Stellar-Solar Acivity: How does it evolve?

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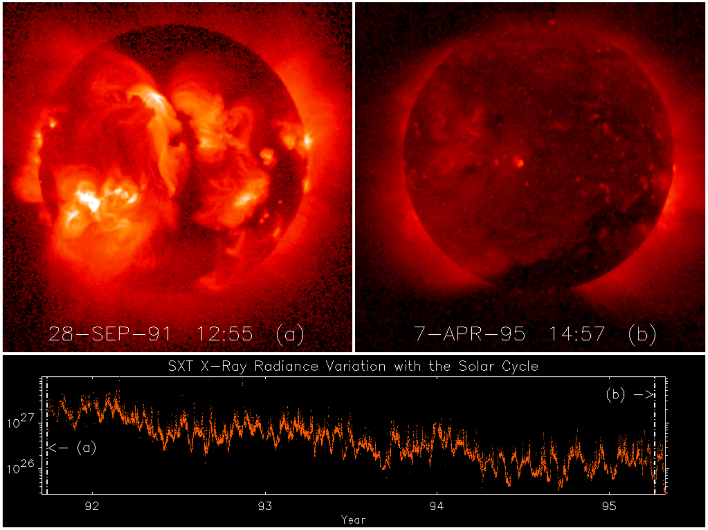
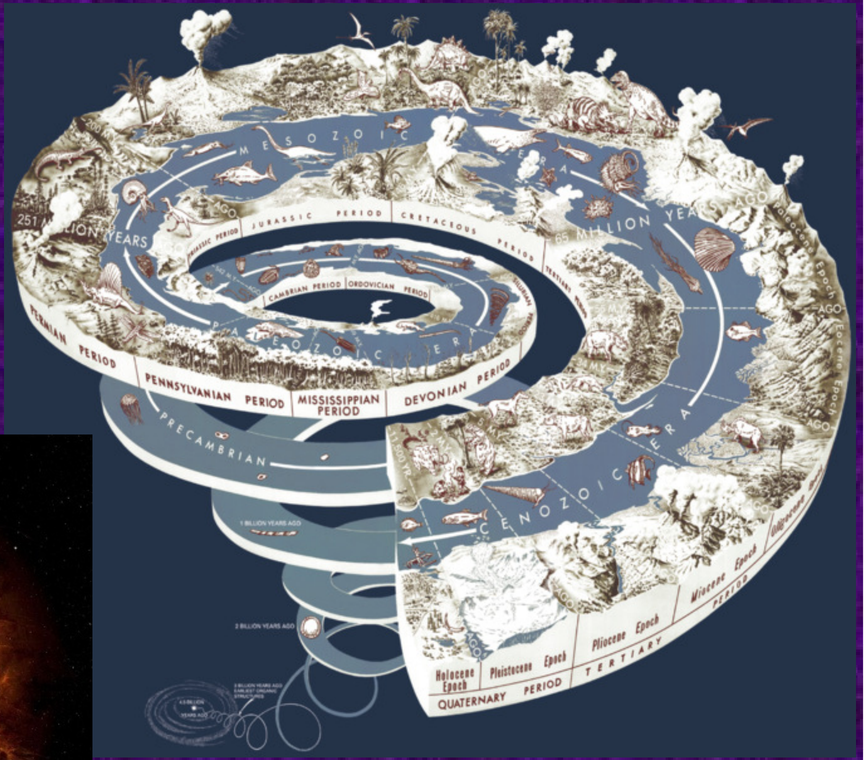




Bulgaria, June 2018

SCOSTEP -- Variability of the Sun and Its Terrestrial Impact (VarSITI) --- Project Solar Evolution and Extrema

- *Several observational projects fulfilled during past 25 years allow us to trace changes of activity of sun-like stars throughout all stages of their lives from an epoch of star formation to an age, when the cycle becomes regular, and up to the present. We will consider distinctions between saturated regime of activity intrinsic to the youngest fast rotating low-mass stars and solar-type activity typical for older suns. We discuss frequencies of superflares on the Sun and other stars, and a role of local and large-scale magnetic fields in formation of flares. All these points are important for understanding space factors affecting on physical conditions on the Earth and its geo- and biosphere.*

- *I – Early evolution of the Sun: Solar interior structure: Luminosity, Radius and Convection Zone parameters vs the time in the first 20 Myr and up to now / Angular momentum evolution*
- *Rotation as a main factor of activity*
- *II – Stellar-solar activity and its evolution: stellar ages, saturated activity regime, The Sun-in-Time*
- *The "chromosphere – corona" diagram*
- *The activity of the young Sun in the photosphere, the chromosphere and the corona*

III – solar-type activity, including cycles (Stellar activity and stellar cycles)

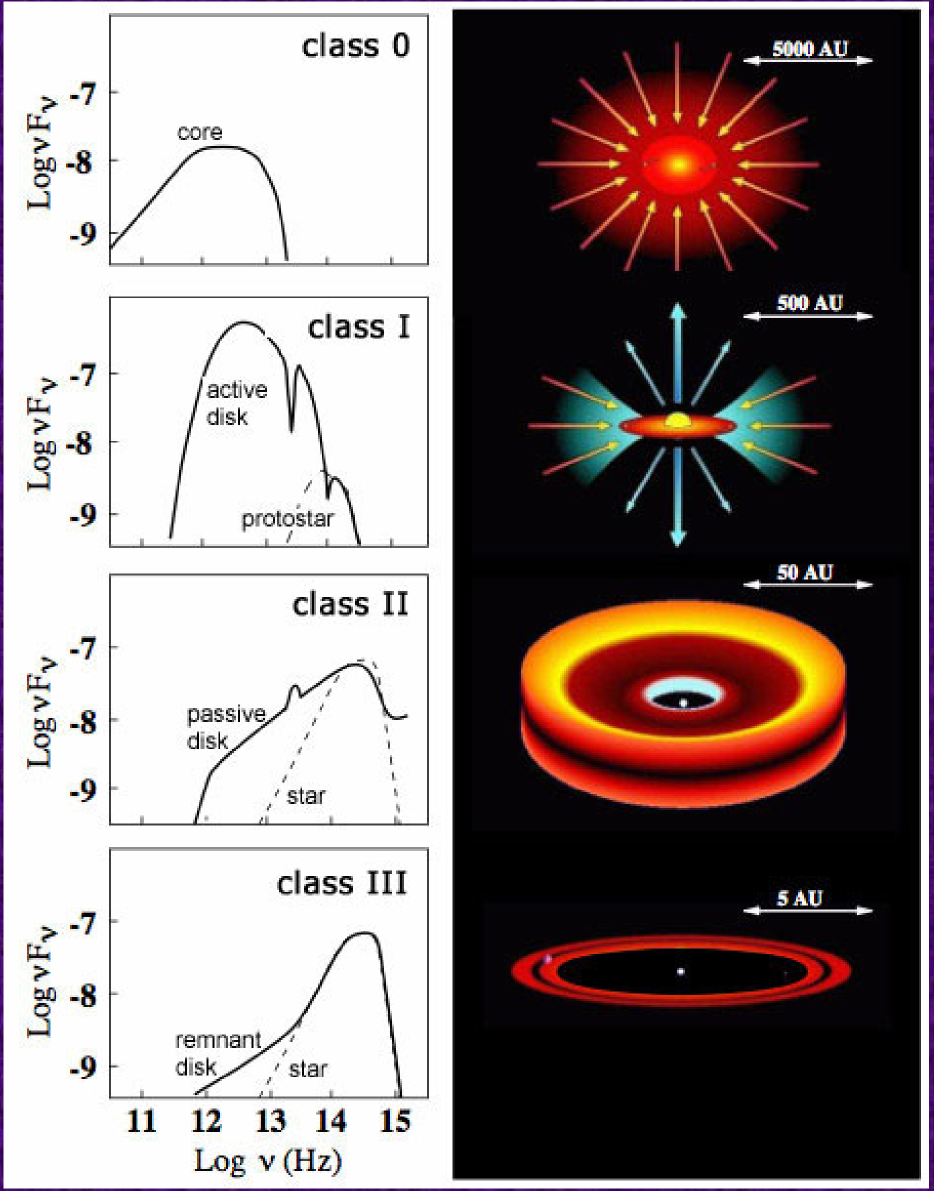
- *Quasi-stationary mass loss (wind) and contribution by CME's*

Non-stationary processes: flares :

impulsive and long-duration events on G, K and M dwarf stars

Conclusions

Early Stages of Formation of Solar-Mass Stars:



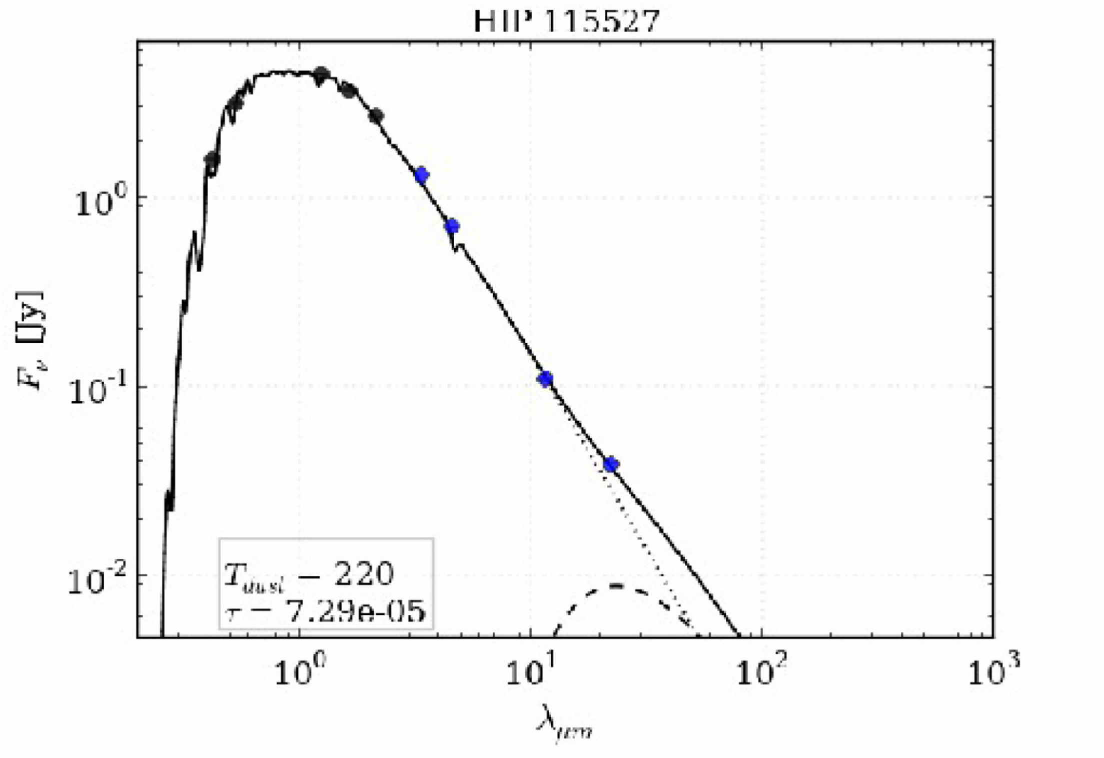
10 000 yr submm protostar

100 000 yr IR protostar

1 000 000 yr T Tau (CTTS)

10 000 000 yr T Tau (WTTS)

Radiation Flux of a Star in the Epoch of Planet Formation



Remnants of the dust cloud are seen as an excess in IR

HD 220476 = NX Aqr = HIP 115527 (G5 V)

P_rot = 7 day, log L_x/L_bol= - 4.2,

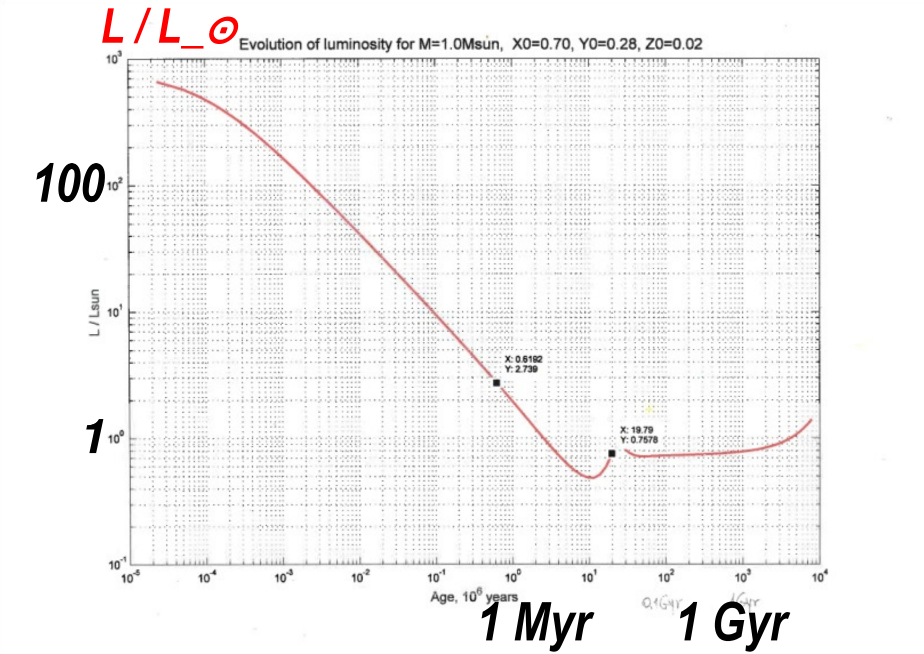
Dust T = 220 K, opt depth 0.00007

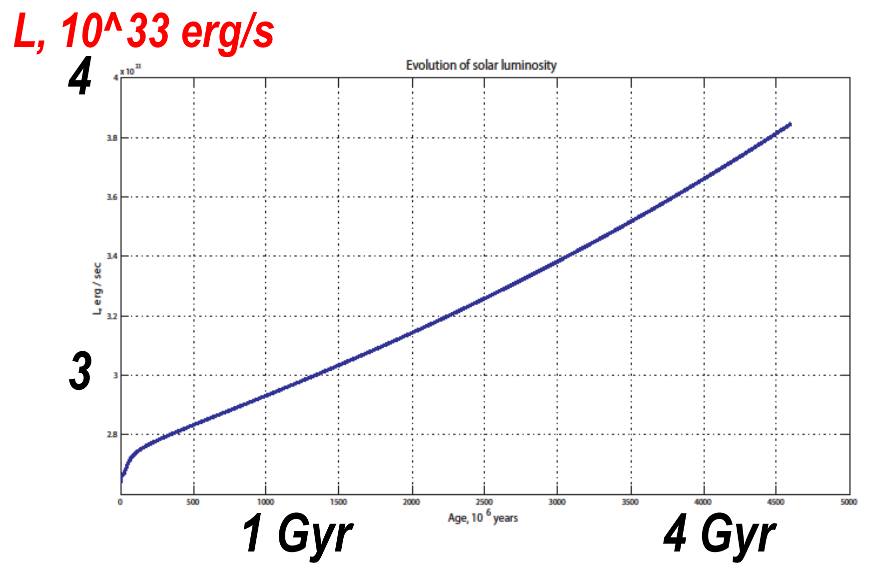
Flux in Jn, Lambda in mkm

Ribas et al. (2013)

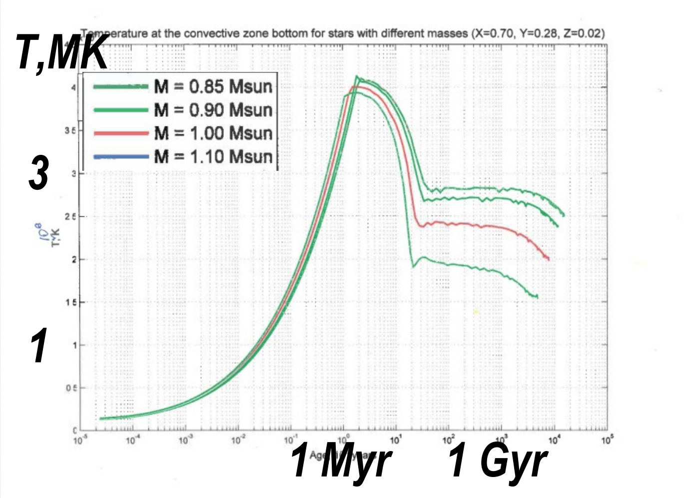
Early Evolution of the Sun: Solar Interior Structure: Luminosity

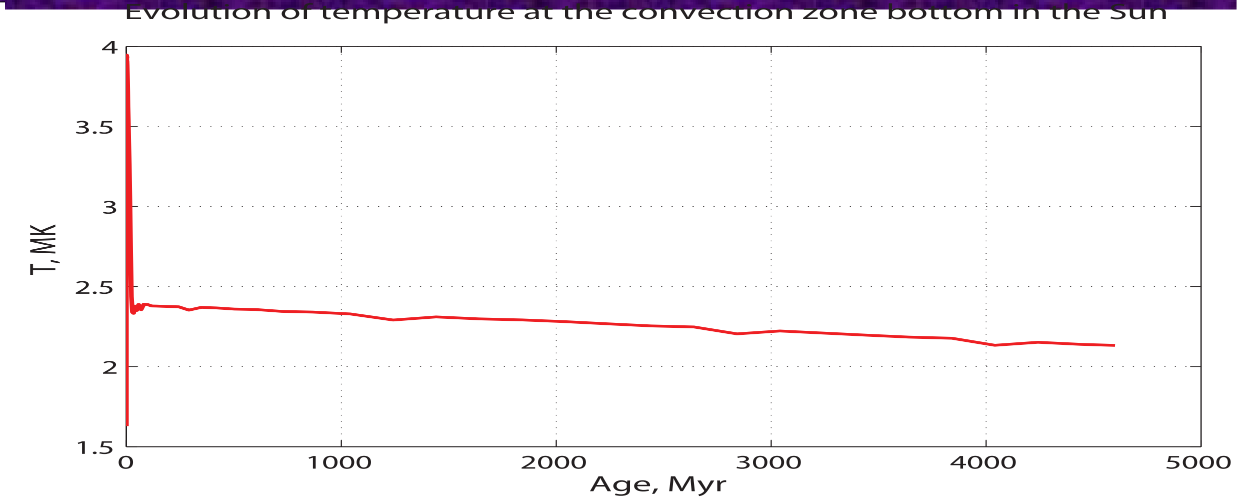
- *The physics of the solar interior*
- *The energetic balance of the standard solar model (SSM) results from equilibrium between nuclear energy production, energy transfer, and photospheric emission*
- *(V. Baturin, A. Oreshina, S. Ayukov, A. Gorshkov, 2017)*

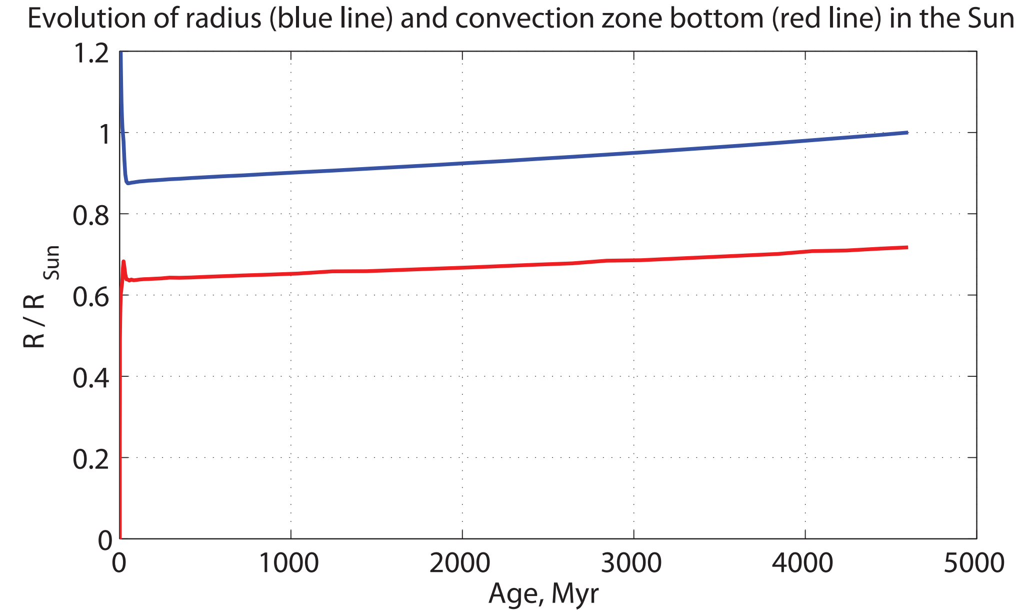




Solar Interior Structure: Radius and Convective Zone Parameters vs the Time in the First 20 Myr and up to now







Rotation as a Main Factor of Activity

The energy of axial rotation is sufficient to ensure the development of active processes. For the Sun, this is $W_{rot} = \frac{1}{2} I \omega^2 =$

$= 1/2 \times (0.25\, R_{\odot})^2\ M_{sun} \sim (2.9 \times 10^{-6})^2 \sim 2.5 \times 10^{42}$ erg.

This amount of the energy W_{rot} enough for maintenance the level of the soft X-ray radiation of the active Sun as much as 10^{27} erg/s

for $2.5 \times 10^{42} / 10^{27} \times 3 \times 10^7 \sim 10^8$ years

This suggests that the rotation is one of the sources, providing energy costs to maintain surface activity.

The missing part of the energy that supports these processes during $\sim 10^9$ years, draws from the energy of convective motions, i.e. eventually, from a thermonuclear source in the center of the Sun (or other late-type stars).

