

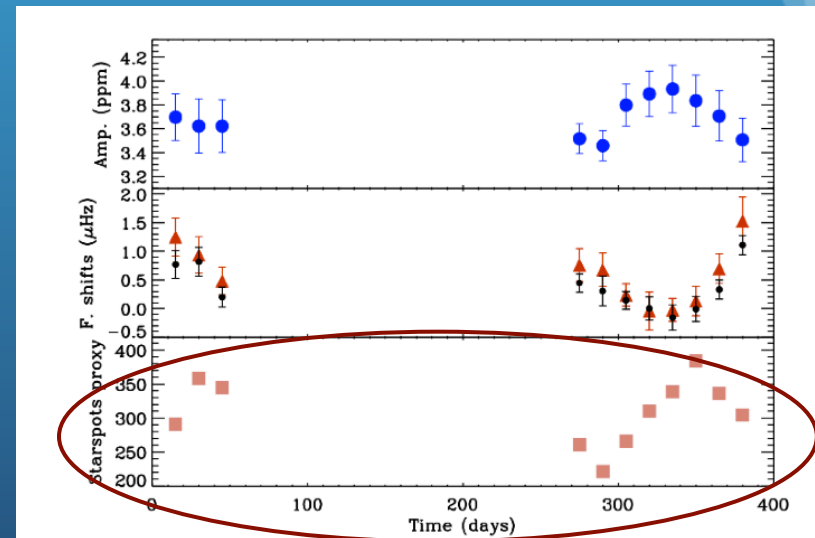
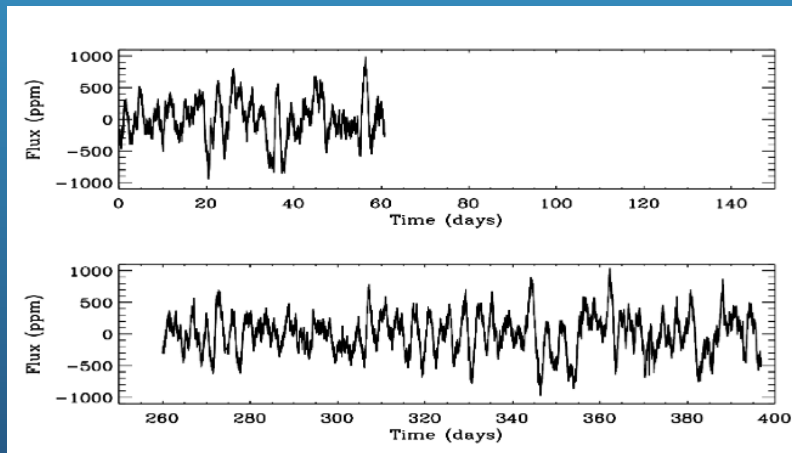
# Solar activity proxies from VIRGO and GOLF observations

## SpaceInn Deliverable 4.2

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# CoRoT observations of HD49933

- A magnetic cycle in a Sun-like star: Garcia et al., Science (2010)
- Light curve modulation: **signature of starspots**
- A global starspot proxy: the standard deviation of the light curve



