SPACE WEATHER ON EXTRASOLAR PLANETS

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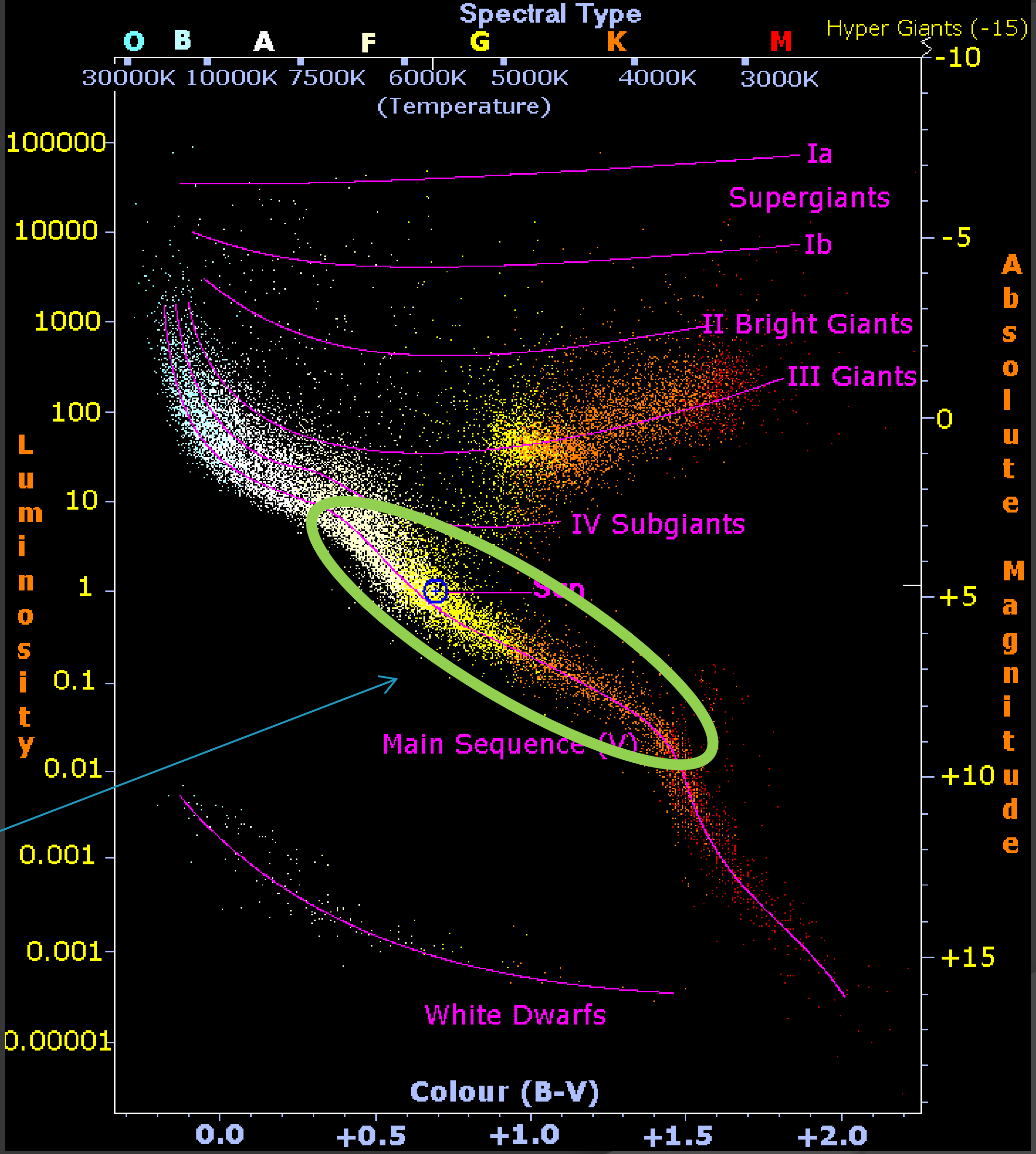
up to now:

more than 2500 exoplanets detected

Interesting for habitability



outline

- stars and habitable planets
- long term variability of stars → space climate
- Short term variability
  - Detection
  - Signs of planet response to Space Weather
- How does space weather affect on
  - Habitability
  - Planetary evolution

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}.