Rotation of Stars in the Gravitational Contraction Epoch

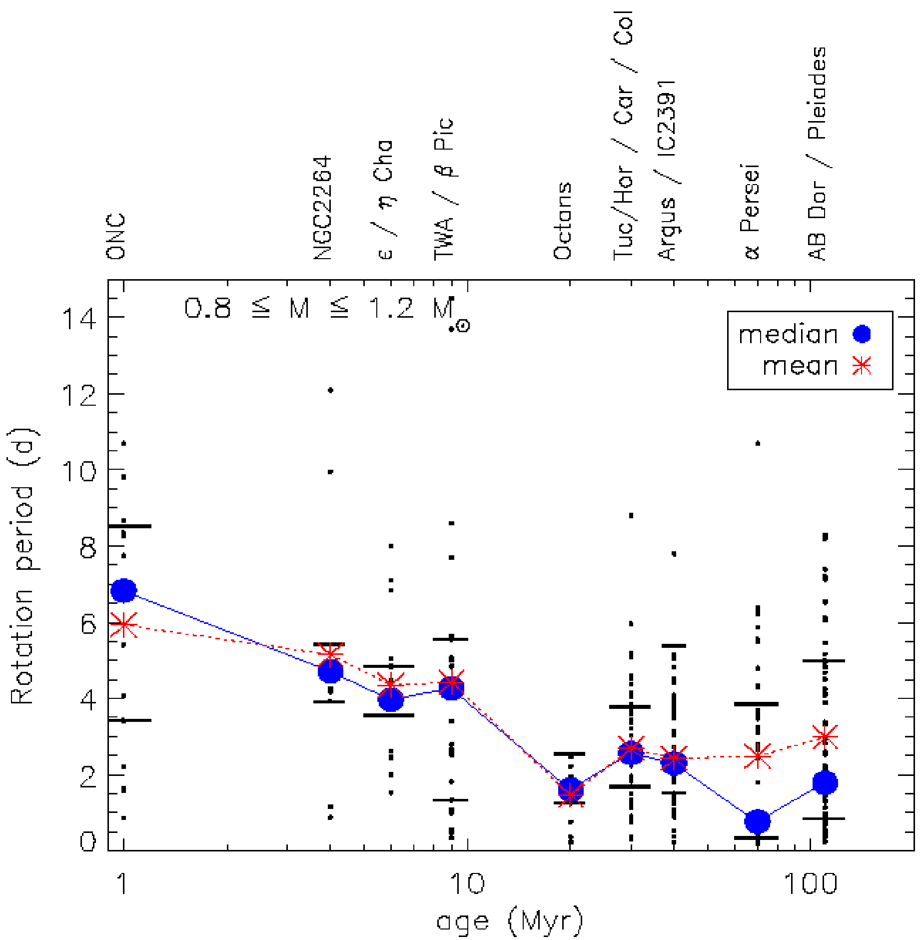
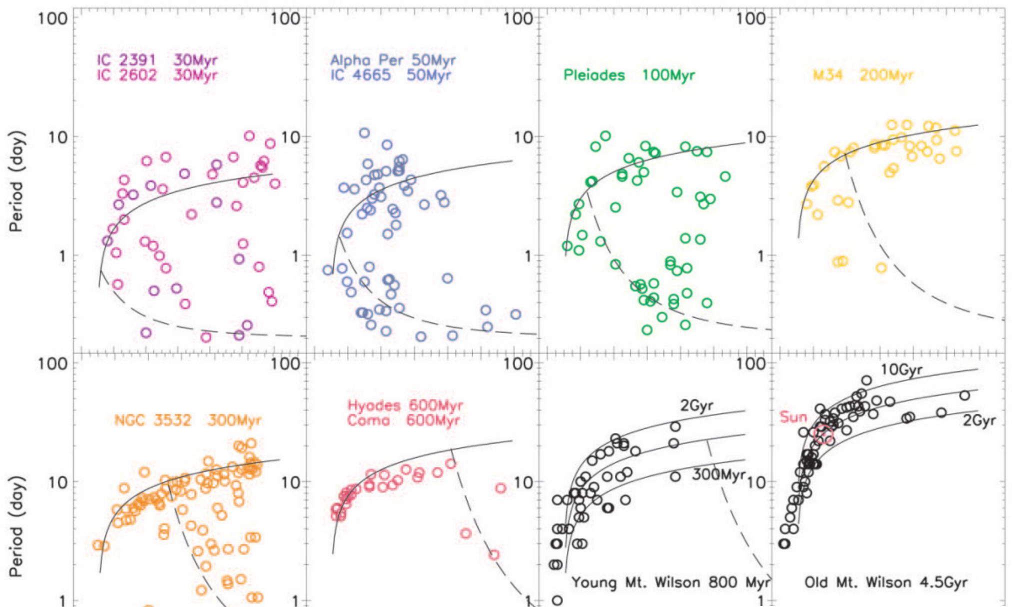


Fig. 7 Rotation period evolution versus time in the 0.8-1.2 solar mass range. Small dots represent individual rotation period measurements. Bullets connected by solid lines are median periods, whereas asterisks connected by dotted lines are mean periods. Short horizontal lines represent the 25th and 75th percentiles of rotation period. This plot updates the right panel of Fig. 12 of Paper I.

Rotation Period Evolution
vs Time
in the 0.8-1.2 M_⊙ range

Messina et al. , 2011
A & A, V. 532, *id.A10,*
45 pp

The Ages of Members of the Open Clusters and HK Project Stars



Open clusters contain both fast and slower rotators

A portion of fast rotating stars decreases versus the age of a cluster

Rotation period of main part of stars in the cluster increases with age

Kepler Cluster Study

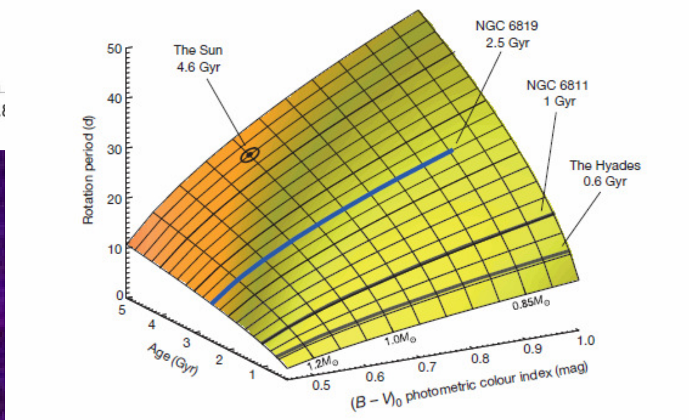
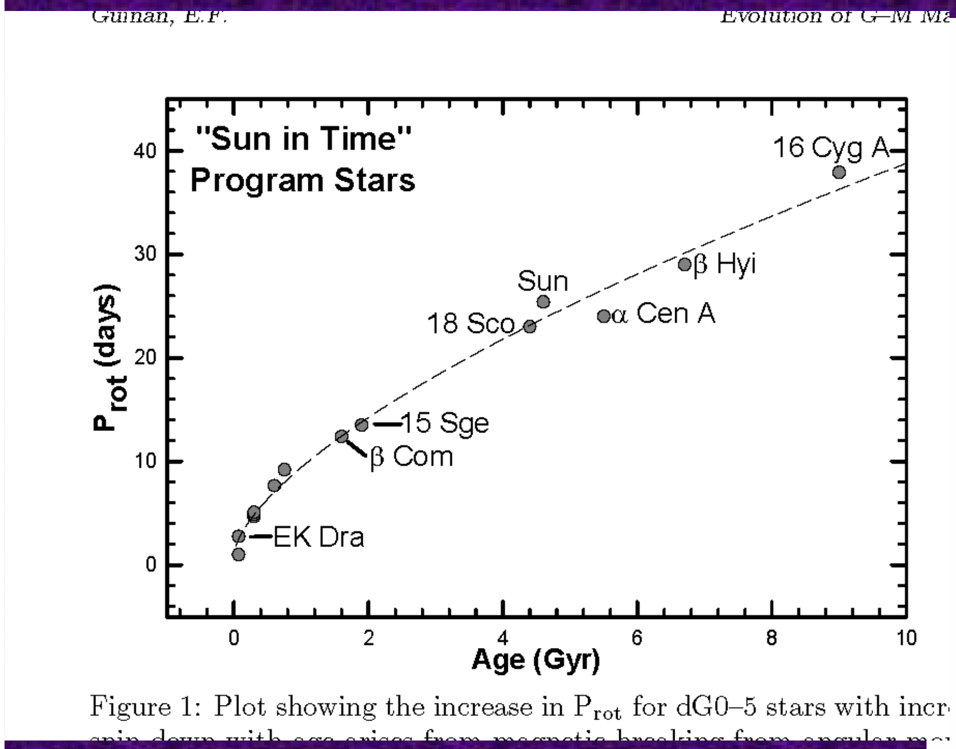


Figure 1 | The schematic P–t–M surface for cool stars. The hypothetical relationship between rotation period, age and colour extrapolated (yellow) to greater ages from the colour–period relations in young clusters using a particular P–t relationship[5], and assuming that the Sun (marked by the black solar symbol; ⊙) resides on it. The blue line indicates the locus of stars in NGC 6819 for which we have determined rotation periods. The dark grey lines at ages of 0.6 and 1 Gyr represent prior observations in the Hyades[15] and NGC 6811[16] clusters, respectively. Stellar masses in solar units are marked on the surface at the corresponding colours. (Figure adapted from ref. 16.)

Gyrochronology:
Age from P_rot

D.Soderblom since 1981 ; S.A. Barnes 2003 ; S.Meibom et al. 2015

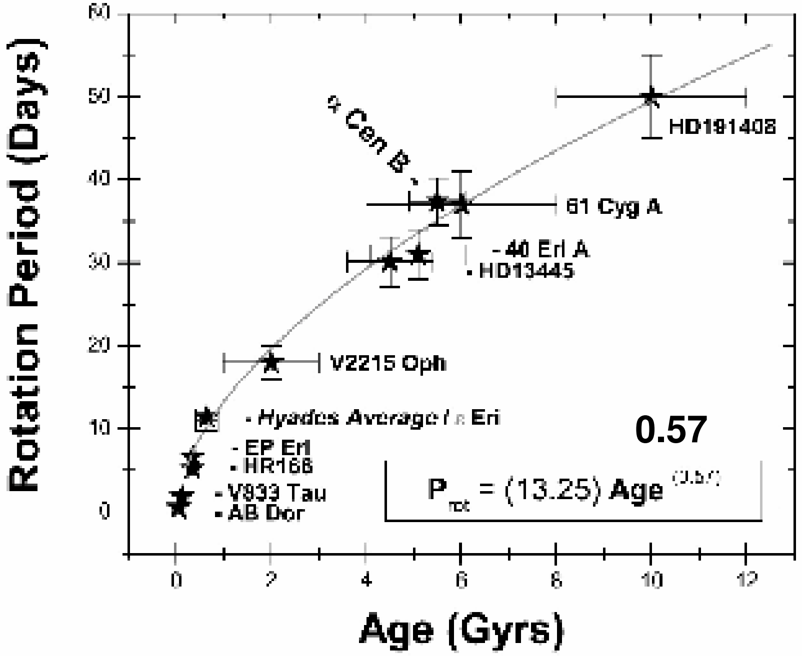
G-, K- and M- Stars in Time:
The Sun in Time, The Living with a Red Dwarf



Guinan, E.F.

Evolution of G–M Ma

Figure 1: Plot showing the increase in P_{rot} for dG0–5 stars with incr



M. Guedel, E. Guinan, S. Skinner 1997; M. Guedel 2004

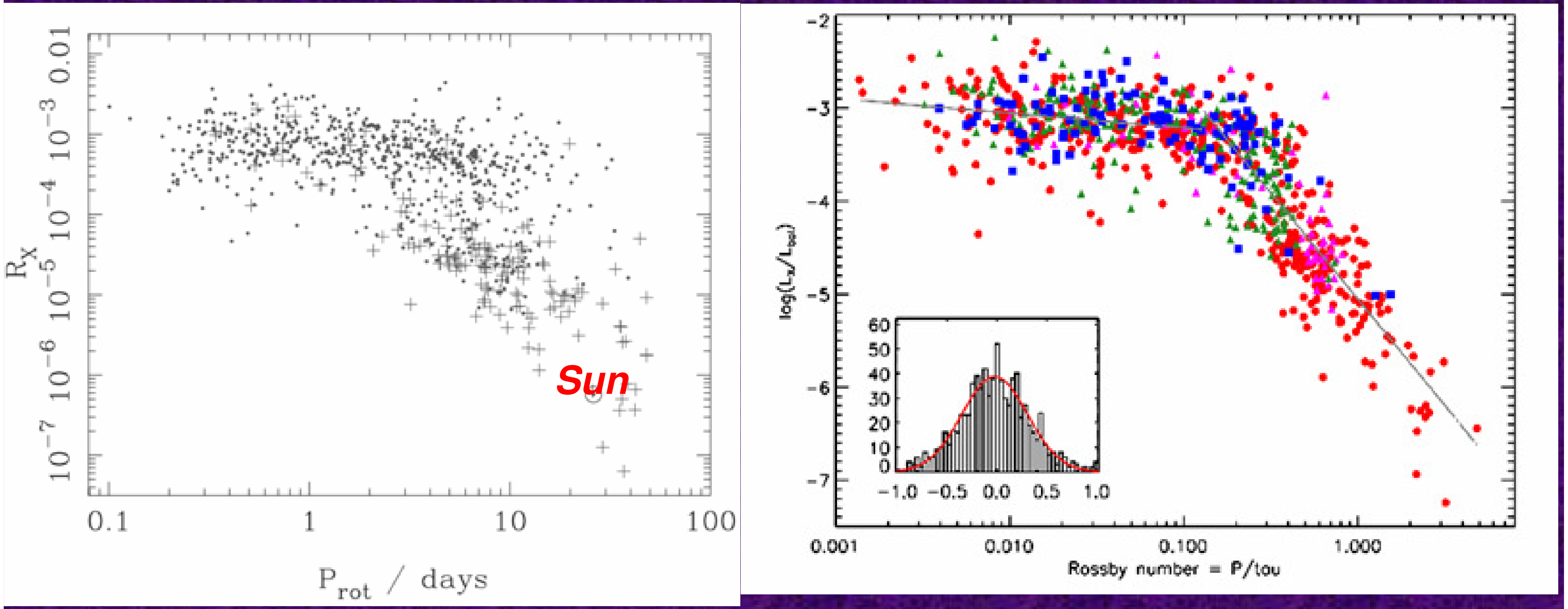
L.E. DeWarf, K.M. Datin, E.F. Guinan ApJ, 2010

"Rotation - Age" relationship changes weakly for various spectral types (or masses)

The X-ray Radiation of Late-type Stars

On Basic Factors Determining Features of Solar-type Activity

Rotation $Rx = \log (L_x / L_{bol})$ vs Rossby number, Ro



N. Wright et al. 2011 : 824 stars

Ro = P_rot /tau A.Reiners et al. 2014

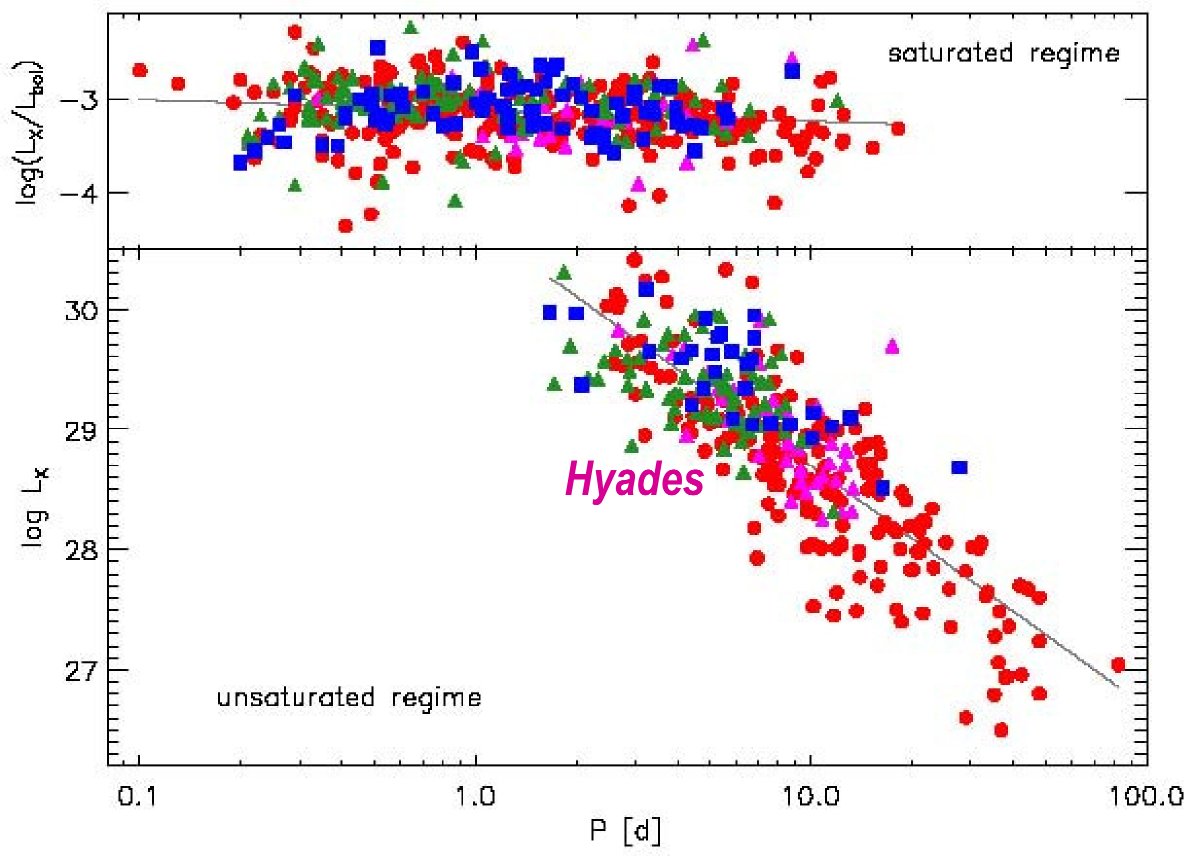
Blue squares: very young stars (up to 50 Myr);

green triangles: young stars (between 85 and 150 Myr);

magenta triangles: intermediate age stars (600–700 Myr);

red circles: field stars

The X-ray Radiation of Late-type Stars: (cont) (Reiners et al. 2014)



The saturated regime of activity

$$P_{\rm sat}\,[{\rm d}] = 1.6\left(\frac{L_{\rm bol}}{L_\odot}\right)^{-1/2} =$$

Solar-type activity

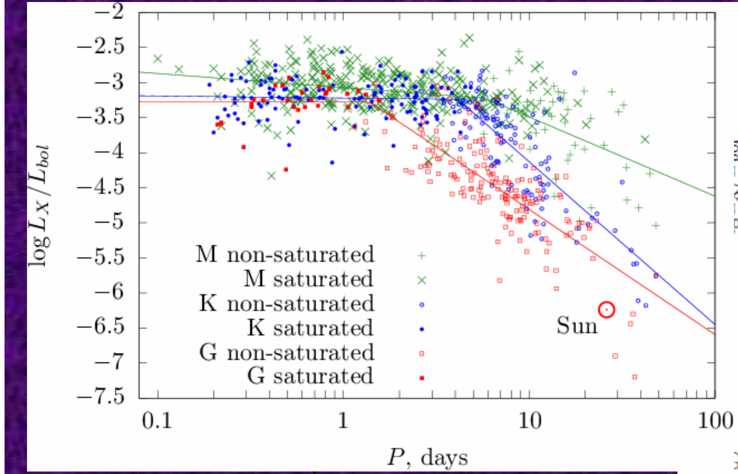
L_x ~ v^2

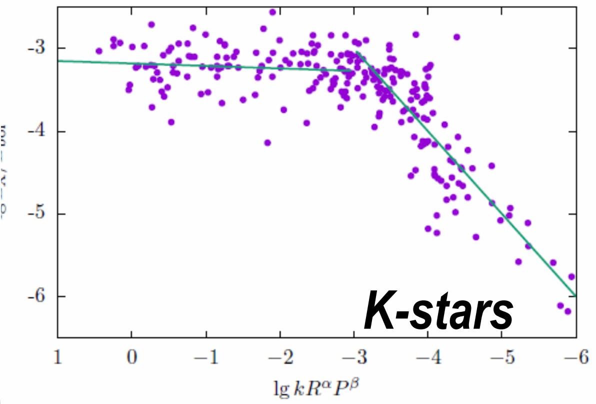
Pallavicini 1981

$$\log L_{\rm X} = (30.71 \pm 0.05) - (2.01 \pm 0.05)\log P,$$

Blue squares: very young stars (up to 50 Myr);
green triangles: young stars (between 85 and 150 Myr);
magenta triangles: intermediate age stars (600–700 Myr);
red circles: field stars

Change in Activity Regime of Stellar Coronae





. 1: The coronal activity index vs. $\lg kR^\alpha P^\beta$ for K stars

Saturated regime changes to solar-type activity at different critical periods vs SpType

$$P_{\mathrm{sat\ G}} = 1.14\left(\frac{L_{\mathrm{bol}}}{L_\odot}\right)^{-0.61},$$

$$P_{\mathrm{sat\ K}} = 1.88\left(\frac{L_{\mathrm{bol}}}{L_\odot}\right)^{-0.36},$$

$$P_{\mathrm{sat\ M}} = 1.21\left(\frac{L_{\mathrm{bol}}}{L_\odot}\right)^{-0.47},$$

