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Visit to Kyoto University and the Superflare Workshop

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Abstract. I report on my visit to Kyoto University in March 2016 to take part in the Superflare Workshop, supported by the International Research Unit of Advanced Future Studies, Kyoto University**.** The Superflare Workshop was very well organized, small, intimate meeting of experts in flares and superflares, and stellar activity in general, both from Japan and from around the world. There was much interesting and valuable discussion of superflares on solar-type stars, solar and stellar activity of various types, possible effects on extrasolar planets and the Earth. In the context of this, there was an overview of plans for the new 3.8m Japanese telescope at Okayama Observatory and spectrograph, and a discussion of how to optimize it for flare and activity science. I was asked to speak about the current state of knowledge about stellar cycles and their activity. My presentation described relations between cycle properties and other stellar observables, and the importance of having a well selected and studied stellar sample to best understand the underlying trends.

Keywords: solar-type stars, magnetic activity, superflares, Sun, optical telescopes

1. My Visit

I visited Kyoto from March 1-5, 2016, to take part in the workshop at Kyoto University entitled "Superflares on Solar-type Stars and Solar Flares, and Their Impacts on Exoplanets and the Earth". The workshop organized by Professors Shibata and Nogami of the Kwasan Observatory and Department of Astronomy. I found it a very well organized workshop with excellent talks and discussion, which I found very stimulating and educational. I was excited to hear about the new telescope and spectrograph plans at Okayama observatory, and the latest research on superflares in Japan. I thank Professors Shibata and Nogami for their very kind invitation to participate and am grateful for their hospitality; I also thank the International Research Unit of Advanced Futures Studies for supporting the visit.

2. Workshop Presentation

I gave a one hour talk plus discussion at the workshop entitled: "Observations of Magnetic Cycles in Late-type Single Dwarfs: What are They Telling Us?". It focused on observational characteristics of stellar cycles, and the importance of having a well-understood and carefully selected stellar sample, in order to correctly identify the underlying trends. I summarize the main points in the following sections.

2.1. Background on Stellar Cycle Studies

Stellar magnetic cycles are the subject of much interest and study, with importance ranging from understanding the origin of magnetic activity (including superflares), winds and spin-down, to implications for exoplanet detection and habitability. Typically, photometry or the Ca II HK lines have been targeted for long-term monitoring. More recently, H-alpha (especially for M dwarfs), X-rays and Doppler and Zeeman Doppler imaging (ZDI) have been added to the list. The new 3.8m telescope team is encouraged to explore still more indicators which should be useful: Ca II IRT, He I 5876 and 10830 A lines, and select molecular bands (e.g., TiO) which can be used to determine absolute spot areas and temperatures (e.g., O'Neal et al. 1996). At high resolution (~10^5), Stokes I magnetic broadening can be discerned to determine the total (instead of net) magnetic flux (and area coverage in optimal cases). Actual line bisectors can also be obtained (rather than the destructively averaged cross-correlation functions often used), which are important for understanding convection, and the effects of plage on radial velocities.

In spite of decades of data (50+ year in some cases), the results have been somewhat muddled and unclear. Part of this is probably intrinsic: correlations between cycle period (P_{cyc}) and rotation period (P_{rot}) are complicated by variations in both. The rotation period varies, of course, due to differential rotation. The cycle period of the Sun has natural fluctations due to e.g., the Waldmeier effect (cycle amplitudes A_{cyc} seem anti-correlated with P_{cyc}). There are also complications from both longer (e.g., the 80-100 year Gleissberg cycle) and shorter (1.2 and 2.4 yr; see discussion in Ferriera Lopes et al 2015) variations which may be perturbations of the cycle (e.g., due to Rossby waves in the tachocline), or other phenomena entirely. If stars have similar periodicities (and it seems likely that they do), we can expect a range of P_{cyc} and A_{cyc}, as well as a range of periods, some of which are perhaps related to the dynamo, but are not the signal of the oscillating dynamo *itself*.

2.2. Choose Your Stellar Sample Carefully!

But I also believe part of the confusion in understanding stellar dynamo cycles is due to overly inclusive stellar samples. I have done this myself! Starting with a simple sample of cycle and rotation periods in high quality single dwarfs (Brandenburg et al 1998), we next move on to include binaries, and even tentatively include evolved stars (Saar & Brandenburg 1999). But now I am a lot older and hopefully a little wiser. In subjects as complex as trying to understand the intrinsically non-linear stellar dynamo process, it is important to keep control of as many variables as feasible. So, more recently I have returned to looking at just at single dwarfs (Saar 2011).