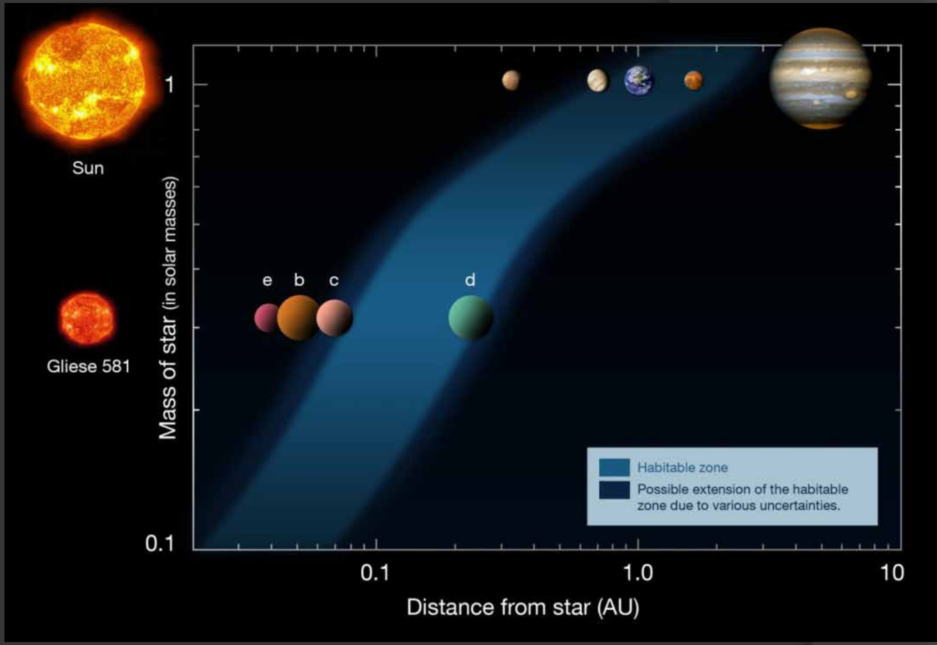
what makes a planet habitable

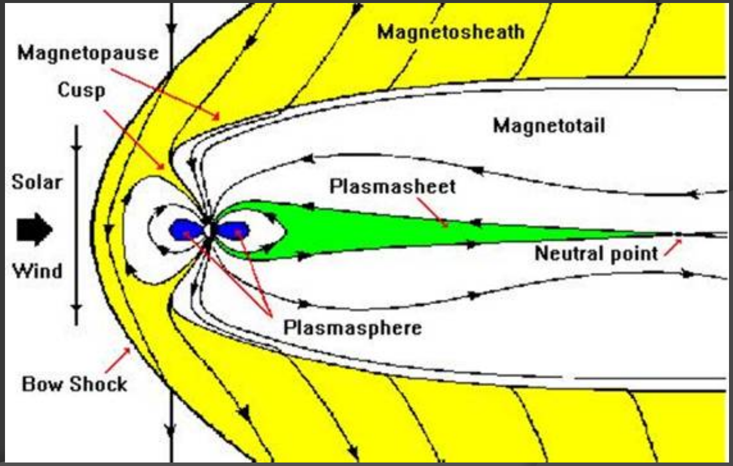
- different kinds of habitable zones HZ
  - circumstellar
  - galactic
  - circumplanetary
  - anything else?
- what is habitability
  - liquid water?
  - temperature range?
  - anything else?