# Photometric magnetic activity of stars

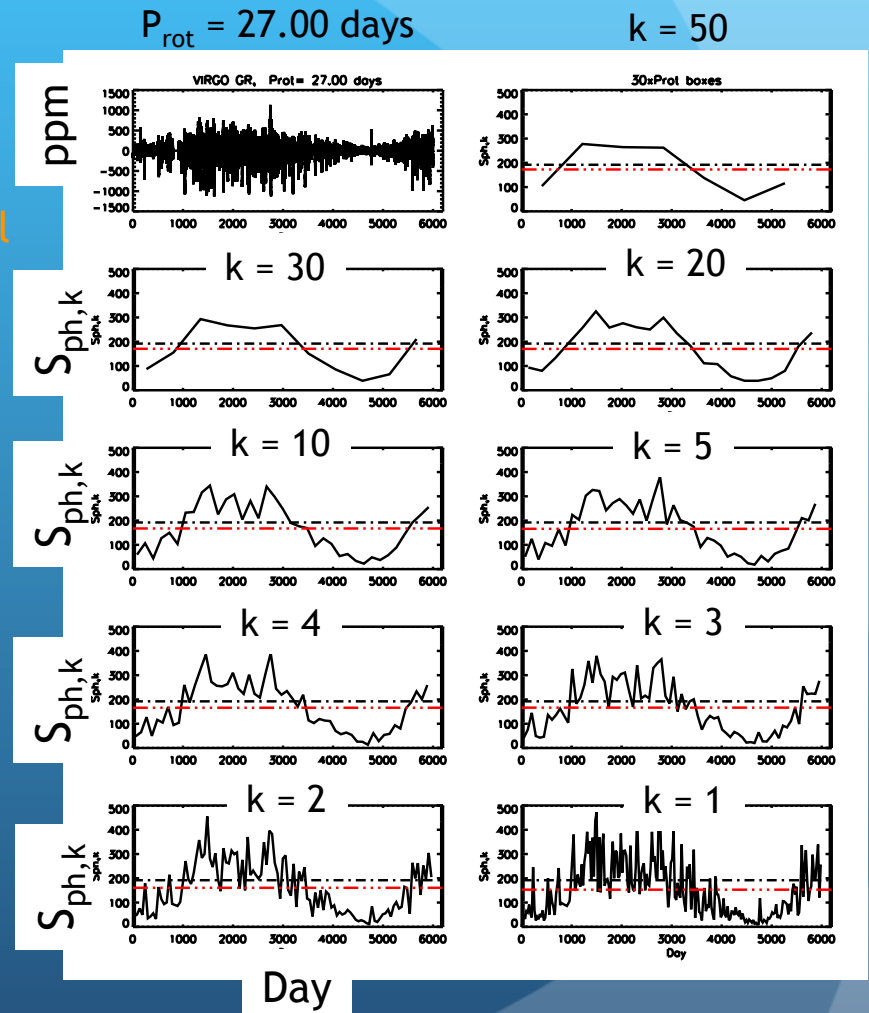
- Characterization of the variability in *Kepler* observations
- Different indices defined by Basri et al. (2010, 2013)
  - The range,  $R_{\text{var}}$ :
    - Considered as a metric of the photometric magnetic activity
    - Stellar flux between 5% and 95% of the brightness
    - Underestimate activity level of very active stars
  - The median differential variability, MDV:
    - Computed for data rebinned from 1 hour up to 8 days

# Sources of light curve variability

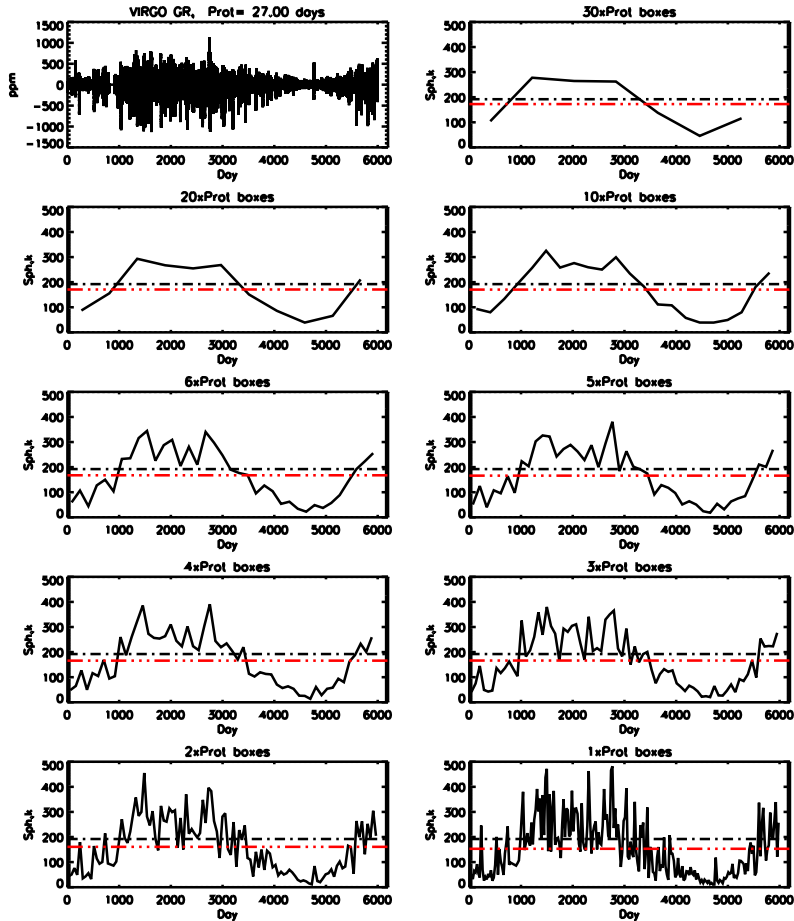
- Can be due to different phenomena:
  - Pulsations
  - Granulation
  - Rotation
  - Starspots
- To properly define an indicator measuring the variability induced by magnetic activity
  - We need to introduce the **rotation period** of the star
  - Relies on the presence of spots (thus magnetic field) on stellar surface

