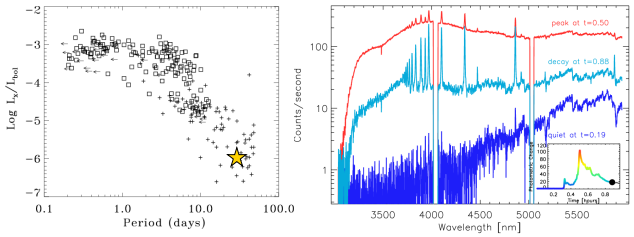
ASTR 7500: Solar and Stellar Magnetism
Hale CGEP Solar & Space Physics



Ben Brown, Prof. Juri Toomre & friends

Lecture 19 Tues 2 April 2013
http://zeus.colorado.edu/astr7500-toomre

Last time (Sarah Gibson)

- Magnetic energy release and eruptions (solar magnetic activity!); flares & CMEs
- Kink & Torus and other plasma instabilities
- Magnetic reconnection
- Observations of eruptions on the Sun, and possible links between coronal cavities and coronal mass ejections

This time: Observing stellar magnetic fields & activity

Question:

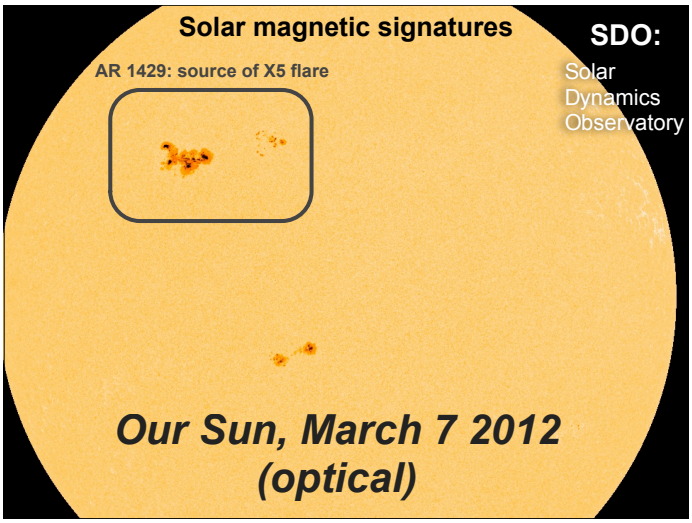
- Based on what we've learned about the Sun, what signatures of magnetism might we look for on other stars?

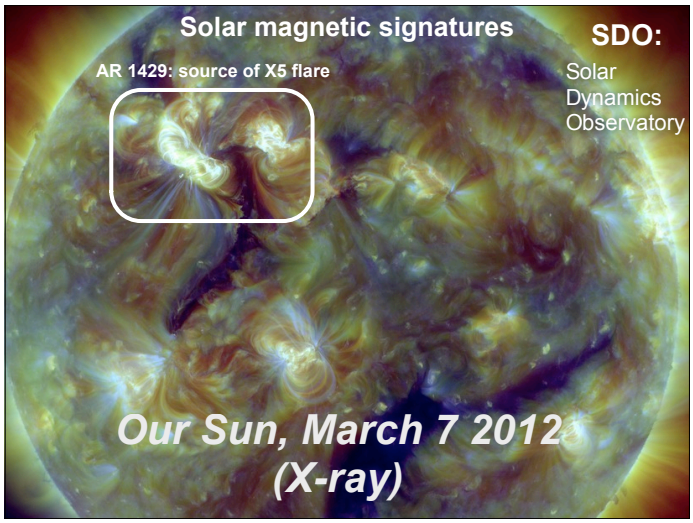
NJIT: give me a non-time-varying signature
Hawaii: give me a time-variable signature
HAO: give me a direct spectral signature
Others: have we missed any?

