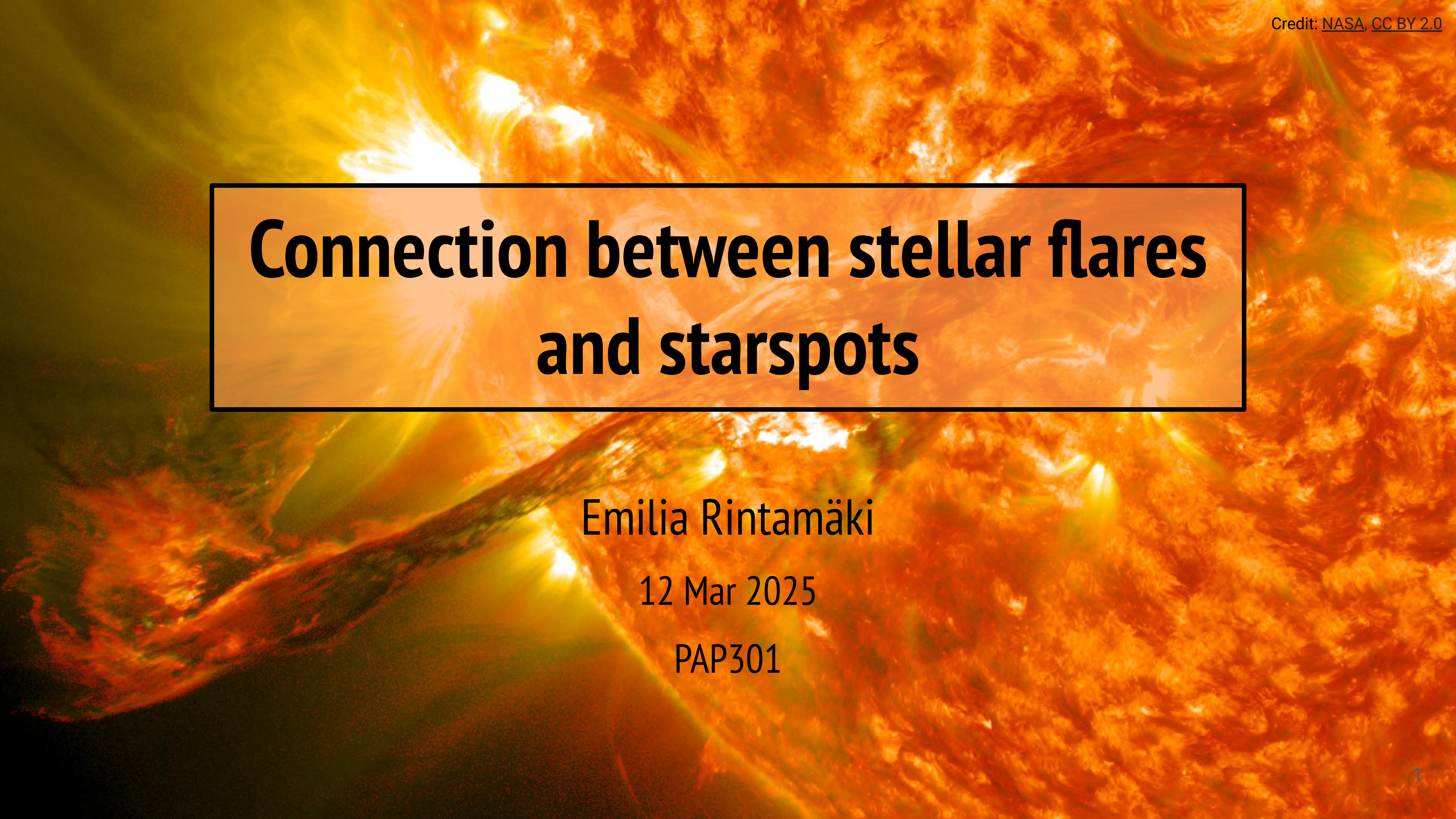

Connection between stellar flares and starspots

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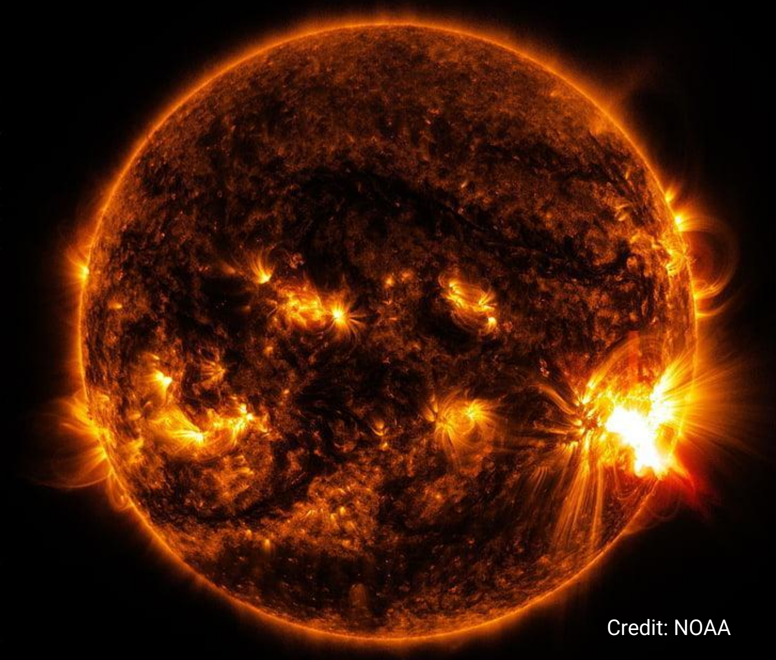
12 Mar 2025

PAP301

Contents

- Introduction to stellar magnetic activity
- Theory
- Research
- Results & conclusions

