Irradiance reconstructions from modern and historical Ca II observations

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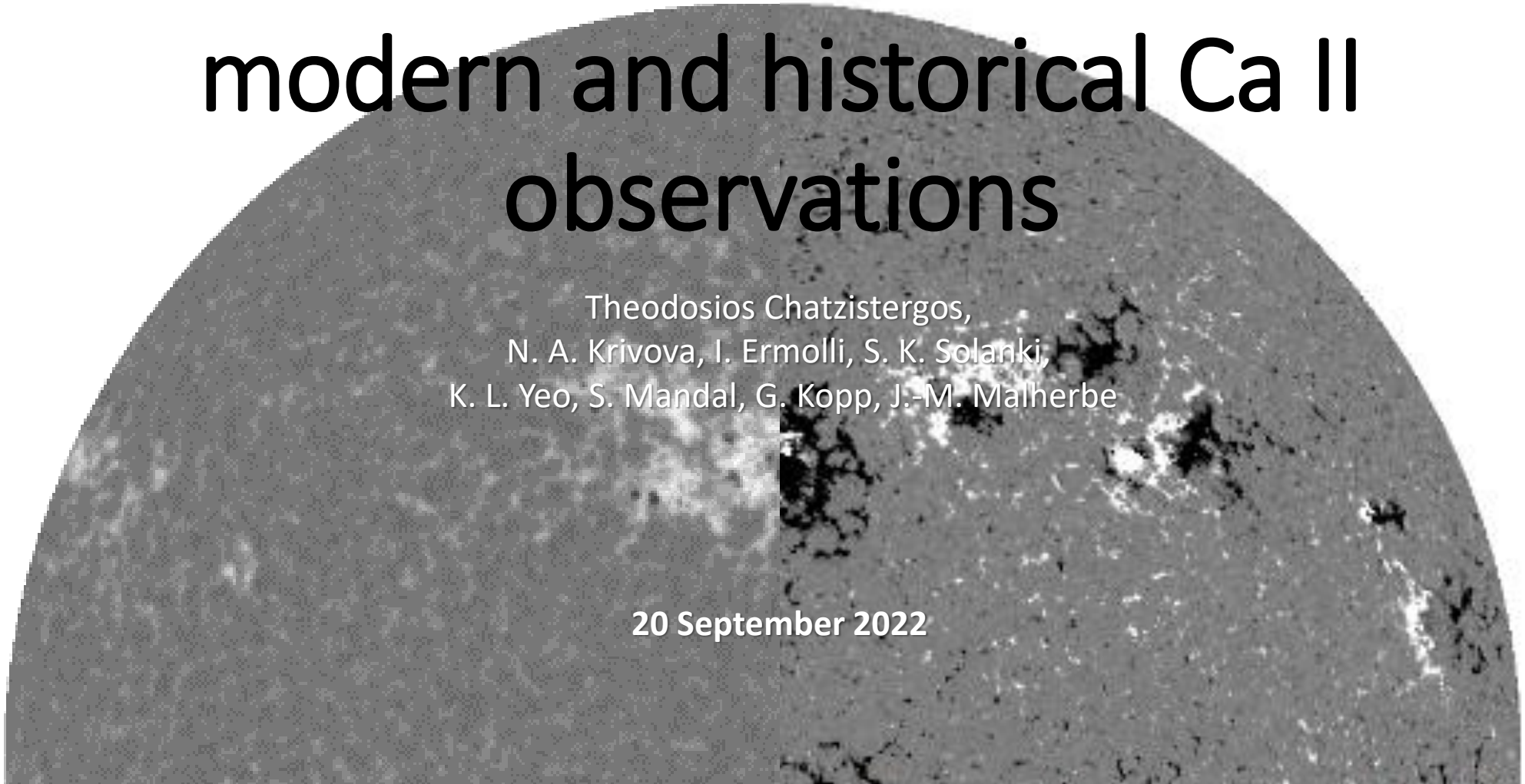
20 September 2022



Outline

1. Motivation
2. Overview of Ca II K data

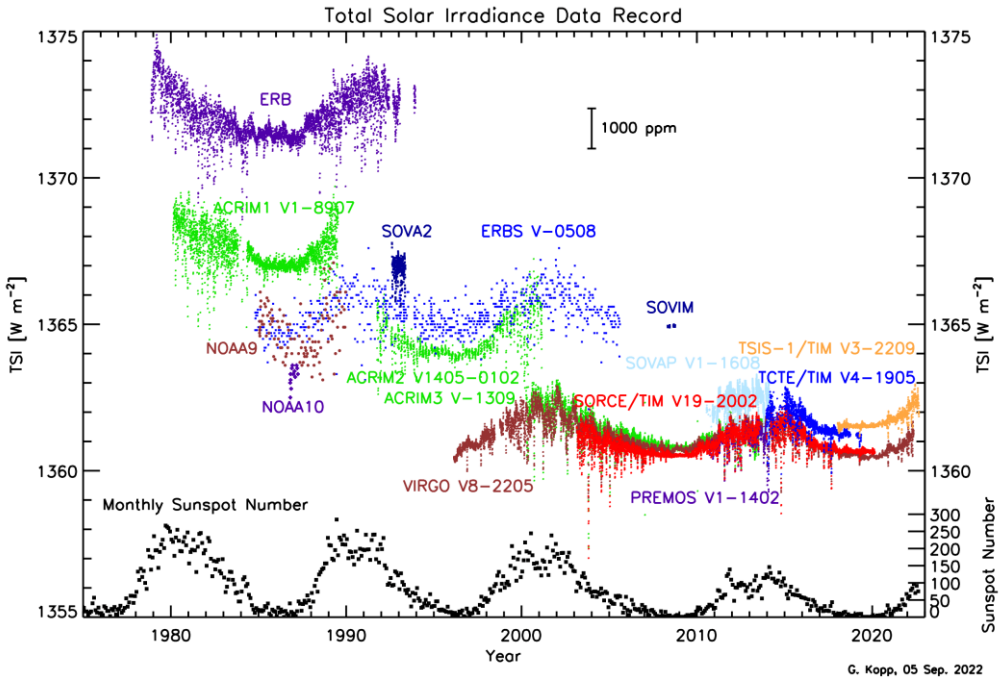
3. Evolution of plage areas
4. Relation between plage and sunspot areas
5. Connection between Ca II K brightness and magnetic field
6. Reconstructions of solar irradiance variations

