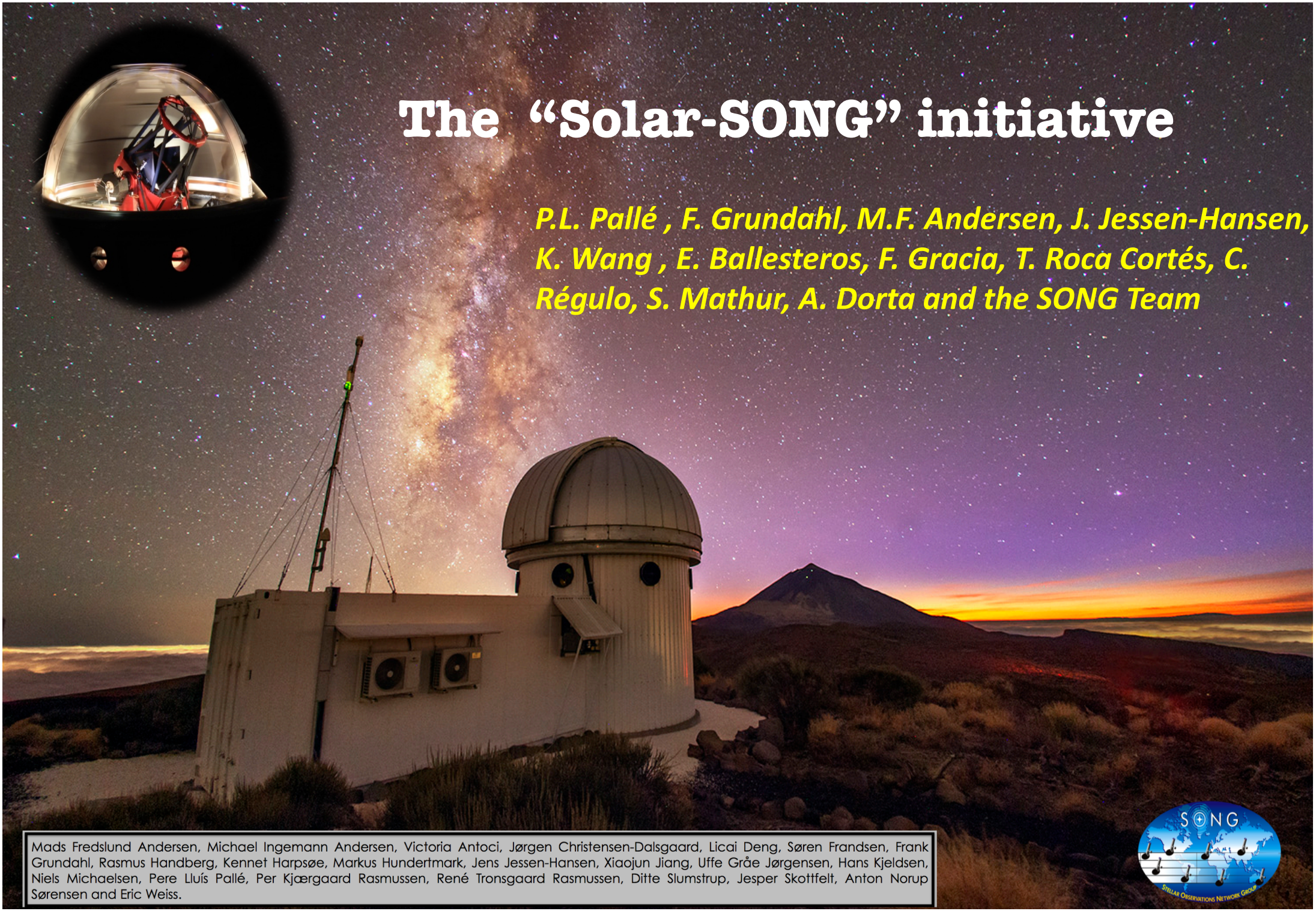
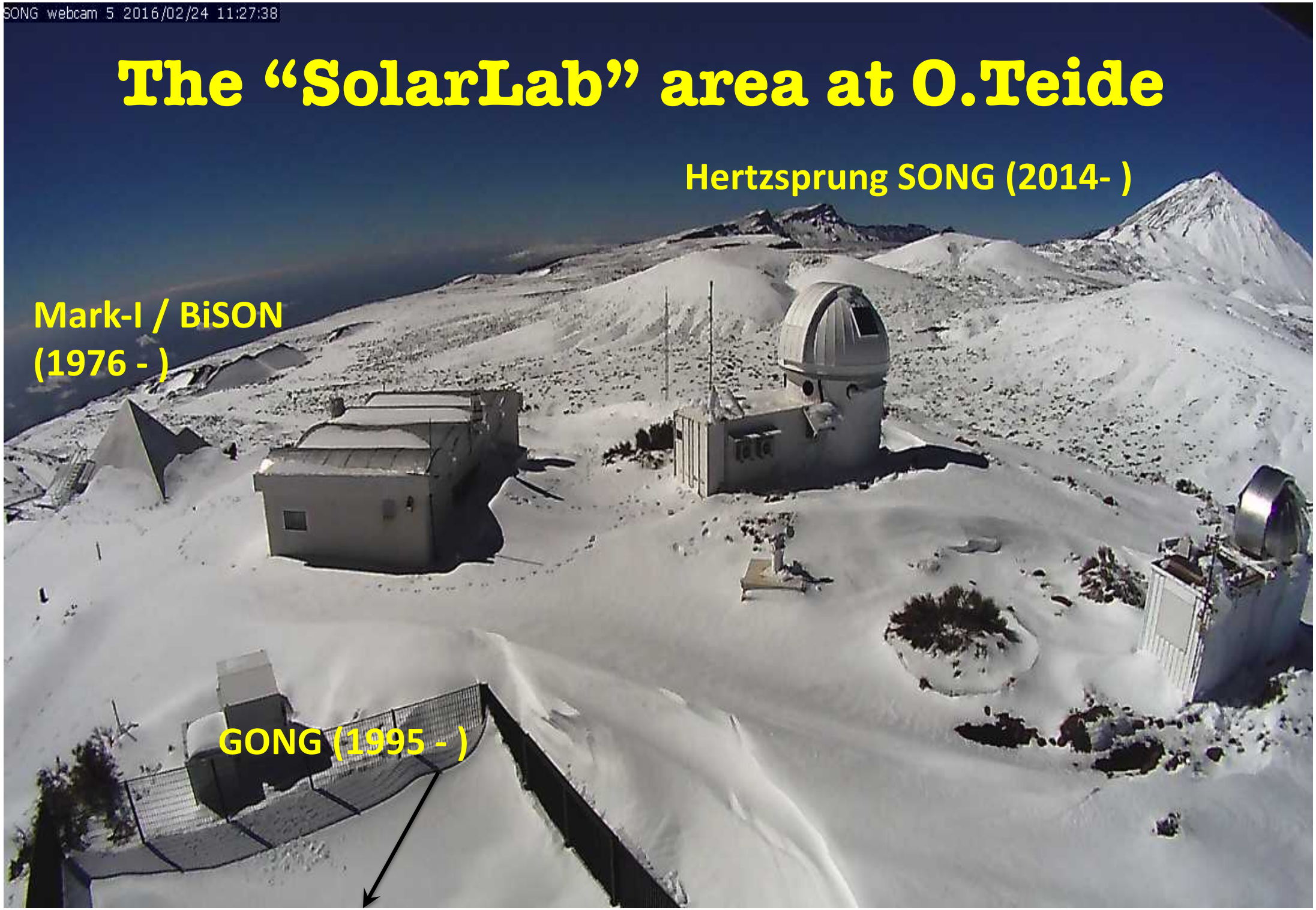


The "Solar-SONG" initiative

P.L. Pallé , F. Grundahl, M.F. Andersen, J. Jessen-Hansen, K. Wang , E. Ballesteros, F. Gracia, T. Roca Cortés, C. Régulo, S. Mathur, A. Dorta and the SONG Team

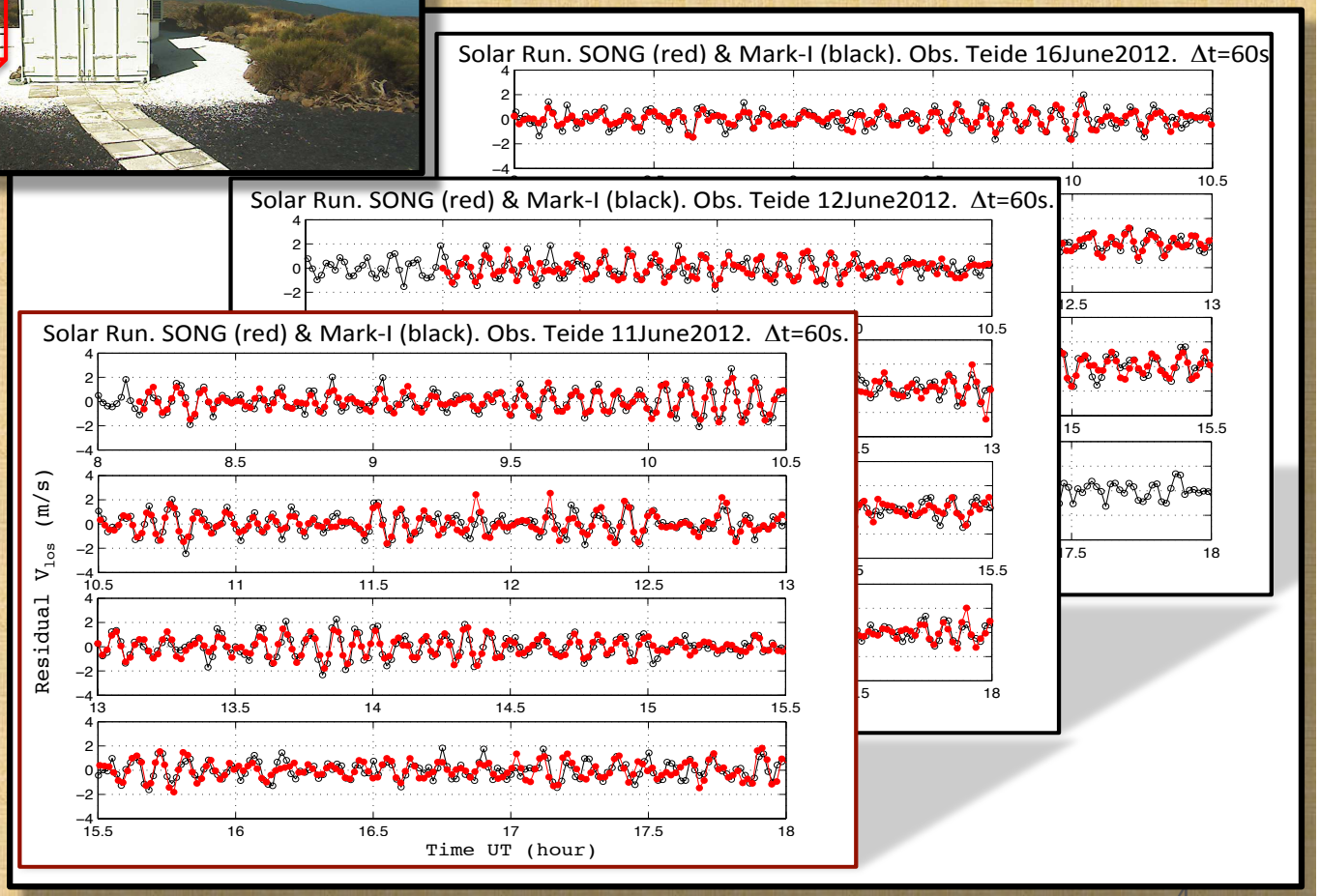
Mads Fredslund Andersen, Michael Ingemann Andersen, Victoria Antoci, Jørgen Christensen-Dalsgaard, Licai Deng, Søren Frandsen, Frank Grundahl, Rasmus Handberg, Kennet Harpsøe, Markus Hundertmark, Jens Jessen-Hansen, Xiaojun Jiang, Uffe Gråe Jørgensen, Hans Kjeldsen, Niels Michaelsen, Pere Lluís Pallé, Per Kjærgaard Rasmussen, René Tronsgaard Rasmussen, Ditte Slumstrup, Jesper Skottfelt, Anton Norup Sørensen and Eric Weiss.