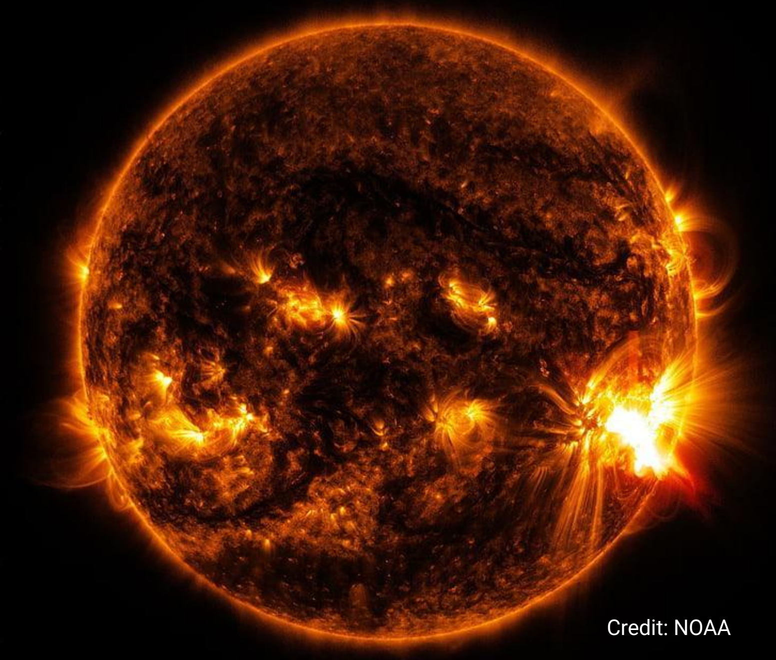


Credit: NOAA

Introduction

Abbreviations

- SMA = stellar magnetic activity
- MF = magnetic field
- EM = electromagnetic
- LC = light curve
- TESS = Transiting Exoplanet Survey Satellite