Total solar irradiance

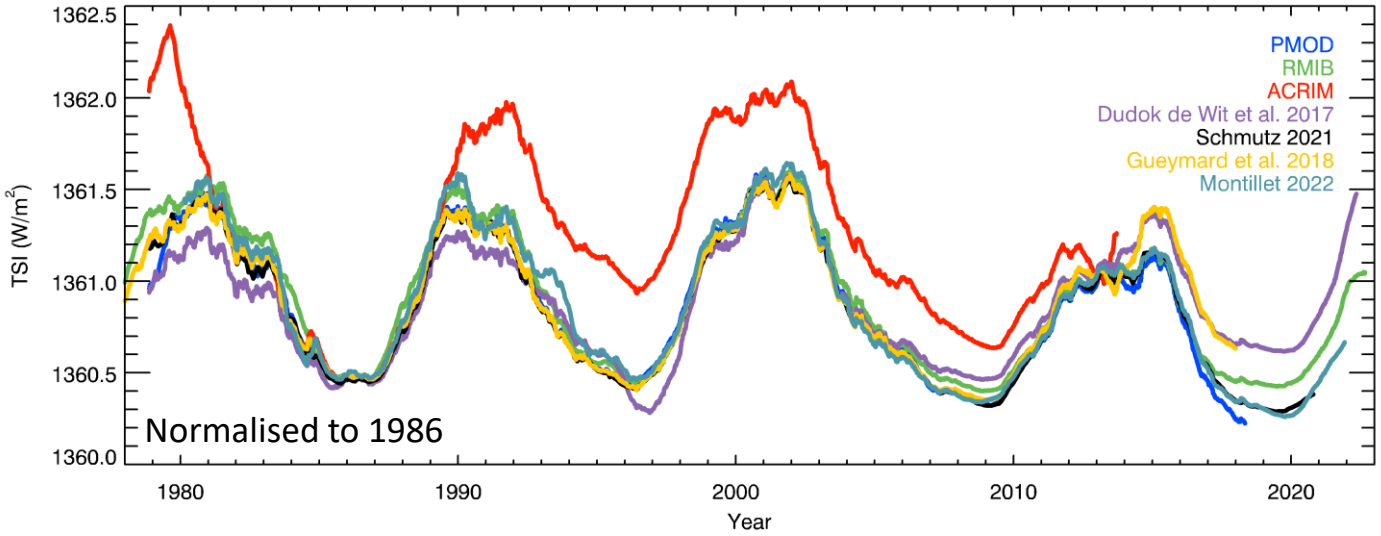
TSI: spectrally integrated solar radiative flux at 1 AU