# Definition of the $S_{ph}$ indice

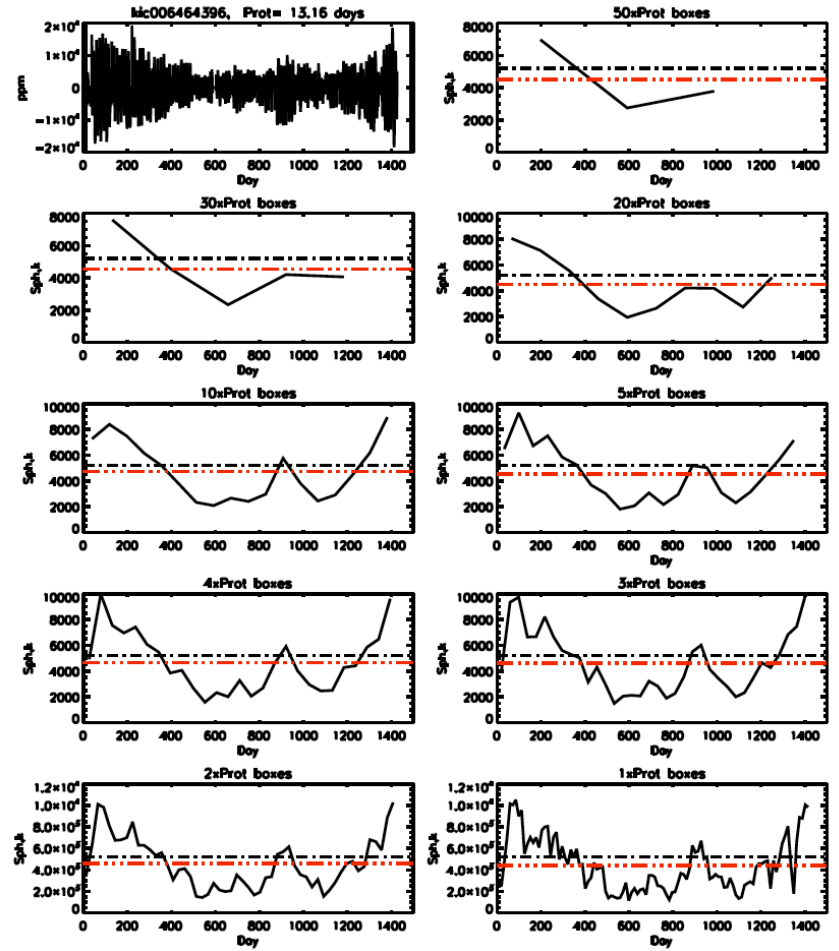
- Define an index taking into account:
    - Rotation of the star
    - Temporal variations of the activity level
  - Standard deviations  $S_{ph,k}$ 
    - Calculated over subseries of  $k \times P_{rot}$
    - $P_{rot}$  = rotational period
    - $k = [30, 20, 10, 6, 5, 4, 3, 2, \text{and } 1]$
- Black lines: stddev(entire time series)  
 – Red lines: mean  $\langle S_{ph,k} \rangle$



