

# **Abstracts for 16<sup>th</sup> Potsdam Thinkshop**

**23rd - 26th September 2019**

## **Louis Amard - Rotation, magnetic braking and metallicity**

The significant convective envelope of low-mass stars is able to generate relatively strong, large scale magnetic fields. Coupled to the stellar winds, it leads the star to lose angular momentum and thus to spin down during their entire main sequence lifetime. Various descriptions of that magnetic braking have been developed with different assumptions. With a database of accurate rotation periods larger everyday and a more and more diverse stellar population, it is particularly timely to ask ourselves how different chemical compositions may affect the rotational evolution. I will describe the effect of different chemical composition on the spin evolution of low-mass stars and show how sensitive it can be to metallicity. We also propose to disentangle some of the most recent angular momentum loss description by taking into account the effect of stellar metallicity on the rotational evolution.

## **Ruth Angus - Combining dating methods for better stellar ages**

A major challenge in measuring the ages of stars is in uniting different dating methods. Different methods, such as the model-driven isochrone placement and asteroseismology and the data-driven gyrochronology and activity-age relations can often predict different ages for the same star. This is usually either because the empirical age relations are poorly calibrated in some parts of parameter space, or because the relations are stochastic: i.e. a range of rotation periods is allowed at a given age and mass. Combining age relations in a useful way requires 1) that the dating methods are self-consistently calibrated and compatible, i.e. the same methods predict the same age for the same star and 2) that they be combined in a way that allows the more informative dating method to provide the majority of age-information in its optimum parameter-space regime (e.g., isochrone placement dominates age information on the subgiant branch, gyrochronology dominates on the lower main sequence, etc). In this talk, I will present a new tool that combines gyrochronology with isochrone placement and outline the next steps towards achieving the goal of combining all available dating methods for better stellar ages.

## **Rainer Arlt - The solar differential rotation as measured from historical sunspot data**

Lightcurves of spotted stars can reveal stellar differential rotation. Sunspots do so for the Sun. Since sunspots have been observed in detail for more than 400 years, we can obtain estimates of the solar differential rotation over time. A few historical sunspot records as well as some attempts to determine the rotation profile are reviewed in this talk.

# **Gibor Basri - Refining Stellar Rotation Periods by Double-Dipping**

The age of precision space-based light curves has vastly increased the number of rotation periods known for main sequence stars. The primary reference for more than 30,000 rotation periods from the Kepler Prime mission has been McQuillan et al (2013). They utilized an autocorrelation (AC) technique, whose results have largely been agreed with by many other analyses and methodologies. The primary uncertainty in the AC method occurs because stars sometimes exhibit two dips per rotation and sometimes only one. Basri & Nguyen (2017) found that this behavior is systematic with stellar rotation period and stellar temperature (more rapid rotators exhibit more single-dip behavior). We examine whether this issue introduces a systematic error in the AC method (and others with similar results). About 8% of the McQuillan periods are double what they should be, mostly for periods greater than about 20 days. We present a refined method for determining rotation periods which also utilizes the distribution of light curve dip durations, and discuss the criteria by which we determine whether the autocorrelation method finds the right value.

## **Axel Brandenburg - The Rotation and Chromospheric Activity of the Solar-Type Stars in M67**

Giampapa et al. (2019, ApJ, submitted, <http://www.nordita.org/preprints>, no.~2017-121) reported the results of a program to measure rotation periods and chromospheric activity in solar-type members of the approximately solar-age and solar-metallicity open cluster, M67. They utilized Kepler/K2 data from Campaign 5 along with contemporaneous spectroscopic observations of the Ca II H and K resonance lines as obtained with the 3.5-m WIYN telescope on Kitt Peak in conjunction with its Hydra multi-object spectrograph. They found that the solar-type M67 stars exhibit a correlation of activity with Rossby number that is opposite to that seen in the inhomogeneous (in age and metallicity) sample of field stars from the Mt. Wilson HK Survey. This unconventional behavior was theoretically predicted for stars characterized by Rossby number (the ratio of rotation period to convective turnover time) exceeding that of the Sun. Such stars are expected to have antisolar differential rotation, but with an increased angular velocity contrast between rapidly rotating poles and a slow equator. Brandenburg & Giampapa (2018, ApJL 855, L22, hereafter BG18) discussed the applicability of these results in the context of the activity and rotation of the M67 solar-type stars based on preliminary determinations of their rotation periods. However, many of the rotation periods utilized previously in BG18 have now been revised. In view of these revised rotation period measurements, we revisit the analysis presented in BG18 that was based, in part, on preliminary periods for 19 solar-type M67 stars. We are now left with only 8 single stars with reliable periods in the present sample. Of these, five are from the original sample, while for another three stars, no periods were previously determined (S724, S777, and S802). However, in the context of trends in dynamo action in solar-type stars, we find that our results remain consistent with the evidence for antisolar differential rotation as BG18 previously discussed.

## **Angela Breimann - The importance of data in understanding gyrochronology models of solar type stars**

Rotation rates of solar-type stars are key to understanding their broader stellar evolution, and give important insights into the physics of stellar magnetic activity and winds. Combined with a spin evolution model, observed rotation rates can also be used to constrain stellar ages, particularly on the main sequence where rotation rates are observed to change on order of approximately a magnitude. Comparatively, other age indicators can struggle during this stage of a star's lifetime due to barely changing stellar structure. In order to reliably estimate ages, accurate data from large surveys is essential. These data give unprecedented opportunities to constrain masses, radii and luminosities consistently across a variety of clusters, and are therefore crucial to understanding where model assumptions might fail. We present the latest in the development of tools for fitting cluster rotation data to physical rotational evolution models, allowing us to constrain stellar ages and the physics of stellar magnetic activity and winds.