The study of differential rotation is instructive in this regard. Barnes et al (2005) presented an analysis of four sizeable sets of surface differential rotation measurements. They found almost no correlation between surface shear, $\Delta\Omega$ and rotation (expressed as rotational frequency Ω): $\Delta\Omega \sim \Omega^{0.1}$. But the largest of their $\Delta\Omega$ datasets came from Hall (1991), which on further investigation, contains almost all close binary stars, with many of these evolved RS CVn variables. Setting the Hall data aside, the remaining stars trace out a pattern where $\Delta\Omega$ first increases, then decreases, as a function of increasing Ω (Saar 2009). Adding newer measurements of single dwarfs confirms this initial picture (Saar 2009; 2011). Apparently, close binaries affect $\Delta\Omega$ in stars, just as they are seen to affect Ω itself, even if the stars are not tidally locked (Meibom et al. 2006). When cast as $\Delta\Omega$ vs. Ro^{-1} (the inverse Rossby number) for single dwarfs F5 and cooler, Saar (2011) found $\Delta\Omega \sim Ro^{-0.9}$ for $Ro^{-1} < 80$, and $\Delta\Omega \sim Ro^{1.3}$ for faster rotators (here $Ro^{-1} = 2\pi\tau/P_{rot}$, where τ is the convective turnover time). A carefully selected sample makes a big difference in the results!

2.3. Cycle Periods and Amplitudes

So it seems prudent that the same type of careful sample selection should be applied when studying cycles as well, *especially* in the view that $\Delta\Omega$ is intimately involved in cycles and dynamo theory. If one gathers together cycle periods from the literature and plots them in non-dimensional ratio, ω_{cyc}/Ω vs. Ro^{-1} on perceives concentration into distinct bands (as suggested by Brandenburg et al 1998) which (although data is still sparse) also change power-law slopes at a Ro^{-1} value similar to where $\Delta\Omega$ peaks and also similar to where magnetic activity (as expressed by e.g., L_X/L_{bol}) reaches a maximum (Saar 2011). The coincidence of all these trends suggests something deeper is at play; we may be seeing some critical change in magnetic generation/dynamos at this point. ZDI suggests a transition to more poloidal field structures at this Ro^{-1} (Donati & Landstreet 2009; note their Ro definition is a bit different). Casting the cycle period in a non-dimensional way also makes the Sun appear less of an outlier than it does when just correlating P_{cyc} with P_{rot} (Böhm-Vitense 2007).

There also seems to be a transition perhaps at twice the solar Ro^{-1}, where (apparent) secondary cycles become common in the cycle data. While keeping in mind (as note above) that similar short "cycles" in the Sun are not true polarity-reversing cycles like the 22-year solar case, some short stellar cycles *do* appear to show polarity reversals using ZDI (Donati et al 2008). This is also roughly the Ro^{-1} value where the brightness variation-activity correlation changes sign from positive (plage/network dominated as in the Sun) to negative (spot dominated; Lockwood et al 2007). Real cycles or no, these secondary periodicities grow stronger in amplitude with increasing Ro^{-1}, even as A_{cyc} of the main cycle decreases (Moss et al. 2008). The appearance of secondary P_{cyc} may be reflected in the transition to strong toroidal fields (Petit et al 2008). Maximum A_{cyc} seen appear to increase with convection zone depth, from F to K dwarfs at least (Saar & Brandenburg 2002).

Thus there seem to be a number of interesting transitions in cycle properties P_{cyc} and A_{cyc} as a function of rotation (and thus age). At lower Ro^{-1} , we see the initiation of shorter, secondary P_{cyc} and a change in the sign of the photometric variation versus activity relation (indicating a transition from plage to spot dominance). At higher Ro^{-1}, magnetic activity saturates, and both DR and ω_{cyc}/Ω change their dependence on Ro^{-1}. There are hints that these transitions may be connected to magnetic topology changes, but more data is needed. Still, it is all rather intriguing!

3. Discussion

There was interesting discussion about trends seen in rotational and cycle periods, "transition points" (e.g., activity saturation, DR and possible ω_{cyc}/Ω peaks, the Vaughan-Preston gap) and relationships, if any, with changes in magnetic topology and/or activity properties. Spectrographic needs for ZDI were also explored.

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