The Sun,  $P_{\text{rot}} = 27.00$  days,  
VIRGO observations

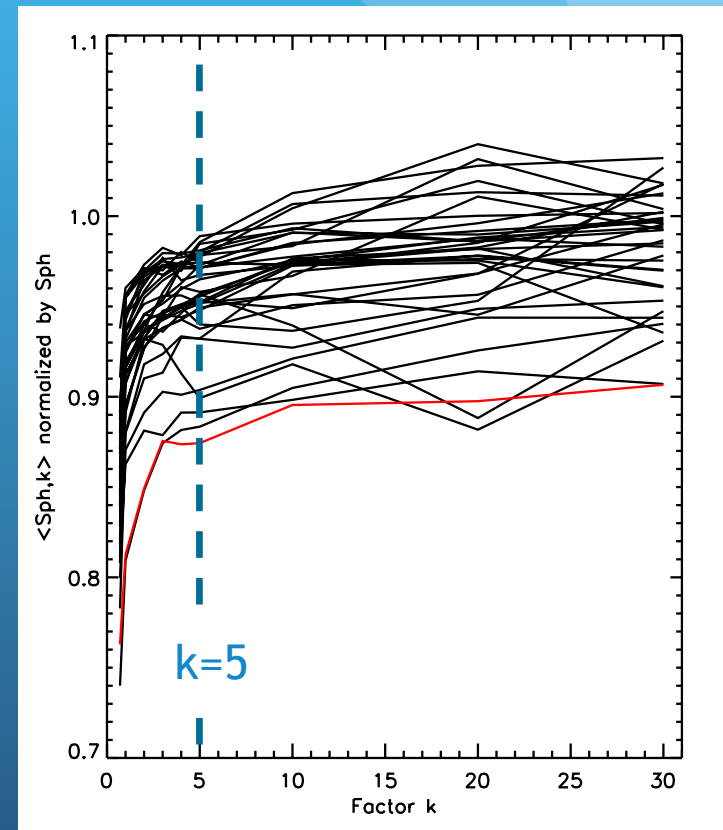


KIC6464396,  $P_{\text{rot}} = 13.16$  days  
Kepler observations



# $S_{\text{ph}}$ over $5 \times P_{\text{rot}}$ sub series

- $\langle S_{\text{ph},k} \rangle$  as a function of  $k$  for 31 M-stars (+ the Sun in red)
- Found that  $5 \times P_{\text{rot}}$  reasonably:
  - Describes the magnetic temporal evolution
  - Provides a correct value of global activity index

