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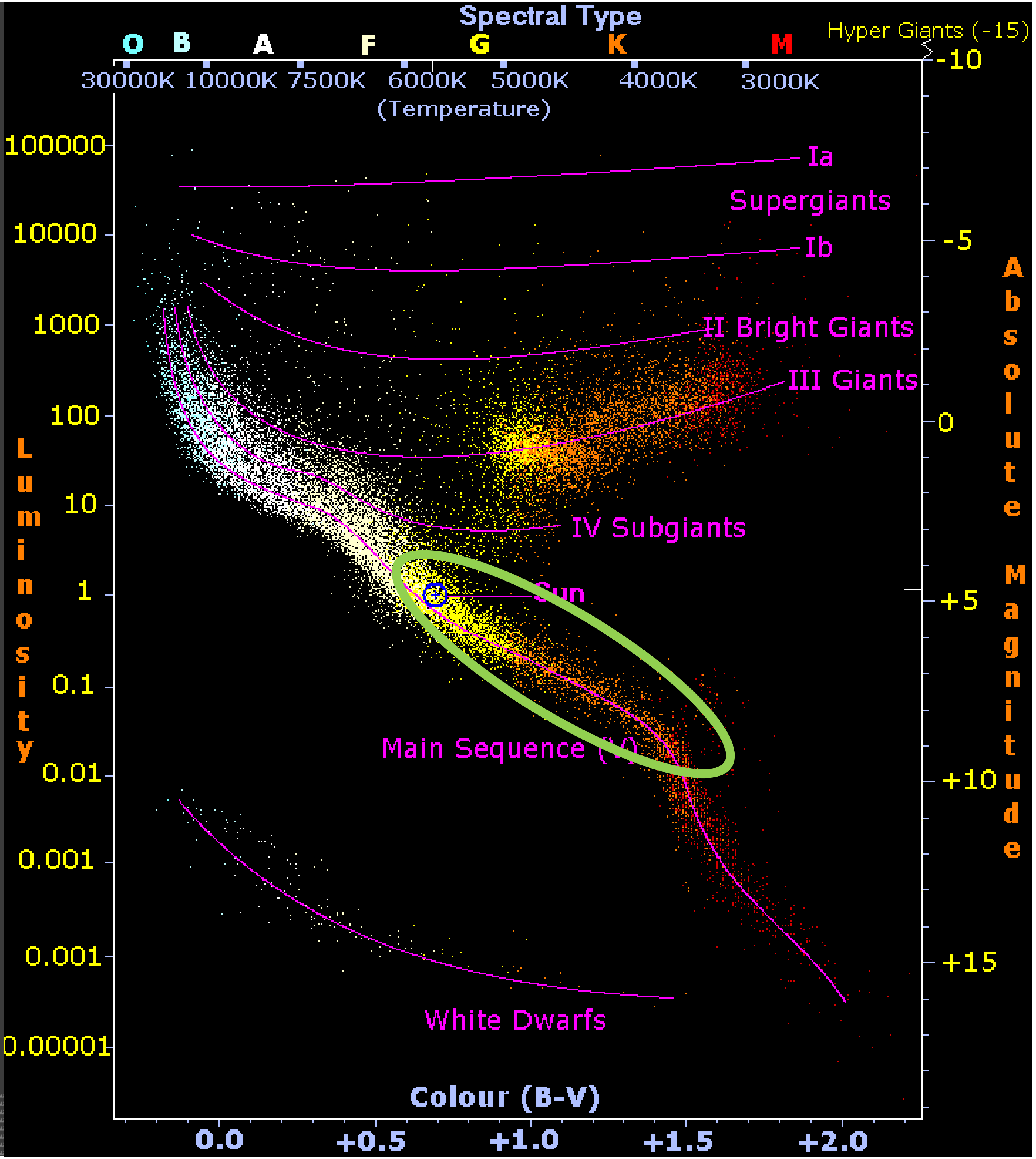
STELLAR WIND AND SPACE WEATHER ON EXTRASOLAR PLANETS

up to now:

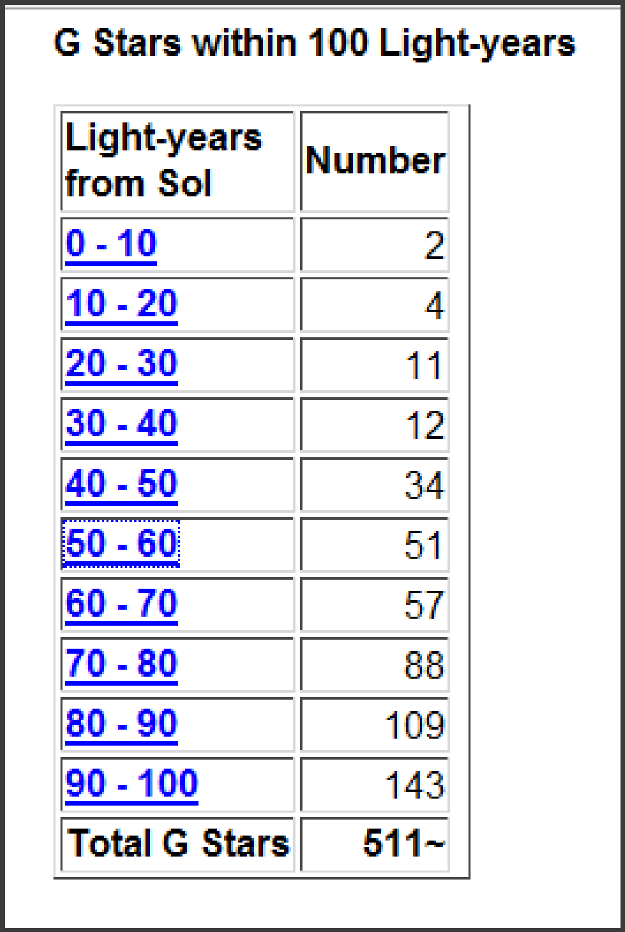
more than 400 exoplanets detected



outline

- stars and habitable planets
- long term variability of stars
- two models
    - varying B
    - varying solar age
- stellar winds, planetary atmospheres
- giant planets
    - migration
    - evaporation

G type stars



G Stars within 100 Light-years

Light-years from Sol	Number
0 - 10	2
10 - 20	4
20 - 30	11
30 - 40	12
40 - 50	34
50 - 60	51
60 - 70	57
70 - 80	88
80 - 90	109
90 - 100	143
Total G Stars	**511~**

G-type main sequence stars:
T: 5290-6050 K
L: 0.66-1.5
M: 0.85-1.1

G-type giants:
Capella
G-type supergiants
L: 10 000
M: up to 9

K-type stars

- M: 0.5…0.8; L=0.1….0.4
- T: 3900….5200 K
- orange
- Examples: Alpha Centauri, Epsilon Indi
- Lifetime: > 15 Gy
- K-type giants:Arcturus, Aldebaran, Pollux;L=60-30; M: 1.0…1.1

M-type stars

- surface temperature of less than 3,600°C.