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

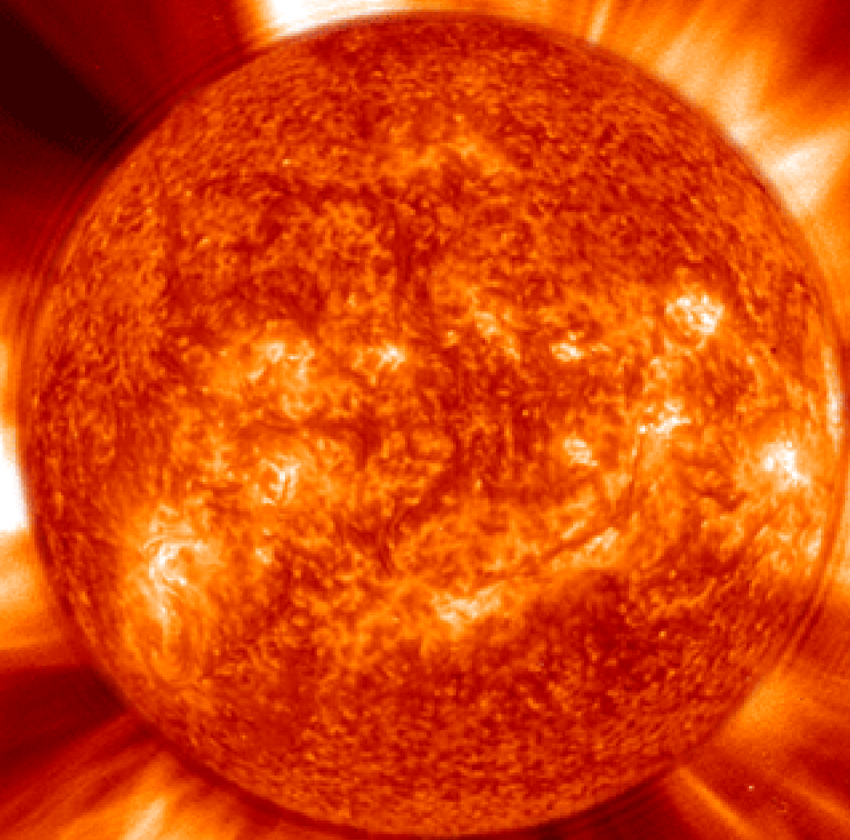
- stellar activity is determined by
  - rotation rate
  - convection zone → turbulence→stellar activity
  - rotation, convection etc. changes with stellar age and mass

