irfu
cea
saclay

cnes
CENTRE NATIONAL D'ÉTUDES SPATIALES

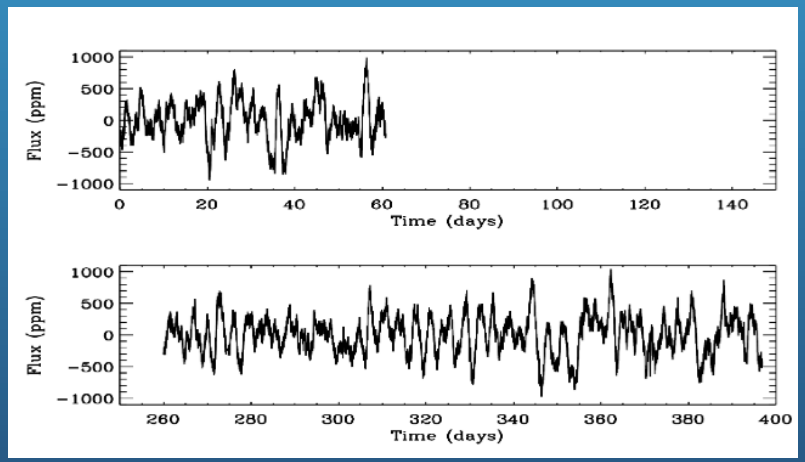
Solar activity proxies from VIRGO and GOLF observations

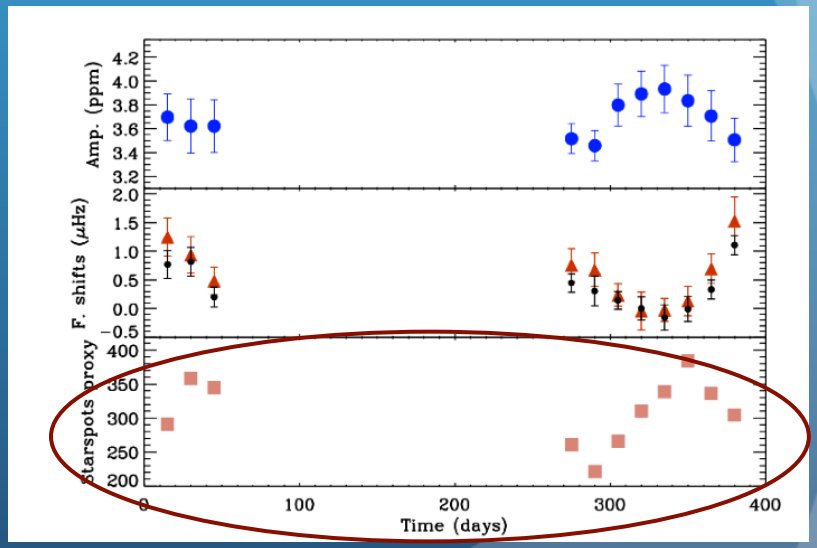
SpaceInn Deliverable 4.2

David SALABERT
CEA Saclay, Gif-sur-Yvette, France

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_{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

