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The Sun as a young star: reproducing the X-ray cycle of ε Eridani with solar magnetic structures

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INTRODUCTION

The magnetic activity in solar-like stars is under an intense debate in the astrophysical community and still not well understood. While it is well known that ~60% of solar-like stars show magnetic activity in the chromosphere, probing the coronal X-ray counterparts is still challenging. The XMM-Newton satellite has detected coronal cycles **in five old solar-like** stars (ages of few Gyr) **with long X-ray cycle periods (8-12 yr)** (see Fig. 1). More recently, **two young solar-like stars (ages of 400-600 Myr and cycles lasting up to 1.6-3 yr)** were added to this sample, **ε Eridani** and ι Horologii, defining at which age and at which activity level X-ray cycles set in (see Fig. 1).

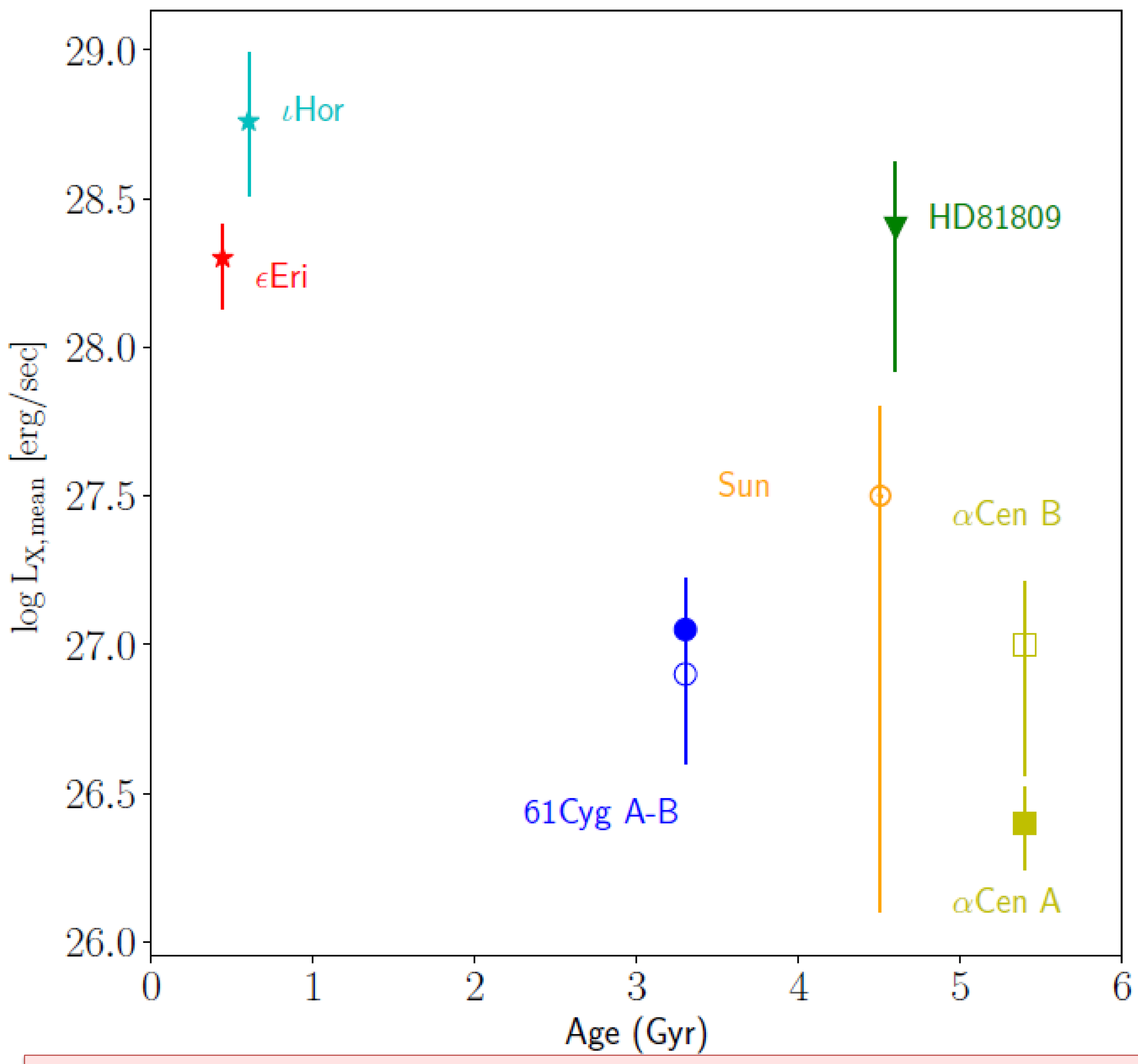

Fig.1 *X-ray luminosity as function of the age of the stars with known X-ray activity cycle. The vertical bars designate the amplitude of the X-ray cycle, i.e. the variation of the luminosity between the minimum and the maximum of the coronal cycle (Coffaro et al. 2020).*

