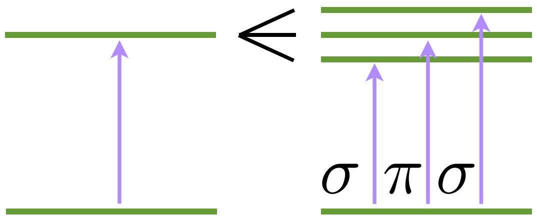
Twists and turns: Space weather around other stars

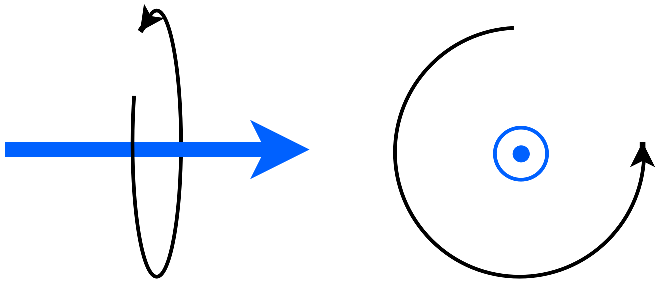
Moira Jardine

St Andrews

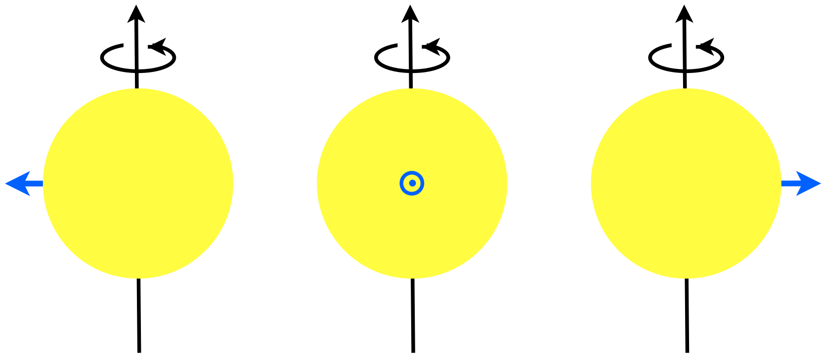
Zeeman-Doppler imaging



Zeeman effect splits light into
different polarisation components



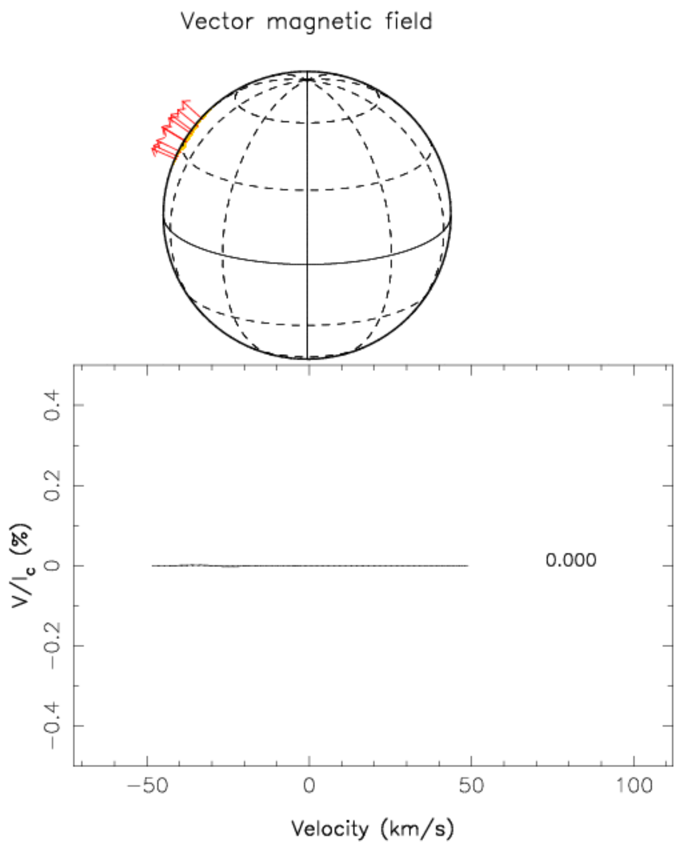
Field orientation
affects polarisation

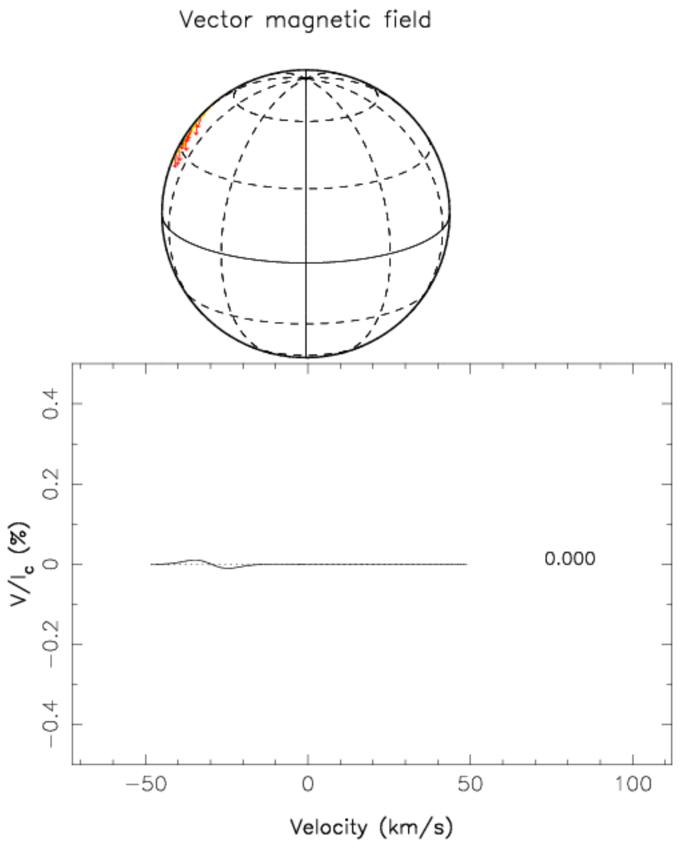


Polarisation signal
varies with rotation

Slide courtesy V. See

Track Stokes V (= ↺ - ↻) as star rotates





Get *large-scale* field

Slide courtesy J.-F. Donati

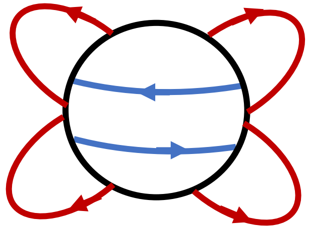
Time series of Stokes profiles fitted with spherical harmonics

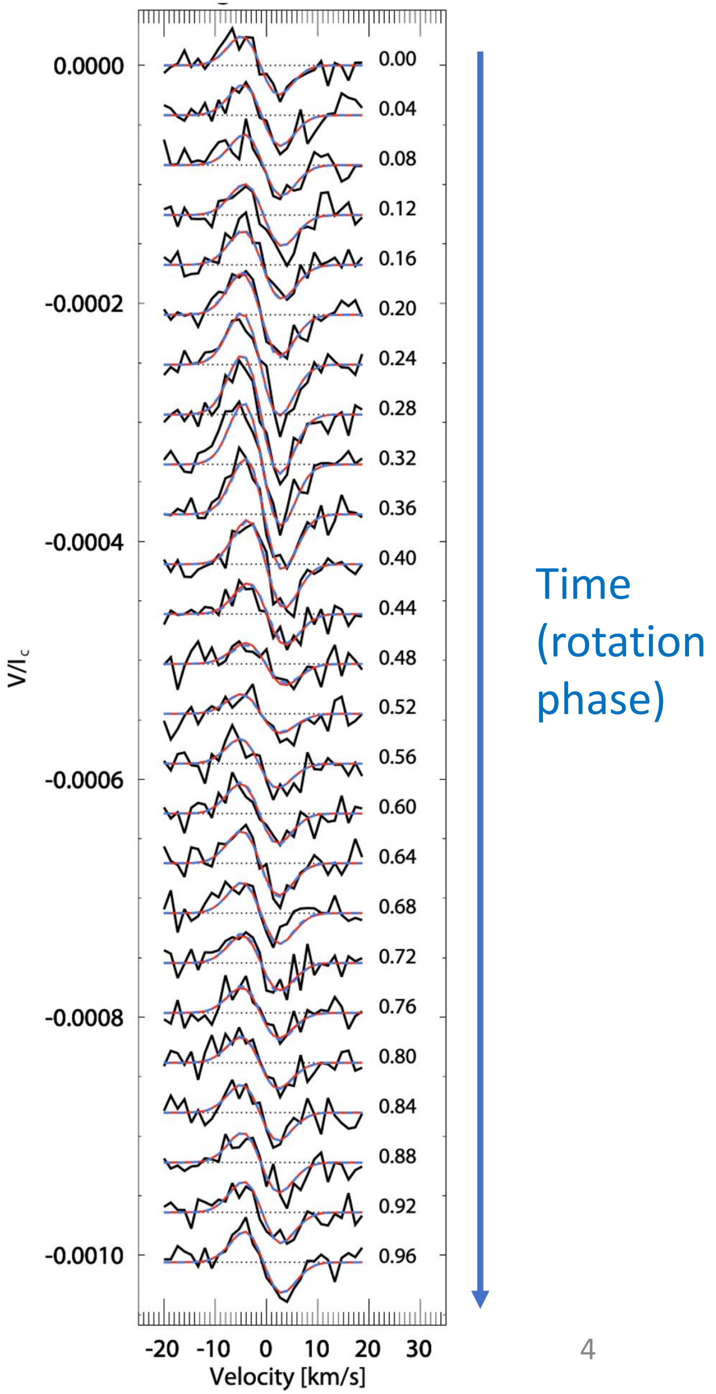
$$B_r(\theta,\phi) = -\sum_{\ell,m} \alpha_{\ell,m} Y_{\ell,m}(\theta,\phi)$$

$$B_\theta(\theta,\phi) = -\sum_{\ell,m} (\beta_{\ell,m} Z_{\ell,m}(\theta,\phi) + \gamma_{\ell,m} X_{\ell,m}(\theta,\phi))$$

$$B_\phi(\theta,\phi) = -\sum_{\ell,m} (\beta_{\ell,m} X_{\ell,m}(\theta,\phi) - \gamma_{\ell,m} Z_{\ell,m}(\theta,\phi))$$

Poloidal *Toroidal*





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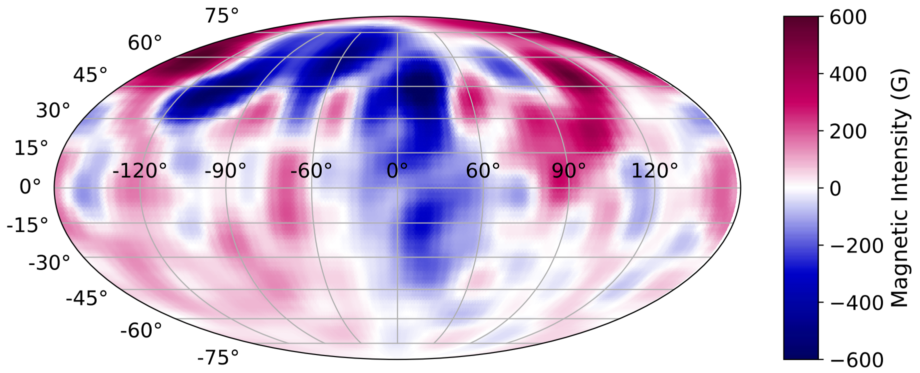
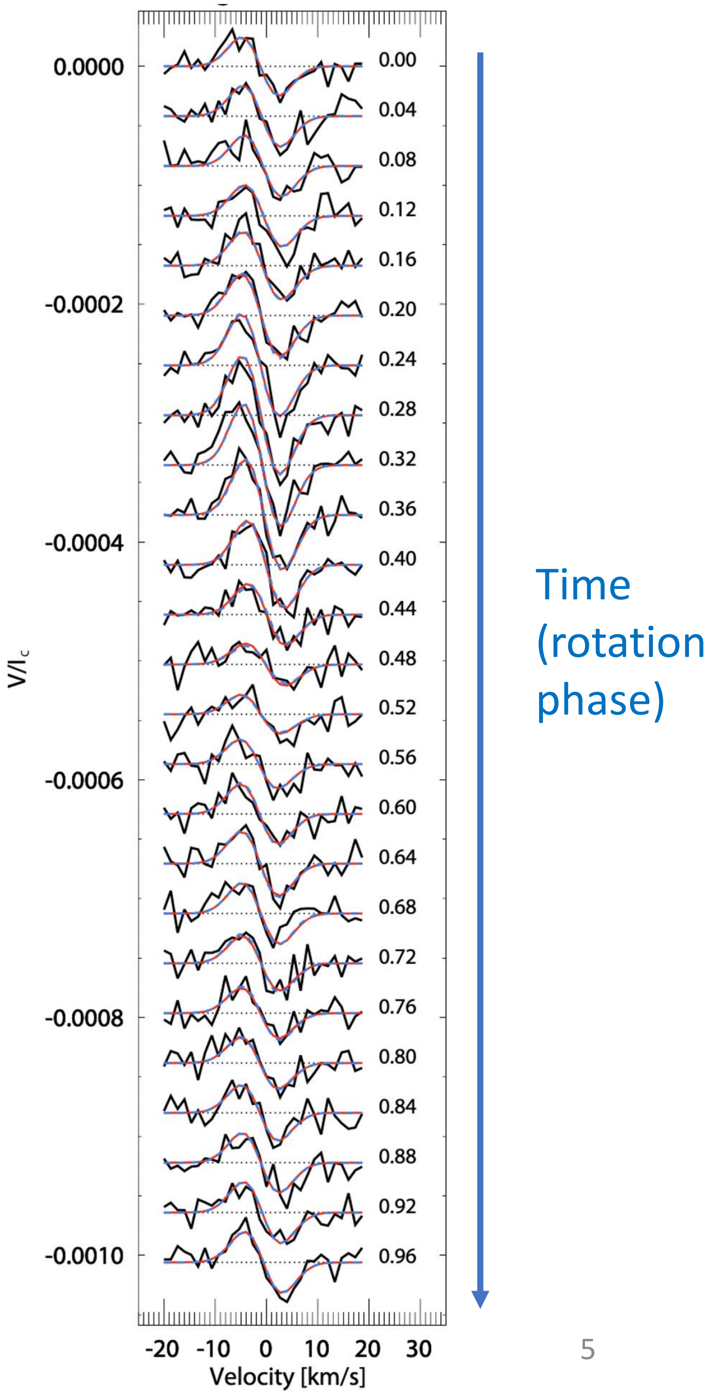
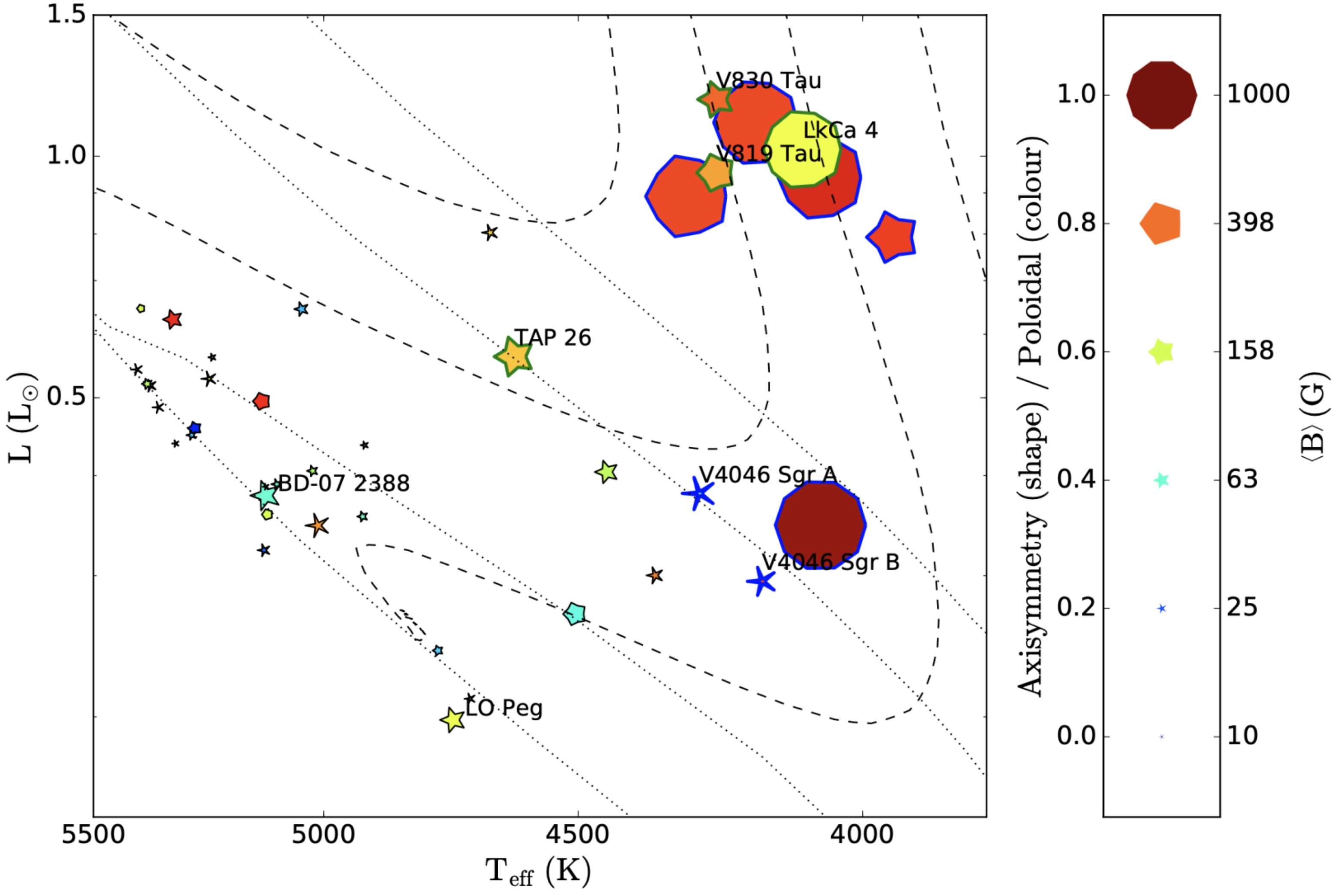




