FFG institut für astrophysik UNIVERSITÄTSSTERNWARTE WIEN PatH universität wien IWF INSTITUT FÜR WELTRAUMFORSCHUNG

Evolution of stellar magnetic fields

and their influence on the habitability of surrounding planets

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and the PatH Collaboration

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PLATO Mission Conference 2017, Warwick, 06 September 2017

www: path.univie.ac.at

FWF NFN

Pathways to Habitability
From Disk to Stars, Planets to Life

Manuel Güdel,

David Bancelin, Sudeshna Boro Saikia, Mohammed Boudjada, Christoph Burger, Ernst Dorfi, Rudolf Dvorak, Siegfried Eggl, Colin Johnstone, Maxim Khodachenko, Bibiana Fichtinger, Markus Gyergyovits, Michael Kapper, Luca Fossati, Kristina Kislyakova, Helmut Lammer, Monika Lendl, Herbert Lichtenegger, Elke Pilat-Lohinger, Birgit Loibnegger, Theresa Lüftinger, Thomas Maindl, Michael Panchenko, Yury Sasunov, Manuel Scherf, Daniel Steiner, Alexander Stökl, Lin Tu, Eduard Vorobyov

DISKS, WATER, STARS, MAGNETOSPHERES, ATMOSPHERES, BINARY STARS

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ÖAW Österreichische Akademie der Wissenschaften

IWF Institut für Weltraumforschung

UNI GRAZ

ICAM

photo credit: Jenny Mottar

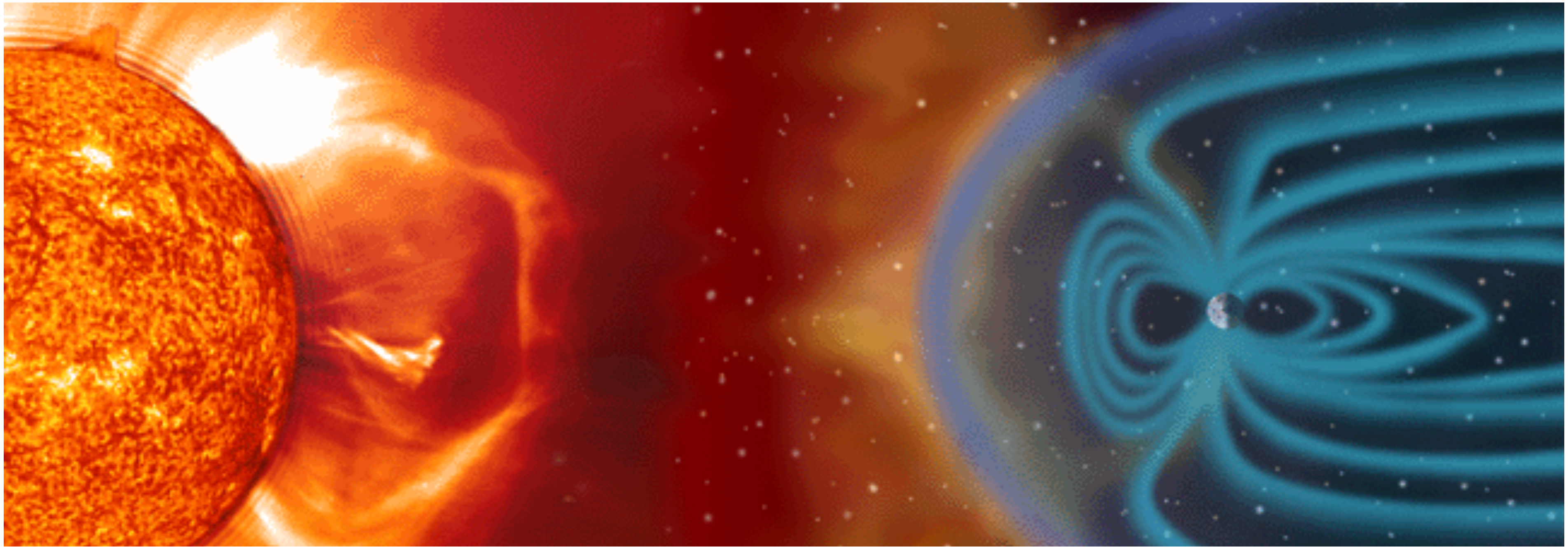
Stars – Shaping their planetary environments

Stellar activity

- Flares, Coronal Mass Ejections (CME's),
- High-energy radiation: UV, EUV, X-rays,
- Stellar Winds

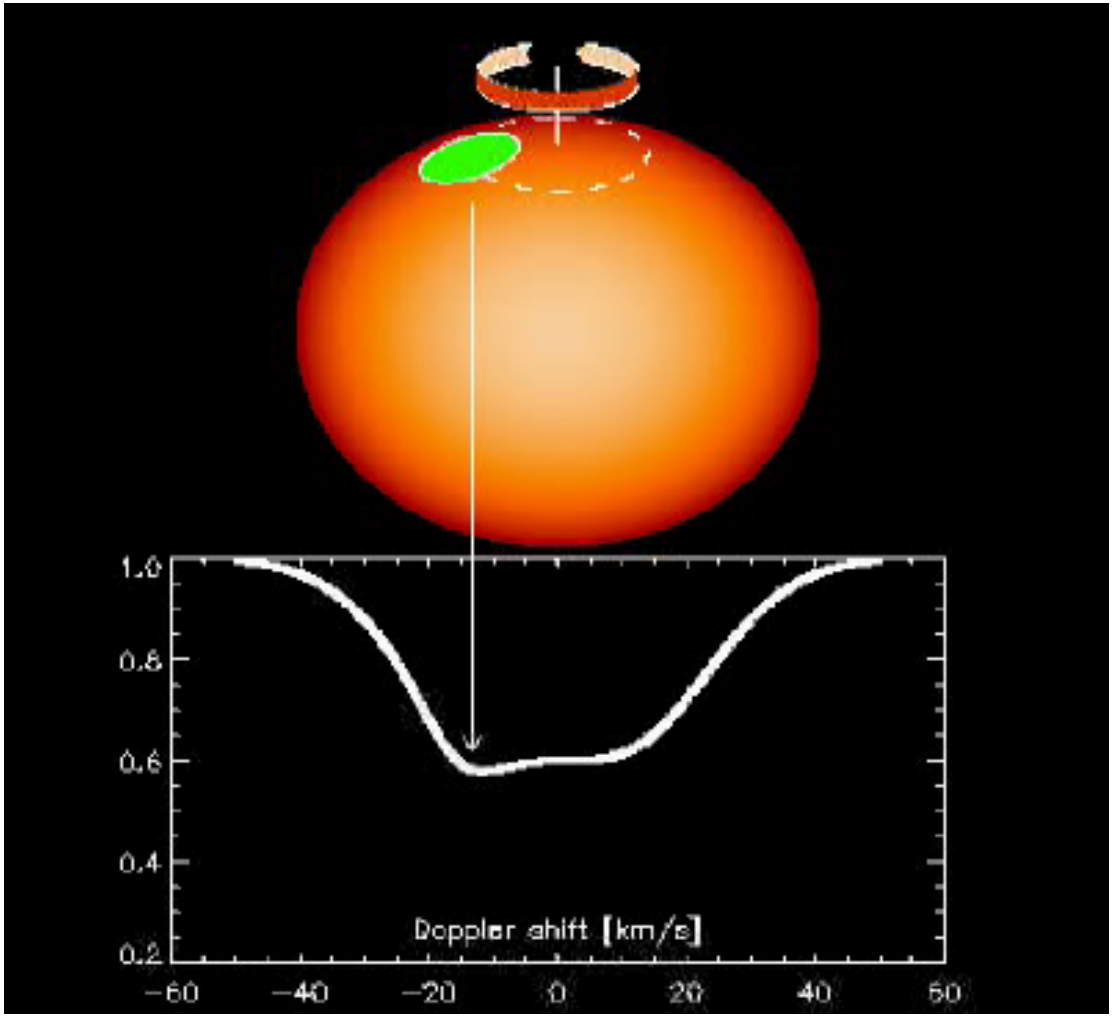
All triggered by the stellar magnetic field

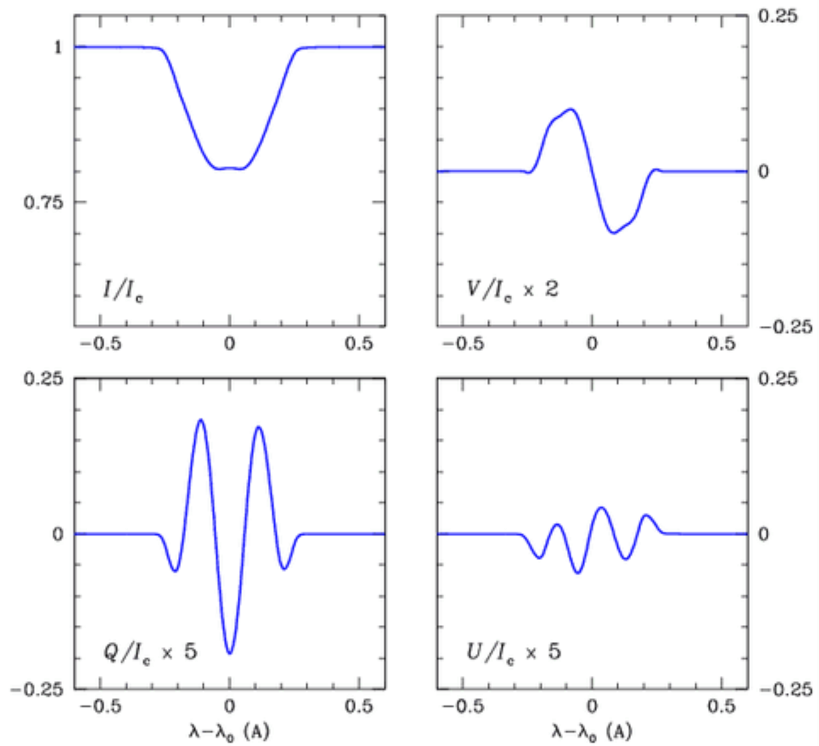
- Radiation-atmosphere interaction
- Magnetosphere-wind interaction
- Magnetosphere-atmosphere system