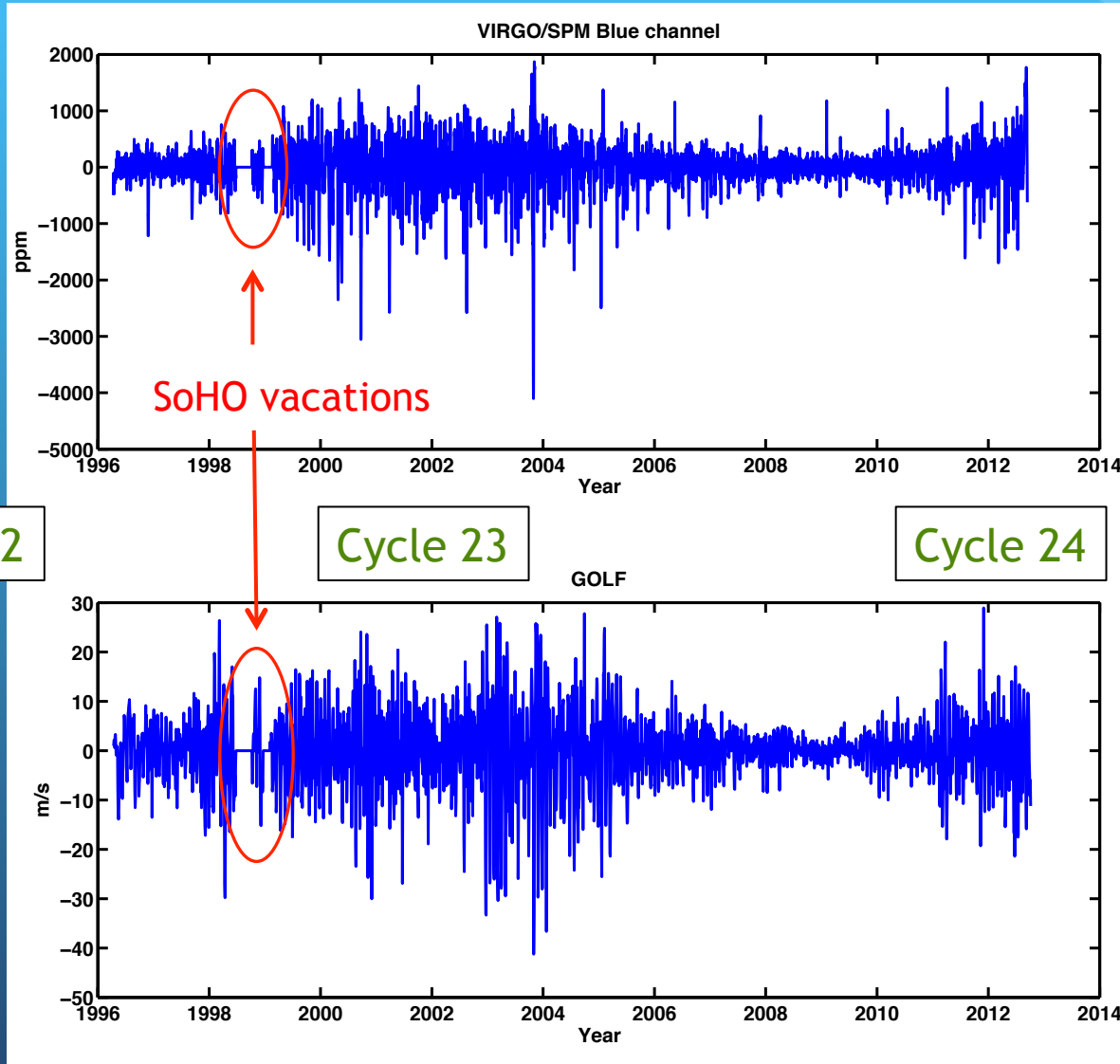


# Solar activity proxies from VIRGO and GOLF observations

- Spaceln deliverable D4.2: monitoring of solar activity
- Measurement of a magnetic proxy derived:
  - from the photometric VIRGO/SPM observations  $S_{\text{ph}}$  in ppm
    - blue, green, and red channels
    - *Kepler*-like composite
      - green+red channels: closest bandwidth with *Kepler* (Basri et al. 2010)
  - from the Doppler velocity GOLF observations  $S_{\text{vel}}$  in m/s
- Observations starting on April 11, 1996
- Observations processed through the KADACS *Kepler* pipeline (Garcia et al, 2011) to monitor long-lived features on solar surface
- Paper in preparation, Salabert et al. 2015

