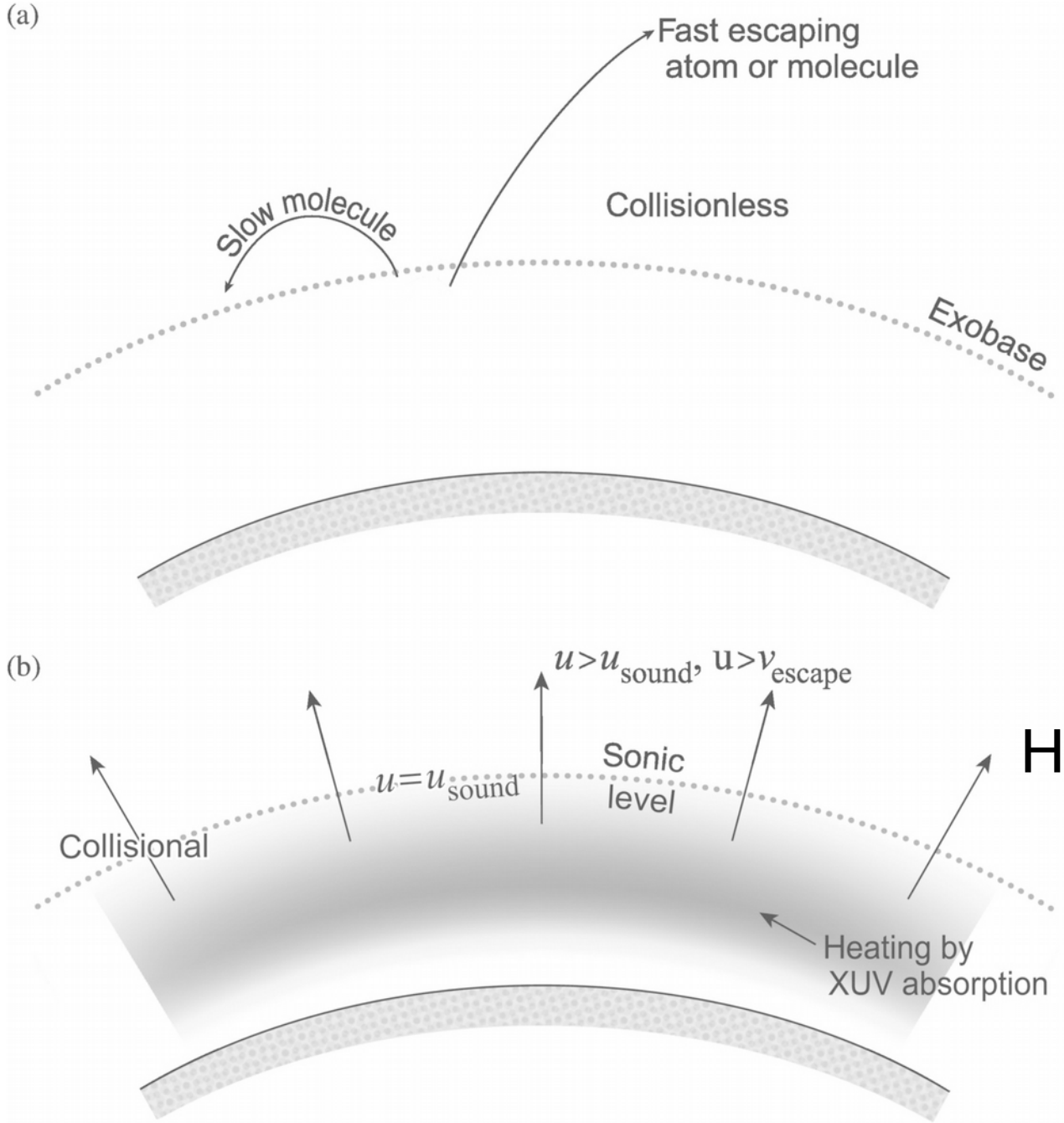
Exoplanet evolution

Atmospheric escape (evaporation)



Jeans

Hydrodynamic

Catling & Kasting 2017

The solar/stellar disk: photosphere to corona

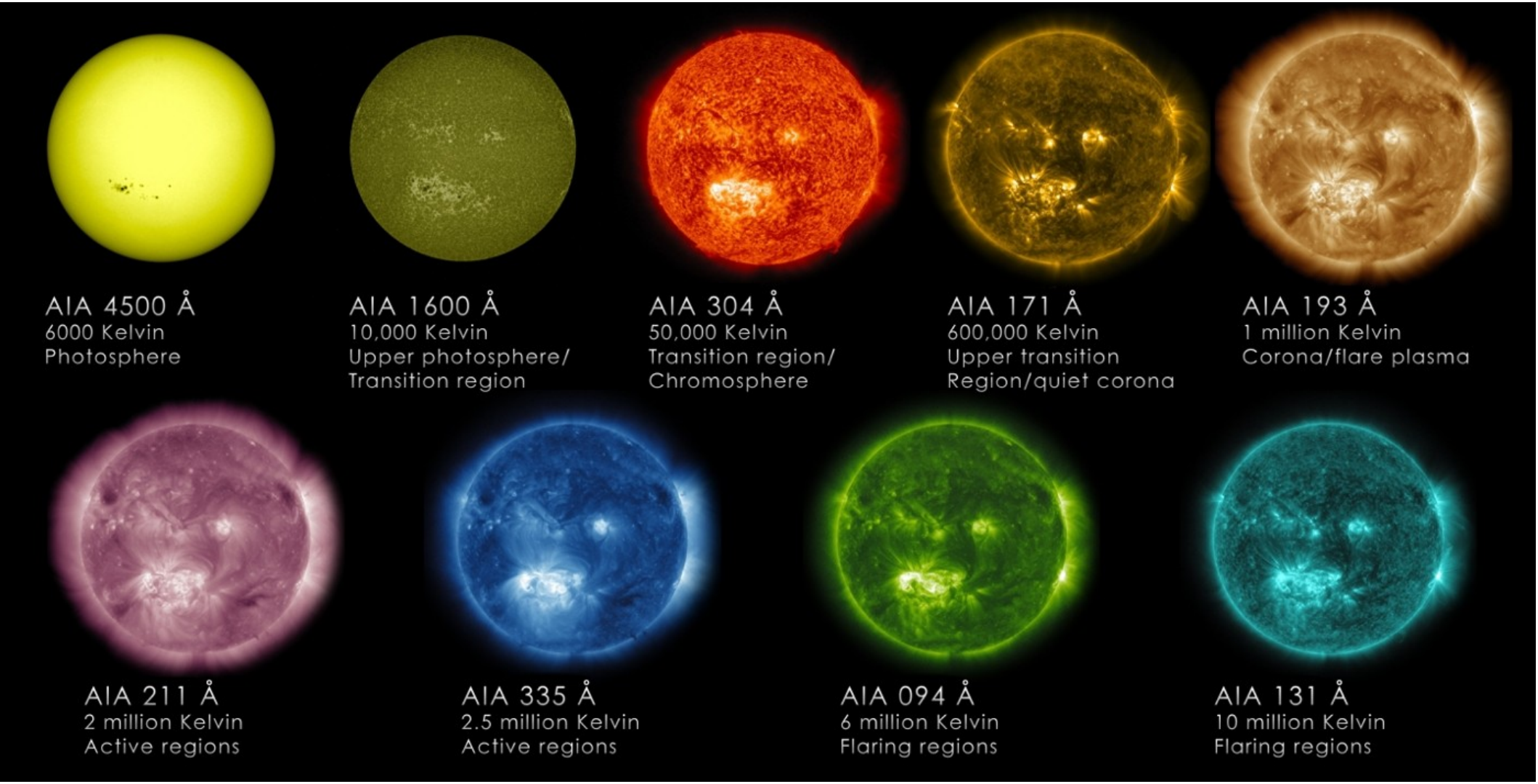
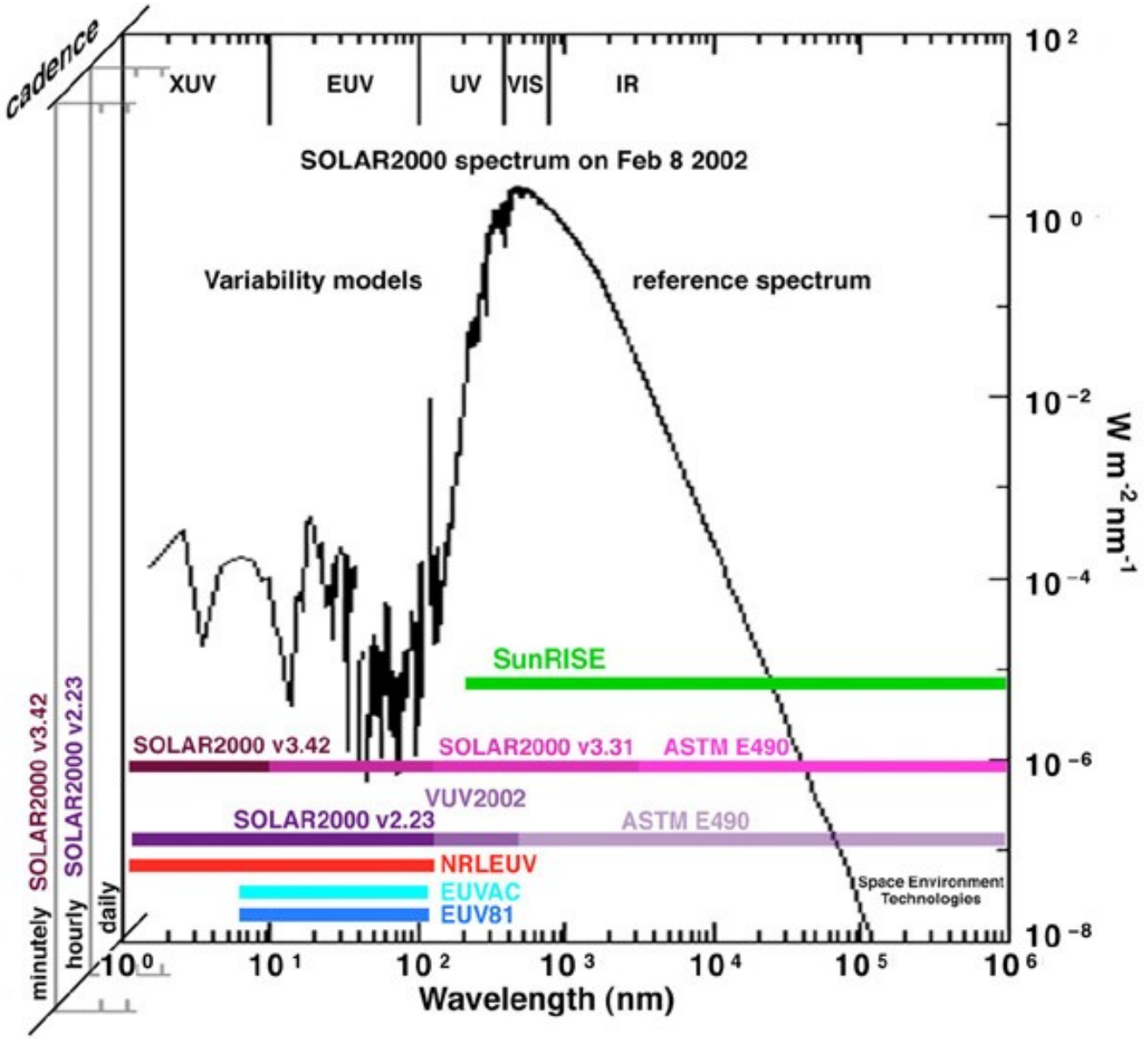