## **Tristan Cantat-Gaudin - Gaia and the membership of open clusters**

The precision and high dimensionality of the Gaia DR2 catalogue allows us to identify secure members, down to low stellar masses, in over a thousand open clusters and in sparse but kinematically coherent coeval populations. The clean colour-magnitude diagrams obtained from reliable membership lists can be used to derive photometric ages and to study features such as extended main sequence turn-offs. I will review some methods recently applied to the Gaia DR2 catalogue, and what can be expected to be achieved from the upcoming Gaia DR3.



# **Jason Curtis - A Temporary Epoch of Stalled Spin-Down for Low-Mass Stars: Insights from NGC 6811 with Gaia and Kepler**

Stellar rotation was proposed as a potential age diagnostic that is precise, simple, and applicable to a broad range of low-mass stars ( $<1$  solar masses). Unfortunately, rotation period measurements of low-mass members of open clusters have undermined the idea that stars spin down with a common age dependence (i.e., square-root of age): K dwarfs appear to spin down more slowly than F and G dwarfs. Agüeros et al. (2018) interpreted data for the 1.4-Gyr-old cluster NGC 752 differently, proposing that after having converged onto a slow-rotating sequence in their first 600-700~Myr (by the age of Praesepe), K dwarf rotation periods stall on that sequence for an extended period of time. We use data from Gaia DR2 to identify likely single-star members of the 1-Gyr-old cluster NGC 6811 with Kepler light curves. We measure rotation periods for 170 members, more than doubling the sample relative to the existing catalog and extending the mass limit from 0.8 to 0.6 solar masses. Standard gyrochronology relations applied to the G dwarfs show it to be 1 Gyr in age, consistent with the isochrone solution. However, when our new low-mass rotators are included, NGC 6811's color-period sequence deviates away from the naive 1 Gyr projection down to 4300 K (K5V, 0.7 solar masses), where it clearly overlaps with Praesepe's. Combining these data with rotation data for other clusters, we conclude that the assumption that mass and age are separable dependencies is invalid. Furthermore, the cluster data show definitively that stars experience a temporary epoch of reduced braking efficiency where rotation periods stall, and that the duration of this epoch lasts longer for lower-mass stars. We will suggest one method for reformulating the empirical relations using periods from older clusters (e.g., NGC 6819, Ruprecht 147, and M67) to tune the stalling timescale, and we are eager to see how these new data can be used to recalibrate theoretical angular momentum evolution models (e.g., core-envelope coupling timescales), so that both classes of models accurately describe the discrete phases of stellar spin-down.

# **Constantine Deliyannis - Correlations Between Lithium Depletion and Stellar Spindown for F-Dwarfs and at Higher Mass**

In Standard Stellar Evolution Theory, depletion of the surface lithium abundance occurs when Li is destroyed at the base of the surface convection zone. For (current) F-, G-, and K-dwarfs, this is predicted to have occurred during the pre-Main-Sequence, only. In sharp contrast to the strictures of the SSET, real dwarfs continue to deplete their surface Li during the MS, and create surprising and extra-ordinary Li-Teff (or Li-mass) patterns such as the F-dwarf Li dip. Considerable and varied evidence points to rotationally-induced mixing as the dominant mechanism causing this extra Li depletion. New insights about the relation between stellar spindown and Li depletion in F-dwarfs are presented. Evidence from open clusters is presented that for higher mass dwarfs, spindown is likewise correlated with Li depletion, creating a second Li dip, but at higher mass and on a longer time scale.

## **Elisa Distefano - Differential rotation and magnetic cycles in Gaia rotating variable stars**

The Gaia Data Release 2 (DR2) reported the rotation period  $P_{\text{Rot}}$  and the amplitude  $A$  of light curve induced by rotational modulation for about 150000 late-type stars. The analysis of the  $P_{\text{Rot}}$ - $A$  diagram permitted to identify three different families of rotating stars that should be characterized by different magnetic properties. A better understanding of this diagram could be achieved with the help of information on the stellar magnetic activity coming from long-term photometry. Indeed long term photometry can be exploited to study magnetic activity cycles and to infer information on the surface differential rotation (see e.g. Distefano et al. 2016) that is a key ingredient in the stellar dynamo models. In the present work we study activity cycles and differential rotation in a small sample of 46 DR2 sources for which ASAS long term photometry is available with the aim to get insights to interpret the feature of the GAIA  $P_{\text{rot}}$ - $A$  diagram.

## **José-Dias do Nascimento junior - Rotation of young Suns observed by TESS**

The Transiting Exoplanet Survey Satellite (TESS) is observing more than 200,000 bright stars in the sky and is an important mission for studies of stellar rotation. TESS mission delivered its full frame images (FFIs) with a cadence of 30 minutes with possibilities to re-extracted light curves carefully to avoid field contamination of backing ground stars. In this work we explore the potential of TESS to measure rotation periods of young solar analog stars. We are mainly interested in two aspects. First understand the impact of light curves limited to 27 days and the wide FOV with possible contamination. For a set of 11 young Suns (between a few million years to 2 billion years), we determined rotational periods for those stars as well we explored lithium, activity levels and differential rotation based on spectroscopy, photometric variability and spot modelling. The first look results from our sample shows a deep connection between lithium and rotation, and mass for different ages.