Diversity and evolution

<u>Growth in radiative core -></u>

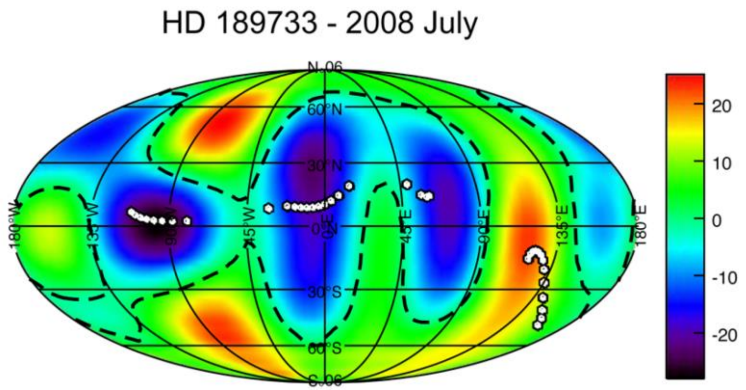
- Drop in field strength
- Growth of non-axisymmetry
- Growth of toroidal field

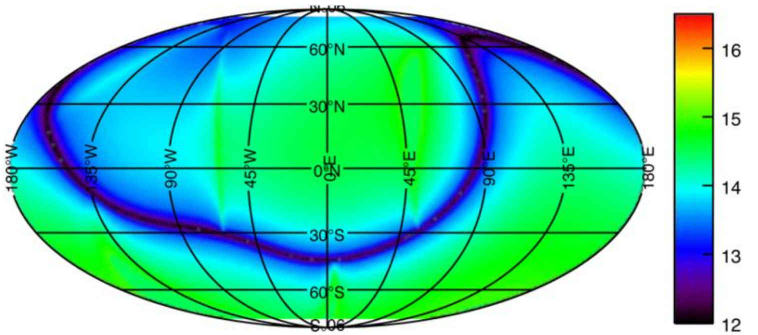


Folsom+2017, see also Gregory+12

Implications for space weather

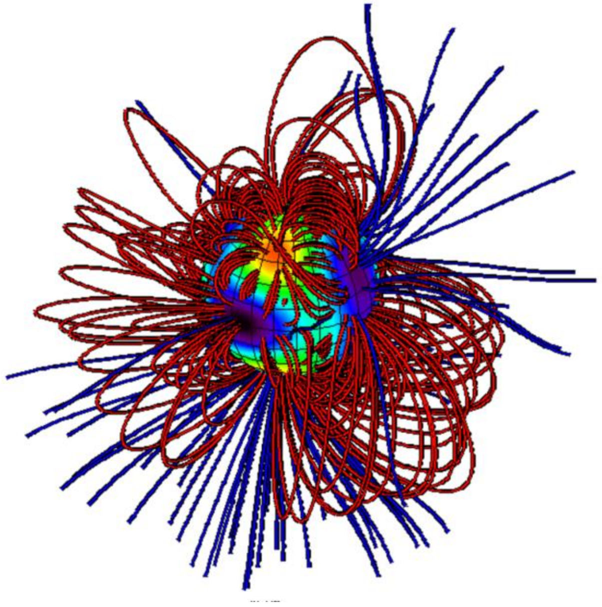
1. Map the star’s magnetic field





Ram pressure

2. Input into MHD model

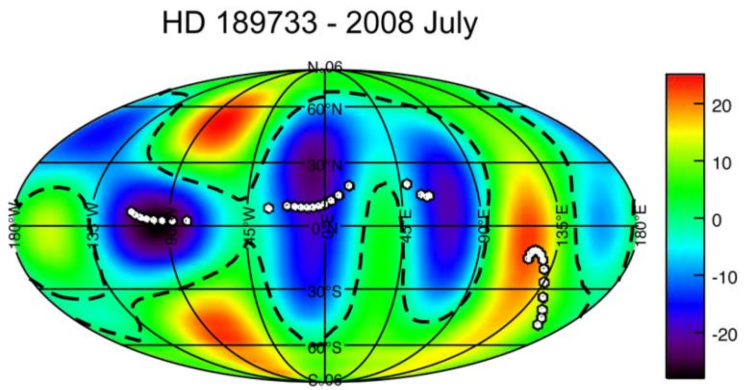


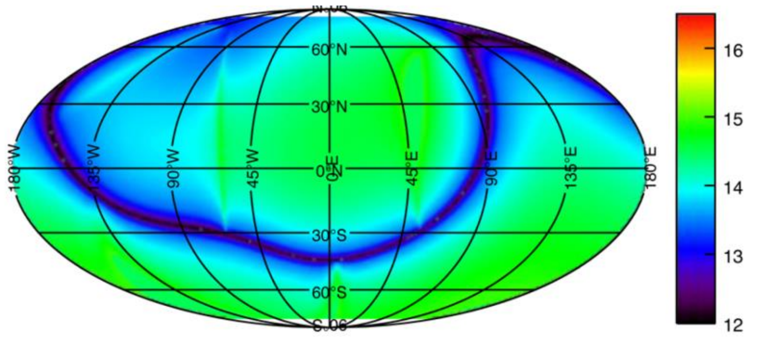
3. Determine local conditions at exoplanetary orbit

See+2015

Implications for space weather

1. Map the star's magnetic field





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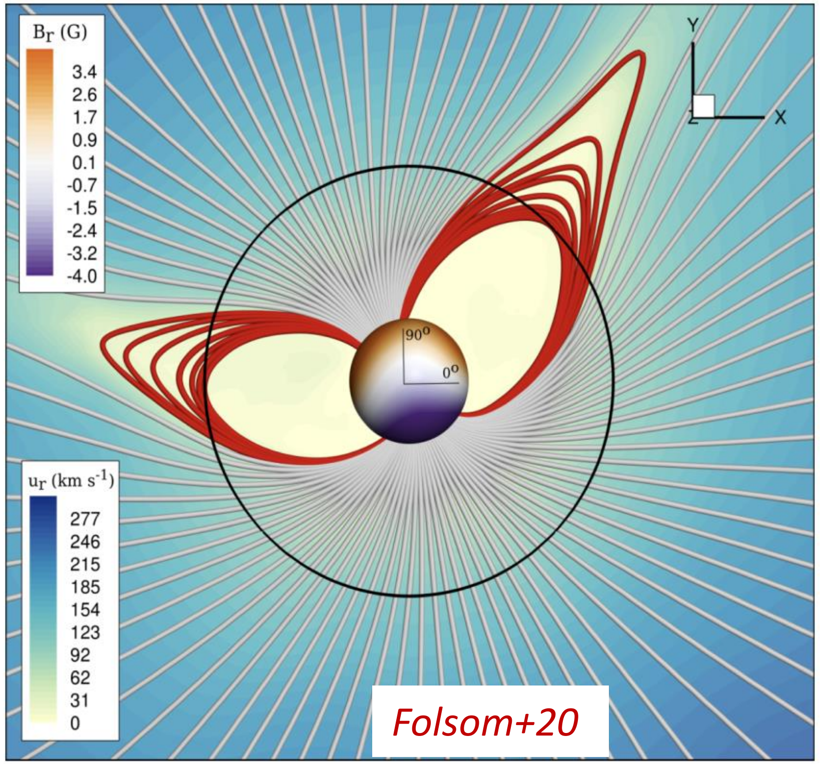


Folsom+20

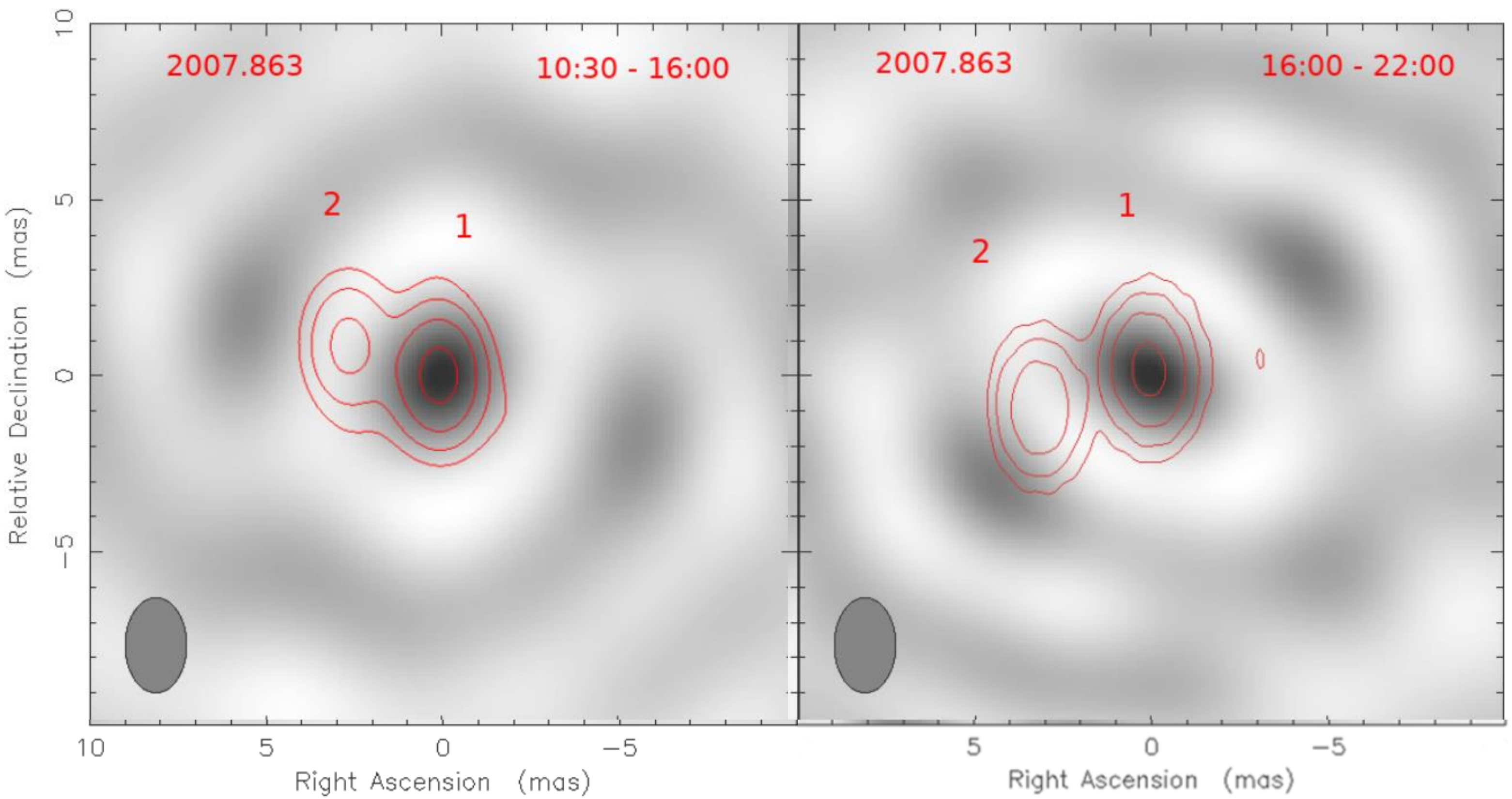
3. Determine local conditions at exoplanetary orbit

See+2015

1. How far does the corona extend?

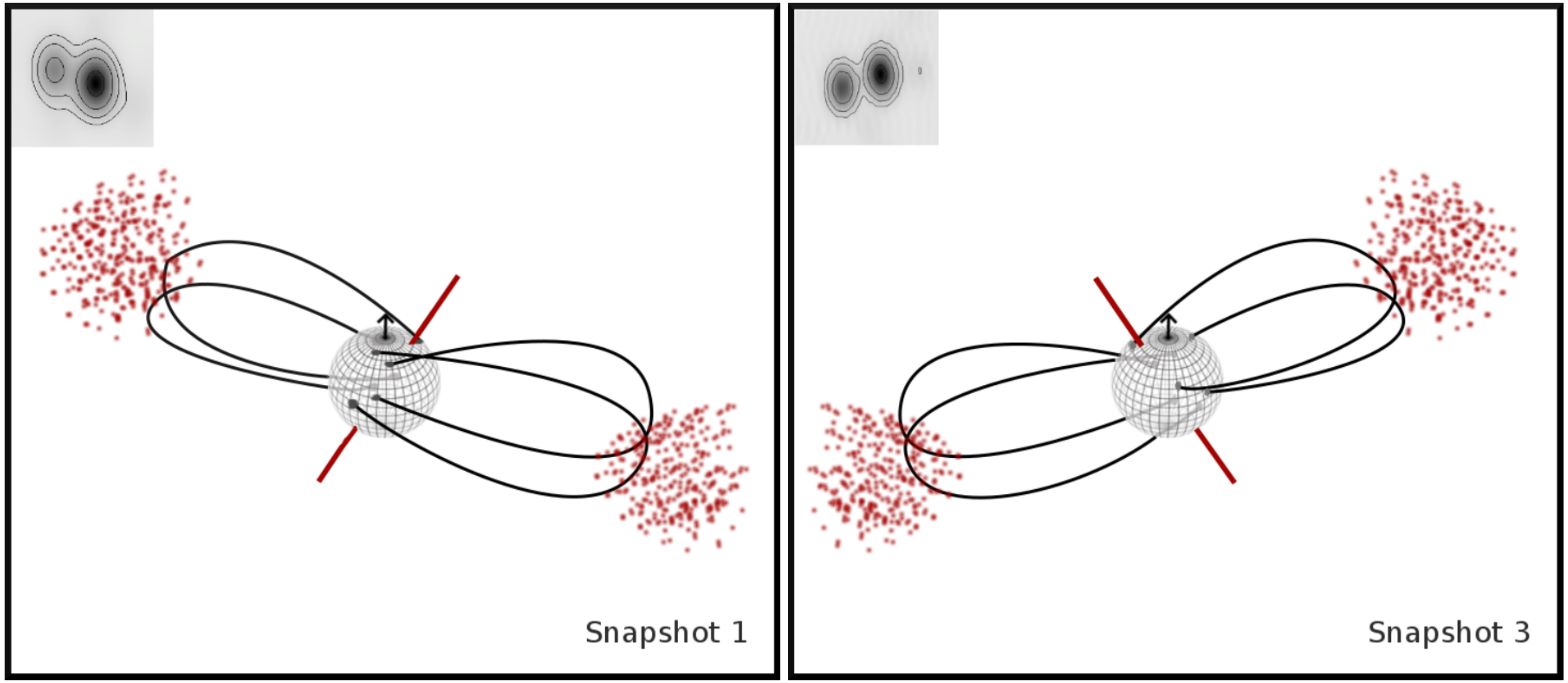
- AB Dor with VLBI at 8.4 GHz
- Two lobes of emission
- Evolution on stellar rotational timescale