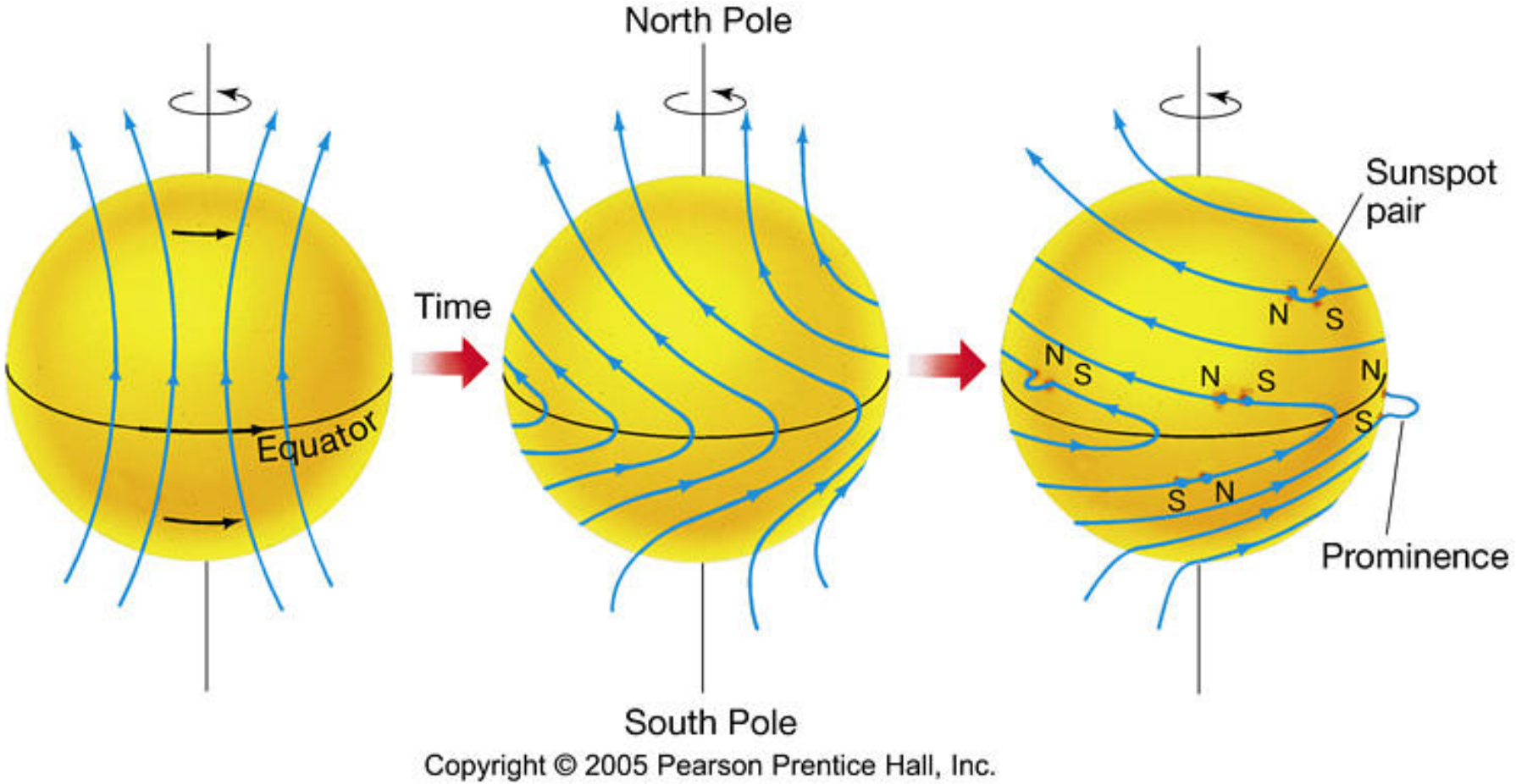
image credit: SDO/NASA

Solar/stellar high-energy output



after W. Kent Tobiska 2005

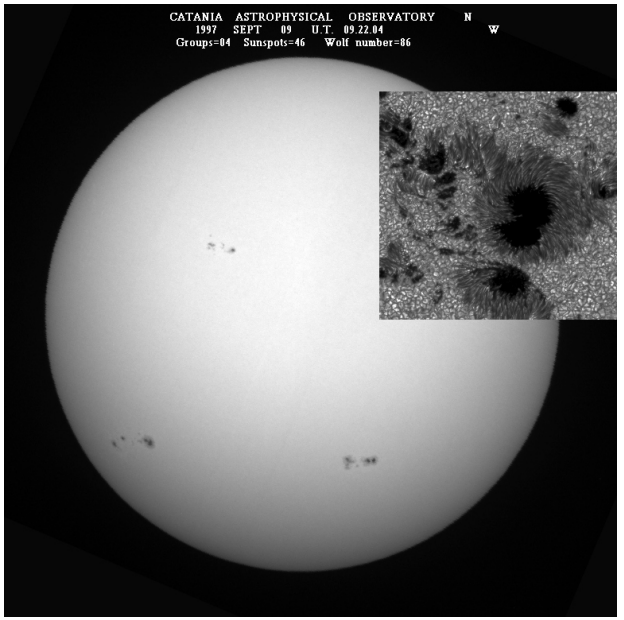
Stellar activity: rotation & dynamo

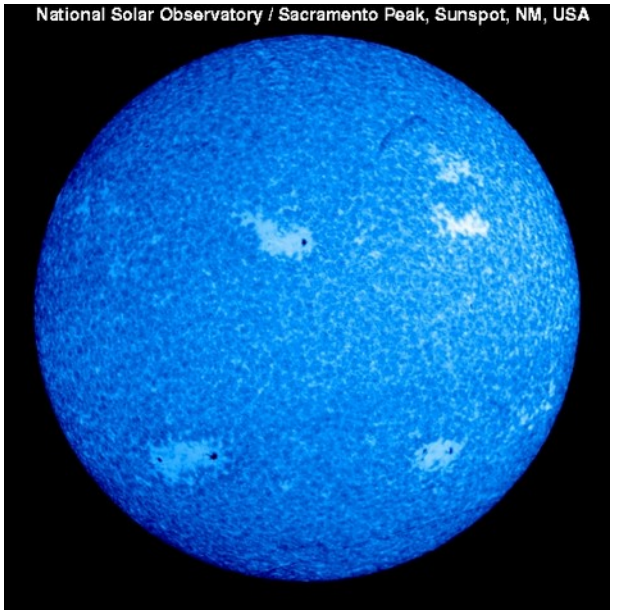


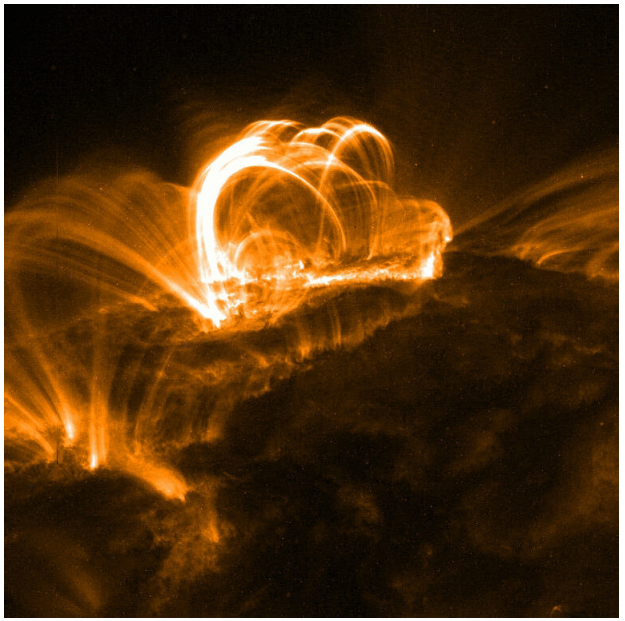
magnetism fueled by (differential) rotation