  Main sequence M stars, red dwarfs, have a mass of less than 0.5 M_{sun} and a luminosity of less than 0.08 L_{sun}; ex.: Proxima Centauri and Barnard's Star

- M-type giant stars, 1.2 to 1.3 M_{sun} luminosities exceeding 300 L_{sun}. The largest stars of all are M-type supergiants, such as Betelgeuse and Antares, of mass of 13 to 25 M_{sun} and luminosity of 40,000 to 500,000 L_{sun}.

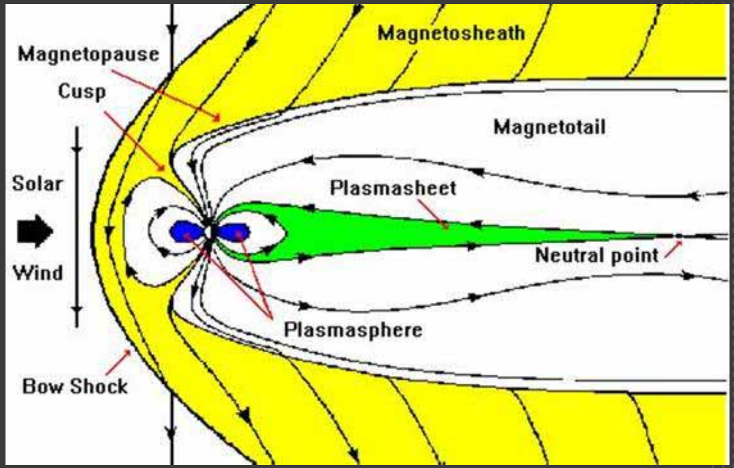
what makes a planet habitable

- different kinds of habitable zones HZ
  - circumstellar
  - galactic
  - circumplanetary
  - anything else?
- what is habitability
  - liquid water?
  - temperature range?
  - anything else?

Space weather effects
stellar winds
stellar radiation

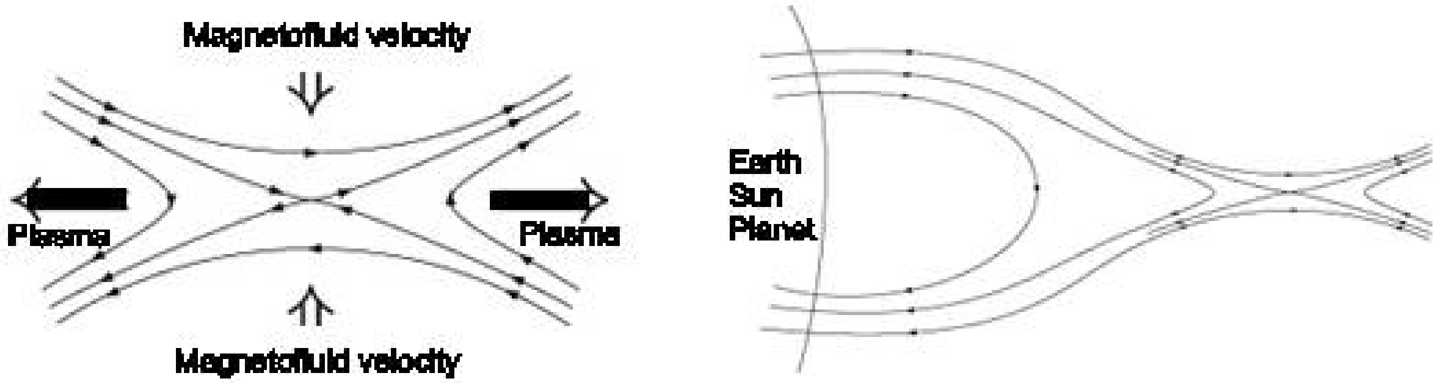
What makes a planet habitable

- right host star
- right distance
- planetary surroundings
  - magnetic field
  - evolution of atmosphere
  - heliosphere
  - stability of planetary system
  - local stellar neighborhood
  - plate tectonics
  - large satellite



target stars

- stellar activity is determined by
  - rotation rate
  - convection zone → turbulence→stellar activity
  - rotation, convection etc. changes with stellar age and mass