SONG webcam 5 2016/02/24 11:27:38
The "SolarLab" area at O.Teide
Hertzsprung SONG (2014-)
Mark-I / BiSON
(1976 -)
GONG (1995 -)

Outline....

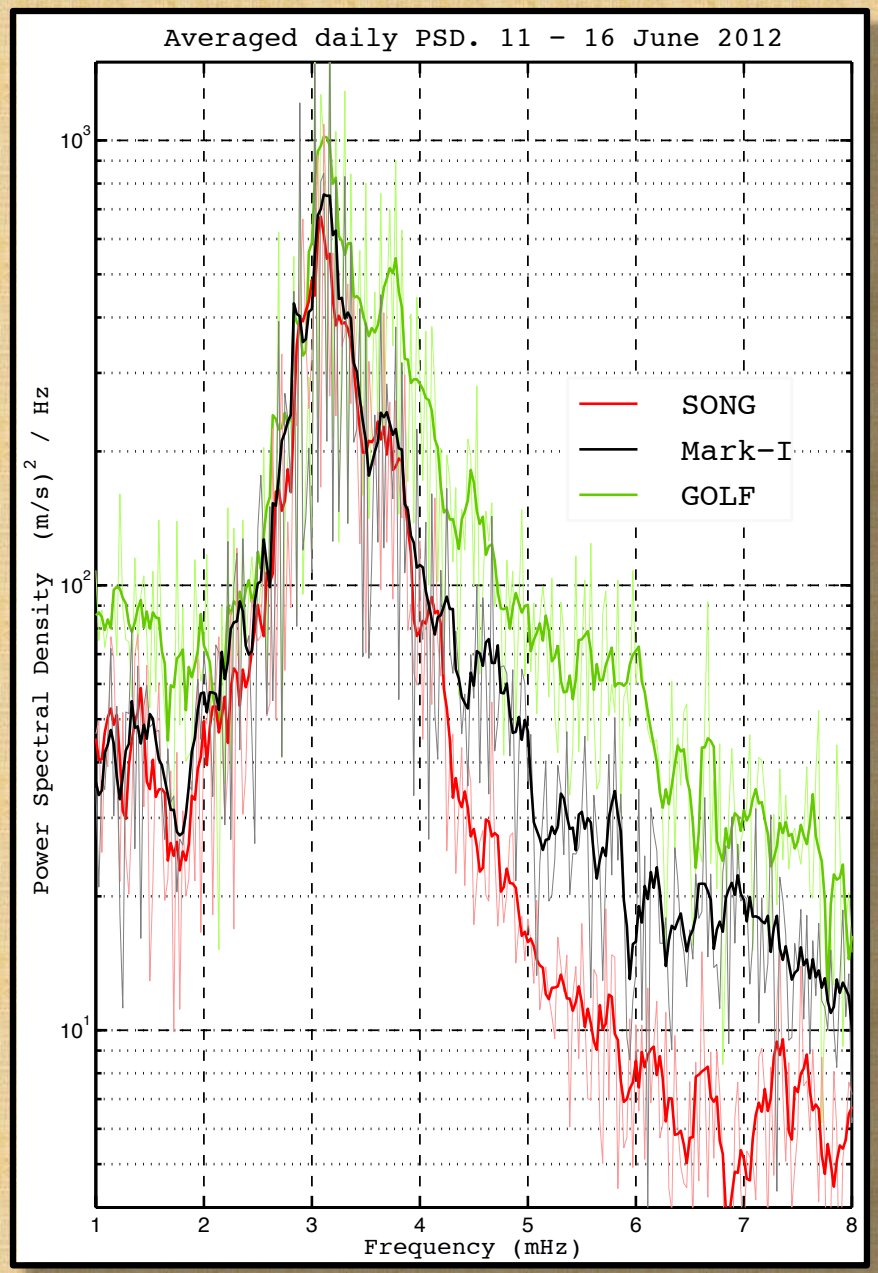
- The "*Solar-SONG*" initiative:
  - How and Why..
  - Extending its original science capabilities
  - Project development
- First light and first targeted campaign
  - Helioseismology results (*Mads .F. Anderson's talk*)
  - Monochromatic (λ) helioseismology ?
- Synoptic capabilities
- Others (*Marian J. Martínez's talk*)
- Way forward and conclusions

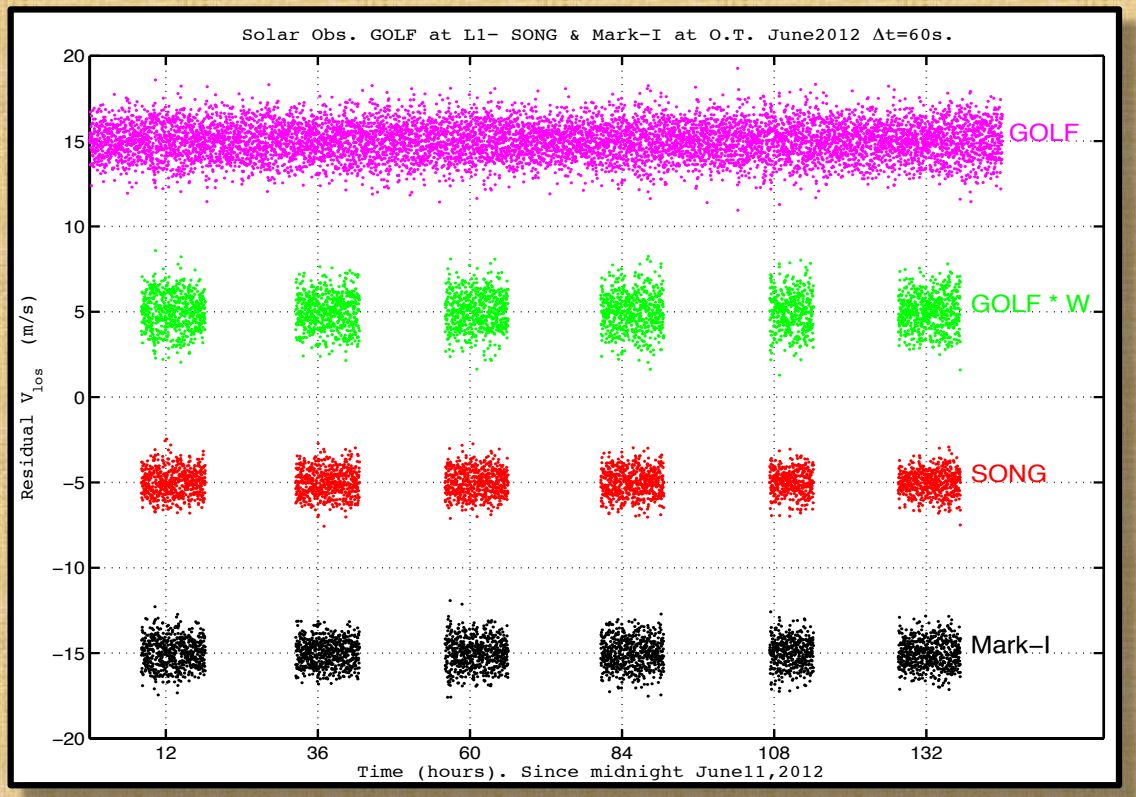
June 2012: while waiting for the "acceptance" of the TELESCOPE!!!



GONG Site Survey NIP plus FO feeding **SONG** spectrograph

Comparative analysis to assess its quality...





6-days of simultaneous space and ground-based RVs:

SONG Mark-I (BiSON) **GOLF/SoHO**

Pallé et al 2013 (2013JPhCS.440a2051P)

A scientific niche for a "Solar-SONG" ..???

- **Targeted helioseismology campaigns** (i.e. , to obtain precise solar seismic global parameters ($\Delta\nu$ and ν_{max}) to be used in the "scalling relations" for those stellar observations obtained with SONG (same instrument, same pipeline, etc..)

- **A "node" of a future Helioseismology Network** or complementary/backup of those already operative (i.e., Mark-I/BiSON, GOLF).

- **Simultaneous helioseismology at different spectral lines**. It will require a different treatment of the echelle spectrum to derive velocities at pre-defined chunks.

- **A potential Solar Synoptic facility**. Long-term (years) daily measurements of the solar RV and to derive solar activity proxies from different spectral lines present in the echelle spectrum.