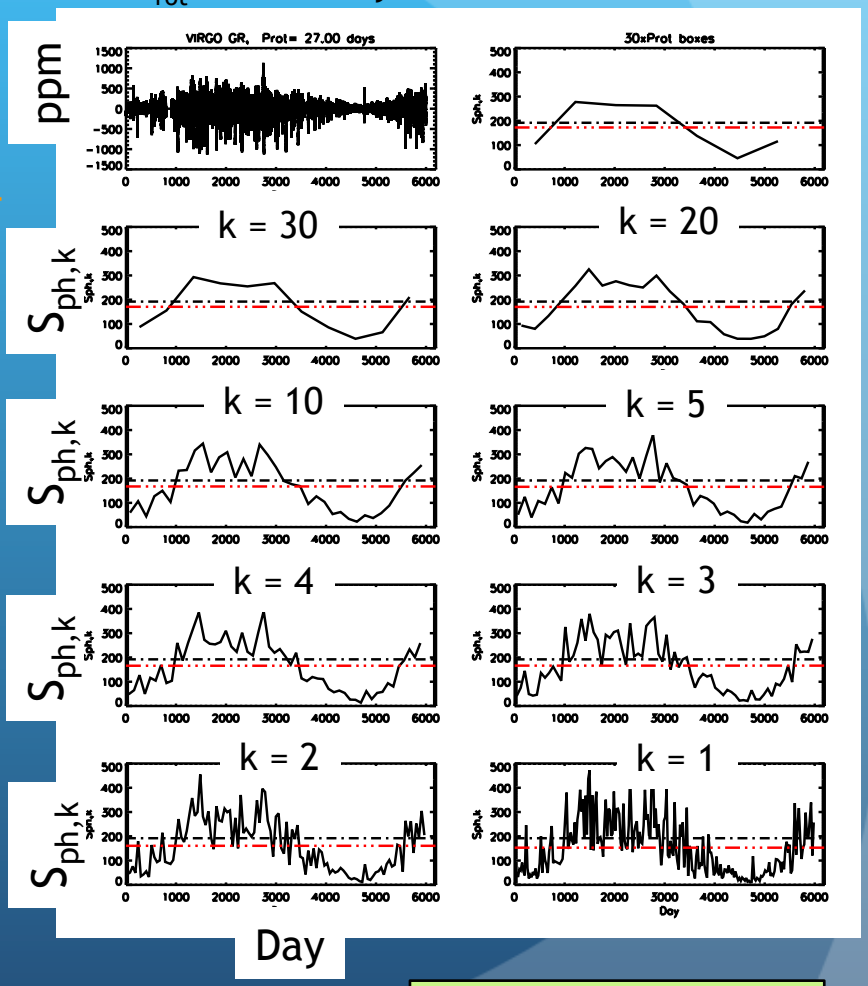
Sources of light curve variability

- 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

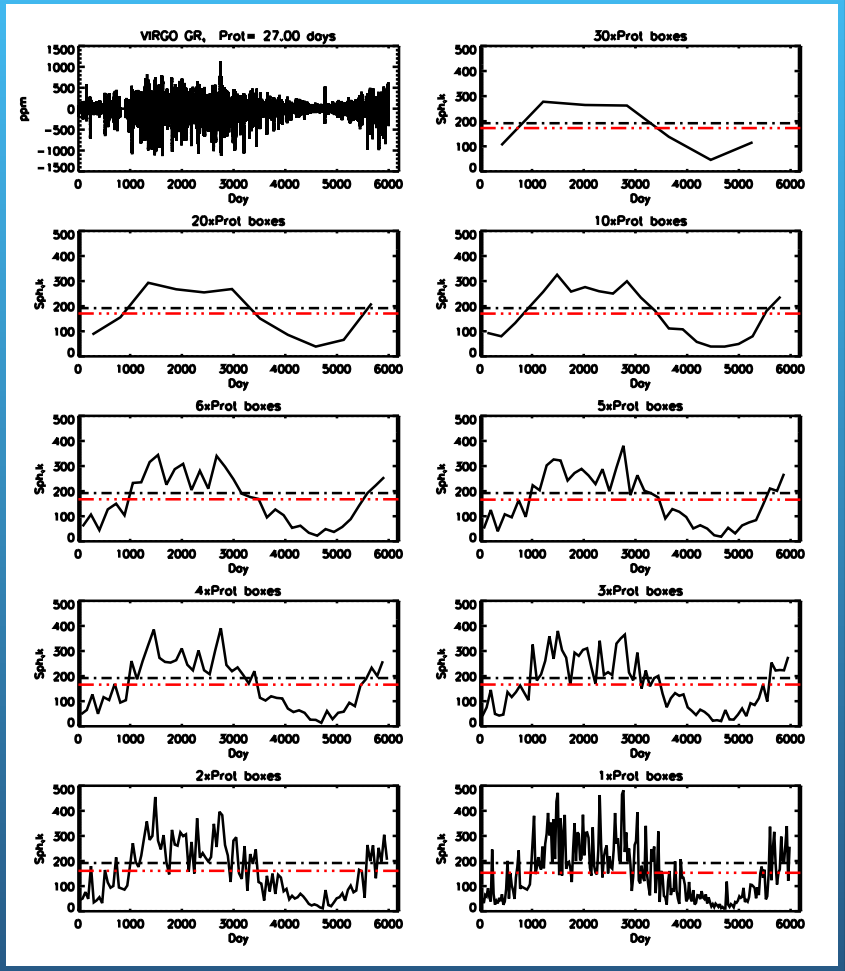
- Define an index taking into account:
  - Rotation of the star
  - Temporal variations of the activity level
- Standard deviations $S_{ph,k}$
  - Calculated over subseries of k x P_{rot}
  - P_{rot} = rotational period
  - k = [30, 20, 10, 6, 5, 4, 3, 2, and 1]
  - Black lines: stddev(entire time series)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