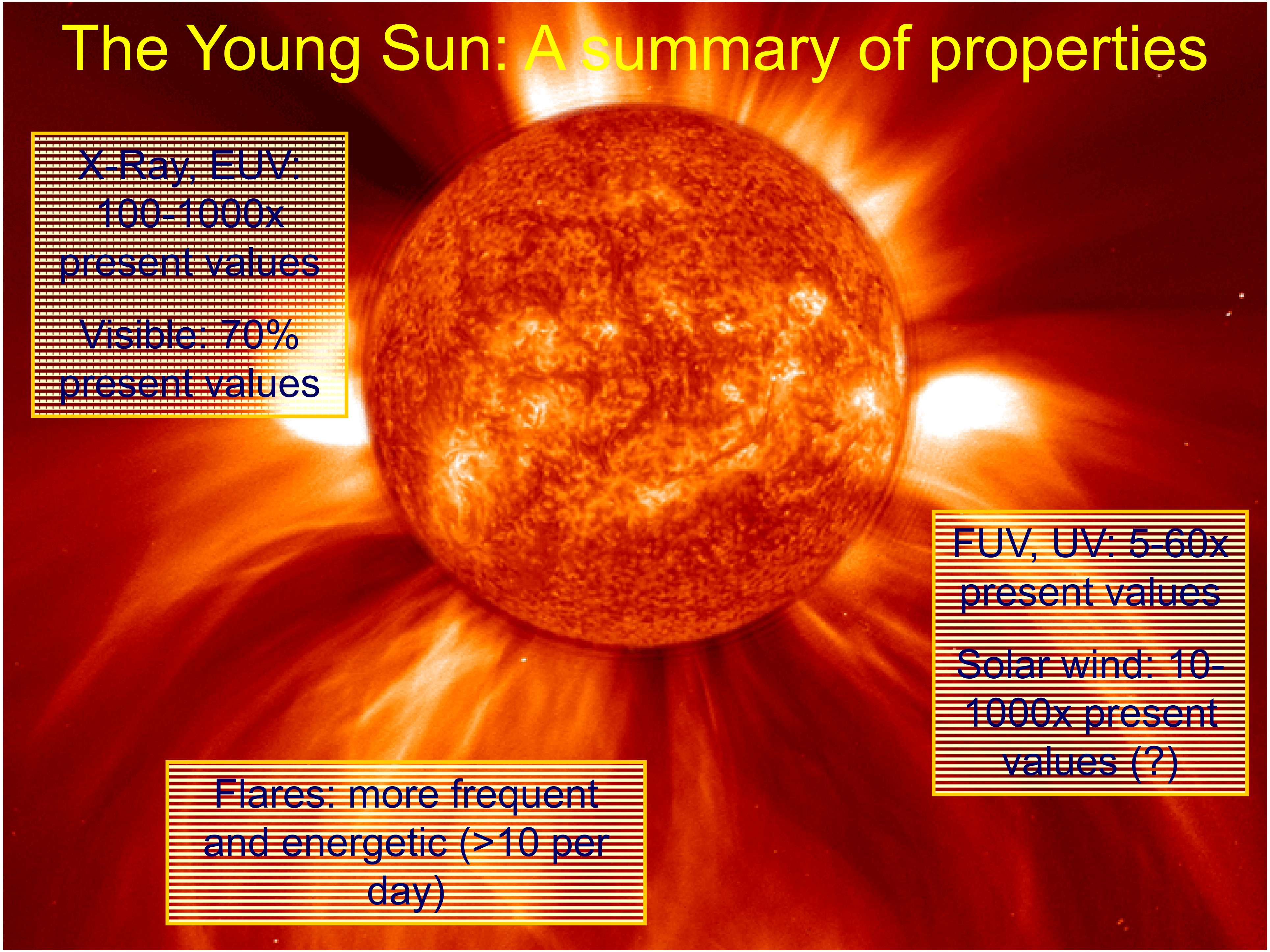


variability of target stars

- faint young sun
  - young stellar activity
    - larger amplitude
    - more variable, irregular
    - sun rotated faster
  - solar luminosity only 70%
- evolution of planetary atmospheres
  - Venus-Earth-Mars

$$P = \sqrt{\frac{2RT}{\enclose{circle}{\mu}}}$$

The Young Sun: A summary of properties



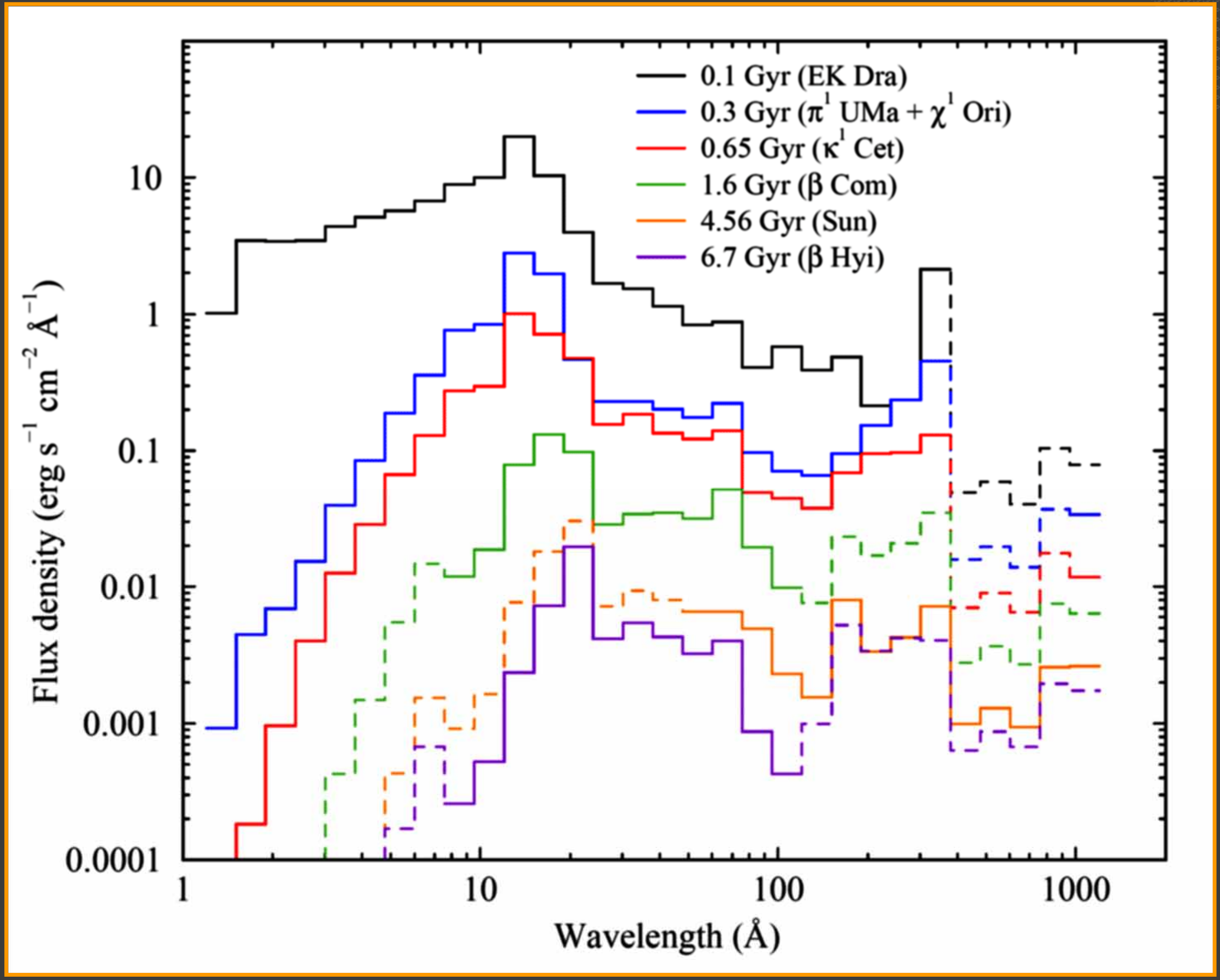
X-Ray, EUV: 100-1000x present values

Visible: 70% present values

FUV, UV: 5-60x present values

Solar wind: 10-1000x present values (?)