X-ray emission only possible because of magnetism

Magnetic activity







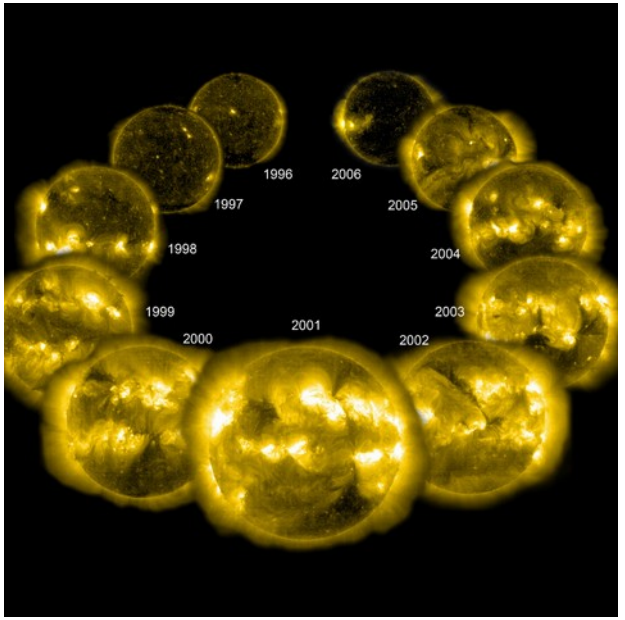
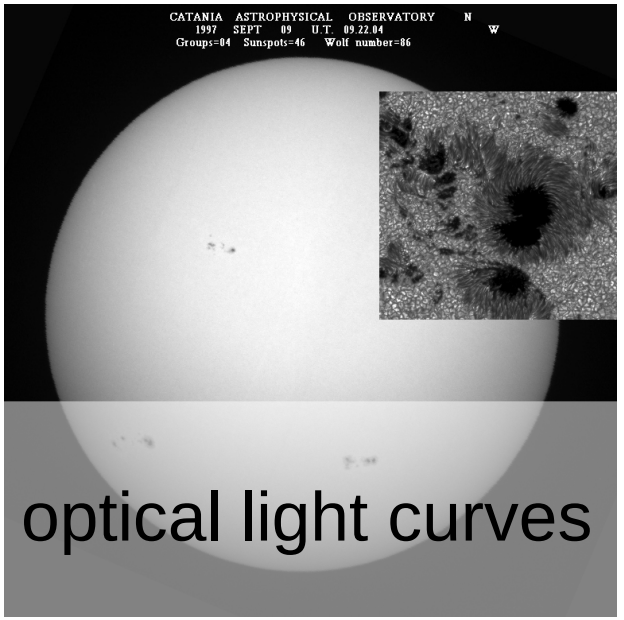
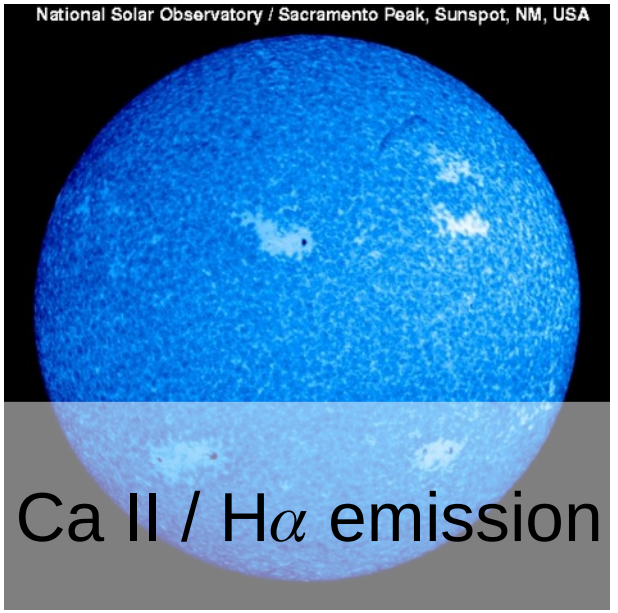