Records of direct TSI since 1978

Space-based measurements of TSI

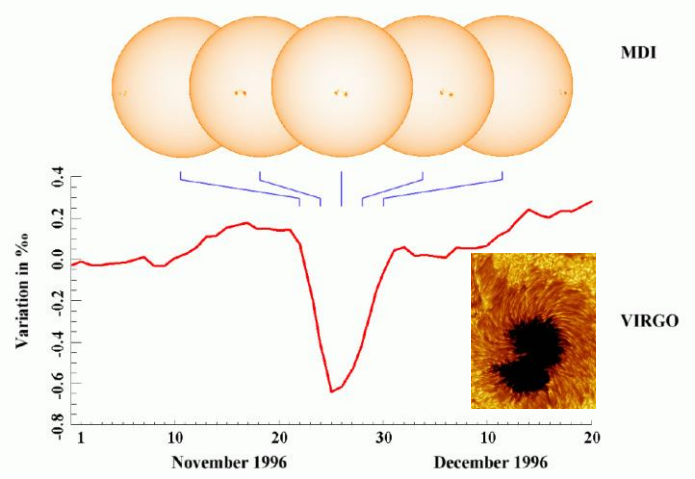


Composites of TSI measurements

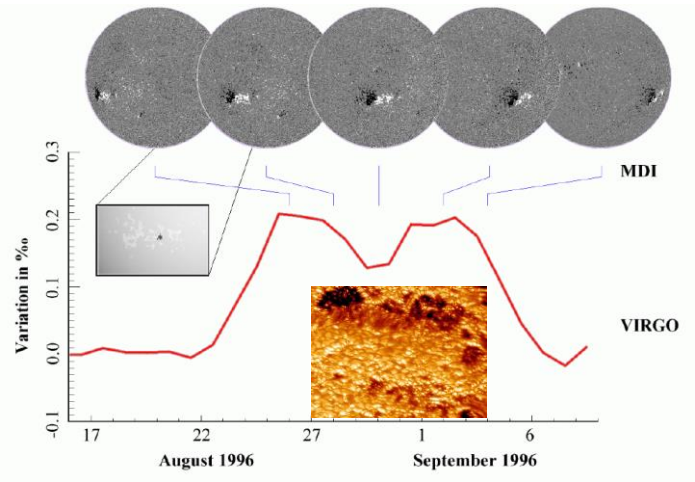


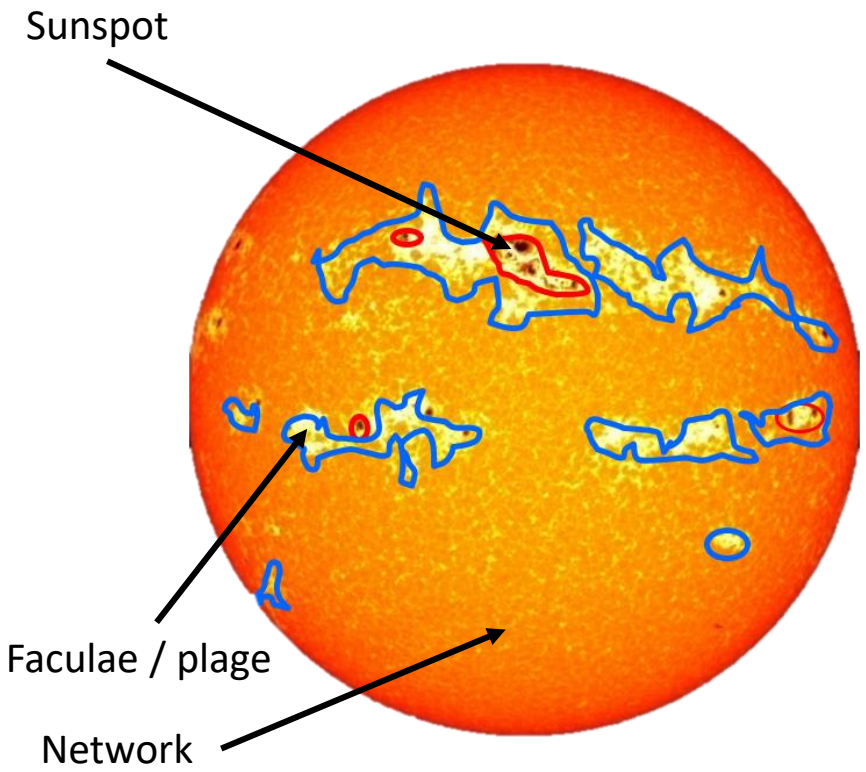
https://spot.colorado.edu/~koppg/TSI/

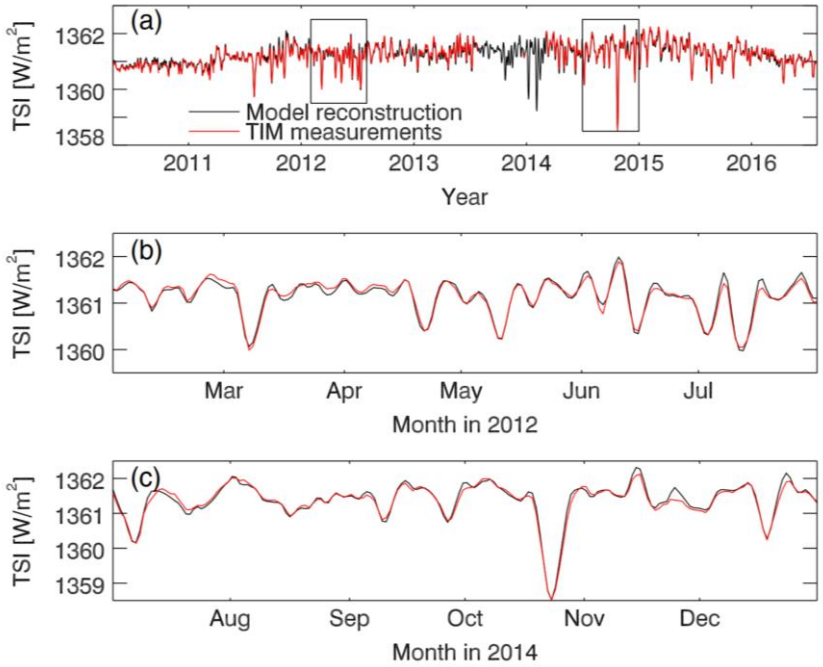
Irradiance reconstruction models



Solanki & Fligge 2002