Flares: more frequent and energetic (>10 per day)



The young post-ZAMS Sun had stronger emissions:

- **100-1000x in X-rays**
- **10-100x in the EUV-FUV**
- **5-10x in the UV**

Ribas et al. (2005, ApJ)

Simulations

how does the stellar wind behave ?

- varying field strength
- evolution of solar like stars

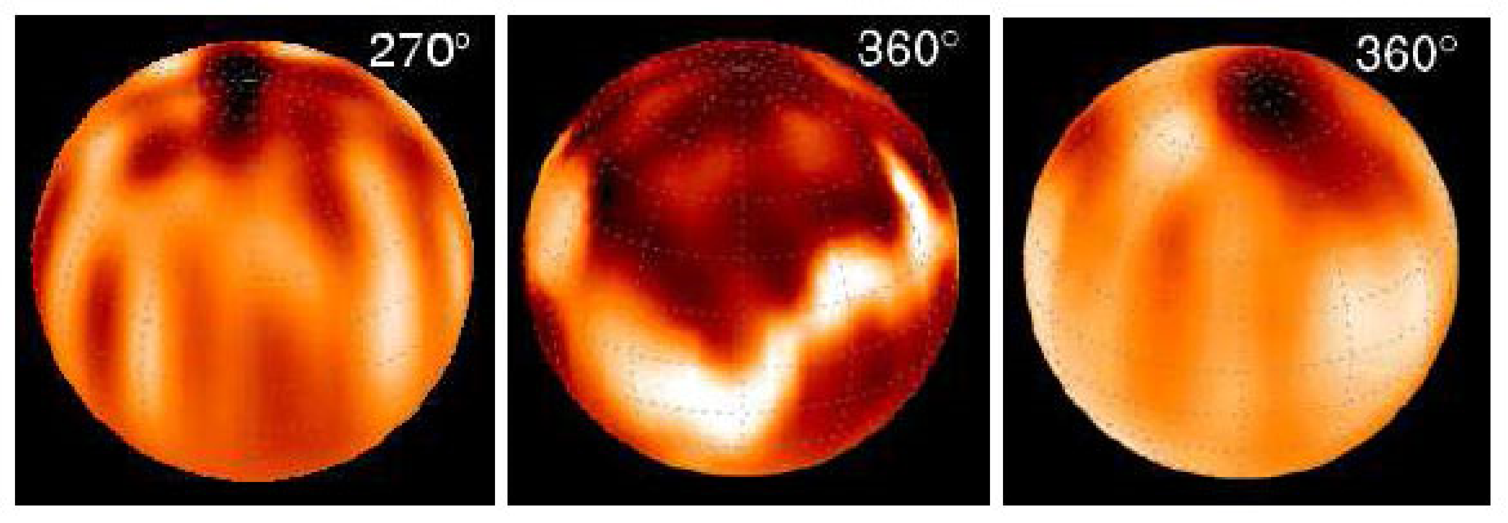
Numerical Model:

Vidotto, A. A.; Opher, M.; Jatenco-Pereira, V. Gombosi, T. I.

- 3D MHD numerical simulations
- magnetized solar-like stellar winds and their dependence on the plasma-β parameter (the ratio between thermal and magnetic energy densities).
- a heating parameter described by γ, which is responsible for the thermal acceleration of the wind.
- analyze winds with polar magnetic field intensities ranging from 1 to 20 G.
- the wind structure presents characteristics that are similar to the solar coronal wind.
  - The steady-state magnetic field topology for all cases is similar, presenting a configuration of helmet streamer-type, with zones of closed field lines and open field lines coexisting.
  - Higher magnetic field intensities lead to faster and hotter winds. For the maximum magnetic intensity simulated of 20 G and solar coronal base density, the wind velocity reaches values of ~1000 km s^{-1} at $r \sim 20r_0$ and a maximum temperature of $\sim 6 \times 10^6$ K at $r \sim 6r_0$.

Evolution of stellar winds from the Sun to red giants
Suzuki, Takeru K.

- global 1D MHD simulations, → investigate the heating and acceleration of solar and stellar winds in open magnetic field regions.
- simulation covers from photosphere to 20-60 stellar radii,
  - takes into account radiative cooling and thermal conduction.
  - impose transverse photospheric motions with velocity ~1 km/s and period between 20 seconds and 30 minutes, which generate outgoing Alfvén waves.
  - the dissipation of Alfvén waves through compressive wave generation by decay instability is quite effective owing to the density stratification, which leads to the sufficient heating and acceleration of the coronal plasma.
- the evolution of stellar winds from main sequence to red giant phases.
  - When the stellar radius becomes ~10 times of the Sun, the steady hot corona with temperature 10^6 K, suddenly disappears.
  - instead, many hot and warm (10^5 - 10^6 K) bubbles are formed in cool ($T < 2 \times 10^4$ K) chromospheric winds because of the thermal instability of the radiative cooling function;
  - the red giant wind is not a steady stream but structured outflow.