Snapshot 1 Snapshot 2



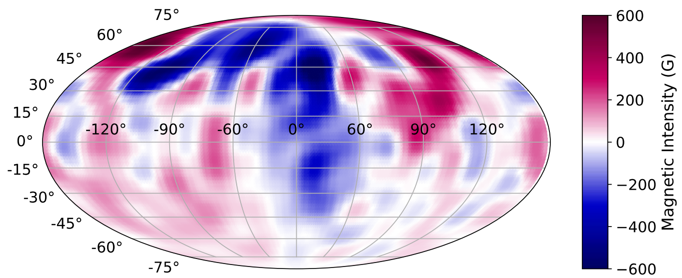
Climent+2020

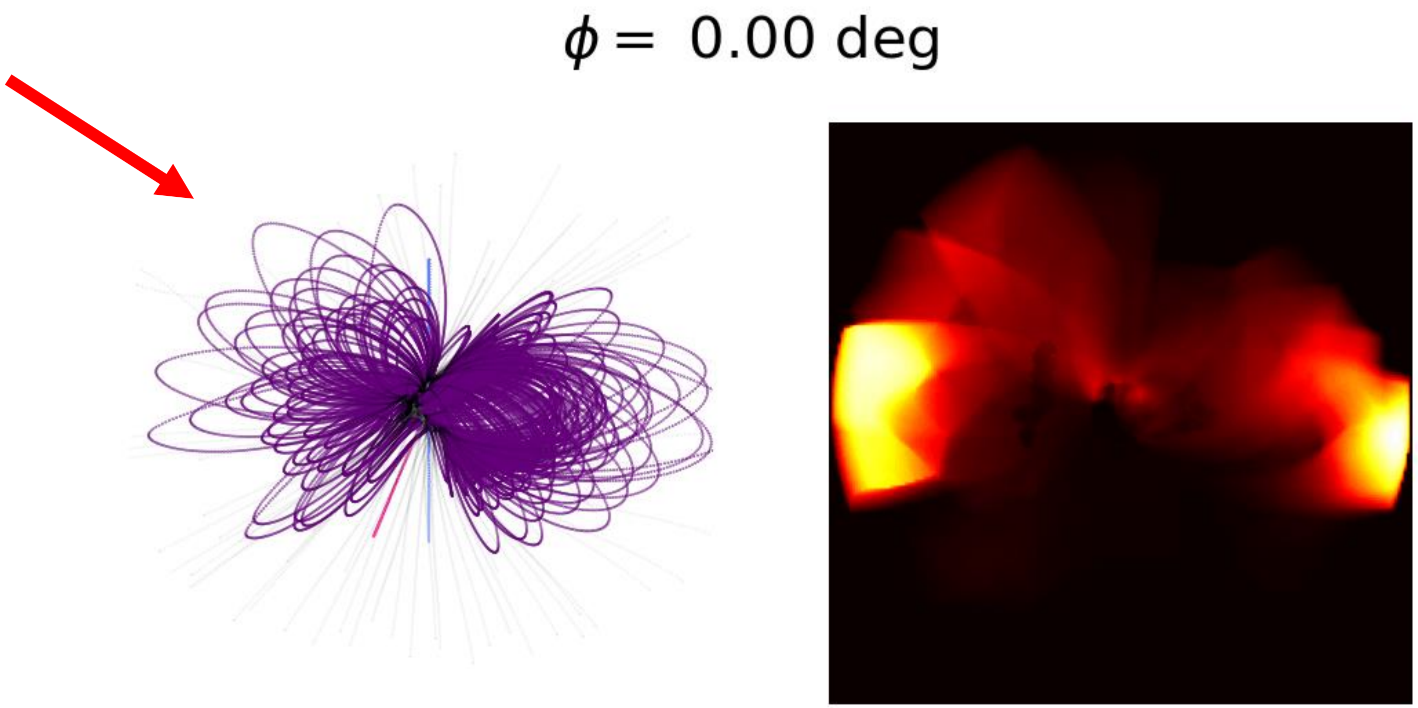
Are we seeing the coronal gas co-rotating?



Climent+2020

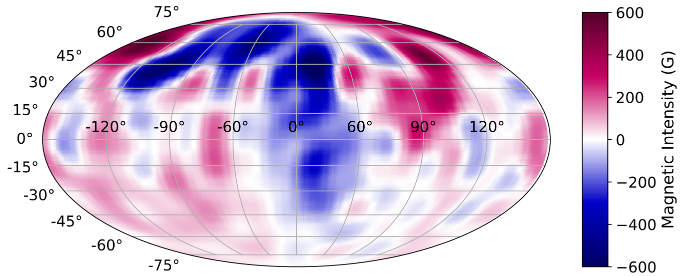
Simultaneous ZDI map -> *synthetic* 8.4GHz images

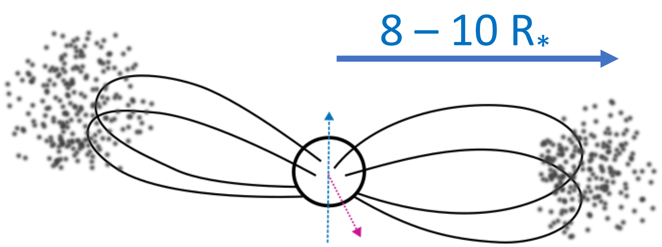




Brasseur+2023

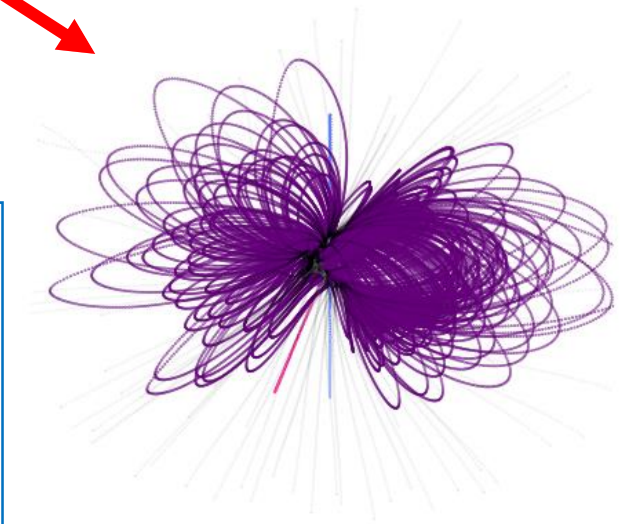
Simultaneous ZDI map -> *synthetic* 8.4GHz images

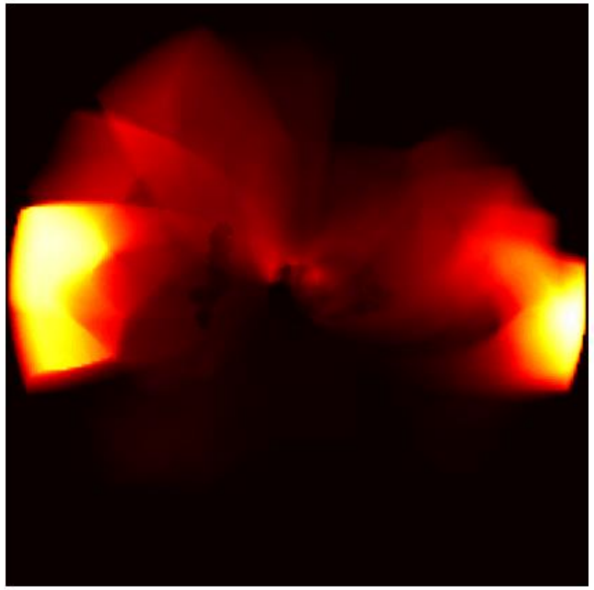




Matches flux magnitude+ lobe separation

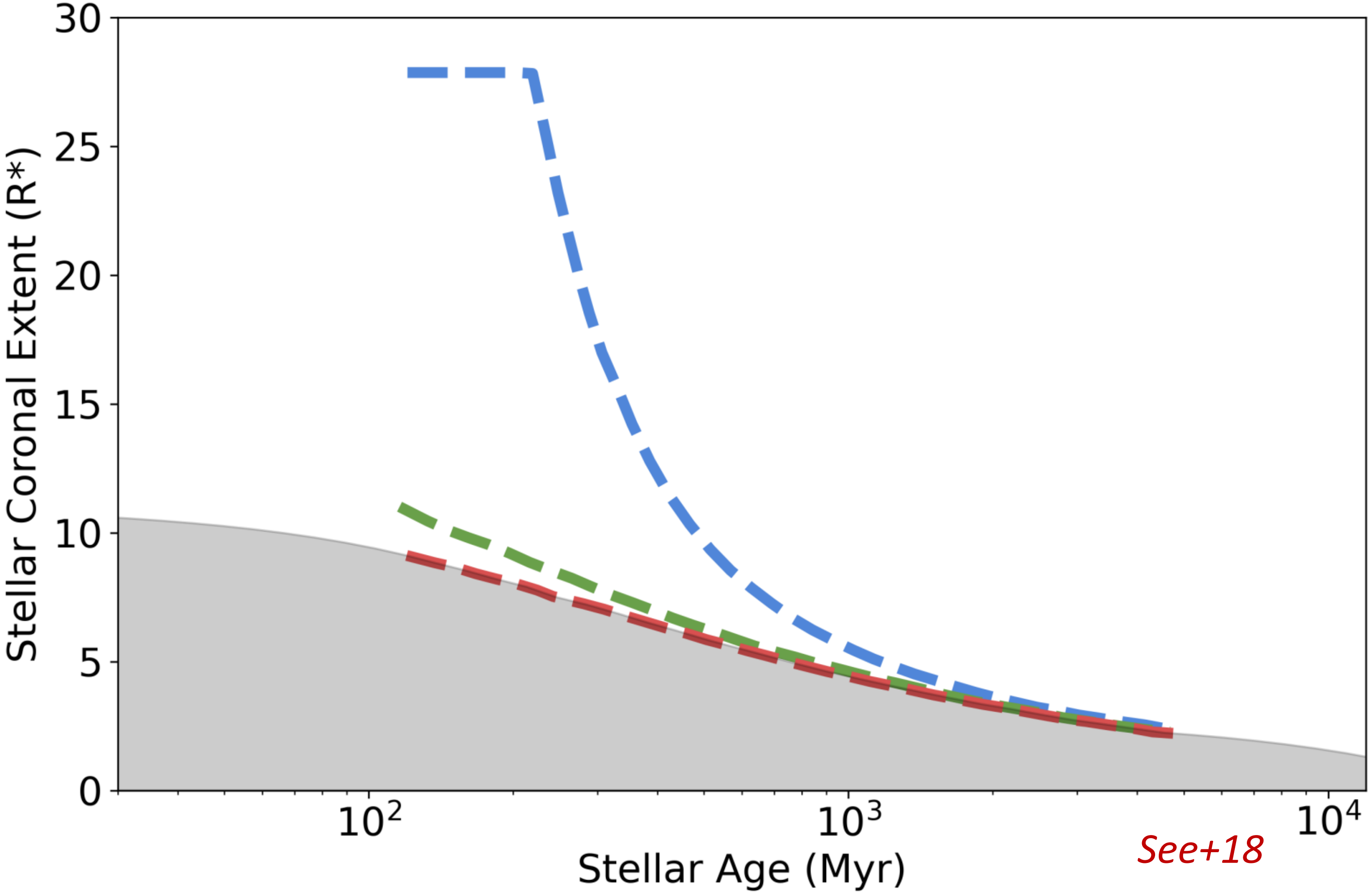
$\phi =$ 0.00 deg





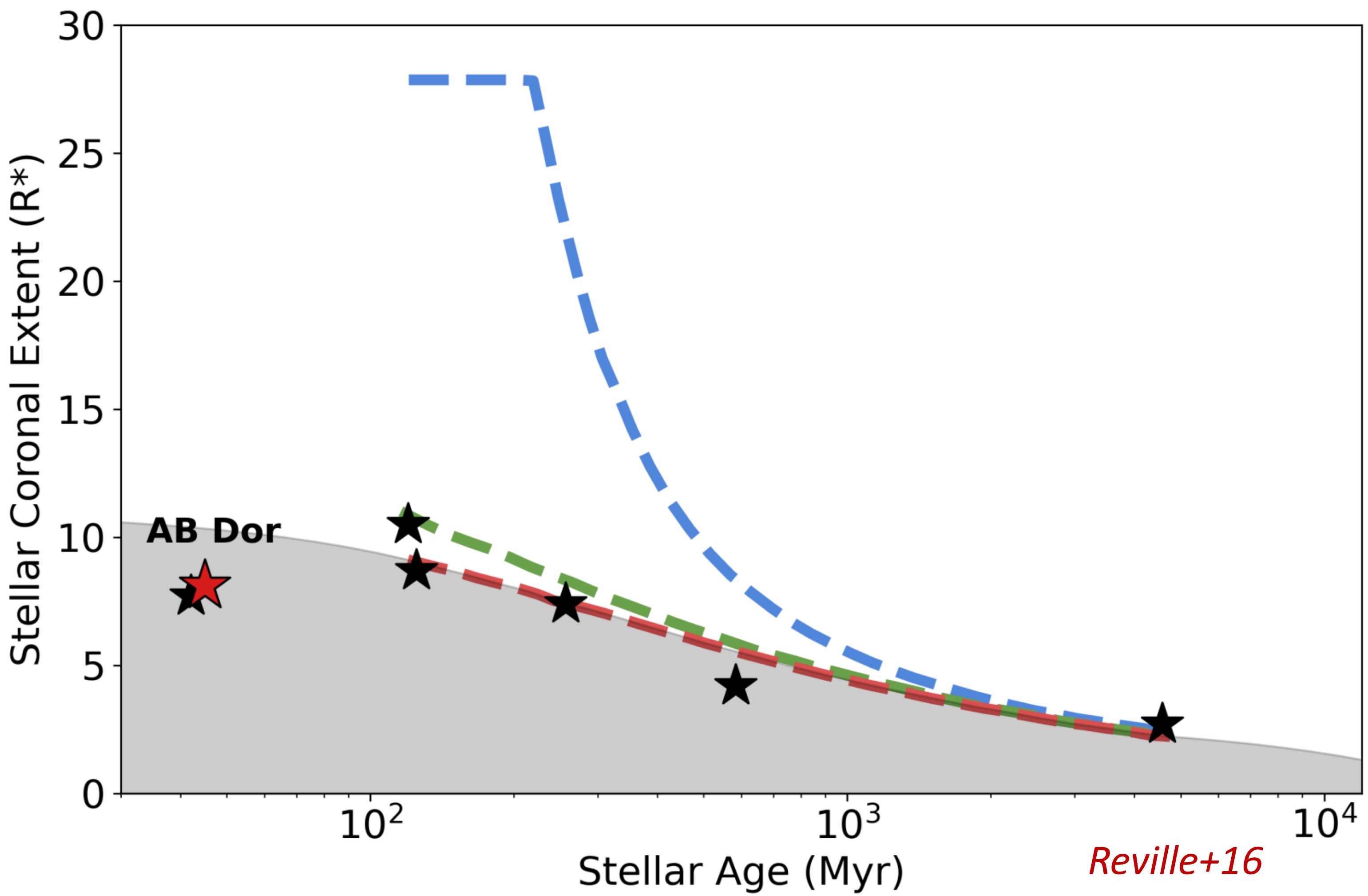
Brasseur+2023

How has the Sun's coronal extent evolved?