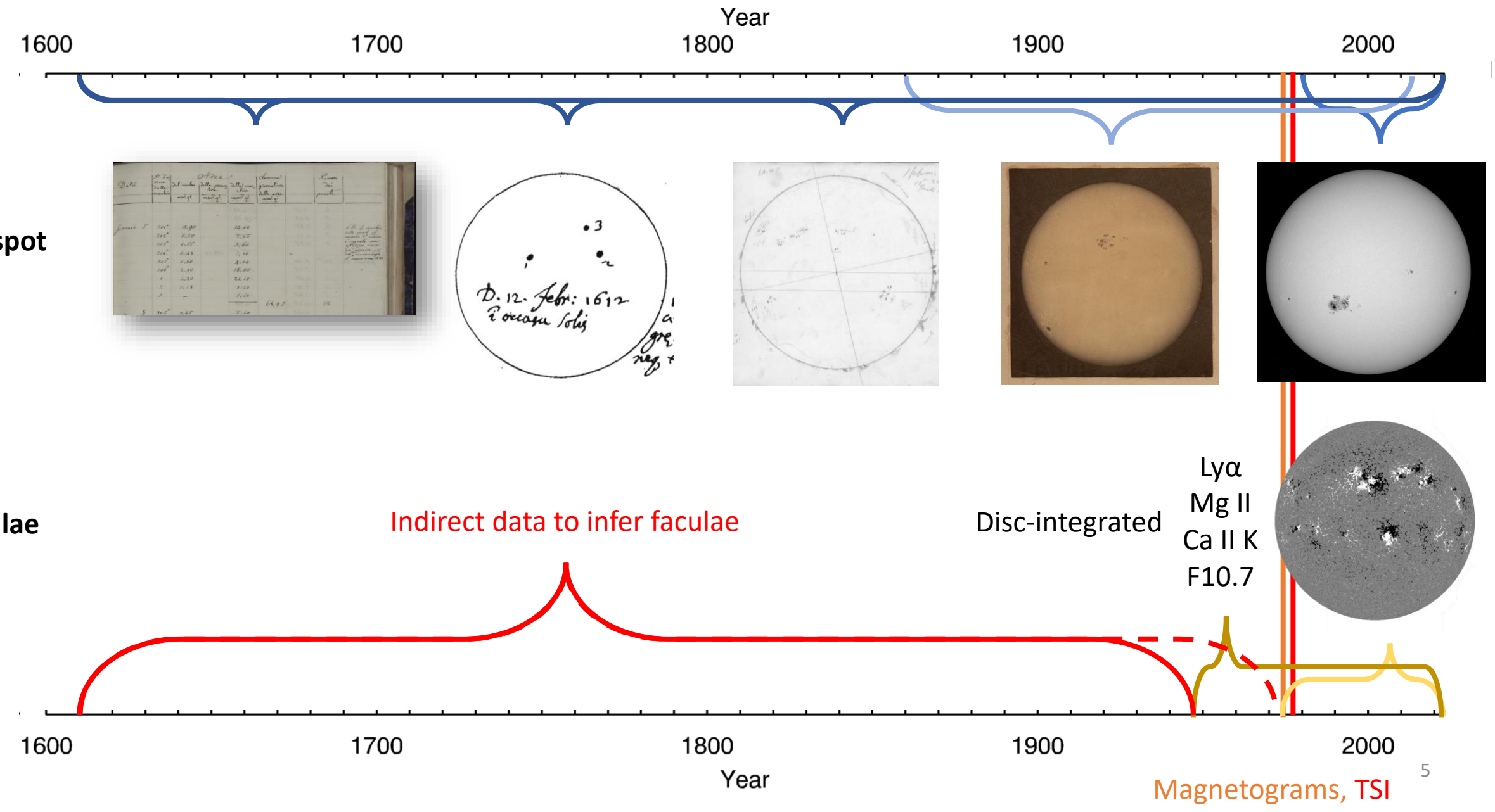






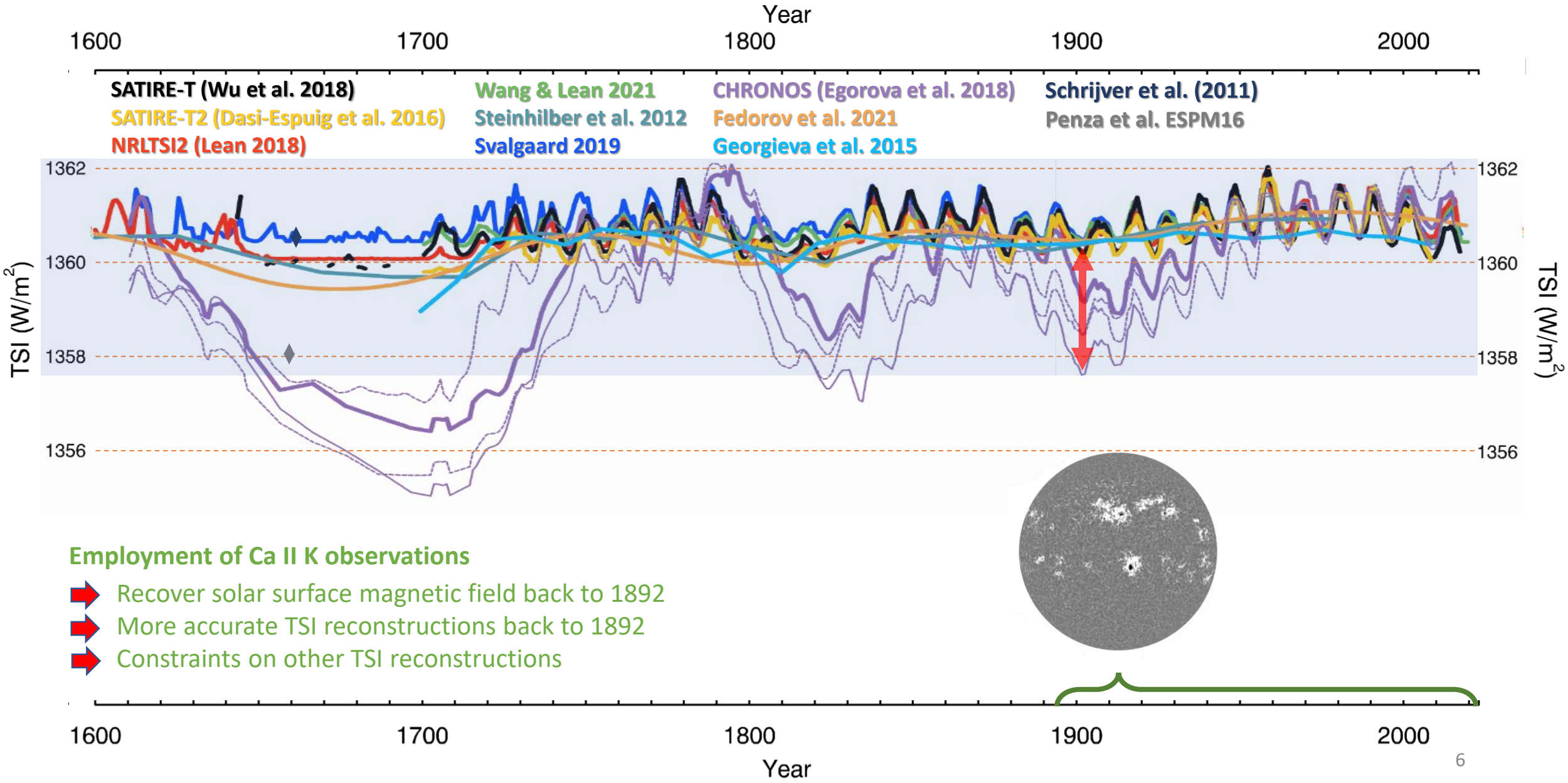
Yeo et al., 2017

Data



Magnetograms, TSI

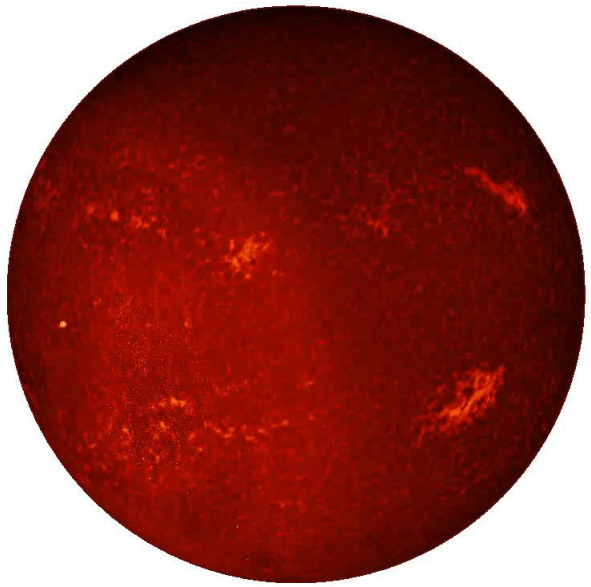
Motivation



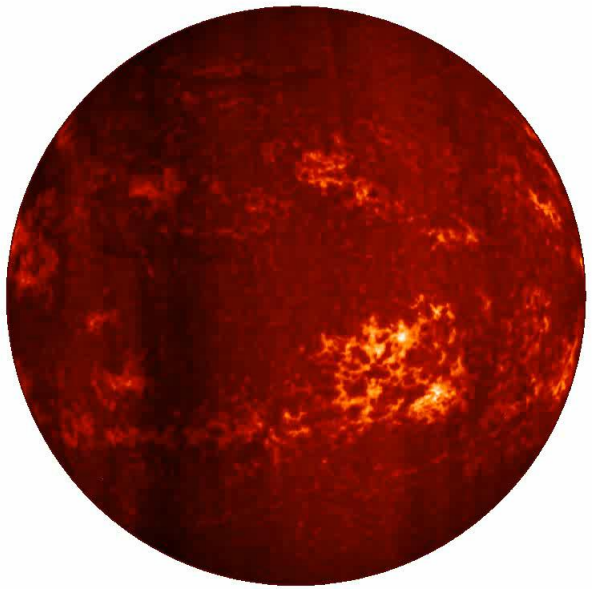
Employment of Ca II K observations

- Recover solar surface magnetic field back to 1892
- More accurate TSI reconstructions back to 1892
- Constraints on other TSI reconstructions