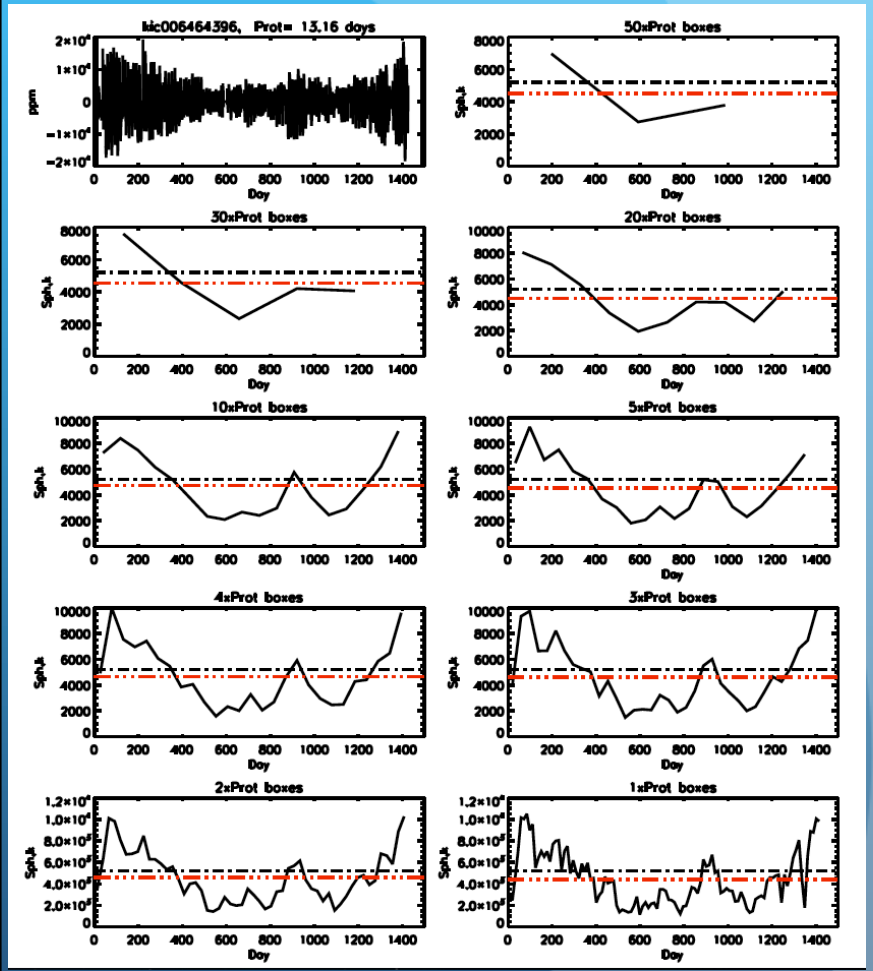
Mathur et al. (2014)
Journal of Space Weather and Space Climate (2014)