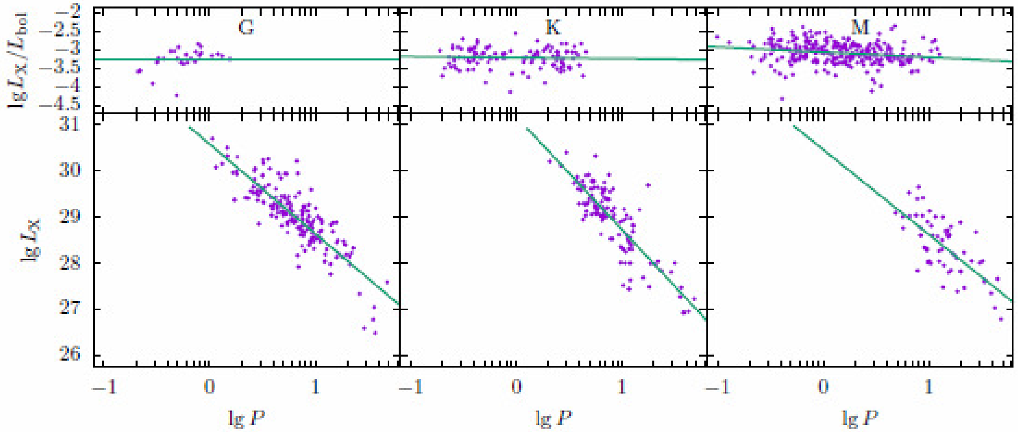


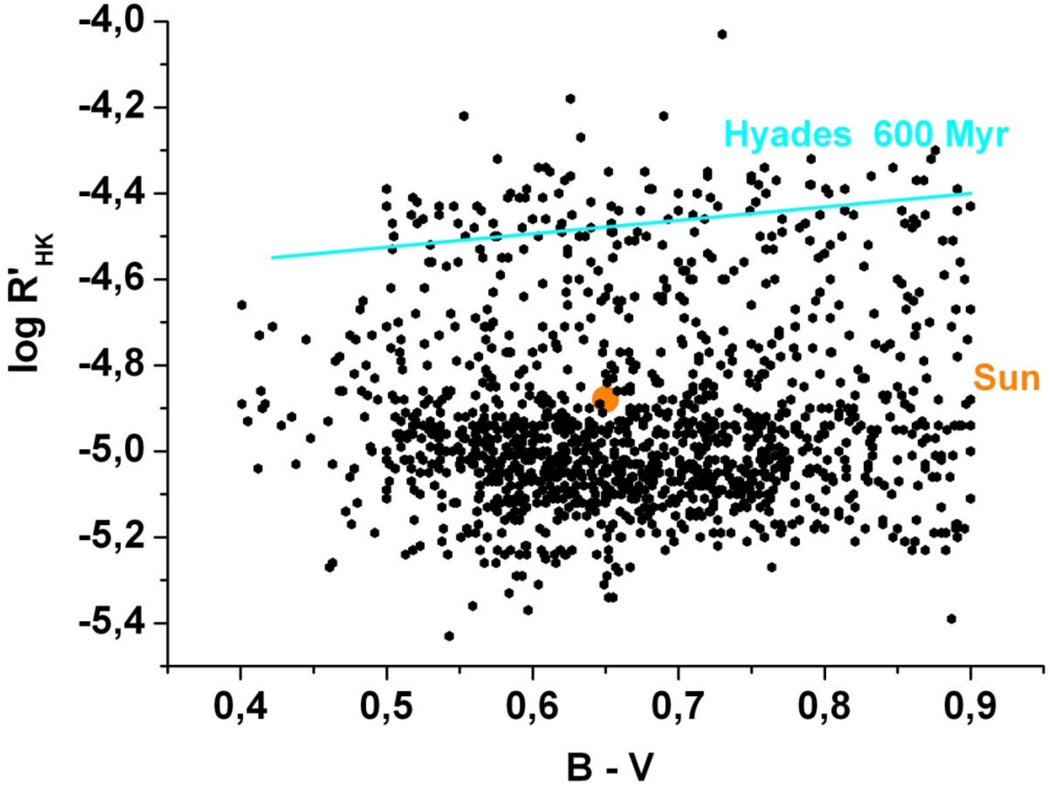
FIG. 2: Coronal activity index vs. logarithm of rotation period for the stars with the saturated activity (upper row) and X-ray luminosity vs. logarithm of rotation period for the stars with the solar-type activity (lower row). See the note on the upper left plot in the text.

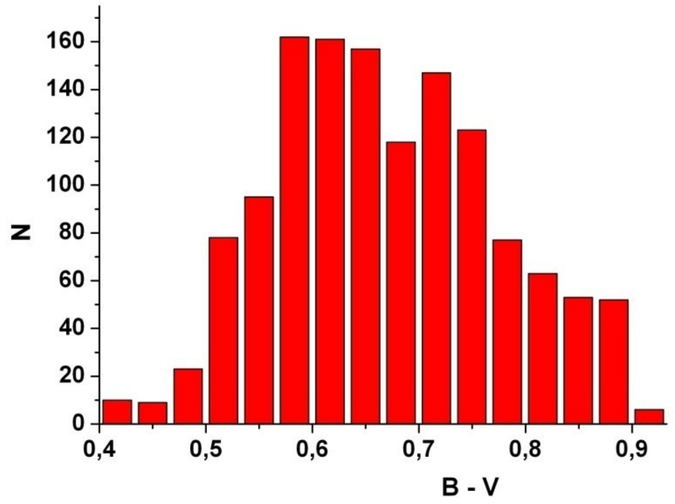
G2 V : P_rot = 1.1 d
K3 V : P_rot = 3.3 d
M4 V : P_rot = 7.2 d

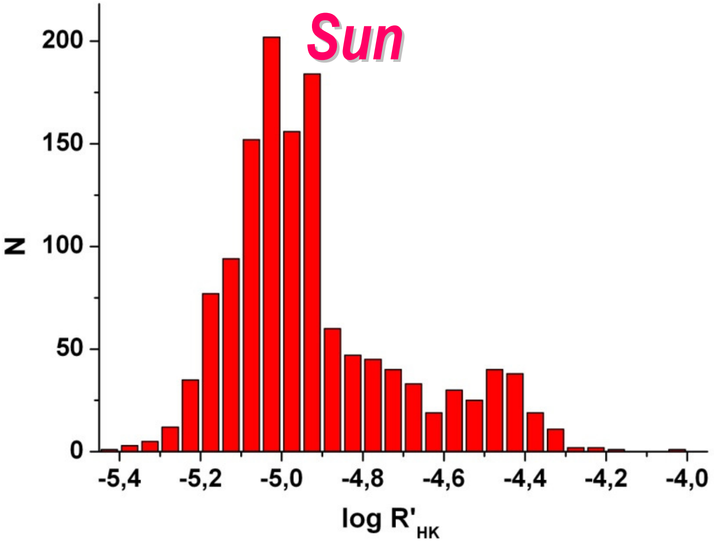
Nizamov, Katsova, Livshits, arXiv:1609.07989, Astron. Letters, 2017

Solar-type Activity of Low-mass Stars:

Chromospheric Activity of Northern and Southern Stars from California, Carnegie & Magellan Planet Search Programs



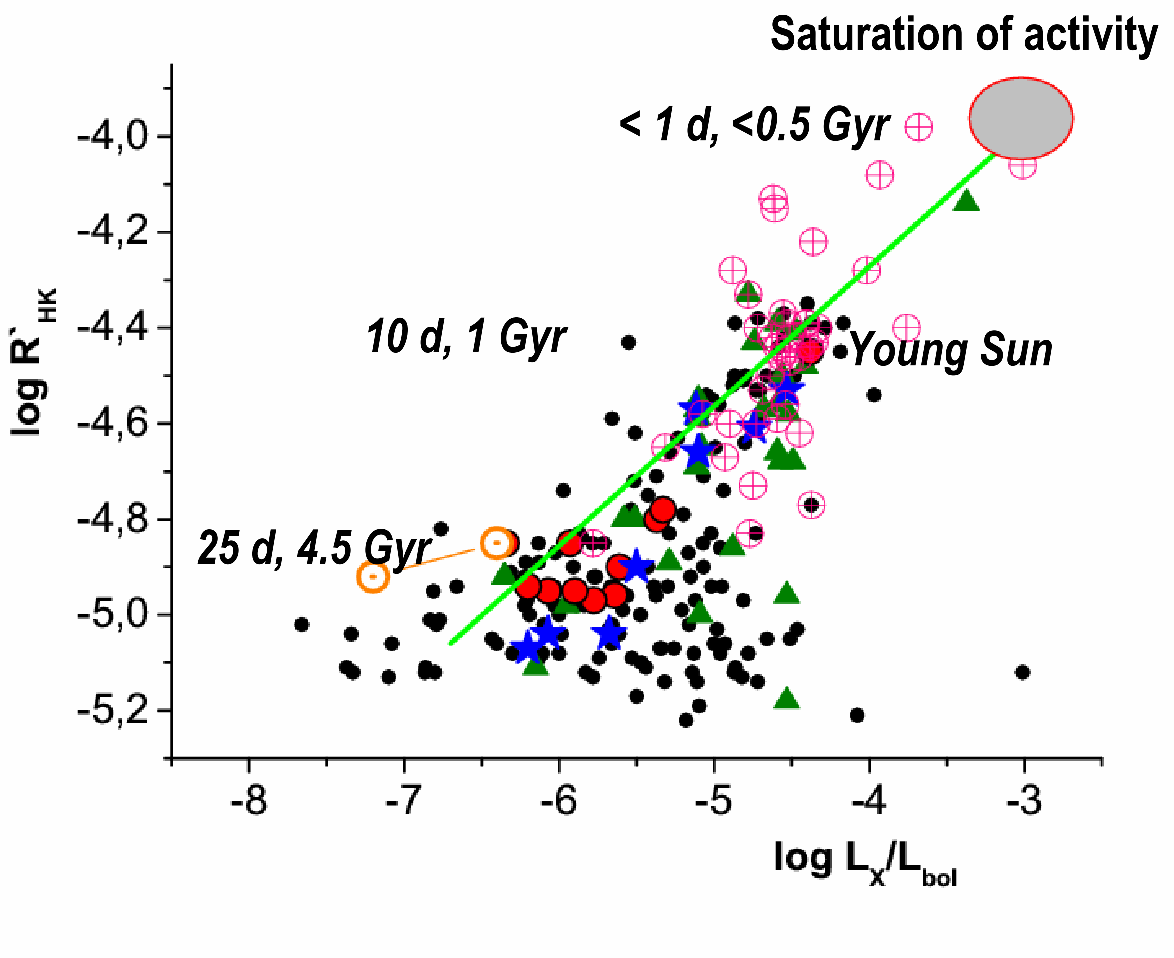




The Sun among other 1334 late-type stars

J. Wright et al. 2004; P. Arriagada ,2011

The Chromospheric and Coronal Activity of F, G, and K stars



⊕ Mishenina *Lithium*

▲ Montes

● Excellent

★ Good

⊙ Sun *max – min*

● *Planet Search Programs*

The term "Solar-type activity" implies formation of cycles

Possible paths of an evolution of solar-type activity

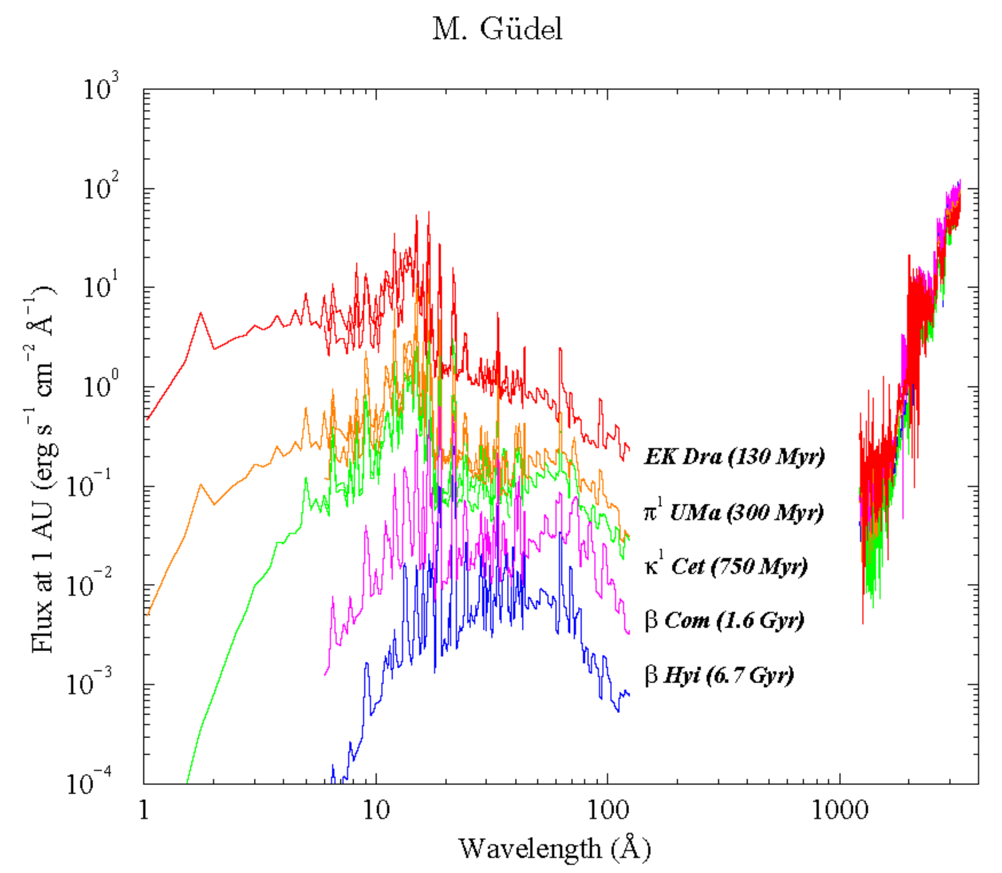
 # E. Mamajek & L. Hillenbrand, 2008 - One-parametric gyrochronology

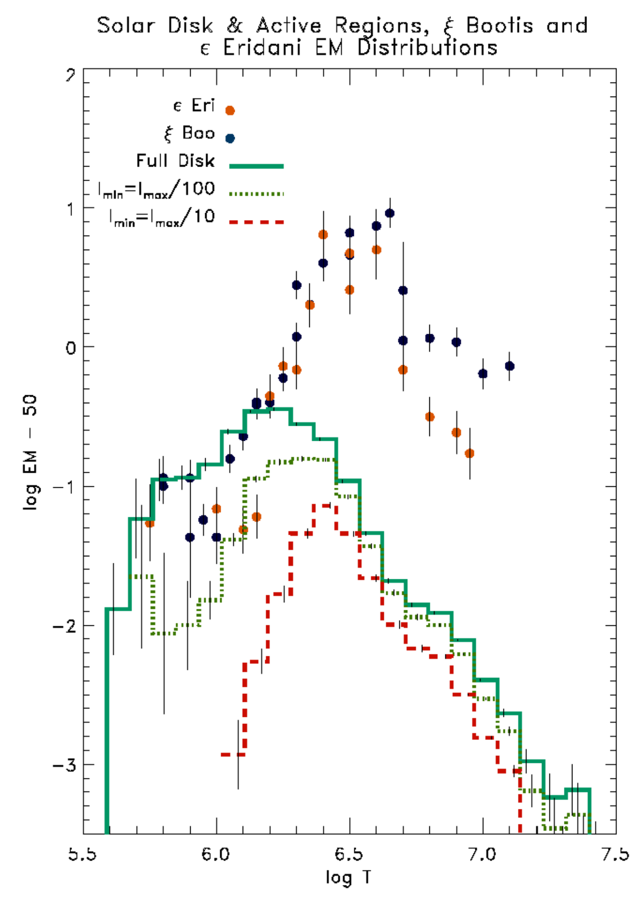
 # M. M. Katsova, M.A. Livshits, 2011 Astron Rep ; # M. Katsova, 2011 (JENAM-2011),

 # D. Montes, J. Maldonado, R. Martinez-Arnaiz et al. A & A , 2010, 2011

 # T. Mishenina, C. Soubiran, V. Kovtyukh, M. Katsova, M. Livshits, A & A , 547, A106, 2012

The Sun in Time: Stellar Coronae – EM, T

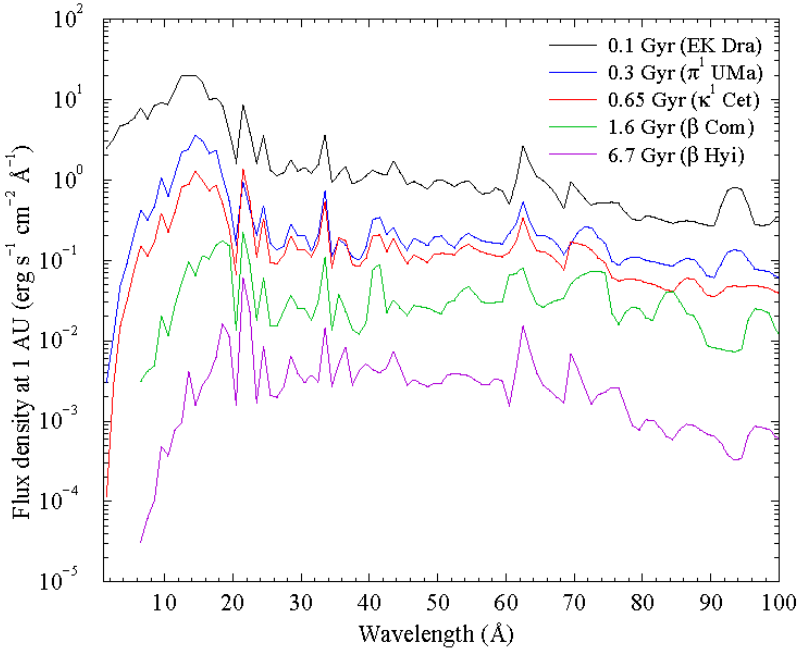




M. Güdel, IAU Symp. 264. 2009

M. Güdel. "X-ray astronomy of stellar coronae" Astron. Astrophys. Rev. 2004

X-Ray and VUV Radiation



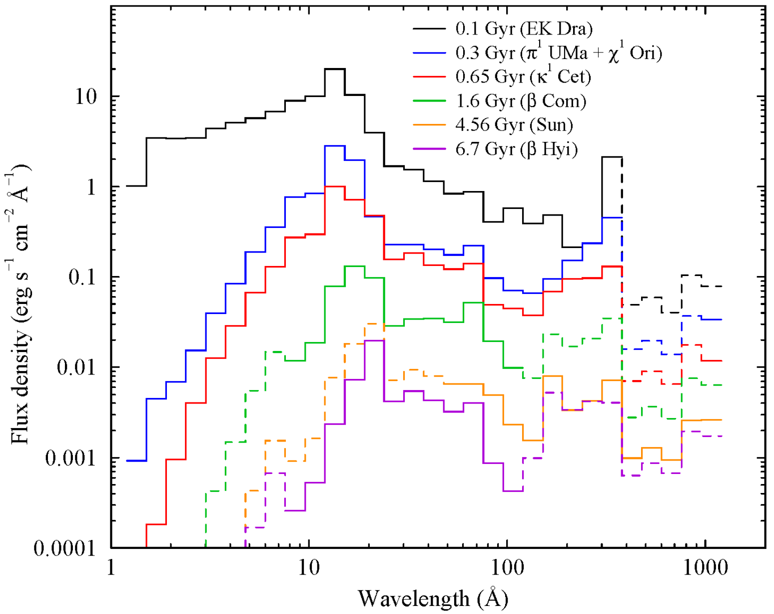
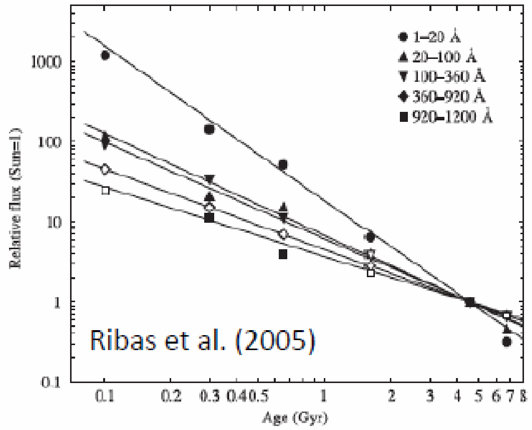


FIG. 7.— Full spectral energy distribution of the solar-type stars at different stages of the main sequence evolution. The solid lines represent measured fluxes while the dotted lines are fluxes calculated by interpolation using a power-law relationship.