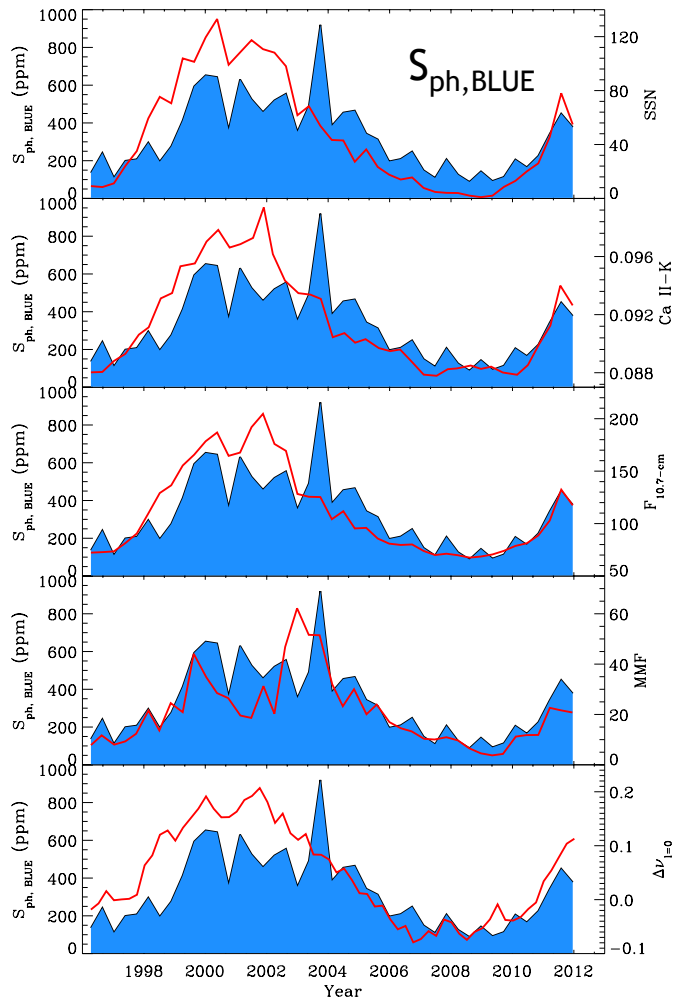


# VIRGO and GOLF observations

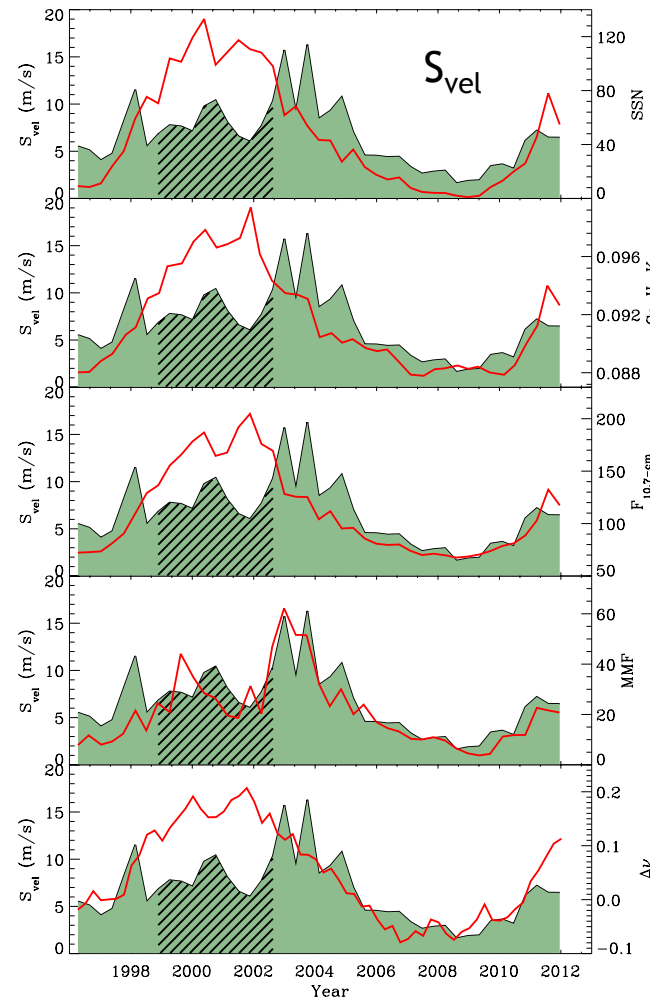


Proxies calculated over  
 $5 \times P_{\text{rot}, \odot} = 135$  days  
subseries

# $S_{ph}$ and $S_{vel}$ compared to common solar activity proxies



VIRGO/SPM Blue channel



GOLF

Sunspots

Ca H-K

$F_{10.7}$

Magnetic field

F. shifts

# Correlation coefficients

Activity proxy	$S_{\text{ph,BLUE}}$	$S_{\text{ph,GREEN}}$	$S_{\text{ph,RED}}$	$S_{\text{ph,COMPOSITE}}$	$S_{\text{vel}}$	SSN <sup>a</sup>	Ca II-K <sup>b</sup>	F <sub>10.7-cm</sub> <sup>c</sup>	MMF <sup>d</sup>
MMF <sup>d</sup>	0.86	0.86	0.86	0.86	0.83	0.77	0.77	0.79	n/a
F <sub>10.7-cm</sub> <sup>c</sup>	0.86	0.90	0.85	0.90	0.75	0.99	0.96	n/a	–
Ca II-K <sup>b</sup>	0.83	0.86	0.83	0.86	0.77	0.96	n/a	–	–
SSN <sup>a</sup>	0.85	0.88	0.84	0.88	0.75	n/a	–	–	–
$S_{\text{vel}}$	0.80	0.79	0.79	0.77	n/a	–	–	–	–
$S_{\text{ph,COMPOSITE}}$	0.97	0.99	0.97	n/a	–	–	–	–	–
$S_{\text{ph,RED}}$	0.96	0.95	n/a	–	–	–	–	–	–
$S_{\text{ph,GREEN}}$	0.97	n/a	–	–	–	–	–	–	–
$S_{\text{ph,BLUE}}$	n/a	–	–	–	–	–	–	–	–

<sup>a</sup> the total sunspot number

<sup>b</sup> the Ca II-K line emission index

<sup>c</sup> the 10.7-cm radio flux

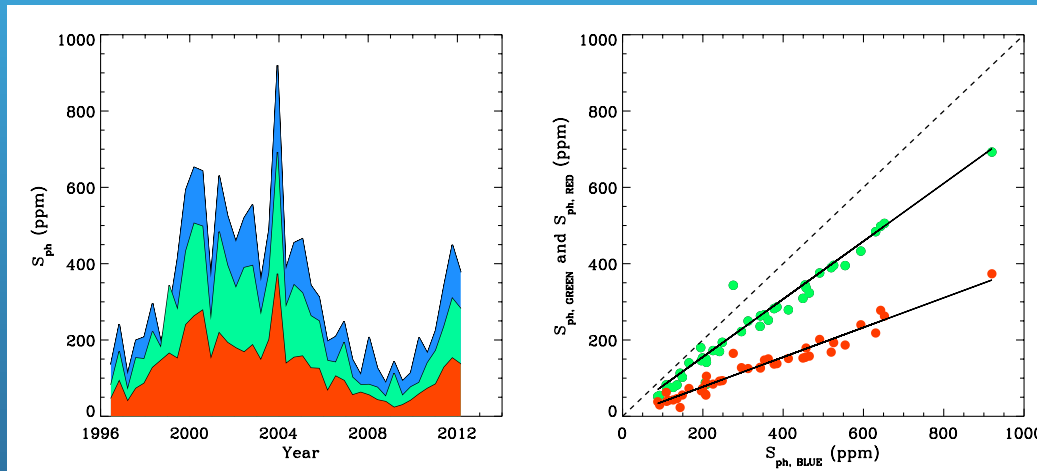
<sup>d</sup> the absolute mean magnetic field

