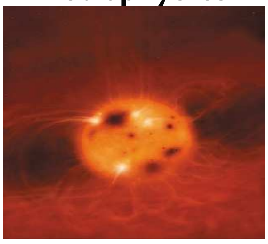
# Star Formation and Plasma Astrophysics



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## STAR FORMATION AND PLASMA ASTROPHYSICS

- Course covers early stages of stellar evolution from star formation though to main sequence.
- Focus on interrelation between a star's rotation rate and its magnetic field strength.
- Through its control of a stellar wind the magnetic field governs the rate at which young stars spin down as they evolve towards the main sequence. At the same time the rotation rate governs the magnetic field strength through the action of a dynamo. Skumanich $\Omega \propto t^{-1/2}$
- This relationship governs many aspects of early stellar evolution.

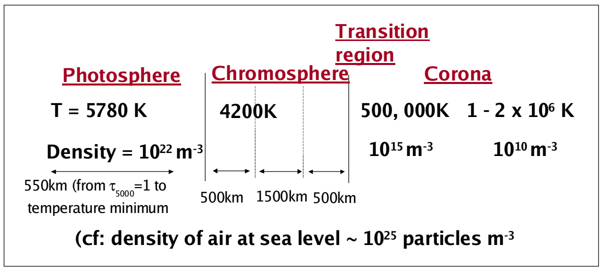


## Magnetic fields and plasmas

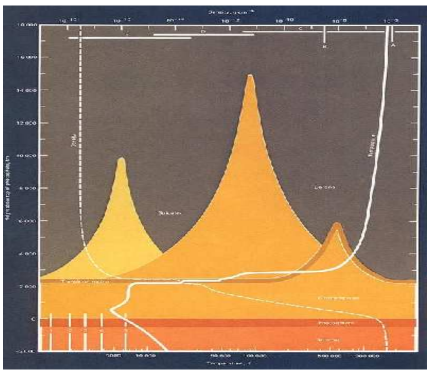
- Magnetic fields inhibit the motion of charged particles which are forced to spiral around field lines. Consequently, charged particles can move along but not across field lines.
- This means that magnetic fields can impose structure on a plasma.
- They can also insulate a region of plasma (as conduction across field lines is very poor)
- Examples:
  - Solar corona
  - Fusion devices (e.g. JET)



## The solar atmosphere

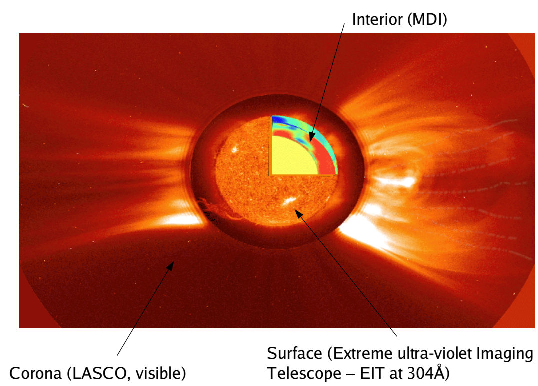




Height (km)
Temperature (K)





## Signatures of magnetic fields: Global

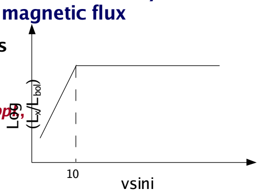
- Presence of an X-ray corona on the Sun
- At coronal temperatures (e.g. $10^7$ K) the thermal speed of a hydrogen atom is greater than the escape speed $v_{rms} > (2GM/R)^{1/2}$
- Hence the presence of an X-ray corona implies that the emitting plasma is confined.
- Structure of solar corona supports this
  - helmet streamers
  - loops
  - coronal holes: solar wind escapes along open field lines



## Stellar X-ray flux

- Stellar X-ray flux varies with rotation rate
- note initial increase in luminosity with increasing rotation rate, then saturation
- often attributed to saturation of the stellar dynamo responsible for generating magnetic flux

A ROSAT survey of the Pleiades shows X-ray luminosity varying with rotation speed (v sin i).
(see Stauffer *et al*, 1994, *Ap. J. Supp*, 91, *pp* 625-657)





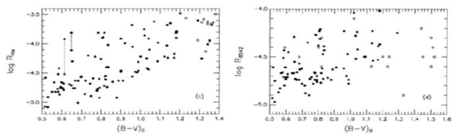

- Chromospheric emission (e.g. Ca II H&K, Mg II, Si II) also indicates the presence of a magnetic field and shows a similar variation with rotation rate.
  - large range in flux density
  - lower limit to flux density (the basal flux) which decreases sharply with increasing (B-V). The basal flux may be due to acoustic heating.
  - Once the basal flux is subtracted out, there is a good correlation between chromospheric and coronal activity indicators.
  - Both appear to be governed by the same process, believed to be the stellar magnetic field.



