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| <b>Authors</b>          | DISTEFANO, Elisa Maria Carmela, Lanzafame, Alessandro Carmelo, LANZA, Antonino Francesco, MESSINA, Sergio, Spada, F. |
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J/A+A/591/A43 Differential rotation in solar-like stars (Distefano+, 2016)

Lower limit for differential rotation in members of loose young stellar associations.

Distefano E., Lanzafame. A.C., Lanza A.F., Messina S., Spada F.

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Keywords: stars: solar-type - starspots - stars: rotation -  
galaxy: open clusters and associations: general -  
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#### Abstract:

Surface differential rotation (SDR) plays a key role in dynamo models and determines a lower limit on the accuracy of stellar rotation period measurements. SDR estimates are therefore essential to constrain theoretical models and infer realistic rotation period uncertainties. We measure a lower limit to SDR in a sample of solar-like stars belonging to young loose stellar associations with the aim of investigating how SDR depends on global stellar parameters in the age range (4–95Myr).

The rotation period of a solar-like star can be recovered by analyzing the flux modulation caused by dark spots and stellar rotation. The SDR and the latitude migration of dark-spots induce a modulation of the detected rotation period. We employed long-term photometry to measure the amplitude of such a modulation and to compute the quantity  $\{\Delta\}\{\Omega\}_{\text{phot}} = 2\pi / P_{\text{min}} - 2\pi / P_{\text{max}}$  that is a lower limit to SDR.

We find that  $\{\Delta\}\{\Omega\}_{\text{phot}}$  increases with the stellar effective temperature and with the global convective turn-over timescale  $\tau_{\text{c}}$ , which is the characteristic time for the rise of a convective element through the stellar convection zone. We find that  $\{\Delta\}\{\Omega\}_{\text{phot}}$  is proportional to  $T_{\text{eff}}^{2.18 \pm 0.65}$  in stars recently settled on the ZAMS.

This power law is less steep than those found by previous authors, but closest to recent theoretical models.

We investigate how  $\{\Delta\}\{\Omega\}_{\text{phot}}$  changes in time in a  $1M_{\odot}$  star. We find that  $\{\Delta\}\{\Omega\}_{\text{phot}}$  steeply increases between 4 and 30Myr and that it is almost constant between 30 and 95Myr. We find also that the relative shear increases with the Rossby number  $Ro$ . Although our results are qualitatively in agreement with hydrodynamical mean-field models, our measurements are systematically higher than the values predicted by these models.

The discrepancy between  $\{\Delta\}\{\Omega\}_{\text{phot}}$  measurements and theoretical models is particularly large in stars with periods between 0.7 and 2d. Such a discrepancy, together with the anomalous SDR measured by other authors for HD 171488 (rotating in 1.31d), suggests that the rotation period could influence SDR more than predicted by the models.

#### Description:

The average rotation period, the parameters  $\{\omega\}_{\text{min}}$ ,  $\{\omega\}_{\text{max}}$ ,  $\{\Delta\}\{\Omega\}_{\text{phot}}$  and  $\alpha_{\text{phot}}$  are reported for 111 late-type stars belonging to loose young stellar associations.

For each target, the main physical parameters are also reported. The Spectral types, the photometric data and the distances are taken by previous works. The masses, the effective temperatures and the convective turn-over time-scales have been inferred by comparing absolute magnitudes with different sets of theoretical isochrones.

#### File Summary:

| FileName   | Lrecl | Records | Explanations                                                                                          |
|------------|-------|---------|-------------------------------------------------------------------------------------------------------|
| ReadMe     | 80    | .       | This file                                                                                             |
| table2.dat | 71    | 111     | List of the target investigated in the present work                                                   |
| table3.dat | 94    | 111     | Results                                                                                               |
| table4.dat | 62    | 111     | Data used to compute absolute magnitudes                                                              |
| table5.dat | 85    | 109     | Stellar parameters inferred by the comparison of J and H magnitudes with different theoretical models |

See also:

J/AJ/138/312 : Activity of bright solar analogs (Hall+, 2009)  
 J/A+A/552/A78 : Solar like stars radial velocities (Zechmeister+, 2013)  
 J/A+A/572/A34 : Pulsating solar-like stars in Kepler (Garcia+, 2014)  
 J/A+A/520/A15 : RACE-OC project: YSOs within 100pc (Messina+, 2010)  
 J/A+A/532/A10 : RACE-OC project. II. (Messina+, 2011)

Byte-by-byte Description of file: table2.dat

| Bytes  | Format | Units | Label  | Explanations             |
|--------|--------|-------|--------|--------------------------|
| 1- 26  | A26    | ---   | ID     | ASAS or SuperwaspID (G1) |
| 29- 45 | A17    | ---   | Name   | Other designation        |
| 46- 60 | A15    | ---   | Assoc  | Association              |
| 61- 64 | F4.2   | mag   | B-V    | B-V colour index (2)     |
| 66- 71 | A6     | ---   | SpType | MK spectral type (2)     |

Note (2): The colour indexes and spectral types have been taken from Messina et al. (2010, Cat. J/A+A/520/A15 and 2011, Cat. J/A+A/532/A10).