- $S_{\text{ph}}$  and  $S_{\text{vel}}$  well correlated with other activity indices
- Photometric  $S_{\text{ph}}$  shows higher correlation than velocity  $S_{\text{vel}}$
- GOLF: in red-wing configuration during maximum of Cycle 23
  - Red-wing period: lower values of  $S_{\text{vel}}$  compared to blue wing
  - Observing heights in solar atmosphere (Jimenez-Reyes et al., 2007):

Blue wing	Red wing
322 km	480 km

# Wavelength dependence of $S_{ph}$

- $S_{ph}$  of the blue, green, and red channels of VIRGO/SPM observations
- Different sensitivities between channels
  - Red channel: much reduced amplitude during maximum of activity



## Sensitivity ratios

$$S_{ph, BLUE} / S_{ph, GREEN} = 1.3 \pm 0.1$$

$$S_{ph, BLUE} / S_{ph, RED} = 2.6 \pm 0.2$$

Blue & green  
channels

Red channel

-20 km

+10 km

- Shorter wavelengths (blue at 402 nm) more favorable than longer wavelengths (red at 862 nm)
- Sensitivity ratios in agreement with amplitude (Frohlich et al. 1997) and gain (Jimenez et al. 1999) ratios of acoustic oscillations

# Spaceln deliverable D4.2

- A new manner to monitor solar activity
- 5 files are produced (in ASCII and FITS formats):
  - 4 for  $S_{ph}$  (VIRGO blue, green, red channels, and *Kepler*-like composite)
  - 1 for  $S_{vel}$  (GOLF)
- Products *already* available on the Spaceln portal
- Files will be updated every ~ 4 months (5x27 days)