Ca II K observations



23/10/1913 08:07:00

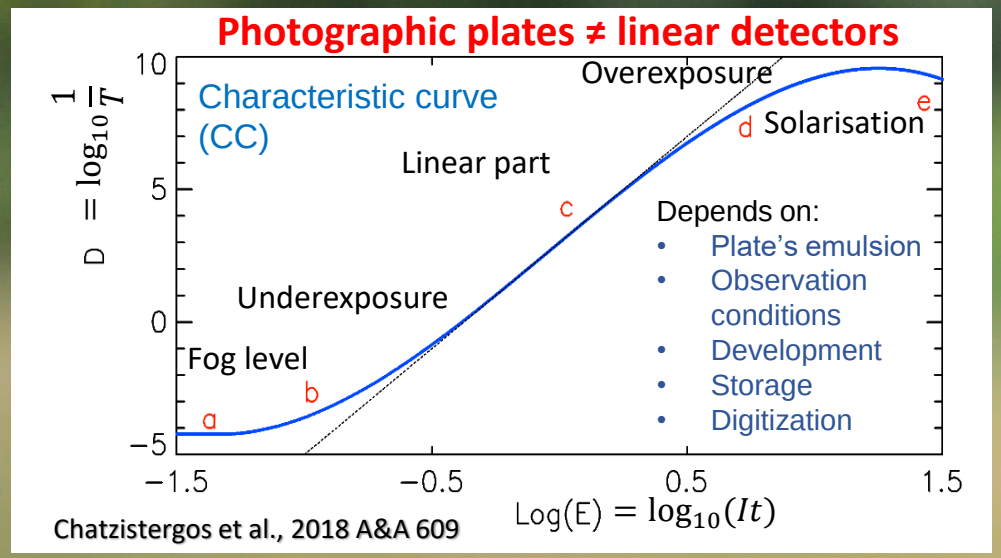


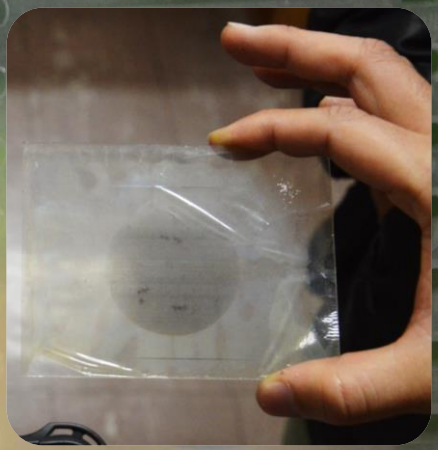
01/01/1958 11:48:00

Centred at 3933.67 Å
Strongest absorption line in solar spectrum

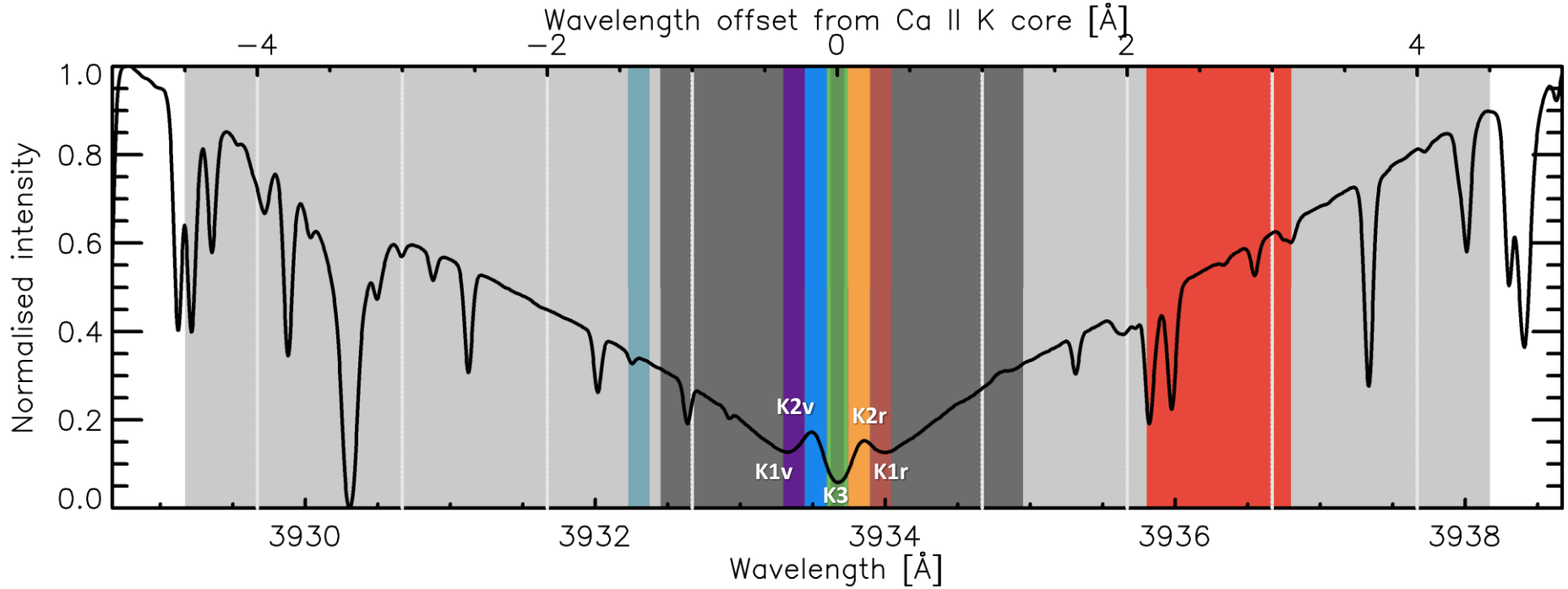
CCD data (since 1980's)
Photographic data (since 1892)

- Only recently available digitally
- Numerous artefacts
- Non-linear response to radiation
- Collections of very diverse data