## **Stephanie Douglas - The Hyades and Praesepe open clusters as benchmarks for stellar rotational evolution**

The Kepler and K2 missions have enabled detailed studies of stellar rotations in a variety of young open clusters, opening a new era for benchmarking the evolution of stellar rotation. The Hyades and Praesepe in particular provide important constraints on models for stellar rotation. Many studies have combined these two clusters into a single set of rotation periods. I will discuss new results showing that, in fact, Solar-type stars in the Hyades rotate, on average, 0.4 days slower than their Praesepe counterparts. This corresponds to a gyrochronological age difference of 57 Myr. However, the lower-mass cluster members do not show an offset. This provides further evidence for stalling in the rotational evolution of these stars, and highlights the need for more detailed analysis of angular-momentum evolution for stars of different masses and ages.

## **Dario Fritzewski - From slow to fast type rotators in NGC 2516 and NGC 3532**

Young open clusters contain both slow and fast rotators while older clusters are populated exclusively by slow rotators. Many questions on the transition from fast to slow type rotators are still open. With new observation we aim to enhance the knowledge about this transition, which takes place, for G and K type stars, between  $\sim 120$  and  $\sim 400$  Myr. We have observed the two very rich, southern open clusters NGC 2516 (150 Myr) and NGC 3532 (300 Myr) and present a large number of new rotation period measurements for them. Based on our homogeneous photometry for both clusters we compare the distribution of rotation periods in detail and study the rotational evolution over this important age range. Further, we compare NGC 2516 with the similarly aged Pleiades and find little evidence for cluster to cluster variation of the rotation period distribution.

## **Stefan Georgiev - High-resolution spectropolarimetry: studying cool magnetic giant stars**

A study of magnetism in selected Red Giant stars using high-resolution spectropolarimetry and multi-line tools (Least Square Deconvolution, LSD) for detection and evaluation of the photospheric magnetic field is presented. In addition, we studied the spectral line activity indicators (Ca H&K, H $\alpha$  and Ca IRT) simultaneously. A method (based on multi-line tools - LSD and synthetic spectra) to accurately determine stellar physical parameters such as rotational and macroturbulence velocities is also presented.

## **Philippe Gondoin - Magnetic activity evolution on Sun-like stars**

Characterizing the time evolution of magnetic activity on Sun-like stars is important not only for stellar physics but also for determining the environment in which planets evolve. In recent decades, many surveys of open clusters have produced extensive rotation periods measurements on Sun-like stars of different ages. I used this information with the aim to improve the description of their magnetic activity evolution. The long-term evolution of Ca II chromospheric and X-ray coronal emission from solar mass stars is inferred by combining a best fit parametric model of their rotation evolution with empirical rotation-activity relationships. The derived scenario is compared with measurements of magnetic activity indices from Sun-like stars in nearby open clusters of various ages.



## **Seth Gossage - Combined Effects of Rotation and Age Spread on Extended Main Sequence Turn Offs**

The extended main sequence turn off (eMSTO) has become recognized as a common, yet puzzling feature of stellar populations younger than 2 Gyr since its discovery in the Magellanic Clouds a decade ago with the Hubble Space Telescope (HST). The eMSTO revealed that star clusters are much more complex than we had thought, and since then the origin(s) of the eMSTO have been hotly debated. With new synthetic stellar populations computed from the MESA stellar evolution code, we explore two of the leading theories of the eMSTO phenomenon: an extended star formation history and a range of stellar rotation rates. I will discuss our exploration of the combined effects of both scenarios, including for the first time a non-parametric model for the rotation rate distribution. We find that slow rotators comprise bluer colors, and fast rotators redder colors in the MSTO, as recently observed. Major aspects of the cluster morphology can be replicated with a distribution of rotation rates alone. Although, we cannot currently rule out a duration of extended star formation from analysis of the MSTO by itself. Future  $V_{\text{ini}}$  measurements for eMSTO stars will yield novel constraints on rotating stellar models that may provide a definitive resolution to this debate.

## **Thomas Granzer - Gains on using robotic telescopes for long-term photometry**

Measuring rotation periods in stars require observing spans comparable to the length of the periods expected whilst at the same time the amount of observing time required per night can be rather short. Even if such an observing schedule can be achieved with variants of queue observing modes, I will argue in this talk that the common calibration procedures realized in robotic observatories additionally result in a precision gain hardly obtainable by other strategies and at basically no costs.

## **David Gruner - With Kepler and Gaia: two eyes on Ru147**

In my talk I'll present the newest results for stellar rotation periods of the oldest nearby open cluster Ruprecht 147. With high precision Gaia astrometry, we are able to identify members of a cluster which is fairly extended on the night sky. We used Gaia photometry and rotation periods extracted from K2 lightcurves to construct a Color-Period-diagram for this 3Gyr old cluster. I'll close with a discussion of the findings and their implications for gyrochronology.

## **Gaitee Hussain - Surface differential rotation and spot lifetimes in MS stars**

I'll review what we've learnt regarding surface differential rotation rates in a range of solar-type (G-K-type) main sequence stars. In particular, I'll examine the relationship between active region lifetimes and surface shear rates in some key systems.