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

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

The Young Sun: A summary of properties



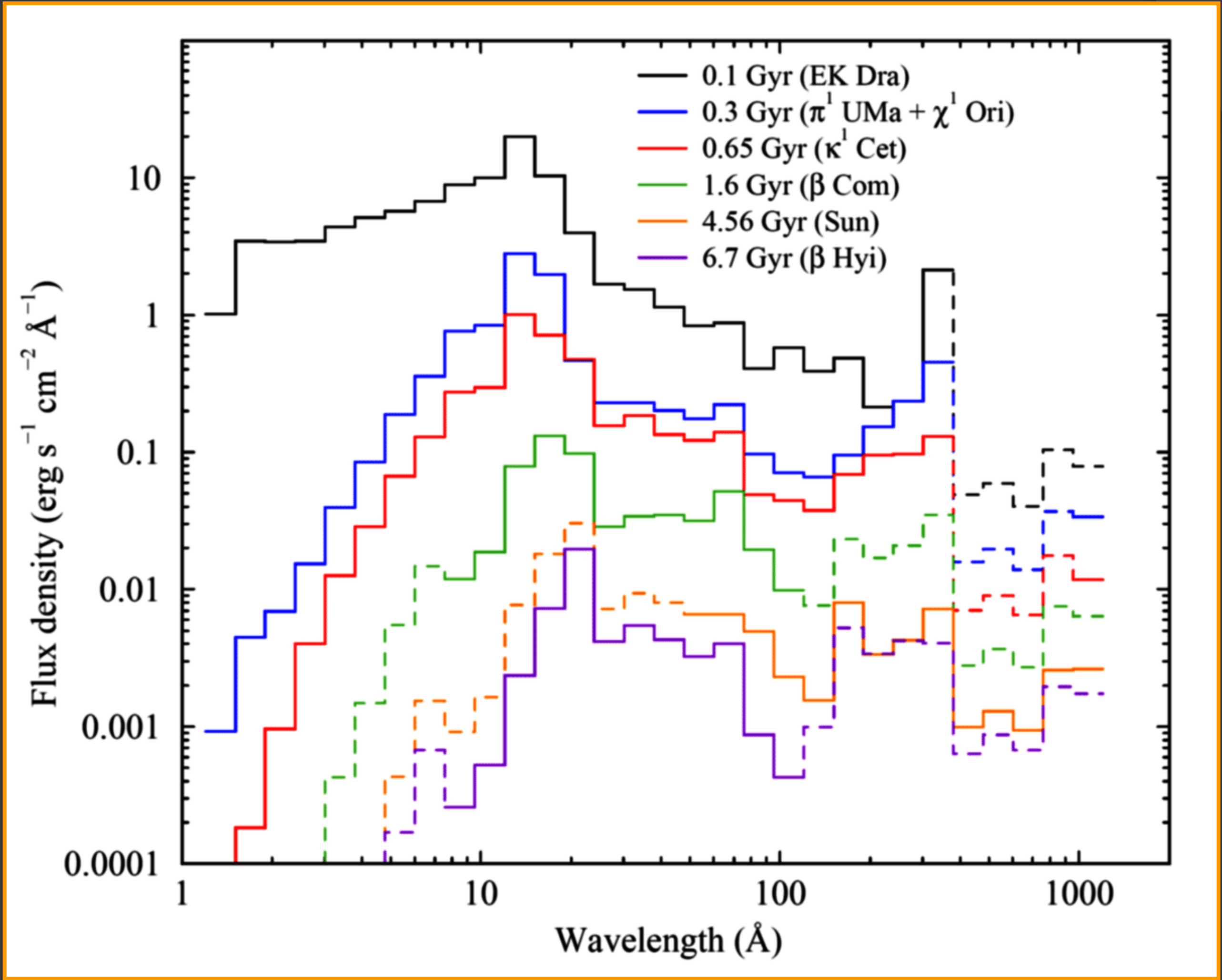
X-Ray, EUV: 100-1000x present values

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:

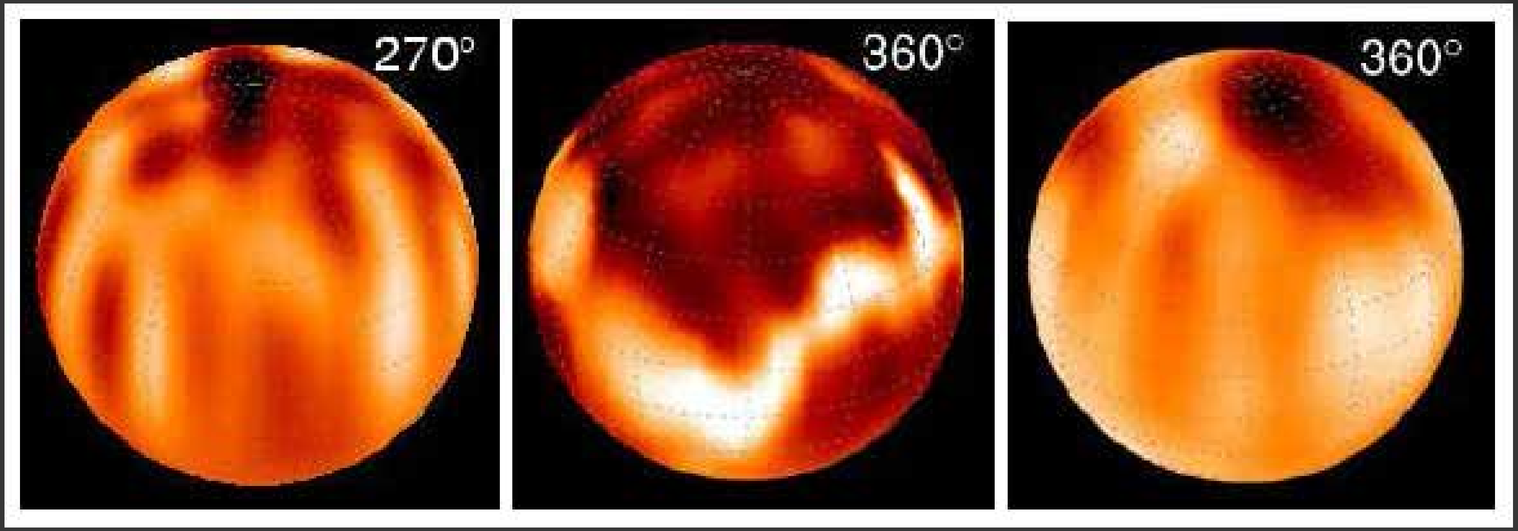
- **100-1000x in X-rays**
- **10-100x in the EUV-FUV**
- **5-10x in the UV**