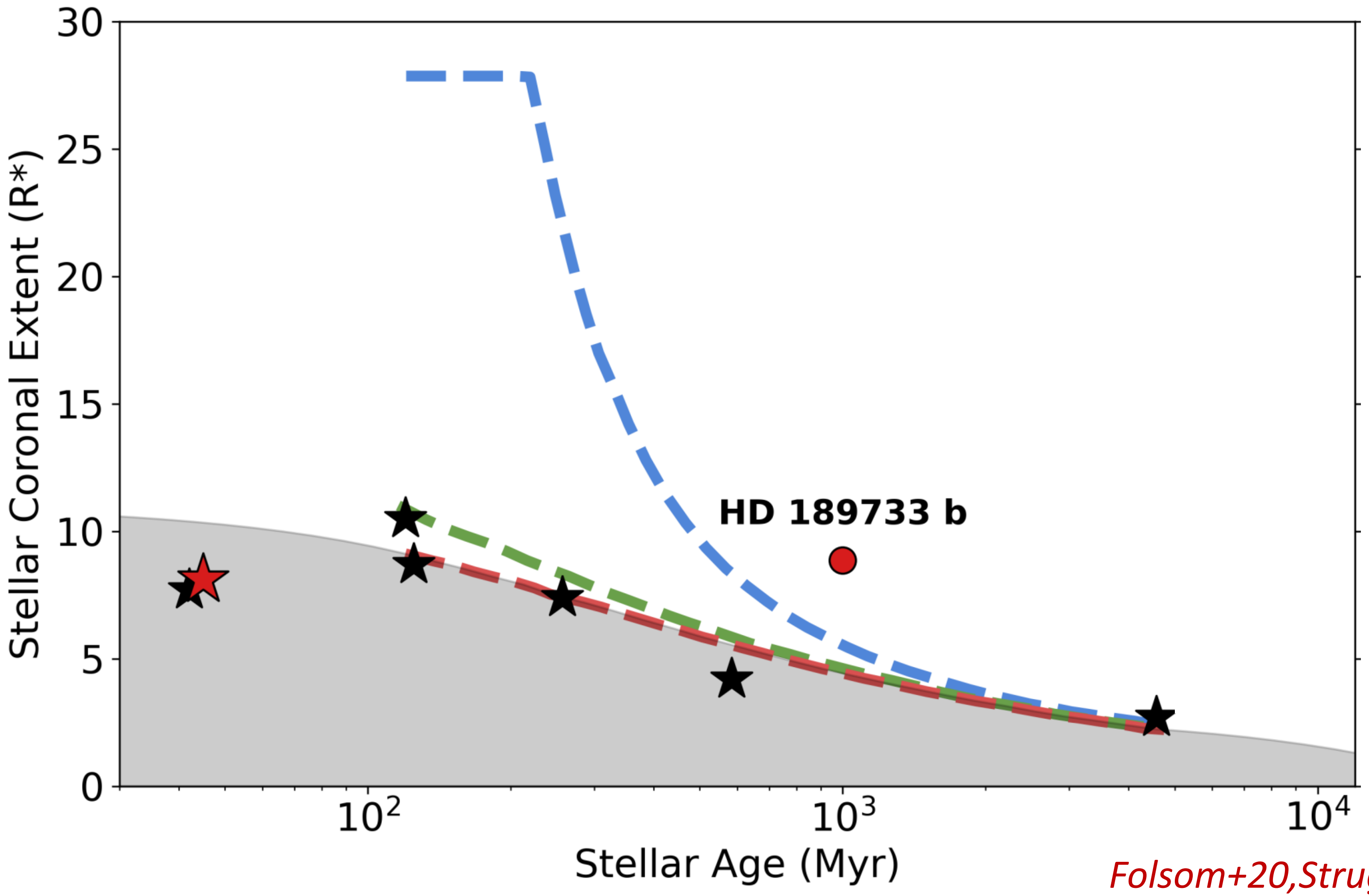
See+18

How has the Sun's coronal extent evolved?



Reville+16

Some exoplanets may orbit inside stellar coronae



Folsom+20,Strugarek+22

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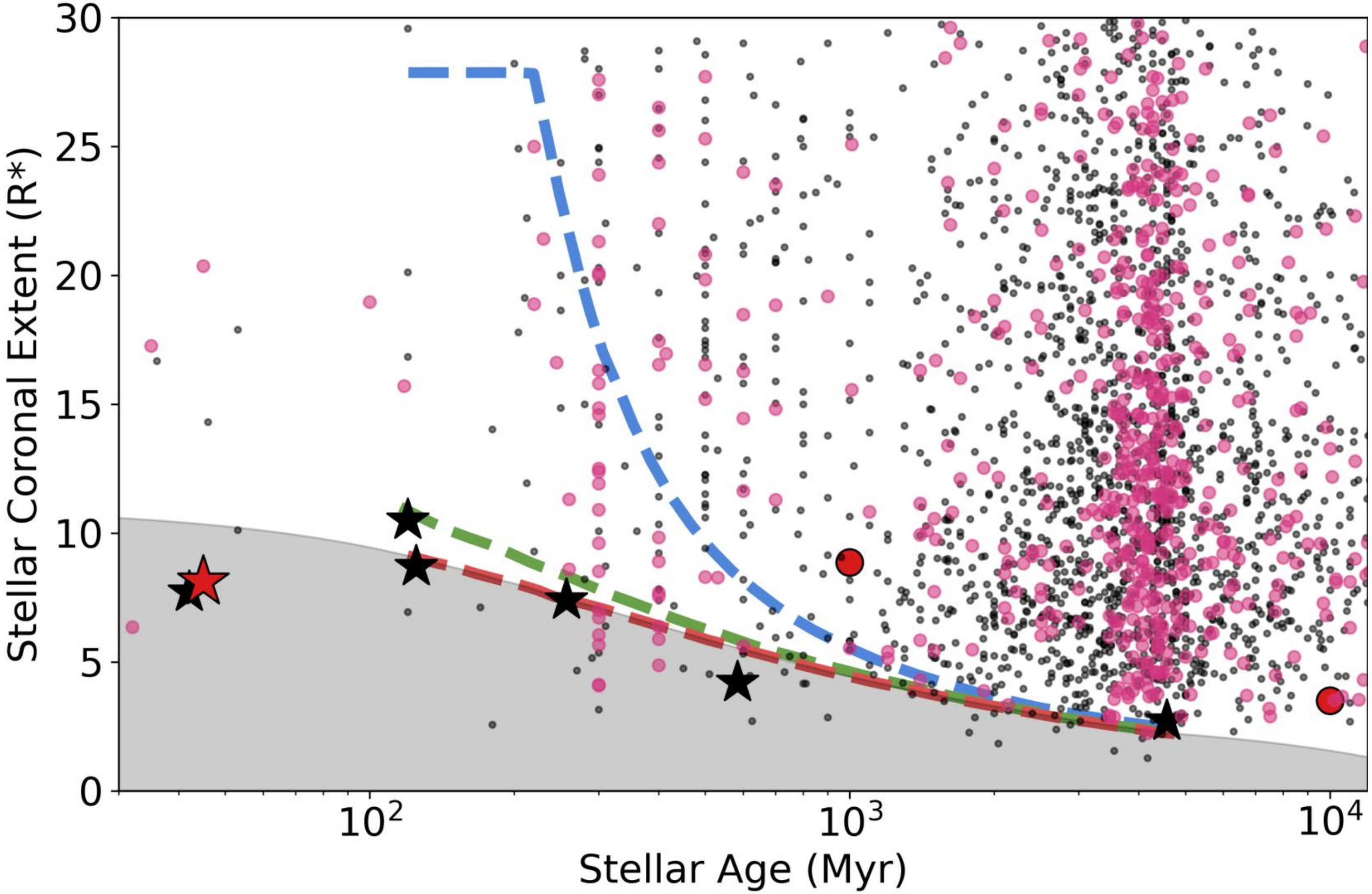


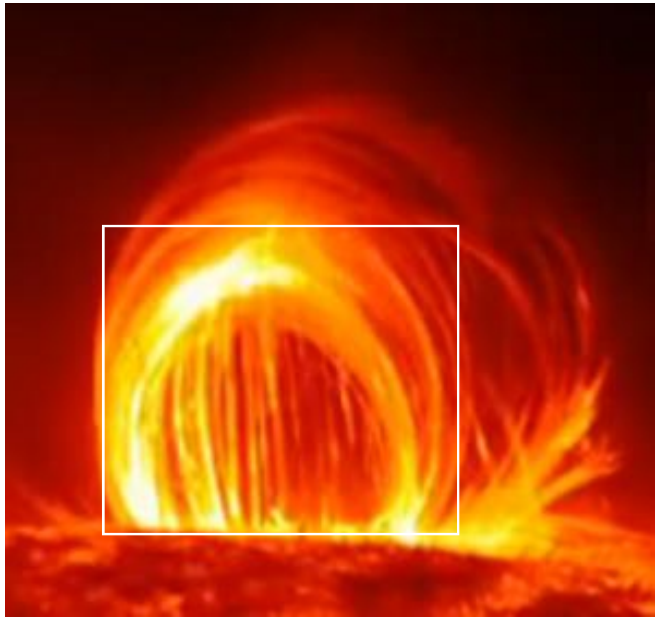
Brasseur+2023

2. *Cooling and heating cycles in stellar corona*

Simulating cooling flows

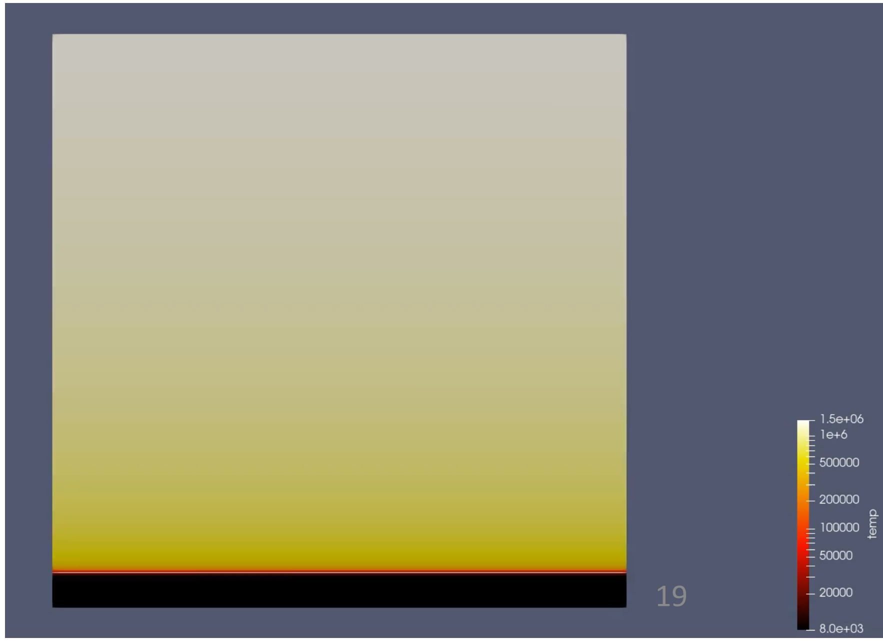
Simulation

Density



Observation

Temp



Daley Yates+23 (cf Zhou+21)