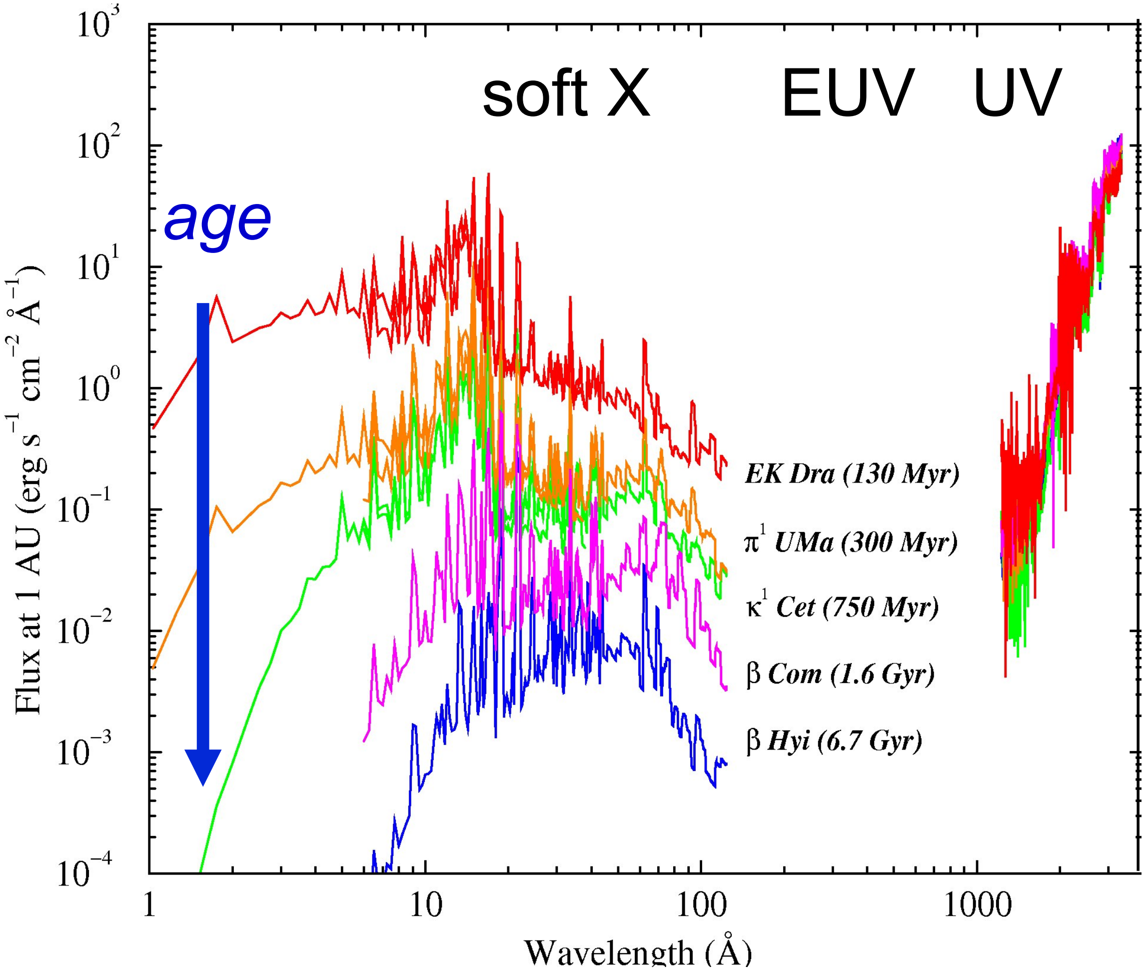
drive atmospheric chemistry and erosion

Zeeman Doppler Imaging





The EUV and X-Ray Sun in Time

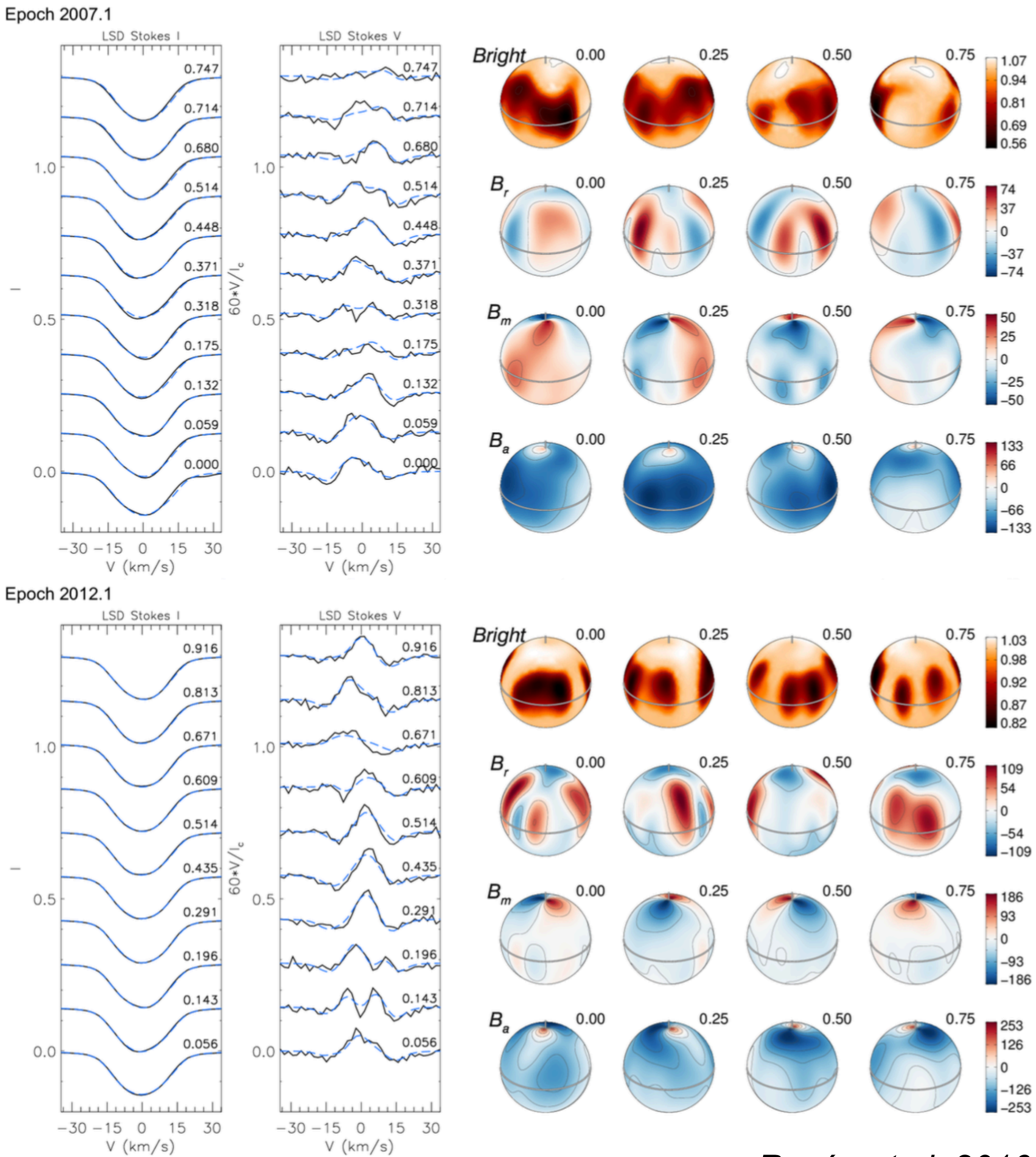


Guinan & Ribas 2002, ASP Conference Proceedings, Vol. 269, 85
Güdel 2004, A&A Review, 12, 71
Ribas et al. 2005, APJ, ApJ, 622, 680; Claire et al. 2012, ApJ, 757, 95

Luminosity (and hardness) decay
more rapidly over much larger scale in X-ray than in UV

ZDI of Young Suns

Stellar surface magnetic field distribution: EK Dra



Rosén et al. 2016

Star	Age (Myr)
EK Dra	100
HN Peg	230
π^1 Uma	270
χ^1 Ori	300
BE Cet	500
κ^1 Cet	600