Credit: NOAA

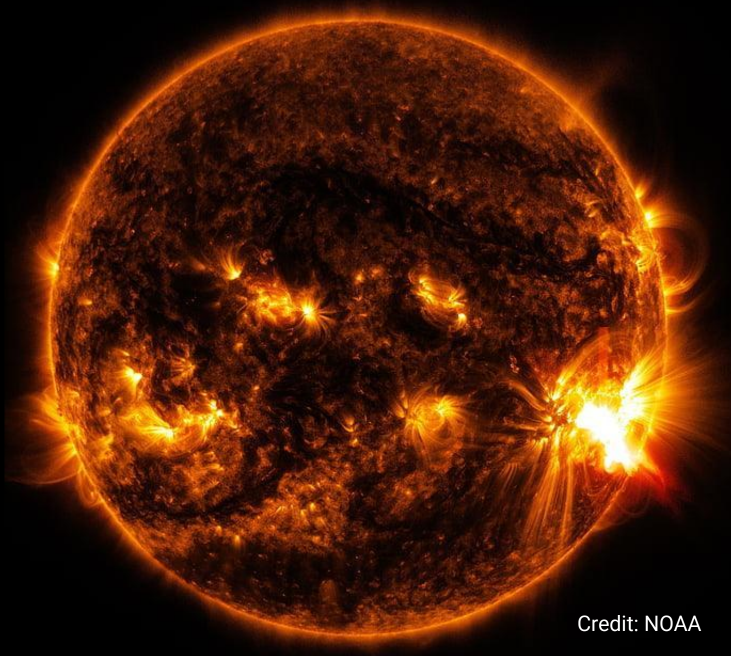
Stellar magnetic activity

= activity of stars caused by MFs

→ observed on stellar surface:
dark spots, bright emission, explosions

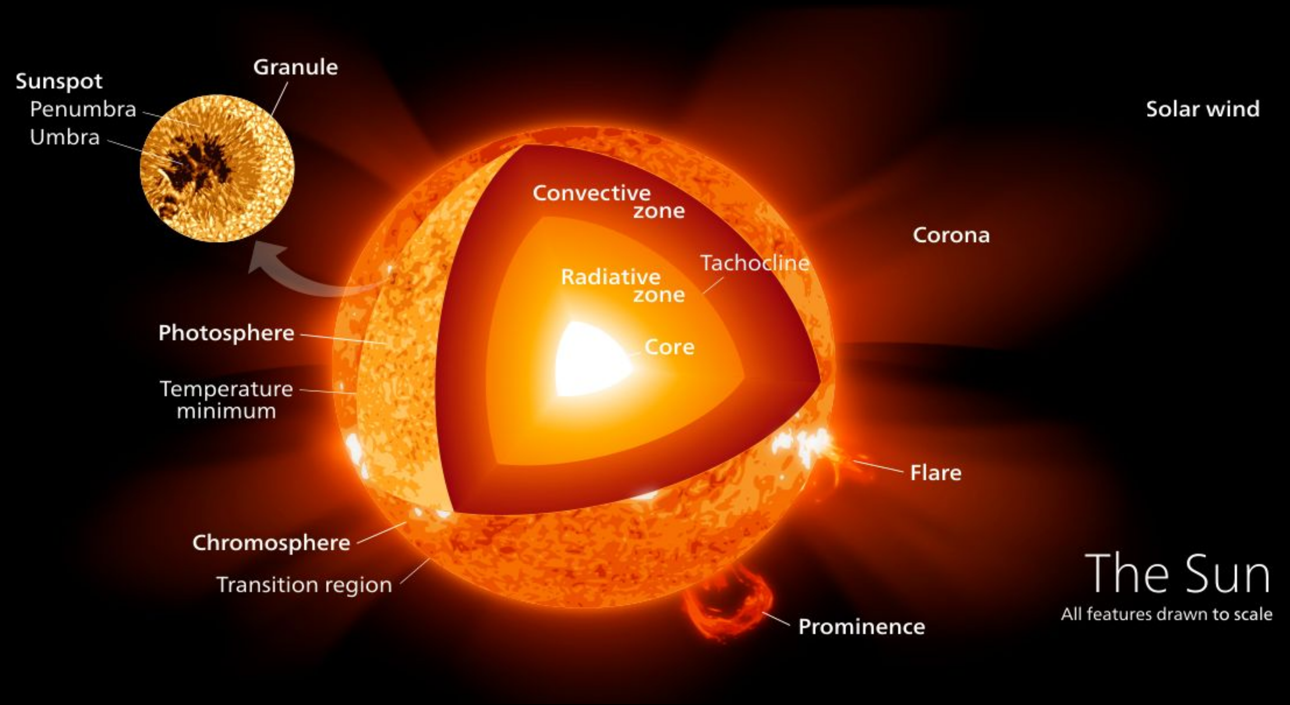
Stellar dynamo

- generates MFs of stars with convective envelope
- convection + rotation
  ➔ magnetic energy



Credit: NOAA

Anatomy of the Sun

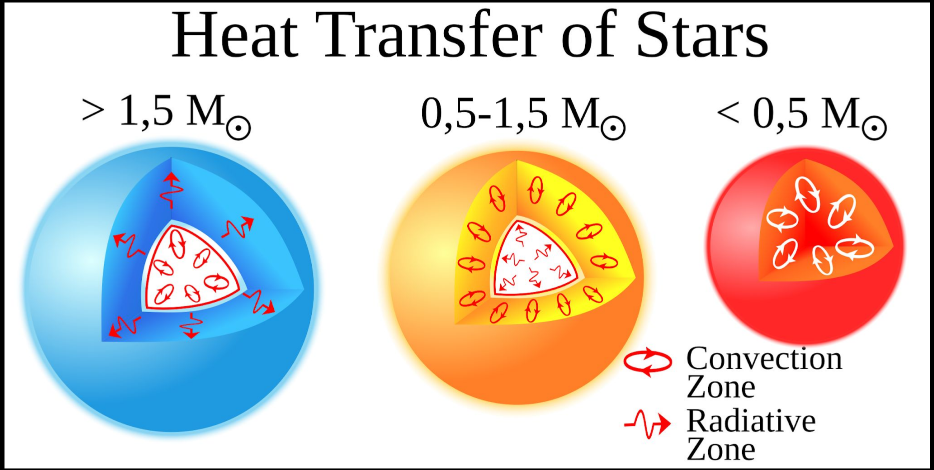


1) Core
2) Radiative zone
3) Convective zone / envelope
4) Photosphere (visual surface)
5) Chromosphere
6) Corona