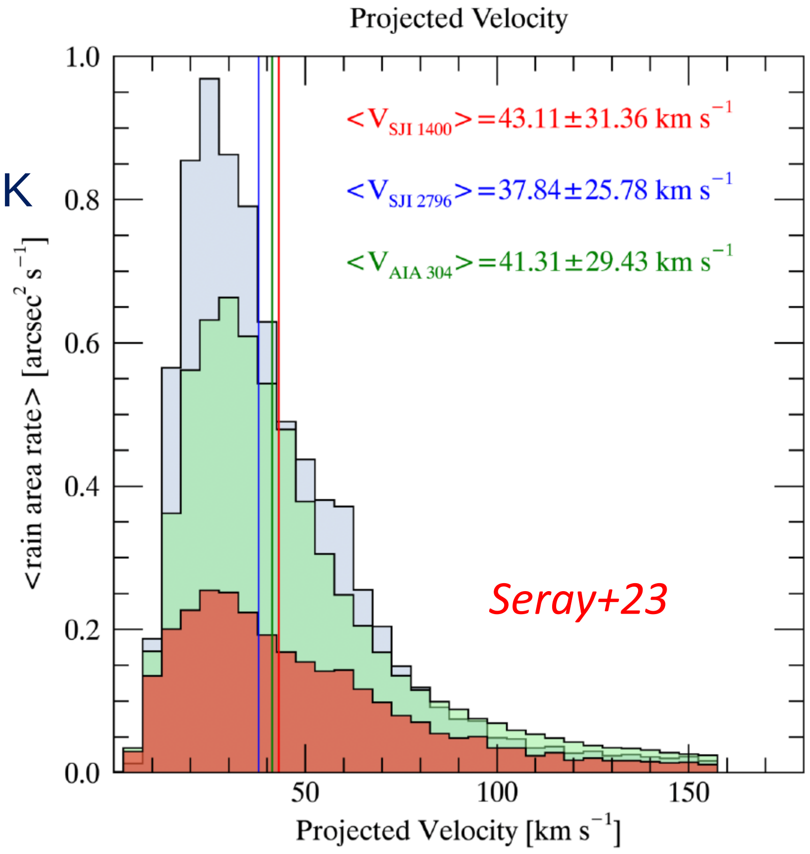
Cooling flows on the Sun and stars

IRIS + AIA/SDO

Mg II: 2796A
Chromos, 10^4 K

He II: 304A
$\approx 10^5$ K

Si IV: 1400A
TR $10^{4.8}$ K



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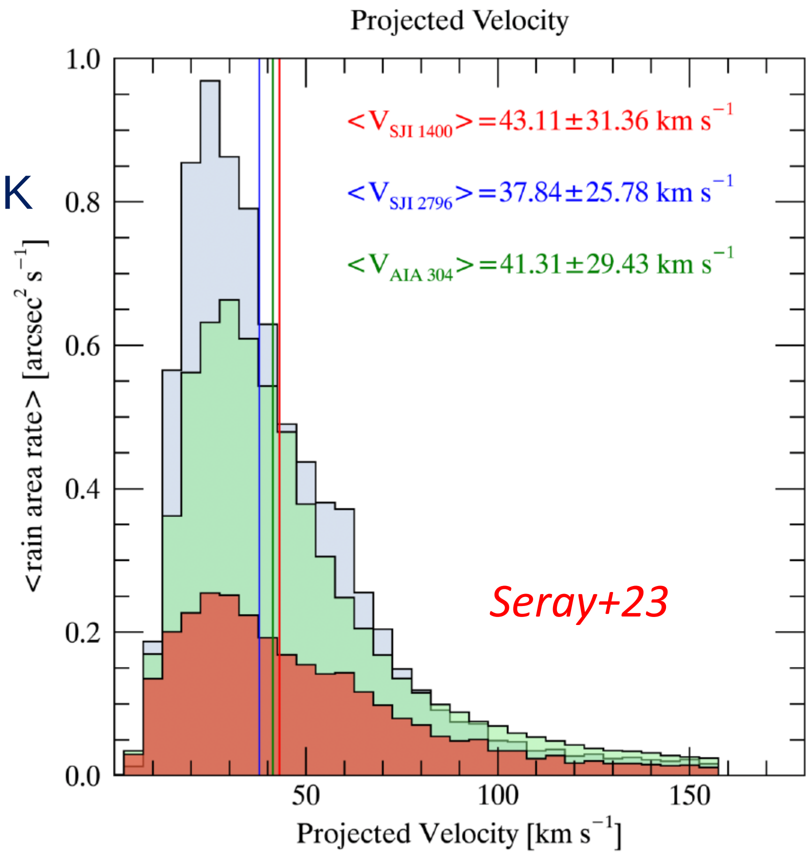
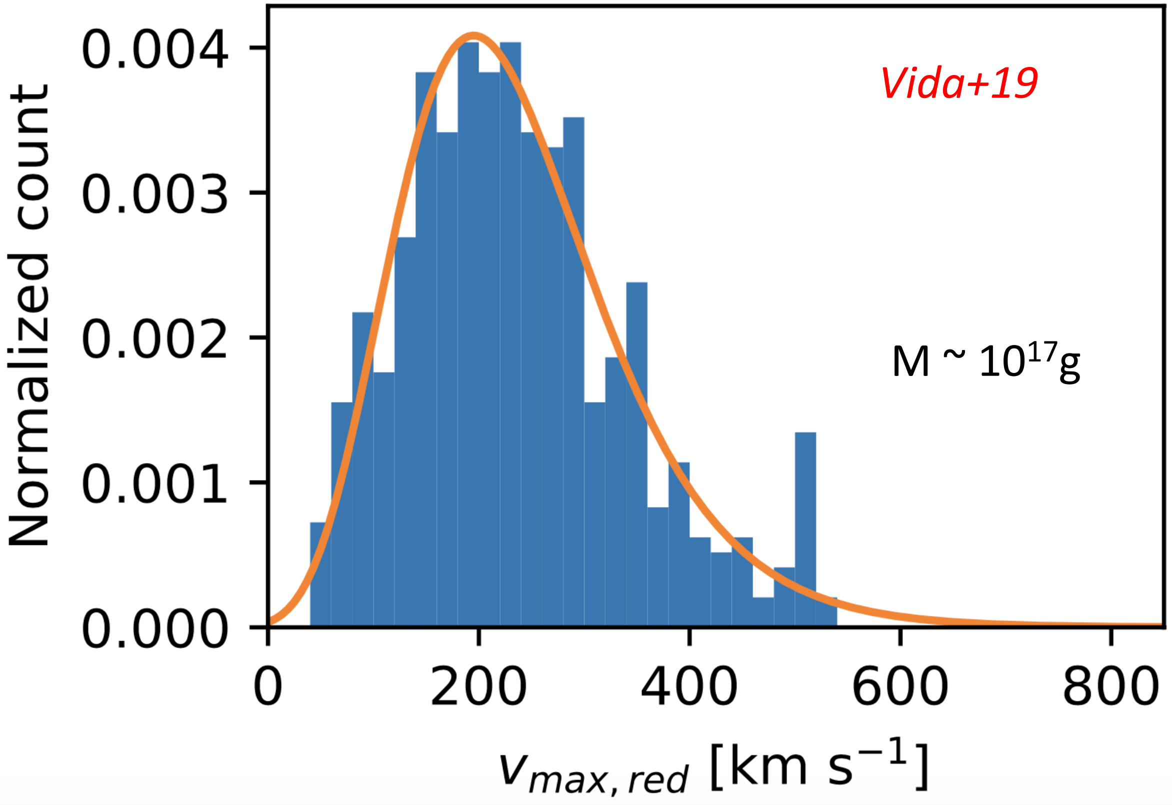


25 M-dwarfs, Balmer line asymmetries in 478/5500 spectra

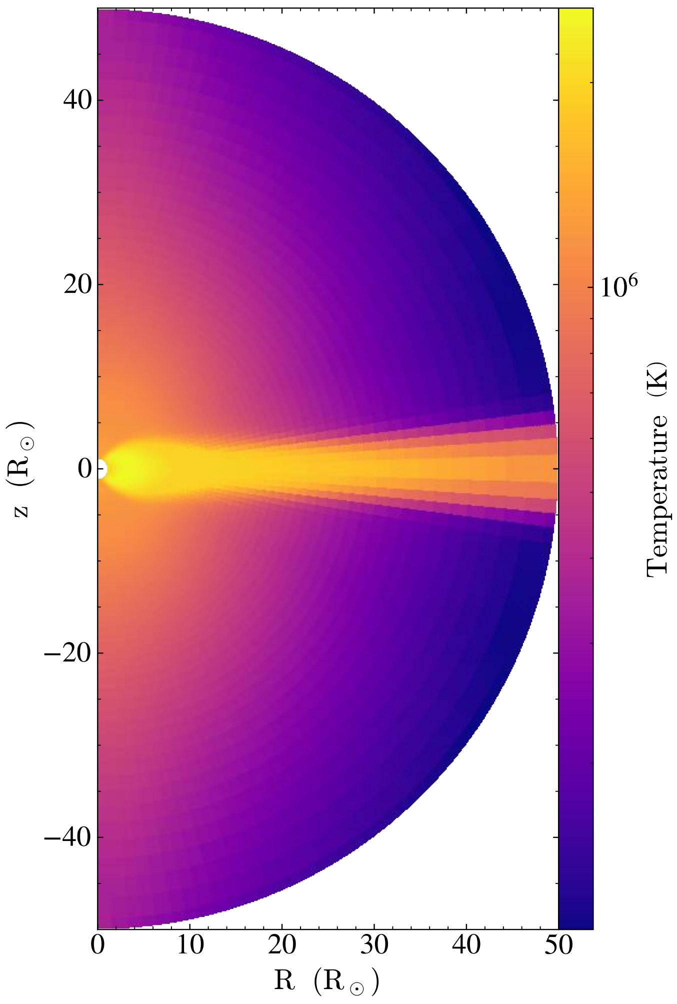


See also: Leitzinger+16,+20, Odert+17, Moschou+19, Maehara+20, Notsu+13,22,Wu+22,Kanodia+22,Namizaki+23, Inoue+23

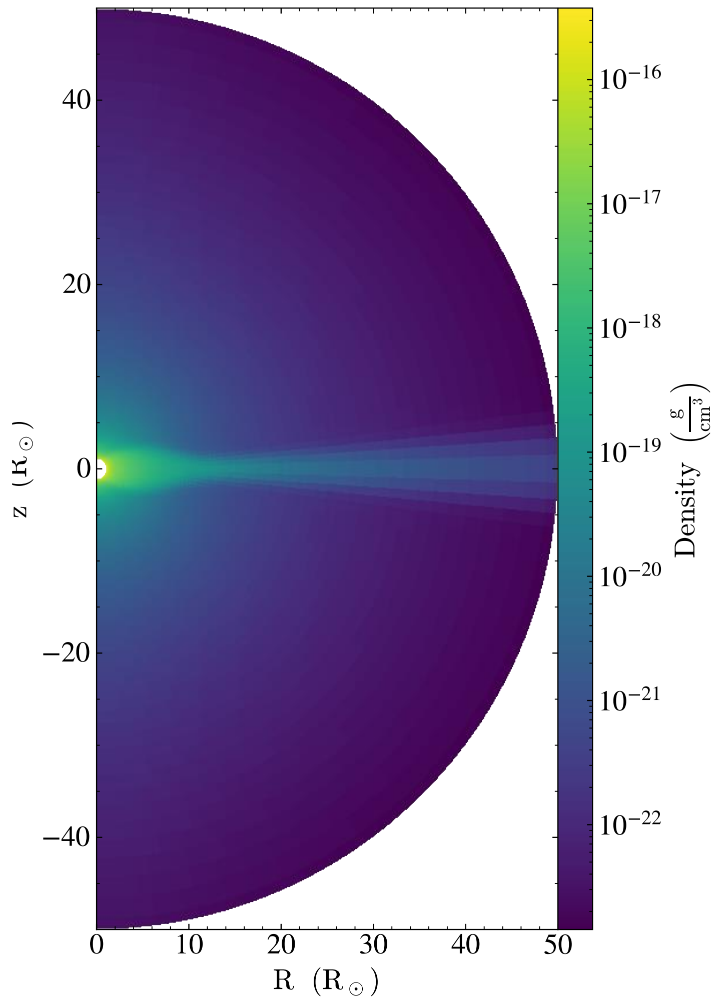
On the (much) larger stellar scale

- 2.5D, AMRVAC
- Initialised with dipole field (200G)
- Rotation period = 0.5d
- Overall scale is 500 times larger

Daley Yates+2023



Temp



Density

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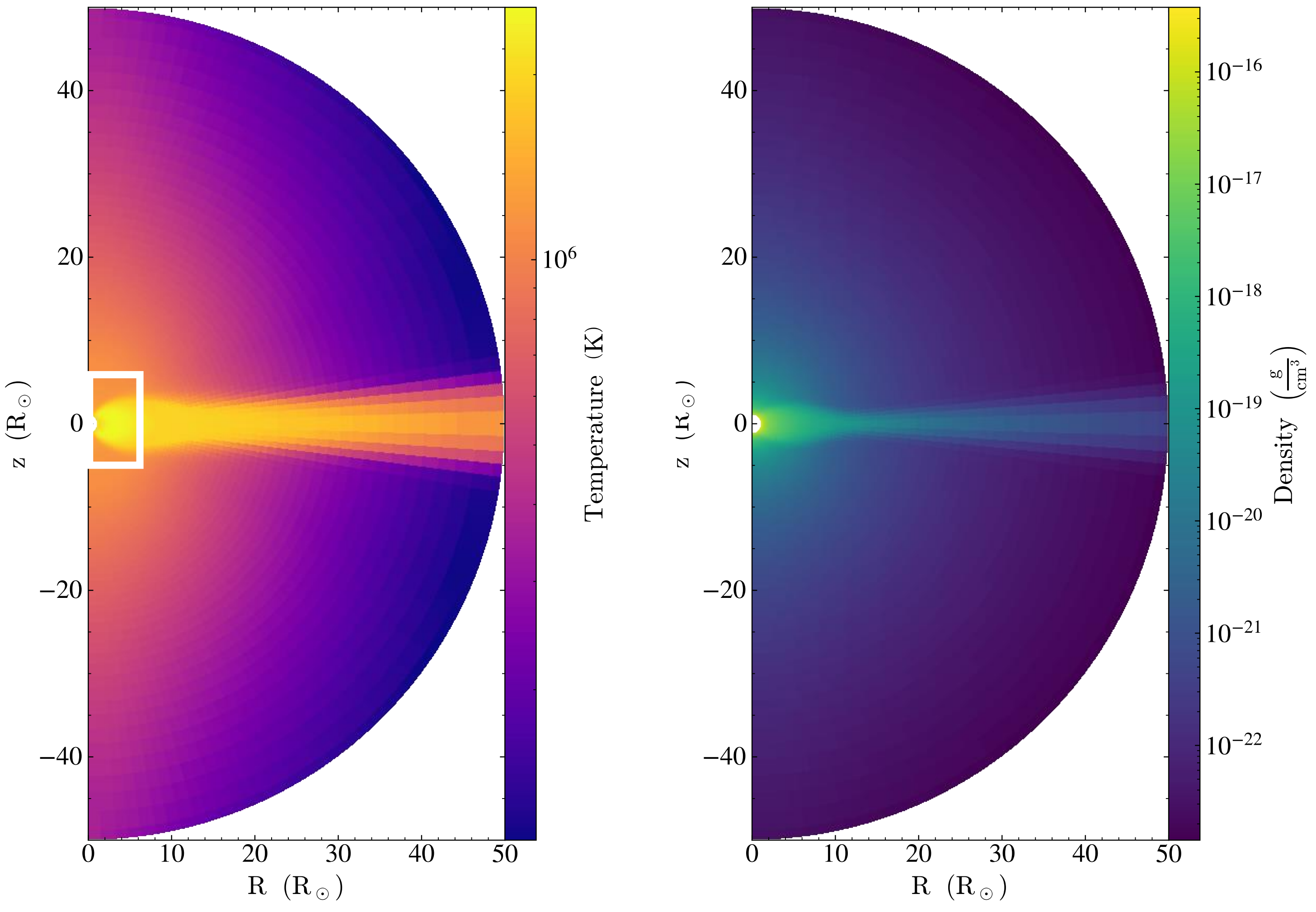
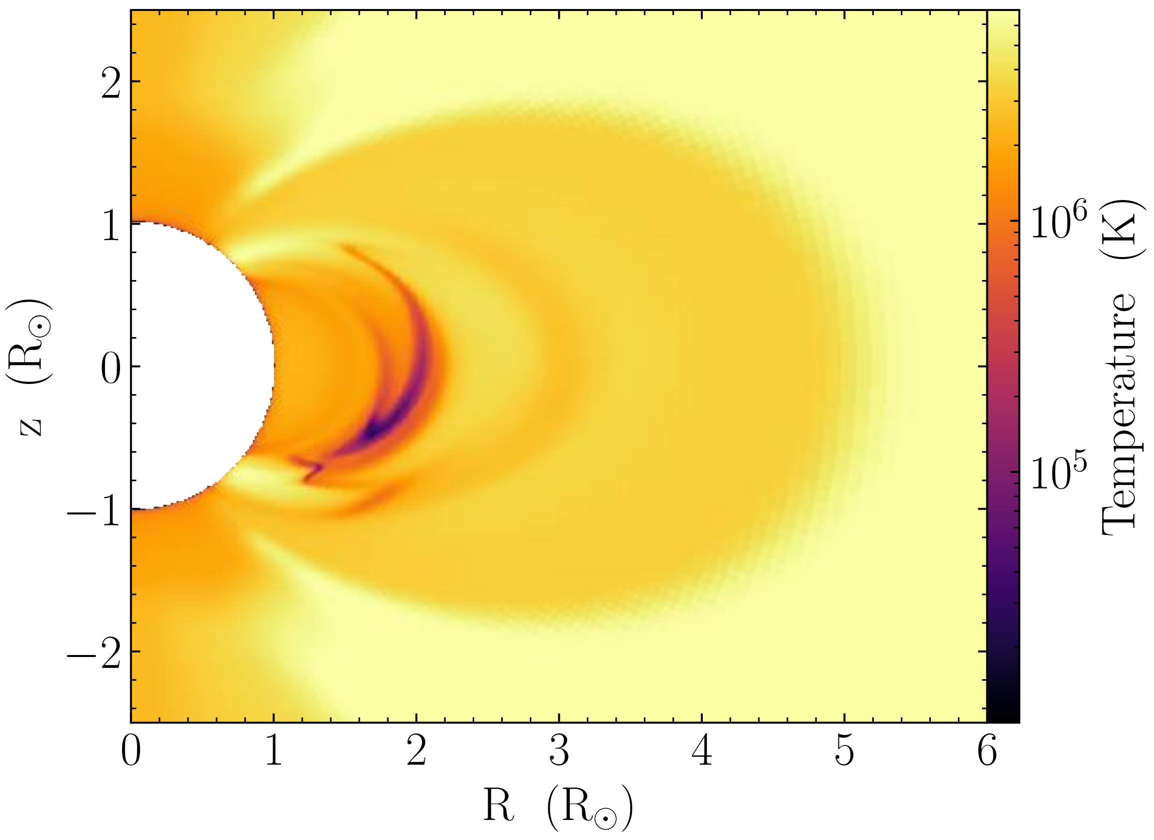
Daley Yates+2023