Three temperature maps of young, active solar analogs, derived from Doppler imaging. From left to right: HD 171488 (P = 1.34 d; Strassmeier et al. 2003), HII 314 (P = 1.47 d; Rice and Strassmeier 2001), and EK Dra (P = 2.7 d; Strassmeier and Rice 1998)

some correlations

- power-law relation between the rotation-period variation, δP, and the average rotation period, P , of the form

$$\delta P = P^{1.42 \pm 0.5}$$

- differential rotation, parameterized by δΩ/Ω, and the activity cycle frequency, ω

$$\omega = e^{-0.055 \pm 0.004} / \delta\Omega / \Omega$$

X-ray output

- Rossby number: ratio between inertial/coriolis force
- The total X-ray output of a stellar corona depends on the available magnetic energy and is therefore a consequence of the dynamo operation.
  - Younger and more rapidly rotating stars are more X-ray luminous;
  - is the case for UV and FUV radiation, the X-ray output decreases as the star ages and its rotation period increases.

$$F_X = (3 \pm 1)10^{28} t_9^{-1.5\pm0.3}$$

how to detect stellar winds

- magnetic fields cause
  - acceleration
  - guiding past Alfven Radius
  - heating

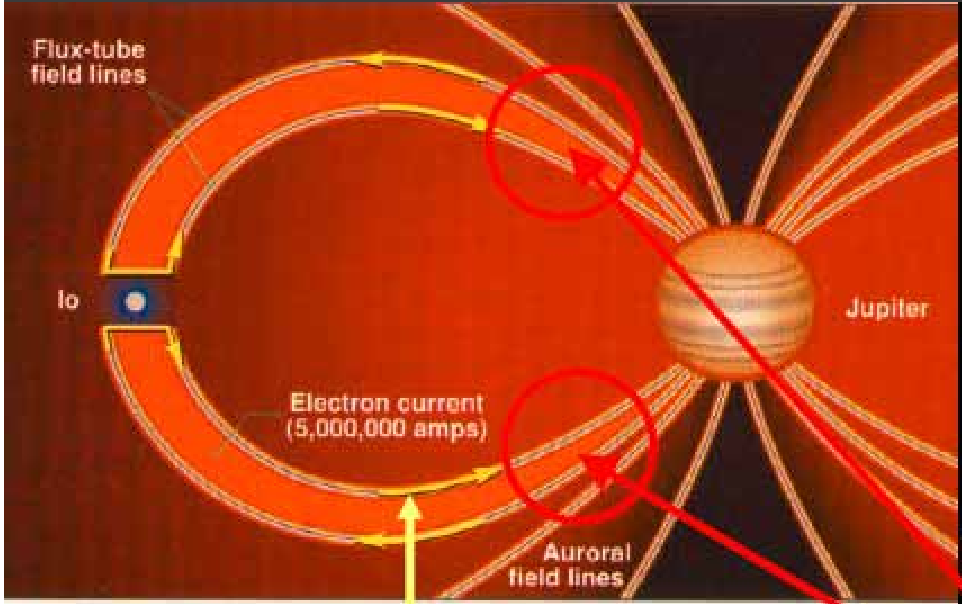
of solar wind

- indirect evidence of stellar wind
  - spin down of rotation rates
  - wind carries away angular momentum from star

- thermal radio emission from the winds
- signatures of charge exchange in X-ray spectra
- Lyman Alpha absorption
- correlation between mass loss rate and x-ray emission.
- correlation stellar age and mass loss rate

$$\dot{M} = F_X^{1.34 \pm 0.18}$$

$$\dot{M} = t^{-2.33 \pm 0.55}$$



Jupiter Aurora

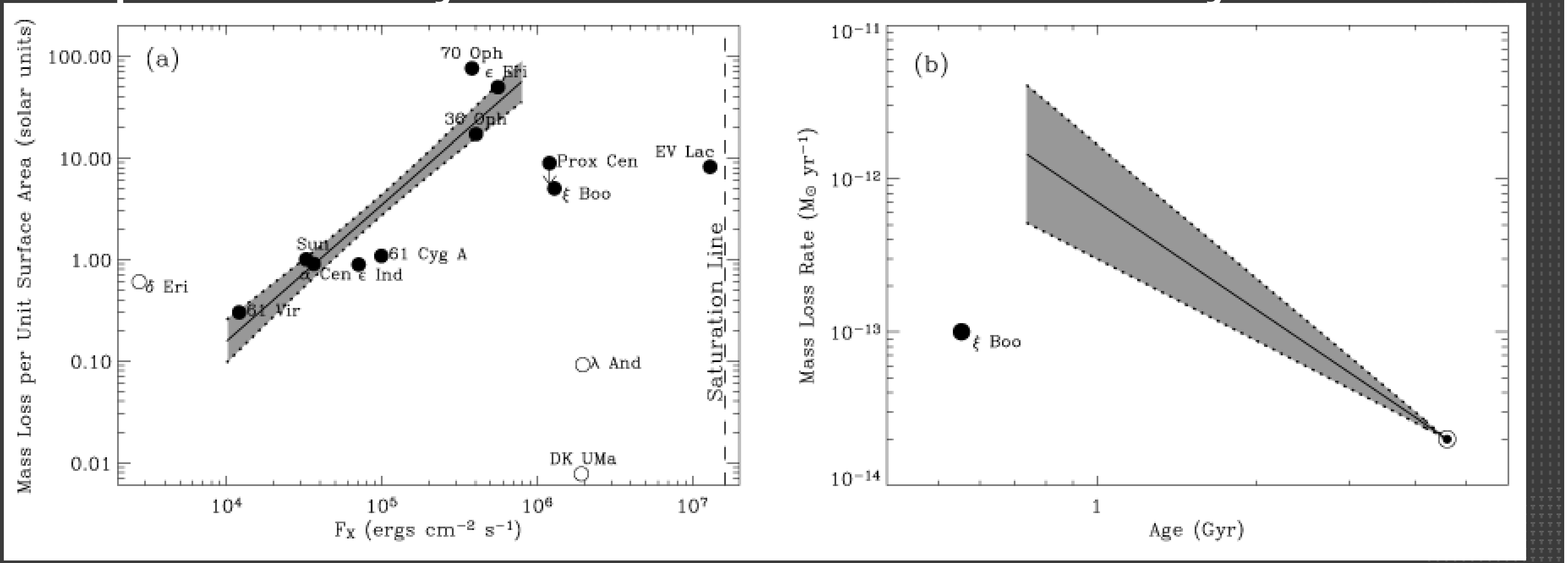
NASA and J. Clarke (University of Michigan) • STScI-PRC00-38

Current system, set up by Alfvén waves

Observed consequences:
Decametric radiation & aurora

Does the interaction of extrasolar planets and their stars cause decametric radiation and planetary aurorae?