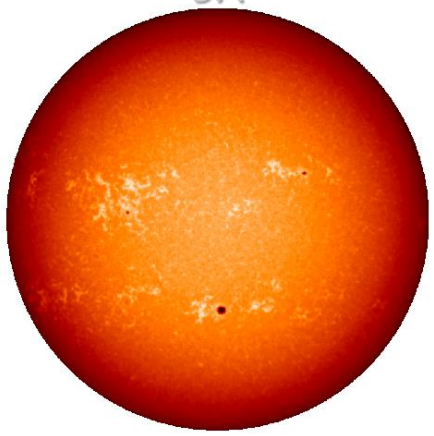




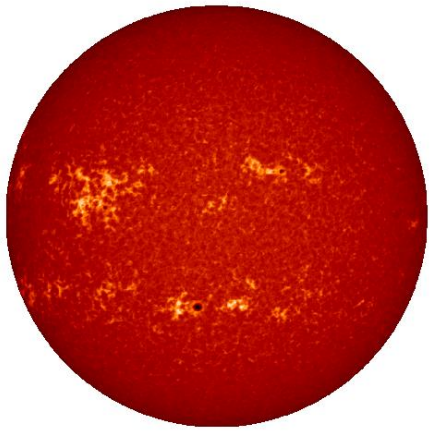
Differences between archives



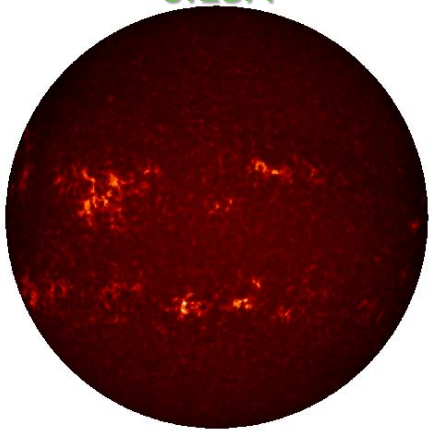
San Fernando
9Å



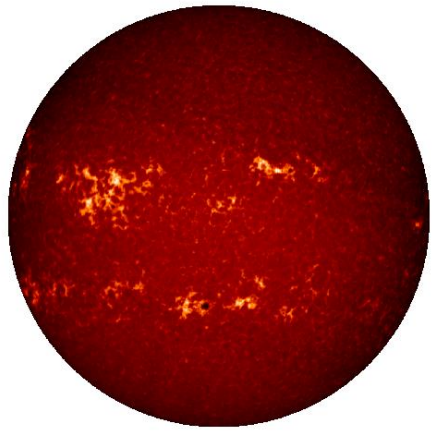
Rome/PSPT
2.5Å



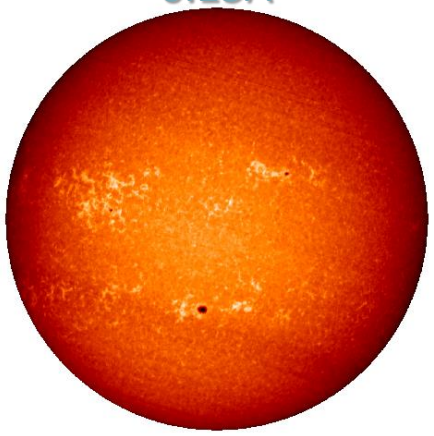
Meudon K3
0.15Å



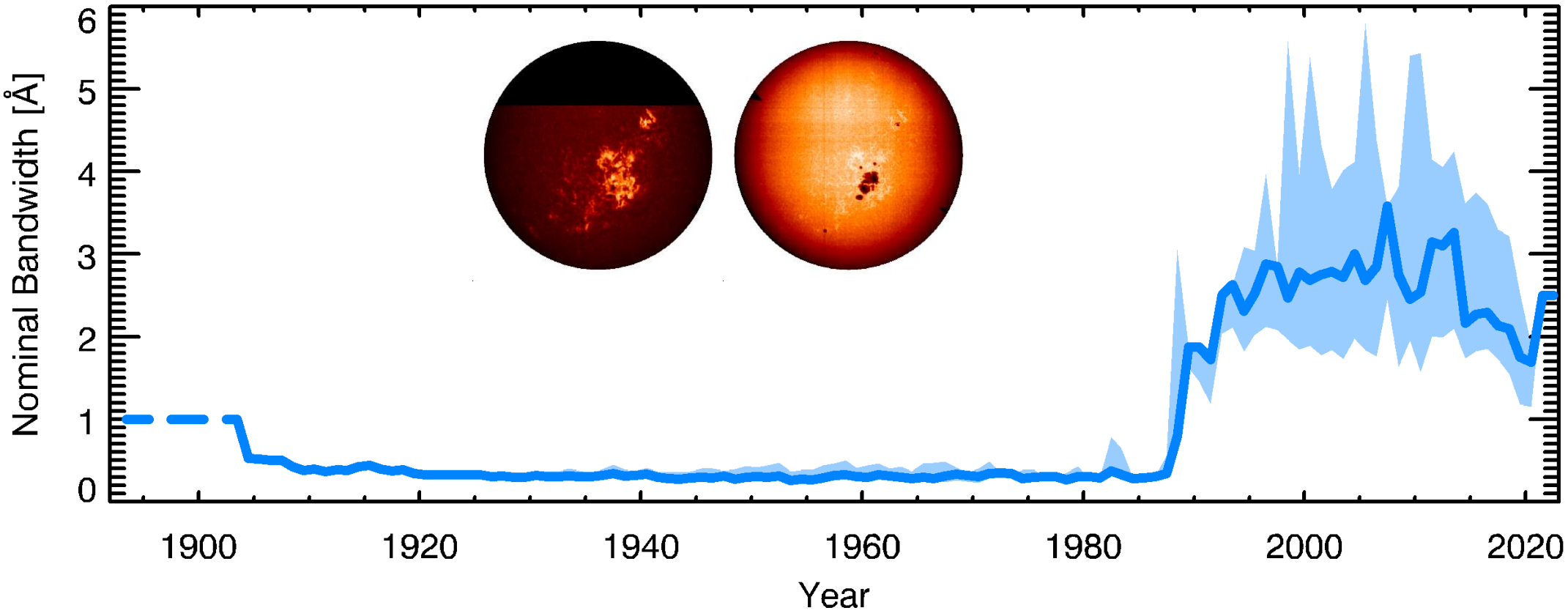
Meudon K1v
0.15Å



Meudon K1*
0.15Å



Main differences between archives



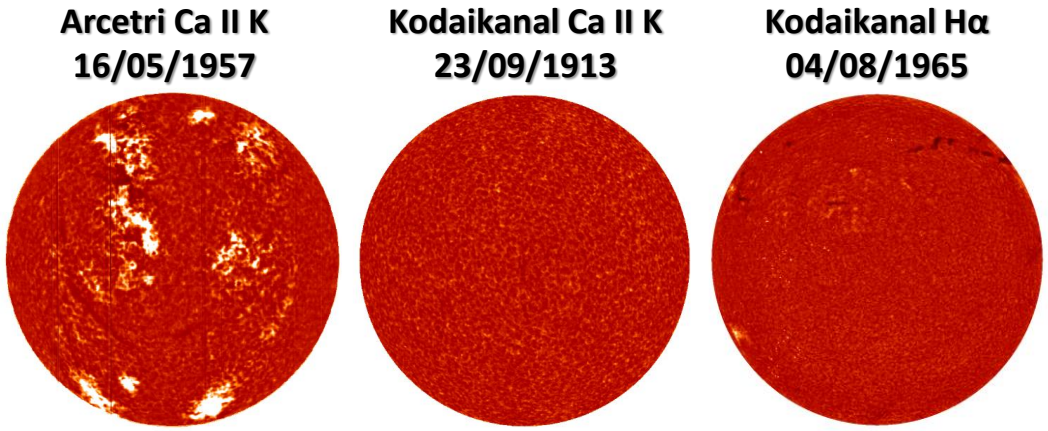