## **Ekaterina Ilin - At a gallop: stellar flares from Kepler/K2 and TESS**

In low-mass stars, stellar rotation and flaring activity are closely linked through the stellar dynamo. The Kepler, K2, and TESS missions have captured signatures of thousands of flares. Their signal was found on all stars from solar analogs to ultra-cool dwarfs, and at all ages from pre-main sequence to early post-main sequence. This new wealth of data enables us to investigate the statistical properties of flaring activity. Such studies can inform our reasoning about the evolution of stellar magnetic fields not only in the highly active specimen but also in the bulk stellar population in the Solar neighborhood. In this talk, we introduce AltaiPony, a handy Python tool for fast automatic scanning of Kepler and TESS light curves for flares. We show how its injection-recovery feature can be used to improve the analysis of flare frequency distributions, and present examples of recent work.

## **Patryk Iwanek - 12 660 spotted stars towards the OGLE Galactic bulge fields**

Since 1992, OGLE variability sky survey has been conducting an intense monitoring of one of the most interesting, but also the most difficult to explore due to strong and highly non-uniform interstellar extinction, region of the Milky Way - the Galactic bulge. Every night we observe over a billion stars in this direction, providing time-series data for many interesting objects. Our extensive experience in variable stars selections has allowed us to detect more than 20 000 spotted stars towards the Galactic bulge.

Recently, we have proposed a new dereddening procedure for individual stars, thanks to which we are able to divide spotted stars into dwarfs and giants. We have found well-defined correlations between rotating period, luminosity and variability amplitude for the giants. Moreover, our two-band, high-cadence photometry has allowed us to find an evident correlation between the changes in brightness and changes in color of the stars. The positive correlation is characteristic for stars that are cooler when fainter, which results from the variable coverage of the stellar surface with spots similar to sunspots. The variability of stars that are cooler when brighter (negative correlation) can be characterized by chemical spots with overabundance of heavy elements inside and variable line-blanketing effect, which is observed in chemically peculiar stars. The null correlation may result from a very high level of the magnetic activity with rapidly variable magnetic field. This division is clearly visible on the color–magnitude diagram, which suggests that it may depend on the radius of the star. In my presentation, I will present the latest results and I will introduce future plans for the next research in the area of stellar magnetic activity.

## **Christoffer Karoff - Different ways of measuring stellar rotation in photometric time series**

Stellar rotation can be measured in photometric time series through a number of different methods, such as periodogram analysis, autocorrelation analysis, asteroseismology and forward modelling of the time series. These methods all have different strengths and weaknesses and differences in the obtained results can arise from both phenomena that are intrinsic to the stars, like differential rotation and phenomena that are not. In order to be able to compare results from different methods it is thus important to be aware of these strengths and weakness.

## **Levente Kriskovics - Surface differential rotation -- from dwarfs to giants**

Differential rotation is a key component of the Omega-effect, which regenerates the large-scale toroidal magnetic fields during a dynamo cycle, however, dynamos in different types of stars work in different ways. In this talk, I aim to give an overview of how surface differential rotation manifest on different types of stars (K dwarfs, solar analogues, giant RS CVns, single giants, first lithium-dredge up, etc) showcasing results on the topic from the last several years, along with some implications of these results. Relations between astrophysical parameters and differential rotation are also discussed.



## **Manfred Küker - Differential rotation, meridional circulation, and cycle periods for early M dwarfs**

Recent observations find two characteristic cycle times for early-type M stars dependent on the rotation period. They are of order one year for fast rotators ( $P_{\text{rot}} < 1$  day) and of order four years for slower rotators. Additionally, the equator-to-pole differences of the rotation rates are known from Kepler data for the rapidly rotating stars and are well reproduced by mean field theory. The resulting amplitudes of the meridional circulation allow the calculation of the travel time from pole to equator at the base of the convection zone. These travel times strongly increase with rotation period and always exceed the observed cycle periods. A flux transport dynamo in early M dwarfs is thus not supported by our model and the data.

## **Antonino Francesco Lanza - Spot modelling of Kepler-17: a planet-hosting star with solar-like differential rotation and a possible Rieger-like cycle**

Maximum entropy spot modelling has recently been applied to more than 1500 days of Kepler photometry of the planet-hosting star Kepler-17 that is accompanied by a hot Jupiter with an orbital period of 1.486 days. It is a G2V star with a mean rotation period of 12 days which makes it a very interesting target for solar-stellar connection studies, especially to understand magnetic activity in the young Sun. By modelling starspots occulted during transits and comparing them with the spots mapped from the out-of-transit light curve, we derive information on the sign of differential rotation, that is found to be solar-like, and a lower limit for its amplitude, that is somewhat dependent on the assumptions of the spot model. There is also evidence of a short-term cycle in the total spotted area with a period of about 48 days and a significance of 5 percent. It could be analogous to the solar Rieger cycles and to a cycle of about 29 days observed in CoRoT-2 [This presentation will be based on Lanza et al. 2019, A&A 626, A38].

## **Alessandro Lanzafame - A new scenario for the low-mass magneto-rotational evolution from the second Gaia data release**

The second Gaia data release contains the identification of some 150000 low-mass rotational modulation variable candidates on (or close to) the H-burning main sequence, together with their rotation period and modulation amplitude, which represents the largest catalogue of this kind ever. The richness, the period and amplitude range, and the photometric precision of this sample make it possible to unveil, for the first time, signatures of different surface inhomogeneity regimes in the amplitude-period density diagram. The modulation amplitude distribution shows a clear bimodality, with an evident gap at periods  $P < 2$  days. The low amplitude branch, in turn, shows a period bimodality with a main clustering at periods of approximately 5-10 days and a secondary clustering of ultra-fast rotators at period approximately less than 0.5 day. The amplitude-period multimodality is correlated with the position in the period-absolute magnitude (or period-colour) diagram, with the low- and high-amplitude stars occupying different preferential locations. Such a multimodality represents a further evidence of the existence of different regimes of surface inhomogeneities in young and middle-age low-mass stars and possible scenarios for their magneto-rotational evolution, which manifestly include rapid transitions from one regime to another, are laid out. In particular, the data indicate that stars spinning up close to break-up velocity undergo a very rapid change in their surface inhomogeneities configuration, which is revealed by Gaia DR2 for the first time. The multimodality can be exploited to identify field stars of age approximately 100-600 Myr belonging to the slow-rotator low-amplitude sequence, for which age can be estimated from the rotation period via gyrochronology relationships.