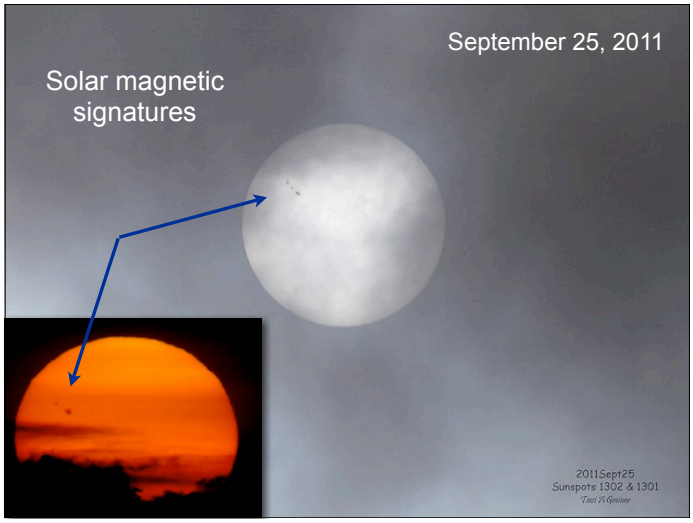
This time: Observing stellar magnetic fields & activity

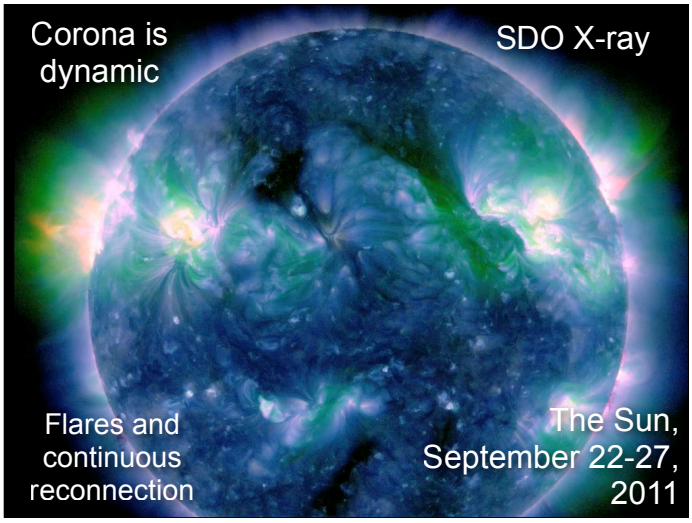
- Signatures of magnetism in other stars (spots, chromospheric & coronal heating)
- Mapping magnetic fields
- Following stellar cycles
- Flares on other stars (M-dwarfs can have very large flares; 100x change in stellar flux!)

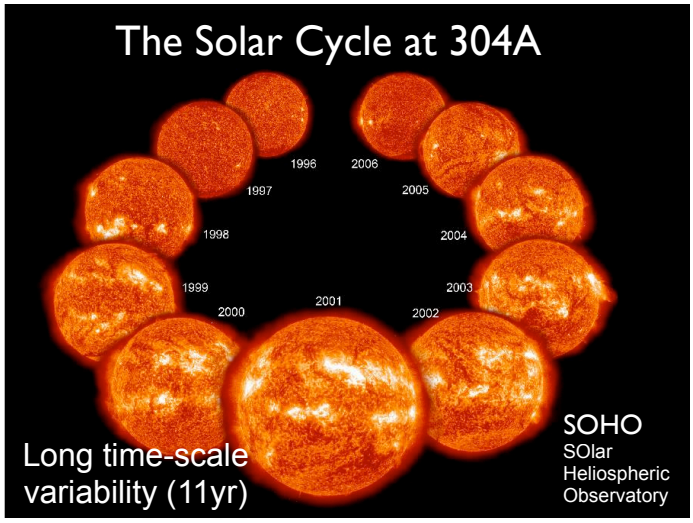
Next time: Simulations of stellar dynamos