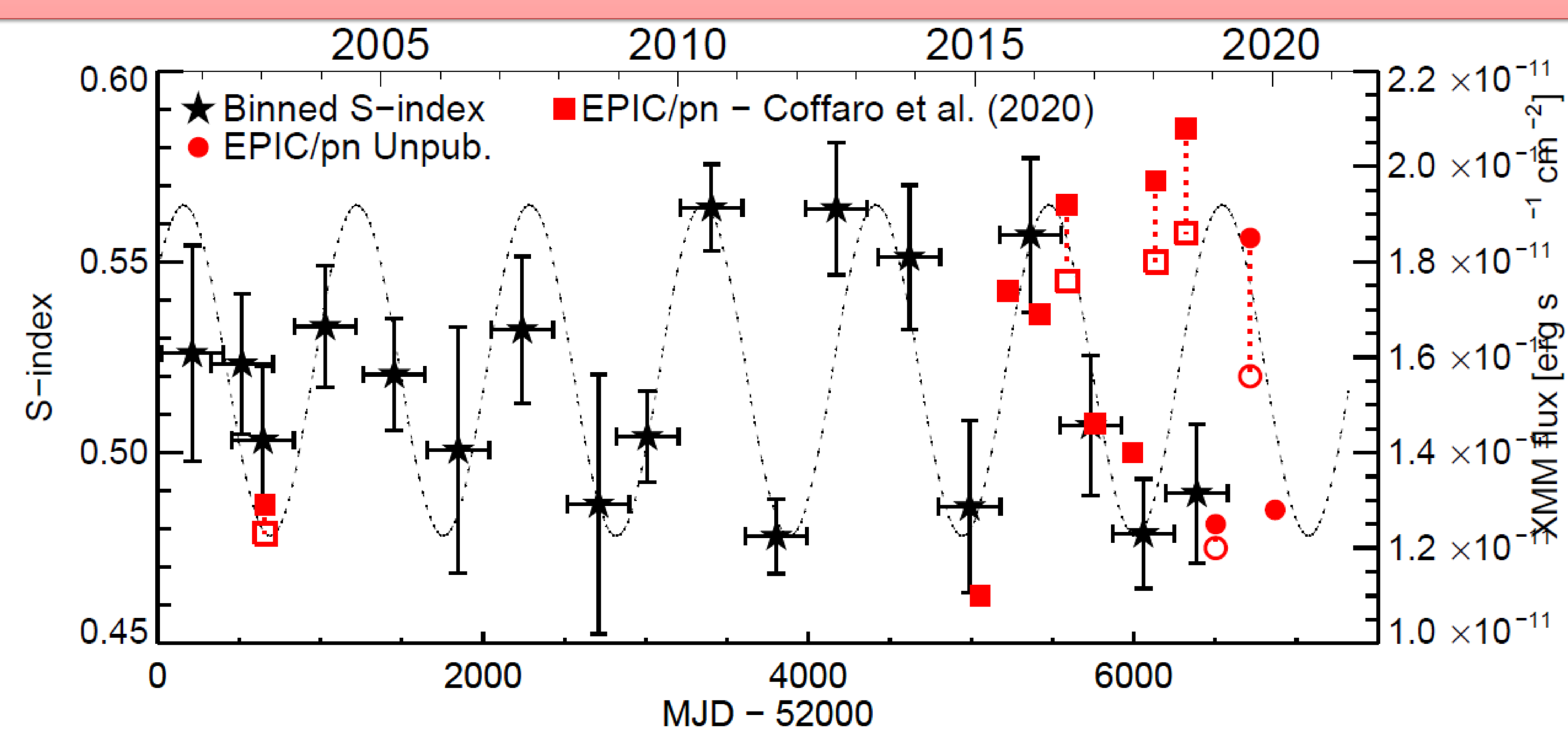

Fig.2 Long-term lightcurve of ε Eridani . The black asterisks are the chromospheric S-index data. The red symbols are X-ray fluxes obtained from the spectral analysis of the XMM-Newton observations (2015-2020). The dotted line is the sinuisodal signal obtained from from a Lomb-Scargle period search on the S-index time series. The period is 2.9 yr (Coffaro et. al 2020).

DISCOVERY OF THE CORONAL CYCLE OF ε ERIDANI

XMM-Newton snapshots, taken every 6 months since 2015, have revealed a cyclic X-ray emission in ε Eridani (see Fig. 2).

ε Eridani is the so-far **youngest solar-like star**, with an age of ~400 Myr, **to show a coronal activity cycle.**

The X-ray variation is in agreement with the previously known Ca II cycle that we have re-analyzed. **The cycle period is ~3 yr**.