## **Jyri Lehtinen - Universal dynamo scaling in young and evolved stars**

We present an updated rotation-activity relation of 155 late-type stars from the Mount Wilson Calcium H&K survey. This survey contains stars with a wide range of activity levels and evolutionary stages from young main sequence stars to red giants. Evident from these data is how the giant stars show similar activity levels to the main sequence stars despite having 10 to 100 times longer rotation periods. We show that this apparent dichotomy is resolved when the stellar activity is scaled by the Rossby number. Since the internal structure of the main sequence and post-main sequence stars differ markedly, we used stellar structure model fits to derive the convective turnover times necessary for calculating Rossby numbers for the studied stars. The Rossby number scaling turns out to be the only viable way to unify the rotation-activity relation of both main sequence and evolved stars. Other proposed scaling relations, that do not include direct a dependence on the characteristics of turbulence, results in clearly distinct branches for these two stellar populations and fail to explain their differences. This suggests that there exists a universal activity scaling, and hence a single underlying dynamo process, for all late-type stars across different evolutionary phases, but that this process has to include turbulence as one of its main ingredients along with stellar rotation.

## **Emily Leiner - The Rotational Evolution of Blue Straggler Stars**

Blue straggler stars, found brighter and bluer than the main-sequence turnoff in many clusters, are thought to form via binary mergers, mass transfer, or stellar collisions during dynamical encounters. All these interactions are expected to spin blue stragglers up to large rotational velocities at formation, resetting their gyro-age clocks. Less is known about the subsequent spin down of these post-interaction stars. I will review our theoretical and observational understanding of blue straggler rotational evolution, including new results demonstrating that post-mass-transfer blue stragglers spin down at the same rate as normal main-sequence stars. As a result, gyrochronology could be a useful new way to age-date blue stragglers and other post-interaction binaries. Furthermore, using the old open cluster M67 as an example, I will demonstrate that rotation can be used to detect a hidden population of post-interaction stars on the cluster main sequence. These detections indicate that up to 10% of the FGK main-sequence stars in older open clusters may have been through an interaction. These results illustrate that mass-transfer and mergers are common outcomes of stellar evolution in binary systems, and that understanding post-interaction rotational evolution has important implications for binary evolution physics, for identifying post-interaction binary populations, and for calibrating precise gyrochronology relationships in clusters.

## **Diego Lorenzo-Oliveira - The past and future of the Sun: What solar twins can tell us about the solar magnetic and rotational evolution?**

Rotation-based ages of old Sun-like stars are rooted in a complex and intricate dependence on age, rotation, turbulent convection, structural variations and mass-loss due to magnetized winds. Classically, the age-dating method that relies on this phenomenon assumes that the rotational periods can be expressed in well-defined functions of the age and mass, the so-called gyrochronology relations. These relations had successfully confirmed the paradigm of rotation-activity-age coupling that powers the global dynamo evolution along the main-sequence and reproduced the main features observed in open clusters spanning a wide range of ages. However, in the light of Kepler data, the presence of apparently old and fast rotators that do not obey the usual gyrochronology relations led to the hypothesis of weakened magnetic braking in some stars. We approached this problem by using a selected sample of solar twins and building a grid of rotational tracks as function of age, mass and metallicity over a large range of possible critical Rossby number to account for the magnetic weakened braking phenomena observed in the Kepler sample. Strong statistical evidence favoring the smooth rotation evolution (critical Rossby number solution  $\sim 2.6$ , or ages greater than  $\sim 8$  Gyr) was found. The lower limit of critical Rossby number estimated is greater than 2.3 or older than 5.3 Gyr (at 95% confidence level) for a solar mass/metallicity star. These limits intercept an age range somewhat older than the Sun and the end of the main-sequence. This study highlights the difficulty to statistically discern both scenarios with the current sample of solar twins.

## Sean Matt - What Causes the Rotation Period “Gap” in Young Clusters?

Period-mass diagrams of young clusters show a rotation period “gap,” where stars are transitioning from being rapid rotators to converging onto a common slow-rotator sequence. A number of explanations for this gap have been put forward in the past few years. These explanations propose either dramatic transitions in stellar magnetism or wind driving, or they require that a substantial amount of angular momentum is hidden in the radiative core (due to “core-envelope decoupling”). It has not yet been shown whether any of these ideas can explain the morphology of the gap over its full mass range from  $\sim 0.1$ - $1.0$  solar masses. We show that the gap seen in young clusters is well explained by a simpler idea, which requires a relatively subtle flattening of the stellar wind torque as a function of rotation rate. Such a flattening could be caused by a systematic deficit (a sort of “super-saturation”) in magnetic field strength and/or mass loss rate, for faster rotators. Finally, since our model reasonably matches the spin-distributions for stars with and without radiative cores, it suggests that significant core-envelope decoupling may not be needed.