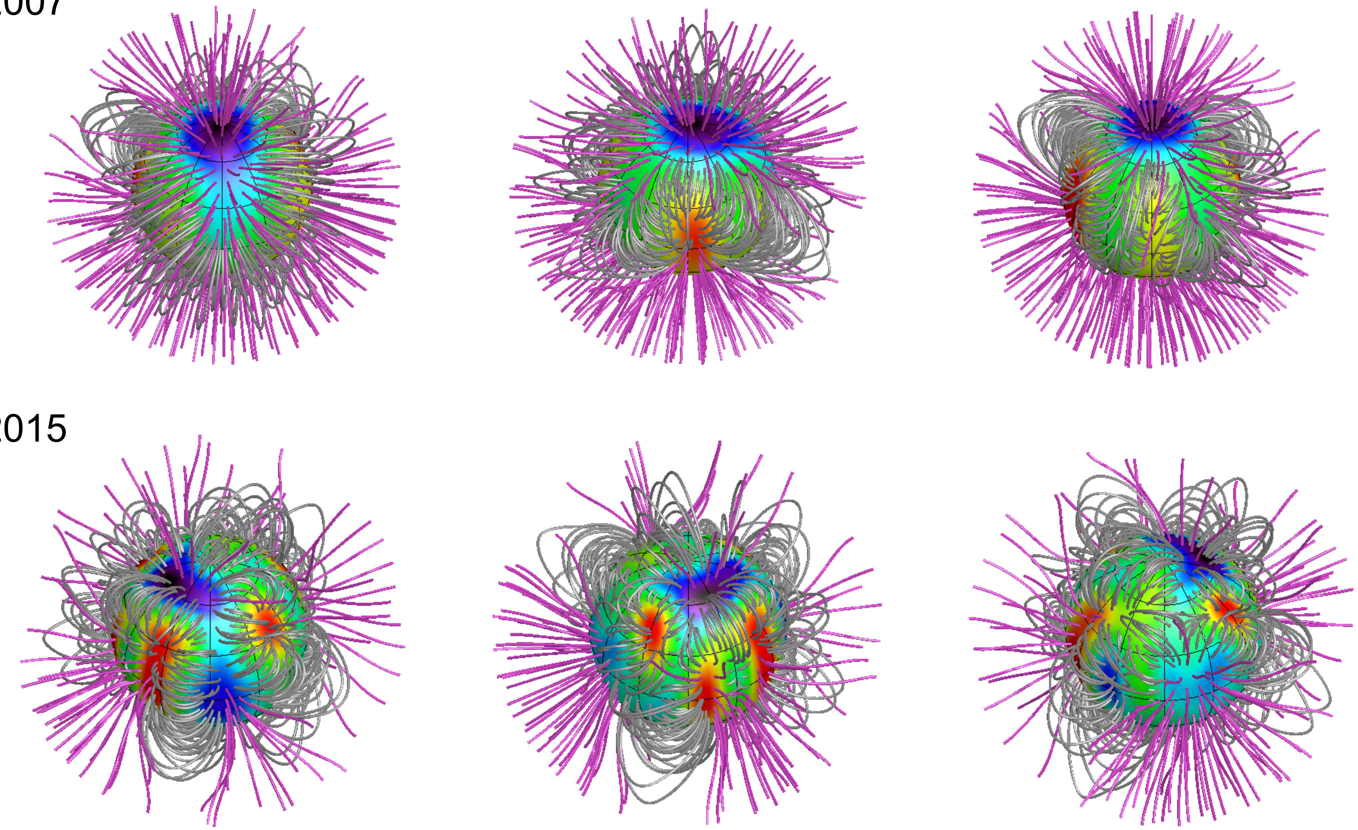
ZDI of Young Suns

Stellar surface magnetic field distribution: π[1] UMa

π[1] UMa

2007

2015



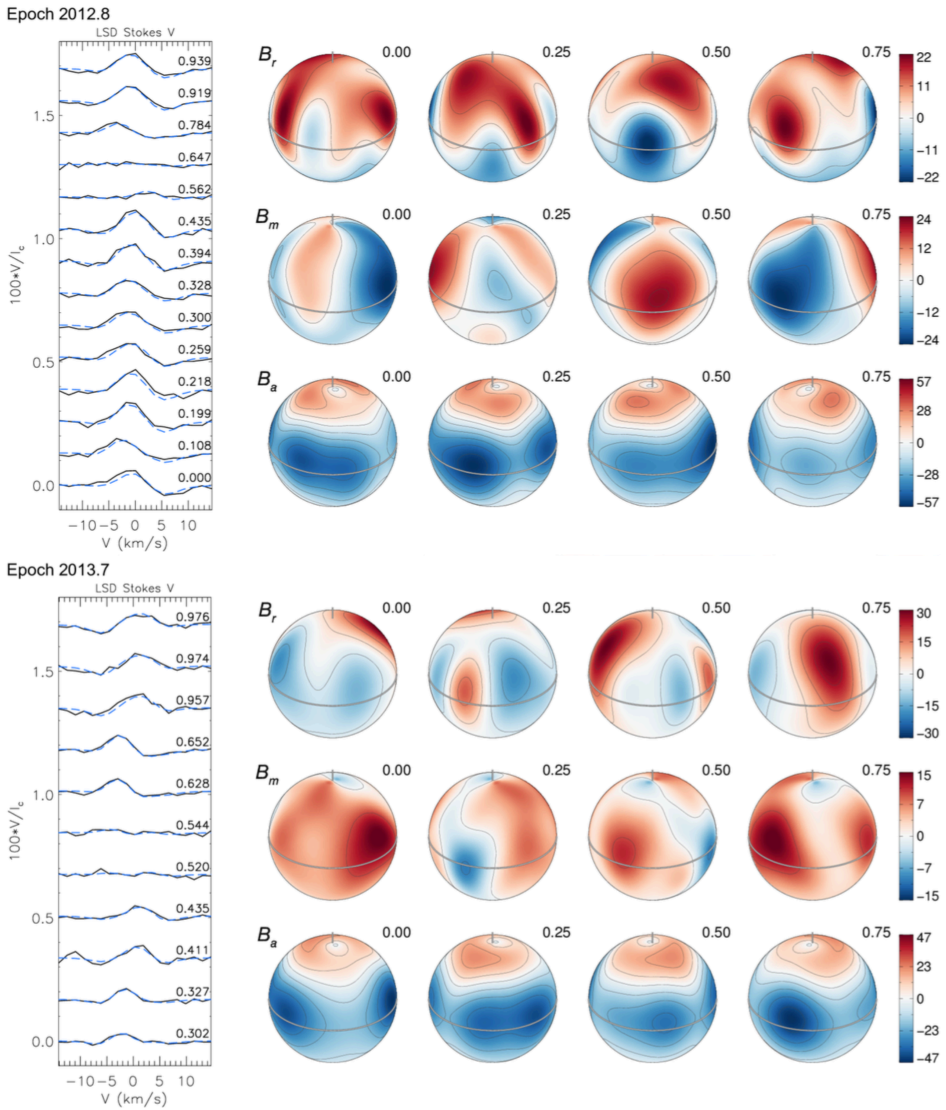
ph = 0.000 ph = 0.250 ph = 0.500

Star	Age (Myr)
EK Dra	100
HN Peg	230
π[1] Uma	270
χ[1] Ori	300
BE Cet	500
κ[1] Cet	600

Lüftinger et al. 2017, Rosén et al. 2016

ZDI of Young Suns

Stellar surface magnetic field distribution: κ^1 Cet



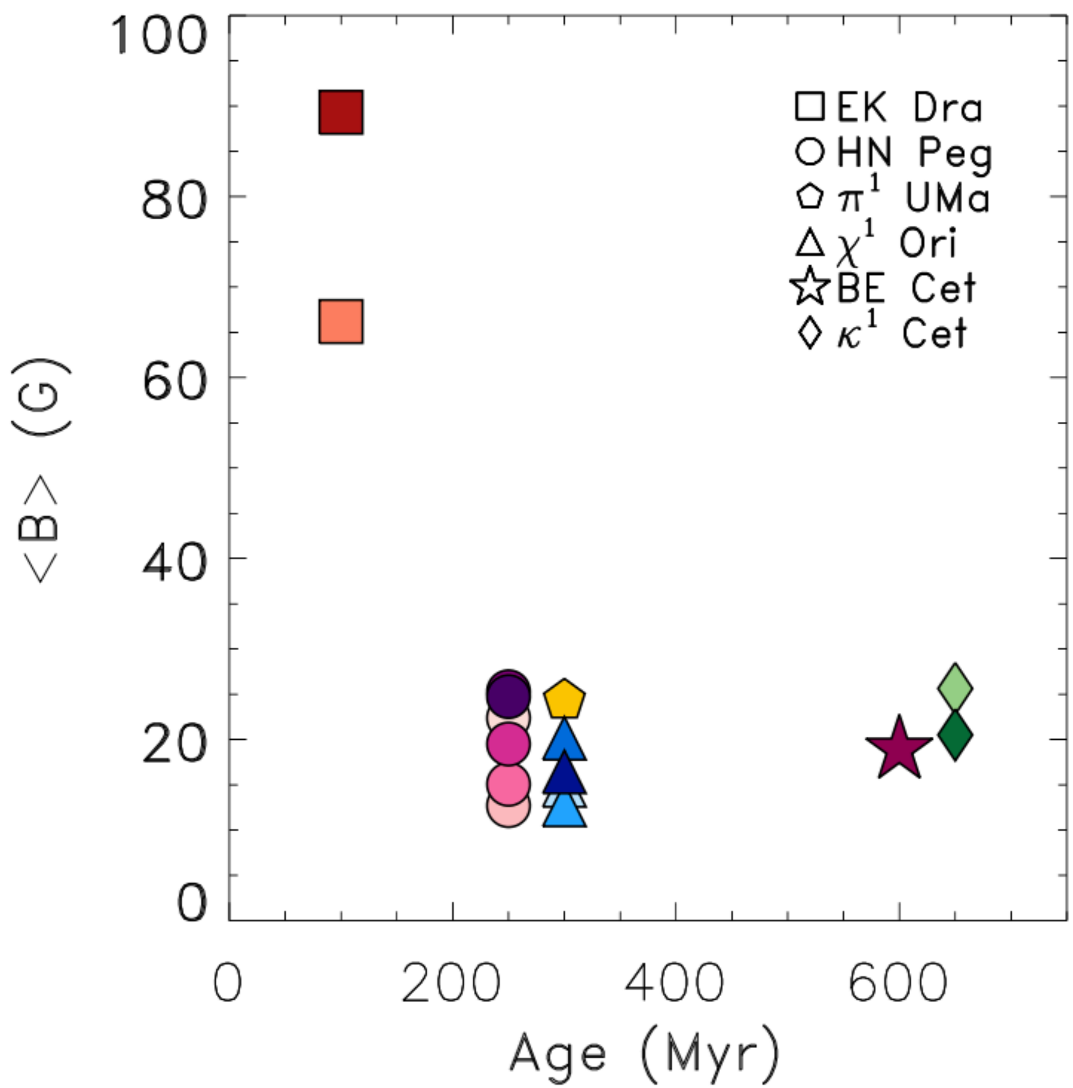
Star	Age (Myr)
EK Dra	100
HN Peg	230
π^1 Uma	270
χ^1 Ori	300
BE Cet	500
κ^1 Cet	600

Rosén et al. 2016,

see also
do Nascimento, 2016

ZDI of Young Suns

Mean magnetic field as a function of age



Star	Age (Myr)
EK Dra	100
HN Peg	230
π¹ Uma	270
χ¹ Ori	300
BE Cet	500
κ¹ Cet	600

ZDI of Young Suns

Points to mention

- χ^1 Ori shows two polarity switches -> period of 2 years, or 6,8 depending on what was happening during 2008.8 to 2010.8.

- Stars in the sample do not all have the same cycle (κ^1 Cet and EK Dra cannot have a two year cycle), if any, and those are not necessarily equal to the solar cycle -> could mean that the sun used to have a different cycle length (when it was younger) than now.