Chatzistergos et al., 2020 A&A 639

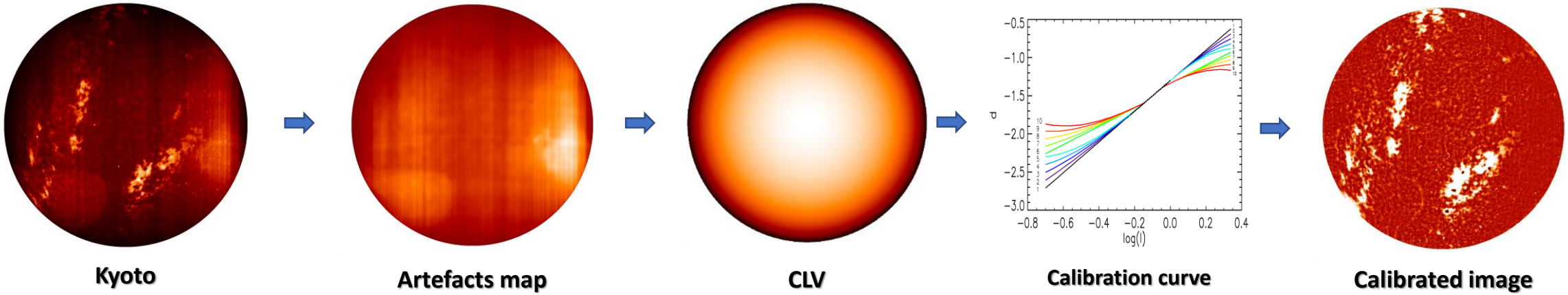
Corrections and calibration developed by me

Automatic process to:
- Photometrically calibrate images
- Compensate for instrumental and physical effects

Evaluated method's accuracy with synthetic data
- Performs better than all other methods in the literature

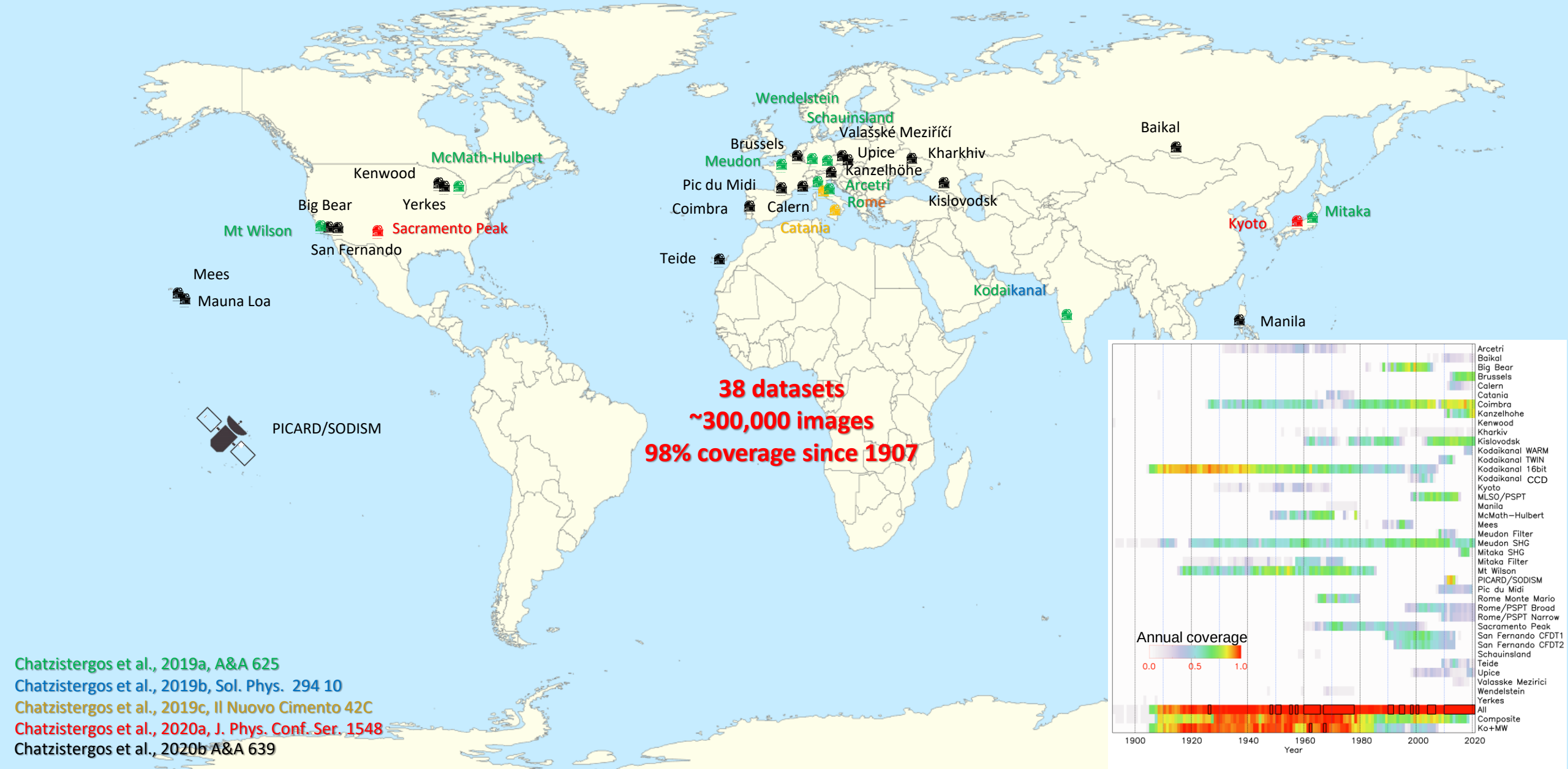
Works consistently with quite diverse data