## **Jorge Melendez - Lithium and beryllium in solar twins**

Solar twins are stars with mass and chemical composition similar to the Sun, therefore they follow about the same evolution and can be used to study the past and future of the Sun. I review our recent works on the evolution of lithium and beryllium, using a differential spectroscopic analysis of solar twins relative to the Sun. There is a clear trend of lithium depletion with increasing ages, while beryllium is only slightly depleted, suggesting a relatively shallow extra-mixing in Sun-like stars. I also discuss the possible connection between lithium and planets.



## **Travis Metcalfe - Understanding the Limitations of Gyrochronology for Old Field Stars**

Nearly half a century has passed since the initial indications that stellar rotation slows while chromospheric activity weakens with a power-law dependence on age, the so-called Skumanich relations. Subsequent characterization of the mass-dependence of this behavior up to the age of the Sun led to the advent of gyrochronology, which uses the rotation rate of a star to infer its age from an empirical calibration. The efficacy of the method relies on predictable angular momentum loss from a stellar wind entrained in the large-scale magnetic field produced by global dynamo action. Recent observational evidence suggests that the global dynamo begins to shut down near the middle of a star's main-sequence lifetime, leading to a disruption in the production of large-scale magnetic field, a dramatic reduction in angular momentum loss, and a breakdown of gyrochronology relations. For solar-type stars this transition appears to occur near the age of the Sun, when rotation becomes too slow to imprint Coriolis forces on the global convective patterns, reducing the shear induced by differential rotation, and disrupting the large-scale dynamo. We use data from Barnes (2007) to reveal the signature of this transition in the observations that were originally used to validate gyrochronology. We propose that chromospheric activity may ultimately provide a more reliable age indicator for older stars, and we suggest that asteroseismology can be used to help calibrate activity-age relations for field stars beyond the middle of their main-sequence lifetimes.

## **Elisabeth Newton - The evolution of rotation and magnetism in low mass M dwarfs**

The ages of M dwarfs in the field of the galaxy are challenging to determine. Consequently, the evolution of rotation and magnetism at field ages is difficult to investigate observationally. We have measured rotation periods for approximately 500 nearby M dwarfs, which we combine with H-alpha measurements from our work and from the literature. We investigate the relationship between rotation, magnetic activity, and stellar mass for M dwarfs, with an emphasis on fully convective stars. We connect the evolution of M dwarfs as traced through clusters to what we observe in the field.

## **Stefanie Raetz - The rotation-activity relation of M dwarfs: From K2 to TESS and PLATO**

Studies of the rotation-activity relation of late-type stars are essential to enhance our understanding of stellar dynamos and angular momentum evolution. Photometric observations with space telescopes such as the K2 and TESS missions provide rotation periods even with low amplitudes as well as a wealth of activity diagnostics. We currently study the rotation-activity relation with K2 for M dwarfs where it is especially poorly understood. Our study is based on the Superblink proper motion catalogue of  $\sim 9000$  bright and nearby M dwarfs by Lepine and Gaidos (2011). The rotation-activity relation based on photometric activity indicators revealed, that, at a critical rotation period of  $\sim 10$ d, the activity level changes abruptly. This phenomenon represents an open problem within the framework of dynamo theory. Despite the outstanding capabilities of K2, the short observational baseline and the low cadence allows us to detect only short rotation periods and long duration flares which represents a strong bias for such activity studies. TESS observes in its two years main mission almost all bright M-dwarfs from the Superblink catalogue. Although TESS observes one sector for only  $\sim 27$ d, it will provide up to thirteen 27d-light curves for  $\sim 2\%$  of the targets due to the overlap of the sectors. TESS drastically enlarges our sample of continuous high cadence monitored bright M-dwarfs and allows us to study in depth the activity and in particular the morphology of flares. In the future, the PLATO mission with its unprecedented precision, short cadence and long observational baseline, allows us to study the magnetic activity indicators in up to now unrivaled detail. In my talk I will explain the results of our K2 study and show the application of the activity analysis methods to TESS data. Furthermore, I will describe how a higher cadence and a longer duration improves the determination of rotation periods and the detection of stellar flares.

## **Luisa Rebull - Rotation in Clusters with K2**

K2 has provided a phenomenal opportunity to study properties of stars in clusters, particularly young low-mass stars, far beyond the expectations of the original Kepler mission. The high-precision photometry provided by K2 allows us to probe stellar variability to lower masses and lower amplitudes than has ever been done before.

Younger stars are generally more rapidly rotating and have larger star spots than older stars of similar masses, so it is straightforward to find variation due to spots rotating into and out of view. K2 has monitored stars from several clusters, most notably Rho Oph ( $\sim 1$  Myr), Taurus ( $\sim 5$  Myr), USco ( $\sim 20$  Myr), the Pleiades ( $\sim 125$  Myr), and Praesepe ( $\sim 700$  Myr). The light curves have yielded thousands of rotation rates, and revealed far greater diversity in light curves than was anticipated. In this talk I will review the results of K2 observations clusters, specifically distributions of rotation rates.