- present day solar mass loss: 10^{-14}M/yr



Mass-loss rates per unit surface area vs. stellar X-ray surface fluxes. MS stars are shown by filled circles. The trend for inactive stars (shaded area) is not followed by more active stars. – Right (b): Inferred mass-loss history of the Sun. Again, the trend shown for inactive stars (shaded area) breaks down for the most active

Güdel, living review

Stellar winds and planetary atmospheres

- Solar UV radiation
  - photoloysis of water, hydrogen escape
  - examples: water loss in atmospheres of Venus and Mars
- Earth: magnetic field
  - shielding against solar wind particles
  - solar wind strongly enhances escape
- solar wind induced sputtering
- non thermal escape:
  - photochemical escape, ion sputtering, ion escape and ionospheric outflow

Absence of a magnetosphere

- interaction of the solar wind with the atmosphere of the planets causes ionization of the uppermost part of the atmosphere.
- This ionized region of atmosphere→induces magnetic moments that deflect solar winds much like a magnetic field,
  - limiting solar wind effects to the uppermost altitudes of atmosphere, roughly 1.2-1.5 planetary radii away from the planet,
  - an order of magnitude closer to the surface than Earth's magnetic field creates.

Problem of close planets

- planets close to their host star
  - tidally locked
  - slow rotation
  - no magnetospheres
- ‚induced‘ magnetosphere→ protection

stellar winds and giant planet migration

- strong stellar wind during T Tauri phase
- Lovelace:
  - can explain giant planet migration
  - timescale 2-20 Myr
  - planet migration depends on the ratio of planet revolution and stellar rotation
  - azimutal ram pressure increases planet‘s angular momentum; planet approaches host star when $P_* < P_P$
- Vidotto et al., 2009:
  - cannot explaint hot Jupiter migration

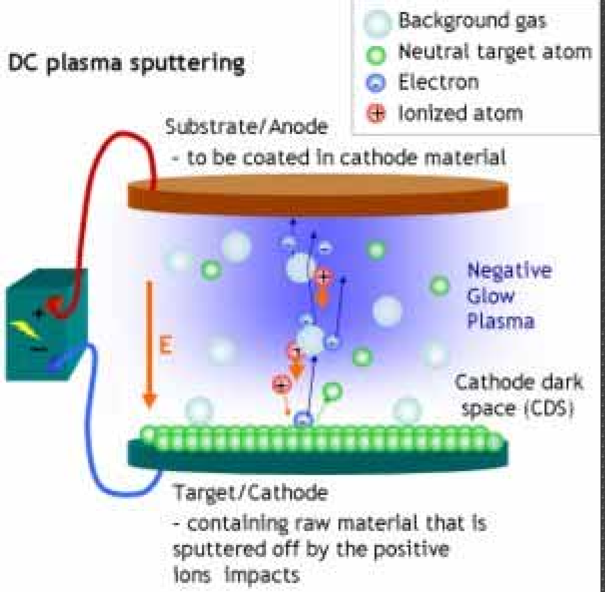
M-stars and flares

- UV habitable zones (UV-HZ), defined in Buccino et al. (2006)
- dM HIP 74995, HIP 109388, HIP 113020 and around two dMe stars: Ad Leo and EV Lac.
- →moderate flares could be an energy source in the biogenesis processes.

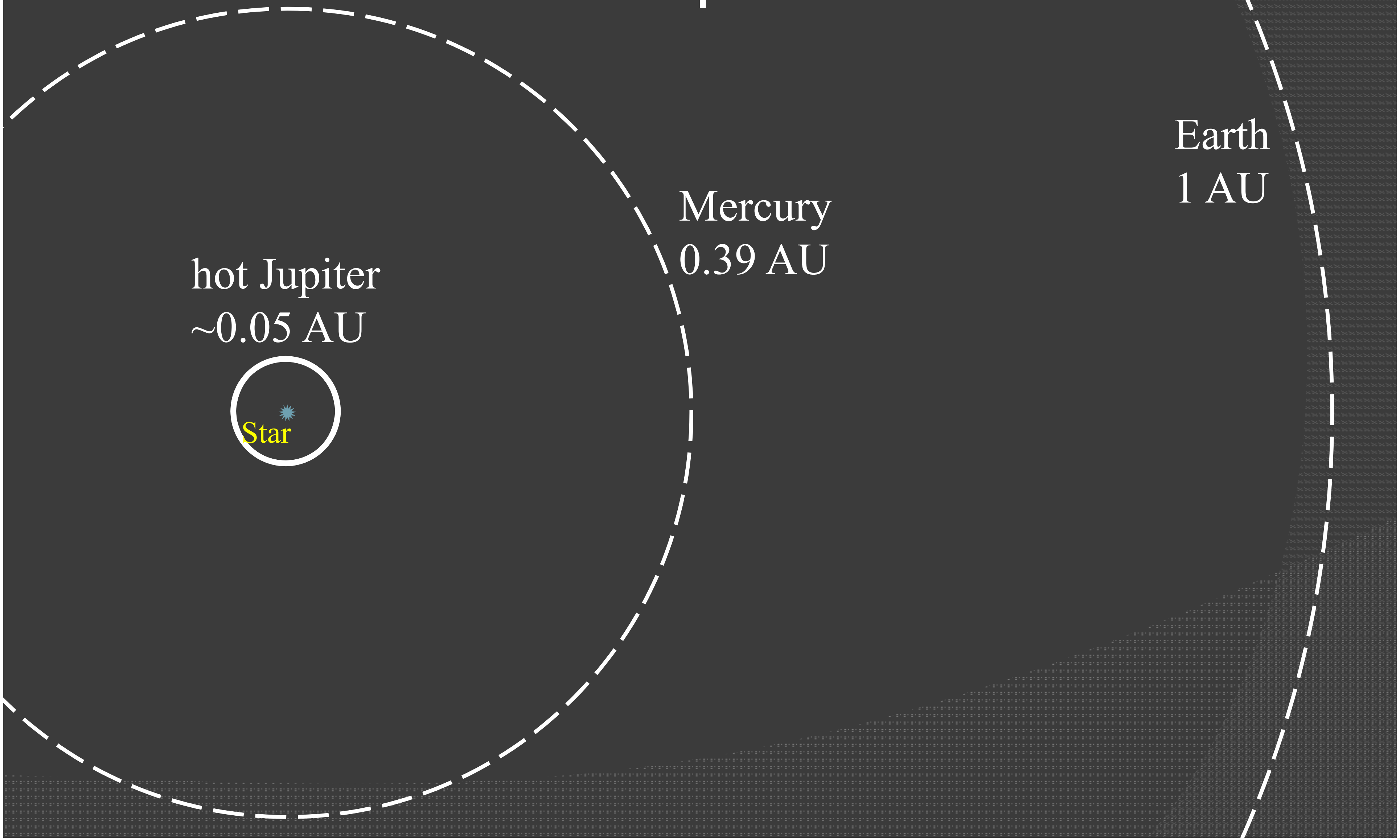
sputtering

- **Sputtering** is a process whereby atoms are ejected from a solid target material due to bombardment of the target by energetic ions.