Ribas et al. (2005, ApJ)

EK Draconis

Young solar analogue, dGe star
Double star 0.9 and 0.5 M
Rotation period 2.7 days ← period signal in radial vel variations

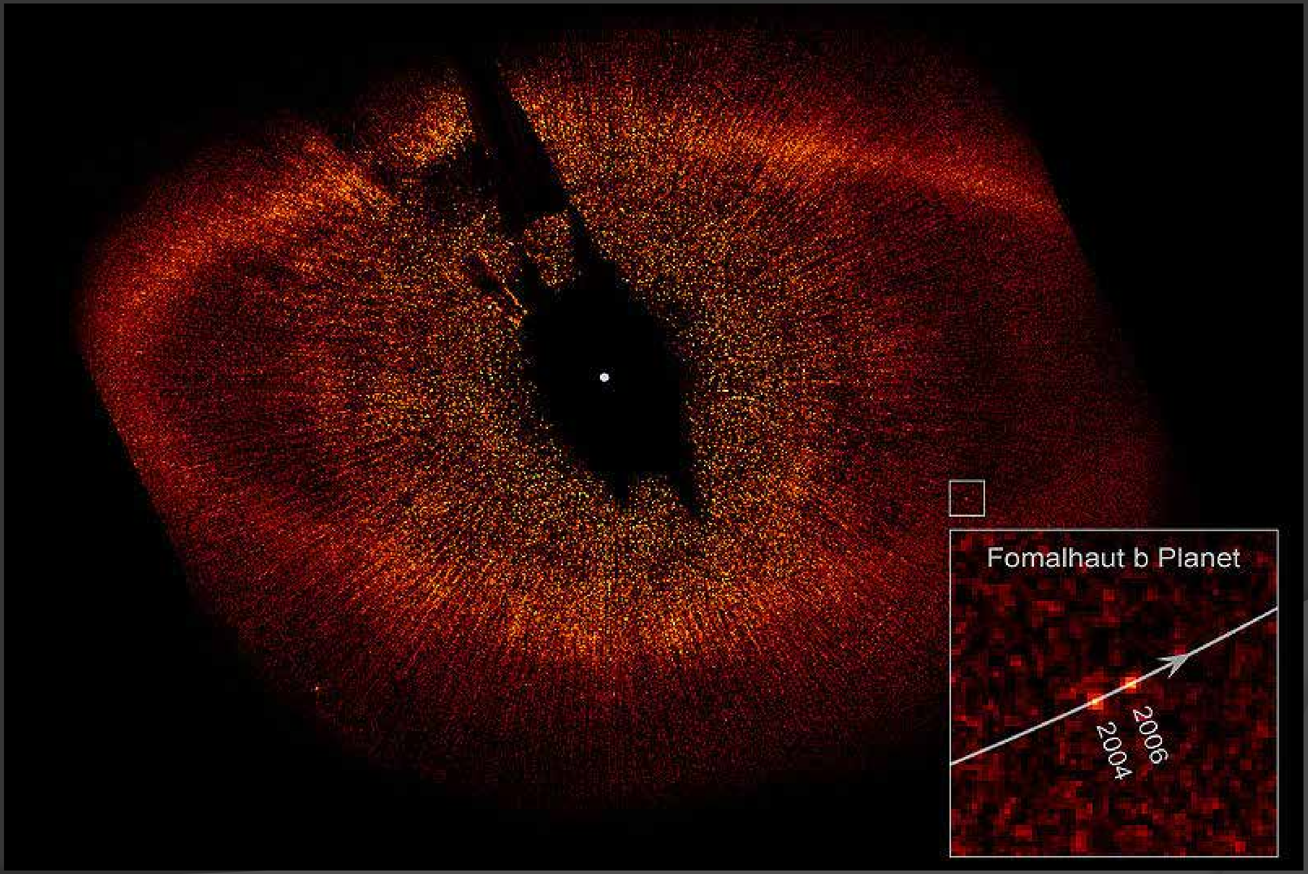
Lit.: König et al., 2005
Log N(Li) Lithium abundance → age only 30-50 Myr
Photosphere similar to sun, chromosphere different
Coupling between chromosphere photosphere
Small differential rotation from distribution of spots
(Järvinen et al. 2007)
Ayres 2010: warm coronal rain from Si IV (140 nm) observations;
two flares with extremely broad profiles observed with HST
Güdel: Observations in microwaves→ 2.7 d rotation period