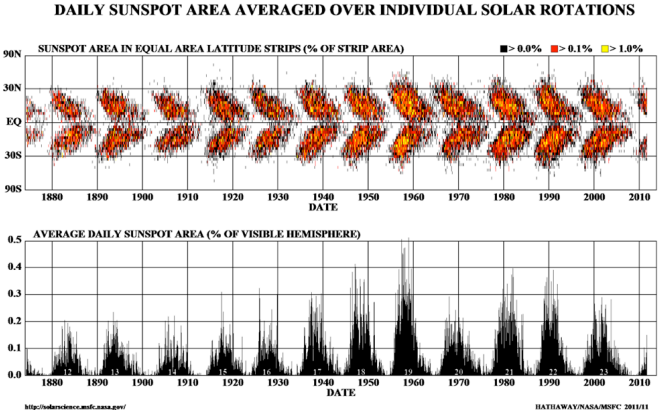






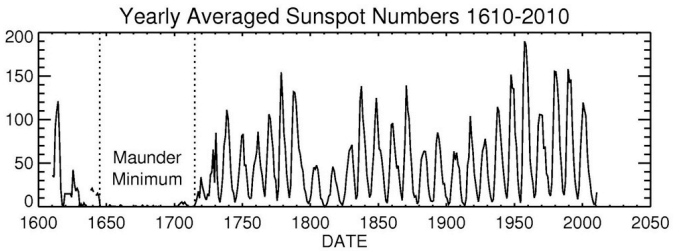


Sunspots & Solar Cycles 11-24



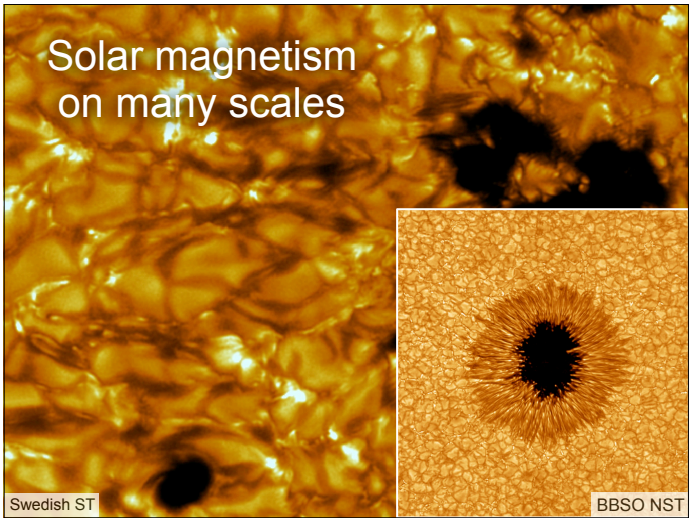
(Hathaway, NASA)

Solar Cycles 11-24

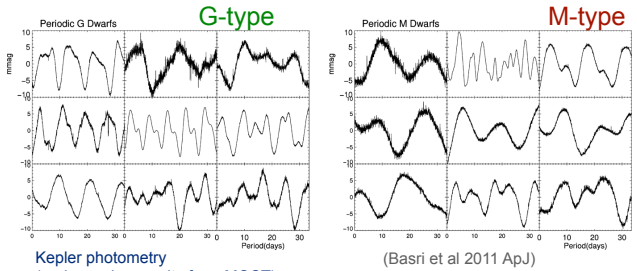


- Solar 11-year cycles fairly constant in period, variable in amplitude. ~400 years of data.
- Occasional “grand minima” (Maunder)

(Hathaway, NASA)



Starspots on other Suns



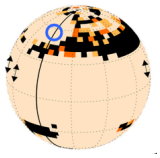
Kepler photometry
(and see also results from MOST)

(Basri et al 2011 ApJ)

20 mmag variation -> 2% changes in stellar flux. Huge!

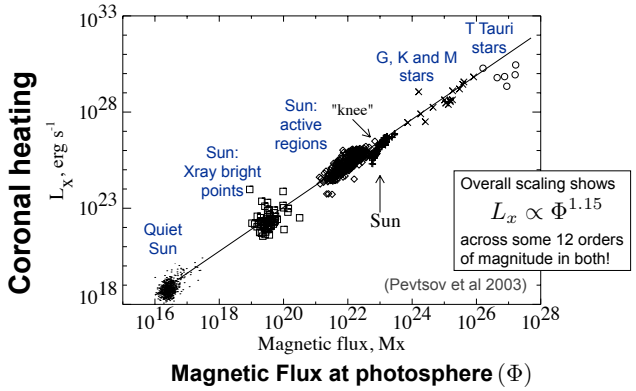
$$\frac{F_{\max}}{F_{\min}} = 10^{(\Delta m/2.5)}$$

Doppler images of "Speedy Mic" (BO Mic): This is not the Sun!