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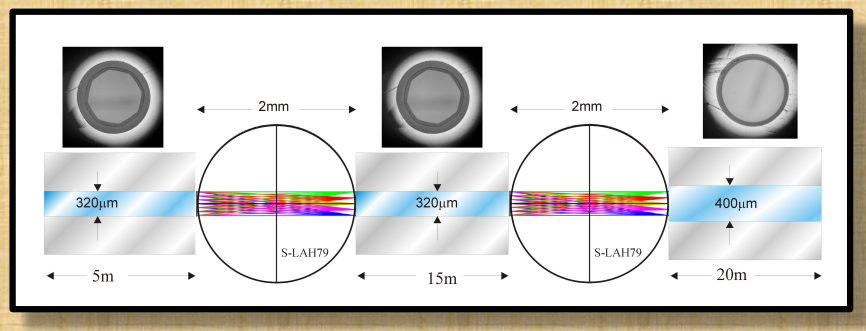
- **Targeted helioseismology campaigns** (i.e. , to obtain precise solar seismic global parameters ($\Delta\nu$ and ν_{max}) to be used in the "scaling relations" for those stellar observations obtained with SONG (same instrument, same pipeline, etc..)

$$R/R_\odot = \frac{\nu_{\rm max}}{\nu_{\rm max}^\odot} \cdot \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \cdot \sqrt{\frac{T_{\rm eff}}{T_{\rm eff}^\odot}}$$

$$M/M_\odot = \left(\frac{R}{R}\right)^3 \cdot \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^2 .$$

Going ahead with the “Solar-SONG” project…



Project submitted & approved funding (“Severo Ochoa-IAC) in late 2016

- Automated Alt-Az Solar Tracker with active guiding
- Fibre-Optic assembly designed to maximize the scrambling
- Extra shutter in the PST outside the spectrograph synchronized with the existing overall control system (switch from solar-to-stellar shutter for day- and night-time observations)
- High-performance servers & storage
- Add to “Conductor” tool

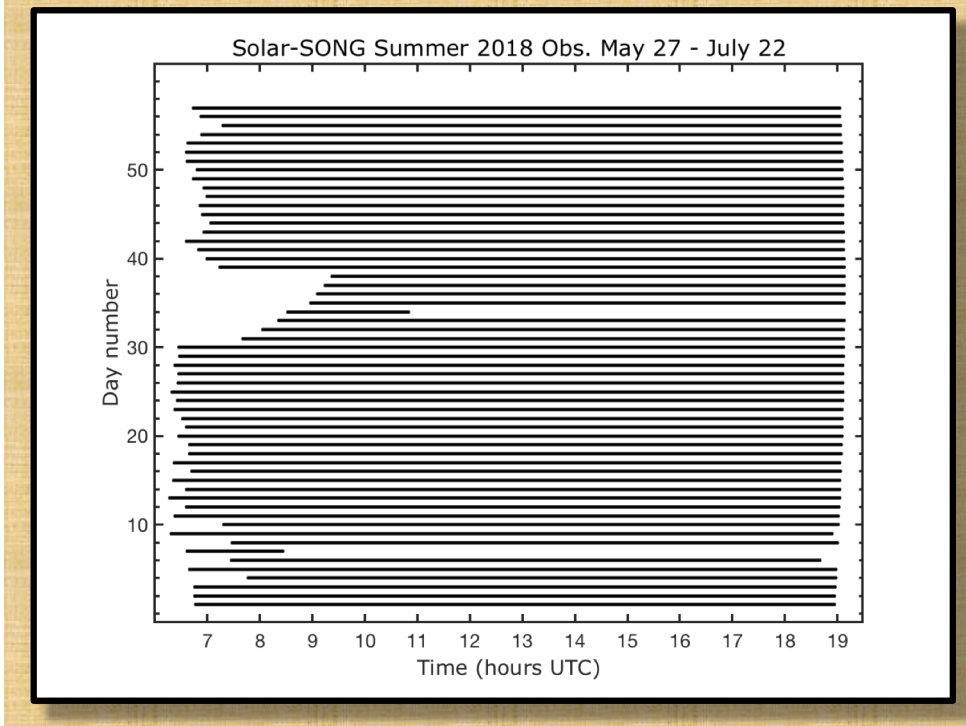
Integration at IAC Tech. Division and deployed and operative in January 2018 at Observatorio del Teide (25 m. SE of Hertzsprung SONG telescope)

Ready for FIRST Helioseismology run (high-cadence) in May 2018

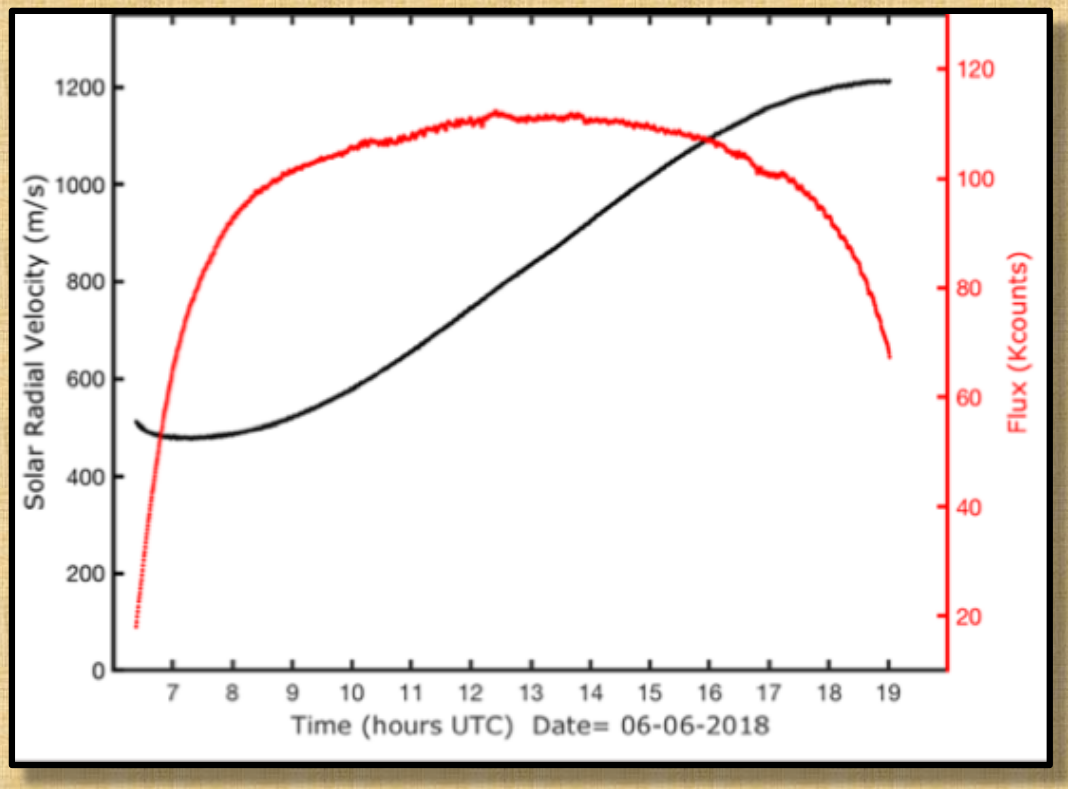
Members of the technical andscience team present during First Light (from left to right): Rene Tronsgaard, Pere L. Pallé, Antonio Pimienta, Ezequiel Ballesteros and Felix Gracia.

Observations, Data Reduction and Analysis..

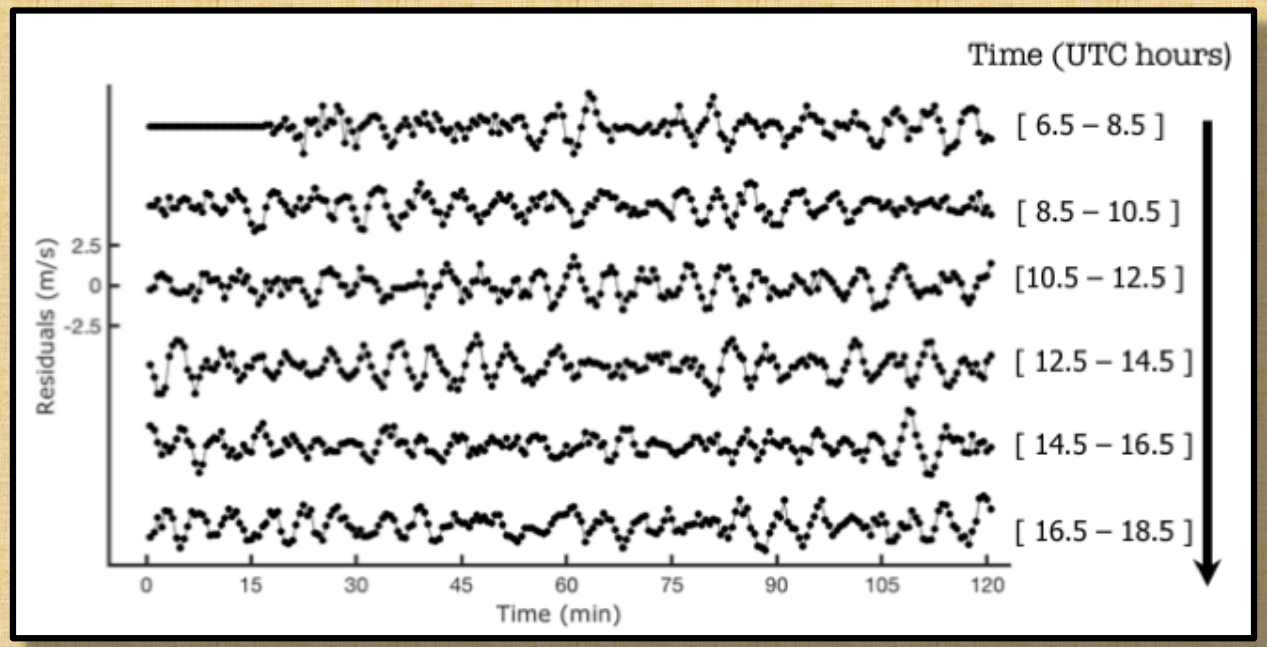
- High-cadence observations during 57 consecutive days (May, 27 to July,22nd).
- Echelle spectra (R≃ 110 000) with Iodine cell every 3.7 s (integration plus read-out time).
- Typically, 12 000 spectra/day (about 12 hours) and with an image size of 8.2 Mb results in a total load of almost 100 Gb per day and ≃ **6Tb** over the whole campaign (i.e ≃ **700 000 spectra**)
- The reduction pipeline to extract the RVs (iSONG) requires some 50.000 cpu-minutes per observing day
- The existing pipeline (see Grundahl et al., 2017) was installed at the IAC HTCondor (High-Throughput Computing) system which can make used of up to 700 cores. The velocity extraction concluded just few days after the end of the observing period.