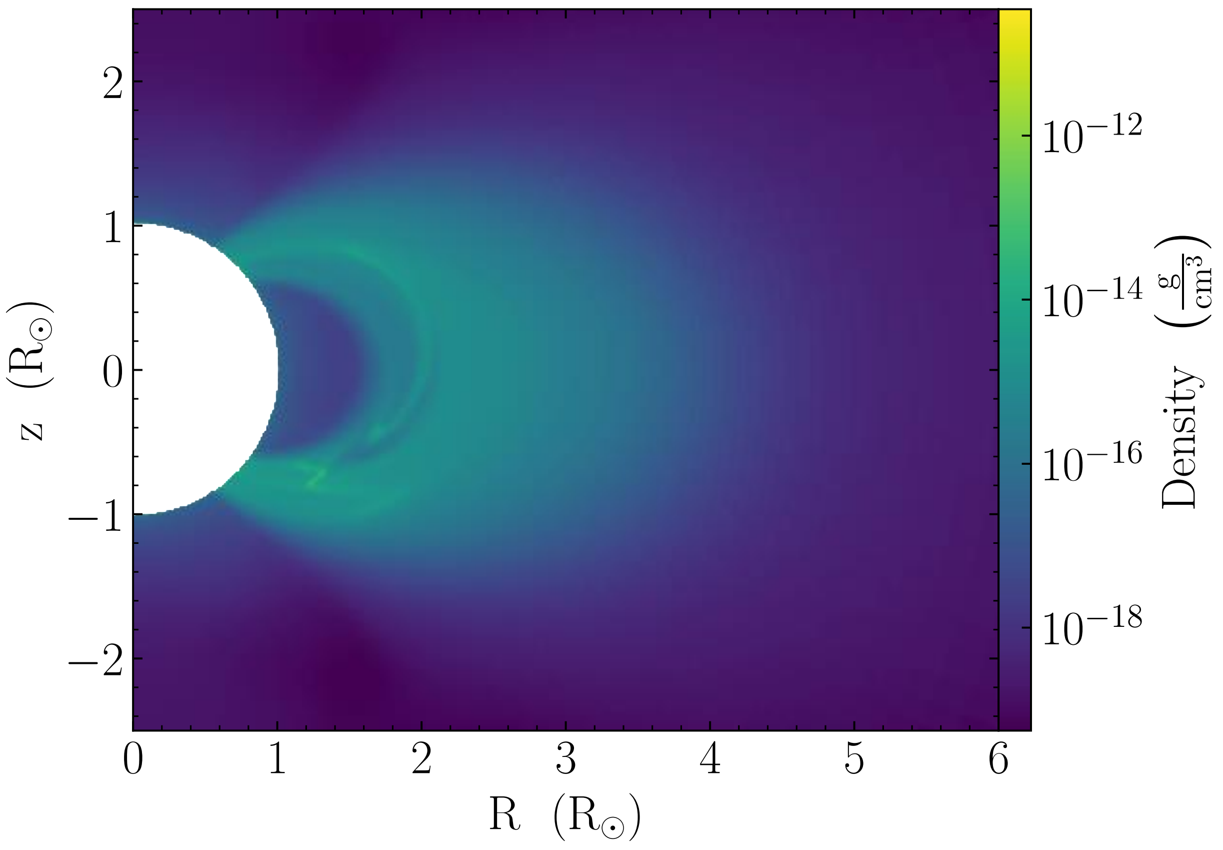
Temp

Density

Condensations develop at several stellar radii



Temp



Daley Yates+2023

Density

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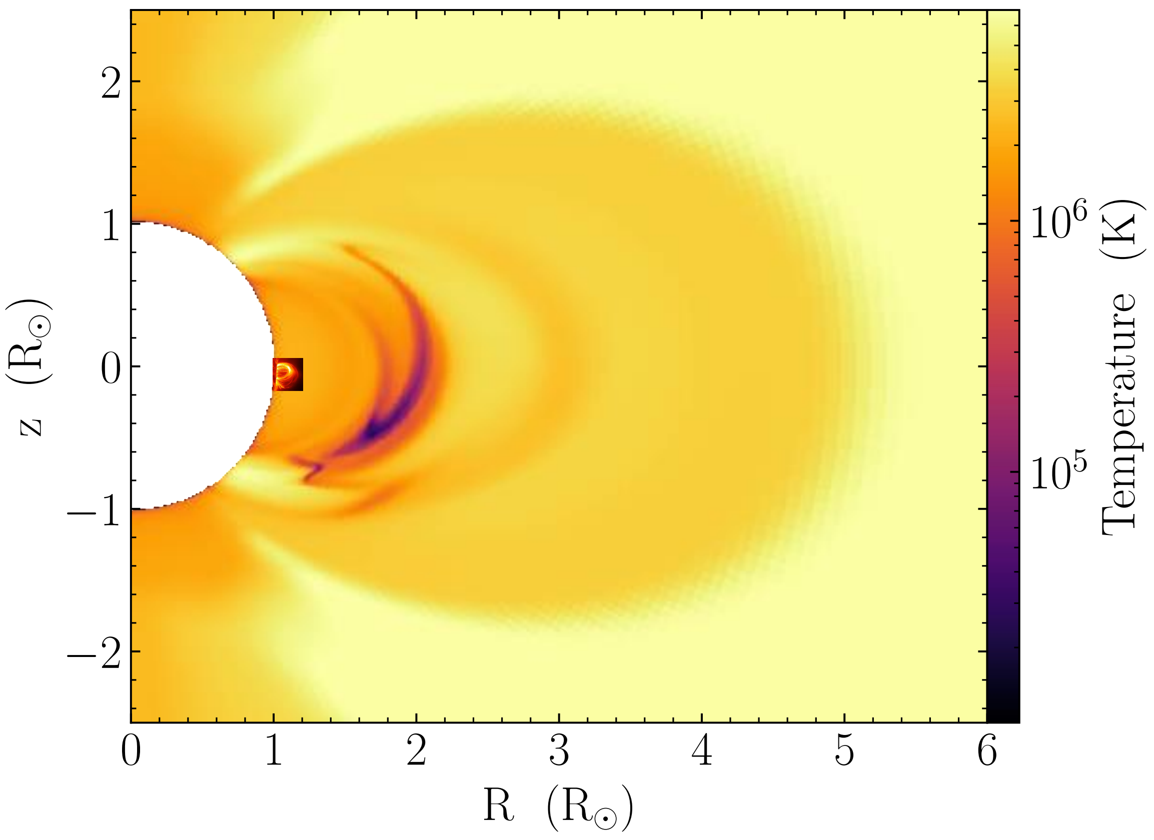
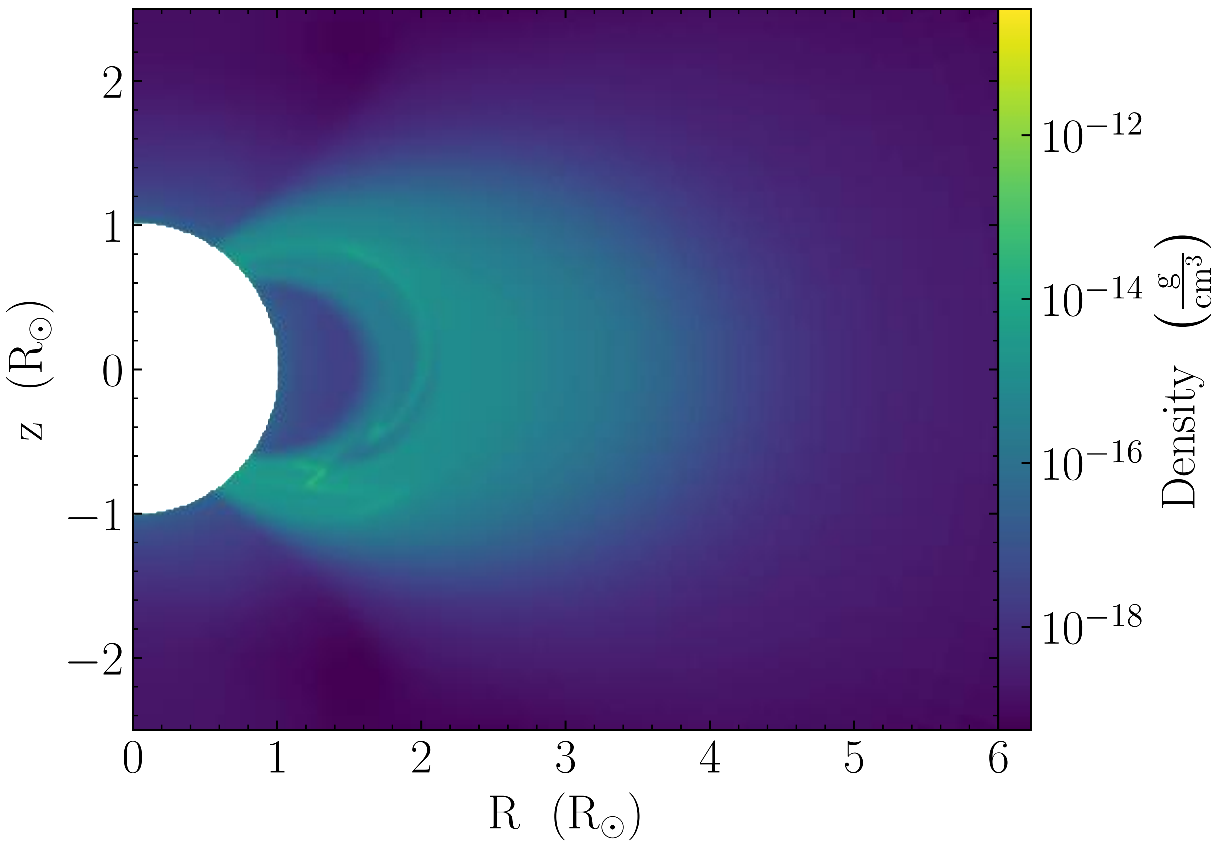


Temp



Daley Yates+2023

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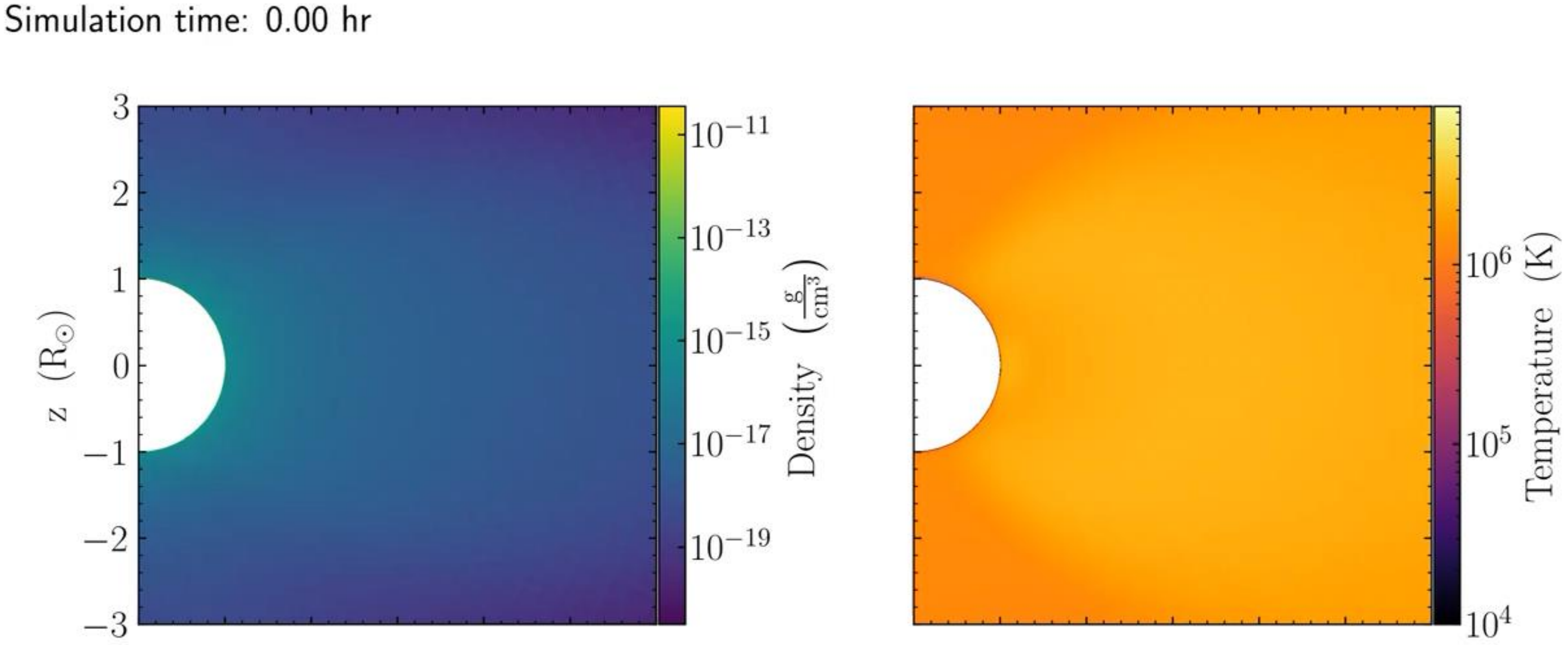
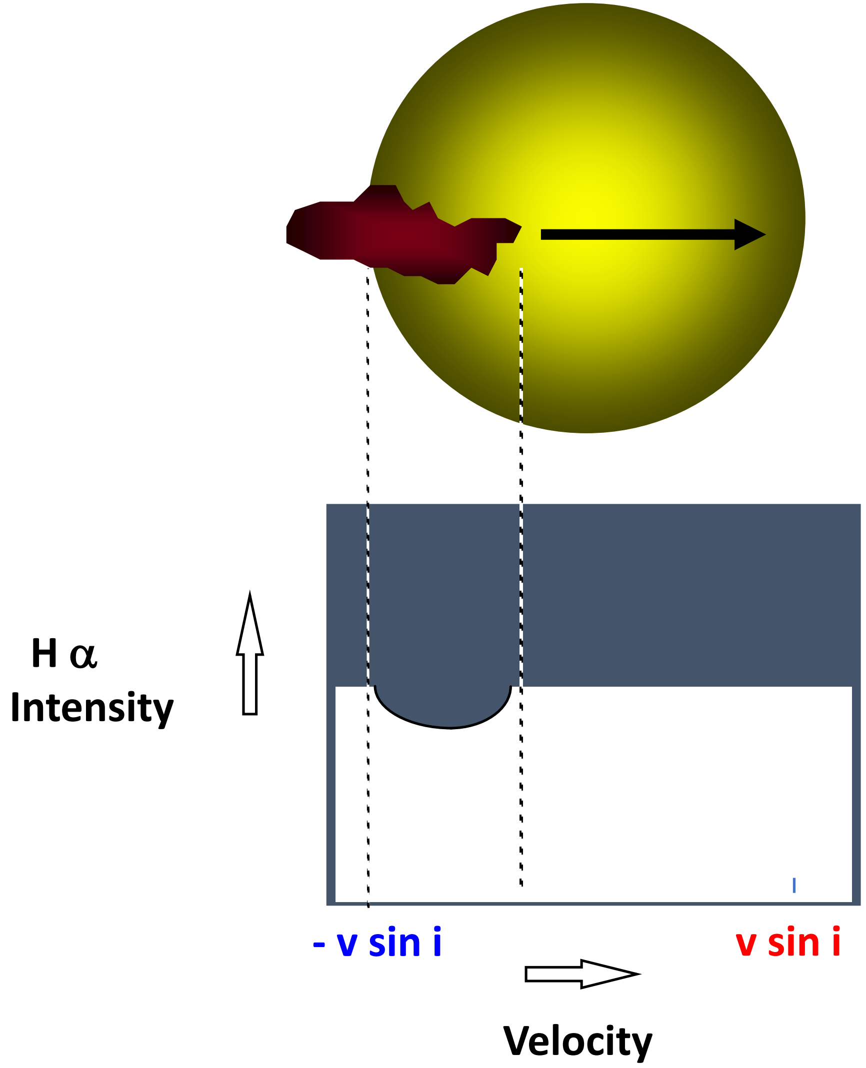
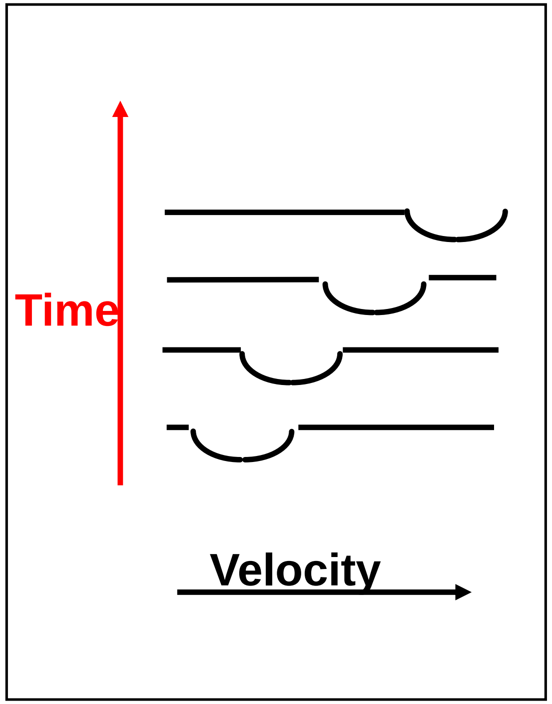