image credit: NSO/NASA/CAO

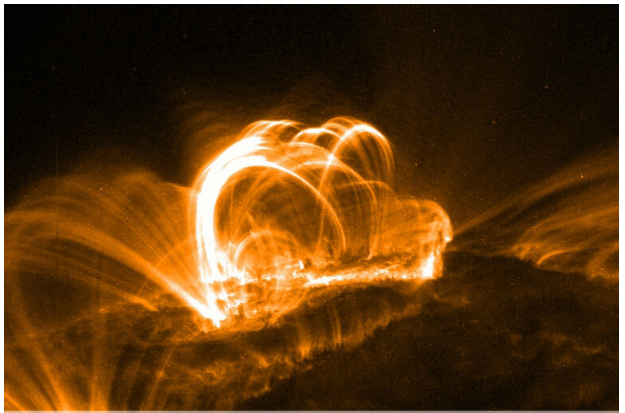
Magnetic activity



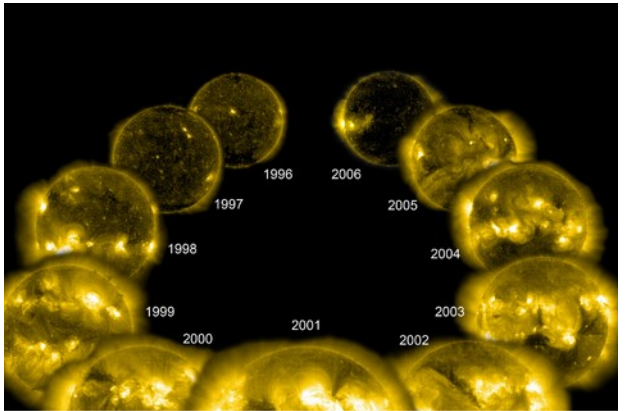
optical light curves



Ca II / Hα emission



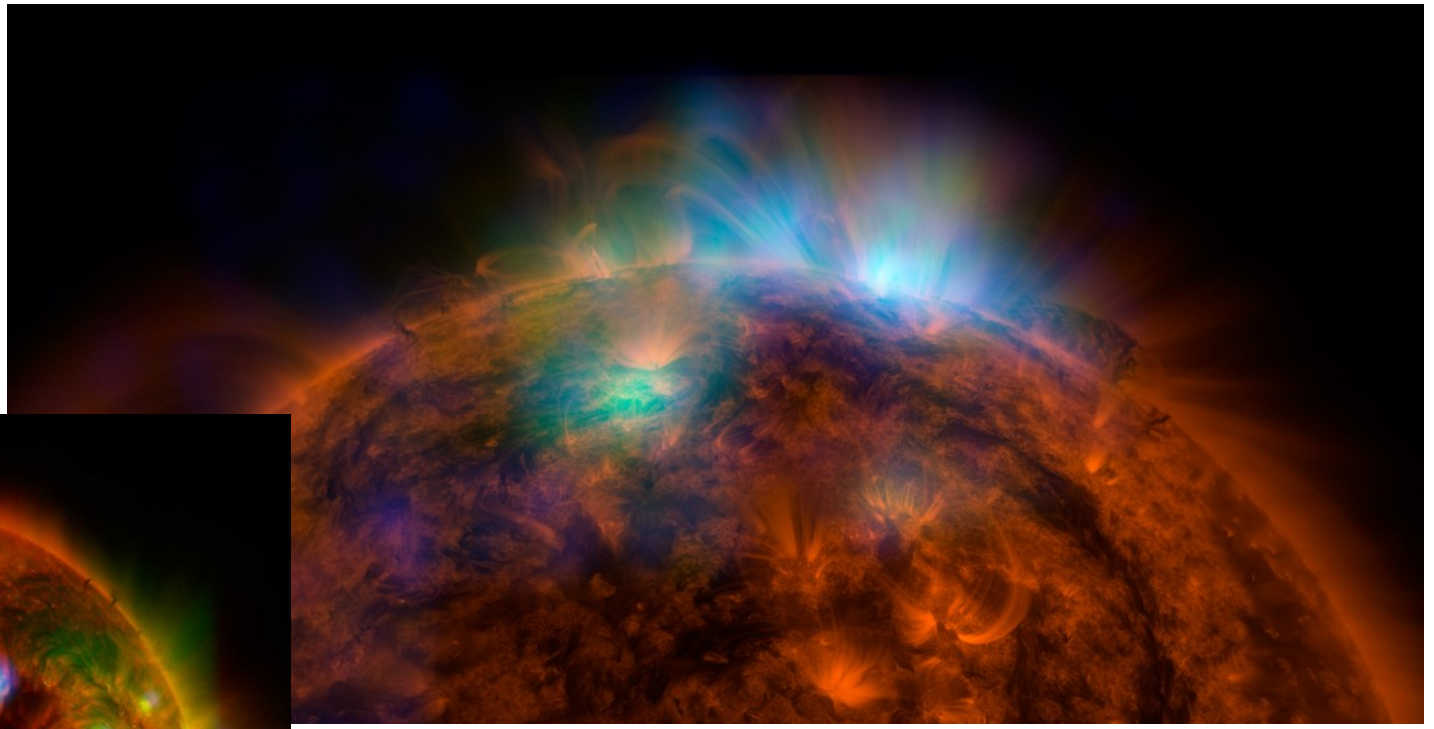
X-ray/EUV emission

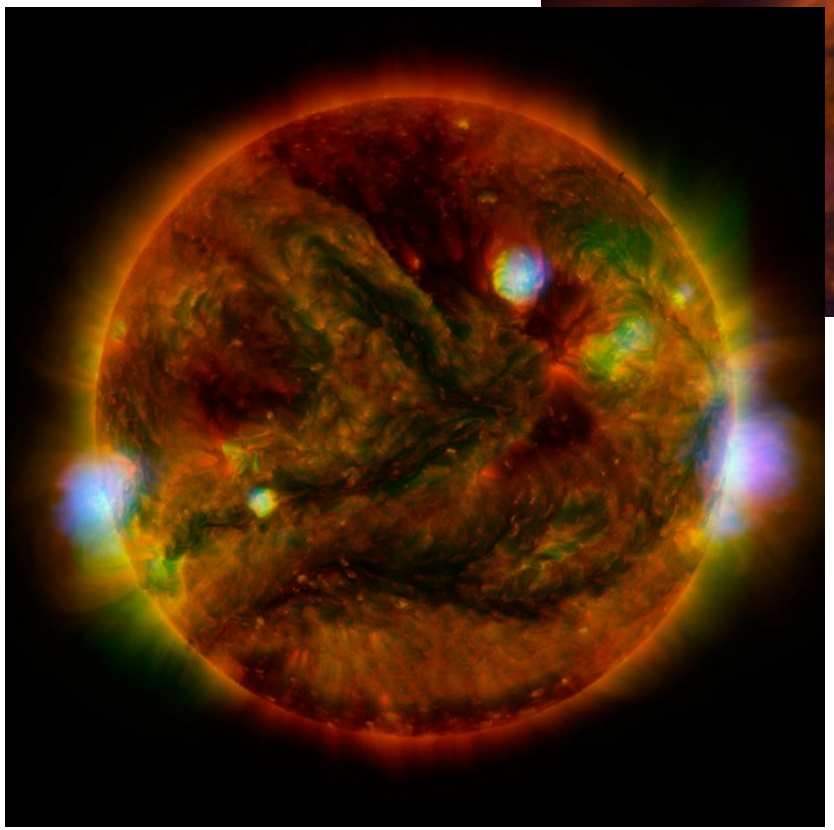


monitoring

image credit: NSO/NASA/CAO

Solar corona in X-rays / EUV

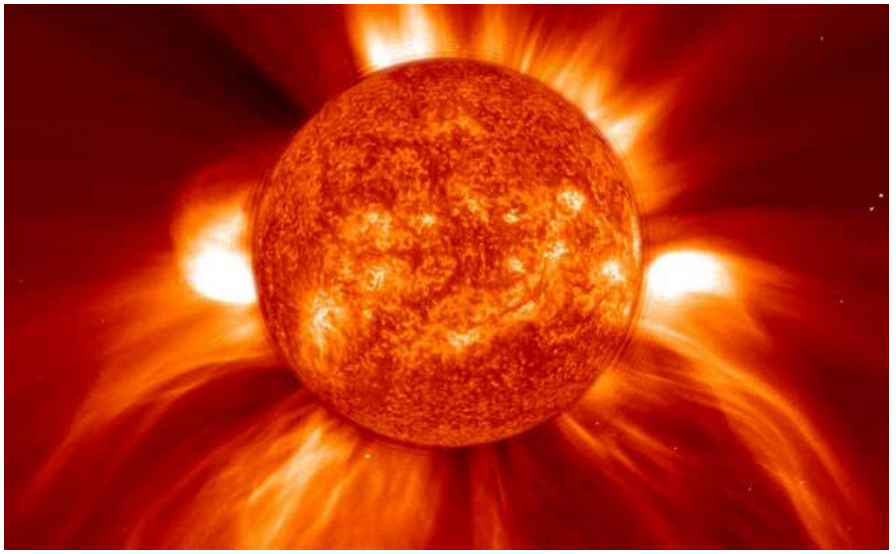




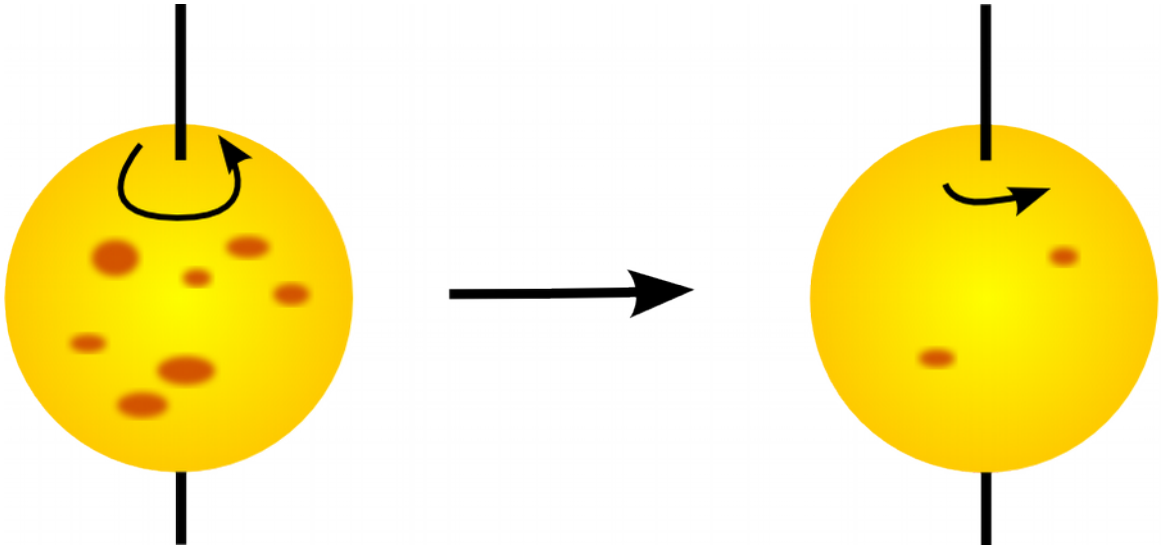
SDO data

“active regions” have magnetic loops that are filled with hot plasma -> this is where most of the X-rays come from

How stars age on the main sequence



loss of angular momentum through stellar wind ("magnetic braking")



Evolution of stellar X-ray emission

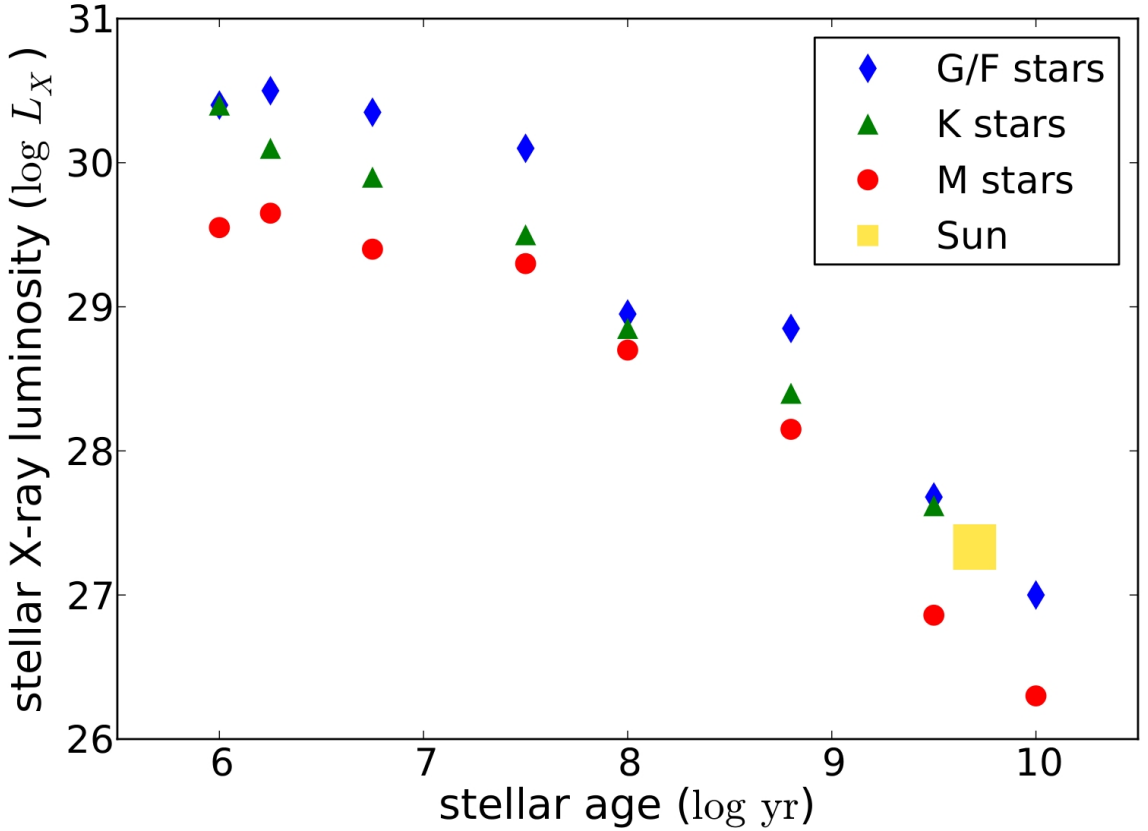
“Should” be self-regulating:

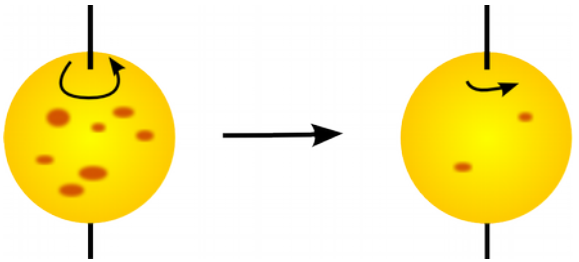
Fast rotation -> high activity -> strong stellar wind -> strong magnetic braking

Slow rotation -> low activity -> weak stellar wind -> weak magnetic braking

So all stars should converge in their rotation and activity... right?

How stars age on the main sequence

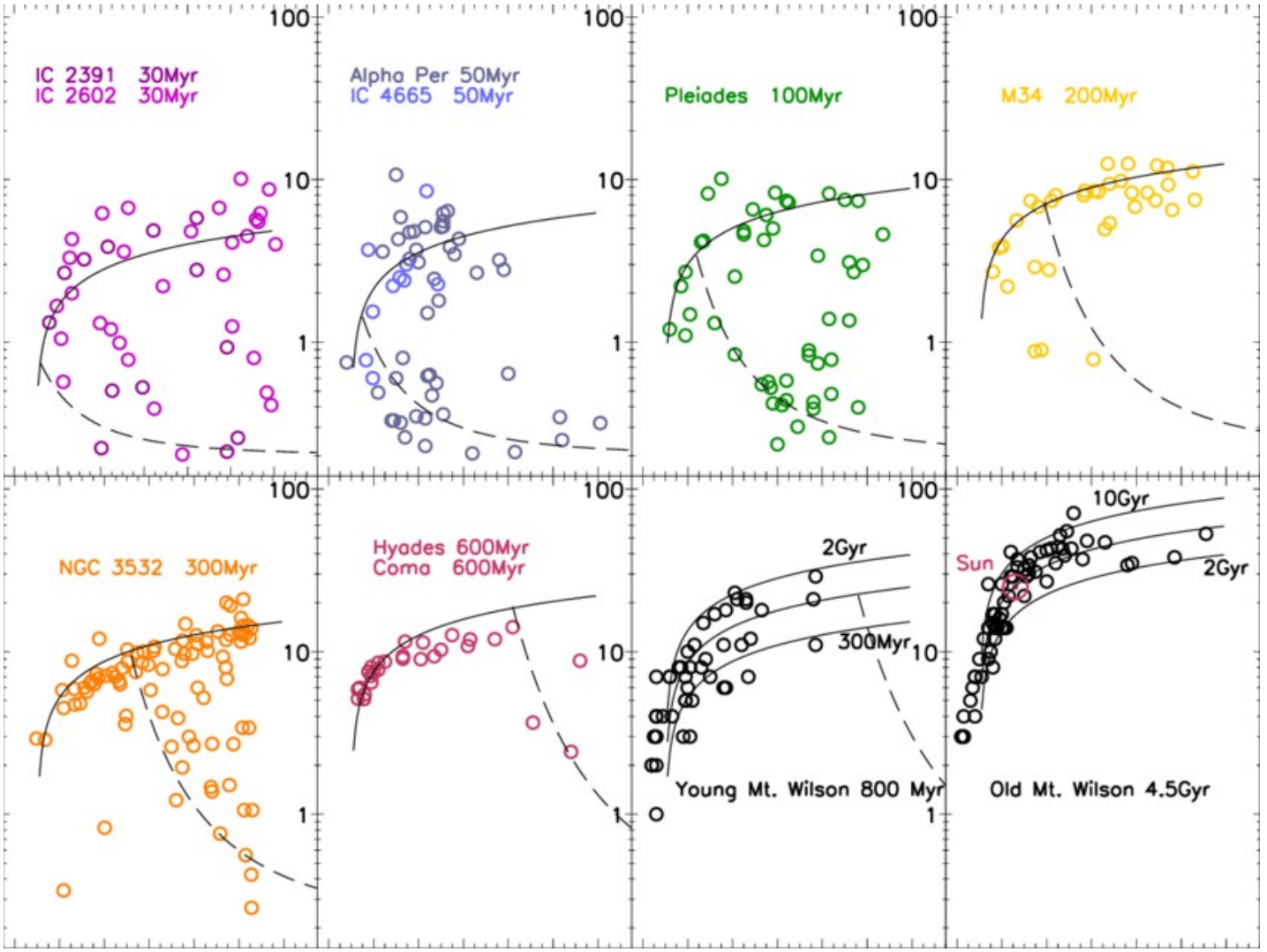




loss of angular momentum through stellar wind ("magnetic braking")