Stars with convective envelopes

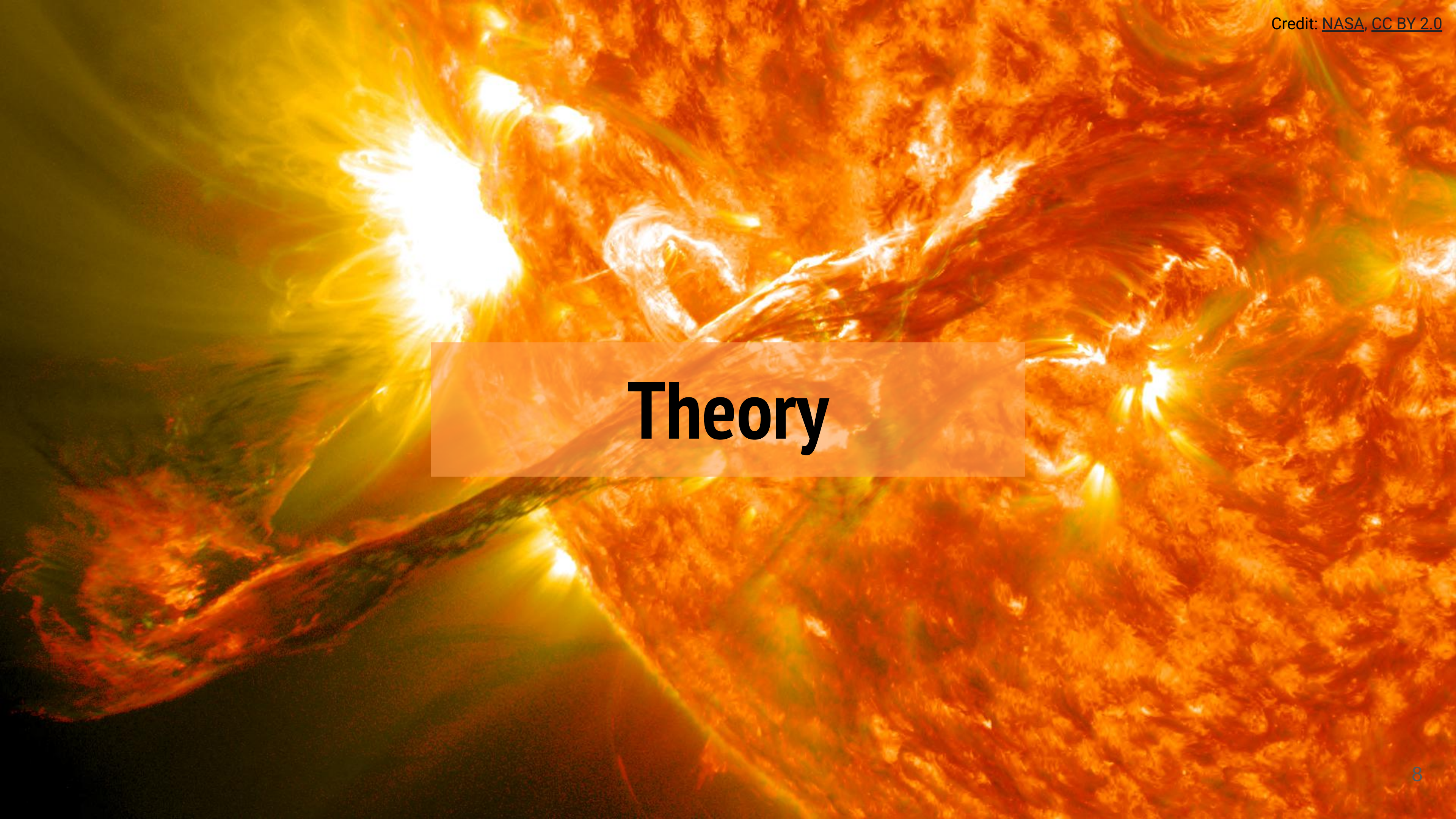
→ sustain dynamo process

→ are magnetically active



- solar-type stars
  - class F, G, K
  - convective envelope

- late-type stars
  - class K, M
  - fully convective
  - late = cool



Theory

Stellar dynamo

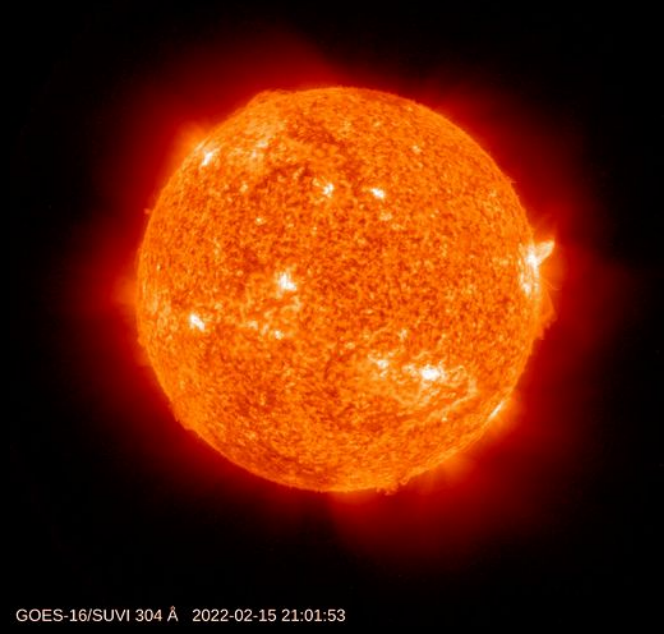
1) convective flows move plasma & induce currents

2) currents generate MFs

3) convection carries plasma & MF towards surface

4) MF lines penetrate the surface

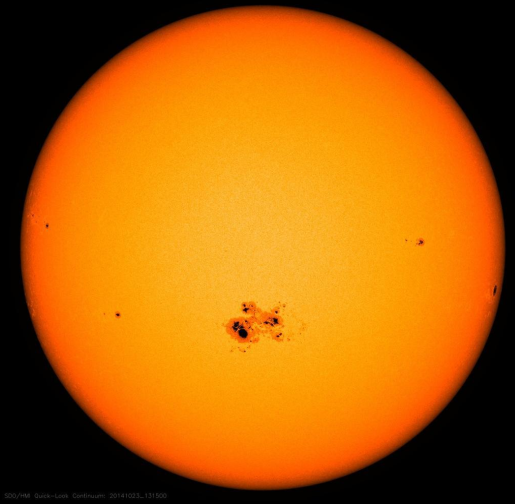
5) observable SMA phenomena occur



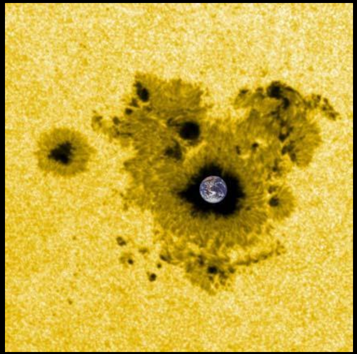
Credit: NOAA

Starspots

- dark spots on stellar surface (photosphere)
- connected with MFs (Hale, 1908)
- strong MFs penetrates the surface
  → convection inhibited
  → hot plasma cannot rise to surface
  → cooler than their surroundings
- decrease the observed brightness of stars



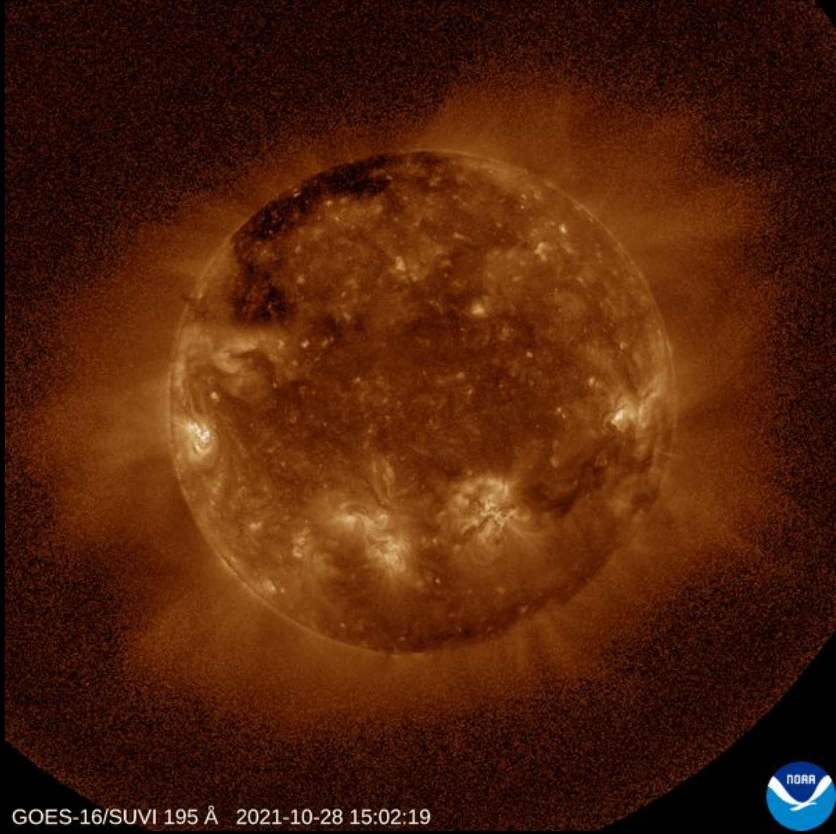
Credit: NASA Goddard Space Flight Center, CC BY 2.0