Observing stellar "slingshot" prominences



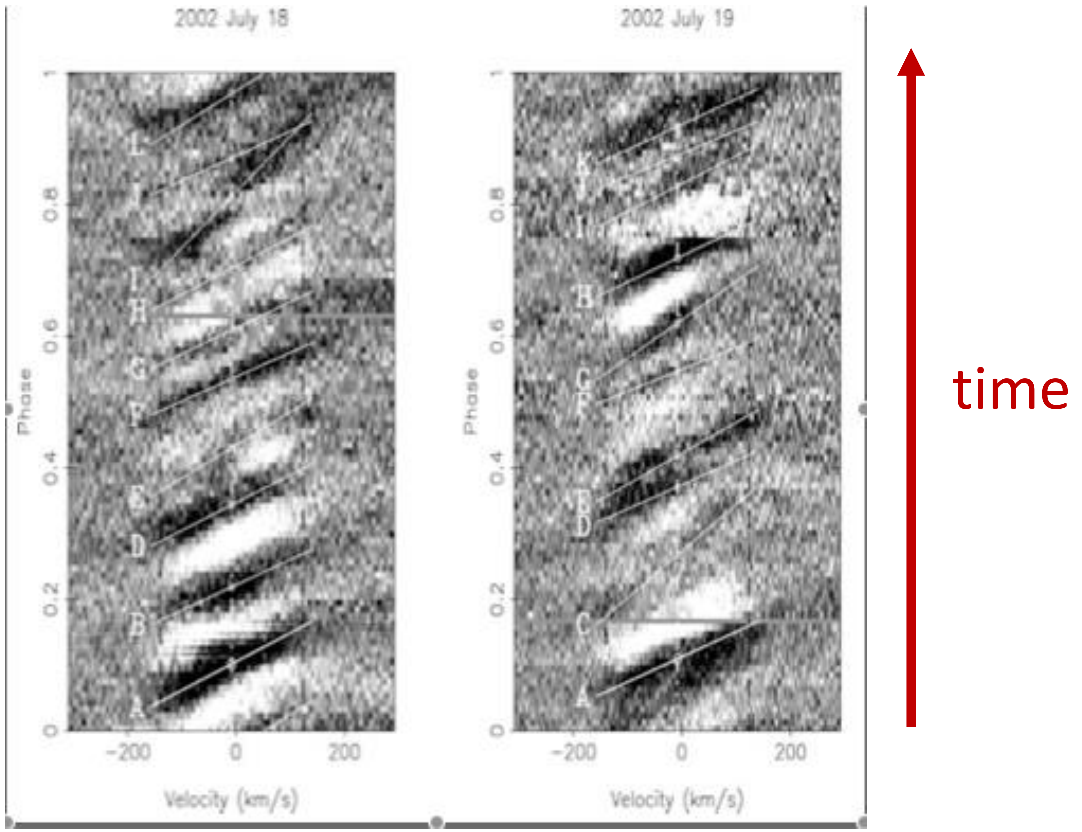
- Absorption dips move through Hα profile as prominence crosses the disk *(Collier Cameron & Robinson 1989)*.
- Typically seen at co-rotation radius



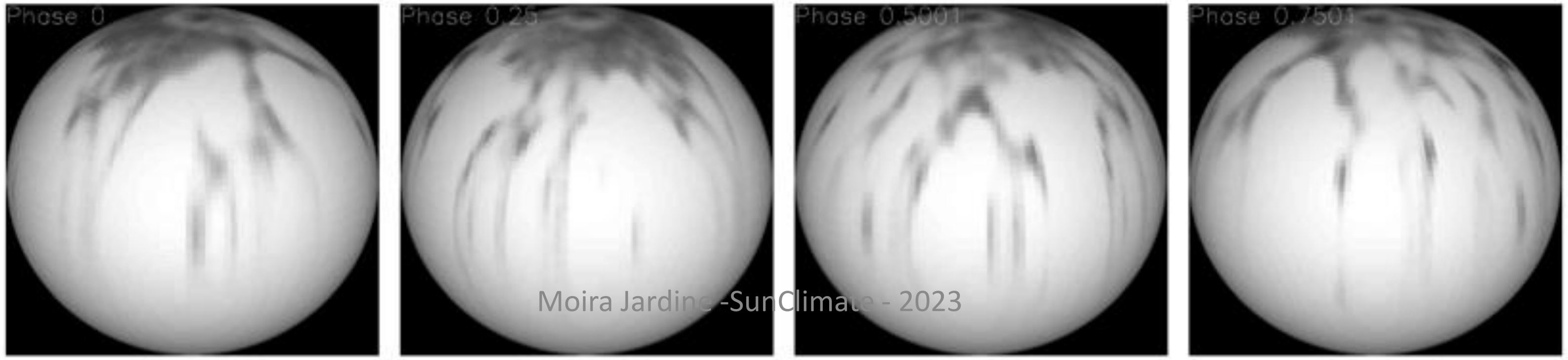
Speedy Mic (BO Mic)

- $M_{\star} = 0.82\ M_{\odot}$, $R_{\star} = 1.06\ R_{\odot}$
- $P_{rot} = 0.38$ d
- Prominence lifetimes ~ 1 day

Dunstone et al (2006)



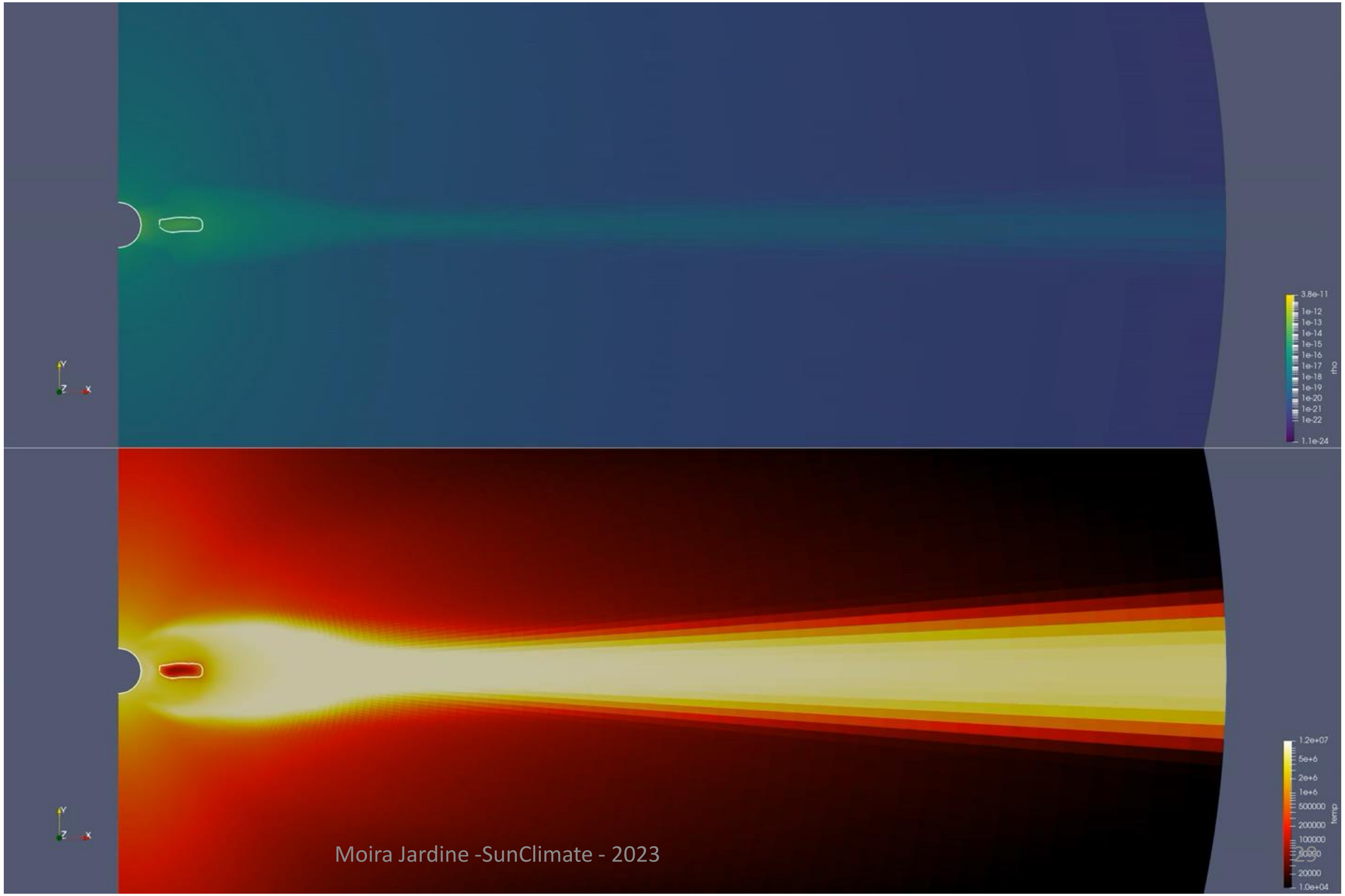
Barnes (2005)



Condensations above co-rotation are *ejected*

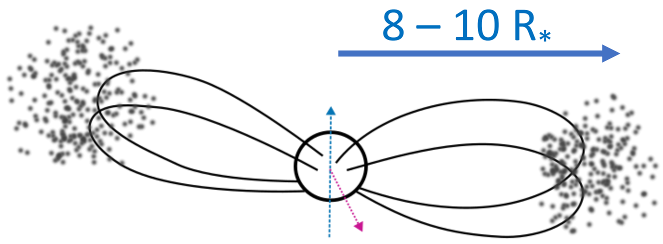
Density

Temp



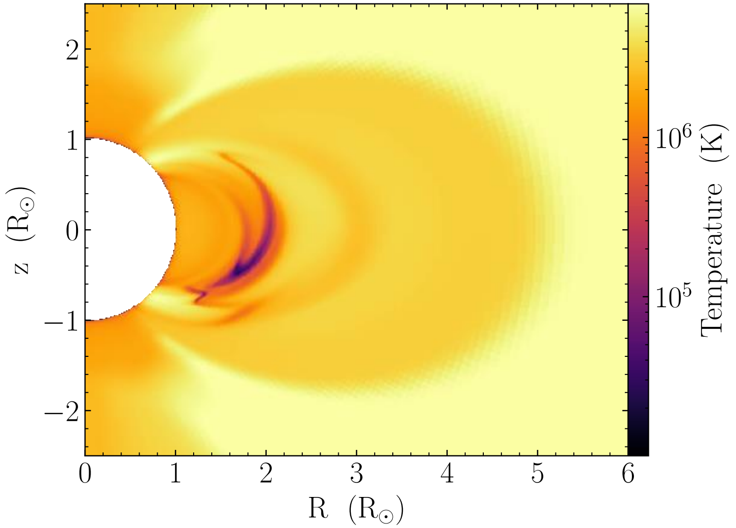
Summary

- Zeeman-Doppler imaging + Radio interferometry -> coronal extents
  - *Do young Suns have larger coronae?*