"The Sun in Time"
(G stars from 0.1…7 Gyr)



Ribas et al. (2005)

I.RIBAS, E. F. GUINAN, M. GÜDEL, M. AUDARD, 2005

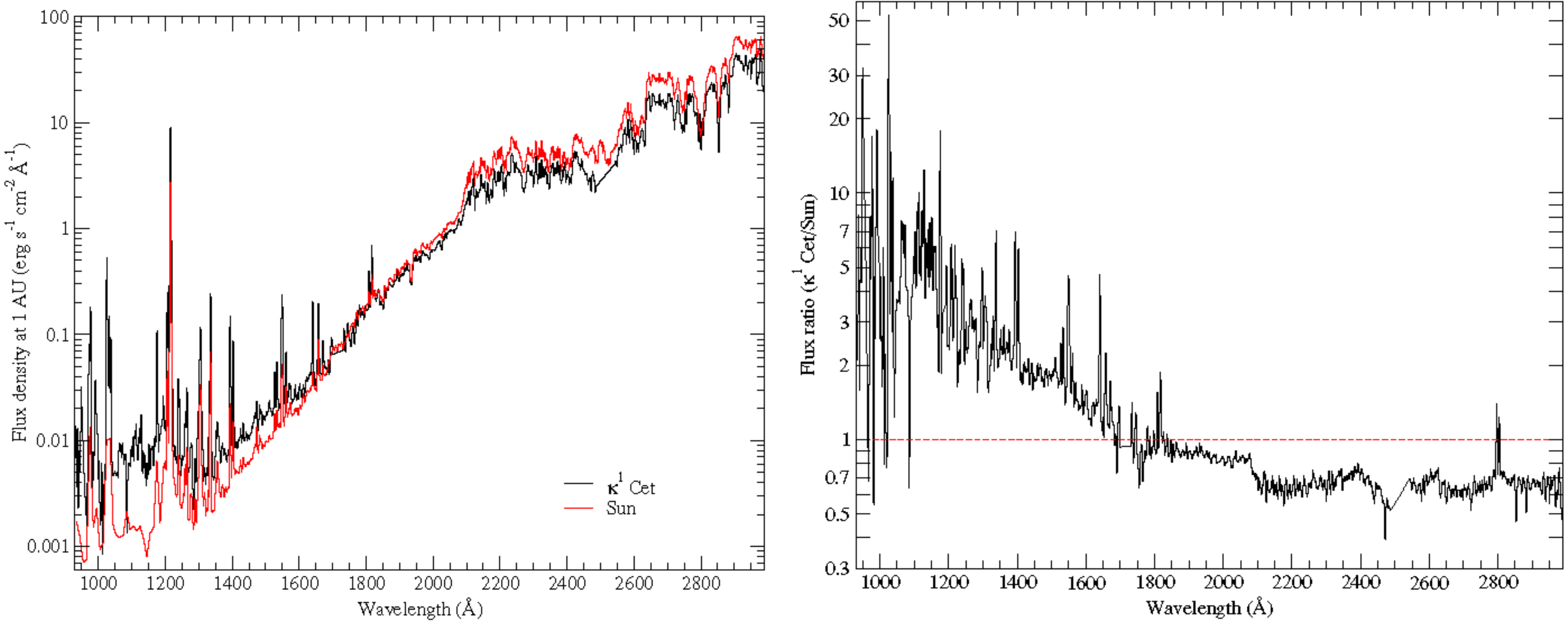
EVOLUTION OF THE SOLAR ACTIVITY OVER TIME AND EFFECTS ON PLANETARY ATMOSPHERES: I. HIGH-ENERGY IRRADIANCES (1–1700 A)

GALEX (Galaxy Evolution Explorer) Data

UV fluxes for 1360 stars NUV 1750 - 2750 A, FUV 1350 - 1750 A

F. Murgas et al. A & A, 2013

Kappa^1 Cet G5 V , P_rot = 9 d I. Ribas et al. 2010



10

3

1

Figure 7. Left: comparison of the observed UV spectra of κ^1 Cet and the current Sun. Right: ratio of the observed UV spectra of κ^1 Cet and the current Sun. (A color version of this figure is available in the online journal.)

For stars more active than the Sun, the FUV contrast is 2 times, for k^1 Cet and the younger stars – 6 times.

General Parameters of the Activity of the Young Sun

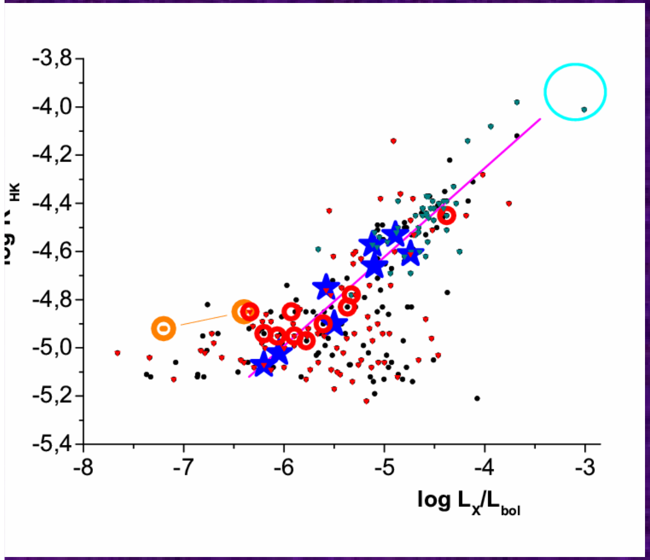
- « Sun-in-Time »: Hot coronae DEM(T) 5 – 8 MK
- Densities at the base of the corona 3 – 5 x 10^9 cм^{-3}
- Spots P_rot S, % L_x, erg/s R_x
- Act Sun (G2 V) 25 d 0.3 10^27 -7
- Young Sun 10 d 3 10^29 -4.4
- → Siblings of the Young Sun
- BE Cet G2 V 8 d 3 10^29 -4.4
- k^1 Cet G5 V 9d 10^29 -4.4
- iota Hor F8 V 8-8.5 d
- HD 220476 = NX Aqr G5 V 7 d
- → EK Dra G0 V 3 d 10–20 10^30 -3

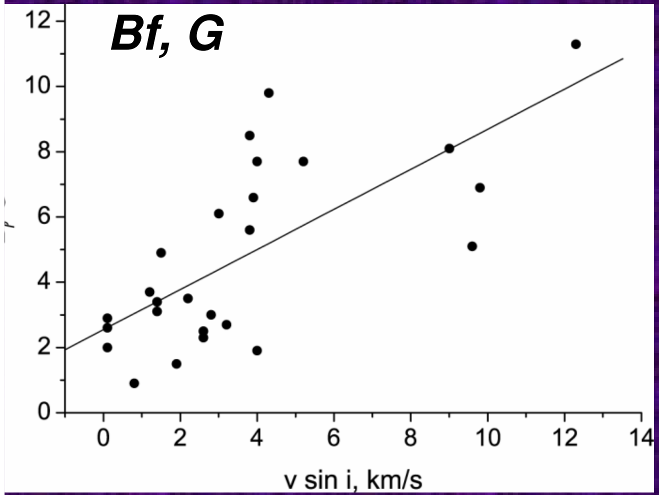
Samples of Measurements of Large-Scale Magnetic Fields on G stars

Name	f B (G)	log R’_HK	P_rot day	
HD 190771	51 ± 6	-4.42	8.8	
HD 73350	42 ± 7	-4.48	12.3	
HD 76151	5.6 ± 2	-4.69	20.5	
HD 146233	3.6 ± 1	-4.85	22.3	(18 Sco)

- P.Petit et al. «Toroidal vs. poloidal magnetic fields in Sun-like stars: a rotation threshold», MNRAS, 2008

General Propertiess of the Magnetic Activity of the Young Sun





Magnetic fields decrease when we pass from fast rotators to slowly rotating stars.

The total magnetic flux of active solar-type stars exceeds that of the Sun at the maximum of the cycle.

The total magnetic flux of the Sun is 10^24 Mx

- *at the maximum and 10^23 Mx at the minimum (Solanki et al. 2002; Vieira & Solanki 2010).*

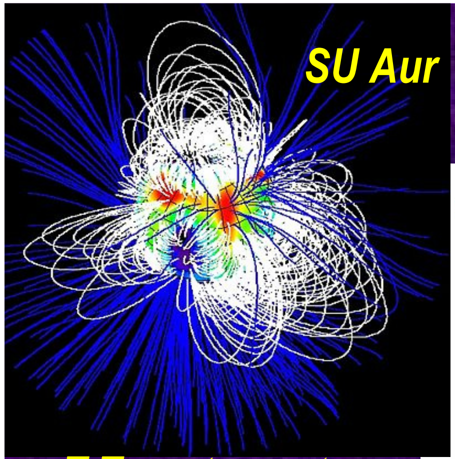
For the Young Sun,

our estimate is 3 × 10^24 □ 10^25 Mx and mean longitudinal magnetic field is 5 G.

Spectropolarimetric observations indicate that the magnetic fields in spots of solar-type stars reach 3 – 5 kG

- *(Saar 1996, Kochukhov et al., 2010)*

Magnetic Fields vs Age



SU Aur

T Tau –type star

H. M. Günther et al. **CS18, 2015** 35

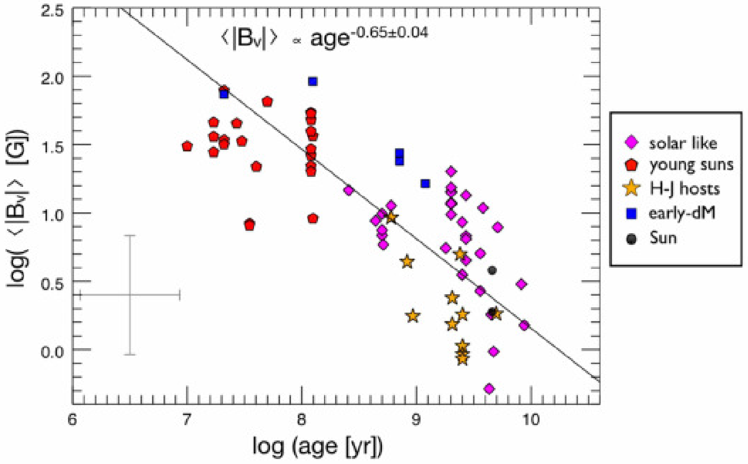


Figure .4: The unsigned average large-scale surface magnetic field $\langle |B_V| \rangle$ is related to age as $t^{-0.65\pm0.04}$ (solid line) and has a similar power-dependence as the Skumanich law. This magnetism-age relation could be used as a way to estimate stellar ages ("magnetochronology"), although it would not provide better precision than most of the currently adopted age-dating methods.

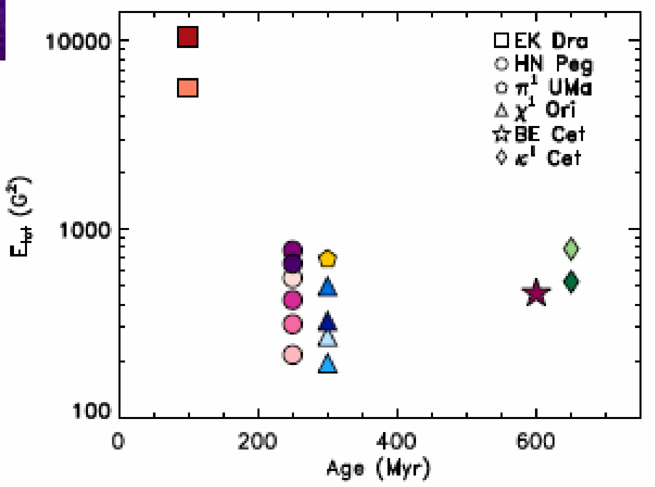
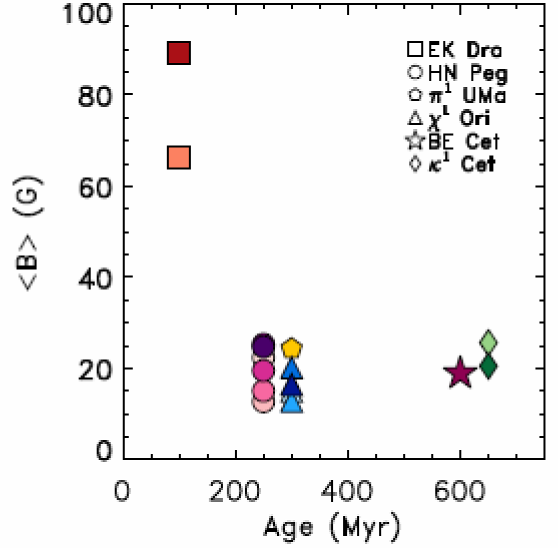


Fig. 2. Total magnetic field energy as a function of age. The stars are represented in the same way as in Fig. 1.



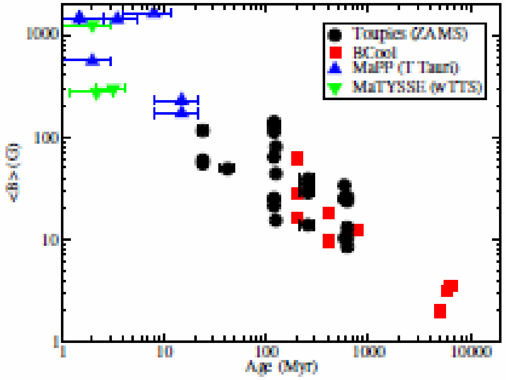


Fig. 10 Average large-scale magnetic field strength from ZDI as a function of stellar age. Data from the Toupies, MaPP, MaTYSSE, and BCool projects are presented here.

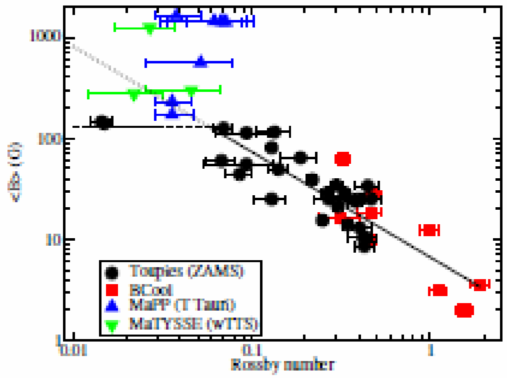
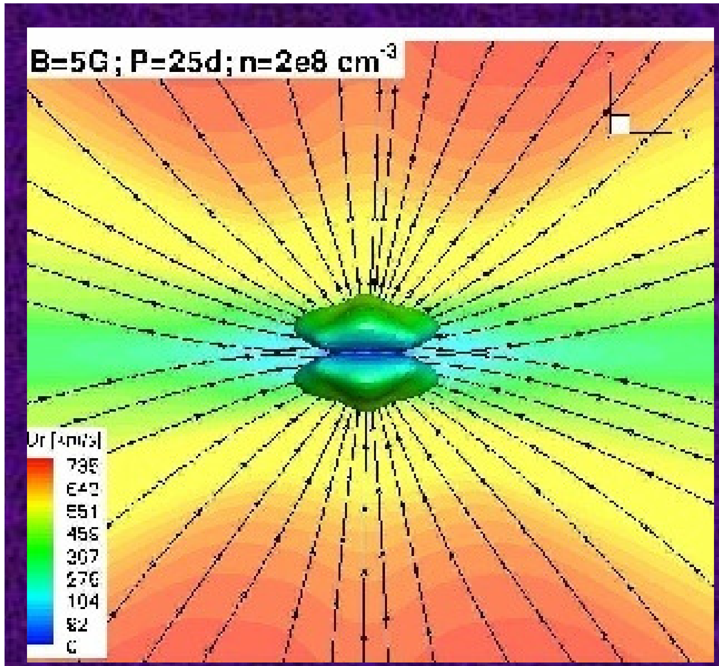


Fig. 11 Average large-scale magnetic field strength from ZDI as a function of Rossby number, for the same sample as Fig. 10. The solid line is a power law fit for larger Rossby numbers, and the dashed line is a hypothetical saturation level for small Rossby number.

L. Rosen et al. 2016

O. Kochukov et al . 2017



Stellar Winds

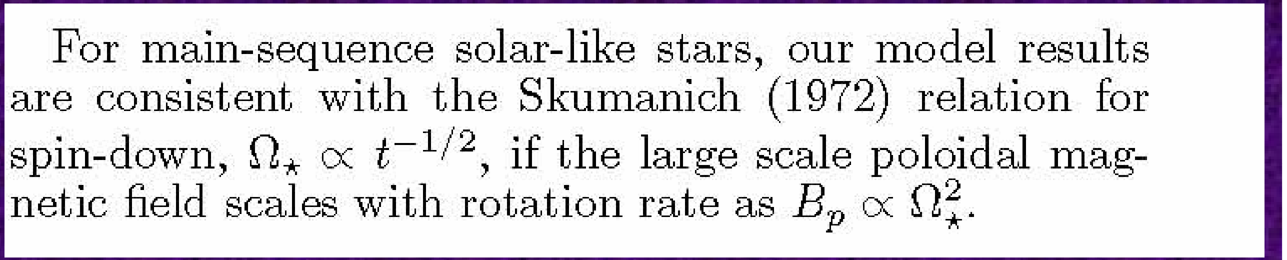
A GRID OF MHD MODELS FOR STELLAR MASS LOSS AND SPIN-DOWN RATES OF SOLAR ANALOGS

O. Cohen, J.J. Drake, 2013

Angular Momentum Evolution (Matt, S. P., et al. 2012, ApJ, 754, L26) :

In a three-dimensional flow, the net torque on the star is

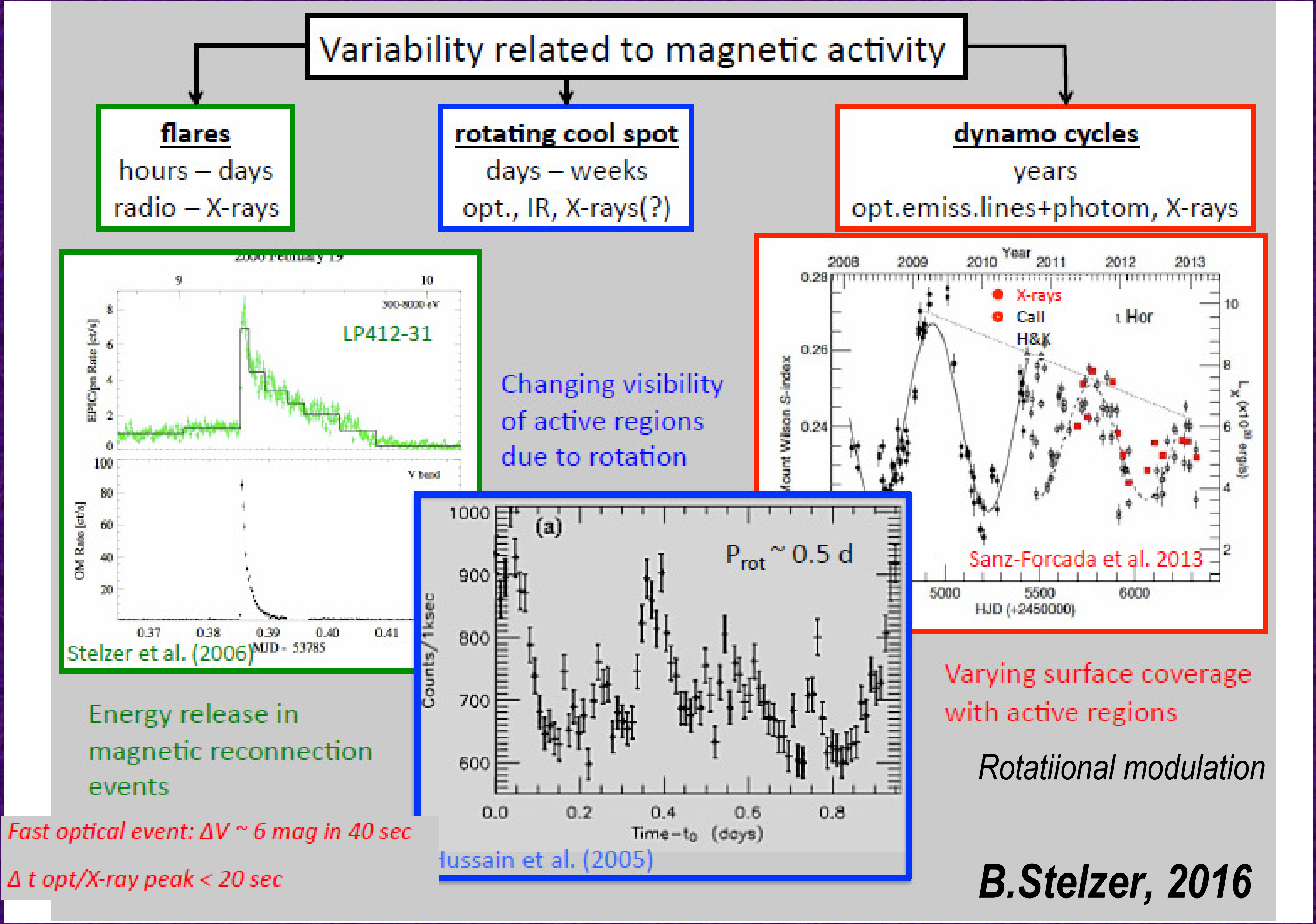
T_w = $\dot{M}$ Ω r^2 (where r is the Alfven radius of a star)


For main-sequence solar-like stars, our model results are consistent with the Skumanich (1972) relation for spin-down, $\Omega_\star \propto t^{-1/2}$, if the large scale poloidal magnetic field scales with rotation rate as $B_p \propto \Omega_\star^2$.

For the Young Sun with P_rot =10 d, B_p is 5 G,
The Alfven radius r = 8.3 R_⊙, and T_w = 2 x 10^32 g cm^2 s^-2,
the mass loss rate, $\dot{M}$ is 6 x 10^(-12)M_⊙ / year.
This mass loss rate is typical for G-type stars in the epoch of the cycle formation.