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)

Pi 1 Uma
G1.5V b star;
IR excess → debris disk
P rot= 4.79 d

Debris disk around Fomalhaut (A3V)
Coronogragph observations



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

- 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.

$$F_X = (3 \pm 1)10^{28} t_9^{-1.5 \pm 0.3}$$

how to detect stellar winds

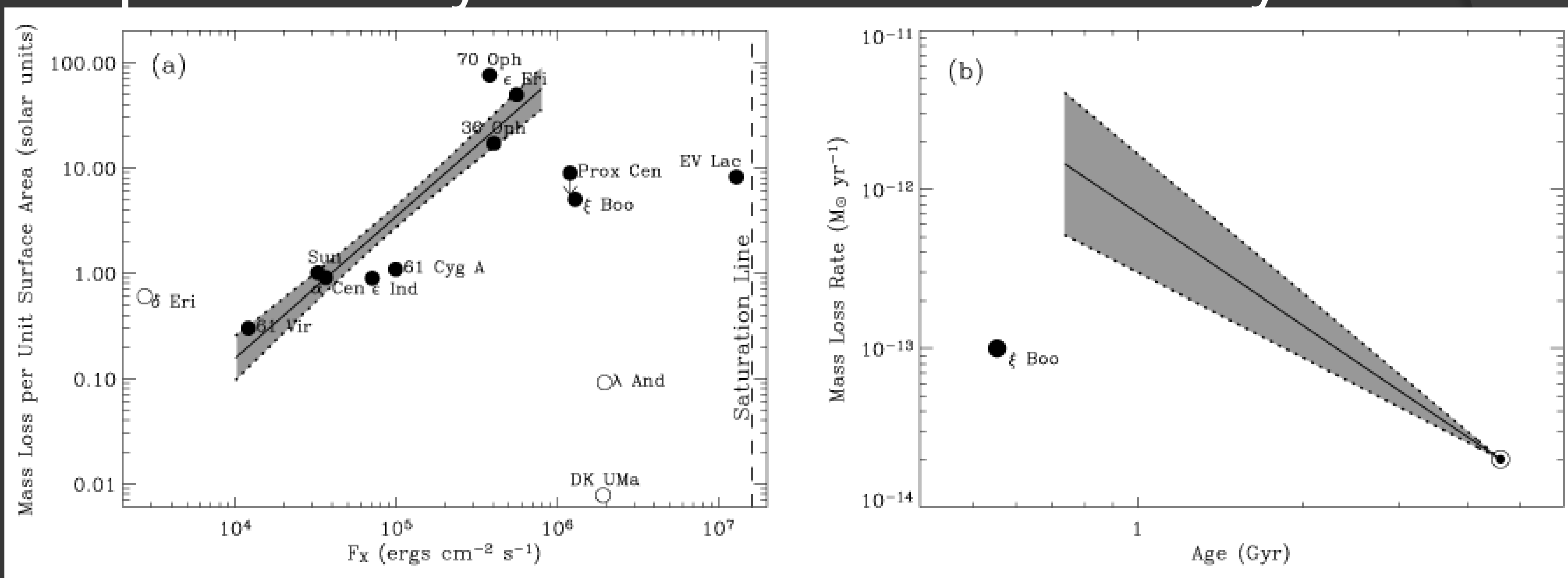
-
- indirect evidence of stellar wind
  - spin down of rotation rates
  - wind carries away angular momentum from star

- 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

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

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

- 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.