VIRGO observations

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

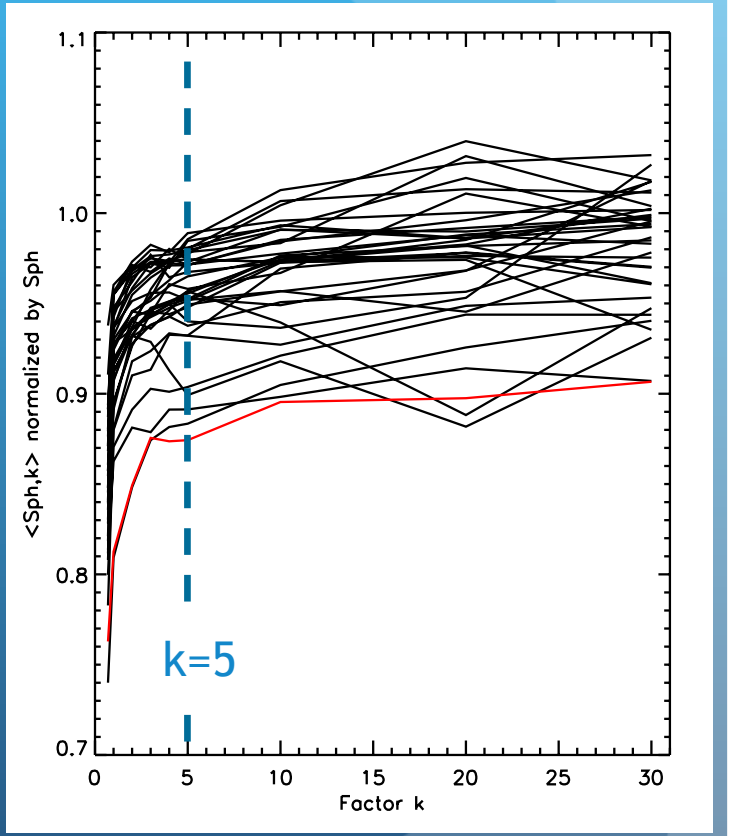


KIC6464396, P_{rot} = 13.16 days
Kepler observations



S_{ph} over 5xP_{rot} sub series

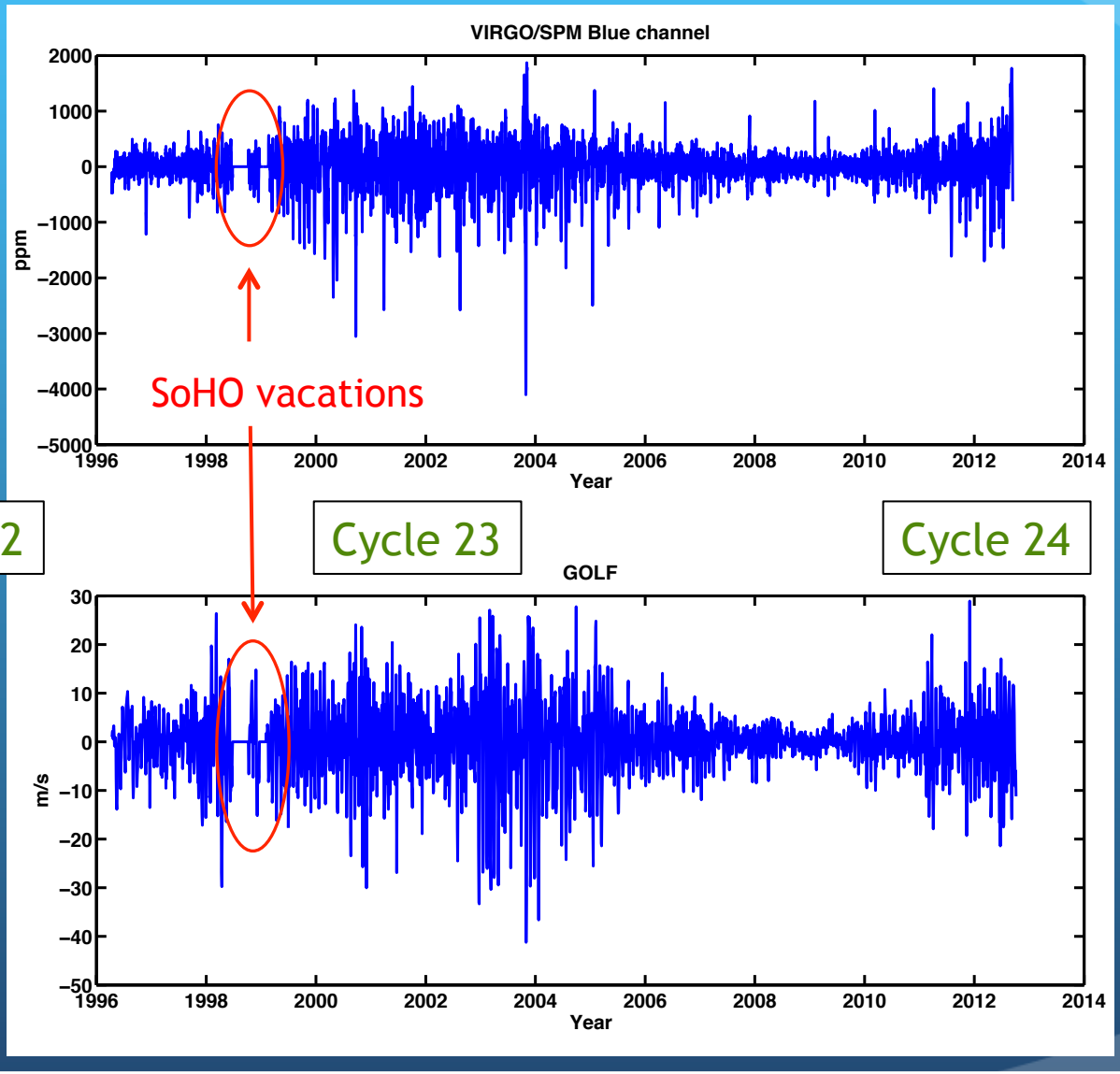
- $\langle S_{ph,k} \rangle$ as a function of k
  for 31 M-stars (+ the Sun in red)
- Found that 5 x P_{rot} reasonably:
  - Describes the magnetic temporal evolution
  - Provides a correct value of global activity index