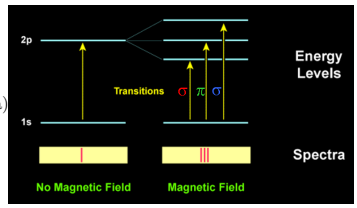
(ESO press release)

Proxies for Magnetic Activity

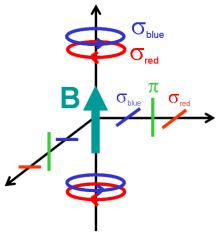


Pevtsov et al. 2003, "The relationship between X-ray radiance and magnetic flux"

How do we measure magnetic flux?



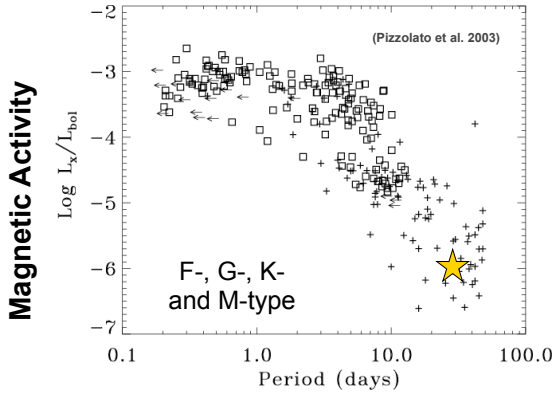
(b)



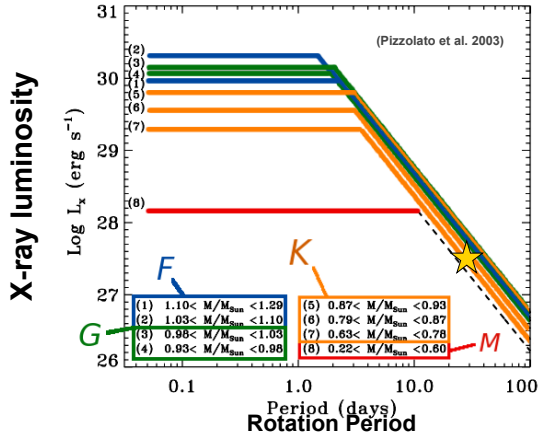
spectra: direct Zeeman splitting, or
spectropolarimetry: circular polarization [line of sight] & linear polarization [transverse field]

"Observations of cool-star magnetic fields," Ansgar Reiners, http://solarphysics.livingreviews.org/Articles/lrsp-2012-1/