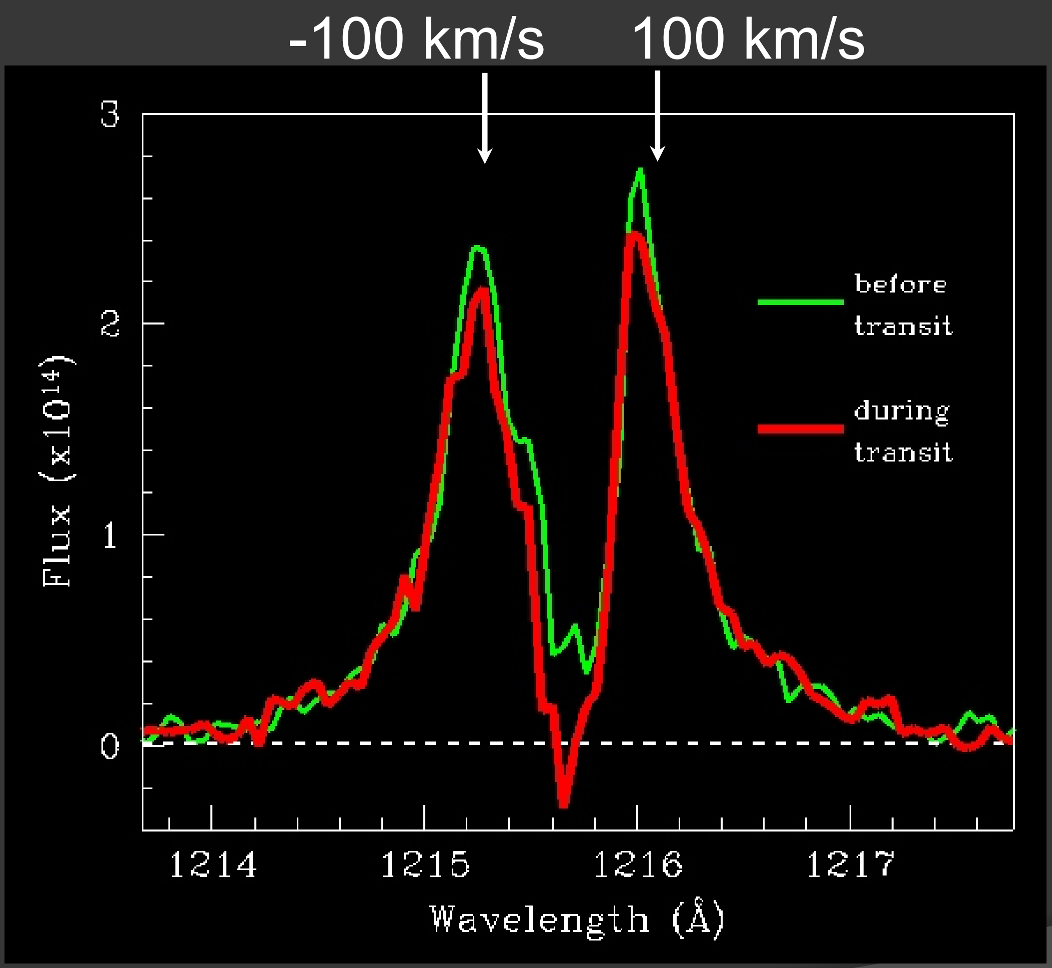
Problem of close planets

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

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.