## **Timo Reinhold - Stellar rotation along the ecliptic - K2 reveals a variability decrease at ages between 600-800Myr**

Rotation period measurements in the Kepler field have revealed a lack of stars with intermediate rotation periods, accompanied by a decrease of photometric variability. The K2 mission provides the opportunity to measure stellar rotation and photometric variability along different fields in the ecliptic plane. Analyzing K2 campaigns 0-18, a large data set covering more than 500,000 stars, we detect rotation periods in about 33,000 stars. The period distribution shows some bimodality, although less pronounced as observed in Kepler. Additionally, we find a local minimum of the stellar variability amplitude at rotation periods close to the "dip" of the period distribution. The periods at the variability minimum correspond to gyrochronology ages between 600-800 Myr. Our results support the proposed idea of a cancellation of bright and dark surface features at these ages, leading to a non-detection of periodicity, along with a decrease of variability. We conclude that the previously observed dearth of rotation periods is not unique to the Kepler field of view, but rather represents a general manifestation of stellar activity.

## **Rachael Roettenbacher - Using Stellar Surface Maps to Measure Differential Rotation**

Multiple starspots simultaneously present on cool, active stars sometimes show evidence of rotating with the stellar surface at different rates. These varying rotation rates are assumed to be the result of differential rotation, and the starspots must be located at different stellar latitudes. Differential rotation has been detected with photometric and spectroscopic observations, and parameters to describe the motion can be determined and compared to that of the Sun. Using the longterm photometric light curves from the Kepler satellite, we invert individual rotations of active stars to create maps of evolving, spotted stellar surfaces. We then cross-correlate the stellar surfaces to determine differential rotation parameters, making use of localized starspots and larger-scale photometric variations across the stellar surfaces. We present our findings of differential rotation parameters consistent with theory and those measured by other techniques. We additionally contextualize these findings and the method in the scope of our large-scale study of stellar activity.

## **Julia M T Roquette - Does the environment matter? Investigating the spin rates of low mass stars in the young Cygnus OB2 association**

In recent decades, observational studies targeting clusters and associations at a variety of ages helped to constrain our understanding of the rotational evolution of low mass stars during the early pre-main sequence. During the first 10 Myrs, a significant fraction of the low mass stars still holds a circumstellar disk. While it is generally accepted that the star-disk interaction dominates their rotational evolution, very few studies take into consideration how the cluster environmental conditions can impact the disk-evolution and therefore change the early rotational evolution of the lower mass stars. Does the environment matter? We tackled this question by investigating the rotational properties of low mass stars in the young massive association Cygnus OB2 (3-7 Myrs, 1.45 kpc). Cygnus OB2 harbors a very rich high mass population of about 160 OB stars, which are responsible for producing intense ultraviolet fields that can make some regions within the association hostile for the disk-evolution. We present partial results of two observational campaigns dedicated to investigating the impact of those OB stars on the rotational properties of the coeval low mass star in the association. We used near-infrared light curves obtained with WFCAM/UKIRT and WIRCAM/CFHT to derive spin rates for approximately a thousand association members. We present a comparison between the results supporting a disk-rotation connection for sub-groups of stars in regions of the association with high and low UV incidence.

## **Günther Rüdiger - Antisolar differential rotation of slowly rotating cool stars**

Rotating stellar convection transports angular momentum equatorward generating the characteristic equatorial acceleration of the solar rotation. New numerical box simulations, however, provide a poleward angular momentum transport for slow rotation and an equatorward transport for fast rotation. The explanation is that for slow rotation always a negative radial gradient of the angular velocity appears which in combination with a so far neglected rotation-induced off-diagonal eddy viscosity term provides antisolar rotation laws with decelerated equator. In consequence, the observation of the differential rotation of slowly rotating stars will thus lead to a better understanding of the actual stress-strain relation and the underlying rotating turbulence.



## **Steven Saar - A Break From the Skumanich Boredom: Weird and Wonderful Happenings On the I Branch**

I outline some interesting new discoveries of what has for a long while been considered a placid, steady evolution (ala Skumnaich) from the wild youth of saturation to eventual (cyclic) dynamo death along the I branch. Much is upended, old details suddenly made relevant, and much room for new theoretical excursions is opened.

## **Jürgen Schmitt - Rotation and ages of stars in the immediate solar environment**

Age determinations for field stars are notoriously difficult and monitoring the core emission in the Ca~II H&K lines is one of the few methods available to determine the rotation rates of solar-like stars at rather low levels of activity. Using the now released Mount Wilson data as well as our own data collected with our robotic TIGRE telescope located in Guanajuato, Mexico, we have begun a systematic effort to determine the distribution of rotation velocities and ages of a complete sample of solar-like stars in the immediate solar environment. Such nearby stars have the great advantage that can also be studied in other wavelength bands such as the X-ray range, so a complete picture of their activity properties can be derived. With the collected data we can derive S-indices as well as lithium equivalent widths for all sample stars, and can perform a comprehensive assessment of the ages of the sample stars through gyro-chronology, isochrone placement on evolutionary tracks as well activity indicators and lithium strength.

## **Victor See - Do non-dipolar magnetic fields impact spin-down torques?**

Low-mass stars with outer convective zones are known to host strong magnetic fields at their surfaces. These fields drive angular momentum- & mass-loss leading to spin-down on the main sequence. One method by which stellar magnetic fields can be characterised is Zeeman-Doppler imaging. This is a powerful technique that can assess the strength and geometry of the large-scale magnetic fields of these stars. This is important because studies have shown that the open flux, which is geometry dependent, is the relevant magnetic property that determines the rate at which stars lose angular momentum.

In this talk, I estimate mass-loss rates and spin-down torques for a sample of stars that have been mapped with Zeeman-Doppler imaging. In total, this sample contains over 100 maps. Using the braking law of Finley & Matt (2018), I also determine whether non-dipolar magnetic field modes contribute to the spin-down torque of these stars. For the majority of the stars, only the dipolar field is important. However, there are regimes where the contribution of non-dipolar fields may be non-negligible.