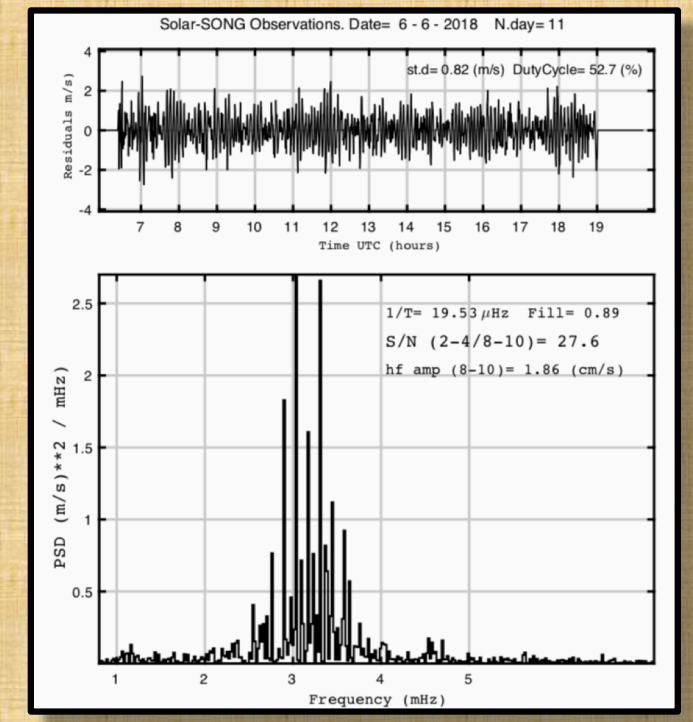


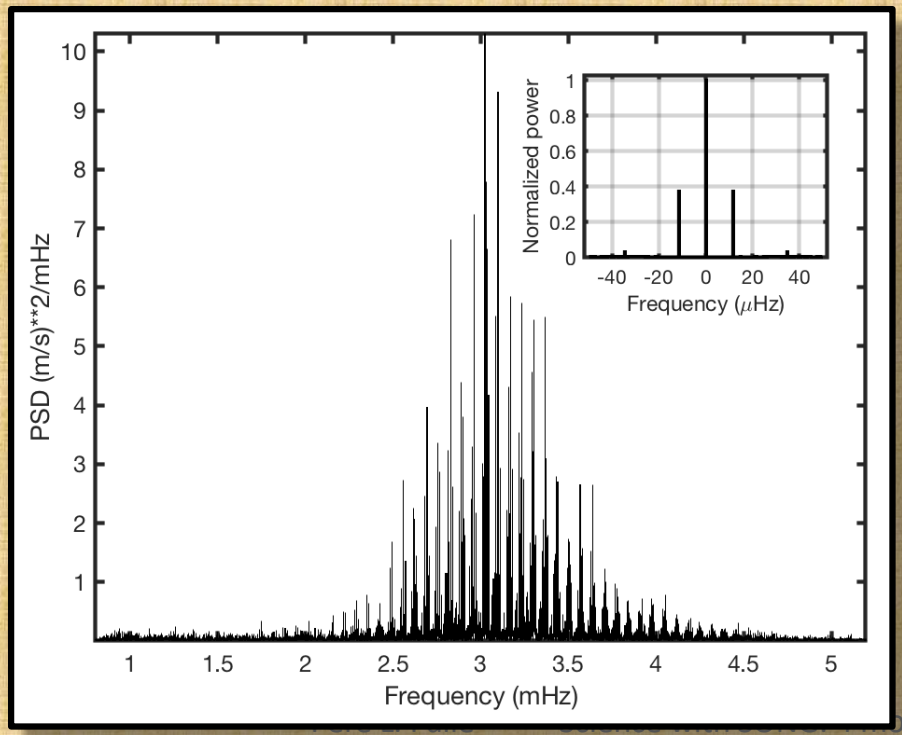
Excellent coverage....



Processed daily files... Uncertainty ≃ 75 cm/s per integration (3.7 s)



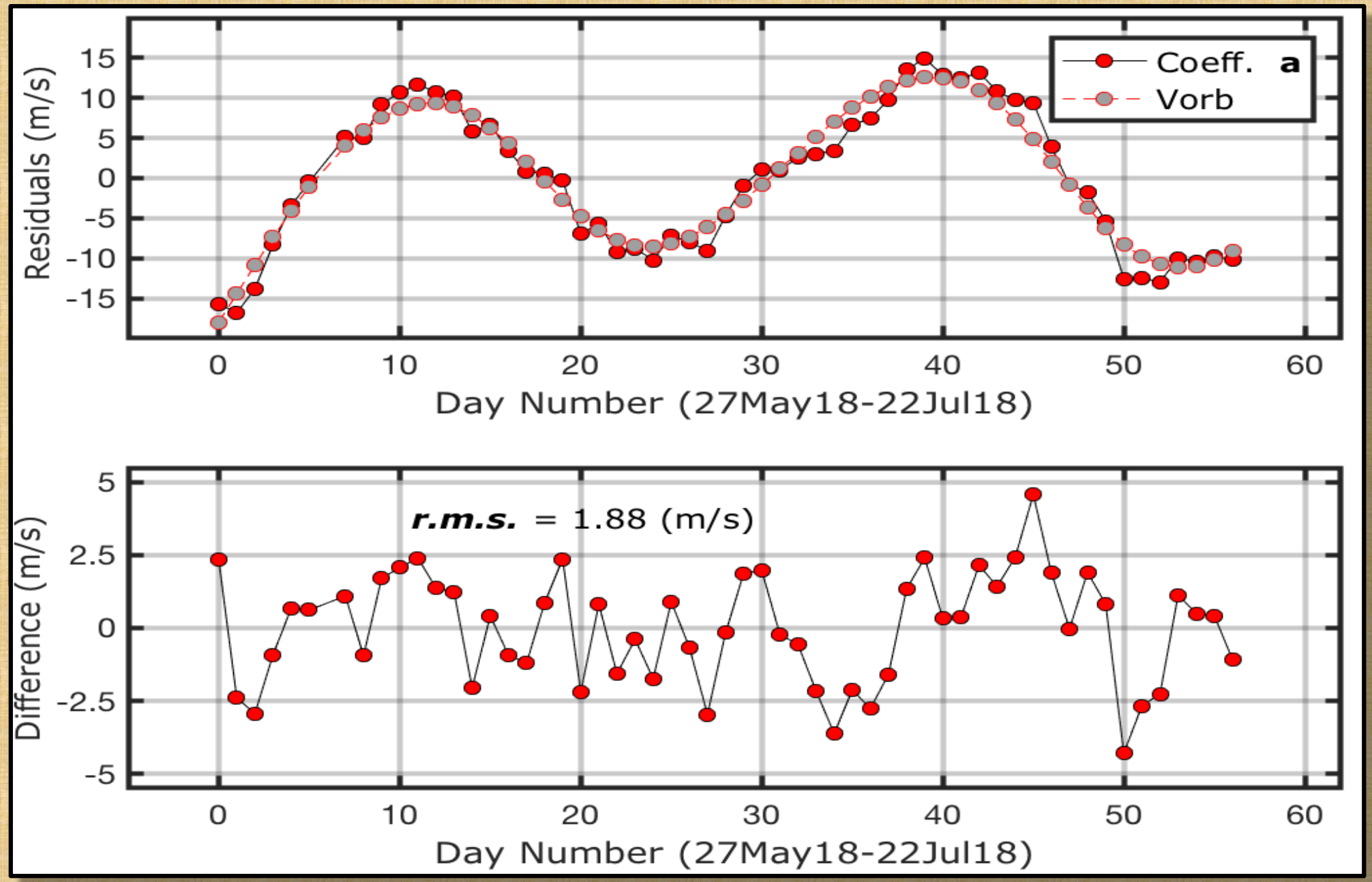




Corrected Vephem and specific FIRCLS no phase-distortion filter.
Band-pass P < 25 min

First 30-day PSD
Duty Cycle = 42.9%

RV sensitivity/stability : Detecting the Moon..... Once more !!!



A scientific niche for a "Solar-SONG" ..???

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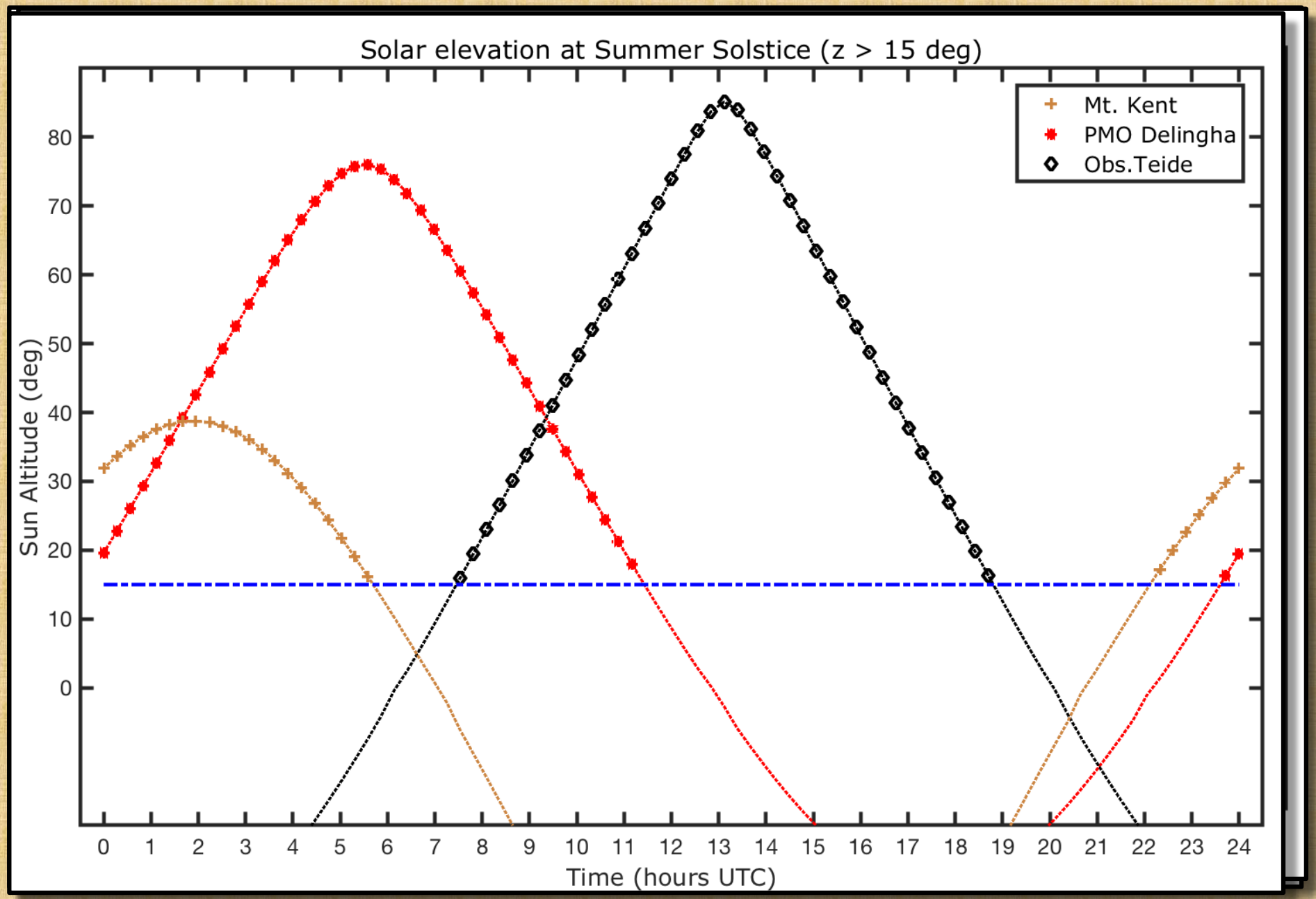
- **A "node" of a future Helioseismology Network** or complementary/backup of those already operative (i.e., Mark-I/BiSON, GOLF).