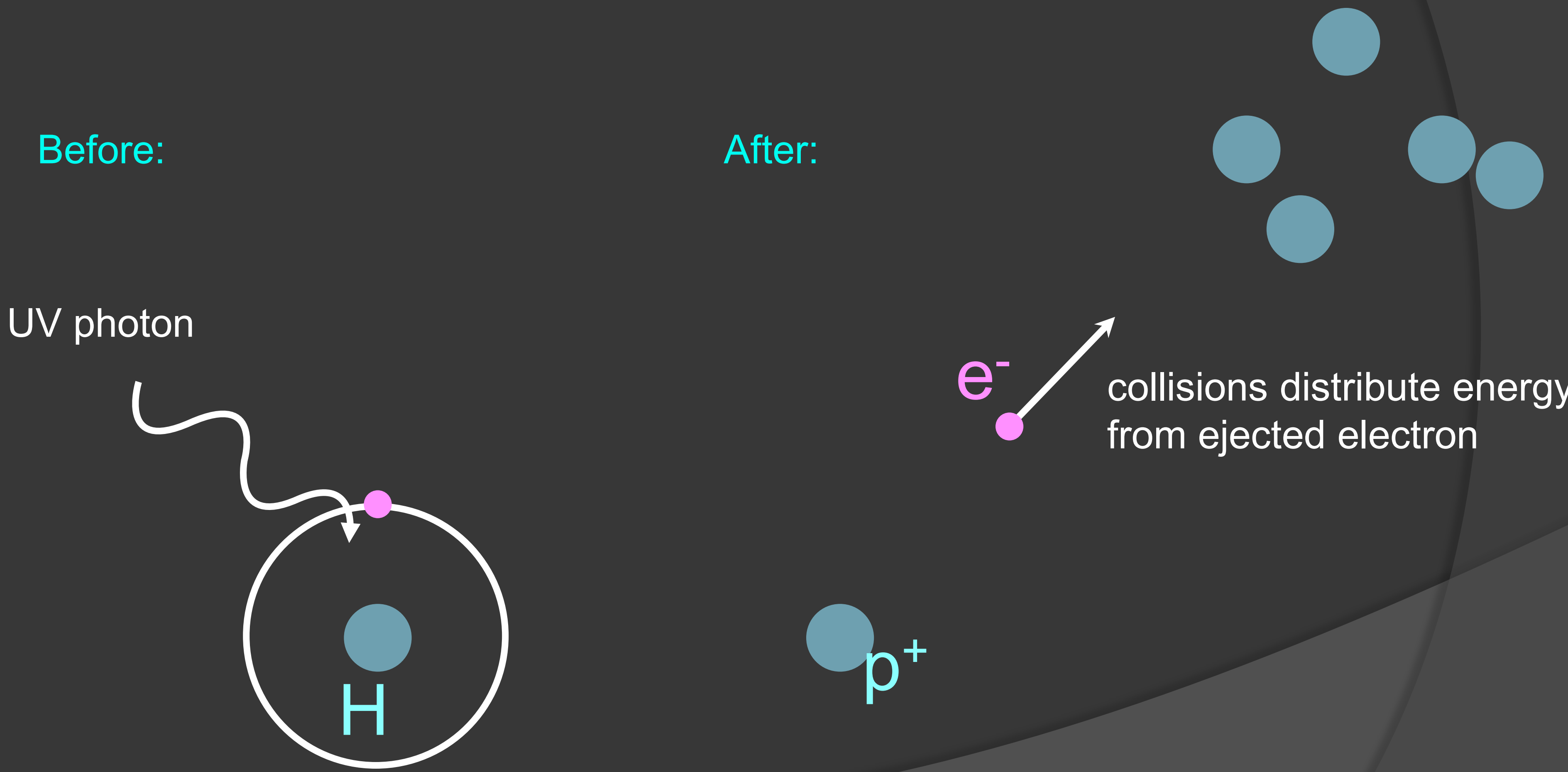
Hydrogen absorption detected around HD 209458b during transit



Vidal-Madjar et al. 2003

Do Hot Jupiters lose a significant fraction of their mass?

UV photons heat the atmosphere by photoionization



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

$\dot{M} \sim 5 \times 10^{12}$ 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