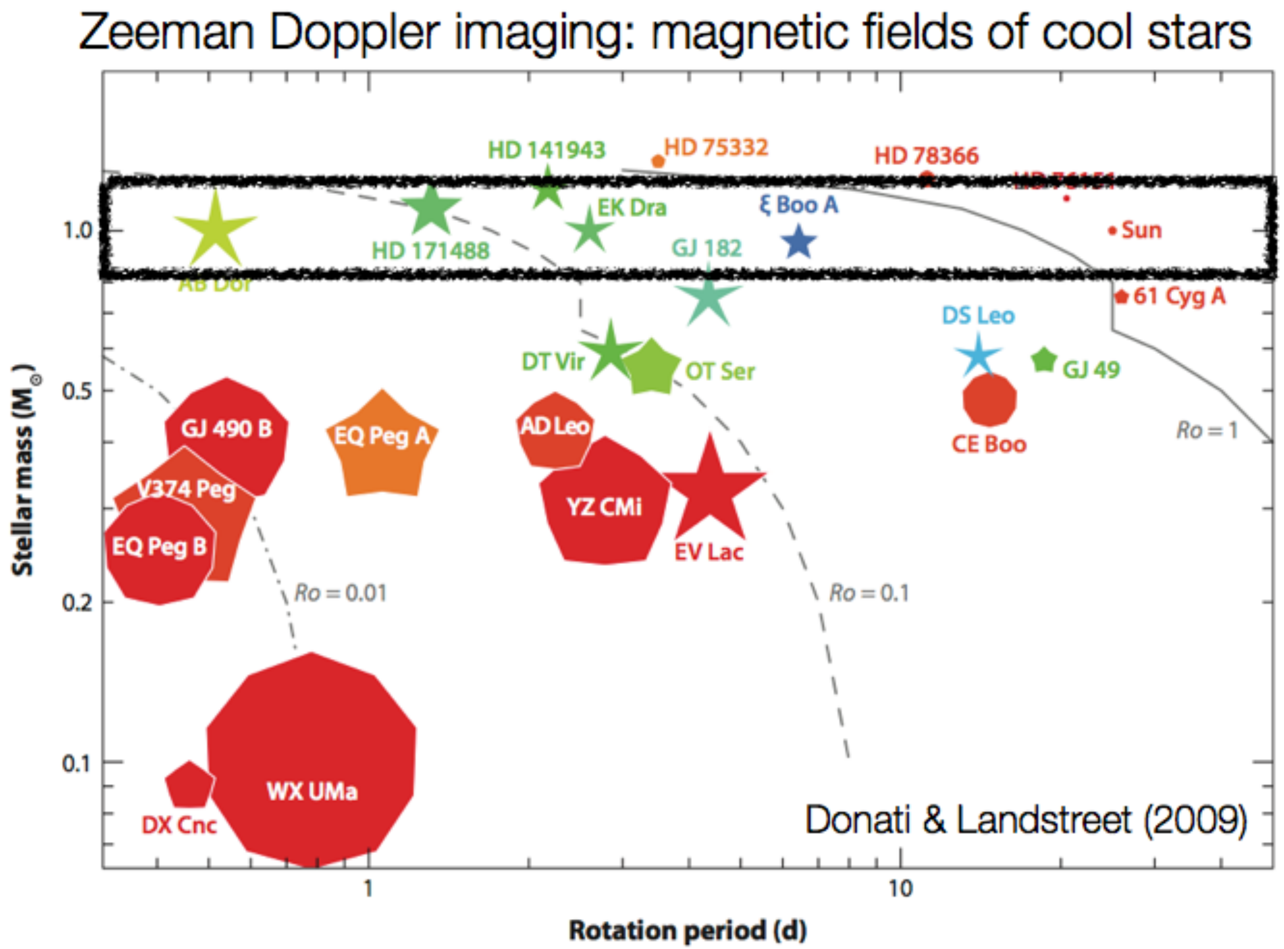
- BE Cet, κ^1 Cet: octupole component twice as large as quadrupole component.

- field topology of rapidly rotating young-solar mass stars: can either be dominantly toroidial or poloidal: the youngest and oldest star seem to have similar field configurations; field topologies also vary significantly for the same star at different observation epochs -> no definitive correlations between age and poloidal/ toroidal component fractions for the age range studied here.

- Younger stars tend to have larger l=2, than l=3, (comp. See et al. 2015 [E_{axis}/E_{tot} seems to always be larger or approximately equal to E_{tor}/E_{tot}]).

Magnetic Fields – shaping the Stars and Planets

Stellar magnetic field topology



- Size: intensity
- Colour:
  - poloidal
  - toroidal
- Shape:
  - ● axisymmetric
  - ★ non-axisym.

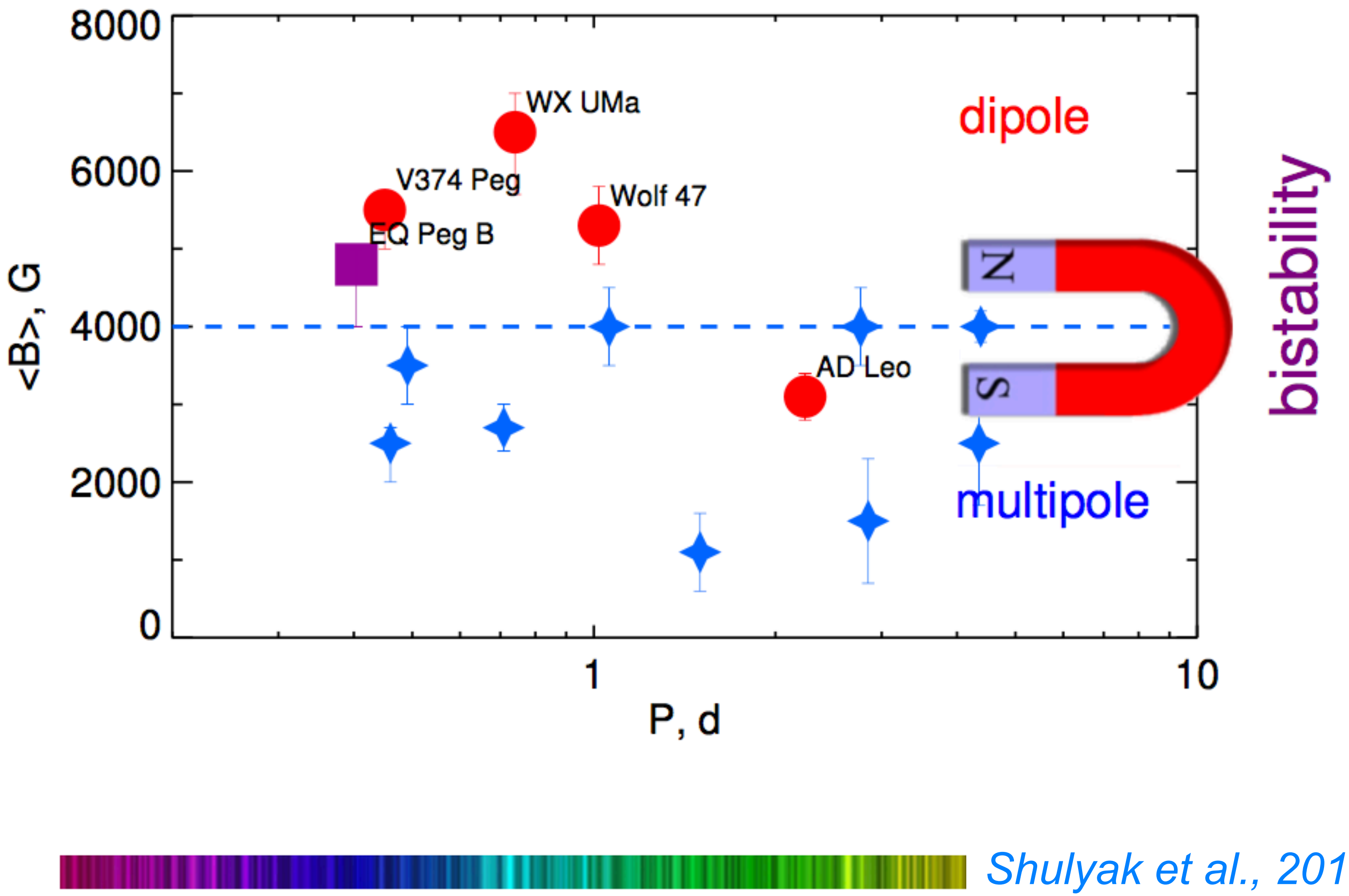
Variety of intensities and topologies

Donati et al., 2008

structure of stellar wind considerably different for different types of stars/stellar ages
➔ need statistical assessment to set conditions for habitable environments

M dwarfs – can have very different magnetic fields

Magnetic field vs. Rotation



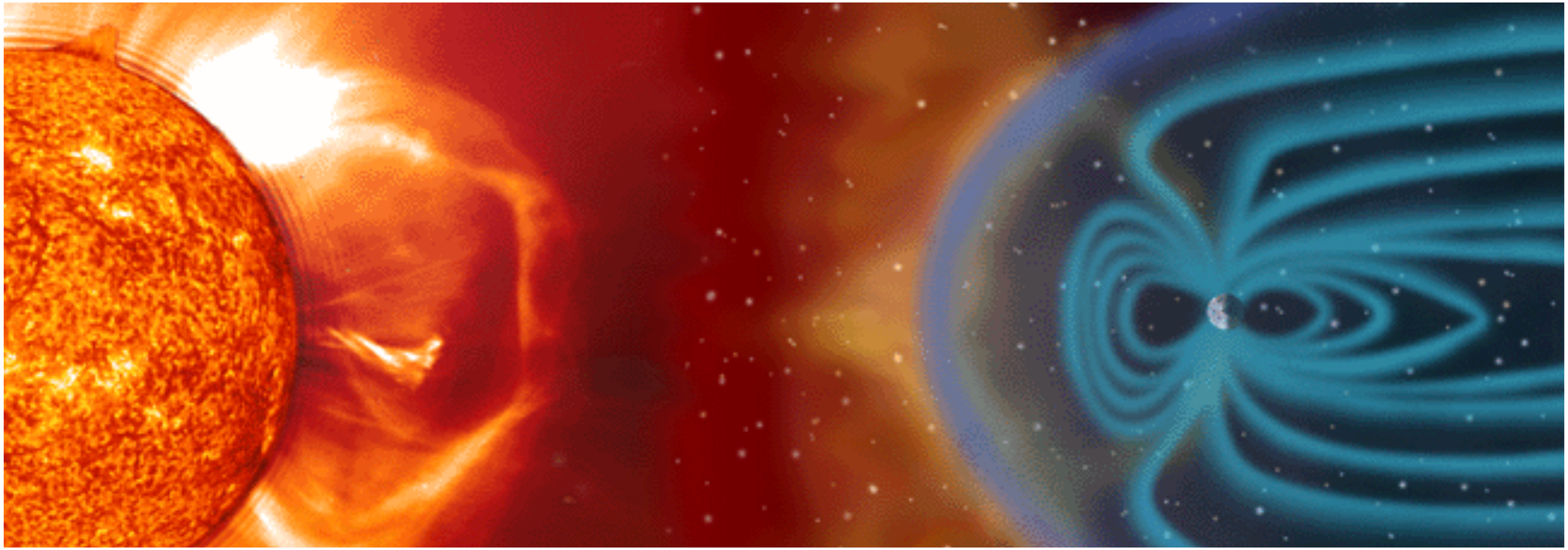
Shulyak et al., 2017

fields of fully convective M dwarfs can get up to ~ 6.4 kG
➔ totally different, probably very harsh, conditions for planets and their atmospheres