plot: an **average** over many stars of a given age

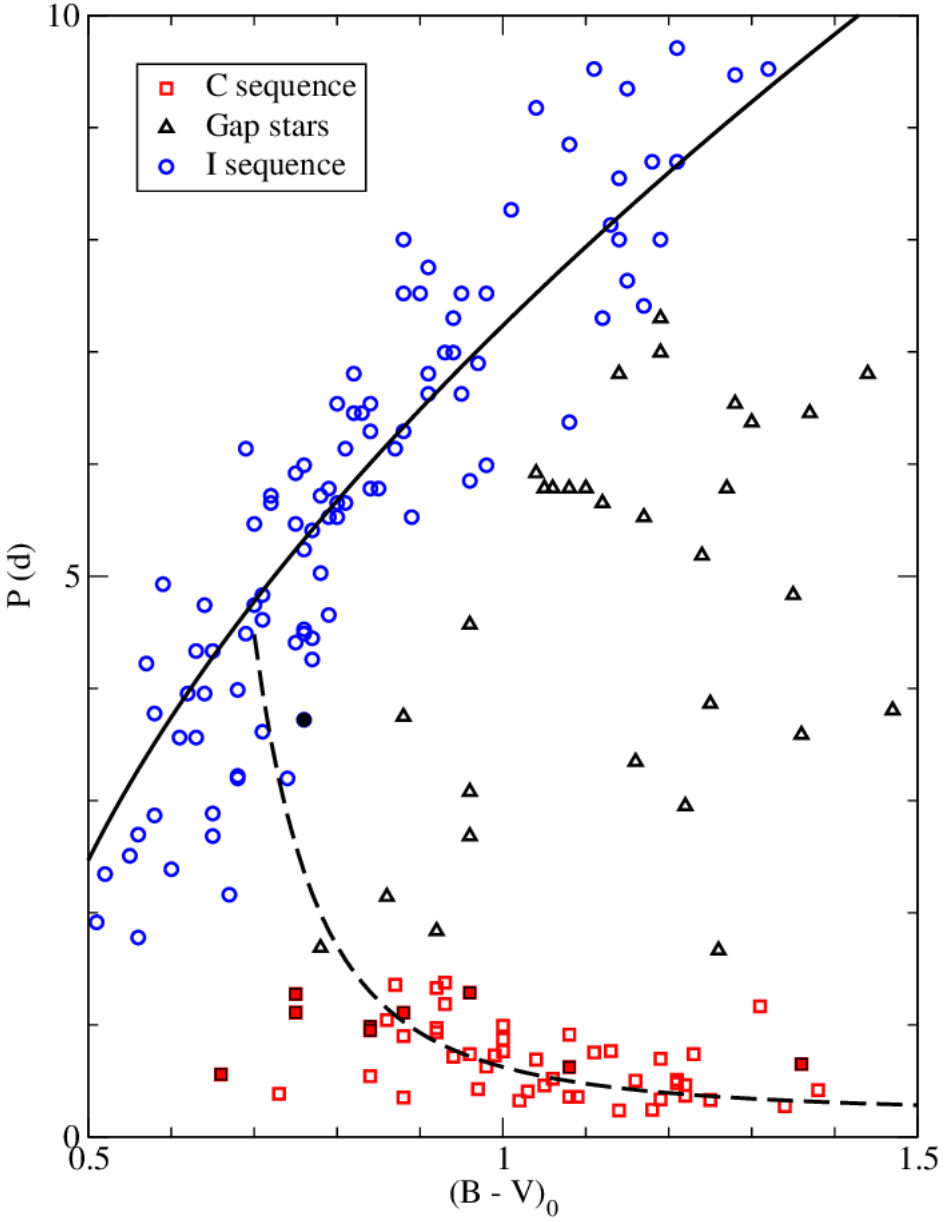
Stellar rotation over time



Barnes 2003

Stellar rotation over time

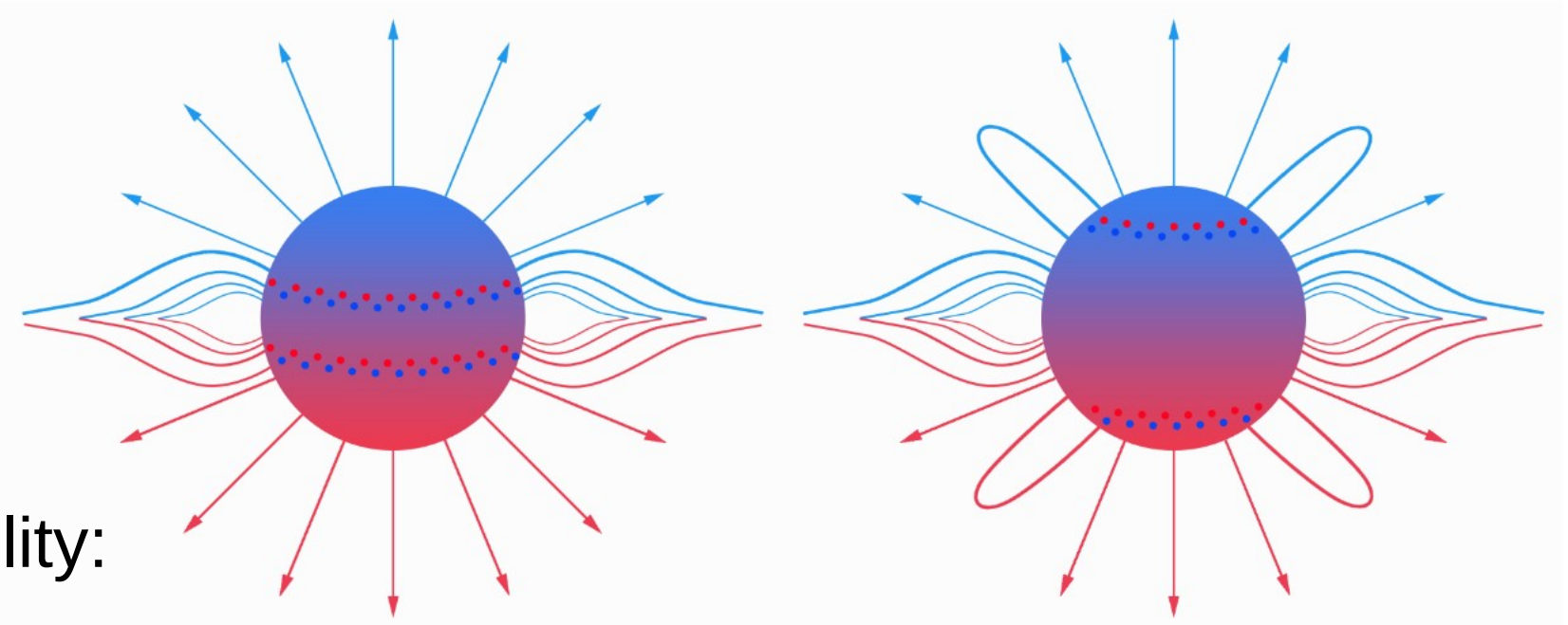
fast rotation slow rotation



Cluster M35,
110 Myr old

Gondoin 2013

Why sudden braking?



Possibility:

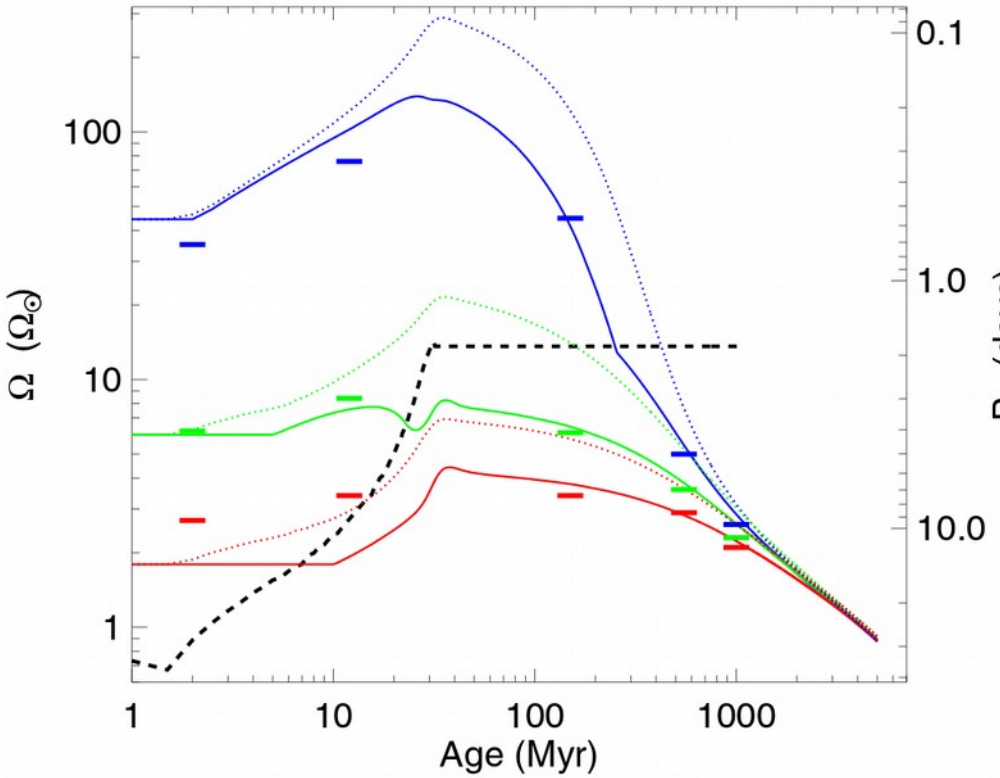
stars with high-latitude spots don’t brake well

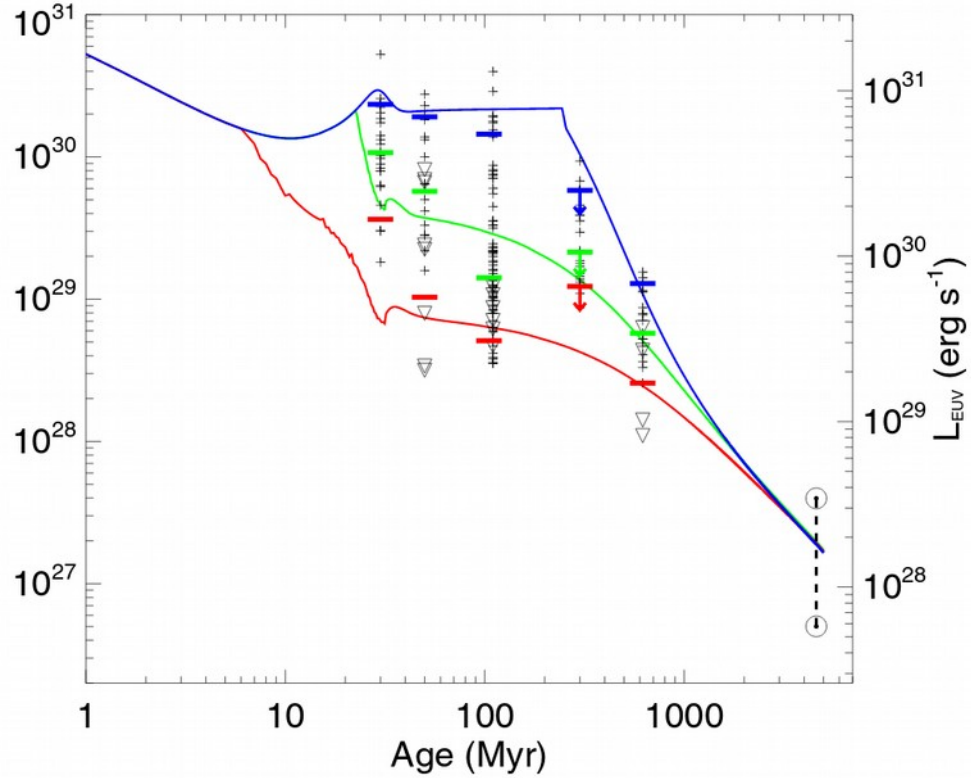
as soon as low-latitude spots appear, braking becomes strong

Still unsolved question!