Performance of a 3-site HELIOSEISMOLOGY SONG Network ...



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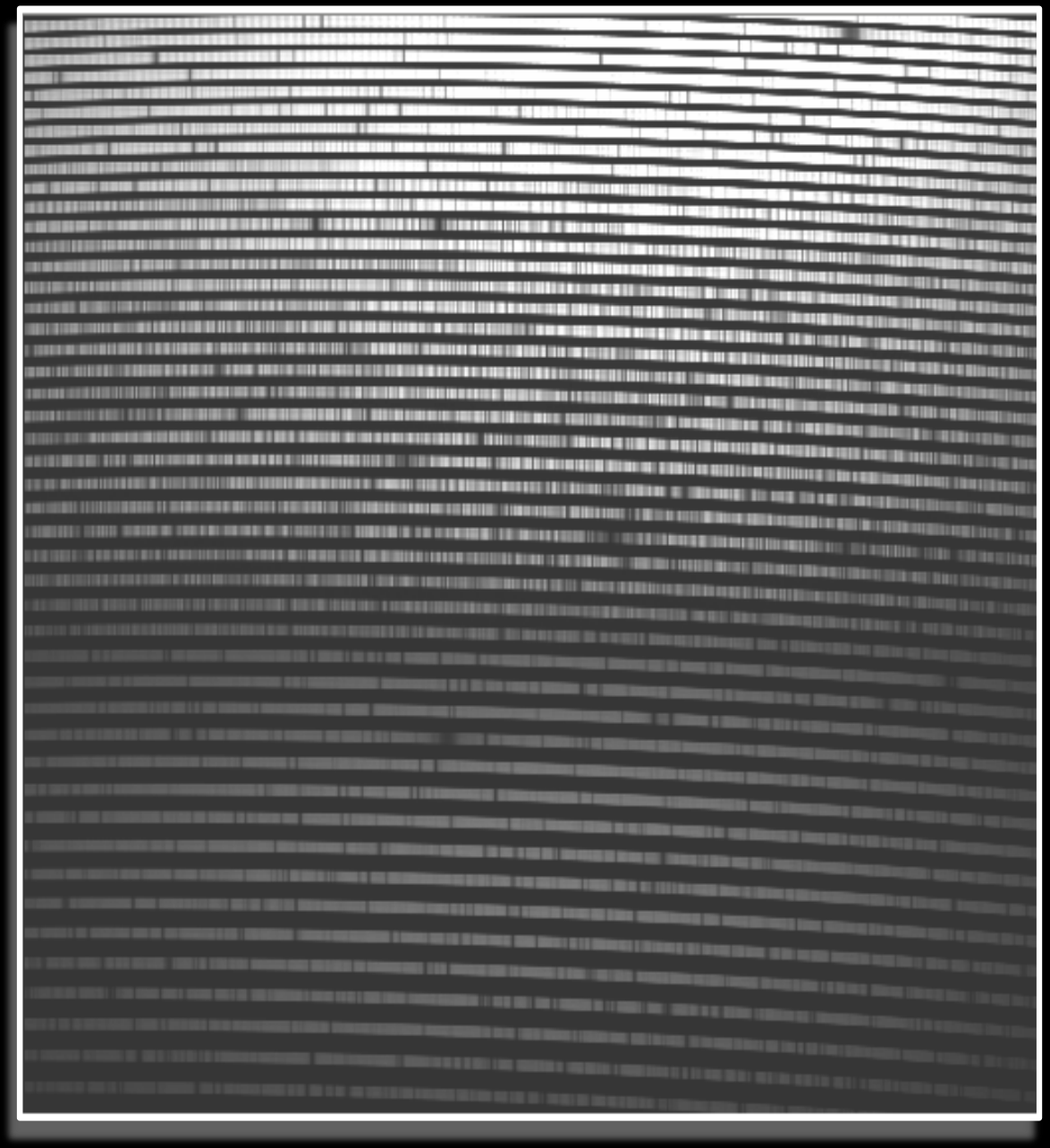
- **Simultaneous helioseismology many different selected spectral lines (novel research).** It will require a different treatment of the echelle spectrum to derive velocities at pre-defined chunks.



Solar wavelength spectrum obtained with Solar-SONG

51 Spectral orders
24 used to compute radial velocity
22 “chunks” per order

≈ 40 Å per order
Average dispersion ≈ 24 m Å/pix
≈ 2 Å width per chunk

Total of 528 independent radial velocity estimates

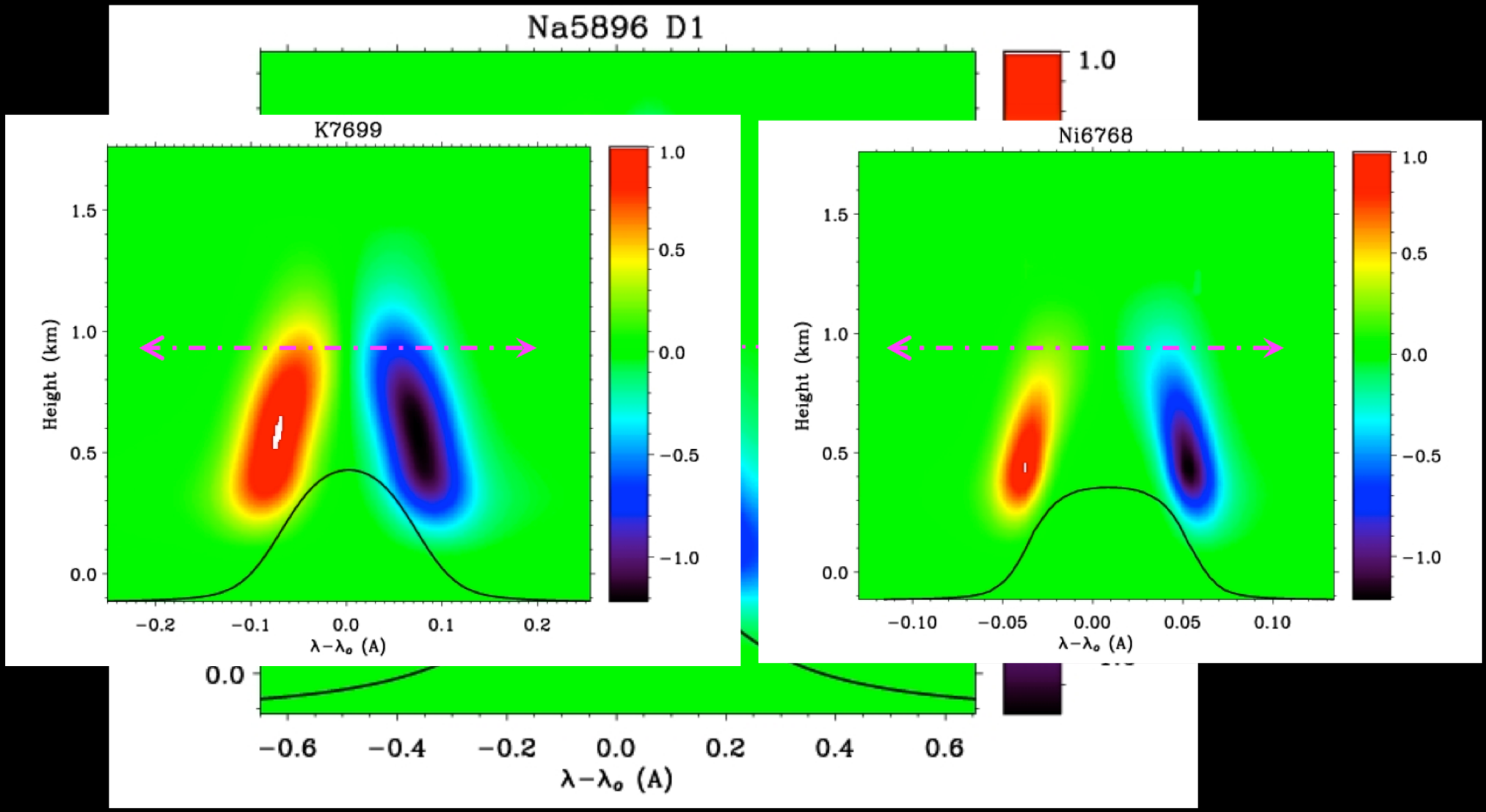
“Combined” to obtain a single value at any given time