Coffaro et al. 2020

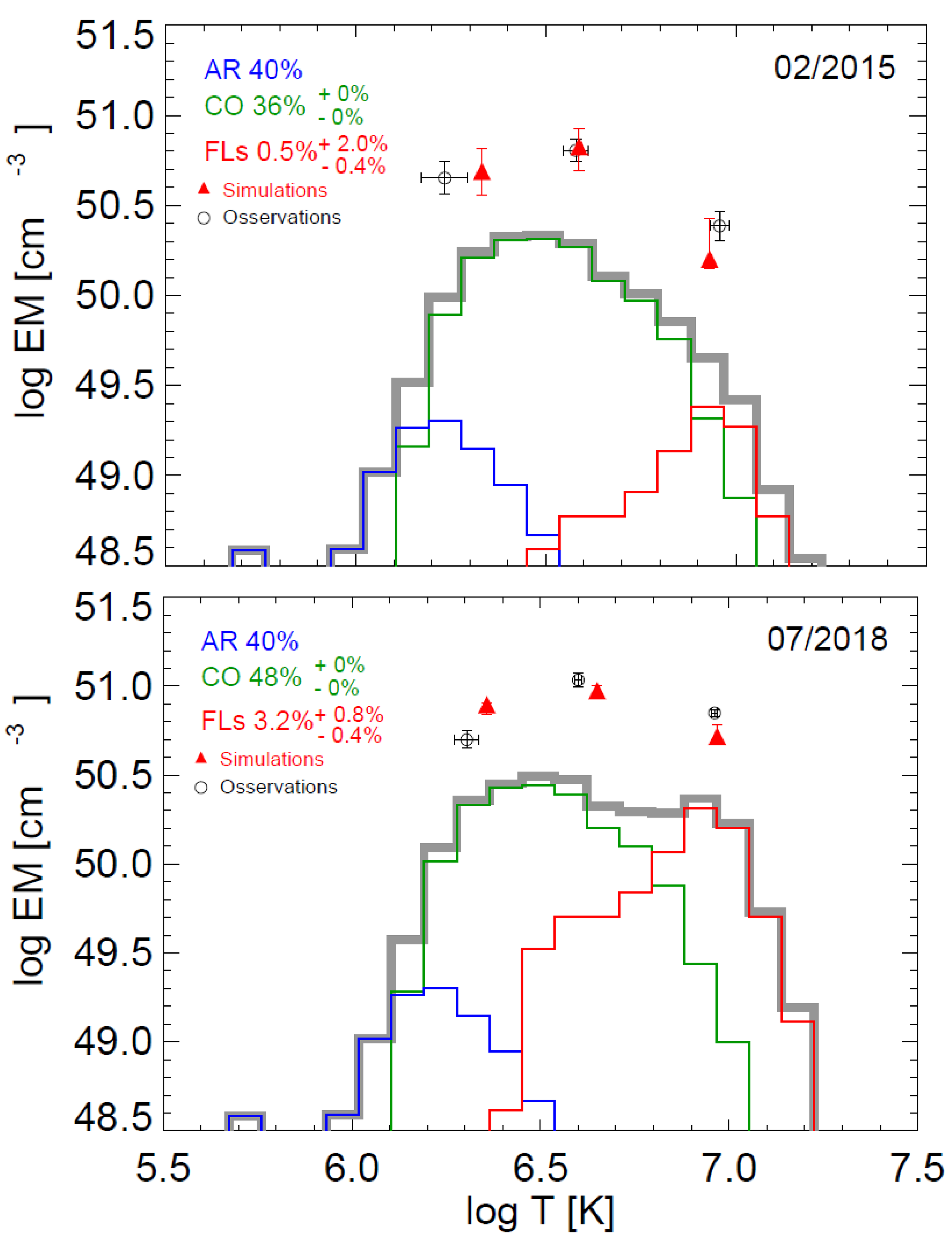

Fig. 3 *Best-matching EMDs to the minimum (02/2015) and the maximum (07/2018) of the X-ray cycle of ε Eridani. The percentages of magnetic structures contributing at the given phases of the cycle are given in the legend of the plots. The coloured lines represent the EMDs of each structures, while the grey line is total EMD. The red tringles and the black dots are respectively the best-fitting parameters obtained from the spectral analysis of the simulated spectra and of the observed spectra of ε Eridani (Coffaro et al. 2020).*

MAGNETIC STRUCTURES IN THE CORONA OF ε ERIDANI

We have developed a new technique which allows us to identify the magnetic structures on the stellar coronae and to study the stellar X-ray variability in terms of these structures.

The magnetic structures, employed in this study, are the same observed on the Sun by the X-ray solar satellite *Yohkoh*: **active regions (ARs), cores of active regions (COs) and flares (FLs).**

Our approach is to simulate a grid of emission measure distributions (EMDs) derived from the analysis of these regions to artificially construct a solar-like corona with the physical characteristics of ε Eridani. The three magnetic structures are allowed to contribute to the total coronal EMD with varying area coverage fraction.

From matching these pseudo-solar EMDs and the observations of ε Eridani, we are able to **associate to each state of the X-ray activity cycle of ε Eridani the percentage of ARs, COs and FLs on the corona of the star** (see Fig 3 and 4).