Credit: NASA's TRACE spacecraft.
Earth image: Apollo 17 astronauts

Stellar flares

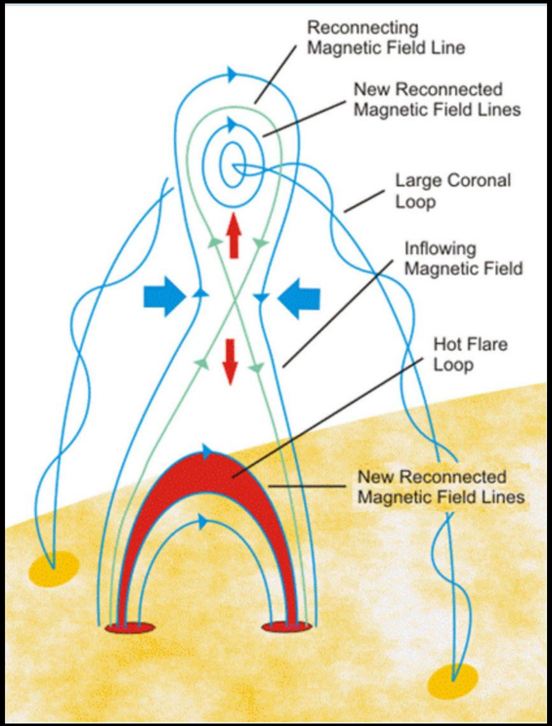
- bursts of EM radiation in chromosphere & corona
- release magnetic energy
- last from seconds to days
- observed on stars with conv. envelopes



Credit: NOAA

Stellar flares

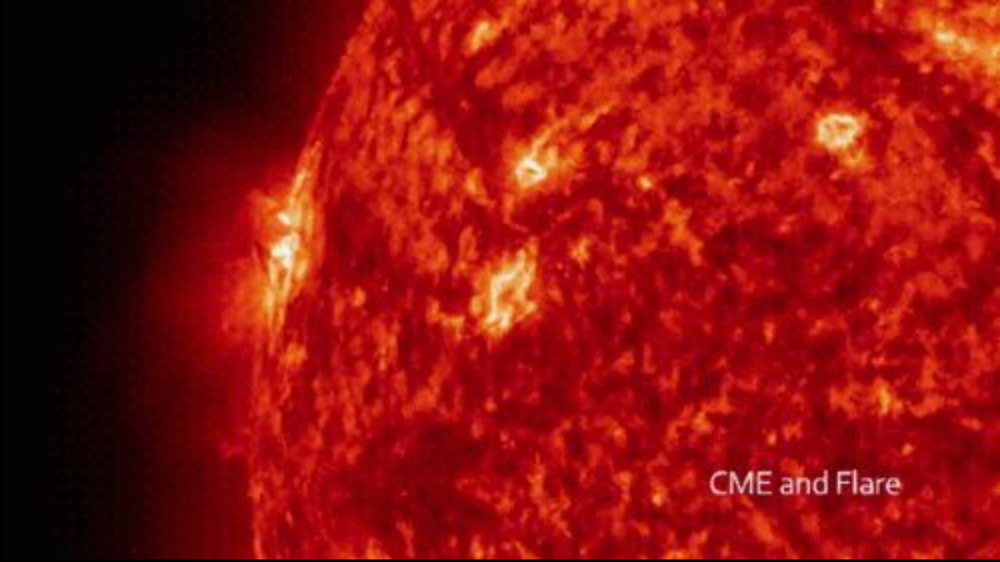
- occur in magnetically active regions
- caused by magnetic reconnection
    1) MF lines penetrate the stellar surface
    2) MF lines cross and reconnect
    3) magnetic loop is ejected off the surface



An illustration of magnetic reconnection and solar flare diagram. Image Credit: Gordon Holman and NASA

Solar flares

- stellar flares on the Sun
- most energetic explosions in the solar system
    - energy of million hydrogen bombs
- affect on everyday life and modern technology on Earth



- intense radiation
    - optical, radio, x-rays, γ-rays
    - ➔ danger to astronauts & electronic instruments in space

