

COLLEGE OF ENGINEERING AND PHYSICAL SCIENCES

Solar and Stellar Variability

Yvonne Elsworth University of Birmingham (UK)

Plan

- This is a very big topic and I will only touch on two aspects of it.
- The Sun's variability.
- Global oscillations and how they respond.
- Extension to other main-sequence, solar-like stars.
- A sample of results
- Activity measures

Spots on the Surface of the Sun



- Image of the Sun's photosphere obtained
 Apr 14, 2018 at 15:58
 UT with HMI
 instrument on board
 SDO spacecraft.
- Sun is very quiet at the moment.

http://tesis.lebedev.ru/en/sun_pictures.html



Sunspot cycle

- <u>https://solarscience.msfc.nas</u> a.gov/SunspotCycle.shtml
- Data over several centuries.
- Many questions about the trends.
- 11-year, 22-year (Hale), 100-year (Gleissberg) and longer.
- Currently heading for a minimum.

Distribution of Sunspots on surface is a function of phase within cycle – Butterfly Diagram



- Each dot represents the latitude of spot.
- At end of the cycle the spots are near the equator.
- Magnetic field reverses.
- Poloidal and toroidal components.

Time vs. solar latitude diagram of the radial component of the solar magnetic field, averaged over successive solar rotations.



• David Hathaway, NASA Marshall Space Flight Center

Current magnetic field on Sun



- Magnetic field is fundamental
 - Image of the Sun's magnetic field obtained Apr 14, 2018 at 15:45 UT with HMI instrument on board SDO spacecraft.
- Typical weak field of order of Gauss, strong field KiloGauss

Activity Measures

- Sunspot number
- Magnetic field measures
- 10.7cm radio emission
- UV and X-ray emission
- Total Solar Irradiance (TSI)
- Solar (UV) H&K lines
- Equivalent width of HeI (1083nm)
- Cosmic ray shielding
-and more



High temperature regions above spots gives X-ray emission

Activity on the Sun

- My interest here is in activity-related variability and impact on oscillations
- Very different timescales years for the activity and minutes for the oscillations.
- BiSON observes the oscillations (in radial velocity) of the Sun-as-a-star over several solar cycles.
- Velocities of order cm/sec are large.
- Precision few mm/sec in speed of light (given enough time) - 1 in 10^{11.}

Birmingham Solar Oscillations Network ≡ BiSON Measures Doppler Velocity at very high precision. First data 1975, network 1991, still gathering data <u>http://bison.ph.bham.ac.uk/</u>



Oscillations

- Stochastically excited and intrinsically damped.
- Outer convection zone.
- Concerned with modes for which pressure is the restoring force (called p modes).
- Not large amplitude oscillations.
- Individual modes of oscillation characterised by frequency, height, width plus indicators of their spatial distribution (ledegree, n=radial order, m=azimuthal order).
- Can be global i.e. involve whole Sun. These are low ℓ modes.
- We can resolve the surface of the Sun and hence observe modes with high & and m.
- Different modes probe different parts of the Sun radius and latitude.

Frequency spectrum of low-degree (low- ℓ) modes (contains overtones of $0 \le \ell \le 3$)

High-overtone ($n \approx 20$) modes



BiSON data

Frequency spectrum of core-penetrating pressure (p) modes of the Sun



BiSON data

Clear correlations in frequency of modes with surface measures of activity – early data



Symbols are different degrees (ℓ)

Elsworth et al. 1990, Nature, 345, 322

.....More Cycles



• Howe et al. MNRAS, 2017

Where is the region of variation?

- Range of modes.
- Must be within a few hundred km of the visible surface.
- From measurements in sunspots we know that a magnetic field can influence the modes.
- Not clear whether we are seeing a direct effect of a change in the cavity size or.....
- Indirect effect of the magnetic field.
- Structure models

What about other stars?

- Work being done on a wide range of topics
- Oscillation detections
- Main sequence, solar type
- Activity measures
- Cycle detection
- Very difficult

HD49933

- For the Sun, not only are frequencies seen to vary with activity but also the height, amplitude and width of modes. Frequency shift and amplitudes are anti-correlated.
- Garcia et al Science 2010 showed similar anticorrelation for HD49933 (F5V).
- Important to have more than one measure because of data quality and (short) duration.

Time evolution from 06/02/07 of the mode amplitude (top); the frequency shifts using two different methods (middle), cross correlations (red triangles) and individual frequency shifts (black circles); and a starspot proxy (bottom) built by computing the standard deviation of the light curve. Data from CoRoT satellite.



Searches in the Kepler set

- Cool main sequence stars
- Some recent work
- Kiefer et al A&A 2017
- Salabert et al A&A 2018
- Santos et al. submitted 2018
- Also earlier Metcalfe, Karoff, Chaplin

Statistically significant frequency variations are found but nothing like as clear as in the Sun and not even sure that they follow the same trends with activity and amplitude.

Links with Rotation and Age



- Frequency shift decreases with stellar age and rotation period
- From Kiefer et al. 2017

Rotation



- Bohm Vitense
 2007 ApJ
- Gyro-chronology

Changes to Rotation Period – Age relationship

- van Saders et al 2016.
- Age related to rotation rate.
- Stars slow down as they age.
- Asteroseismology gives ages for older stars.
- Data did not fit the predictions in that the slow down was less than expected.
- Demonstrate models with lower magnetic braking that fit the data.
- Rossby number defined as the ratio of the rotation period to the convective overturn timescale.
- Critical Rossby number above which magnetic braking ceases to matter.

Egeland paper

- Recently on the archive.
- All the activity measures you ever wanted.
- sunstardb: A DATABASE FOR THE STUDY OF STELLAR MAGNETISM AND THE SOLAR-STELLAR CONNECTION by Ricky Egeland.
- ApJS Special Issue Data: Insights and Challenges in a Time of Abundance".
- Travis Metcalfe student.

Summary

- Solar Oscillations probe activity cycle of Sun.
- By no means all problems solved.
- Stellar oscillation frequency and amplitudes for solar type stars also show temporal changes.
- Some but not all are like the Sun.
- More data would be good.
- Gyrochronology improved/extended by use of asterosesimology.
- Magnetism links