mathrm{O})^{\mathrm{SSM}}} \Big/ \left[\frac{\phi(^{8}\mathrm{B})}{\phi(^{8}\mathrm{B})^{\mathrm{SSM}}}\right]^{0.785} = \left[\frac{C+N}{C^{\mathrm{SSM}}+N^{\mathrm{SSM}}}\right] (1 \pm 0.4\%\,(\mathrm{env}) \pm 2.6\%\,(\mathrm{D}) \pm 10\%\,(\mathrm{nucl}))$$

Serenelli et al. 2013

or similar for any combination of CN fluxes → C+N core abundances

New solar models

- Paper currently in prep. for B22 generation of SSMs

- New solar mixtures
  - AAG21 – supersedes Asplund et al. 2009
  - MB22 – new 3D based analysis, new atomic data and small improvements here and there
    - (full 3D O analysis in Bergemann et al. 2021)

- Small updates in observational constraints (e.g. $L_{\odot}$, to match IAU recommended nominal value)

- New B22-MB22
  - good reference for solar/stellar/particle physics
  - good reference for 'Sun as a star'

- Structures, ν-distributions, etc to be made available through ChETEC-INFRA

- Always room for non-standard (stellar) physics: rotation, magnetic fields, extra-mixing, etc etc

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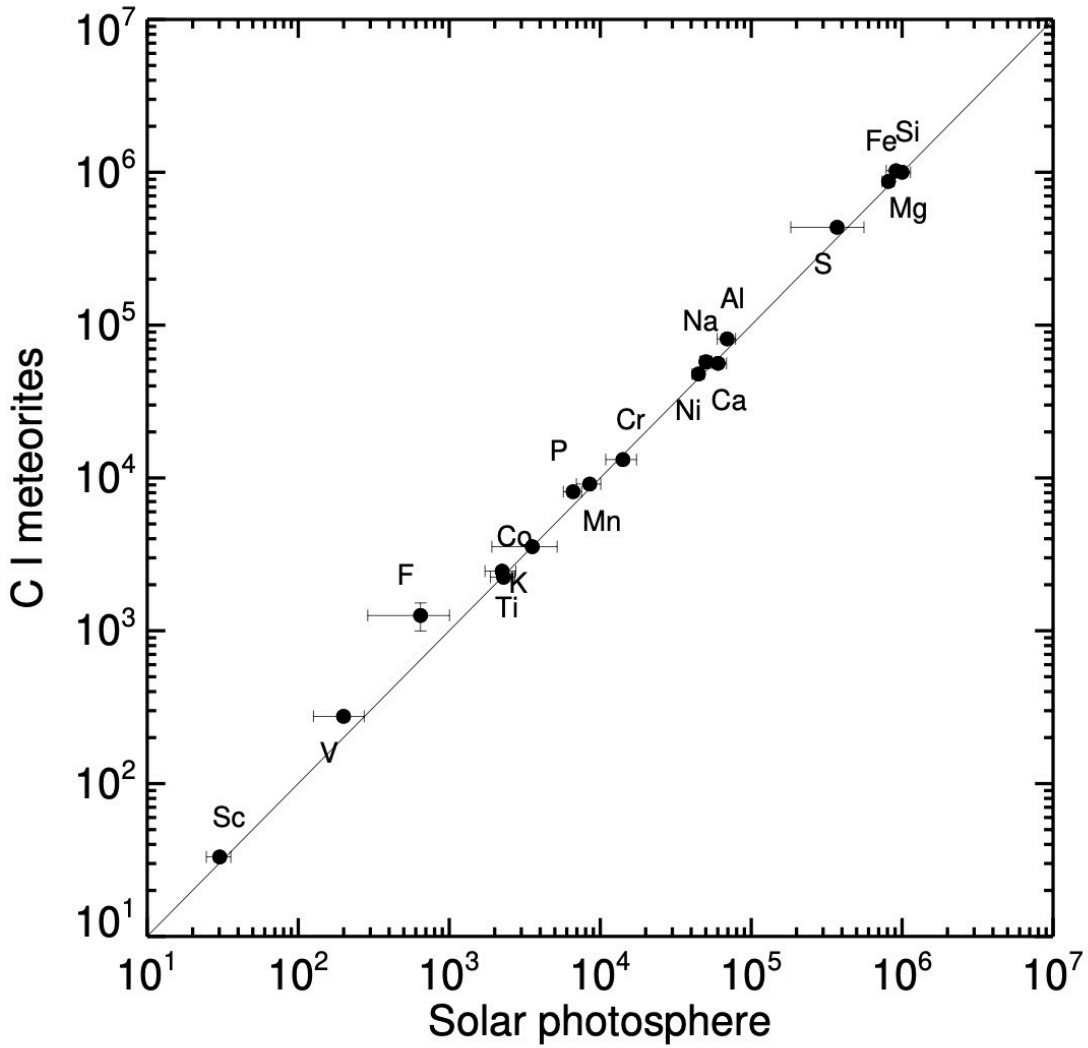
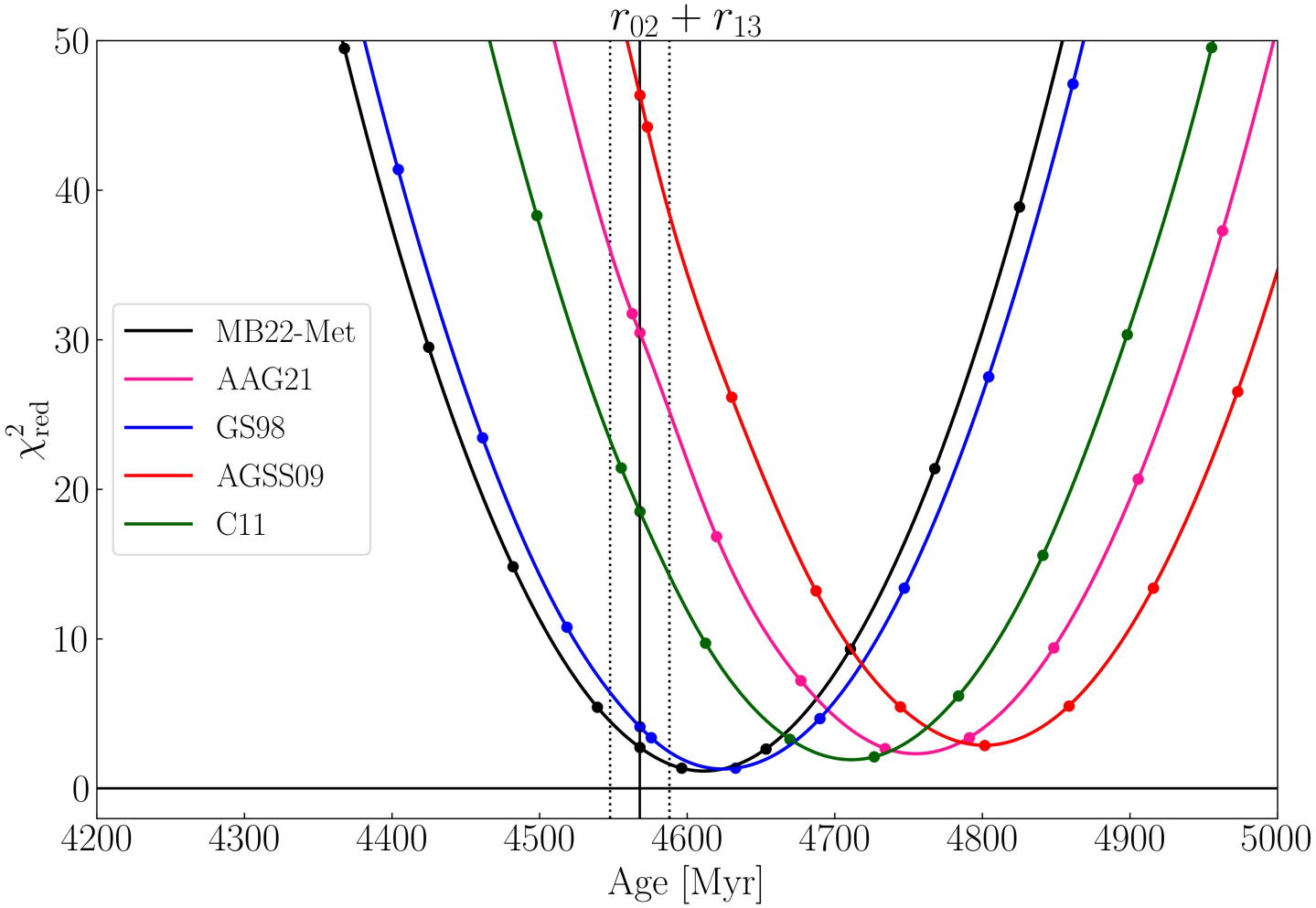
Meteoritic vs Photospheric



Other SSM properties

Model	$R_{CZ}/R_{\odot}$	Y_S	$\langle \delta c/c \rangle$	Y_{ini}	Z_{ini}
MB22-phot	0.7120	0.2440	0.0010	0.2737	0.0178
MB22-met	0.7118	0.2453	0.0011	0.2750	0.0179
AAG21	0.7197	0.2343	0.0027	0.2638	0.0155
AGSS09-met	0.7231	0.2316	0.0041	0.2614	0.0149
GS98	0.7122	0.2425	0.0010	0.2718	0.0187
C11	0.7162	0.2366	0.0021	0.2658	0.0169

The Sun as a star



	Solar age (Gyr)	χ^2 (33 dofs)
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