Solar activity proxies from VIRGO and GOLF observations

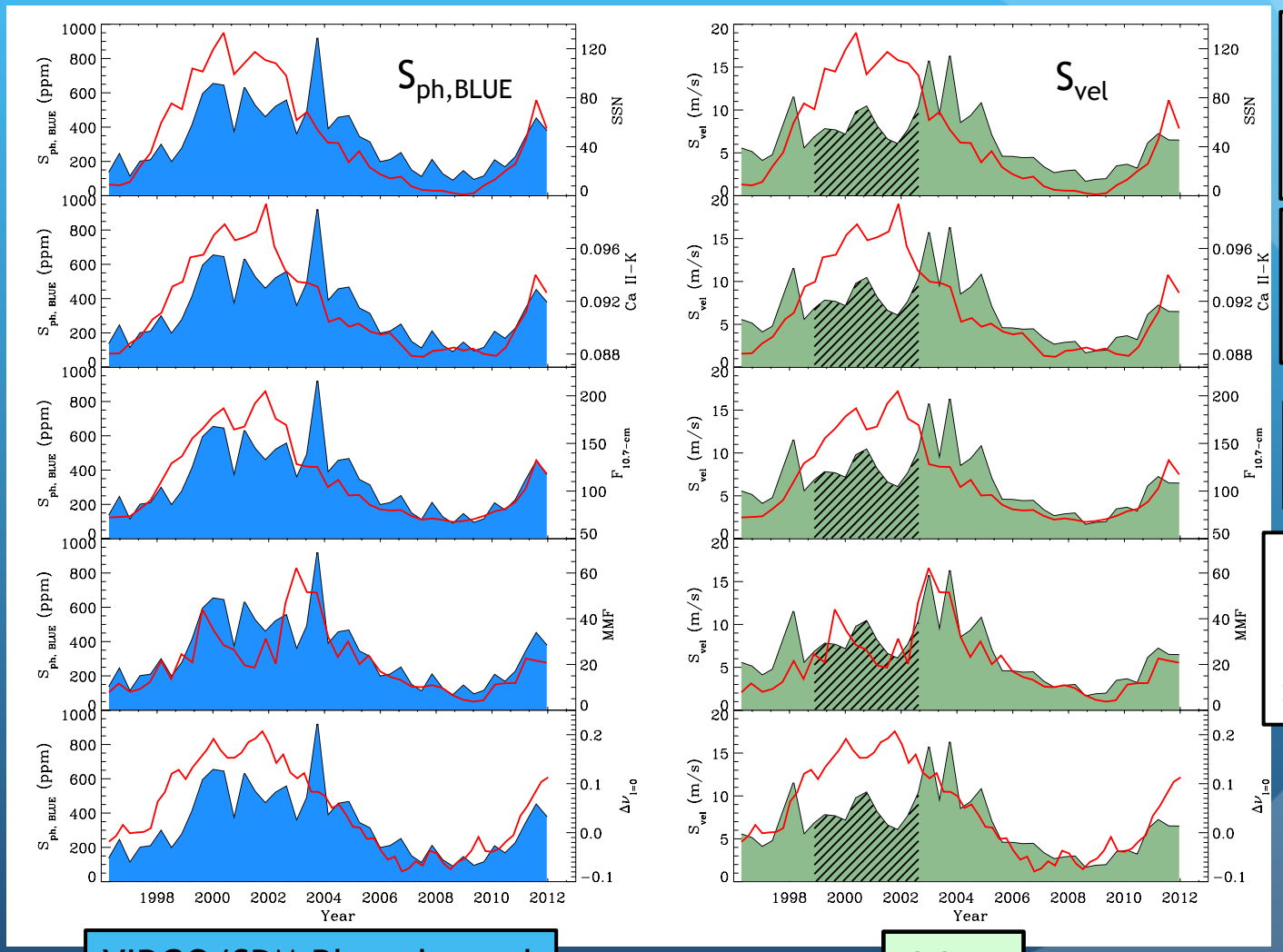
- SpaceInn deliverable D4.2: monitoring of solar activity
- Measurement of a magnetic proxy derived:
  - from the photometric VIRGO/SPM observations S_{ph} in ppm
    - blue, green, and red channels
    - *Kepler*-like composite
      - green+red channels: closest banwdith with *Kepler* (Basri et al. 2010)
  - from the Doppler velocity GOLF observations S_{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 $5 \times P_{rot,\odot} = 135$ days subseries

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



Correlation coefficients

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

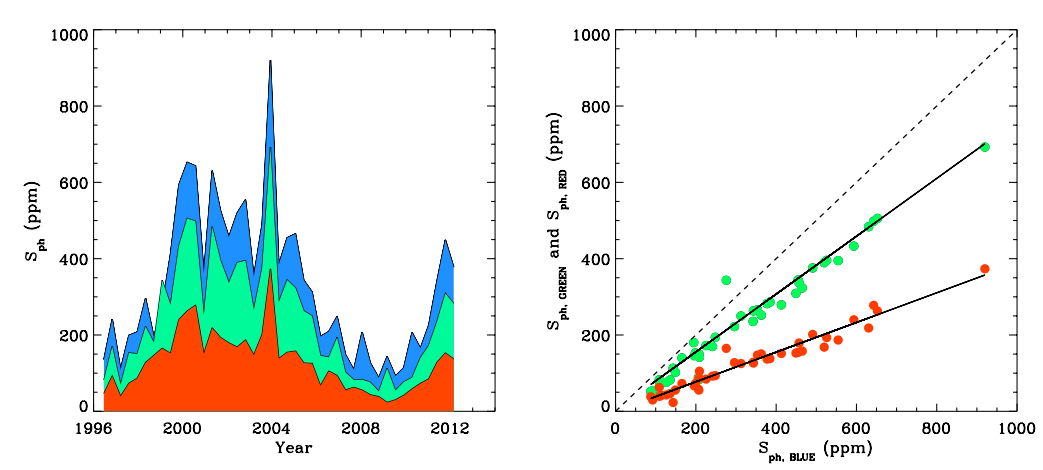
[a] the total sunspot number
[b] the Ca II-K line emission index
[c] the 10.7-cm radio flux
[d] the absolute mean magnetic field