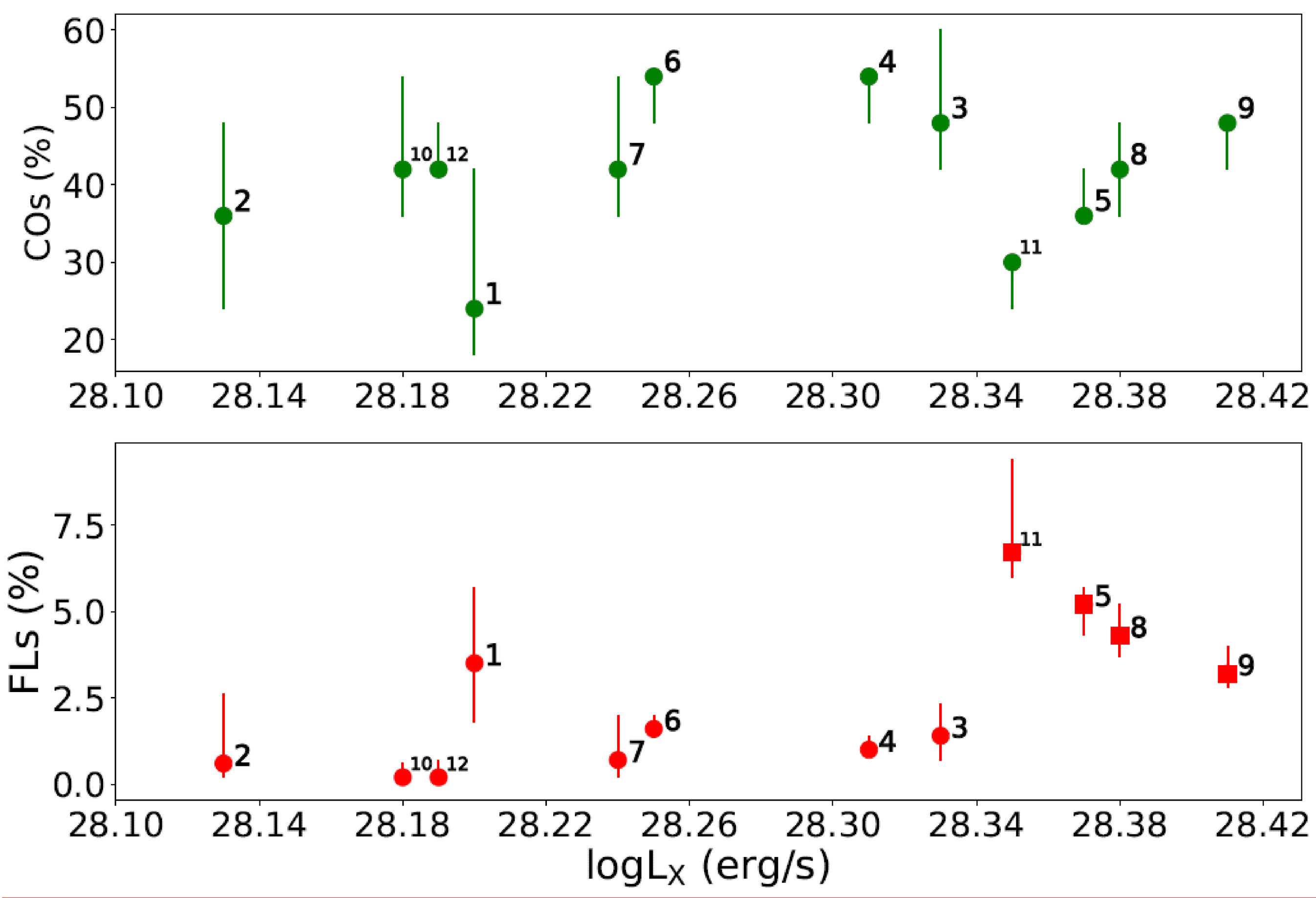

Fig. 4 *Percentages of COs and FLs obtained from the simulated EMDs as function of the observed X-ray luminosity. The ARs are fixed at 40%. The numbers denote the n-th observation of ε Eridani (Coffaro et al. 2020).*

CONCLUSIONS

- **ε Eridani is the youngest star that shows a short X-ray acitivity cycle**
- **Its X-ray cycle displays a low amplitude due to a massive presence of magnetic structures, from 75% to 95% of the total corona, that do not allow the X-ray luminosity to significately change.**

OUTLOOK

- **New monitoring campaigns of both the corona and the chromosphere to shed light on the divergence between the X-ray cycle and the Ca II cycle in the most recent years (see Fig. 2).**

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