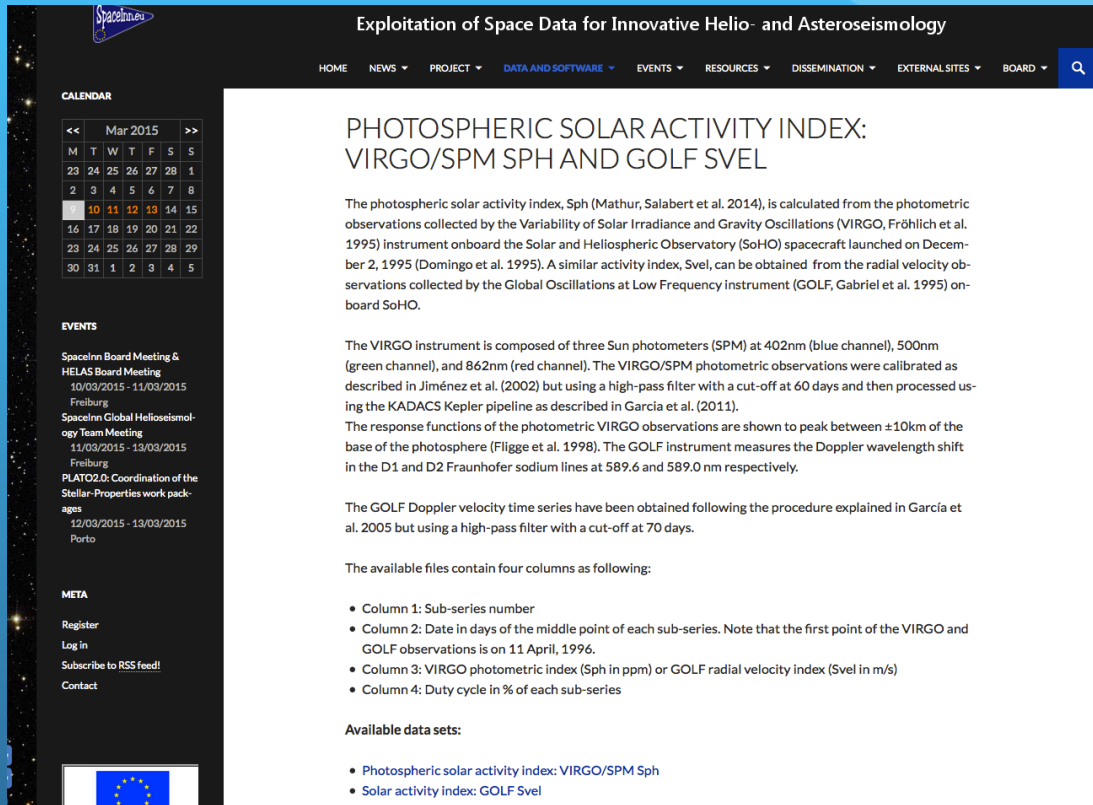
For GOLF  $S_{vel}$  only

Series index	Date (M/D/Y)	Sph, Svel	Duty cycle	...	Flag (Blue W / Red W)	% of Red measurements
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Example of header:

Keyword	Description
INSTRUMENT	Source of the observations
UNITS	Unit of the measurements, in ppm or in m/s respectively
$P_{rot}$	Rotation period in day used to calculate the activity proxies
FACTOR	Factor used to multiply to $P_{rot}$ to define the length of the analyzed sub series
CADENCE	Observational temporal cadence in seconds
LENGTH	Length of the analyzed sub series in days

# SpaceInn deliverable D4.2



The screenshot shows the SpaceInn website interface. At the top, the title is "Exploitation of Space Data for Innovative Helio- and Asteroseismology". The navigation menu includes: HOME, NEWS, PROJECT, DATA AND SOFTWARE, EVENTS, RESOURCES, DISSEMINATION, EXTERNAL SITES, BOARD, and a search icon. On the left sidebar, there is a "CALENDAR" for March 2015, an "EVENTS" section listing meetings like "SpaceInn Board Meeting & HELAS Board Meeting" and "SpaceInn Global Helioseismology Team Meeting", and a "META" section with links for "Register", "Log in", "Subscribe to RSS feed!", and "Contact". The main content area features the title "PHOTOSPHERIC SOLAR ACTIVITY INDEX: VIRGO/SPM SPH AND GOLF SVEL".

## PHOTOSPHERIC SOLAR ACTIVITY INDEX: VIRGO/SPM SPH AND GOLF SVEL

The photospheric solar activity index, Sph (Mathur, Salabert et al. 2014), is calculated from the photometric observations collected by the Variability of Solar Irradiance and Gravity Oscillations (VIRGO, Fröhlich et al. 1995) instrument onboard the Solar and Heliospheric Observatory (SoHO) spacecraft launched on December 2, 1995 (Domingo et al. 1995). A similar activity index, Svel, can be obtained from the radial velocity observations collected by the Global Oscillations at Low Frequency instrument (GOLF, Gabriel et al. 1995) on-board SoHO.

The VIRGO instrument is composed of three Sun photometers (SPM) at 402nm (blue channel), 500nm (green channel), and 862nm (red channel). The VIRGO/SPM photometric observations were calibrated as described in Jiménez et al. (2002) but using a high-pass filter with a cut-off at 60 days and then processed using the KADACS Kepler pipeline as described in García et al. (2011). The response functions of the photometric VIRGO observations are shown to peak between  $\pm 10$ km of the base of the photosphere (Fligge et al. 1998). The GOLF instrument measures the Doppler wavelength shift in the D1 and D2 Fraunhofer sodium lines at 589.6 and 589.0 nm respectively.

The GOLF Doppler velocity time series have been obtained following the procedure explained in García et al. 2005 but using a high-pass filter with a cut-off at 70 days.

The available files contain four columns as following:

- Column 1: Sub-series number
- Column 2: Date in days of the middle point of each sub-series. Note that the first point of the VIRGO and GOLF observations is on 11 April, 1996.
- Column 3: VIRGO photometric index (Sph in ppm) or GOLF radial velocity index (Svel in m/s)
- Column 4: Duty cycle in % of each sub-series

**Available data sets:**

- Photospheric solar activity index: VIRGO/SPM Sph
- Solar activity index: GOLF Svel

<http://www.spaceinn.eu/data-access/photospheric-solar-activity-index-virgospm-sph/>

+ Paper in preparation, Salabert et al. 2015