Stellar light curves – way to observe SMA

Stellar flares

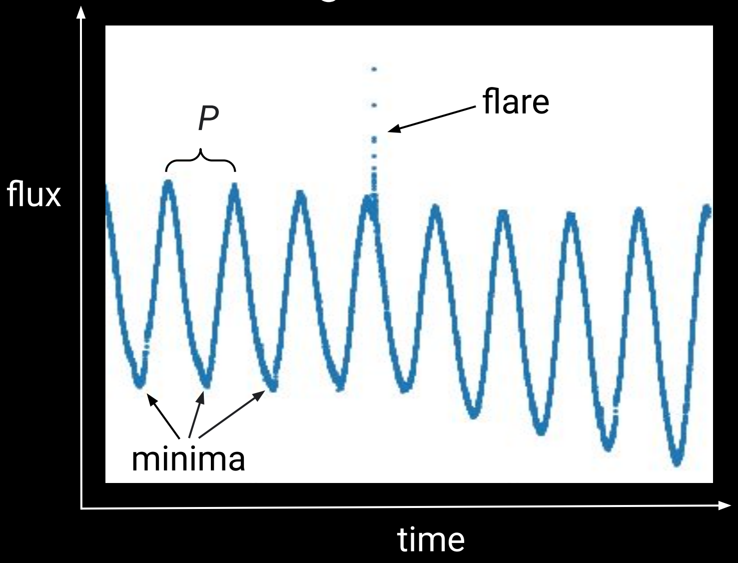
- cause sudden, irregular brightnenings

  → sharp peaks in the flux

Starspots:

- cause periodic minima of the flux
  - star rotates → spots move in and out of the view
- reveal stellar rotational period *P*

Photometric light curve
= star's brightness over time




Credit: NASA, CC BY 2.0
Research

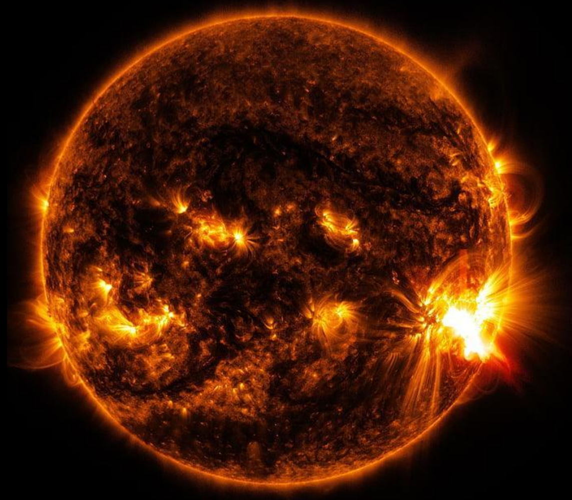
Research question

- Is there a connection between stellar flares and starspots?

- flares and spots are both signs of SMA
  - both occur in magnetically active regions

    → could flares originate from spots?

- knowledge of solar-type stars → knowledge of the Sun and its behavior



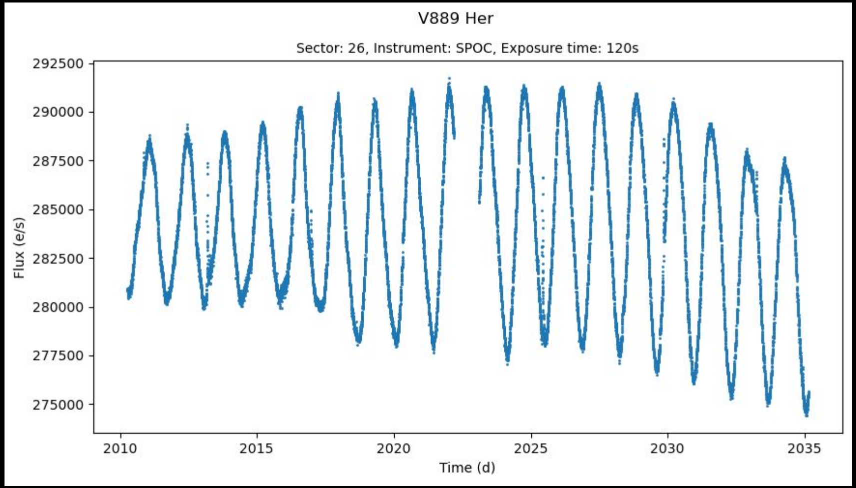
Credit: NOAA

TESS data

- TESS = Transiting Exoplanet Survey Satellite
- accessed via MAST portal
  (Mikulski Archive for Space Telescopes)
- light curves of two targets:
  - LQ Hya: 3 LCs
  - V889 Her: 4 LCs

Chosen Light curves:

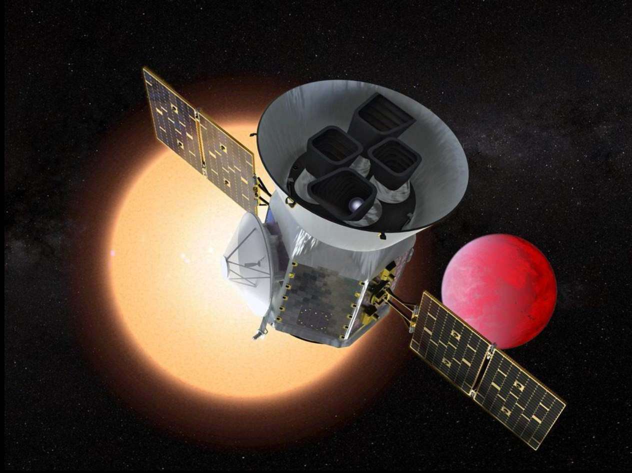
Target name	Start date (Y-M-D)
LQ Hya	2019-02-02
LQ Hya	2021-02-09
LQ Hya	2023-02-12
V889 Her	2020-06-09
V889 Her	2021-06-25
V889 Her	2022-06-13
V889 Her	2024-06-18



Targets

LQ Hya & V889 Her

- solar-type stars (class K & G)
- magnetically active
- young & rapidly rotating