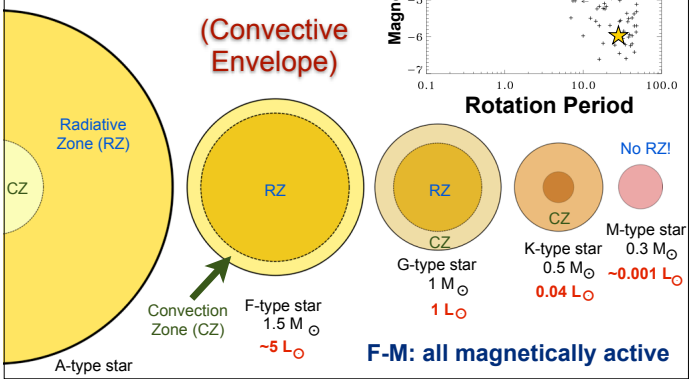
Magnetic Activity in Other Suns



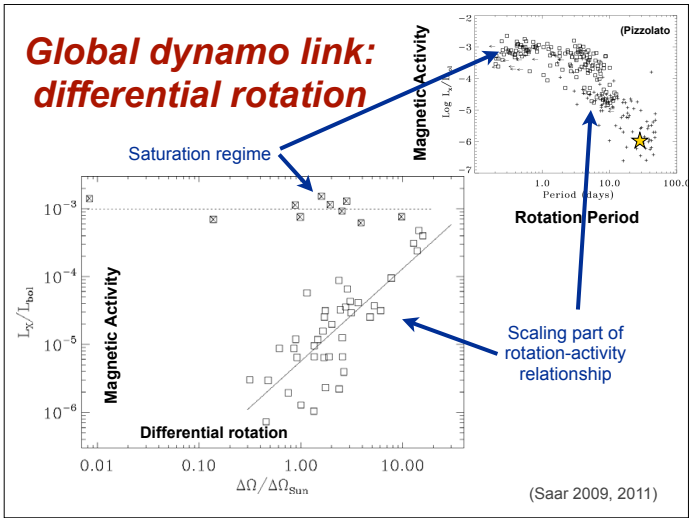
Magnetic Activity in Other Suns



Magnetic Activity in Solar-like Stars

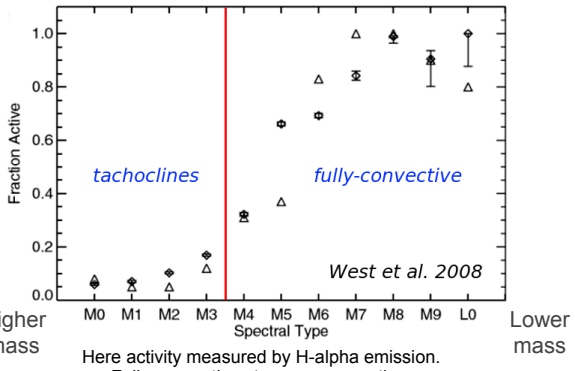


Global dynamo link: differential rotation



(Saar 2009, 2011)

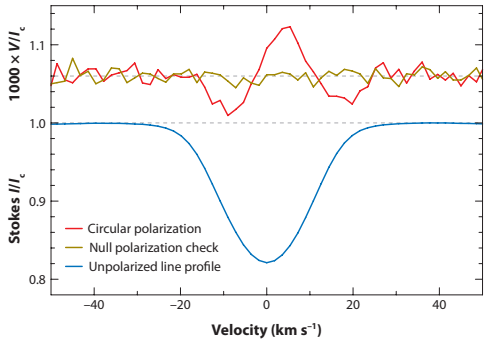
Magnetic activity at the bottom of the main-sequence



Higher mass — Lower mass

Here activity measured by H-alpha emission.
Fully convective stars are very active.

Mapping Stellar Fields



Weak signature (1/1000), so average over many thousands of lines to increase signal-to-noise (LSD = Least Squares Deconvolution).
Inverse problem: deep questions about impact of averaging, etc.

(Donati & Landstreet, 2009, ARA&A)

Mapping Stellar Fields with ZDI

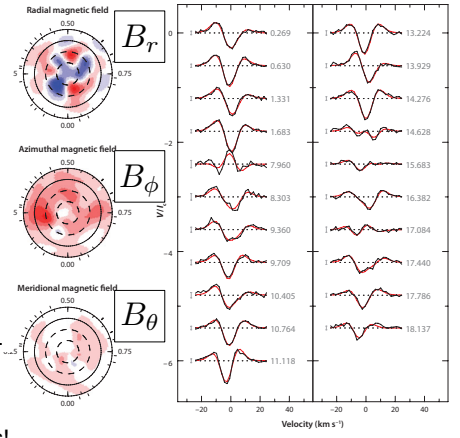
ZDI: Zeeman Doppler Imaging

Make many, many observations of a single star.

Use stellar rotation velocity (Doppler) to map features.

Can infer some latitudinal information for long-lived features.

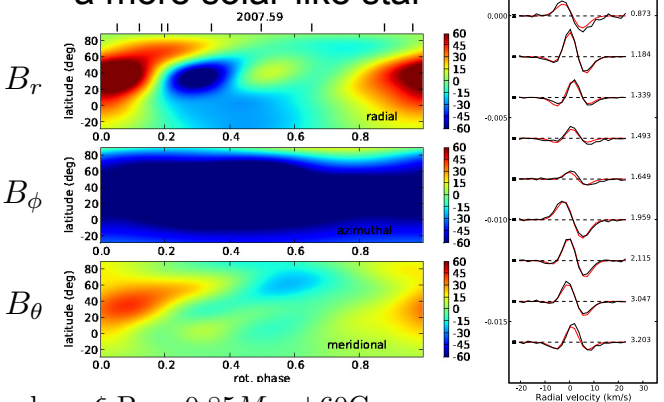
Here: M-dwarf star, color scale ±400 G. Strong average fields!