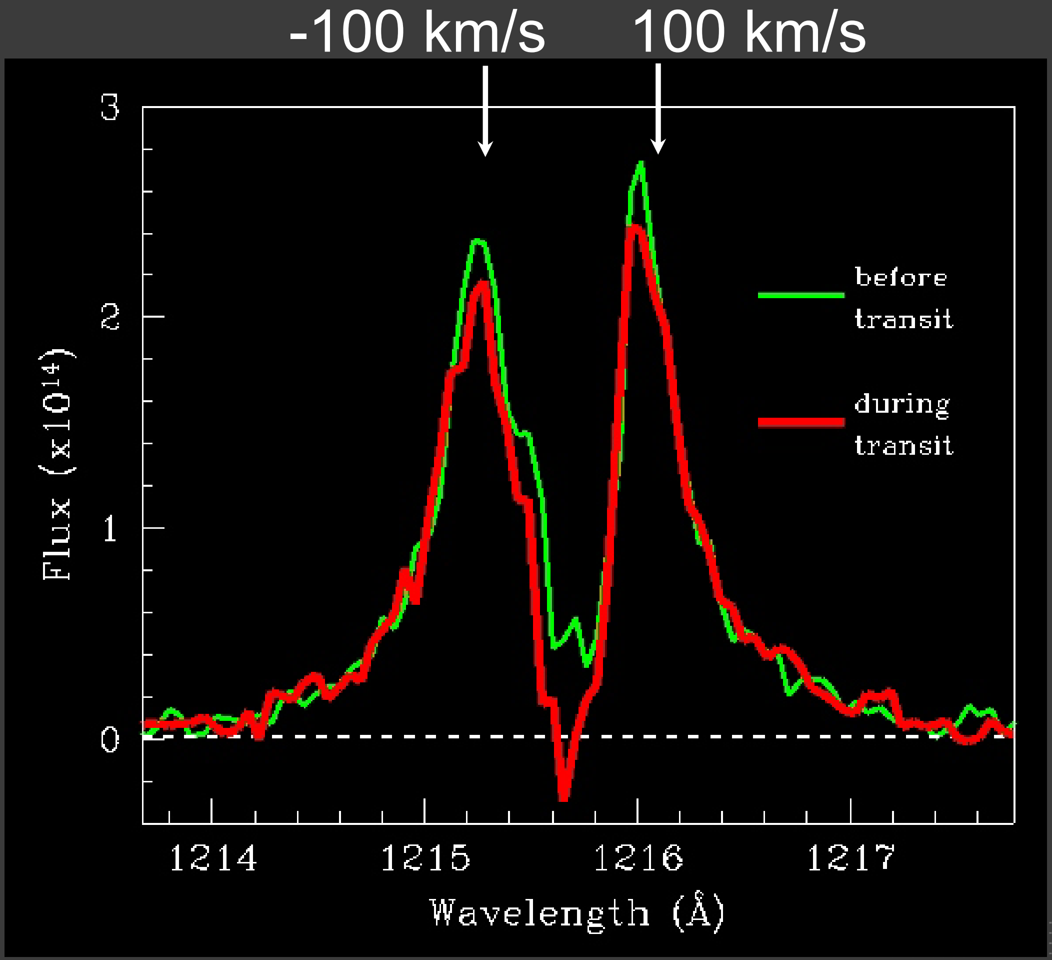
Sputtering is one of the forms of space weathering, a process that changes the physical and chemical properties of airless bodies, such as asteroids and our moon. It is also one of the possible ways that Mars has lost most of its atmosphere and that Mercury continually replenishes its tenuous surface-bounded exosphere



~20% of the exoplanets discovered to date are hot Jupiters



Hydrogen absorption detected around HD 209458b during transit



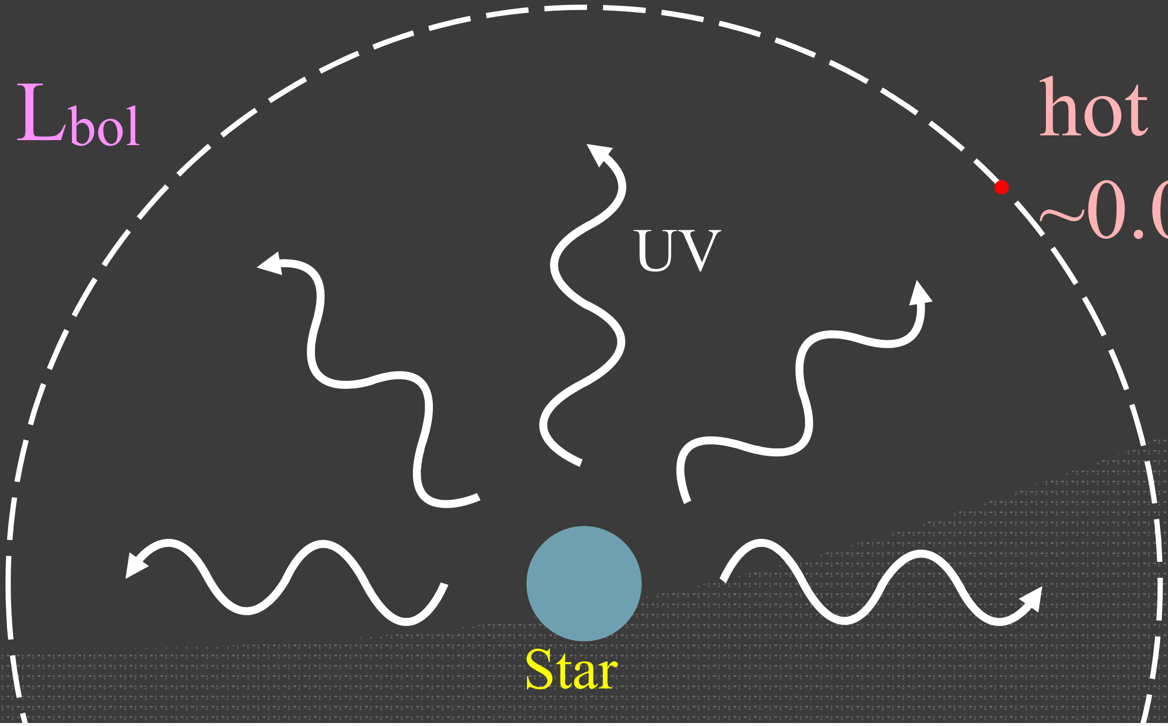
Vidal-Madjar et al. 2003

Do Hot Jupiters lose a significant fraction of their mass?