Stars and their magnetic fields – Shaping planetary environments

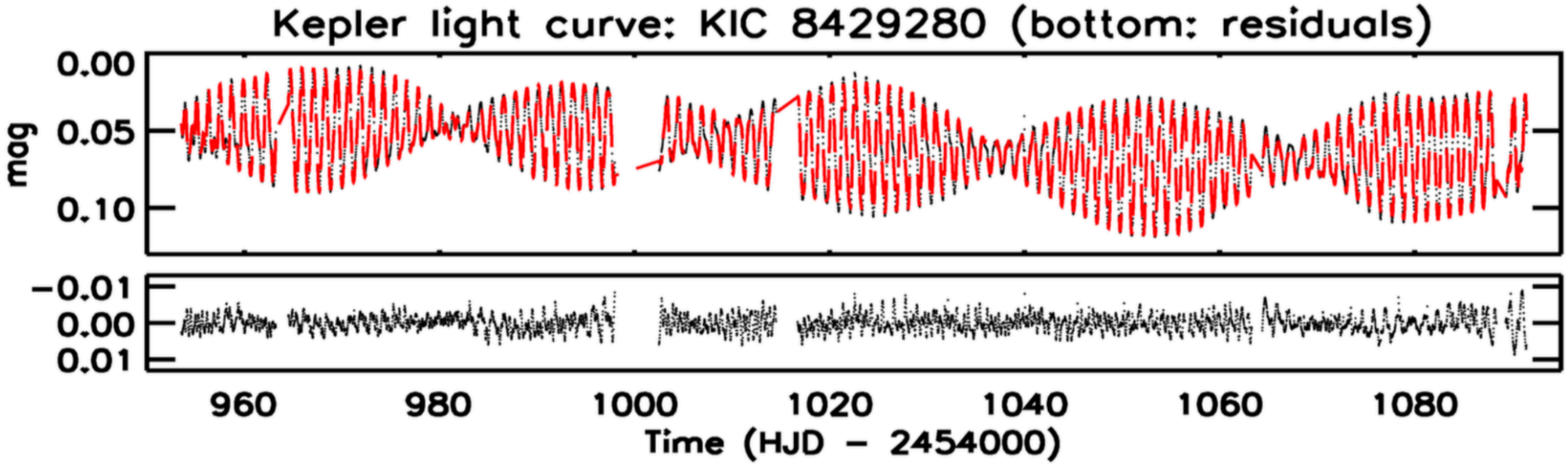
Magnetic fields, stellar activity

- Want to put this on an (even better) statistically significant basis
- PLATO data – also from ground? - has the potential to contribute a lot!
- Follow up program also in spectropolarimetry?

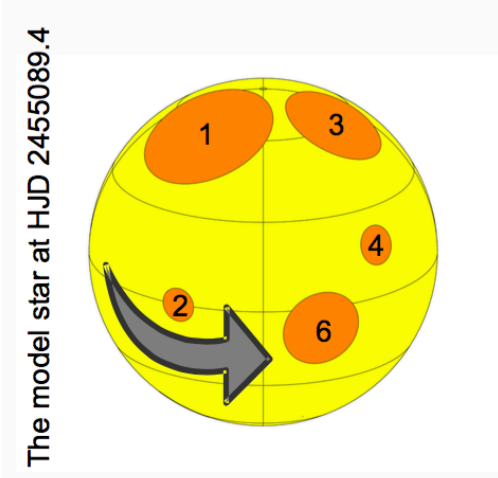


drive atmospheric chemistry and erosion

Bayesian approach to spot modelling: Kepler photometry



Q0+Q1+Q2 data of KIC 8429280, a young K2 V star (< 50 Myr), chromospherically active and fast rotating (v*sini* = 37+/-3 km/s)



best fit spot model based on Bayesian analysis:

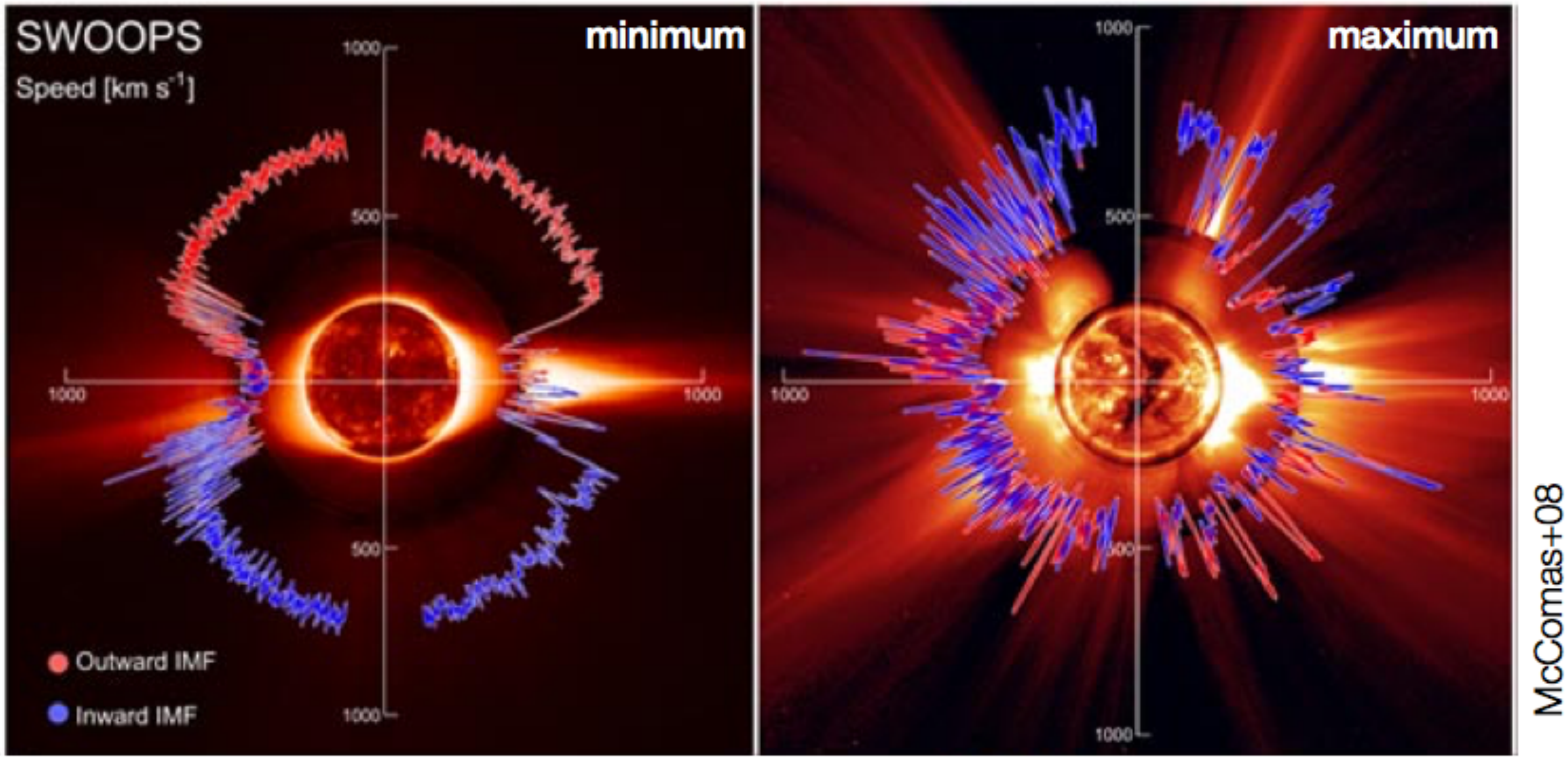
- 6 spots, as depicted in the left figure
- solar like differential rotation surprisingly large:
  -0.2656 (+0.0012, -0.0011*) rad/d*

➔ *PLATO photometry!*

Effects of the field geometry on winds

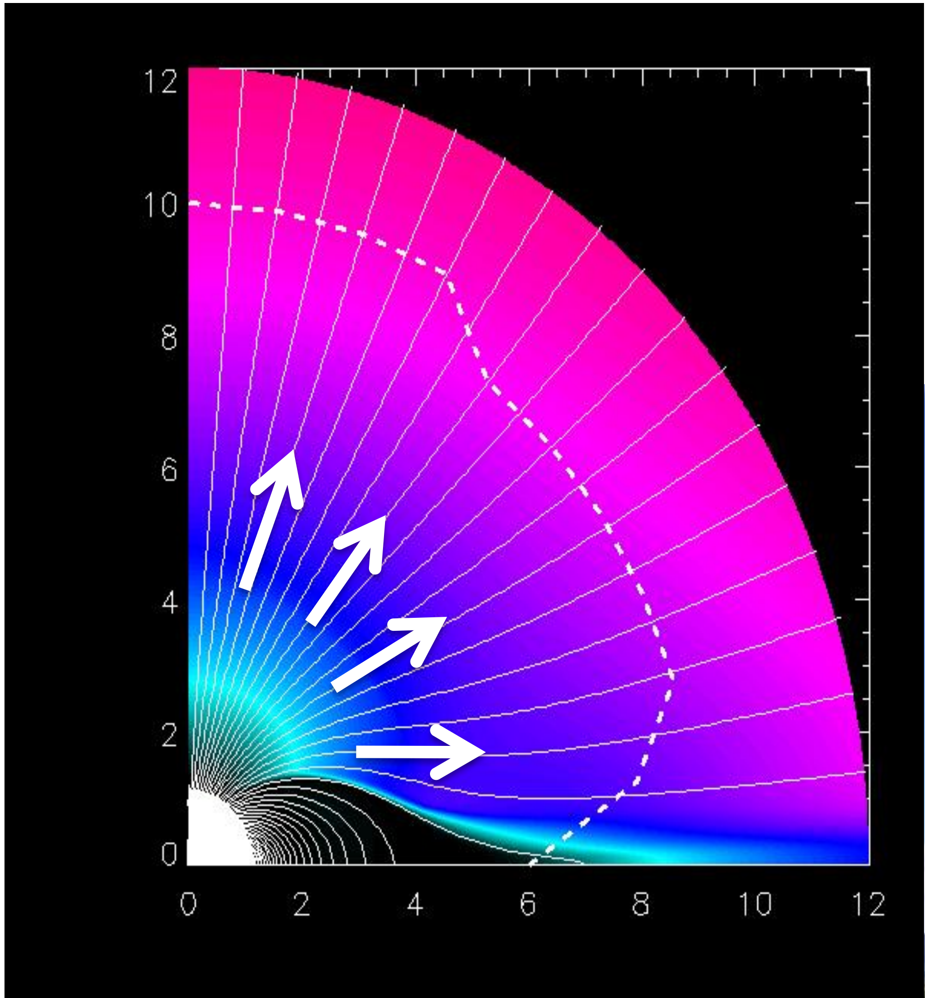
- Stellar wind structure depends on the stellar magnetic field