The contemporary Sun mass loses rate is 3 x 10^(-14) M_⊙ / year

Solar-type Activity at Different Time Scales and Wavelengths



Variability related to magnetic activity

flares
hours – days
radio – X-rays

rotating cool spot
days – weeks
opt., IR, X-rays(?)

dynamo cycles
years
opt.emiss.lines+photom, X-rays

Stelzer et al. (2006)

Energy release in magnetic reconnection events

Fast optical event: ΔV ~ 6 mag in 40 sec

Δ t opt/X-ray peak < 20 sec

Changing visibility of active regions due to rotation

ussain et al. (2005)

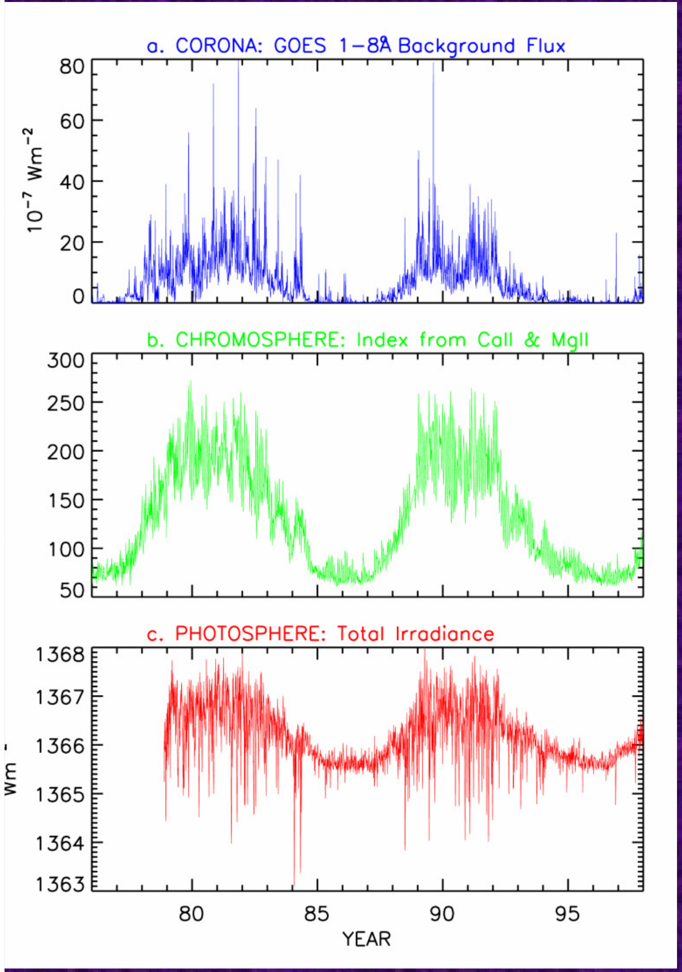
Sanz-Forcada et al. 2013

Varying surface coverage with active regions

Rotatiional modulation

B.Stelzer, 2016

Cycles and Long-term Variability of the Sun and some other Stars

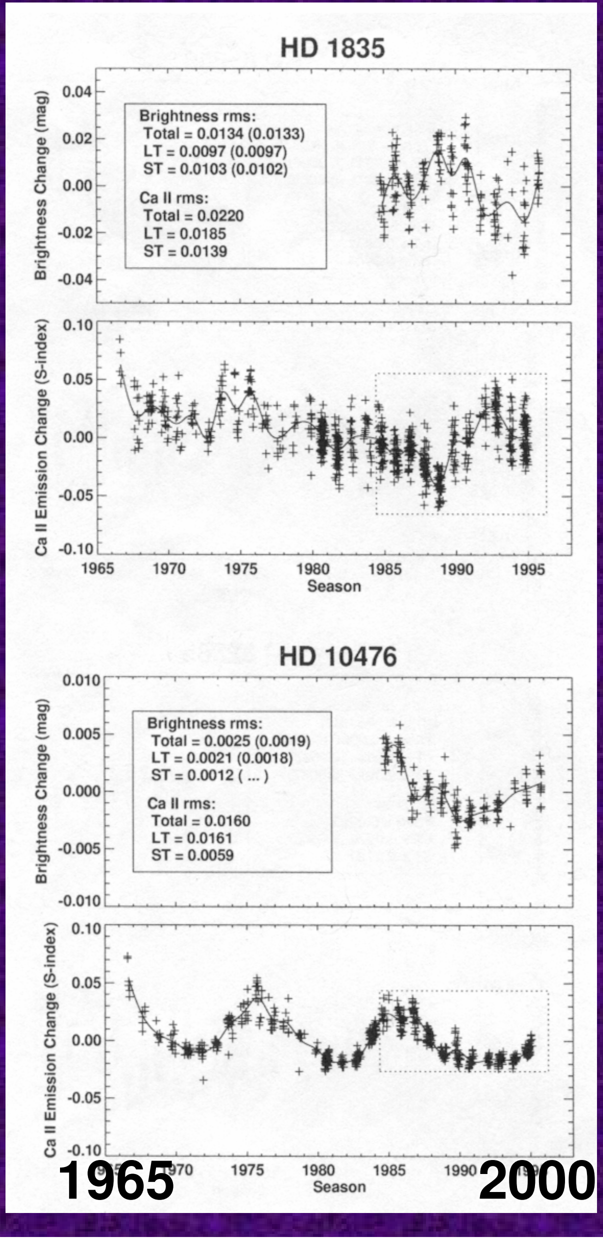


X-rays

Ca II

Total Solar Irradiance

1975 **2000**



HD 1835 G2 V

P_rot = 8 d

V – phot band

Ca II

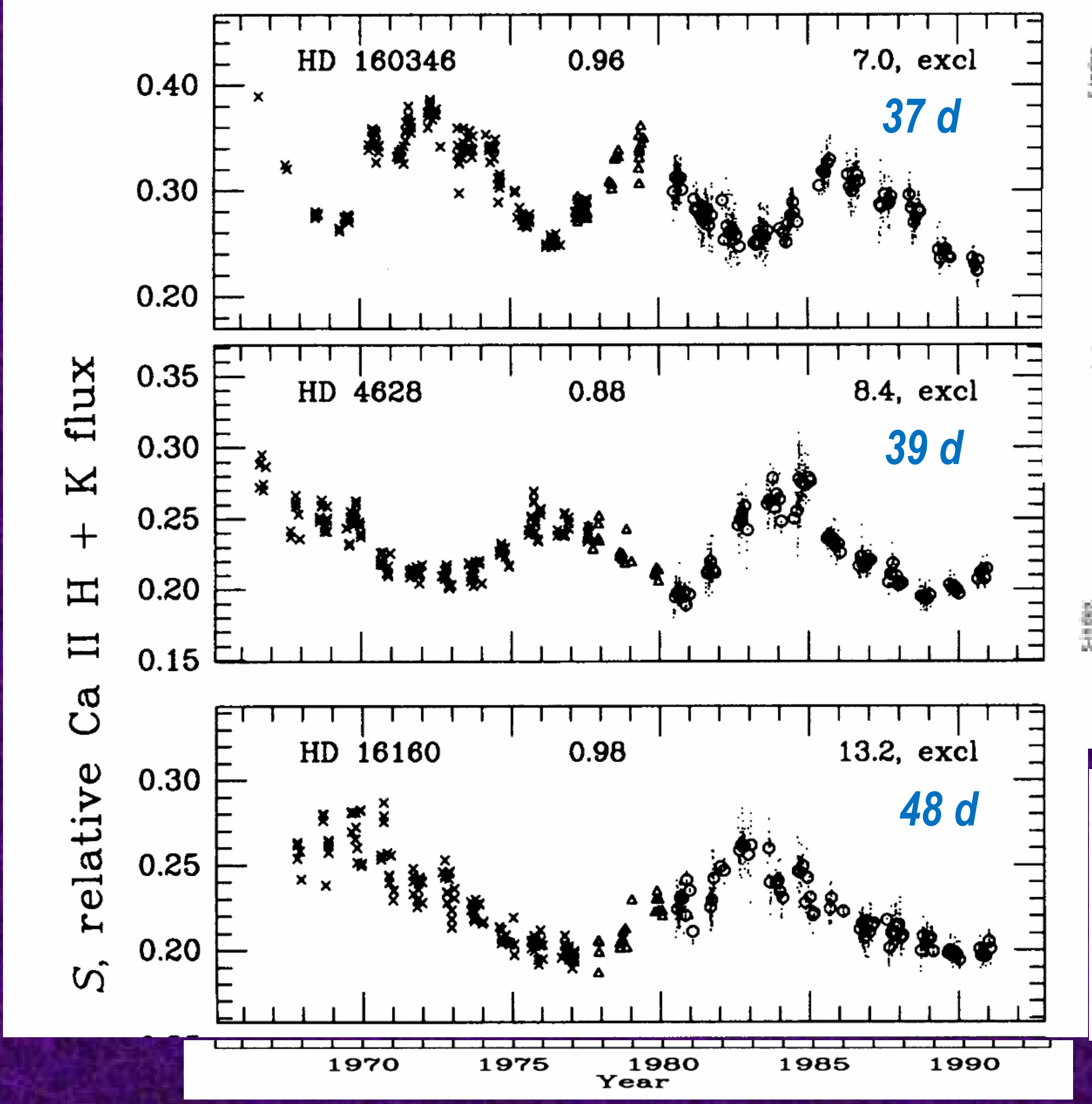
HD 10476 K1 V

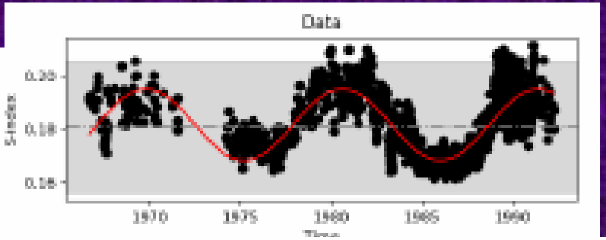
P_rot = 35 d

V – phot band

Ca II

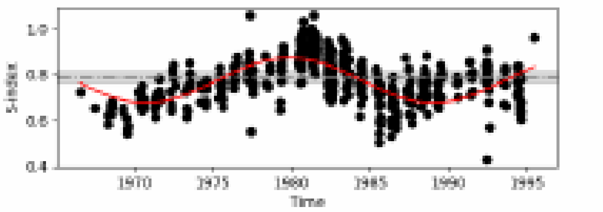
Long-term Variability in the HK Project: Stellar Cycles - I



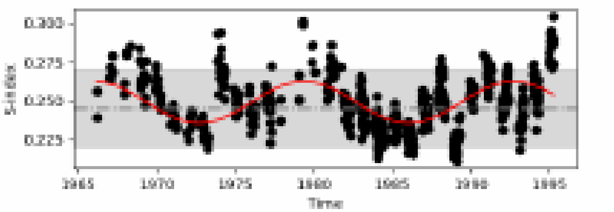


Sun

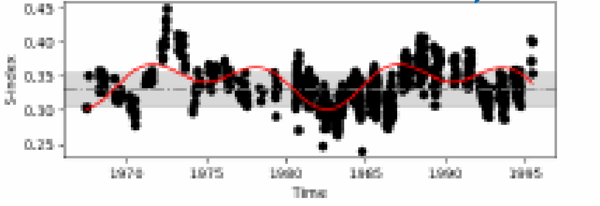
HD 156026 K5 V Good, 21 d



HD 78366 G0 V Good, 10 d



HD 149661 K0 V Good, 21 d



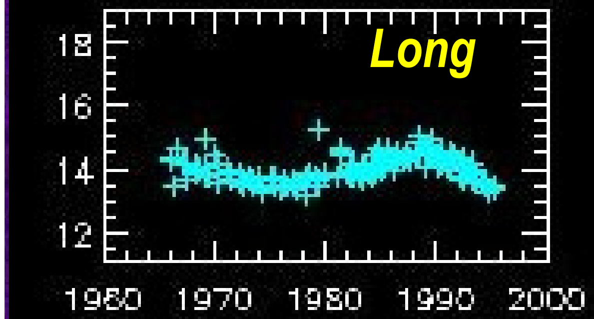
S.Baliunas et al. 1995, ApJ

Long-term Variability in HK Project: Stellar Cycles - II

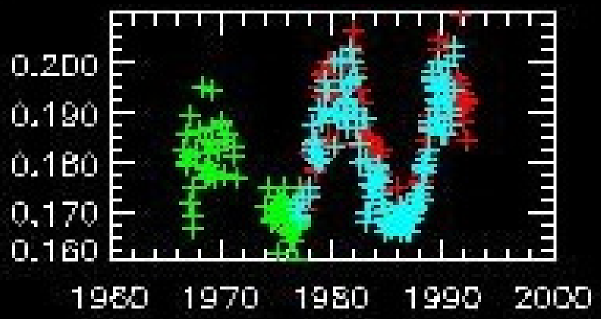
P_rot = 14 d

P_rot = 25 d

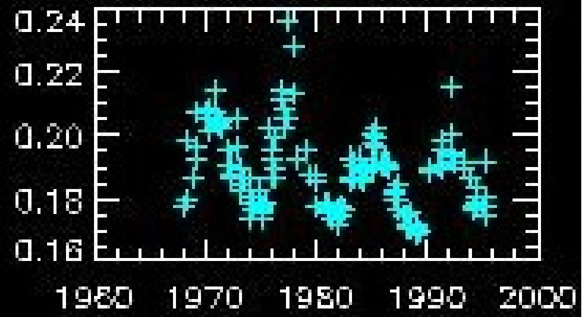
P_rot = 31 d



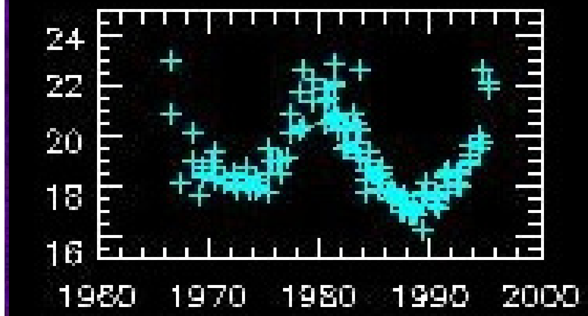
HD136202 (F8IV-V) 23 yrs



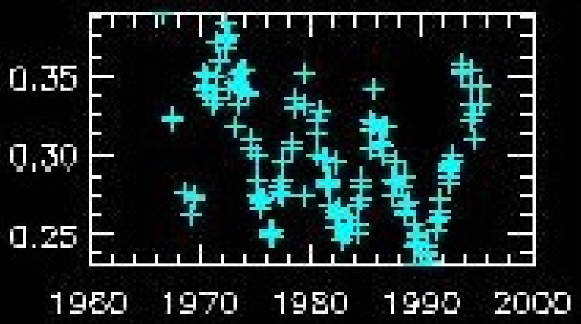
Sun (G2V) 10.0 yrs



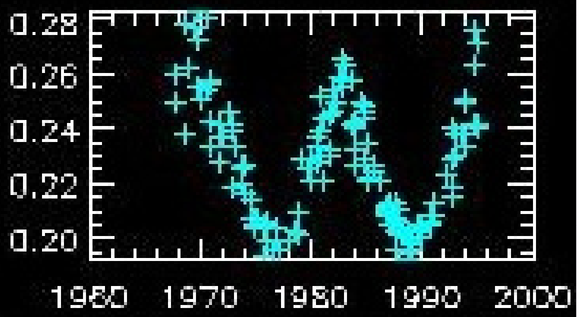
HD103095 (G8VI) 7.3yrs



HD166620 (K2V) 15.8yrs



HD160346 (K3V) 7.0yrs



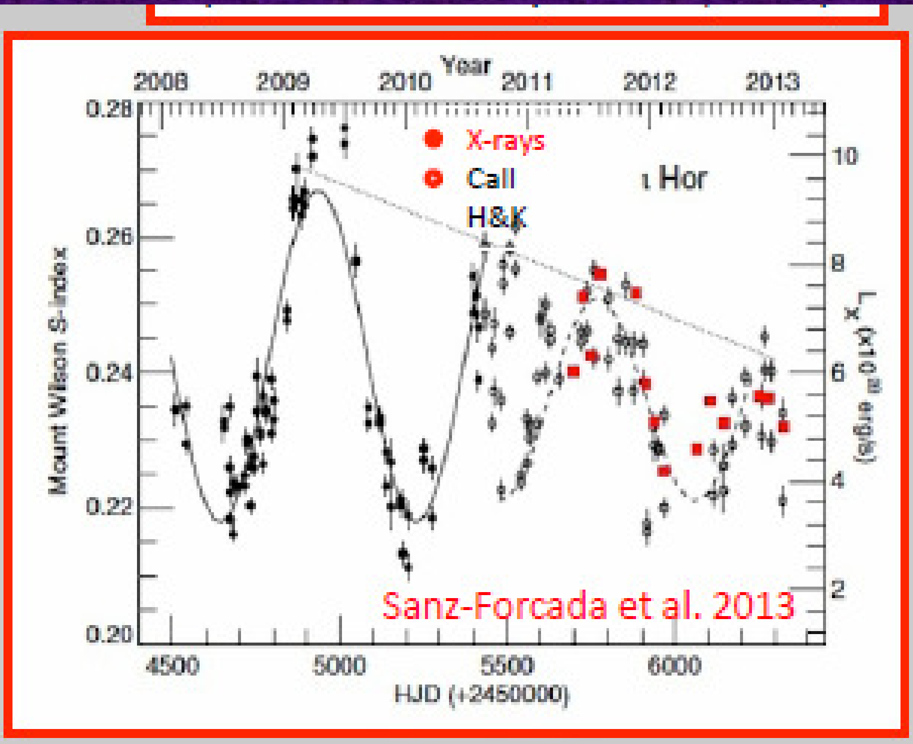
HD16160 (K3V) 13.2yrs

P_rot = 43 d

P_rot = 37 d

P_rot = 48 d

Long-term Evolution of X-ray Activity



Sanz-Forcada et al. 2013

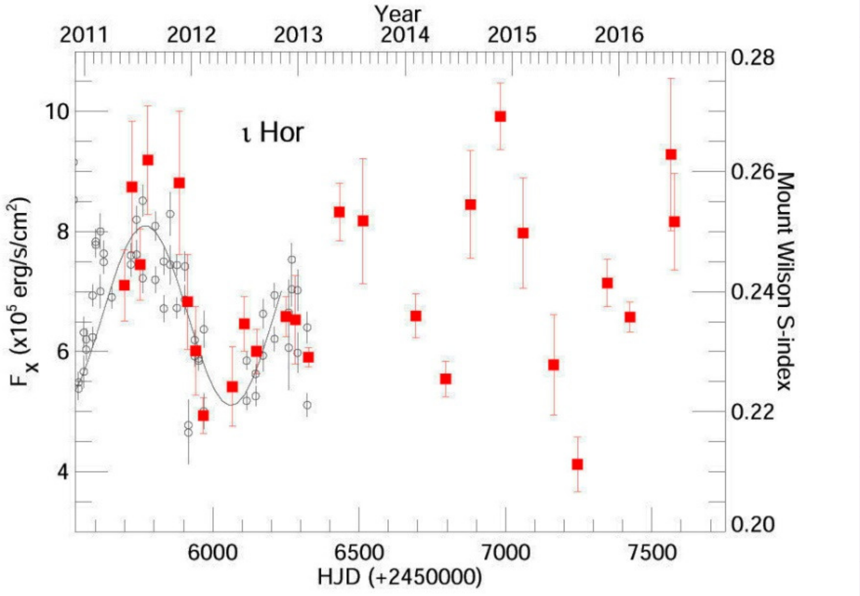


Fig. 2 X-ray and Ca II lightcurve of ι Hor. Black open symbols – Ca II S-index, recent unpublished Ca II data is not shown; red – *XMM-Newton* X-ray flux. Sanz-Forcada et al., in prep.