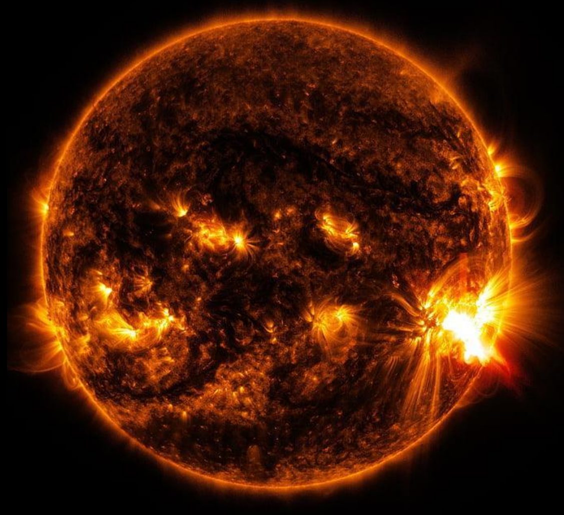

TESS. Credit: NASA's Goddard Space Flight Center

Target name	Class	Variable type	Age	Radius	P_{rot}	T_{eff}
LQ Hydrae	K0–K2 V	BY Dra	50 My	1.0 $R_\odot$	1.6 d	4909 K
V889 Herculis	G2 V	BY Dra	30–50 My	1.09 $R_\odot$	1.3 d	5718 K

Methods

- flare detection program
  - based on support vector machine

1) finds the periodicity of LC → “trend”
2) detects sudden brightenings from LC → flares


Credit: NOAA

- analysis of flare timings:

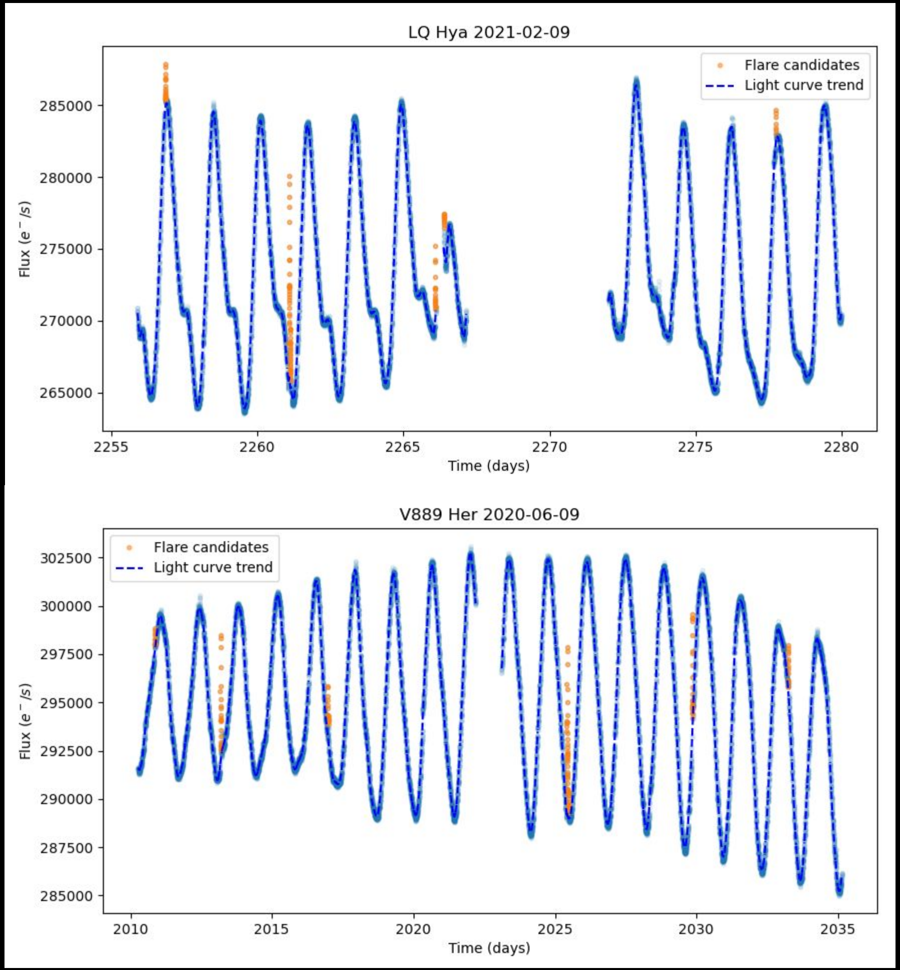
1) flare timing vs. min / max flux → flare phase
2) Kuiper test

Flare detection

The program detects 40 flare candidates from 7 LCs

- LQ Hya: 10 candidates
- V889 Her: 19 candidates

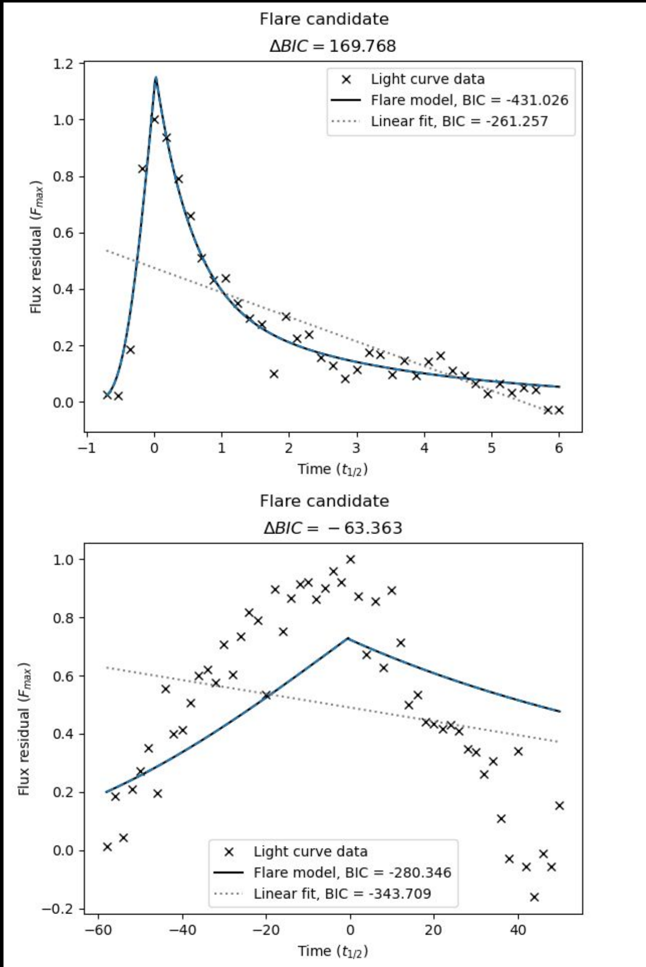
Next, we need to filter out false candidates!