Solar wind as measured by Ulysses



courtesy: A. Vidotto

Observing Stellar winds - indirectly



- attempts to directly detect thermal Bremsstrahlung radiation in radio from these winds: **non-detections give important upper limits** on the wind strengths

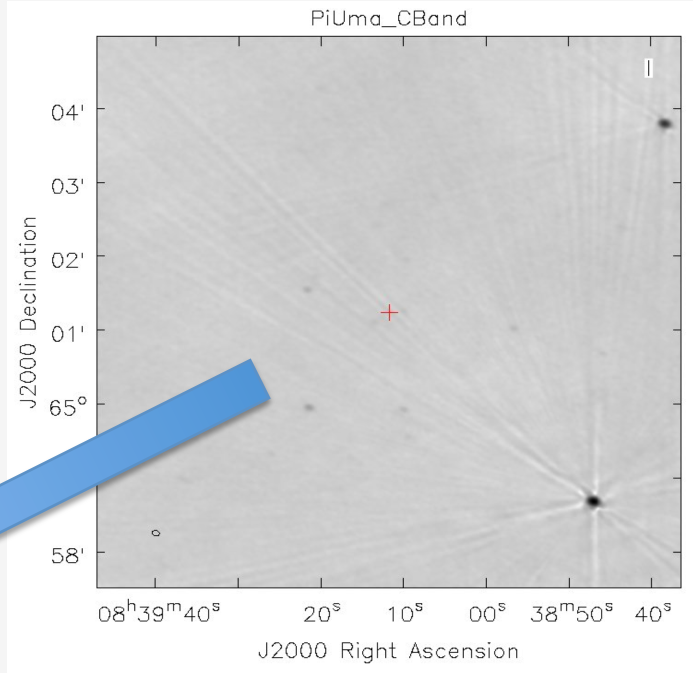
Mass loss rate estimates

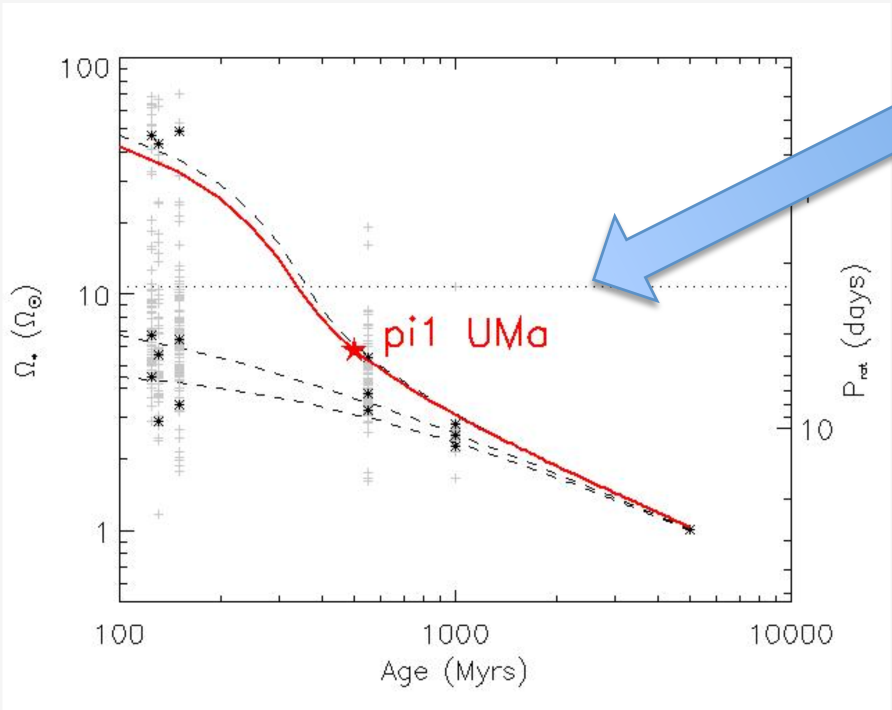
- kappa Cet:

  $M_{dot} < 4.1 \times 10^{-12} M_{sun}/yr$
- pi^1 UMa:

  $M_{dot} < 5.0 \times 10^{-12} M_{sun}/yr$

Fichtinger et al., 2017





ESPaDOnS/NARVAL observations of:

EK Dra (100 Myr),
χ^1 Ori (300 Myr)
κ^1 Cet (700 Myr)
pi1 UMa, new set in 2015

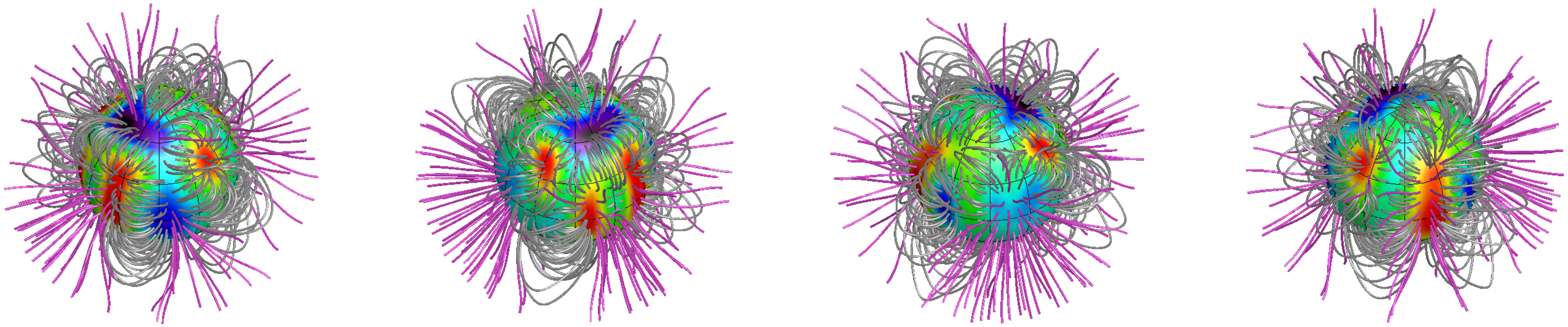
➔ **ZDI**

for wind calculations on κ^1 Cet also see Airapetian & Usmanov 2016

Couple the Whole System

Stellar surface magnetic field distribution

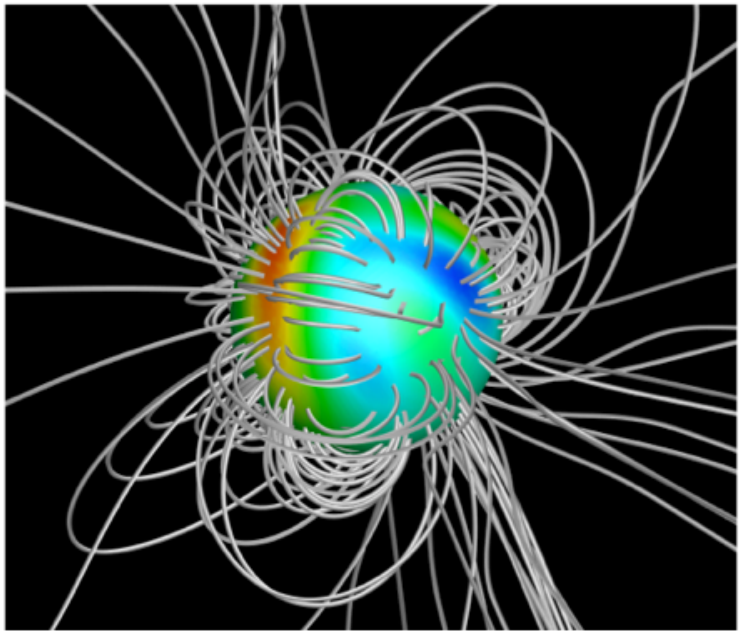
π¹ UMa



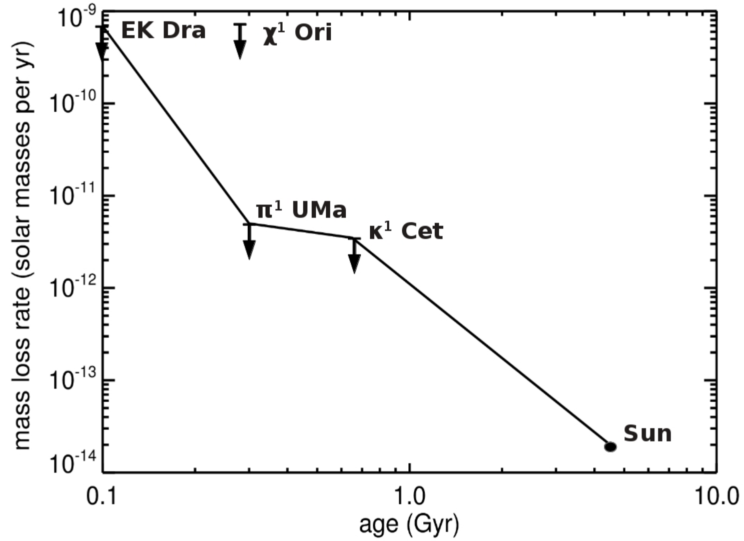
ph = 0.000 ph = 0.250 ph = 0.500 ph = 0.750