Iota Horologium,

P_rot = 8 – 8.5 d

P_cycle ~1.6 yr

Stellar magnetic field geometry and chromospheric cycle : rapid 120-day magnetic cycle τ Boo

S. Jeffers et al . and
Bcool collaboration,
arXiv astro-ph,
May 25, 2018

τ Boo - F7 planet –hosting
dwarf
P_rot = 4 day

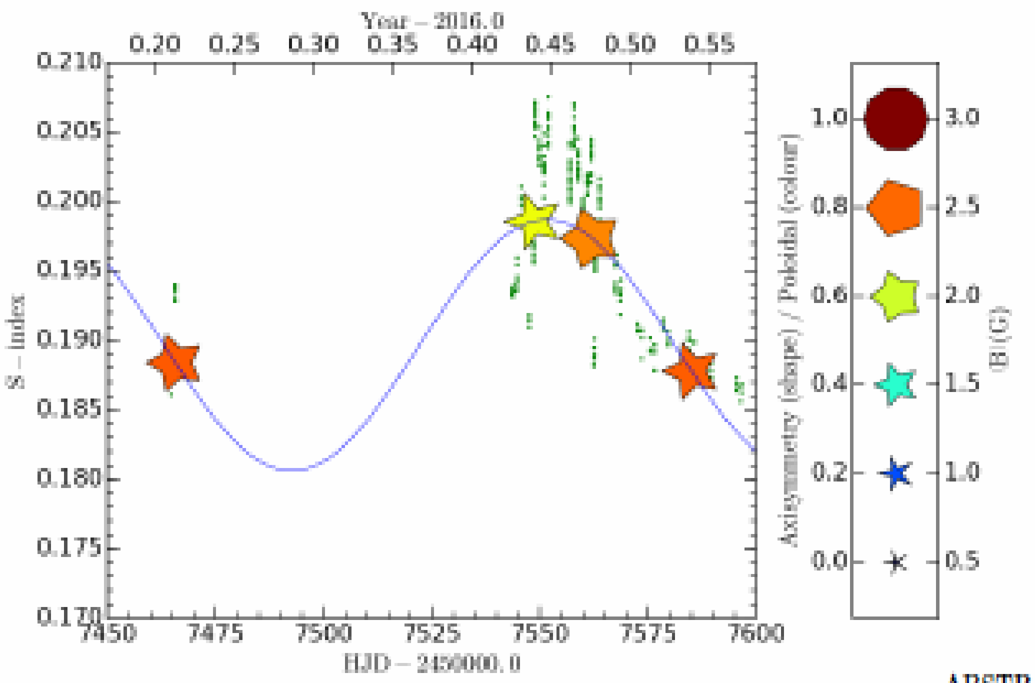
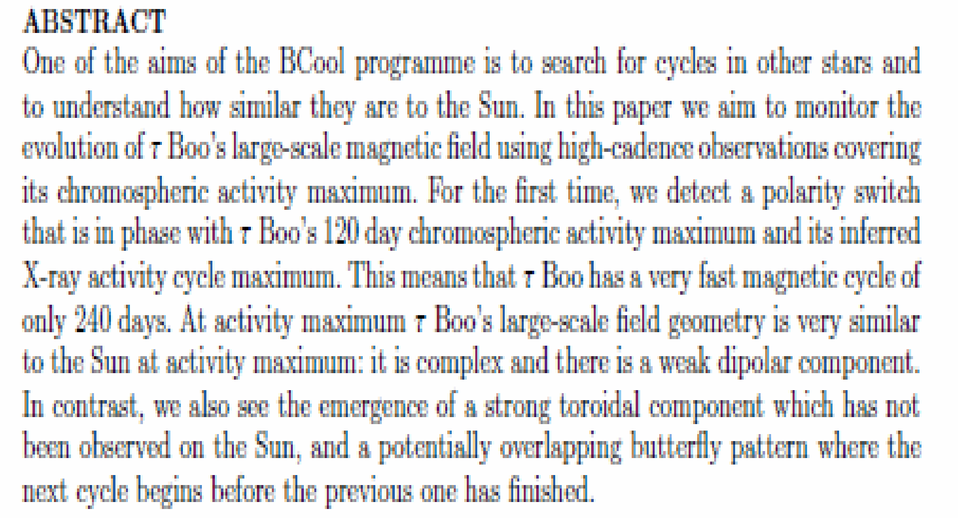


Figure 3. The evolution of τ Boo's large-scale field during S-index maximum. The symbol shape indicates the axisymmetry of the field (non axisymmetric by pointed star shape and axisymmetric by decagon), the colour of the symbol indicates the proportion of poloidal (red) and toroidal (blue) components of the field and the symbol size indicates the magnetic field strength. The green points are the individual S-index measurements. The blue line indicates the S-index cycle and is a continuation of the S-index cycle from Mengel et al. (2016).



ABSTRACT

One of the aims of the BCool programme is to search for cycles in other stars and to understand how similar they are to the Sun. In this paper we aim to monitor the evolution of τ Boo's large-scale magnetic field using high-cadence observations covering its chromospheric activity maximum. For the first time, we detect a polarity switch that is in phase with τ Boo's 120 day chromospheric activity maximum and its inferred X-ray activity cycle maximum. This means that τ Boo has a very fast magnetic cycle of only 240 days. At activity maximum τ Boo's large-scale field geometry is very similar to the Sun at activity maximum: it is complex and there is a weak dipolar component. In contrast, we also see the emergence of a strong toroidal component which has not been observed on the Sun, and a potentially overlapping butterfly pattern where the next cycle begins before the previous one has finished.

Cycles in Stellar Chromospheres and Coronae

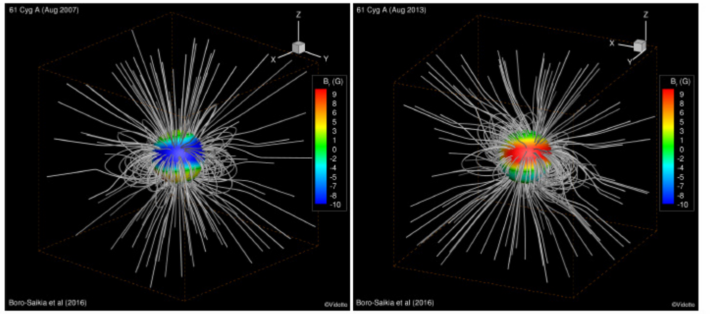
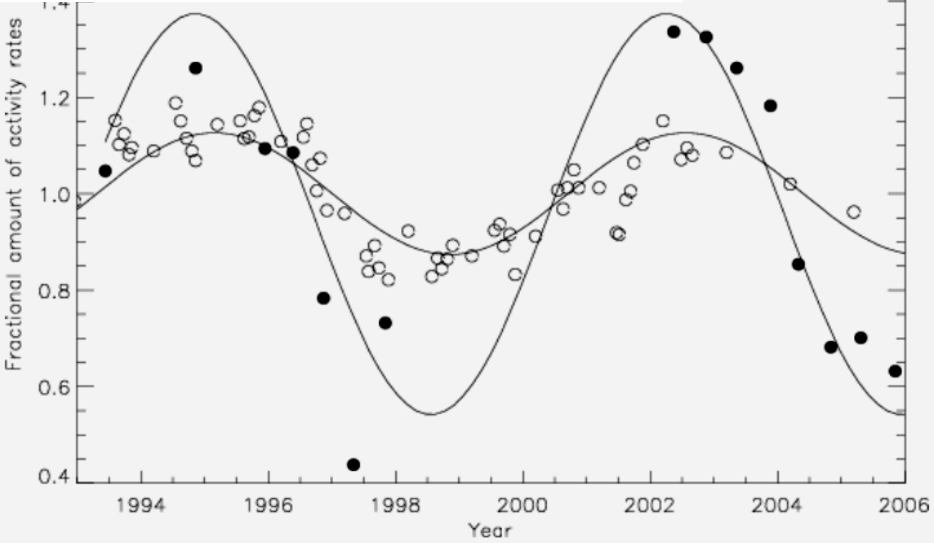
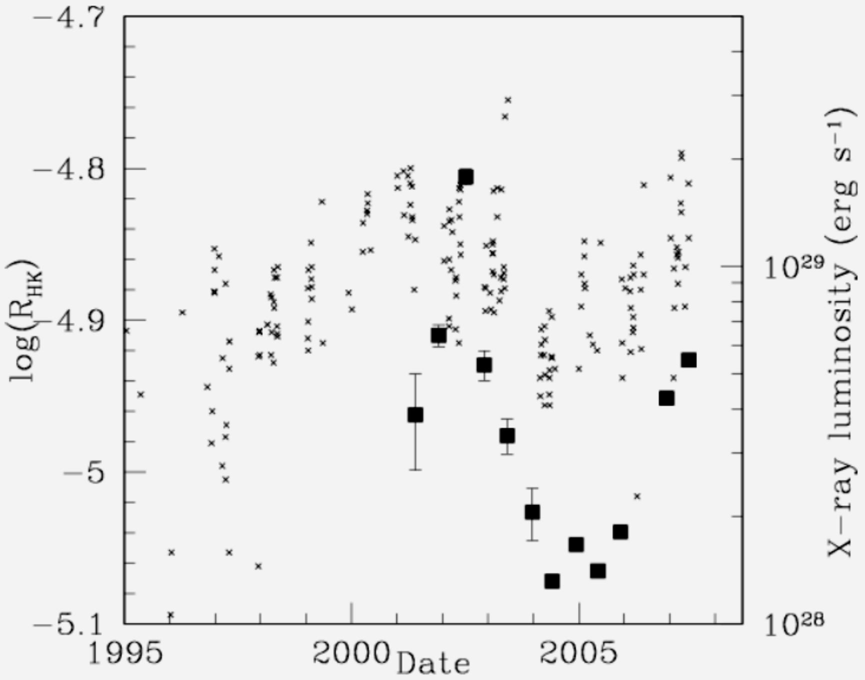


Figure 2: The star 61 Cyg A shows polarity reversals on the large-scale field with a period of a full magnetic cycle (i.e., two reversals) of around 7 years. The reversals are in phase with the chromospheric and coronal cycle. Figure based on the ZDI maps of [29] for Aug 2007 (left) and Aug 2013 (right). The magnetic field lines are extrapolated using a potential field source surface method, which takes into account the radial component of the observed field from [29].

Magnetic 7-yr cycle on 61 Cyg A
A. Vidotto, 2017

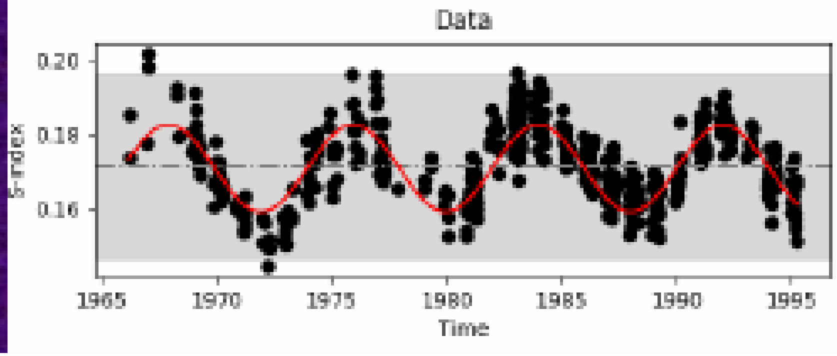




61 Cyg A (K5 V)
P_rot = 35 d
P_cyc = 7.3 yr

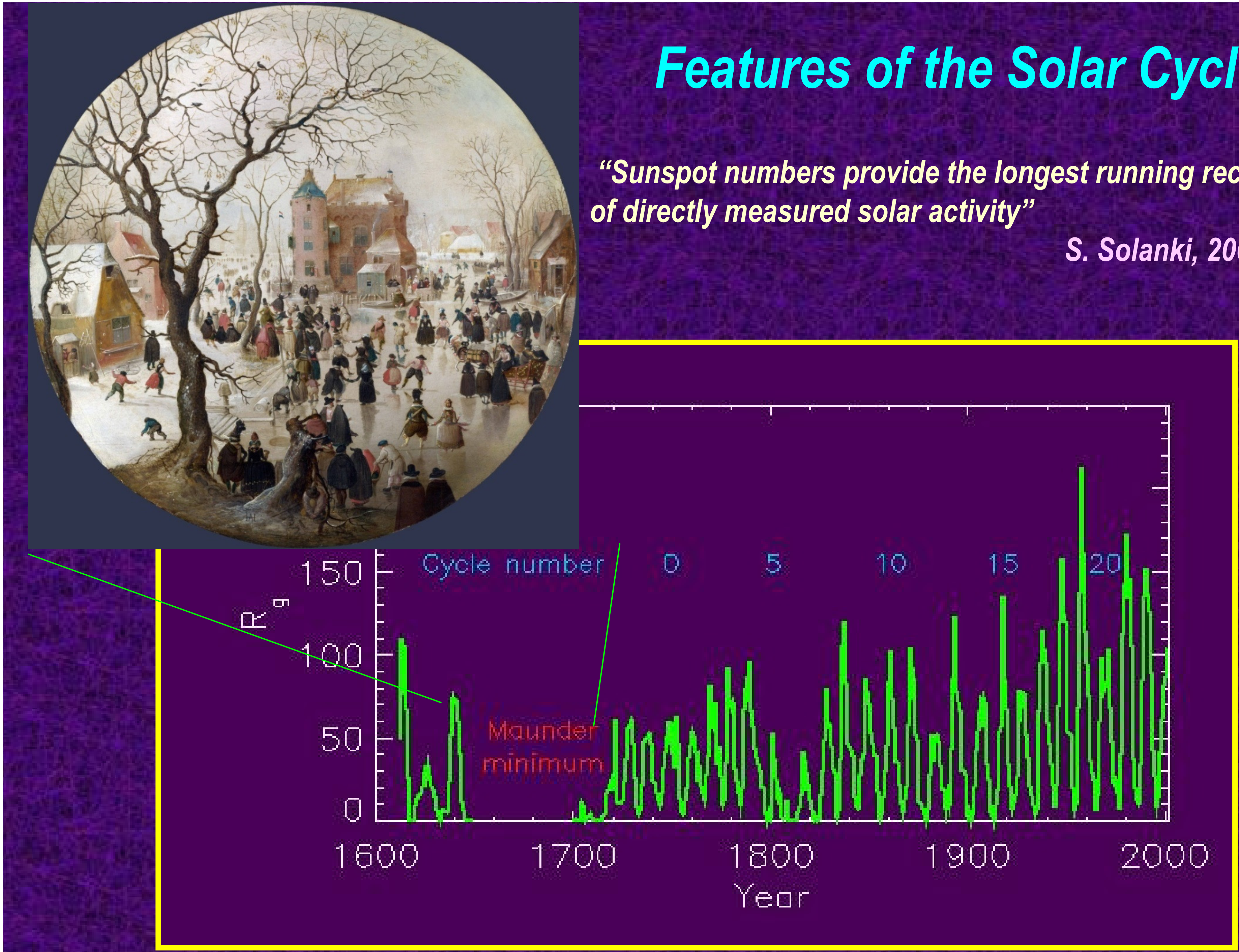
HD 81809 (G2 V)
P_rot = 41 d
P_cyc = 8.2 yr

I. Pagano, IAU Symp.264, 2009

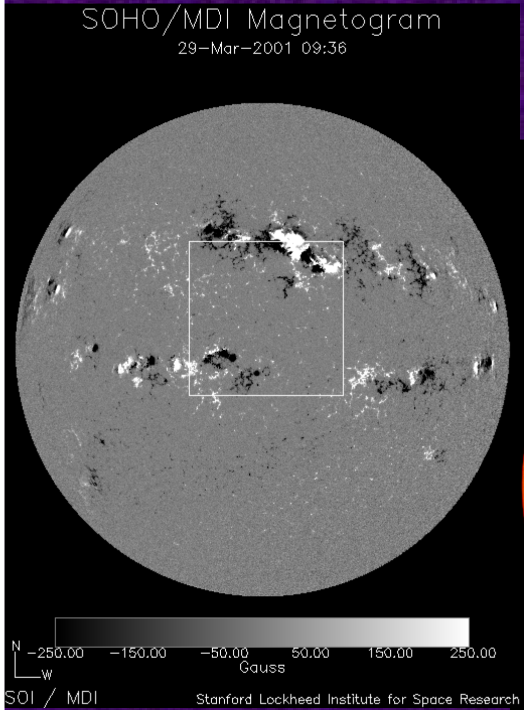


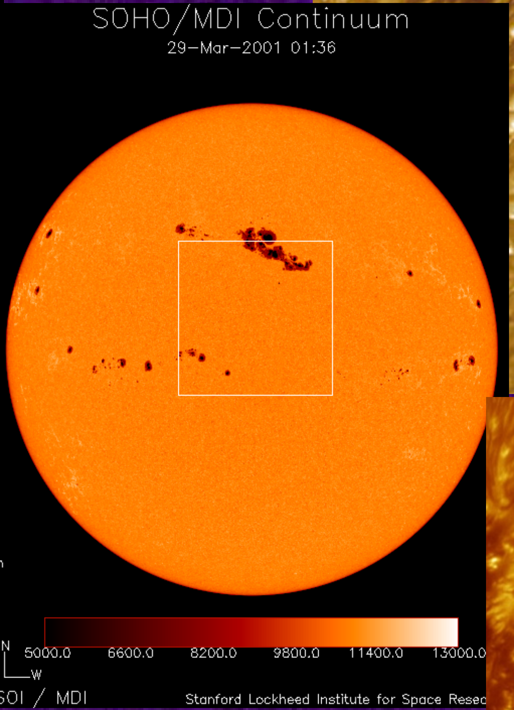
Features of the Solar Cycle

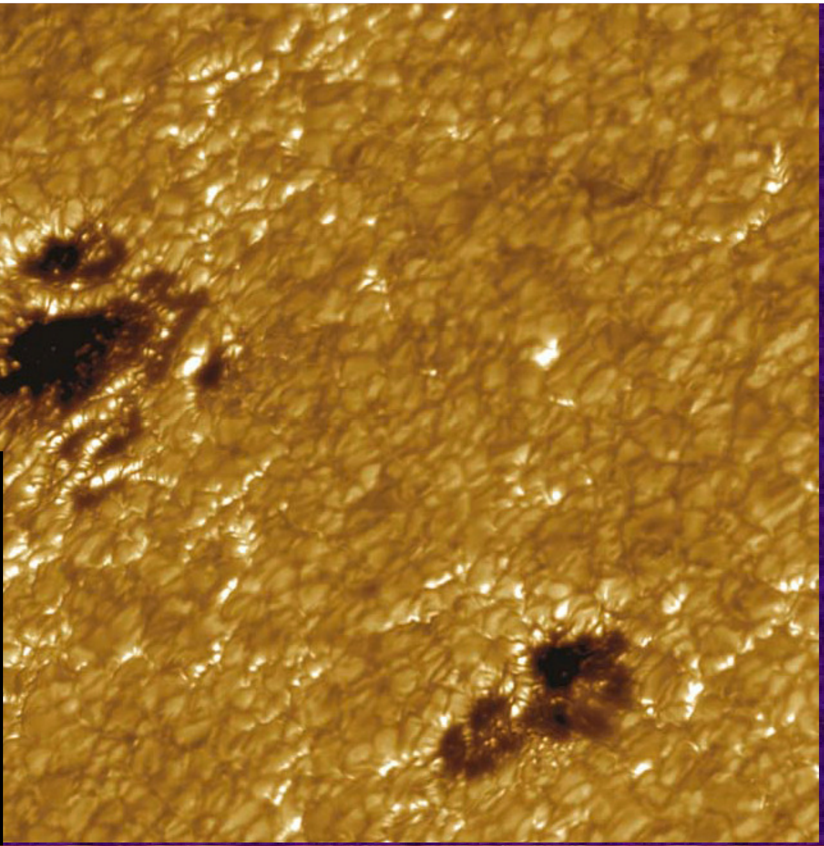
> *"Sunspot numbers provide the longest running record of directly measured solar activity"*
>
> *S. Solanki, 2003*

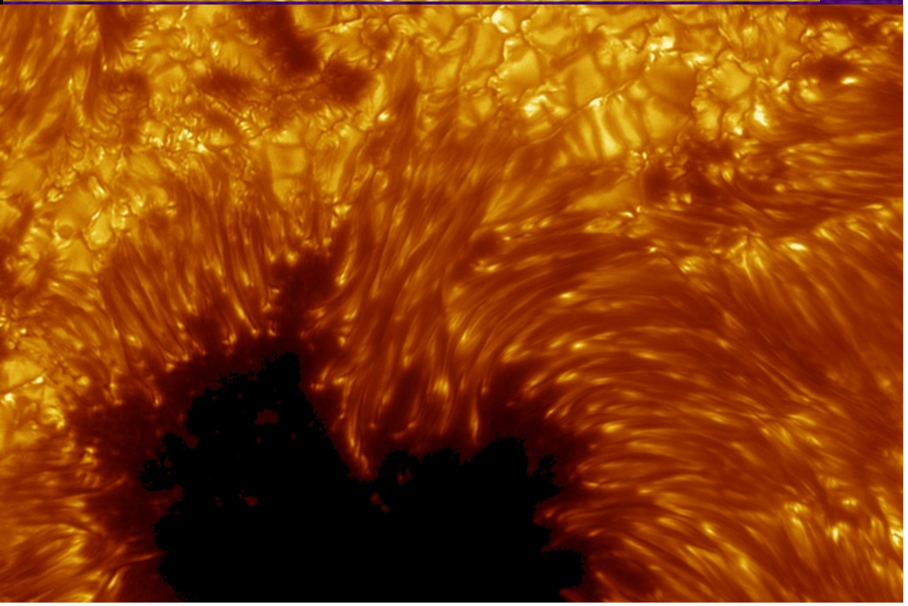


Local (Small-Scale) Magnetic Fields on the Sun



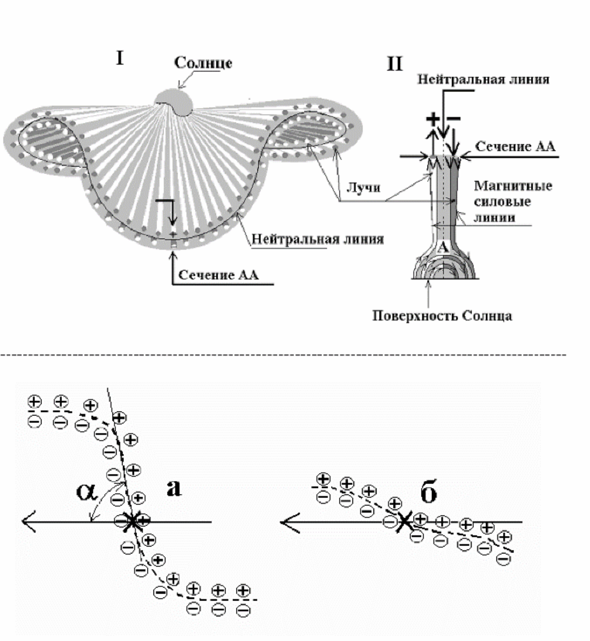


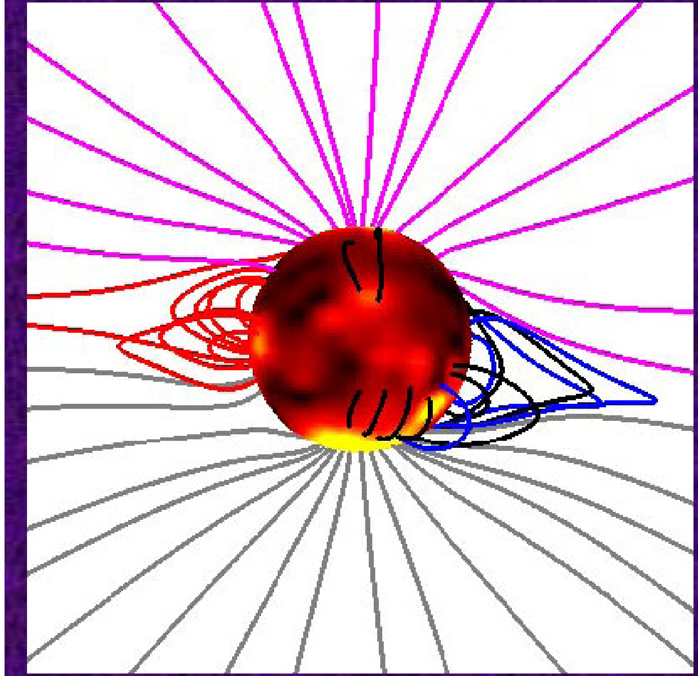


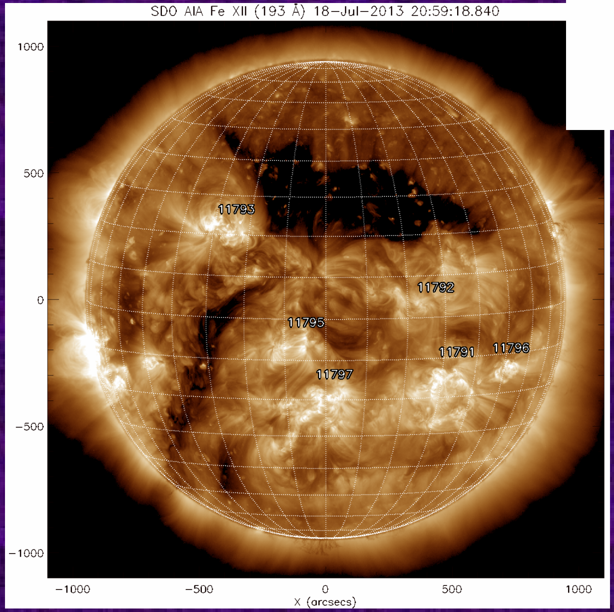


Most of quasi-stationary and non-stationary processes are associated with an evolution of local magnetic fields