Garraffo et al. 2015

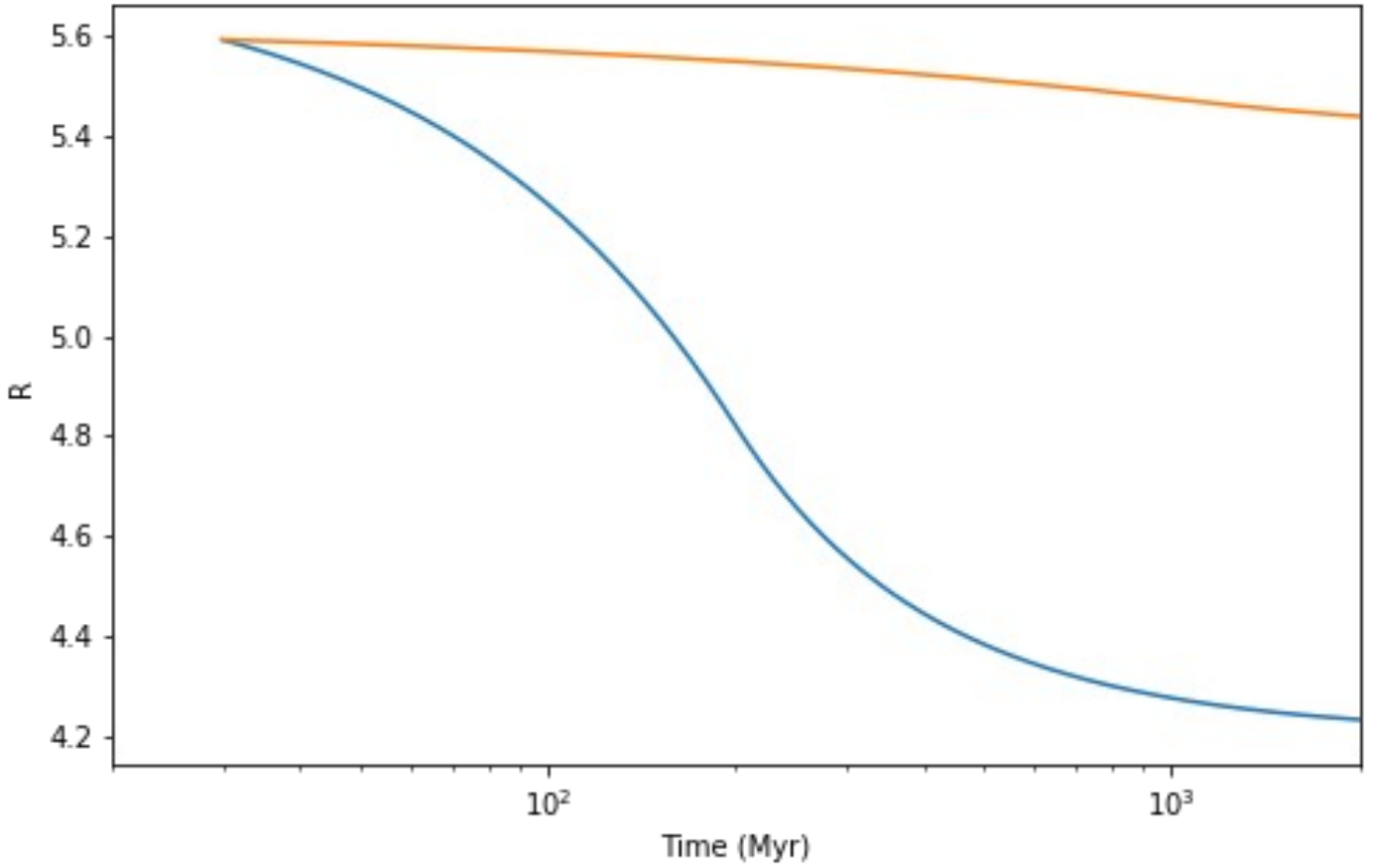
History of a star matters to exoplanet atmosphere





Tu et al. 2015

History of a star matters to exoplanet atmosphere



radius shrinkage for a small exoplanet with a host star with fast versus slow spin-down

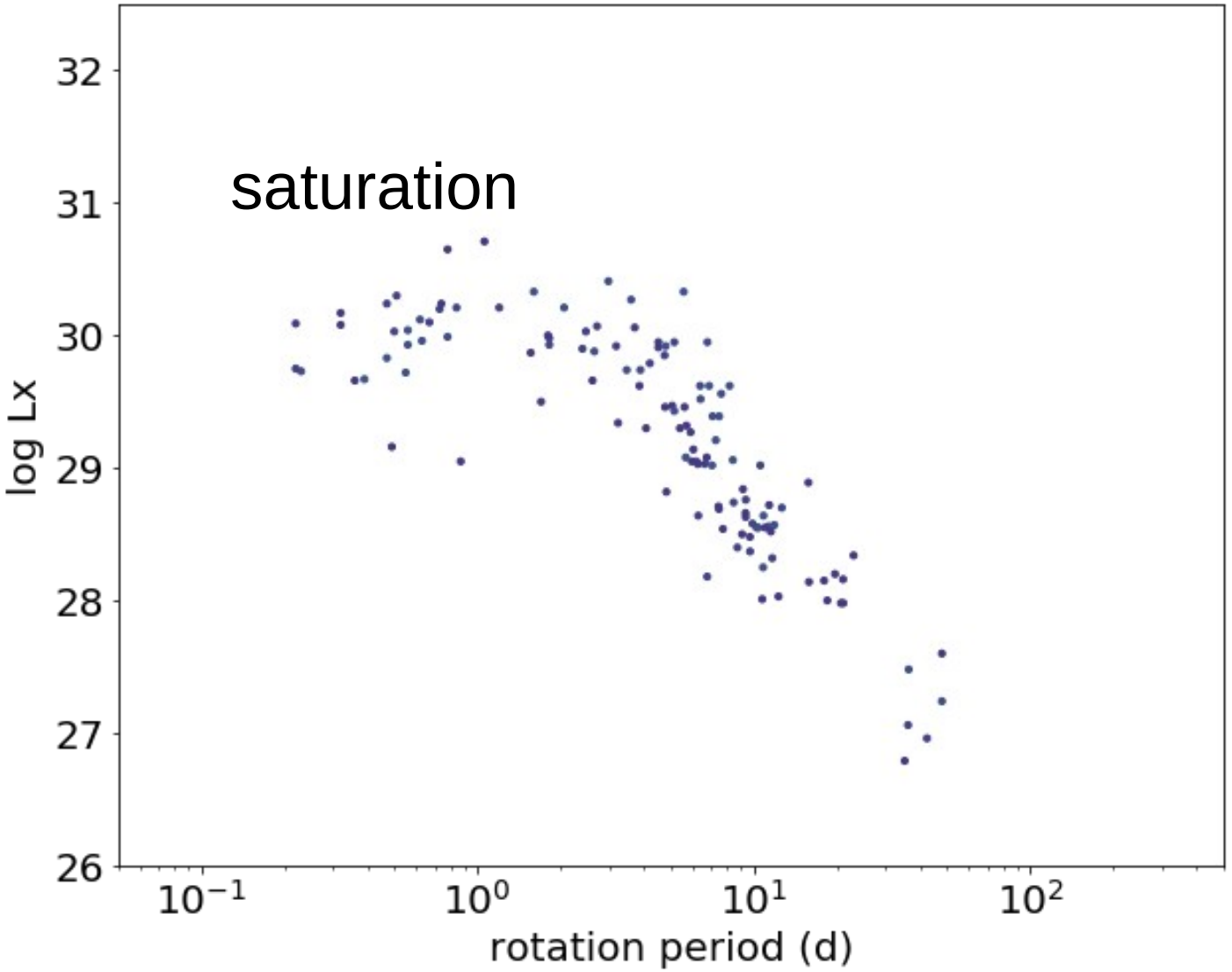
Poppenhaeger, Ketzer et al. in prep.

Rotation vs. X-rays of sunlike stars

Rotation / X-ray evolution versus age seems to be complicated for a single star.

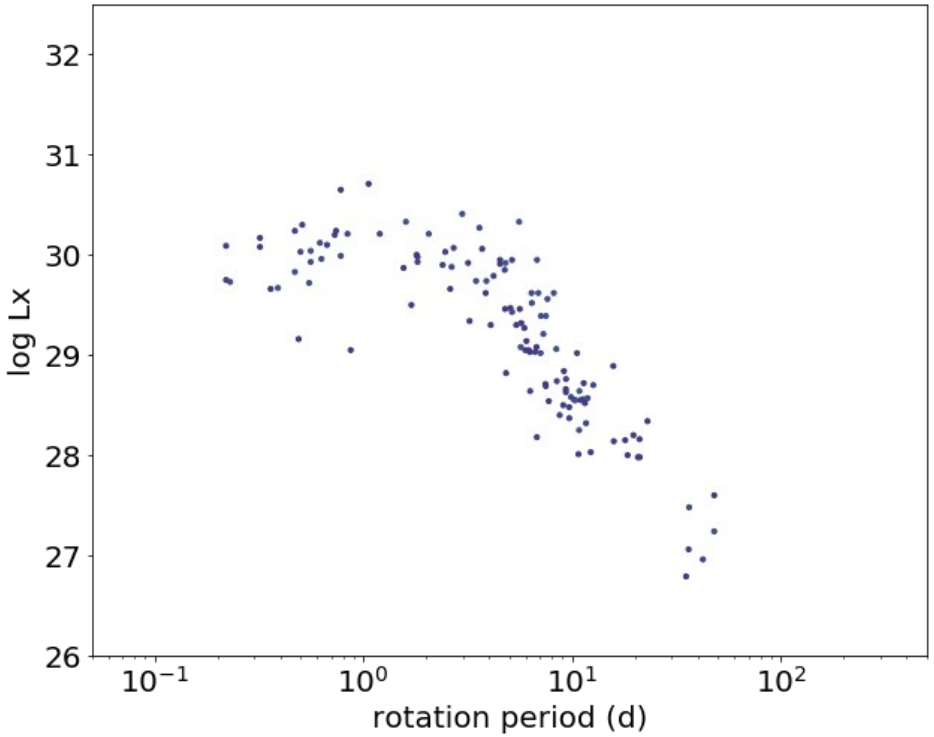
But since the X-ray output is fueled by stellar rotation, is the rotation versus X-ray relationship (neglecting age) simpler?