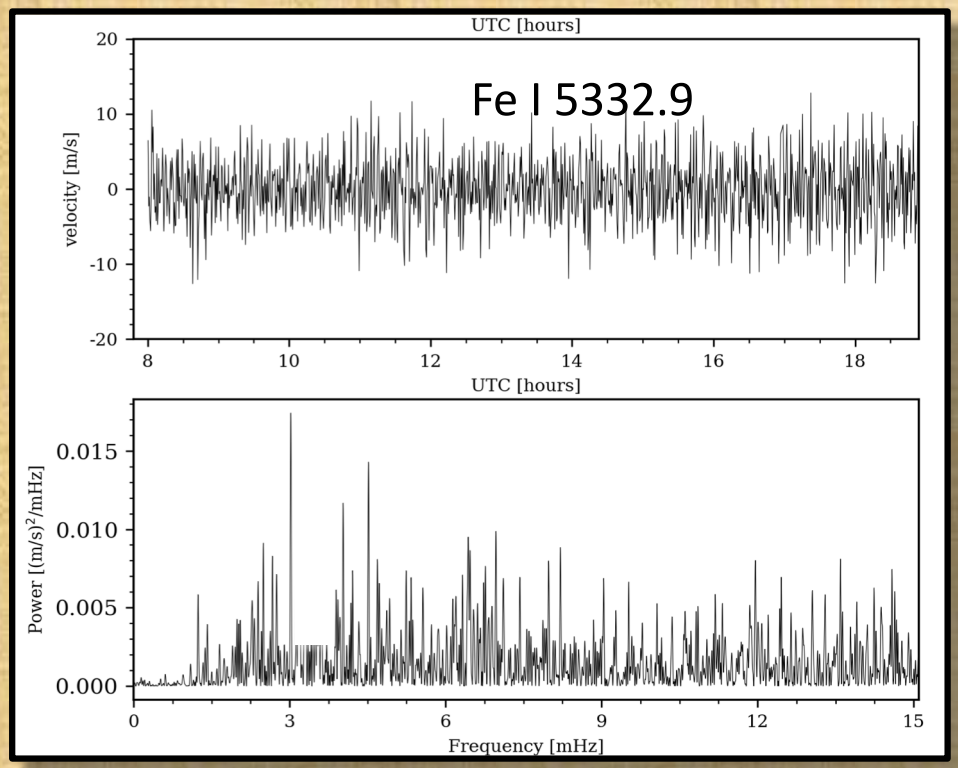
or…..

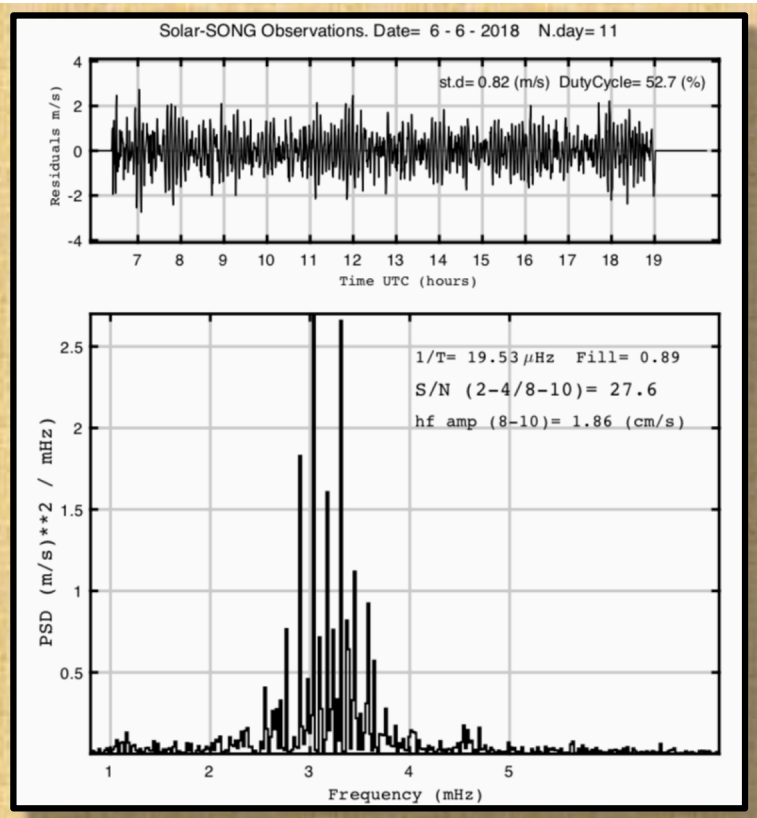
Individual “chunk” : simultaneous time series at different selected wavelengths (interesting solar spectral lines)

Response Functions (RFs) describe the effect that perturbations of a given physical parameter have in the emergent line intensity

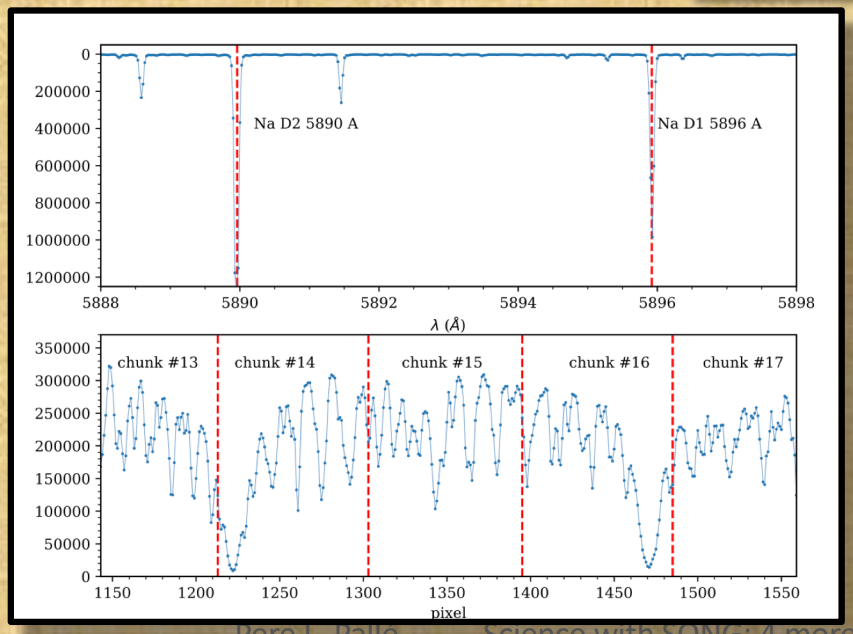
$$RF_V(\lambda, s_i) = \frac{\delta I_{\pm,i}(\lambda)}{V \cdot \Delta s}$$







Work in progress...



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A potential Solar Synoptic facility..

IAU Inter-Division B and E Working Group:

Coordination of Synoptic Observations of the Sun

1. **Establishing "standard"** (IAU approved) time series of solar data (e.g., sunspot number time series, solar irradiance).

2. **Providing official support** (non-monetary, but via support letters, expressing group's opinion etc) for research in synoptic studies and new initiatives.

3. Discussing new funding/business models to ensure the long-term survival of data collection by synoptic facilities or solar data archives.

4. **Establishing closer synergies between synoptic facilities**

5. Discussing and defining data standards to ensure long-term coherency of (past) data sets.

6. Promoting **a better coordination in the data collection/observing activ**ities done nowadays for real-time continuous solar monitoring use.

7. Long-term preservation of past and current datasets

8. Establishing a better citation and traceability of data usage for important datasets.

9. Increasingly, solar synoptic observations are conducted by amateur astronomers.

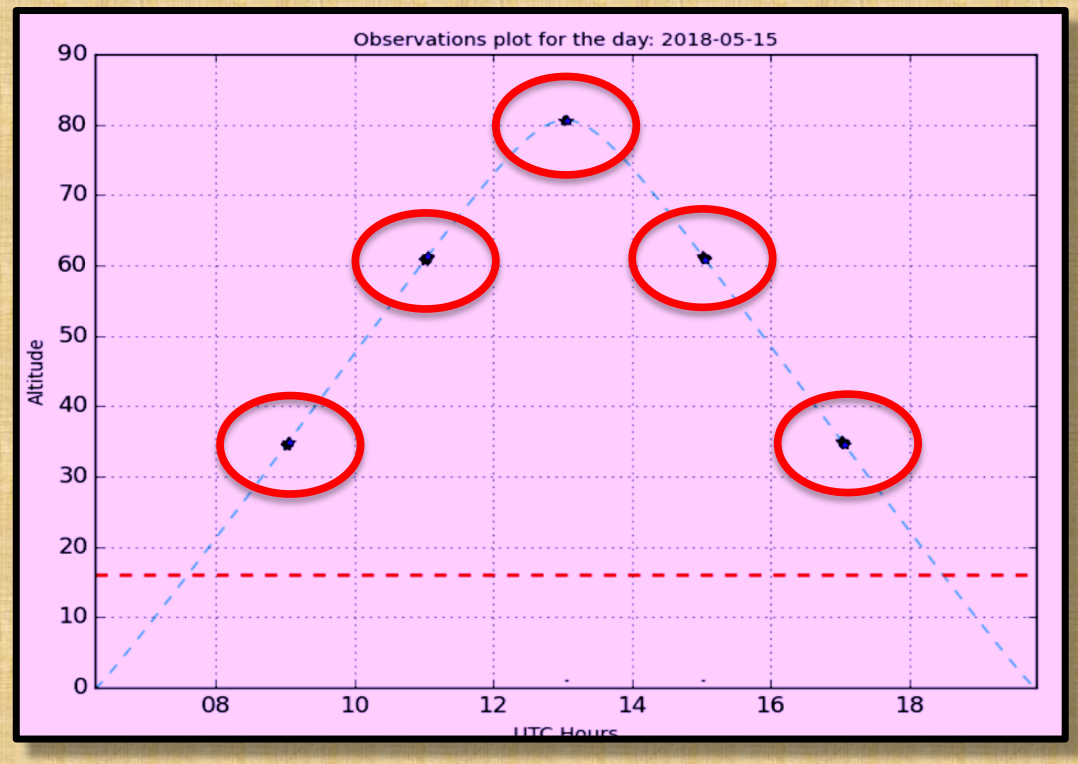
10. **At the WG web page (http://www.nso.edu/IAU-Com12), we try comping a list of conferences that could be of interest for the WG members and a list of existing synoptic programs.**

The long-term Solar Synoptic program with Solar-SONG

Acquiring High=Res wavelength spectra (With & without I2)