Large-Scale Magnetic Field of the Sun





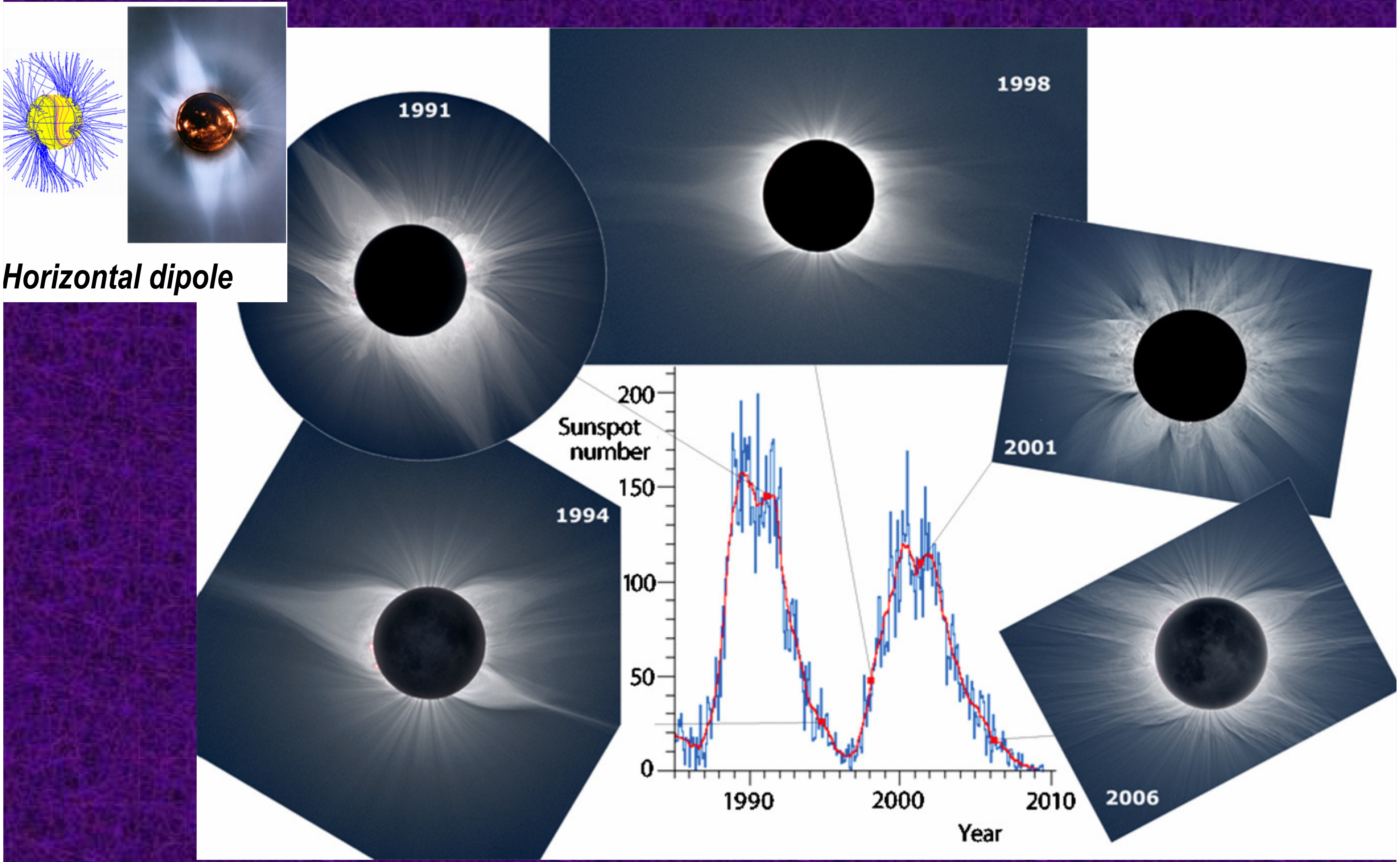


22-year magnetic cycle – reversal of a dipole

Coronal holes – open field lines

The large-scale magnetic field is seen in the global dipole, coronal holes, active longitudes, sectorial structure of interplanetary magnetic fields etc.

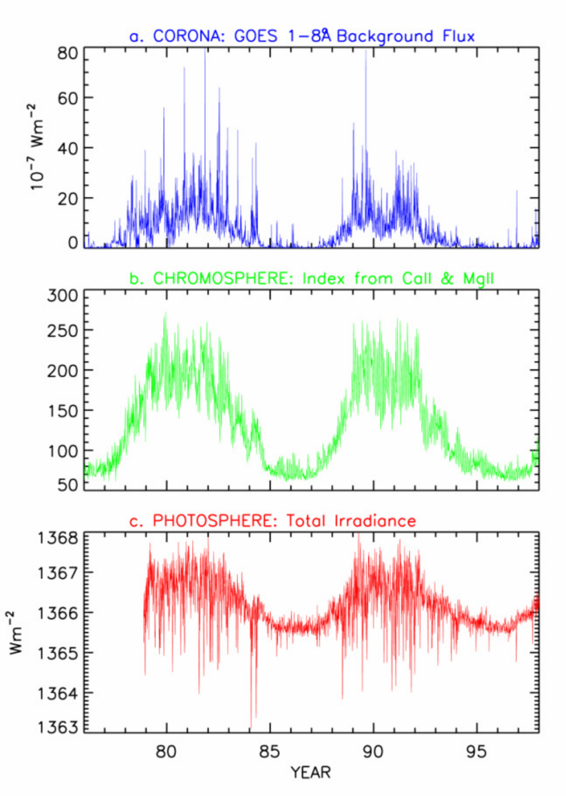
White-light Corona throughout the Cycle



Horizontal dipole

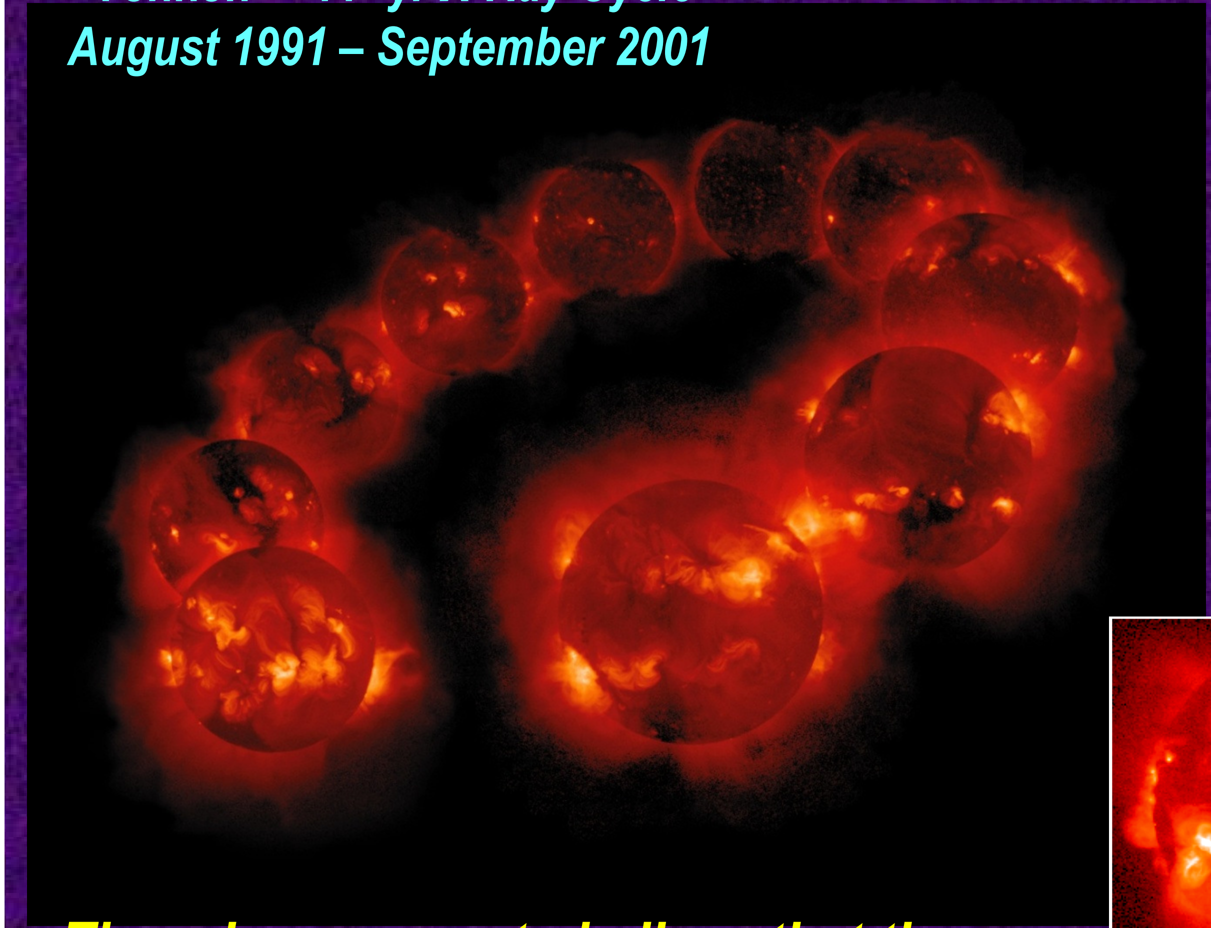
S. Habbal, 2010

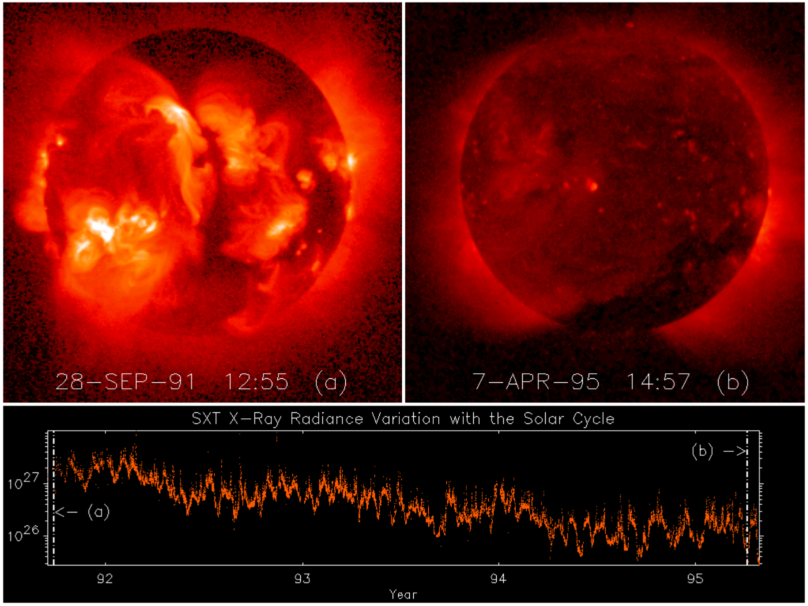
The Solar Cycle



Yohkoh – 11- yr X-Ray Cycle

August 1991 – September 2001

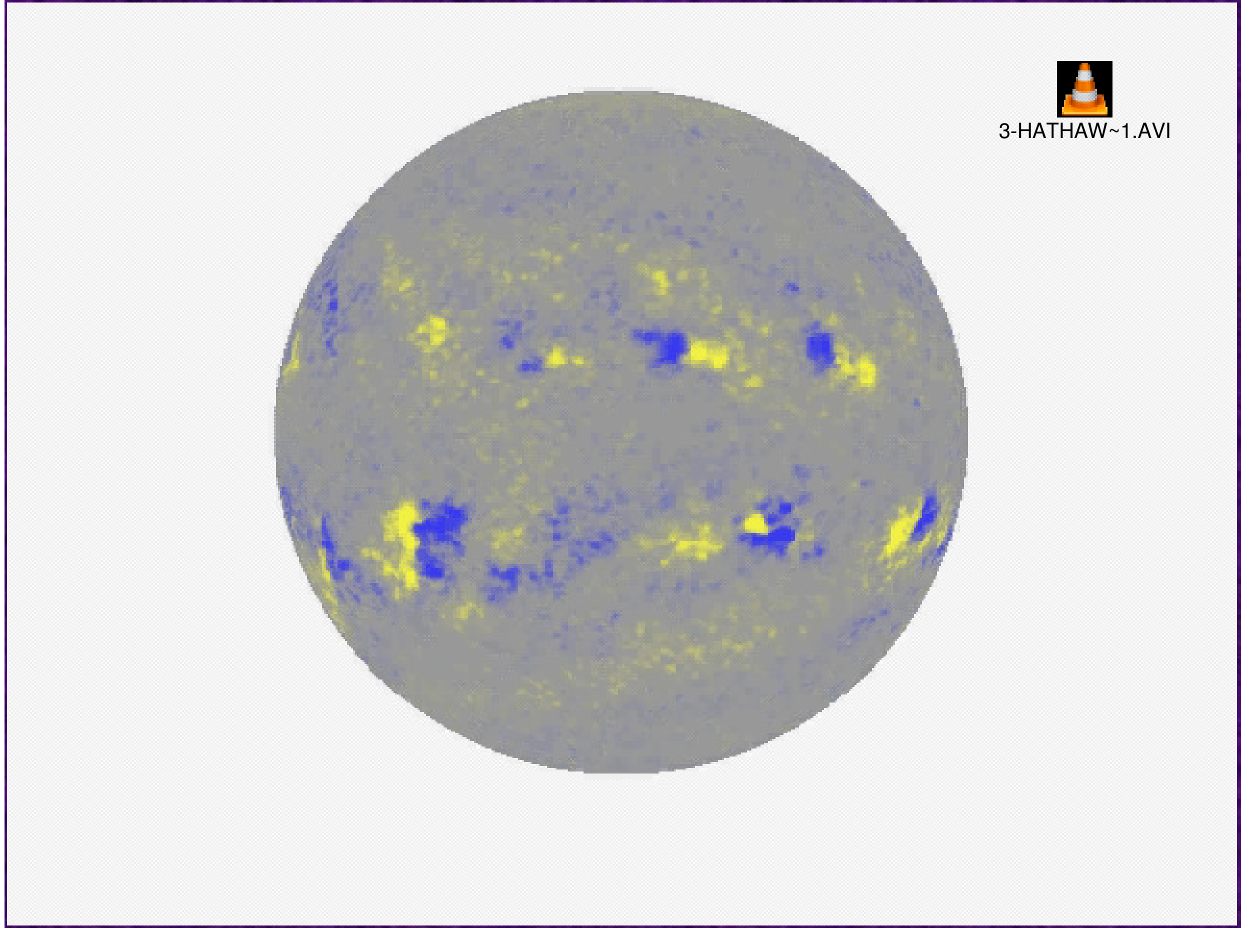




There is a reason to believe that the large-scale magnetic field governs activity at different horizontal scales and heights of the solar atmosphere

Latitudes of Local Magnetic Fields in the Photosphere During a few Solar Cycles

Many evidences for coexistence of small-scale and large-scale dynamos



Courtesy: D.H. Hathaway

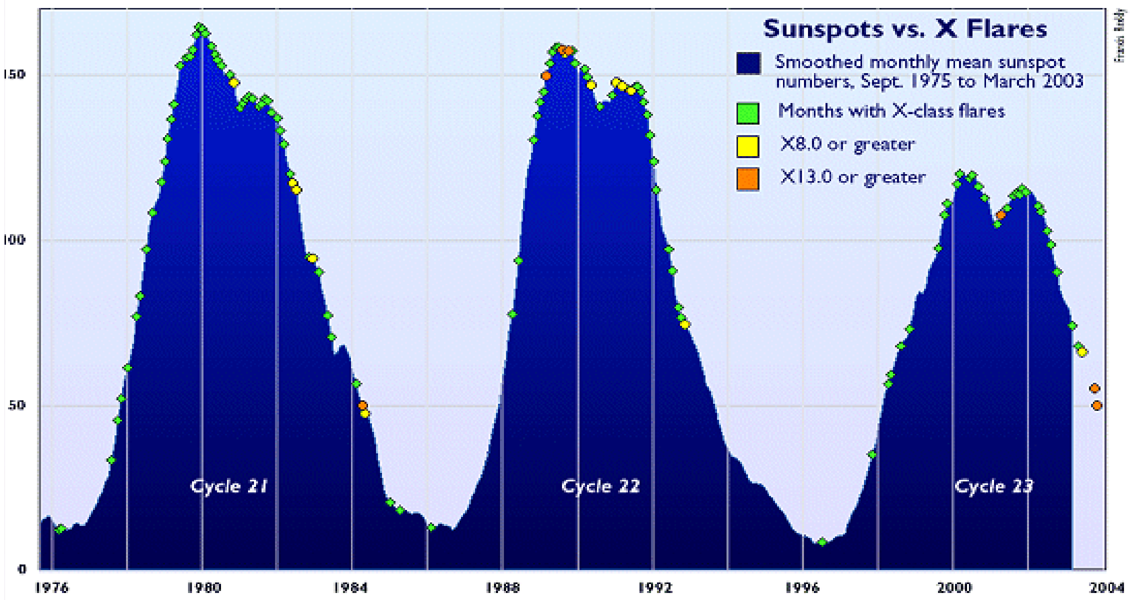
Weak diffuse fields drift poleward in contrast to equatorward migration of sunspot belt

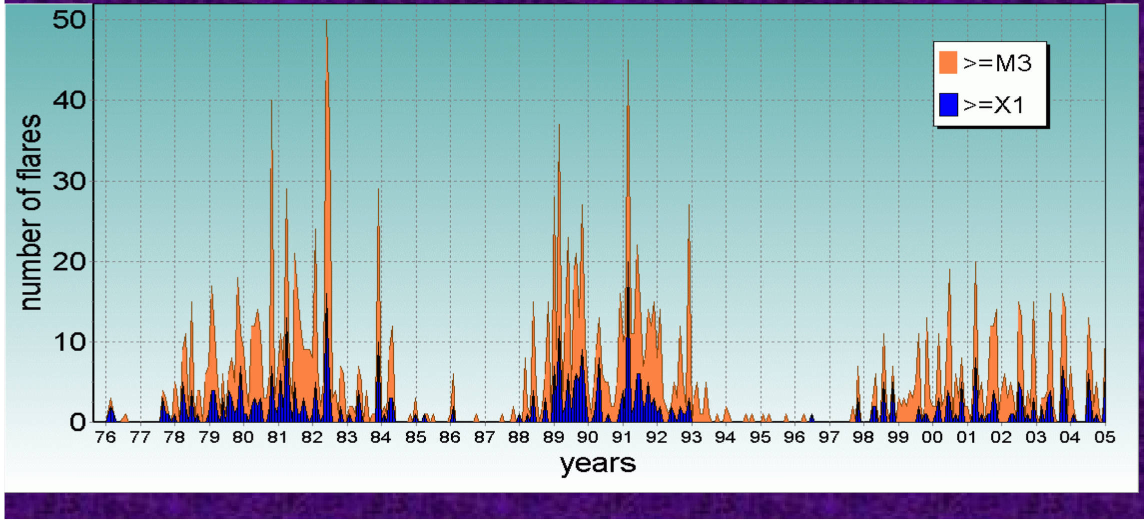
but maintain a certain phase-relationship with the sunspot belt