- S_{ph} and S_{vel} well correlated with other activity indices
- Photometric S_{ph} shows higher correlation than velocity S_{vel}
- GOLF: in red-wing configuration during maximum of Cycle 23
  - Red-wing period: lower values of S_{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

SpaceInn 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 SpaceInn portal
- Files will be updated every ~ 4 months (5x27 days)

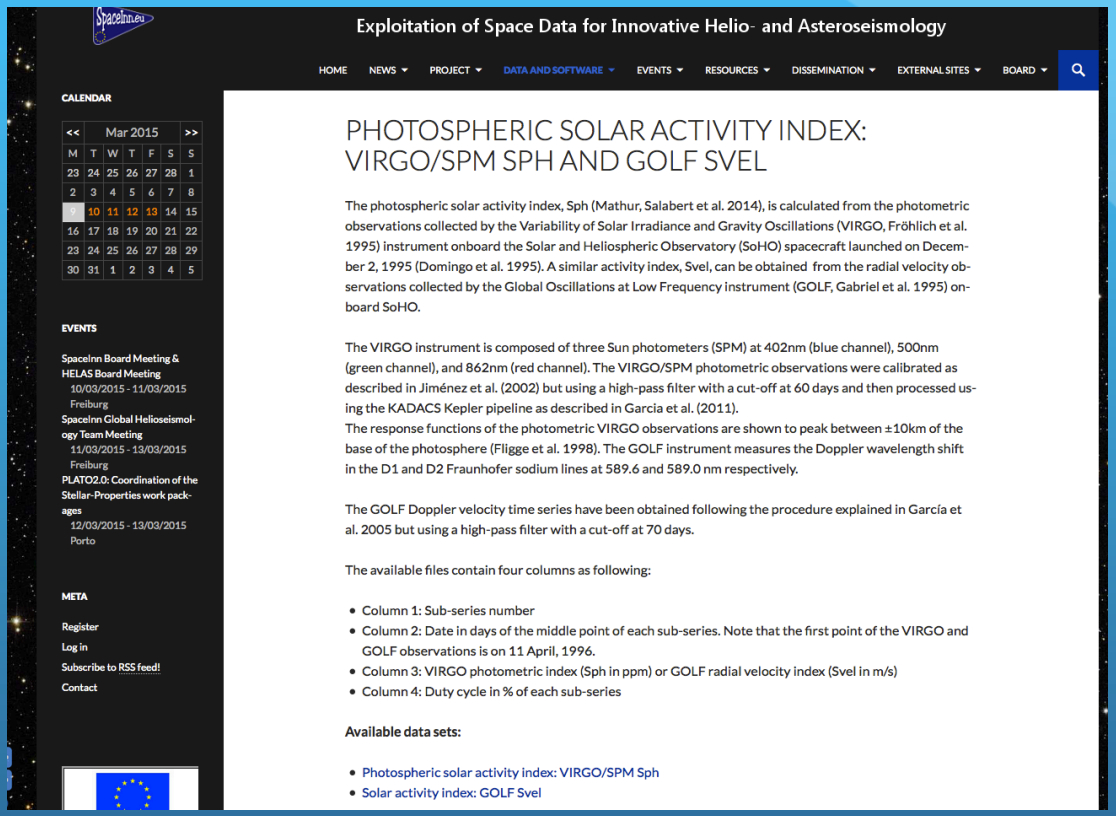
For GOLF S_{vel} only

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

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



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

+ Paper in preparation, Salabert et al. 2015