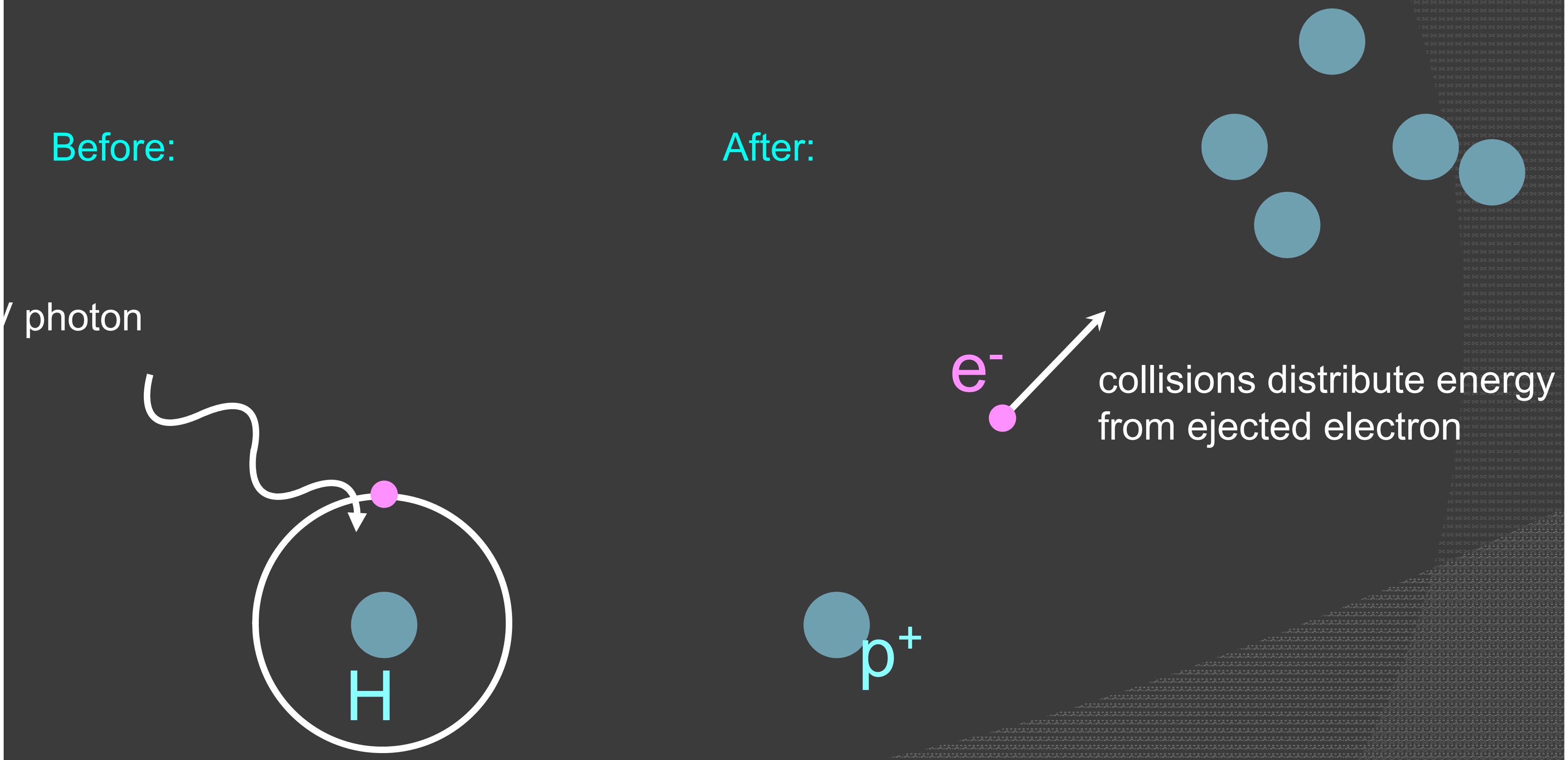
0.05 AU is an extreme environment

- hot Jupiters probably formed further out and migrated in
- once parked, they are bathed in UV radiation

$L_{UV} \sim 10^{-6} L_{bol}$



UV photons heat the atmosphere by photoionization



collisions distribute energy
from ejected electron

The energy-limited maximum mass-loss rate is large:

$M \sim 5\text{x}10^{12}$ g/s

This would mean a Jupiter mass planet at 0.05 AU evaporates *completely* in 5 Gyr

(Lammer et al. 2003; Baraffe et al. 2004, 2005;
Lecavelier des Etangs et al. 2004)

And observations show hot Jupiters are systematically less massive than other exoplanets *(Zucker & Mazeh 2002)*

But Hubbard et al. (2007) are unable to reproduce the mass distribution of hot Jupiters using mass-loss theories

HD 209458b

- distance from host star: 7 million km
- T: 1000 K, host star 150 Lj, solar like
- HD 209458 b: revolution period 3.5 d, 330 Earth masses
- transit every 3.5 days 3 hr duration, 1.5% of the star occulted
- first planet discovered with evaporating H, tail
  200 000 km extension; 10000 t/s evaporating
- HST observations: have observed HD 209458b passing in front of its parent star,
  - oxygen and carbon surrounding the planet in an extended ellipsoidal envelope
  - O is important for life..

Conclusion

- space weather effects
  - stronger for young stars G,K,M
  - stronger for K, and M
    - planets in HZ closer
    - activity amplitude more violent
- 10% of all stars are G type
  - Galaxy: 10 % of all stars in GHZ
  - 1 billion candidates remain…
- evaporating hot Jupiters