## **Federico Spada - The rotational evolution of solar-like stars: wind braking vs. rotational coupling**

Solar-like stars ( $M < 1.3 M_{\text{sun}}$ ) lose angular momentum through their magnetized winds. Measurements of surface rotation periods of the approximately coeval stars in Galactic open clusters provide important clues on the rotational evolution of solar-like stars. In the color-period diagram of young main sequence clusters (e.g., the 100 Myr-old Pleiades, or older) a sequence of relatively slower-rotating stars gradually emerges; so far, this sequence has been observed in clusters up to 4 Gyr of age. In general, stars belonging to the slow rotators sequence evolve coherently towards longer periods in progressively older clusters. Recent observations of the  $\sim 700$ -Myr old Praesepe and the 1-Gyr old NGC 6811 clusters, however, seem to contradict this general pattern. While the 1  $M_{\text{sun}}$  stars on the slow rotators sequence of the older NGC 6811 have longer periods than their counterparts in the younger Praesepe, as expected, the two sequences overlap at lower masses ( $\sim 0.8 M_{\text{sun}}$ ). In other words, low-mass stars seem to have not been spinning down at all in the intervening 300 Myr. I will present a model for the rotational evolution of solar-like stars that is consistent with the recent observations of the slow rotators sequence. In particular, the apparent halt in the surface braking of low-mass stars between 700 Myr and 1 Gyr arises naturally in the model from simple assumptions on the wind braking law and the internal rotational coupling. More specifically, the angular momentum transported from the interior temporarily compensates for the loss due to wind braking at the surface. The constraints placed by this simple model on the processes that redistribute angular momentum in stellar interiors, as well as its predictions for stars of different masses and ages will be discussed.

## **Alejandro Suárez Mascareño - Do exoplanet hunters dream of stellar activity?**

Since the arrival of high precision radial velocity measurements (RV), stellar activity became one of the main causes of concern of the exoplanet community. Intrinsic variations of the magnetic regions on the stellar surface induce RV variations both at the timescales of the stellar rotation and the magnetic cycle of the stars. This was considered to be an unbeatable obstacle for some time. A dreaded idea that brought sadness to the hearts of exoplanet hunters. Fearing they would never be able to detect the small signals caused by Earth-mass planets, they resorted to extreme selection criteria that excluded most stars as potential candidates. Looking at the quietest among the quietest stars they realized it was not enough, for no matter how quiet a star is, it would always be noisier than an Earth-mass planet. That could have been the end, but the answer lied right in front of their eyes. For it was not to turn their eyes away from stellar activity, but to embrace it and understand it. And so many astronomers began a journey into the realm of stellar studies only to discover a fascinating new world that actually had always been around the corner. We present the results of a study conducted over hundreds of stars in the solar vicinity, with spectral types ranging from F0 to M6, combining measurements from different ground sources (from HARPS and HARPS-N, to the Mount Wilson HK project), aimed at the detection, characterization of such signals and their statistical properties. These results should allow for a better understanding of the behaviour of late type stars, the influence of stellar activity in their RV measurements and their dynamo mechanism.

## **Krisztián Vida - A photometric study of TRAPPIST-1 analogues in TESS data**

Based on the Gaia database we searched for nearby late-type dwarfs, similar to the host star of the TRAPPIST-1 system. We analyzed light curves of these targets, derived from TESS full-frame images with a cadence of 30 minutes. In this talk I will discuss the rotation and magnetic activity of these systems, and its possible effects on their habitability.

## **Jörg Weingrill - Colour Period Diagrams in the Era of Gaia DR2**

The rotational evolution of main sequence stars is still not fully understood for specific masses and ages. Also the influence of additional parameters like e.g. metallicity have to be investigated more carefully. In order to gain a better understanding, we need to probe stellar open clusters in different age regimes to improve our models. I present two open clusters (NGC6633, IC4756) whose stellar memberships vastly improved with the advent of Gaia DR2. The rotation periods have been determined with Lomb Scargle and Clean respectively and refined using phase dispersion minimization. Using astrometric membership helps to clean up the colour magnitude diagrams. Gaia DR2 colours prove to be more reliable than most ground based surveys.

## **Veronika Witzke - The effect of metallicity on the detectability of rotational periods in Sun-like stars**

The accurate determination of stellar rotation periods is important for estimating stellar ages as well as for understanding stellar activity and evolution. While for many stars rotation periods can be determined, there is an immense amount of stars, especially with low photometric variability or irregular pattern of variability, for which rotational periods are unknown. Here, we investigate the connection between the detectability of rotational periods and the metallicity for Sun-like stars using Kepler data. To analyse the influence of the metallicity on the detectability of the rotation periods, we select Sun-like stars with detected rotational periods, and without a significant period detection from McQuillan et al. (2014). We focus on stars with effective temperatures in the range 5600-5900 K, and surface gravities  $\log g > 4.2$ , where for stars with known periods we further restrict the sample to rotation periods in the range of 24 - 30 days. For these sample we analyse the detection fraction of rotational periods for Sun-like stars with metallicity between  $M/H = -0.4$  and  $M/H = 0.4$ . We find a dearth of periodic stars with near-solar rotation period and metallicity. The observational trends are explained using a stellar brightness variations model that accounts separately for spots and facular flux contributions. Varying the metallicity mostly changes the facular contrast, leading to an increased detectability of rotational periods for metallicities sufficiently different from the solar value.