# Modeling the corona of stars more active than the Sun using 3D MHD simulations

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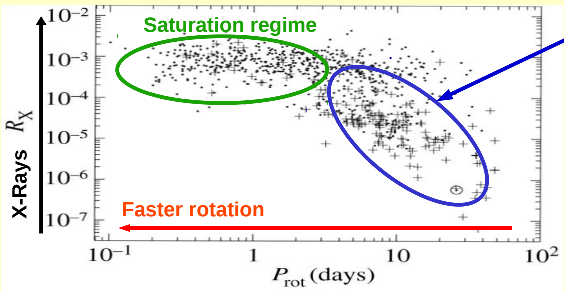
## Abstract

Observations show that faster rotating stars tend to have stronger magnetic field at the surface. This should lead to an increased energy input to the corona and thus to a brighter and hotter corona, just as seen in observations of X-ray luminosity . Our goal is to apply a model of the solar corona to stars more active than the Sun and understand the relation between the surface magnetic field and the heat input into the corona. For this purpose we use the Pencil Code to solve the MHD equations with the heating being through the Ohmic dissipation of currents. In our project we change the strength of the magnetic field at the bottom boundary (i.e the unsigned flux) as a first step to understand how the heat input into the corona will change quantitatively. Preliminary results show that the average temperature in the model corona relates to the coronal energy input as expected from the Rosner, Tucker and Vaiana (RTV) scaling laws. More importantly, we can also quantify how the coronal energy input relates to the magnetic flux at the surface indicating that the corona with temperatures from 1 MK to 10 MK can be heated by flux-braiding/nanoflare heating.

## INTRODUCTION



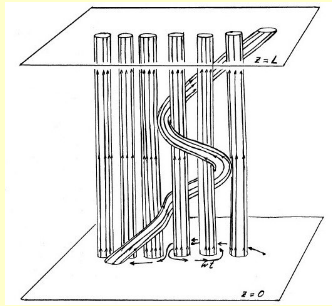

Testa et al 2015

**Main interest:**
**Stars where X-ray luminosity depends on rotation**

**Faster rotation:**

- **stronger magnetic field (Dynamo)**
- **higher coronal energy input**
- **higher coronal temperature**
- **higher X-ray luminosity**

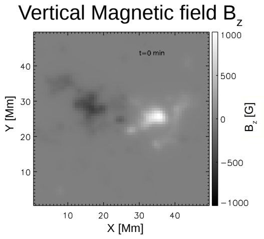
### Model 3D Corona



Parker 1983

## Numerical setup

Vertical Magnetic field $B_z$

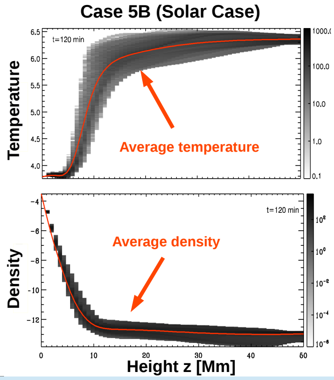



- Prescirbed photospheric driver motion
- Based on model by Bingert & Peter 2011
- Resolution of 64x64x64 grid points
- Change the total unsigned magnetic flux at the bottom boundary by a factor of 20 (by simply multiplying B)
- All other parameters remain the same
- Using Pencil Code (https://github.com/pencil-code/)

| Cases | Φ[Mx] |
|---|---|
| Reference | $8.4\times10^{20}$ |
| 2B | $1.7\times10^{21}$ |
| 5B | $4.2\times10^{21}$ |
| 10B | $8.4\times10^{21}$ |
| 20B | $1.7\times10^{22}$ |

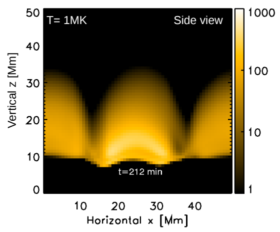
## Results

Case 5B (Solar Case)

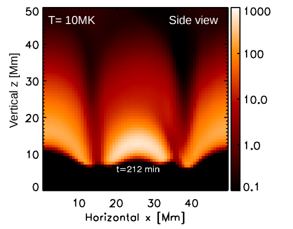



- Probability density function of logT, logρ
- Snapshot at t=120 min (saturated phase).
- Spatial variability at any height.
- Temperature rises to 1 MK, consistent with previous models.
- Density drops to $10^{-13}$ kg/m$^3$, consistent with previous models.

Pseudo emission of AIA 171 Å: Case 5B



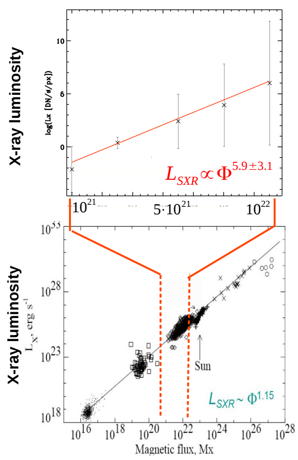

Pseudo X-ray emission of SXT/al-poly: Case 10B




Temperature response function provides emissivity at each gridpoint:

- Emissivity calculated through CHIANTI atomic data base or simpler approximations.
- With our model we can synthesize EUV and X-ray emission despite low resolution.

## Comparing X-ray luminosity to observations




- Non-linear increase of the X-rays with a steep slope of 5.9.
- Observations show an almost linear increase with a slope of 1.15 .
- More numerical experiments with a different spatial structure of the initial magnetogram are required.

Pevtsov et al 2003

## CONCLUSIONS:

- **Low resolution runs are able to capture basic aspects of coronal dynamics and heating (preliminary high resolution runs confirm this result).**
- **X-ray emission increases with the total surface flux.**
- **Slope of power law relating X-ray luminosity to magnetic flux is much steeper in models than in observations.**
- **Problem: We only increase |B| and keep spatial structure of B at bottom boundary constant. Then Poynting flux S ~ |B|$^2$ consistent with our results.**
- **Solution: More realistic models with different filling factors of B at bottom boundary or larger spatial extent of active region.**

References:

S. Bingert, H. Peter, 2011, A&A, 530, A112
P. Testa, S.H. Saar, J.J. Drake, 2015, The Royal society, 373
E. Parker, 1983, ApJ, 264:642-647
A. Pevtsov, G. Fisher, L.W. Acton, D. W. Longcope et al., 2003, ApJ, 598: 1387-1391

Poster

1. Fundamental physical processes and modeling

# Modelling the corona of stars more active than the Sun using 3D MHD simulations

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Solar-like stars are surrounded by a million K hot corona. Observations show that faster rotating stars tend to have stronger magnetic field at the surface. This should lead to an increased energy input to the corona and thus to a brighter and hotter corona, just as seen in X-ray observations.
3D numerical magnetohydrodynamic (MHD) models of an active region in the Sun were successful in reproducing aspects of the coronal structure and dynamics. Our goal is to apply this model to stars more active than the Sun and understand the relation between the surface magnetic field and the heat input into the corona. For this purpose we use the Pencil Code to solve the MHD equations with the heating being through the Ohmic dissipation of currents. These are induced by the surface magnetic field being driven around by convective motions.
In our project we change the strength of the magnetic field at the bottom boundary (i.e the unsigned flux) as a first step to understand how the heat input into the corona will change quantitatively. Preliminary results show that the average temperature in the model corona relates to the coronal energy input as expected from the Rosner, Tucker, Vaiana(RTV) scaling laws. More importantly, we can also quantify how the coronal energy input relates to the magnetic flux at the surface indicating that the corona with temperatures from 1 MK to 10 MK can be heated by flux-braiding/nanoflare heating.