True or false flare candidate?

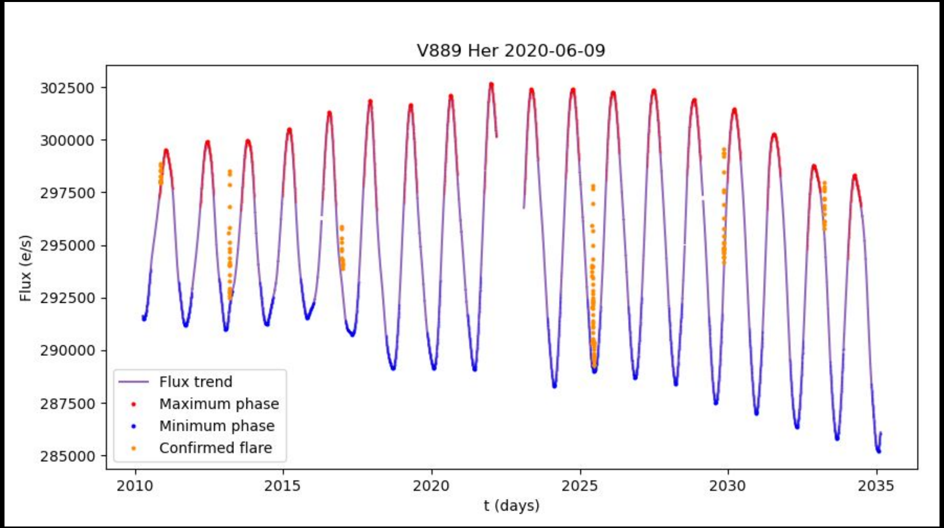
- Shape of a flare:
  1) a steep rise
  2) a sharp peak
  3) an exponential decrease

- flare model vs. linear fit
  - smaller BIC → better fit
  - ΔBIC ≫ 0 → a true flare
  - 29 candidates accepted as flares
  - 11 candidates rejected



Phase of flares

- LC is divided into 3 phases:
  - min phase (spots in view)
  - mid phase
  - max phase (no spots)
- each phase covers 33% of one period
- flare timings are compared to the phases → flare phases



➔ if flares prefer min phase, they may originate from spots!

Results & conclusions

Results

- LQ Hya: 60% of flares in max phase, 10% of flares in min phase

  → flares correlate with the brightness

  → flares prefer the max phase

- V889 Her: 32% of flares in max phase, 26% of flares in min phase

  → no strong correlation

  → flares do not prefer any phase

Number of confirmed flares:

	LQ Hya	V889 Her
min phase flares	1	5
middle phase flares	3	8
max phase flares	6	6
flares in total	10	19

Results

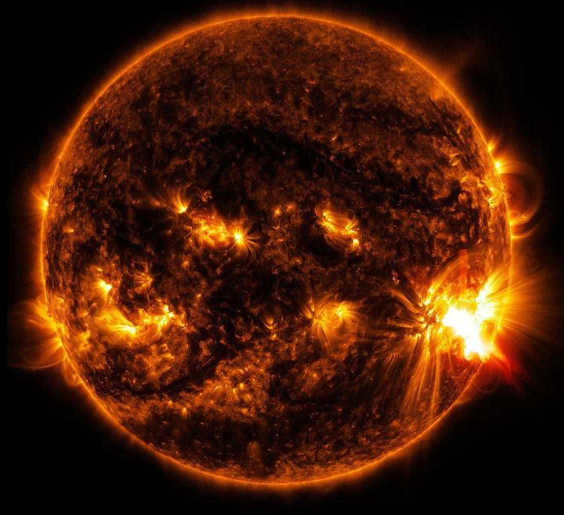
- flares occur most rarely in min phase
  - ➔ negative correlation between flares and spots
  - ➔ contradicts the assumptions
- results agree with other studies (Martin et al. 2024, Doyle et al. 2018)

Number of confirmed flares:

	LQ Hya	V889 Her
min phase flares	1	5
middle phase flares	3	8
max phase flares	6	6
flares in total	10	19

Conclusions

- SMA cause stellar flares and starspots
- connection between flares and spots was studied by LC data analysis
  - no correlation found between flares and spots, negative correlation instead → why?
- study of solar-type stars help us to understand the behavior of the Sun



Credit: NOAA

References

- Basri, G. (2021). *An introduction to stellar magnetic activity*. IoP Publishing.
- Korhonen, T. (2022). *Identifying stellar flares from optical light curves*. Master's thesis, University of Helsinki.
- Lehtinen, J., Jetsu, L., Hackman, T., Kajatkari, P., and Henry, G. W. (2016). *Activity trends in young solar-type stars*. Astronomy & Astrophysics, 588:A38.
- Kowalski, A. F. (2024). Stellar flares. Living Reviews in Solar Physics, 21(1):1.
- ESA. The Structure of the Sun. Accessed: 10 Mar 2025
- Martin et al. (2024). *The benchmark m dwarf eclipsing binary cm draconis with tess: spots, flares, and ultra-precise parameters*. Monthly Notices of the Royal Astronomical Society, 528(1):963–975

Thank you!