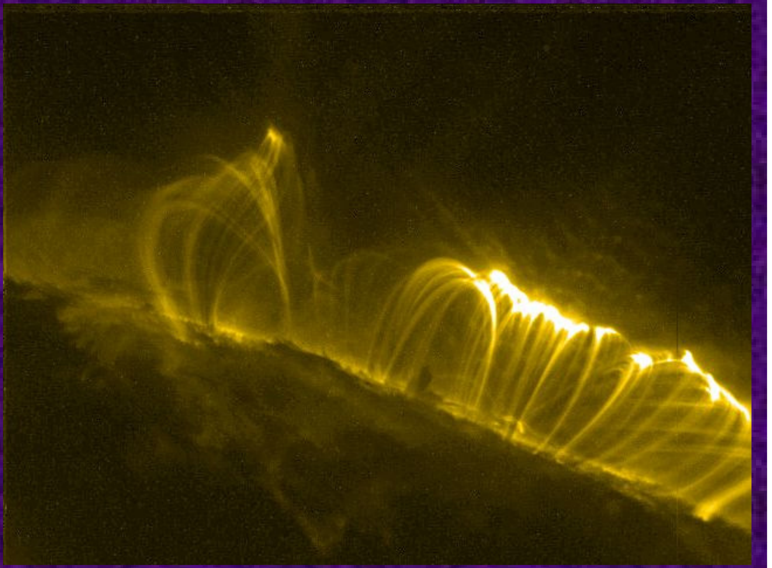
Polar reversal takes place during sunspot maximum

Polar field changes sign from positive to negative when sunspot cycle has already been negative

Non-stationary Phenomena on the Sun and other late-type stars







Coronal Mass Ejection (CME) / Flare Events

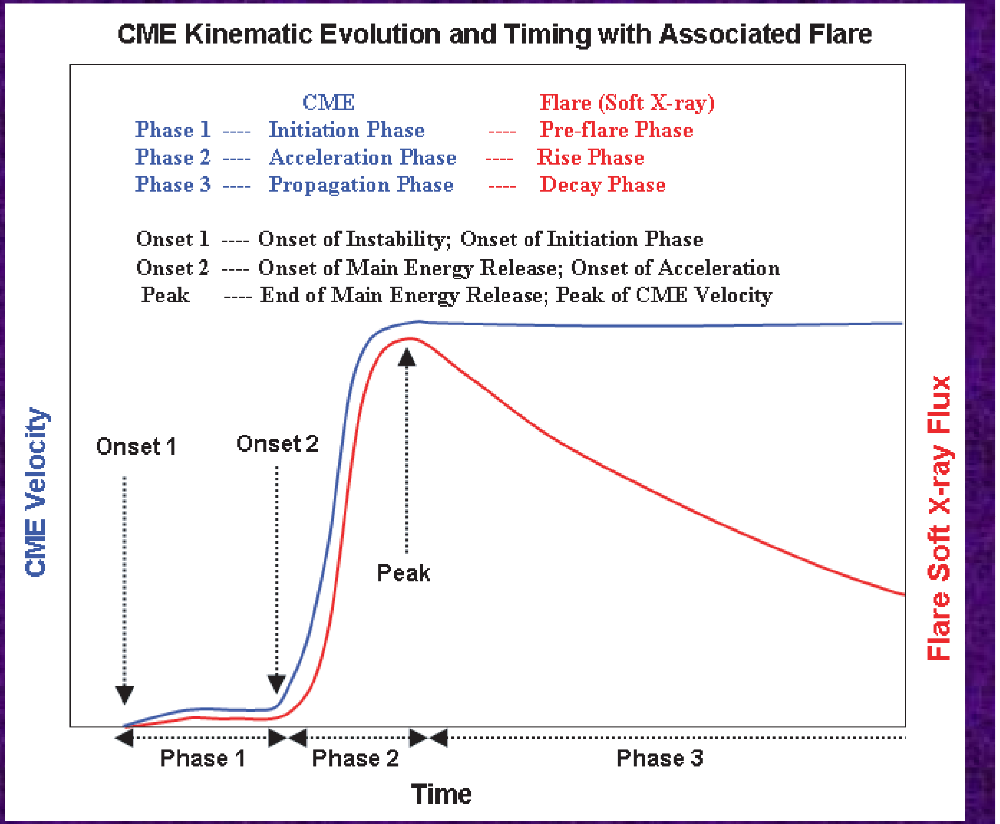
The flare: what's this?

* *Breakdown of stability of MHD-configuration*

** *Sudden energy release, electron acceleration, explosive evaporation as a response of the chromosphere to the impulsive heating*

*** *Formation of the system of loops, filled up by the hot plasmas*

**** *The mass loss due to CME's on the G-type star with P_rot =10 d is 10% of the mass loss due to the stellar wind. This portion is 20-30 times higher than that for the contemporary Sun*



"Comparison of the temporal behaviour between the soft X-rays and CME velocity in simplest case"

J. Zhang and K. P. Dere 2006, ApJ, 649:1100-1109

Stars -Toward a Model of Superflares

\# Comparison with the present day-Sun:

the averaged over the Carrington rotation the magnetic fields of the Sun as a stars at high activity level (for example, in 1980), |B_l| = 0.5 G.

For G-type stars |B_l| = 4.72 ± 0.53 G .

\# The mean value of |B_l| is around 5 G (Marsden et al., 2013) – "Bcool collaboration".

\# THUS, the magnetic field of Young Suns is 10 times stronger than that in the present epoch and this is not due to large spottedness

\# Young Suns: The maximal possible flare energy of dG with solar-type activity with an established cycle is close to 10^{34} erg.

\# The syndrom of large solar flares is an effective particle acceleration

Flares on the Young Sun

- *Kappa Cet (G5 V, P_rot = 9.4 d, log Lx = 29)*
- *Flares Frequency Occurrence with E > 10^32 erg*
  - *5 events per day → 1825 events per year*

(from EUVE data – M. Audard et al. 2000, ApJ)

The contemporary Sun :

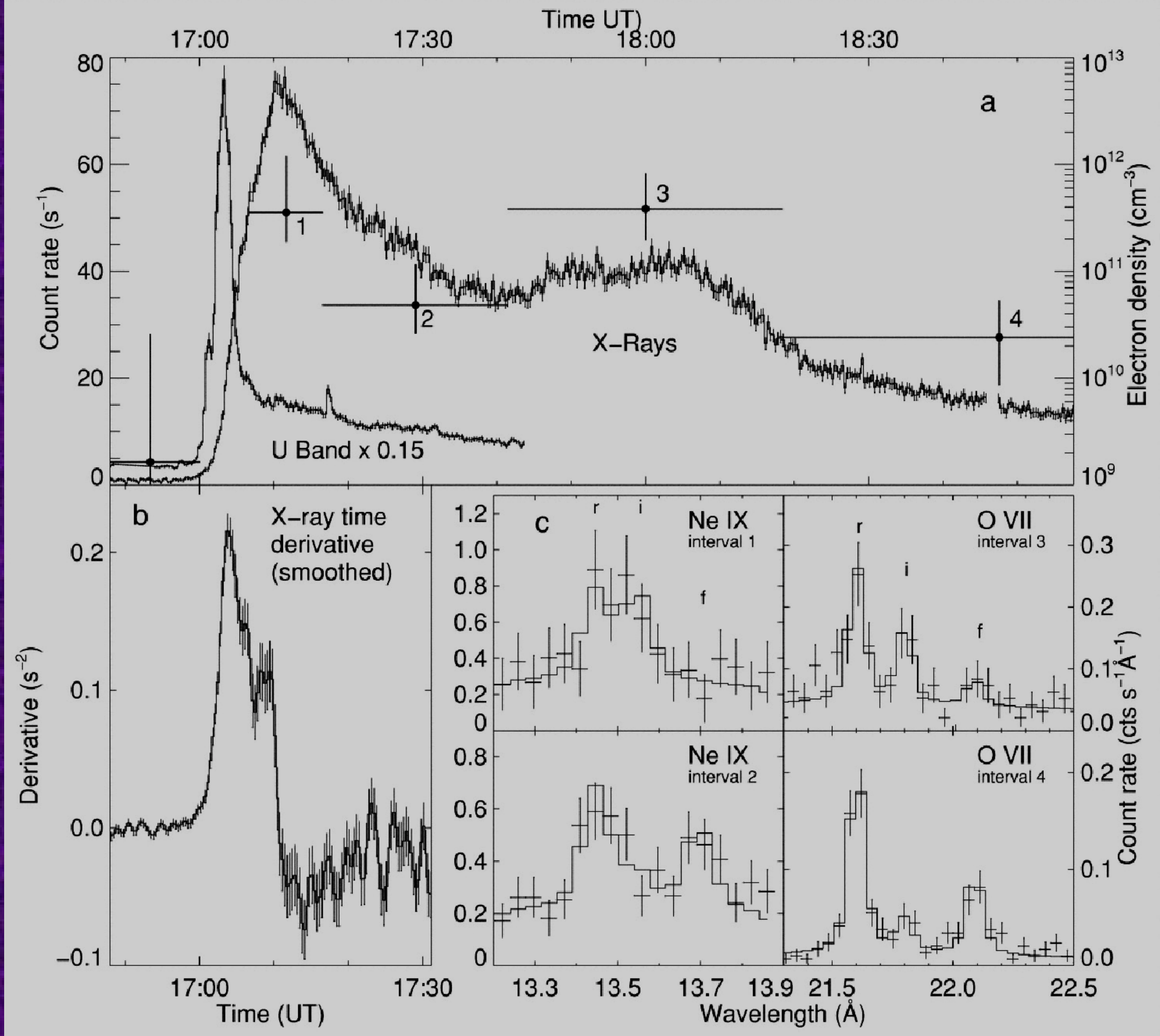
1144 proton (E ≥ 10 MeV) flares during 1975-2003 –

41 events per year (Belov et al., 2005).

The Young Sun could demonstrate superflares

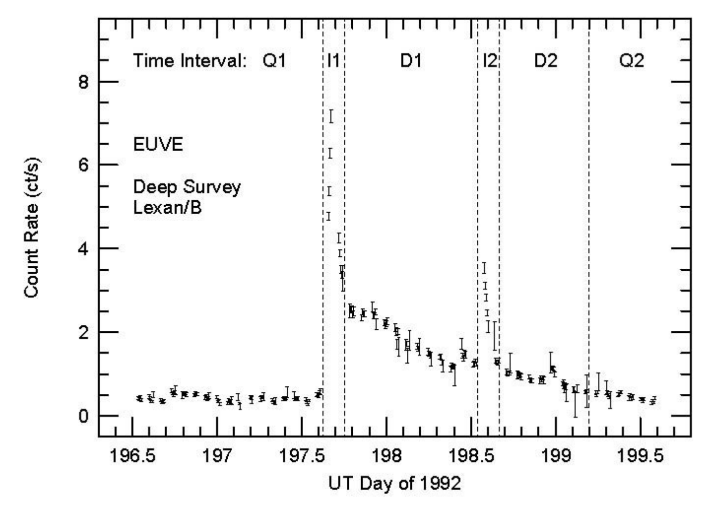
with E ≤ 10^34 erg

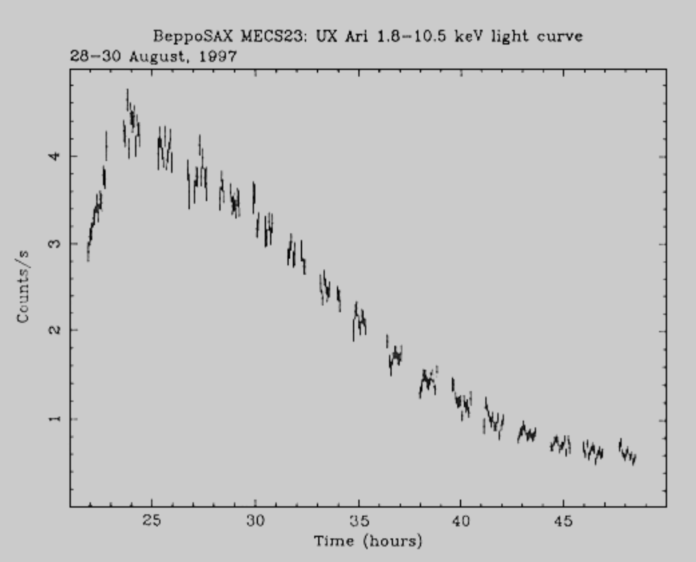
The Flare on Proxima Centauri = α Cen C (dM 5e)



- ***XMM-Newton :***
- ***This is a stellar analog of the typical large X-class flare on the Sun***
- ***12.08.2001***
- ***Guedel M. et al. 2002, 2004***

Long-Duration Flares



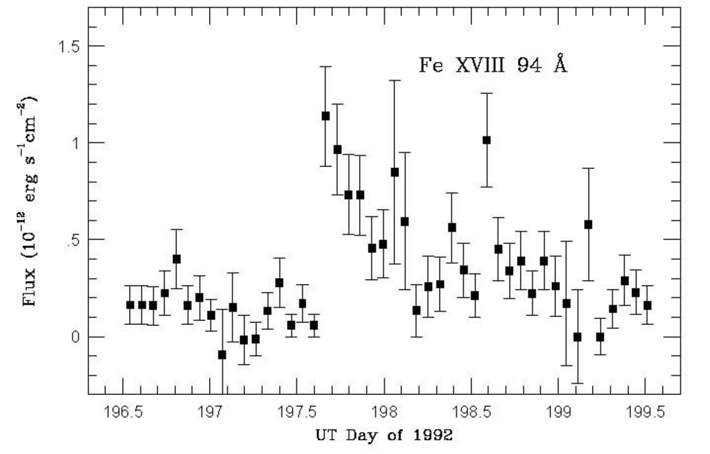


Extreme UV Explorer

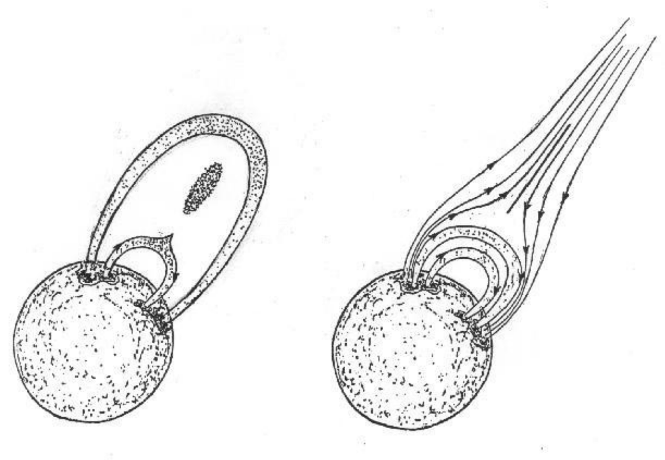
UX Ari: G5 V+K0 IV, Beppo SAX

I. Livshits, M. Livshits, R. Pallavicini

A&ATr 2001; АЖ 2002; AdvSpRes 200



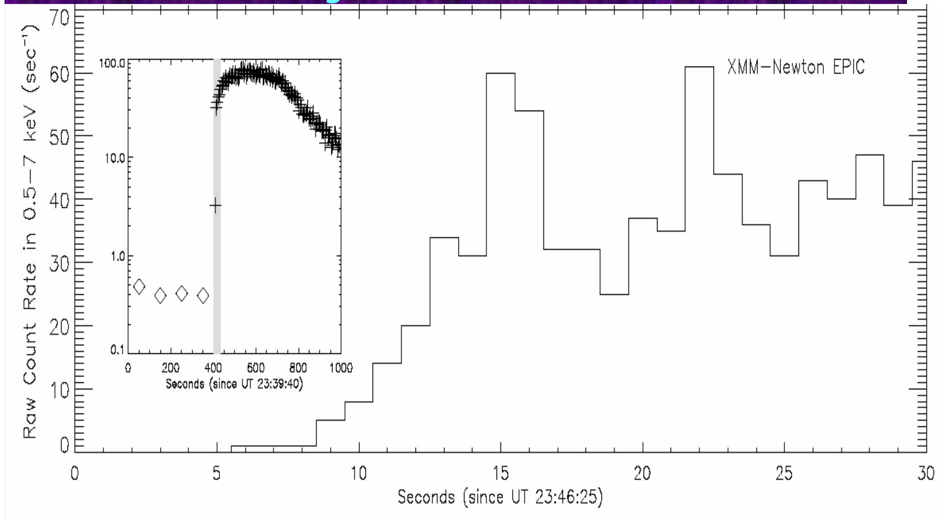
AU Mic
(dM2.5e)
1992,
15-17 July

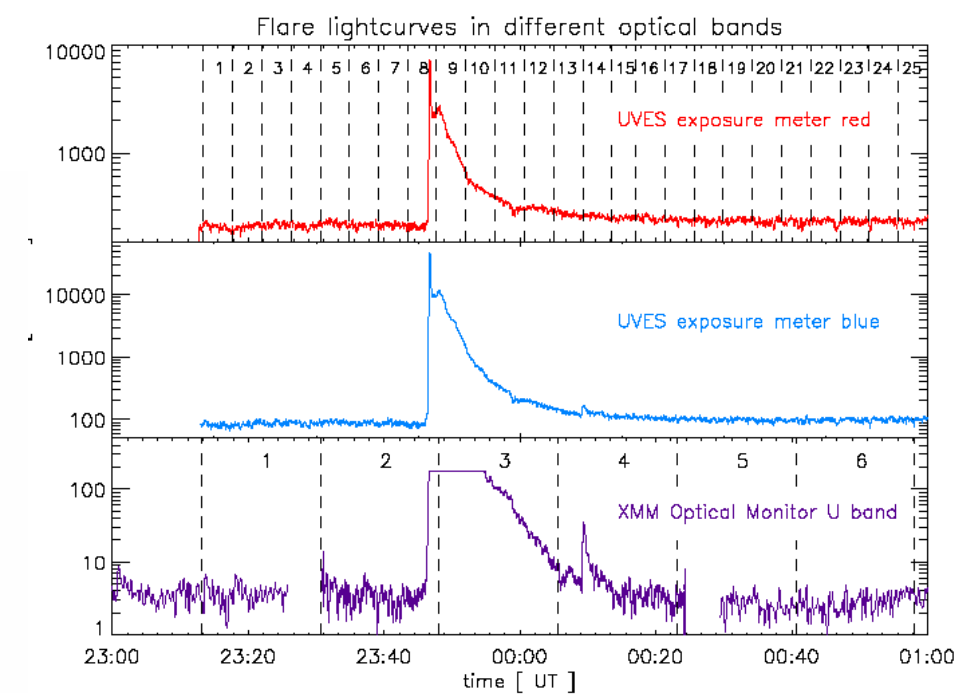


M. M. KATSOVA, J. J. DRAKE,
AND M. A. LIVSHITS, ApJ, 1999

Flare on CN Leo (dM 6e)

May 19th, 2006





X-Ray radiation : the pulse – 2 peaks with 5-6 s distance, the maximum after 200 s, total duration > 600 s (XMM-Newton).

Spectra: Ultraviolet-Visual Echelle Spectrograph (UVES)

6400 Å - 10080 Å, 3050 Å - 3860 Å , spectral resolution about 40000, the temporal resolution 100 s and 2000 s relatively.

Photometry: ground-based and onboard: Δ U>7^m with 1s-resolution.

When the total energy of a stellar flare exceeds 10^34 ergs, similar to this case, the nature of such an event differs from the solar–like processes: explosion of the plasma in the optical flare source. Kepler-case !

Maehara et al. 2015 : 1547 single solar-like stars
with 5300 K $< T_{eff} <$ 6300 K and $4.0 < \log g < 4.8$.

187 flares with the total energy from 2×10^{32} erg to 8×10^{35} erg
were registered in the only 23 such stars

The mean flare occurrence frequence
for events with the total energy

10^{33} erg – one event per 70 years,
10^{34} эрг occurs once in about 500 years
10^{35} эрг – once in about 4000 years

The average rate of appearance of an X100 class flare on a star with P_rot = 25 days, like the Sun, is one event in 500-600 years

Only 0.2 to 0.3% of solar-type stars show superflares .

On the origin of superflares on G-type stars of different ages and their maximum energy see

Katsova & Livshits Solar Phys. 2015 V. 290 P. 3663

Meaning and Consequences

- *Initial conditions in a proto-star rule a scenario of further evolution of activity. The stellar mass determines a depth of the convection zone. Relationship between chromospheric and coronal activity levels depends on the depth of the convection zone, i.e. it is changed vs spectral class.*
- *The saturated regime of activity changes at earlier epochs of evolution to the solar-type activity and it occurs at various rotation periods for G-, K- and M stars.*
- *If to suppose that local magnetic fields are generated in sub-photospheric layers and large-scale fields are originated in a tachocline, then it is possible to trace a relative input of every of scales on the first branch.*
- *Cyclic activity is formed simpler during interaction between rotation and small-scale convection (as it follows from dynamo theory). Therefore, on the Sun large-scale magnetic field does yet rule activity, but it differs from cyclic activity of K stars with "Excellent" cycles.*
- *For further progress, it requires specific long-term monitoring of stellar magnetic fields including Zeeman Dopler Imaging.*

Thanks for your attention!