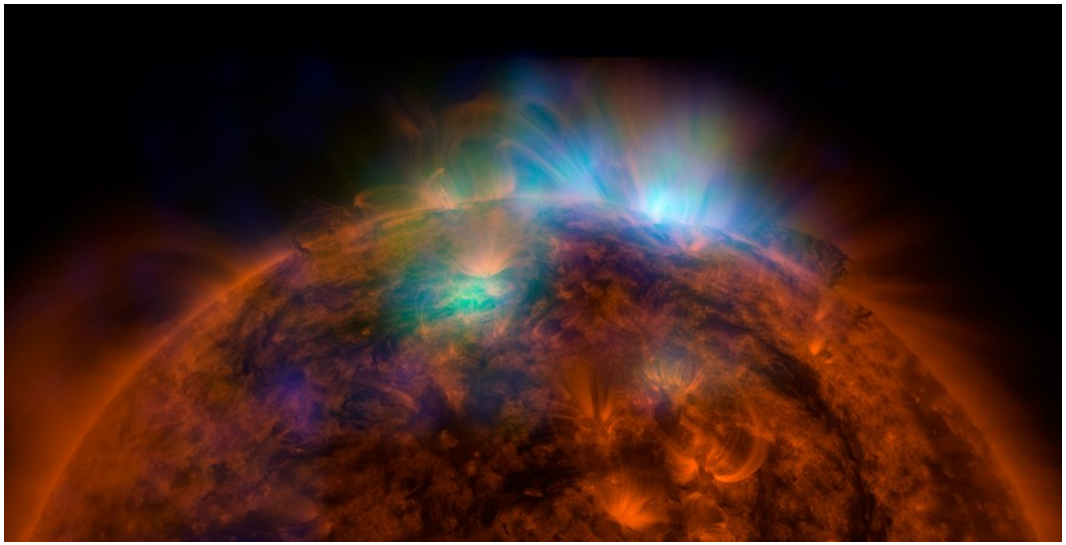
Rotation vs. X-rays of sunlike stars

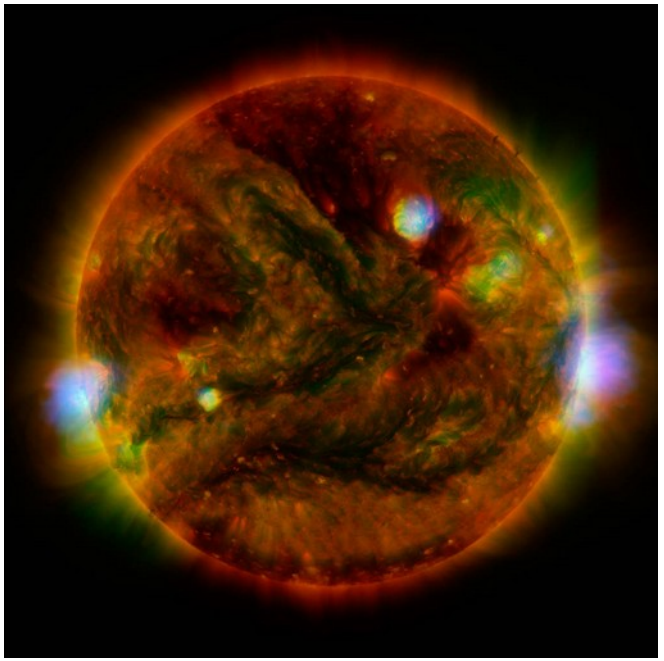


example: early K stars (K0 - K4)

Why saturation?



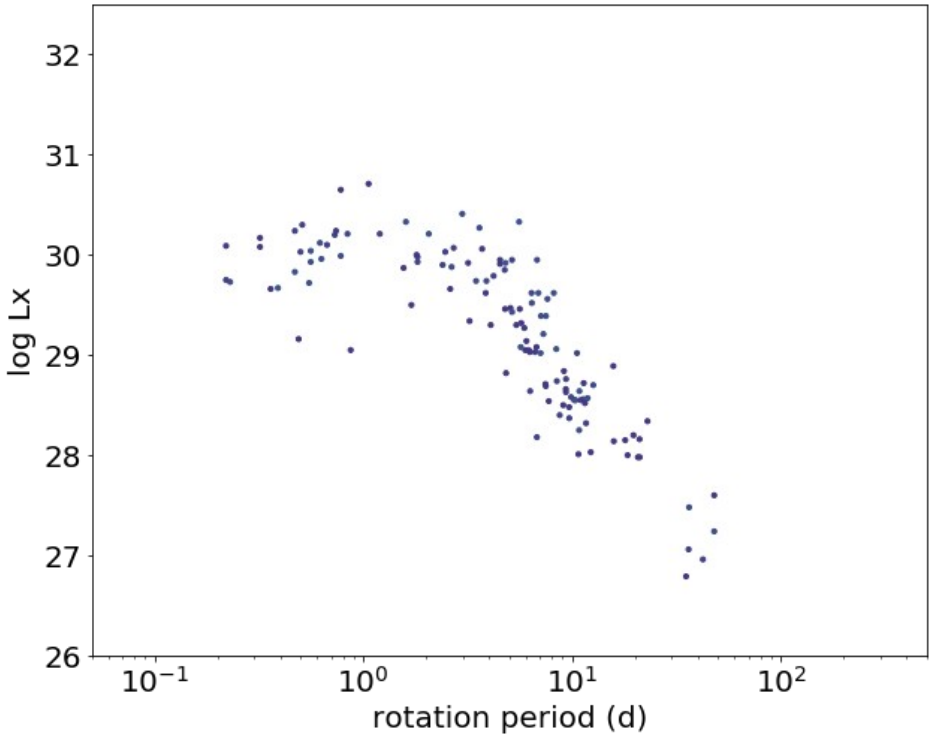


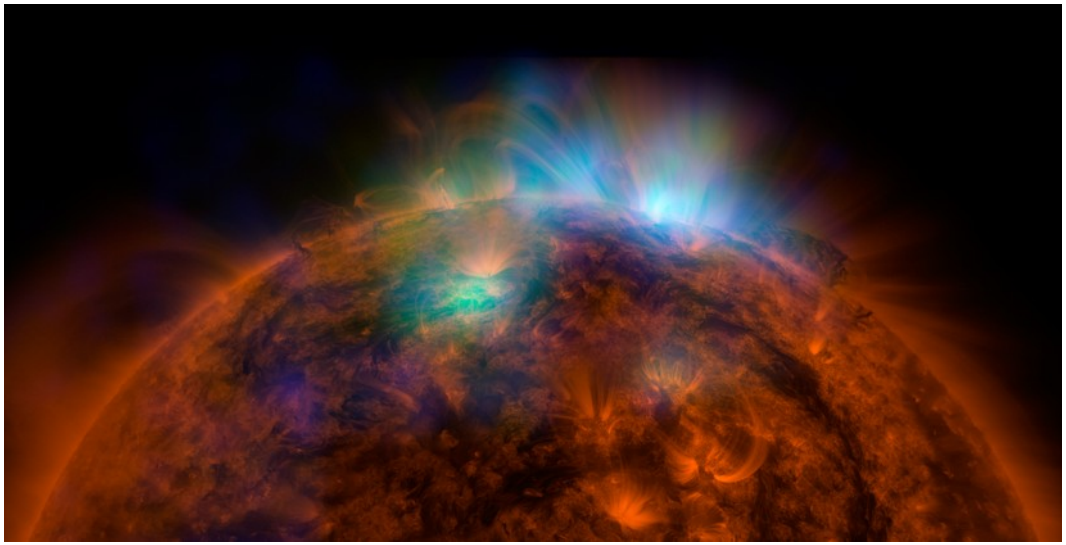


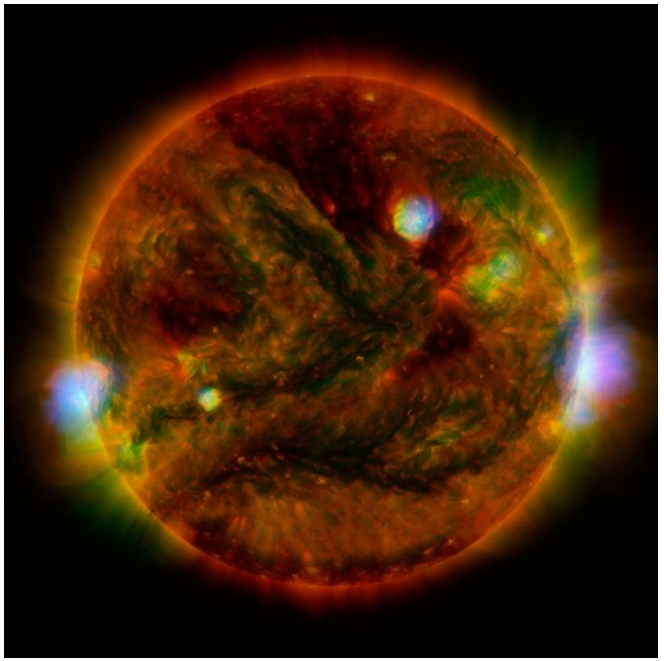
Task:

Come up with ideas why saturation might happen

How to test ideas?







Task:

Come up with observing strategies that can test your explanation idea