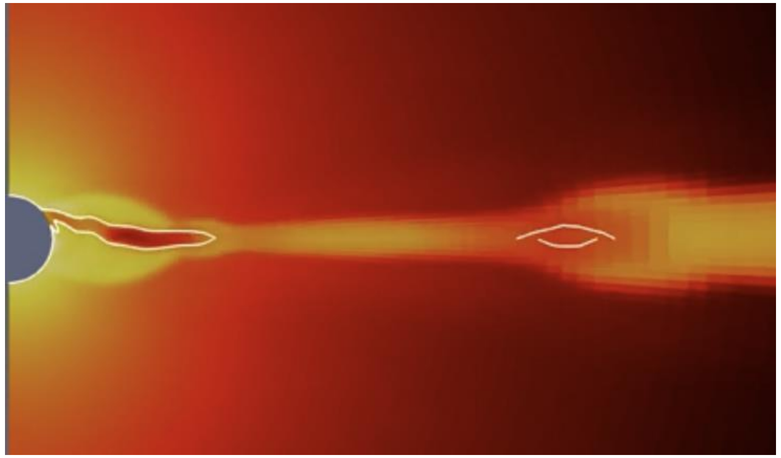


- Condensations are large-scale, ubiquitous + dynamic

Below co-rotation, they fall



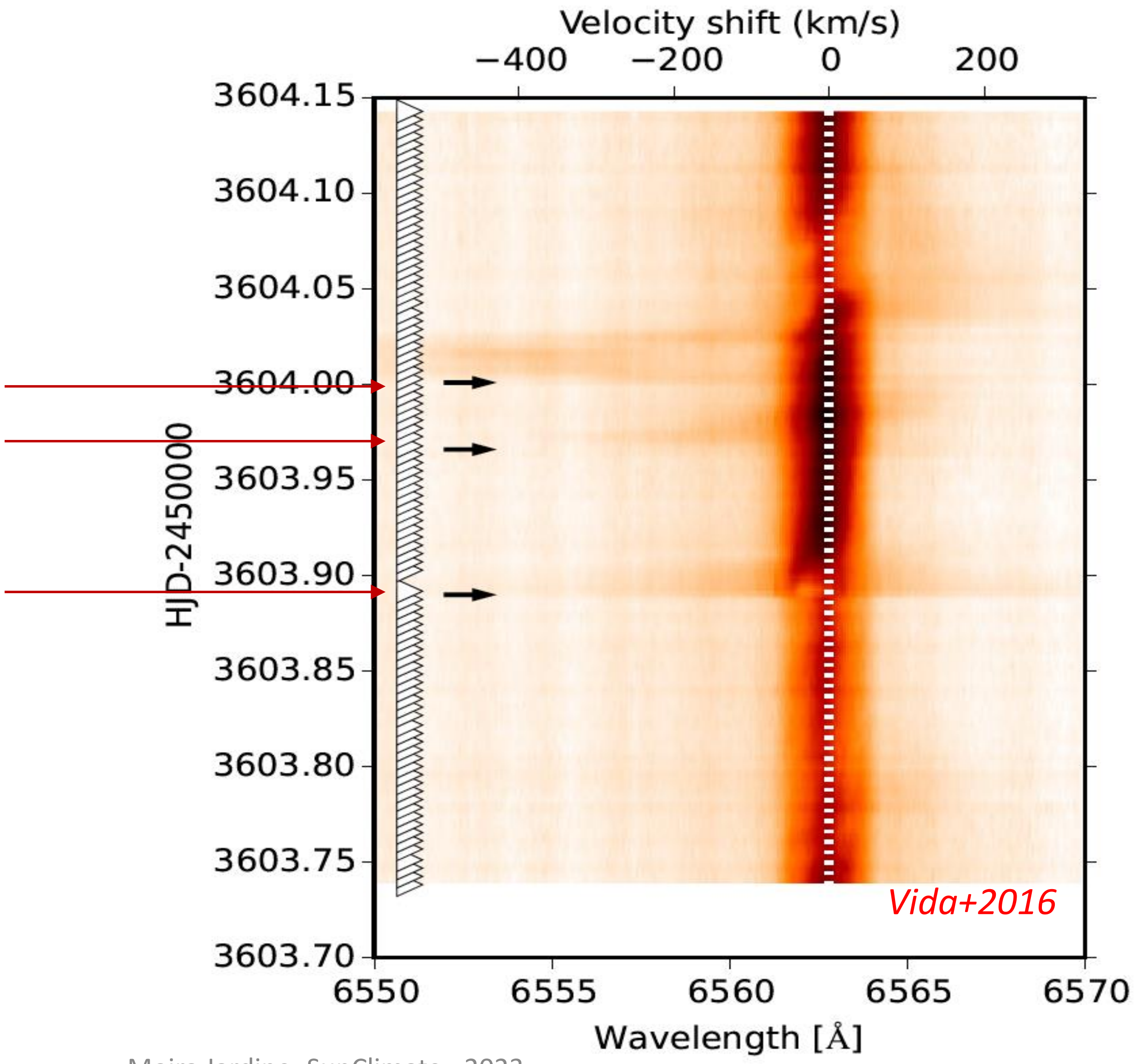
Above co-rotation, they are ejected



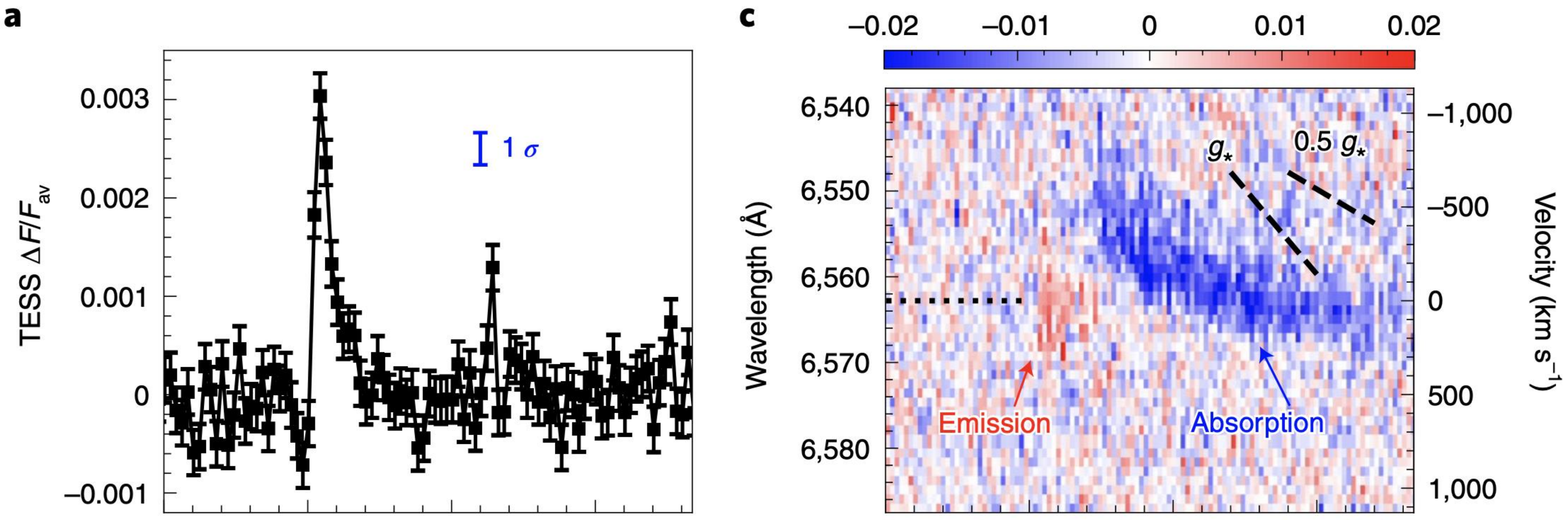
Observing flares/mass ejections from low mass stars

Ejecta:

- Asymmetries in blue wing of Hα
- Max projected speed 675 km/s
- Fewer ejections than flare rate suggests



Observing prominence eruption + flare on EK Dra*



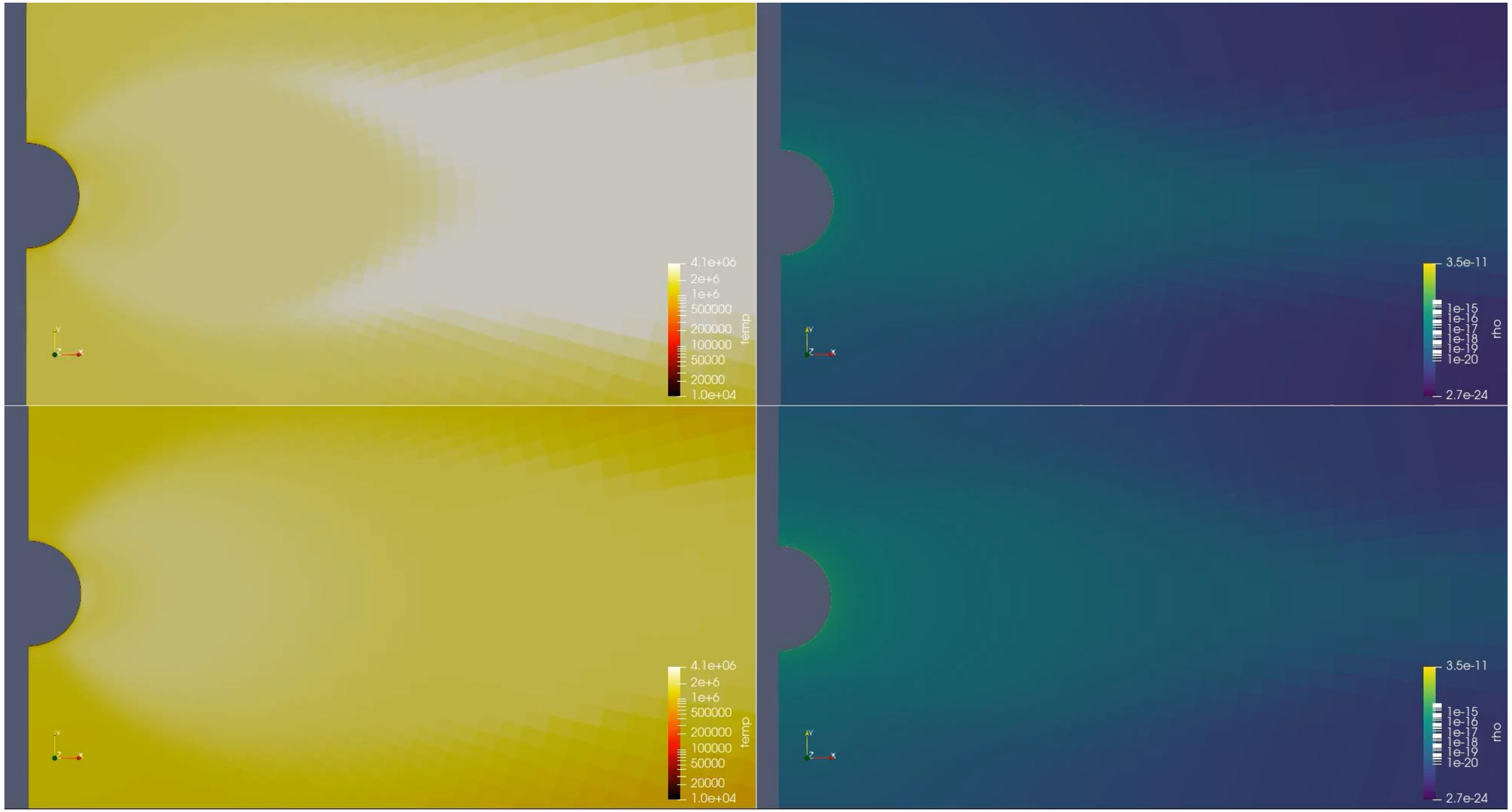
*G-type, age 50-125My

Namekata+2022

Increasing rotation rate

P_{rot} = 0.5 d

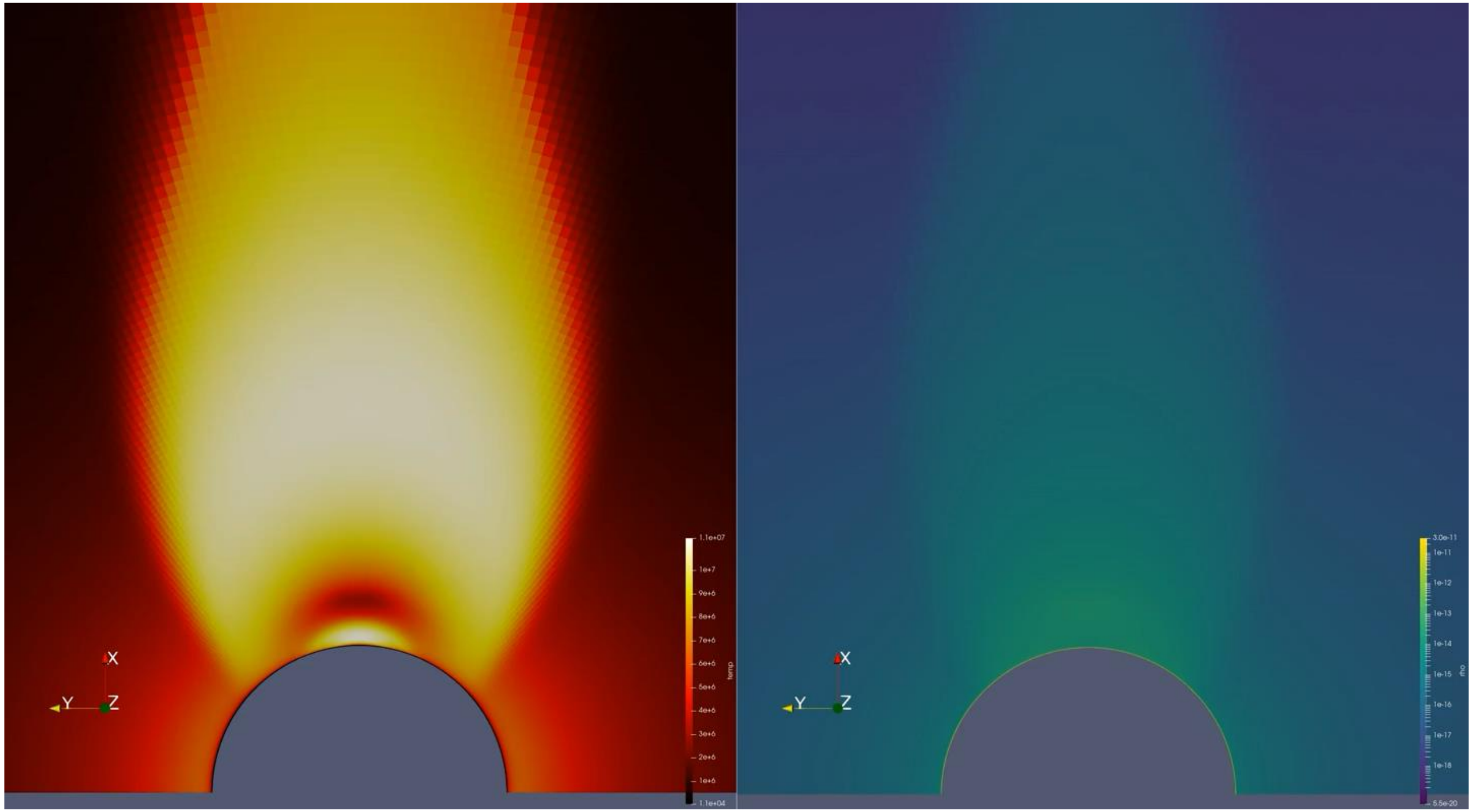
P_{rot} = 1.0 d

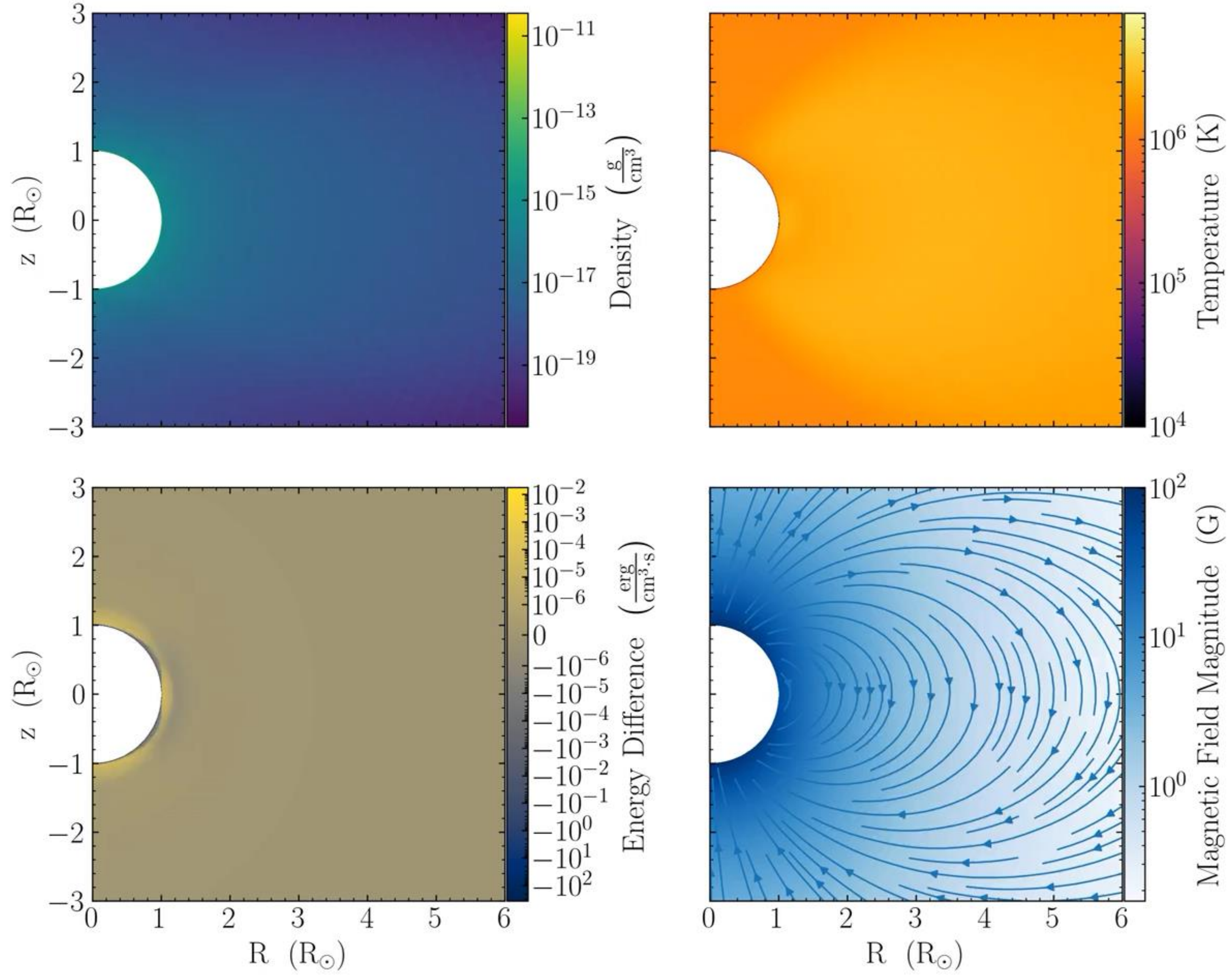


Temp

Density

Daley Yates+2024, in prep


X
Y
Z
1.1e+07
1e+7
9e+6
8e+6
7e+6
6e+6
5e+6
4e+6
3e+6
2e+6
1e+6
1.1e+04
temp
X
Y
Z
3.0e-11
1e-11
1e-12
1e-13
1e-14
1e-15
1e-16
1e-17
1e-18
5.5e-20
rho



Density $\left(\frac{g}{cm^3}\right)$
Temperature (K)
Energy Difference $\left(\frac{erg}{cm^3 \cdot s}\right)$
Magnetic Field Magnitude (G)
z $(R_\odot)$
R $(R_\odot)$