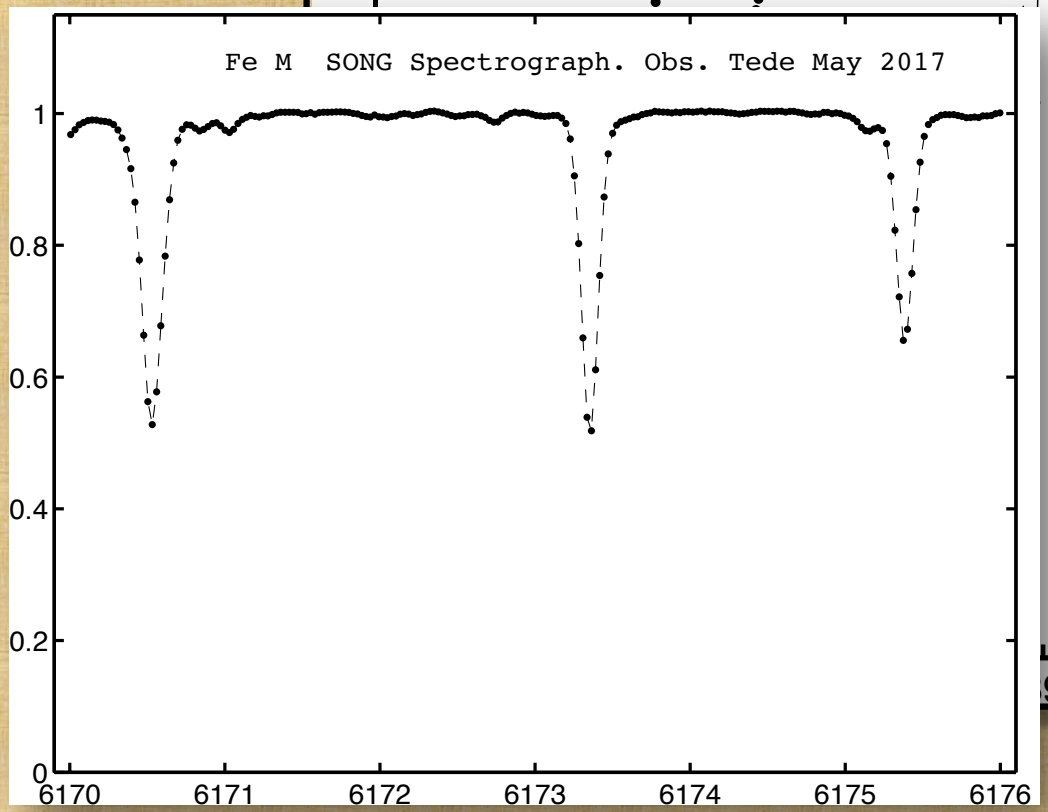
- Totally flexible cadence of the observations (long-term Synoptic too)
- Selected best suited lines: magnetic and non-magnetic
- Ca II H &K lines not achievable (YET !!!)
- H-alpha**, Mn**, Na,..etc... ARE !!!

- **To derive and study different solar activity proxies**
- **Daily RV**

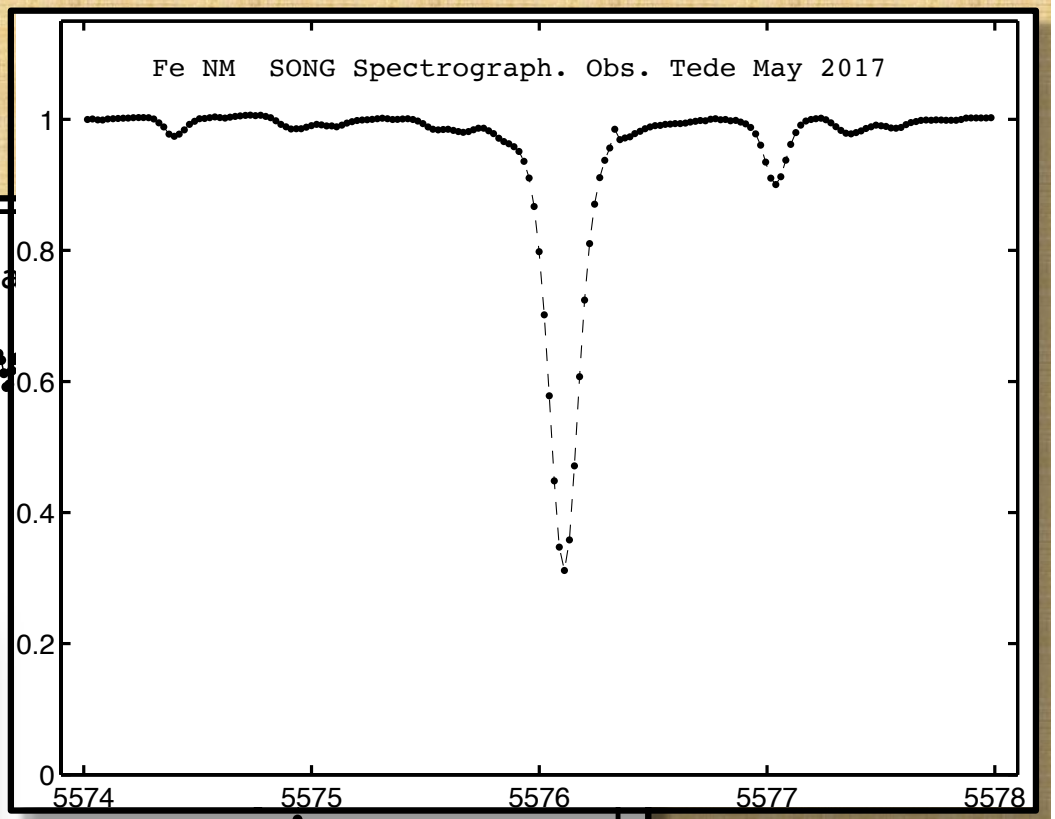


Actual routine (no manpower required)

- 2 x 20 solar spectra with & without
- 5 visits per day (flexible)

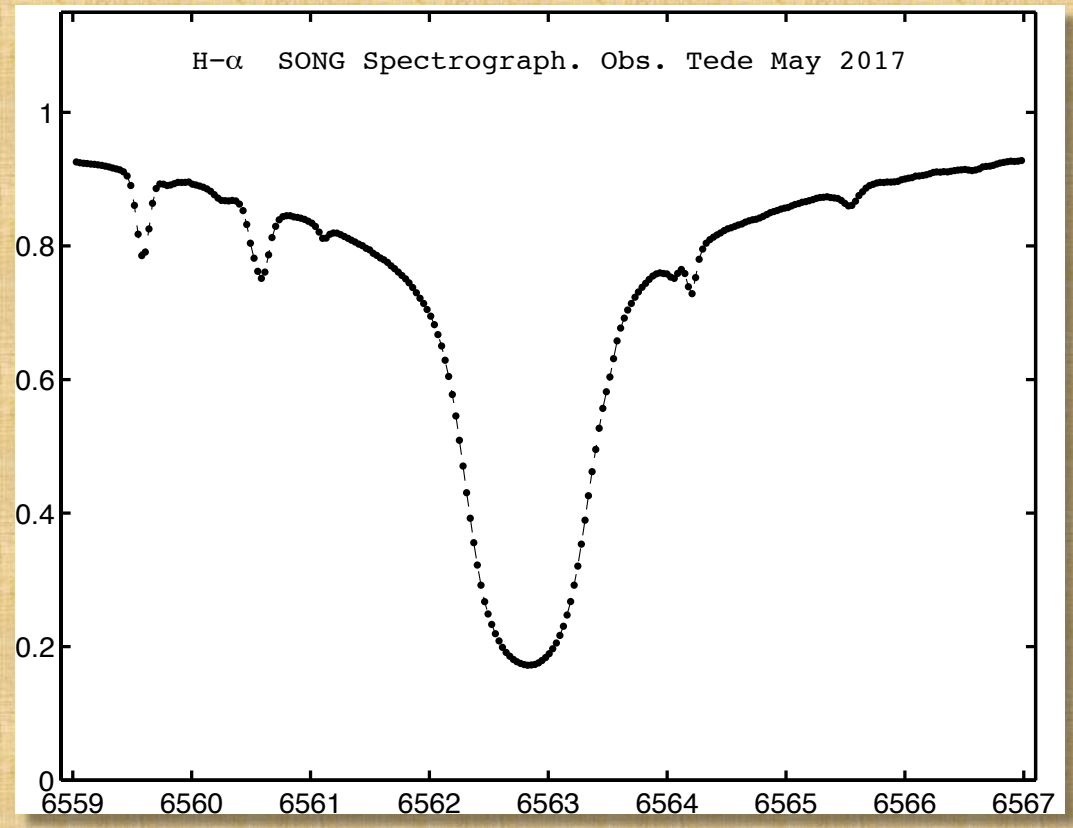

Fe M SONG Spectrograph. Obs. Tede May 2017
1
0.8
0.6
0.4
0.2
0
6170
6171
6172
6173
6174
6175
6176

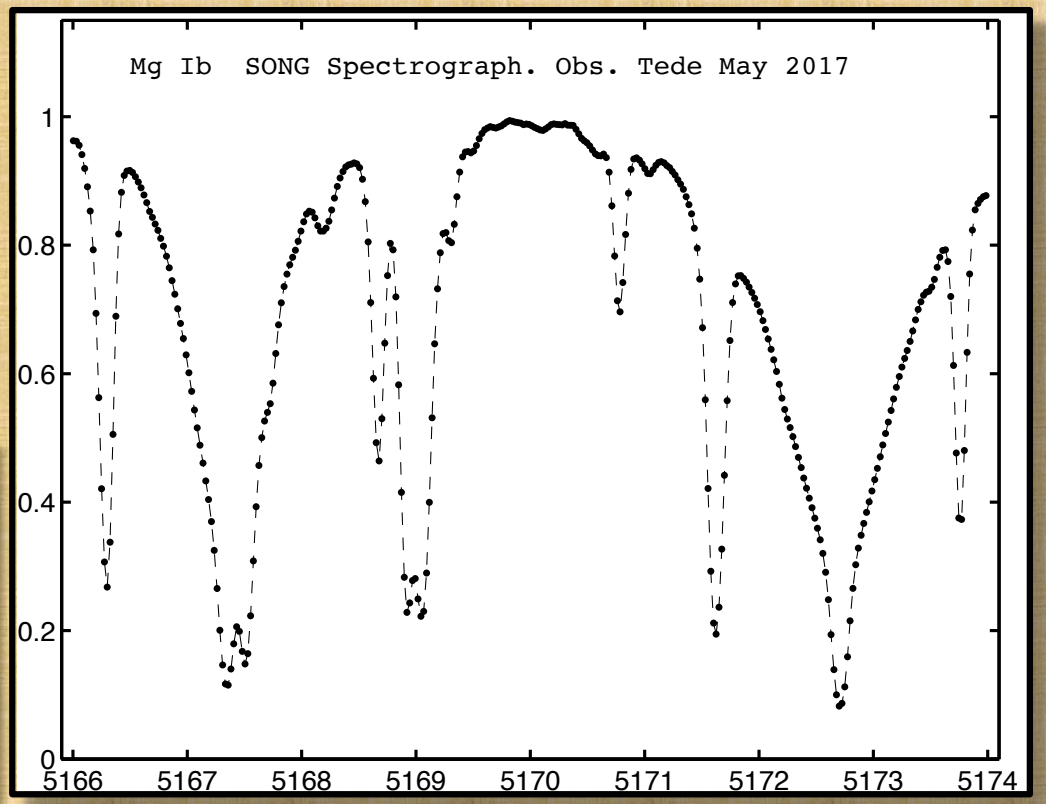
Na D2 & D1 SONG Spectrogra
1
0.8
93 5894 5895 5896 5897 5898