(Lueftinger et al. 2017)

wind structure around the Young Sun π¹ UMa



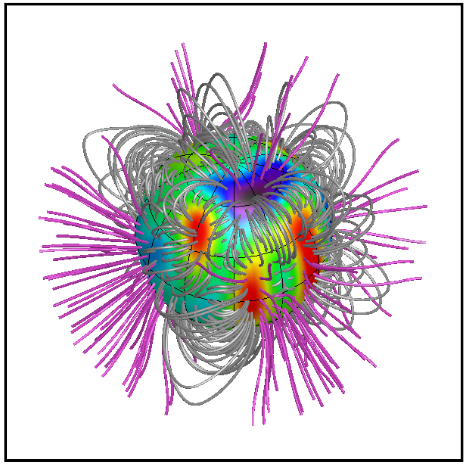
Observations of winds

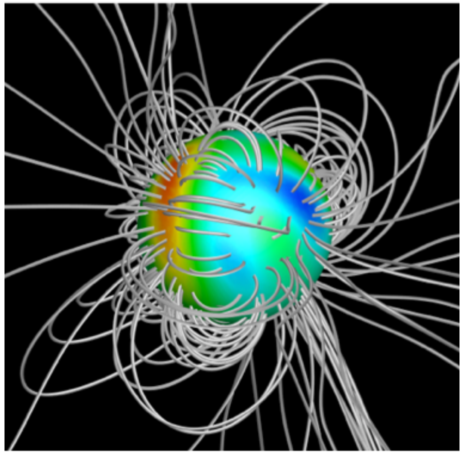


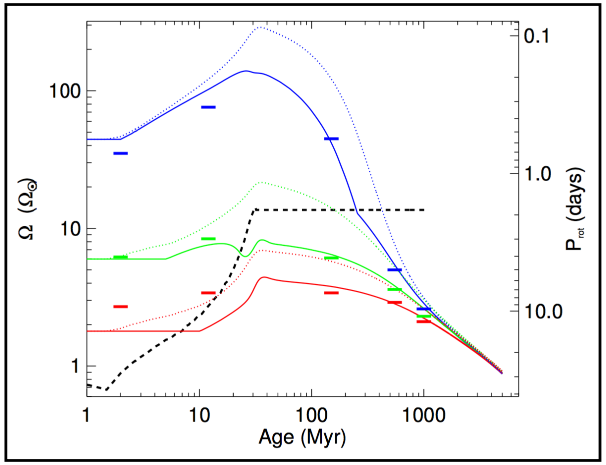
Fichtinger et al. 2017

Our Research Network: Pathways to Habitability

A complete model for magnetic fields, spin-down and winds:





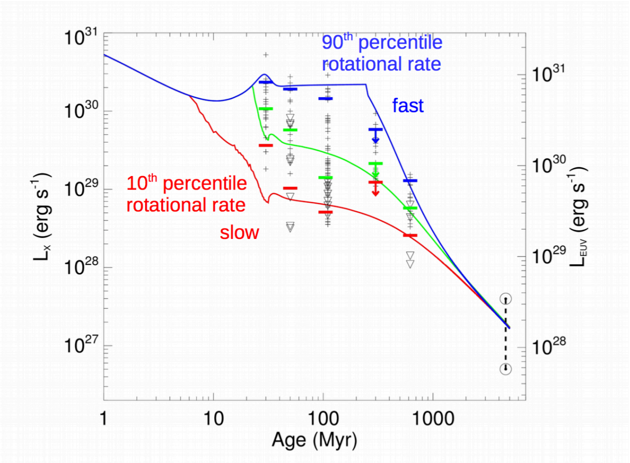


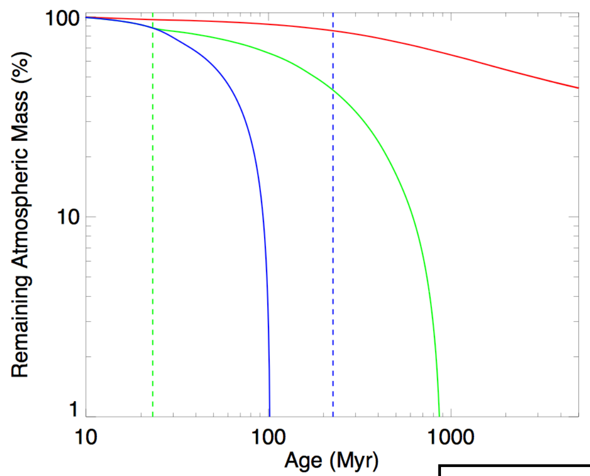
"All ages" (10 Myr – 10 Gyr):	Include pre-main sequence evolution
"All masses" (0.1-1.5$M_{\odot}$):	Including fully convective stars
"All initial conditions":	Use observed rotation distributions
"Detailed physics":	Core-envelope decoupling in star
	Role of coronal mass ejections

Required to model atmospheric irradiation and planetary wind interactions

Putting it all together:

coupled stellar + atmospheric evolution





Tu et al. 2015

- H protoatmospheres
- N_2/CO_2/H_2O secondary atmospheres

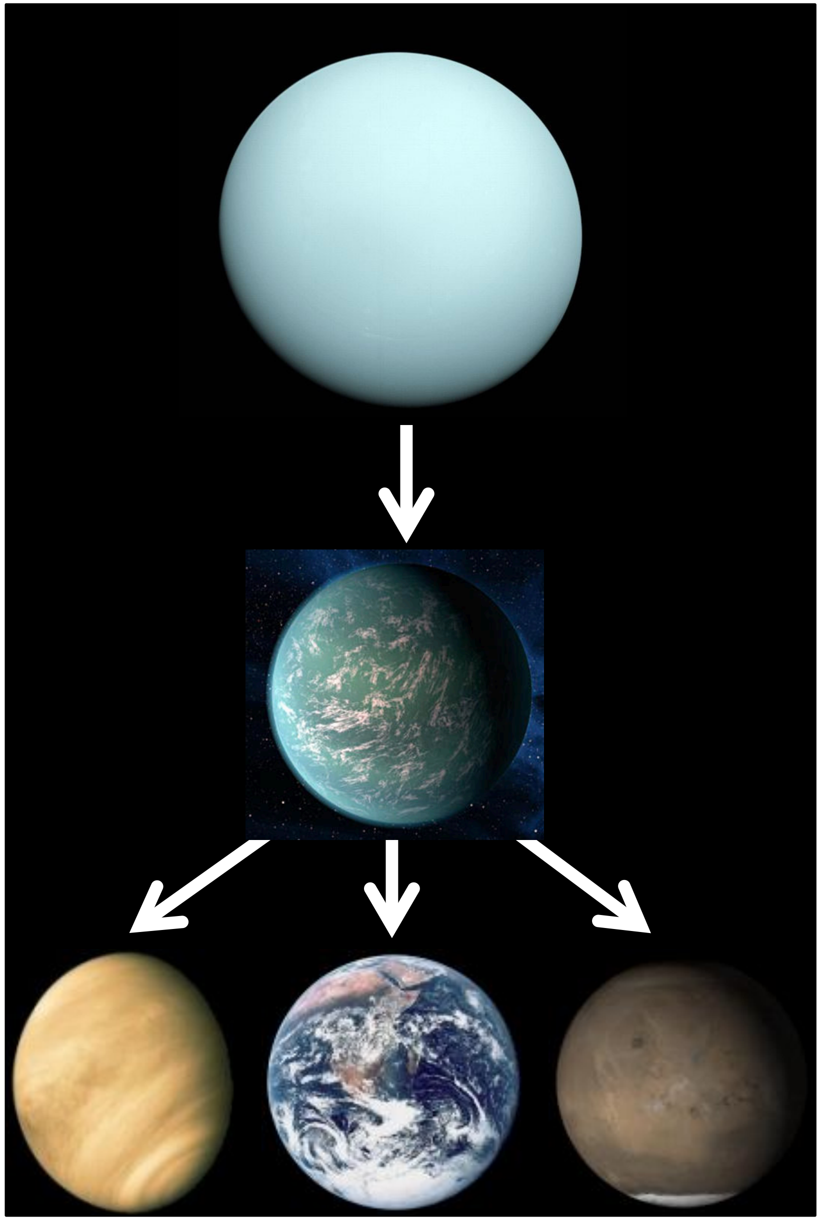
atmospheric evolution models:

VENUS/EARTH/MARS

Constrain early solar system conditions!

Constrain conditions in the habitable zones of G - M stars

Talk of M. Guedel

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THANK YOU!!!
Theresa Lueftinger
and the PatH Collaboration
Department of Astrophysics, University of Vienna
2003/05/26 00:00

Bayesian approach to spot modelling with high PLATO - light curves

e.g. two spots on a stellar surface ➛

nine free parameters:

two periods, two epochs, two latitudes, two spot areas, and the star's inclination

splitting the nine-parameter problem (unsolvable) into two parts:

1. **finding the two periods and epochs (times of minimal light) - AMOEBA**
2. **scanning the remaining parameter space – FROEHLICH, BPI**
3. **Bayesian data analysis: the whole likelihood mountain is considered, integrating all parameters, except one, we obtain the marginal probability distribution of this parameter**