(Donati & Landstreet, 2009, ARA&A)

Mapping Stellar Fields with ZDI

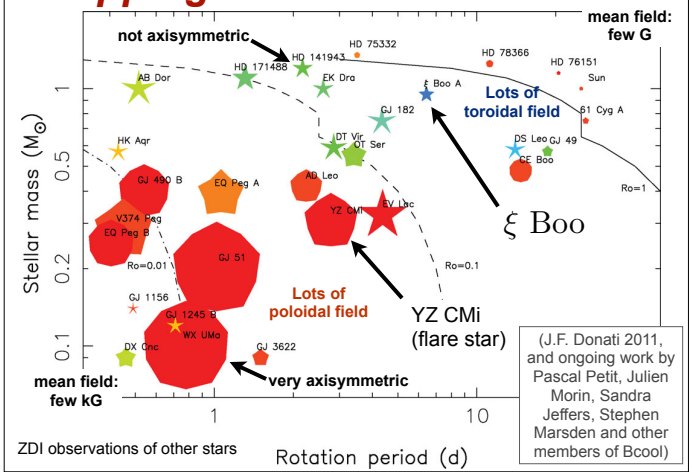
a more solar-like star



here ξ Boo, $0.85 M_\odot$, ± 60G

(Morgenthaler et al. 2011, 2012)

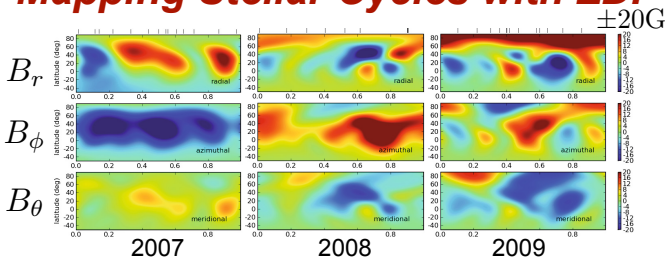
Mapping Stellar Fields with ZDI



ZDI observations of other stars

(J.F. Donati 2011, and ongoing work by Pascal Petit, Julien Morin, Sandra Jeffers, Stephen Marsden and other members of Bcool)

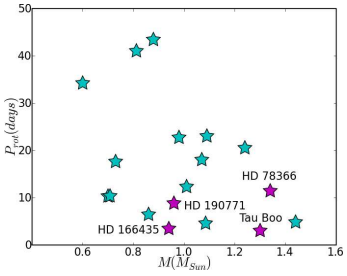
Mapping Stellar Cycles with ZDI



- ZDI maps show magnetic reversal during a cycle in rapidly rotating solar-type star. (Petit et al. 2009)
- ZDI is a difficult inverse problem; major hounds-and-hares exercises are ongoing within the Bcool project using modern stellar dynamo simulations.
- Also done for massive stars by MiMeS project.

Mapping Stellar Cycles

- Now found for several other stars, spanning from F- to G-type at variety of rotation rates (purple stars in fig). Not yet found for lower mass (late G-, K-type).

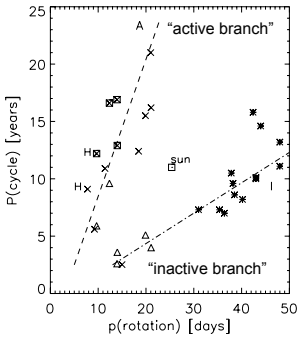


- The international Bcool project is actively continuing this work for solar-type stars. Expect mapping magnetic cycles will be a major stellar magnetism focus in next decade.