Fe NM SONG Spectrograph. Obs. Tede May 2017
1
0.8
0.6
0.4
0.2
0
5574
5575
5576
5577
5578

ic Lines

Chromospheric Lines





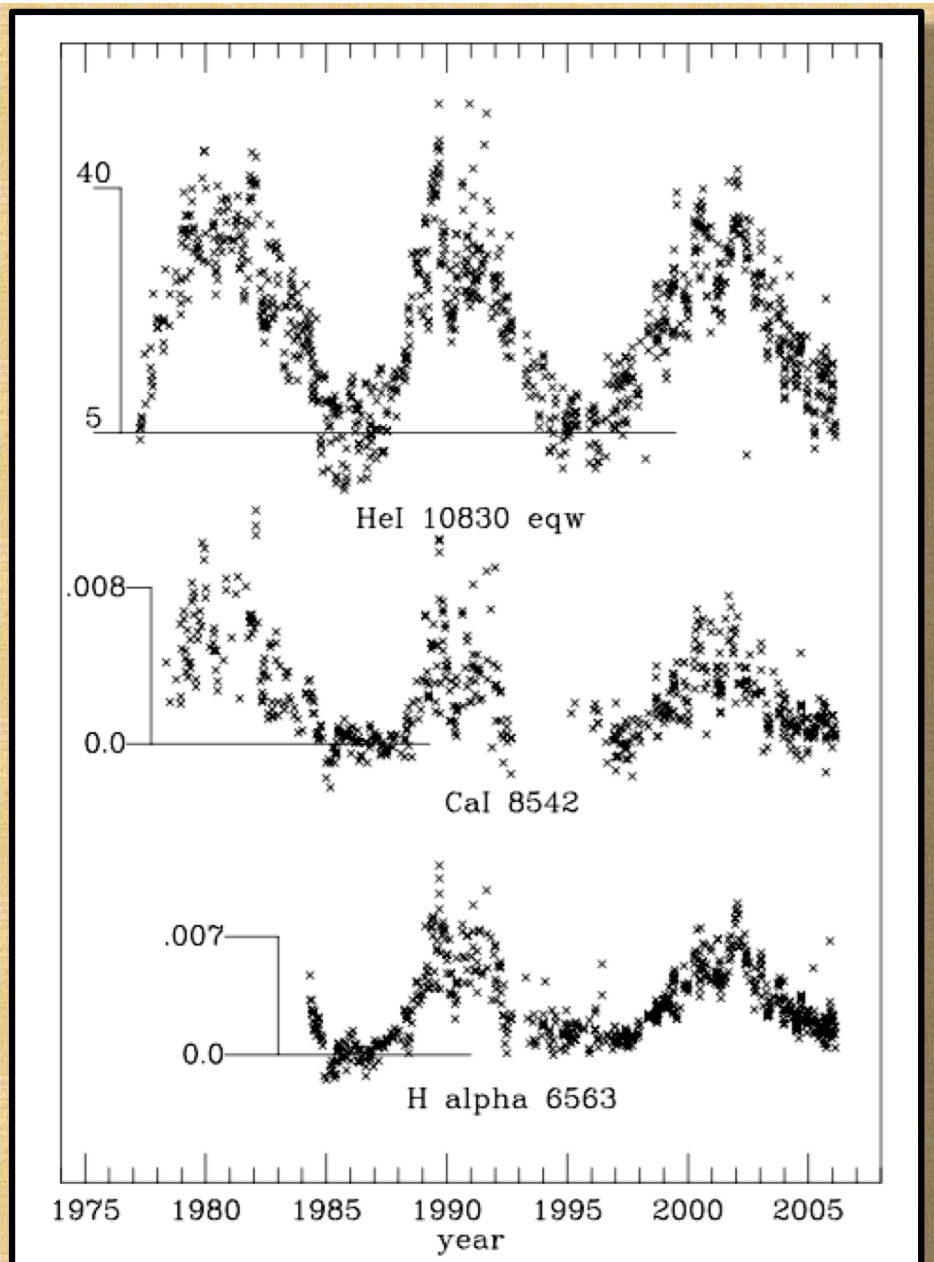


FIG. 11.—Variability of chromospheric lines from full disk measurements using the 13.5 m McMath-Pierce spectrograph. *Top*: He I 10830 equivalent width; *middle*: Ca II 8542 central depth (mean = 0.81); *bottom*: Hα central depth (mean =

Hα

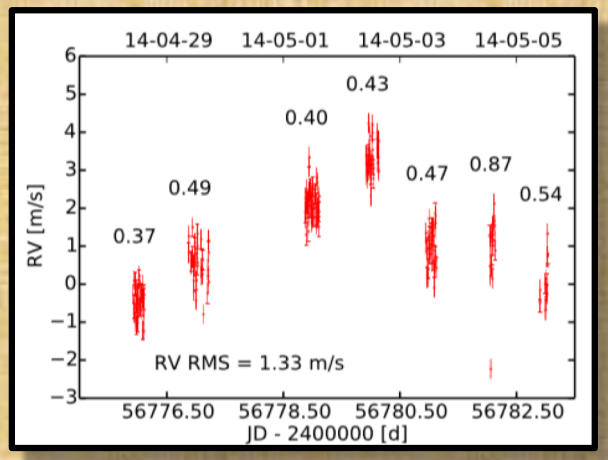
GOOD SENSITIVITY TO BE USED AS A "PROXY" OF SOLAR MAGNETIC ACTIVITY

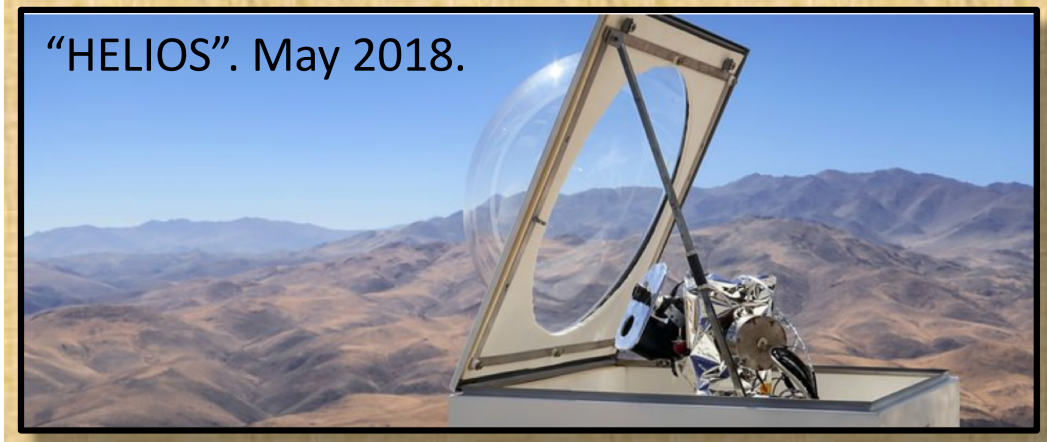
Related and contemporary initiatives...

Detection of an "Earth-like" will require a much better understanding of "our Sun like"..

HARPS-N Solar Telescope. PI. David F. Phillips

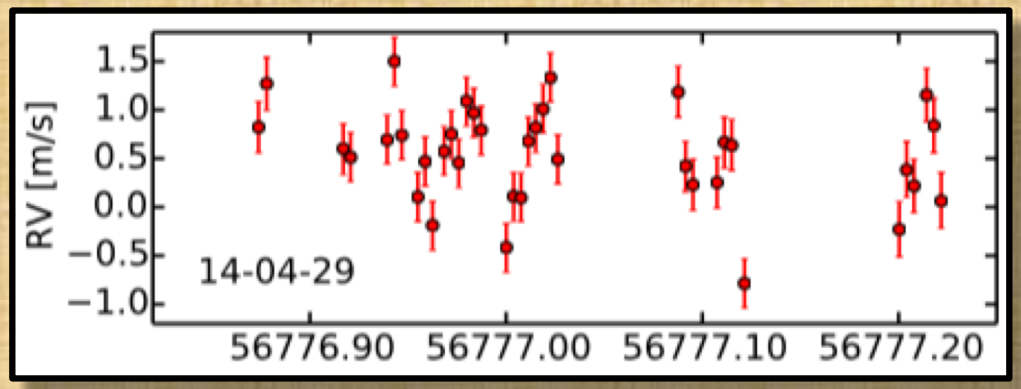
Feeding HARPS-N (attached to La Palma TNG 3.6 m telescope)





"HELIOS" Solar Telescope. P.I: X. Dusmusque

Feedings HARPS (attached to La Silla ESO 3.6 m telescope)



Way forward.....

- Lessons learned from our first run (i.e., better solar tracker-guiding, review FO assembly, ..)
- The "second" node of Solar-SONG. Mt. Kent. Australia (winter 2019-20 ??)
- Helioseismology at different heights on the solar atmosphere ("chunk" analysis)
- Assessment of the Synoptic Program ( )
- Design study for polarimetric unit (aimed to measure Hanle signal induced by Sun's global dipole [*])

** [Vieu, Martínez González, Asensio Ramos, & Pastor Yabar 2017, MNRAS]*

Conclusion

SONG is ready to extend its science capabilities to some domains of Solar Physics such as Helioseismology, synoptic observations to obtain solar activity proxies and, perhaps, also polarimetry (under study).

Thanks for your attention... !!!