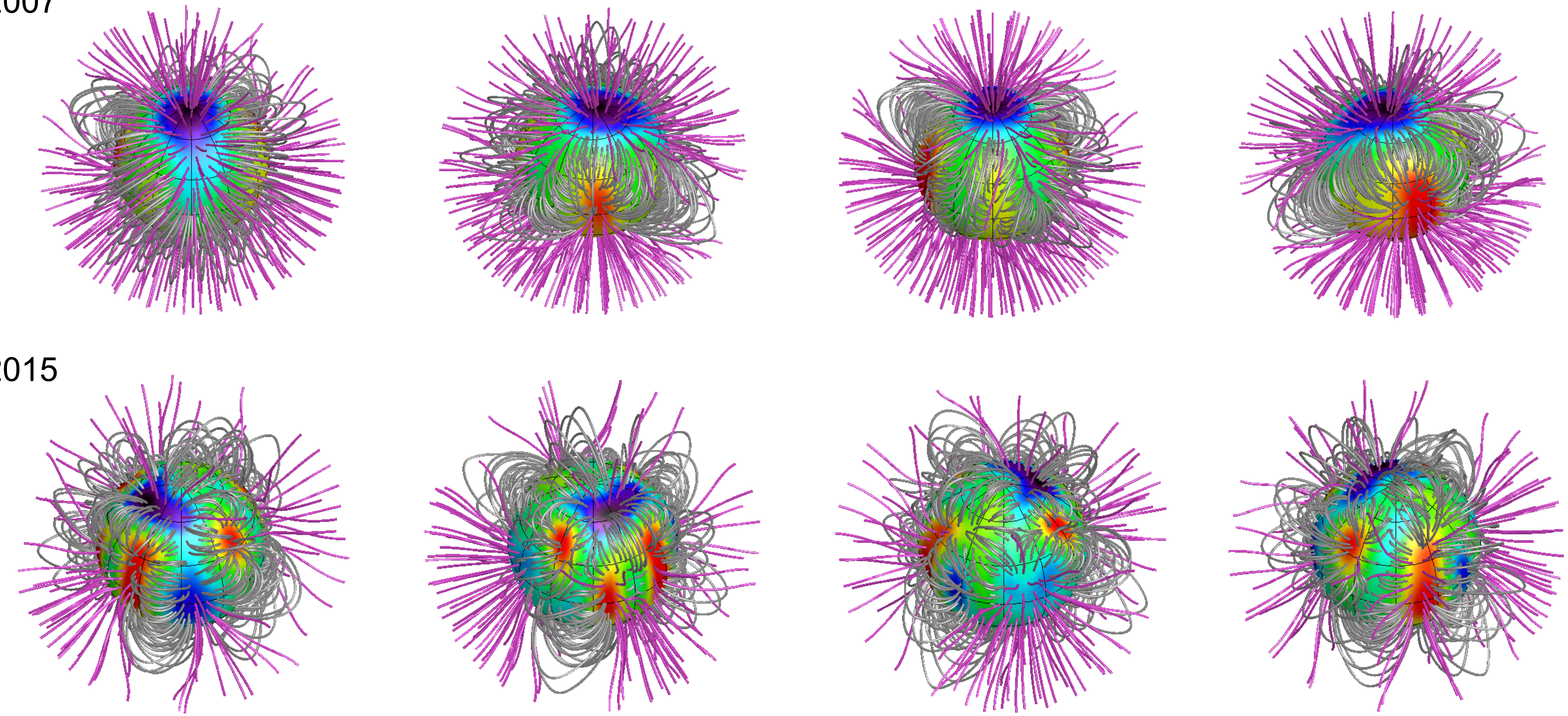
ZDI of Young Suns

Stellar surface magnetic field distribution: π^1 UMa

π^1 UMa

2007

2015



ph = 0.000 ph = 0.250 ph = 0.500 ph = 0.750

Lüftinger et al. 2017, Rosén et al. 2016

Getting the Fields: ZDI of Young Suns

The sample

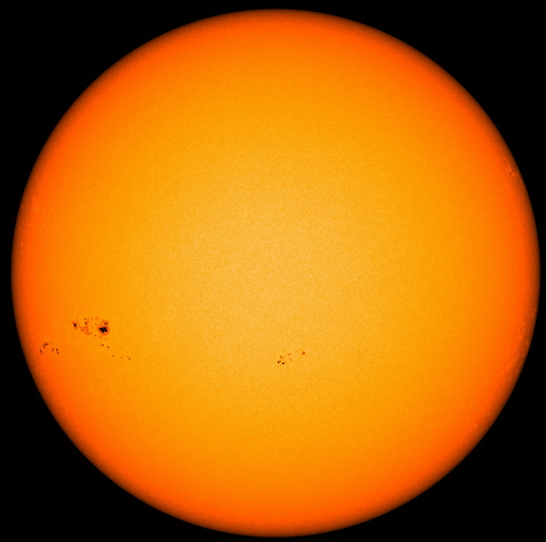
✧ All stars are selected from the "Sun in Time" sample

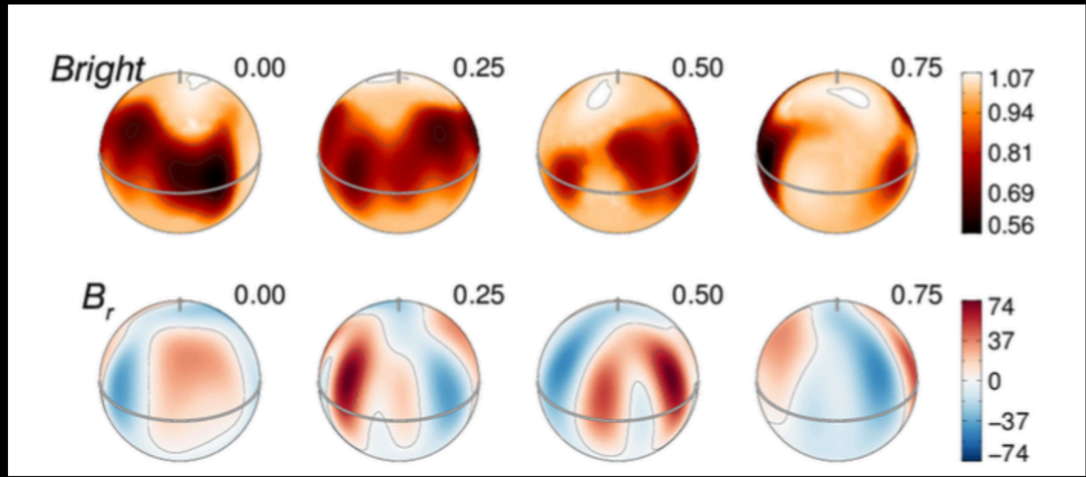
Star	T_{eff} (K)	Mass ($M_{\odot}$)	P_{rot} (d)	Age (Myr)	Membership
EK Dra	5845	1.044	2.6	100	Pleiades
HN Peg	5974	1.103	4.6	230	Hercules-Lyra
π^1 Uma	5873	1.00	4.9	270	Ursa Major
χ^1 Ori	5882	1.028	5.08	300	Ursa Major
BE Cet	5837	1.062	7.65	500	Hyades
κ^1 Cet	5742	1.034	9.2	600	-

(Guedel, 2007)

Zeeman Doppler Imaging

4500Å: 6000 K photosphere





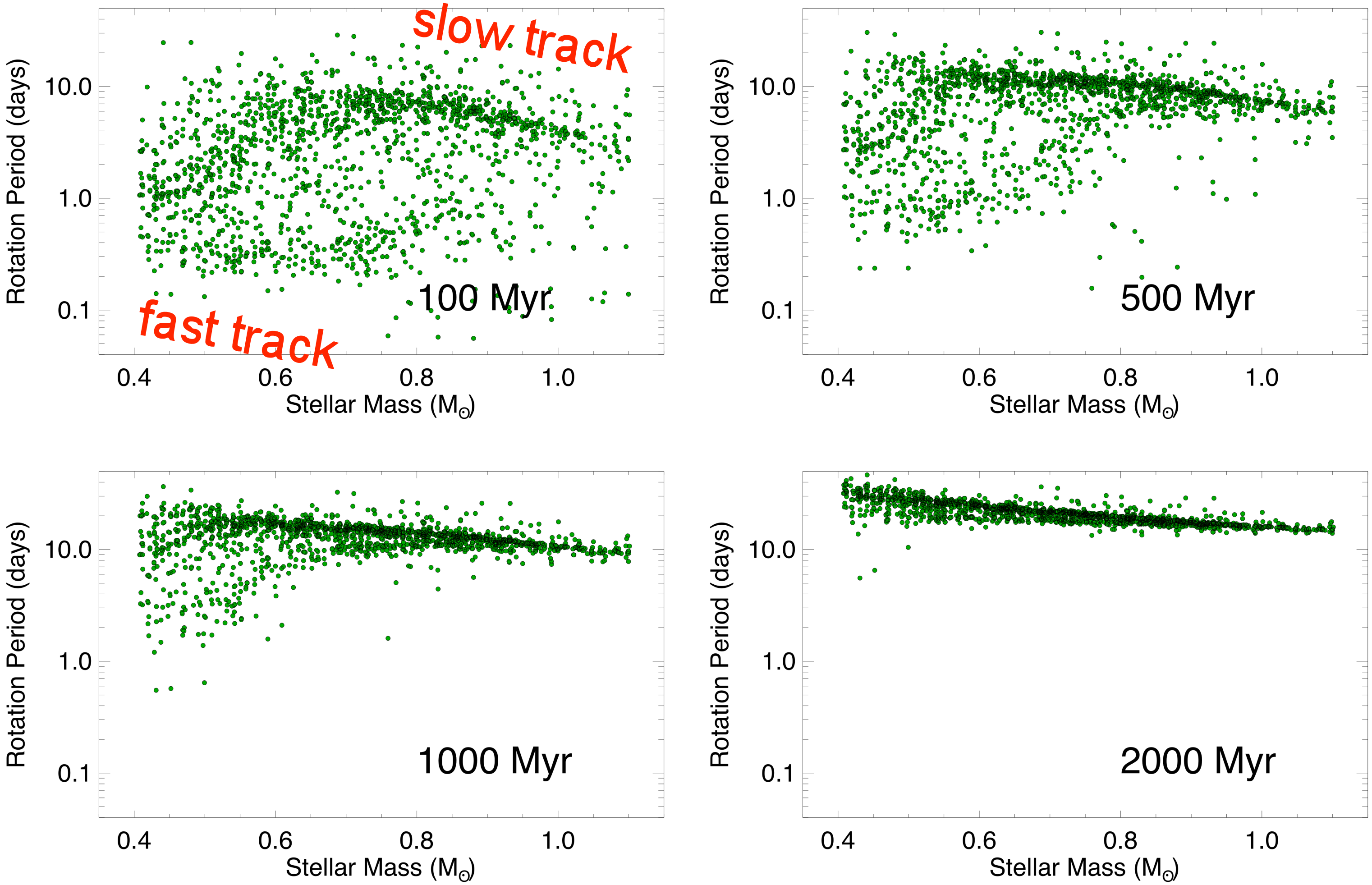
The optical Sun

Young sun: EK Dra

NASA/SDO/GSFC

Rotational evolution matters - a lot!

Rotational Evolution – Wind Evolution



Distribution of stellar rotation rates between 100 and 2000 Myr

Talk of M. Guedel

Johnstone et al., 2015