(Morgenthaler et al. 2011, 2012; Petit et al. 2012)

Cycles in other stars: Mount Wilson project

- Monitor ~100 solar-type stars (F- through K-), every few nights, for ~30 years
- Measure Ca H & K as activity proxy
- Found cycles in ~25 stars (F7-K7)
- Dependence on stellar parameters unclear so far

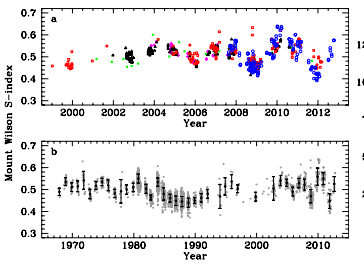


(Wilson 1968, Baliunas et al. 1995, Bohm-Vitense 2007)

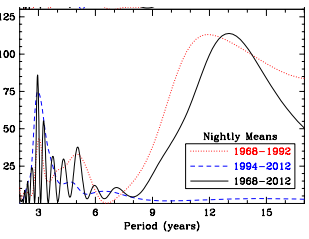
Data: a Ca H & K cycle

ϵ Eridani (K2V)

Ca H & K data: 1968-2012



Lomb-Scargle periodogram (peaks at ~3 and ~12 years)



Mt Wilson project ended in early 2000's; Lowell observatory continuing observations, some observations by SMARTS (2007-2012). Hard, long term monitoring projects but very necessary for understanding cycles.

(Metcalfe et al. 2013)

What we learned today

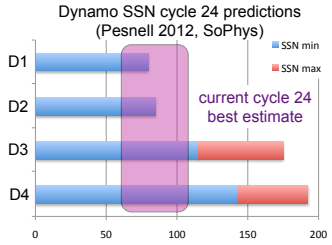
- We see signatures of magnetism on other stars
- Short-time-variable signatures include: photometry (spots; rotation period), ZDI magnetic maps (rotation period), flares (minutes-hours).
- Long-time-variable signatures include: chromospheric emission (e.g., Ca H&K; H-alpha), coronal X-ray emission, total surface flux.
- We see cycles on many other stars. Shortest is ~1.5 years; typical is ~10 years (similar to Sun).

Questions of Solar and Stellar Magnetism

- How does the solar dynamo build organized magnetic fields that survive transiting the turbulent convection zone?
- Why do the global solar fields cyclically reverse polarity?
- What role does rotation play in the dynamo?
- Is the Sun a typical magnetic star?

Next time: Simulations of stellar dynamos

Global Dynamo Models



2D: Mean-field models

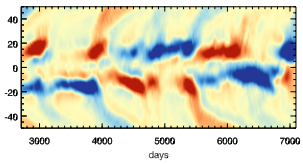
- α–Ω type
- interface dynamos
- flux-transport and many variants (e.g. Babcock-Leighton)

Computationally inexpensive: simulate many cycles, try many ideas
In a position to try solar predictions (but parameterize convection)

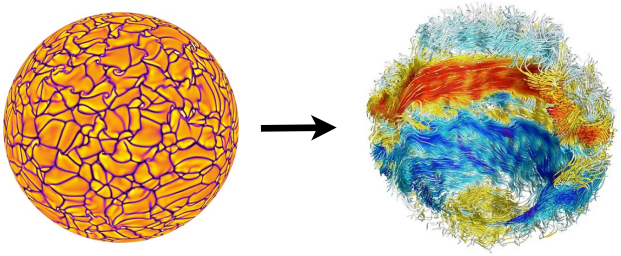
3D: Convection, Rotation & Magnetism

- global-scale flows, magnetism, coupling from first principles
- now achieving cyclic behavior, buoyant magnetic structures

Computationally expensive
Solar parameters well out of reach



Next time: Global simulations of stellar dynamos



Convective flows Large-scale B-fields

- Convection builds global-scale magnetic fields
- Cyclic reversals of polarity now being found

Learning more about stellar magnetic activity

"Observations of cool-star magnetic fields," Ansgar Reiners, http://solarphysics.livingreviews.org/Articles/lrsp-2012-1/

"Magnetic fields of nongenerate stars," J.F. Donati & J.D. Landstreet, 2009, Annual Reviews in Astronomy and Astrophysics

Next time: Simulations of stellar dynamos