Byte-by-byte Description of file: table3.dat

| Bytes  | Format | Units | Label    | Explanations                       |
|--------|--------|-------|----------|------------------------------------|
| 1- 26  | A26    | ---   | ID       | ASAS or SuperWasp ID (G1)          |
| 28- 32 | F5.2   | d     | <P>      | Average rotation period            |
| 34- 39 | F6.3   | rad/d | omin     | Lowest angular frequency           |
| 41- 45 | F5.3   | rad/d | e_omin   | Error on lowest angular frequency  |
| 47- 52 | F6.3   | rad/d | omax     | Highest angular frequency          |
| 54- 58 | F5.3   | rad/d | e_omax   | Error on highest angular frequency |
| 60- 64 | F5.3   | rad/d | DOp      | {Delta}{Omega}_phot_ = omax-omin   |
| 66- 70 | F5.3   | rad/d | e_DOp    | Error on DeltaOmega_phot           |
| 72- 76 | F5.3   | ---   | alphap   | {alpha}_phot_ = (omax-omin)/omax   |
| 78- 82 | F5.3   | ---   | e_alphap | Error on alpha_phot                |
| 84- 86 | I3     | ---   | Np       | Number of time-series points       |
| 89     | A1     | ---   | fQ       | [ABC] Quality flag (1)             |
| 93- 94 | A2     | ---   | fT       | Time-series flag (2)               |

Note (1): Quality flag as follows:

A = stars with Np > 200  
 B = stars with Np between 100 and 200  
 C = stars with Np < 100

Note (2): This flag indicates the time-series used to compute DeltaOmega\_phot\_.

Byte-by-byte Description of file: table4.dat

| Bytes  | Format | Units | Label | Explanations                |
|--------|--------|-------|-------|-----------------------------|
| 1- 26  | A26    | ---   | ID    | ASAS or SuperWasp ID (G1)   |
| 29- 34 | F6.2   | mas   | Plx   | ?= Parallax                 |
| 36- 42 | F7.3   | pc    | Dist  | Distance                    |
| 46- 50 | F5.2   | mag   | DM    | Distance modulus            |
| 52- 55 | F4.2   | mag   | JMAG  | ?= Absolute J magnitude (1) |
| 57- 60 | F4.2   | mag   | HMAG  | ?= Absolute H magnitude (2) |

62 I1 --- Ref [1/6] Reference (3)

Note (1): This magnitude has been obtained by adding the Distance Modulus DM to the 2MASS J magnitude. The Distance Modulus has been inferred by using the parallax or the distance reported in other works

Note (2): This magnitude has been obtained by adding the Distance Modulus DM to the 2MASS H magnitude

Note (3): The reference number indicates the work from which the parallaxes and/or the distance have been taken, as follows:

- 1 = Torres et al., 2006, Cat. J/A+A/460/695
- 2 = Torres et al., 2008hsf2.book..757T
- 3 = Perryman et al., 1997A&A...323L..49P
- 4 = Zuckerman et al., 2000ApJ...544..356M
- 5 = De Silva et al., 2013, Cat. J/MNRAS/431/1005
- 6 = Murphy et al., 2013, Cat. J/MNRAS/435/1325

Byte-by-byte Description of file: table5.dat

| Bytes  | Format | Units | Label     | Explanations                                                                         |
|--------|--------|-------|-----------|--------------------------------------------------------------------------------------|
| 1- 26  | A26    | ---   | ID        | ASAS or SuperWasp ID (G1)                                                            |
| 28- 31 | F4.2   | Msun  | MSiess    | Mass from Siess et al. (2000A&A...358..593S) models (1)                              |
| 36- 42 | F7.2   | K     | TeffSiess | Effective temperature from Siess et al. (2000A&A...358..593S) models (1)             |
| 44- 47 | F4.2   | Msun  | MBar      | ?= Mass from Baraffe et al. (1998, Cat. J/A+A/337/403) models (1)                    |
| 50- 56 | F7.2   | K     | TeffBar   | ?= Effective temperature from Baraffe et al. (1998, Cat. J/A+A/337/403) models (1)   |
| 58- 61 | F4.2   | Msun  | MSpada    | ?= Mass from Spada et al. (2013ApJ...776...87S) models (1)                           |
| 66- 72 | F7.2   | K     | TeffSpada | ?= Effective Temperature from Spada et al. (2013ApJ...776...87S) models (1)          |
| 74- 79 | F6.2   | d     | tauC      | ?= Turnover convective time-scale from Spada et al. (2013ApJ...776...87S) models (1) |
| 81- 85 | F5.3   | ---   | Ro        | ?= Rossby number (2)                                                                 |

Note (1): Stellar parameters inferred by the comparison of the J and H magnitudes with the theoretical isochrones of Siess et al. (2000A&A...358..593S), Baraffe et al. (1998, Cat. J/A+A/337/403) and Spada et al. (2013ApJ...776...87S).

Note (2): The Rossby Number is computed as  $Ro = \langle P \rangle / \tau_C$

Global notes:

Note (G1): ASAS\_JHHMMSS+DDMM.m or SWASP1\_JHHMMSS.SS+DDMMSS.s

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Elisa Distefano, eds(at)oact.inaf.it

(End)

Patricia Vannier [CDS] 15-Apr-2016