## Hα chromospheric fluxes

•Hα line is filled due to chromospheric flux

•Pleiades:
- Young cluster 70 Myr
-Spread at a given spectral type ---> rotation
- Increase in chromospheric activity as spectral type decreases





## Rossby Number

- Dynamo efficiency related rotation period and convective turnover time
- Rossby number:

  $R_o = P/\tau_c$ (P = period$\tau_c$= convective turnover time)

- Plots using Rossby number remove the mass/spectral type dependence of the rotation-activity relation
- Magnetic flux and hence magnetic induced emissions increase with decreasing Rossby number

(see handout)

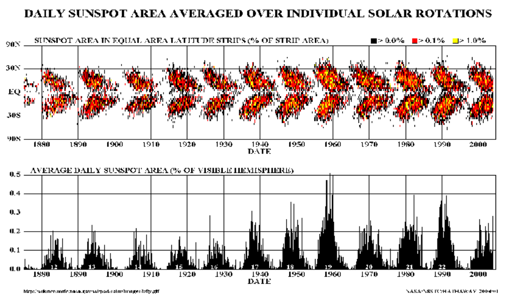
– Summary: global indicators show magnetic activity varies greatly across the HR diagram.



## Signatures of stellar magnetic fields: local

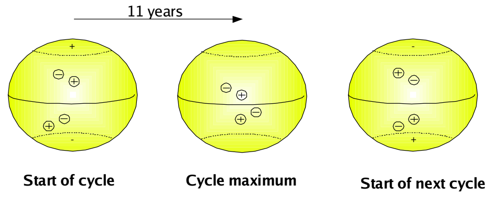
Sunspots:

- Magnetic field strengths ~ 1kG (1G = $10^{-4}$ T)
- Dark central umbra ~ 1500K cooler than surroundings as the intense magnetic fields inhibit convection
- Numbers show (approx) 11yr cycle but note
  - cycle length varies from 7-17 yr
  - long term trends e.g. Maunder Minimum from 1645: 70 years of no spots
  - net polar flux varies over 22 yrs
- Latitude range 40° to 5°
  - spot latitudes drift towards the equator over each cycle (the butterfly diagram)





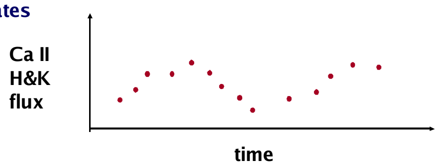

## The polarity of sunspots and polar regions






## Active regions:

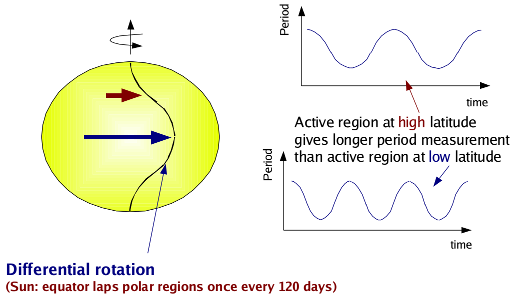
- Ca II H&K emission shows periodic variation as star rotates




- Mt. Wilson Ca II H&K survey showed:
  - that many stars have activity periods similar to the Sun
  - but some have apparently random variations or no variation at all.



## Period change as an indicator of magnetic cycles






## Starspots – magnetic field strength

- Magnetic field strengths measured by Zeeman splitting of lines ($\Delta \lambda \alpha B \lambda^2$) to be 1-10 kG but
  - broadening of lines due to rapid rotation may mask the splitting
  - only high field strengths can be measured
  - more accurate for longer wavelengths
  - may give misleading results if polarities are mixed within a resolution element and so they effectively cancel out
- Doppler imaging of rapidly-rotating stars suggests that spots may appear at much higher latitudes than on the Sun and also in more than one band.