Chatzistergos et al., 2018, 2019, 2020

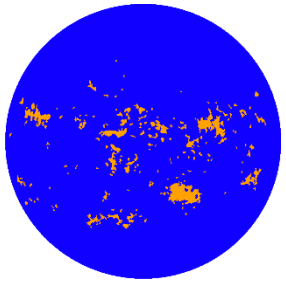
Ca II K archives

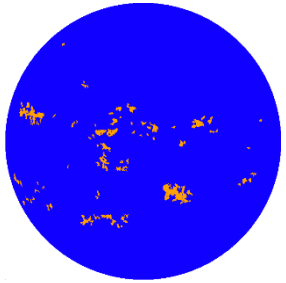


Chatzistergos et al., 2019a, A&A 625
Chatzistergos et al., 2019b, Sol. Phys. 294 10
Chatzistergos et al., 2019c, Il Nuovo Cimento 42C
Chatzistergos et al., 2020a, J. Phys. Conf. Ser. 1548
Chatzistergos et al., 2020b A&A 639

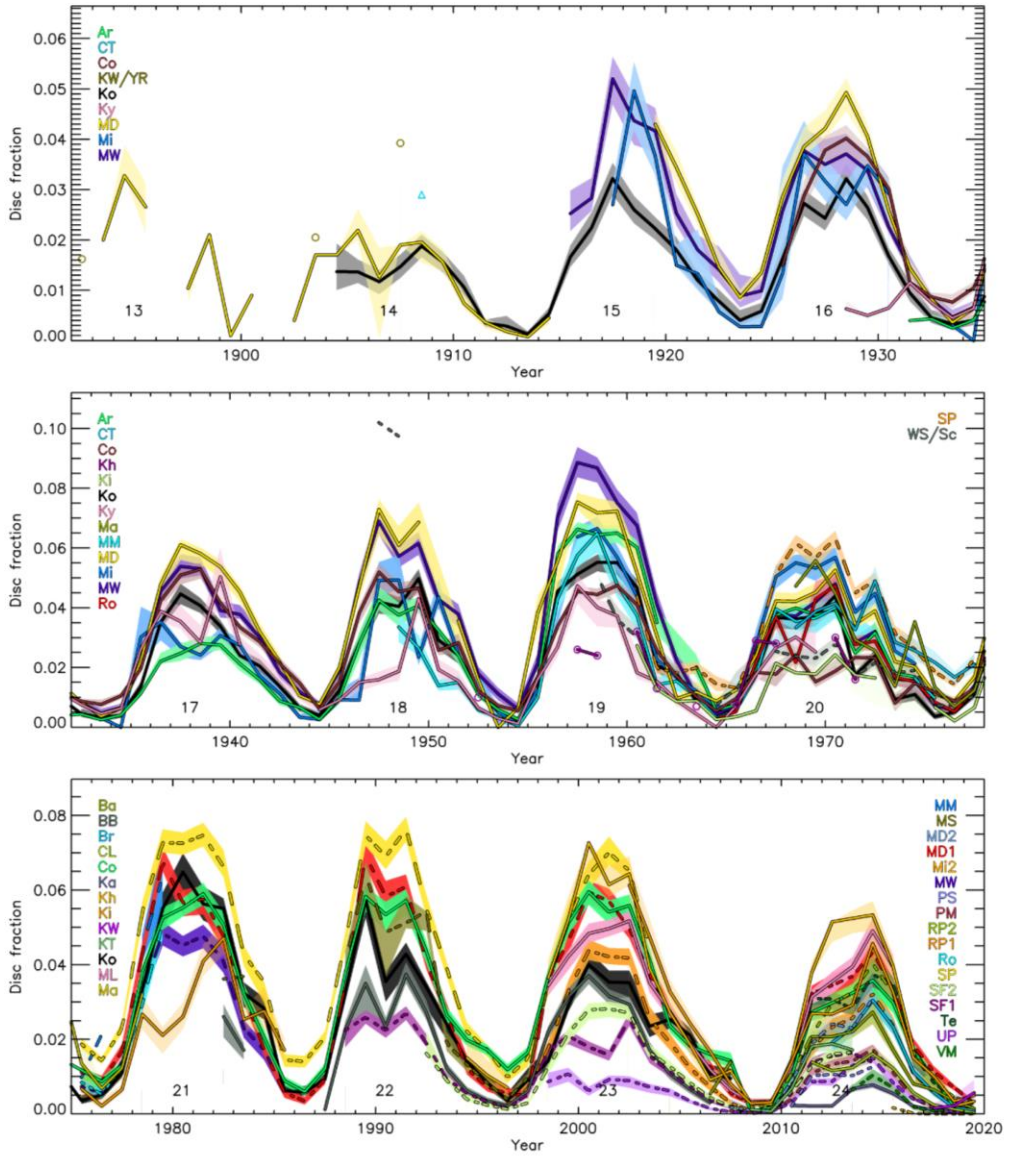
Plage coverage over the 20th century

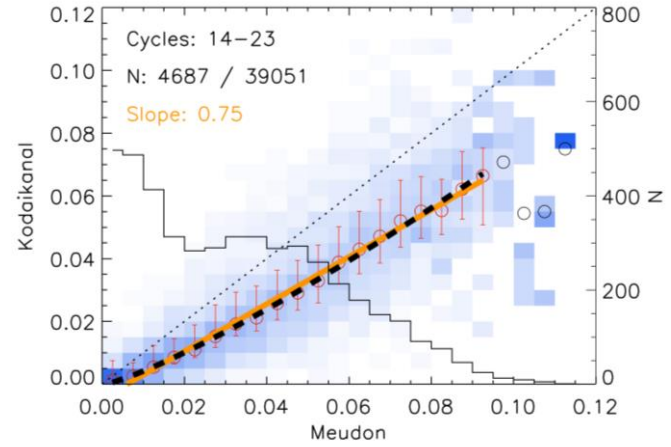
Meudon
0.15Å

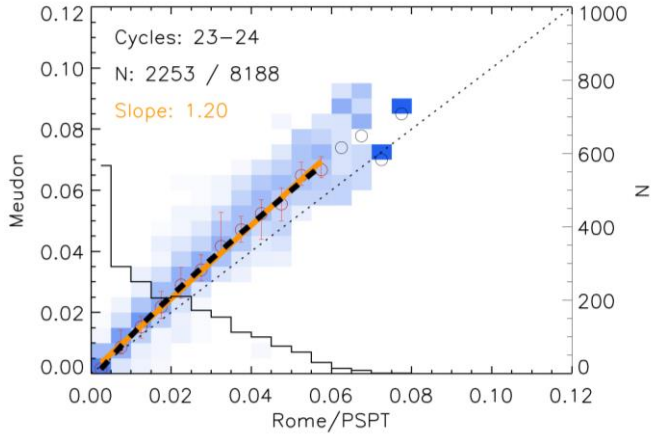




Kodaikanal
0.5Å

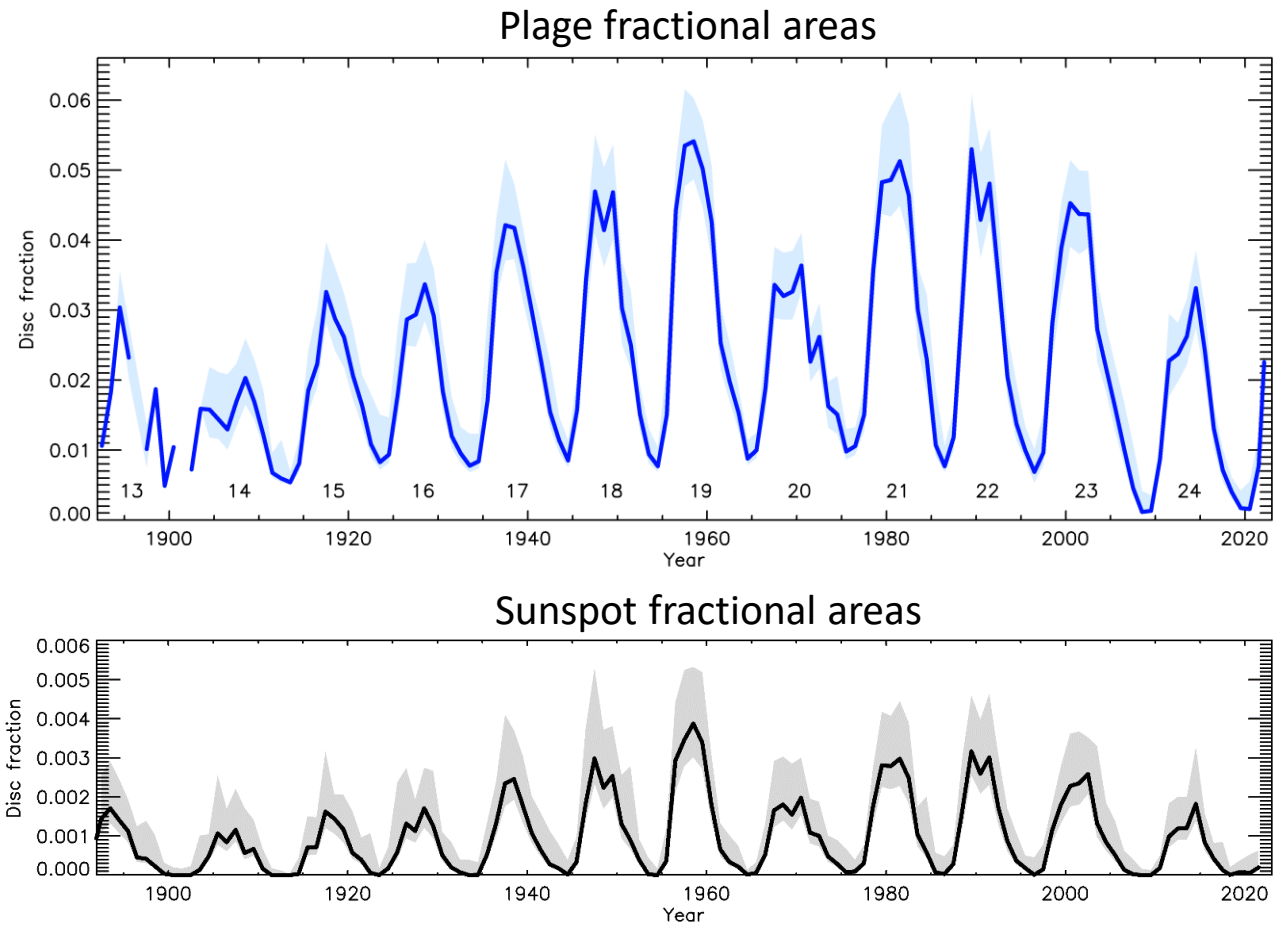






Chatzistergos et al., 2020b, A&A 639

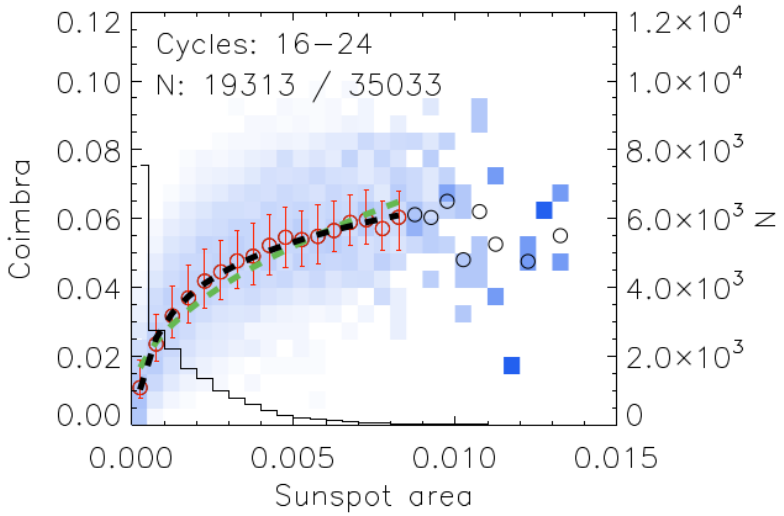
Plage coverage over the 20th century

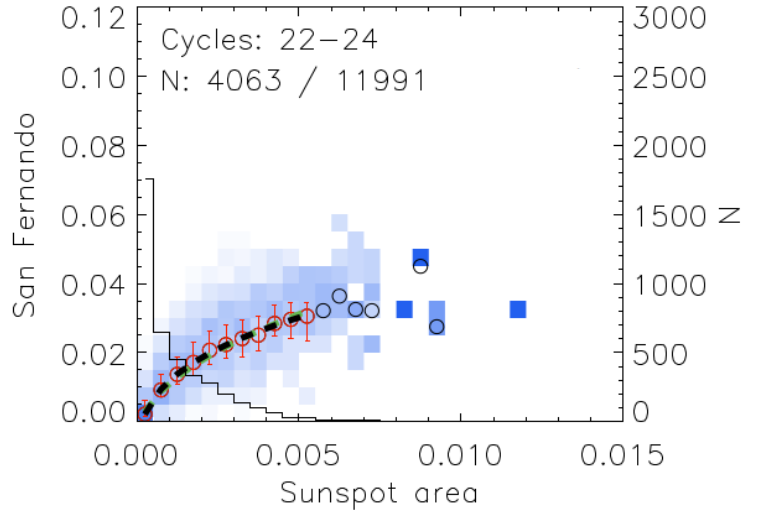


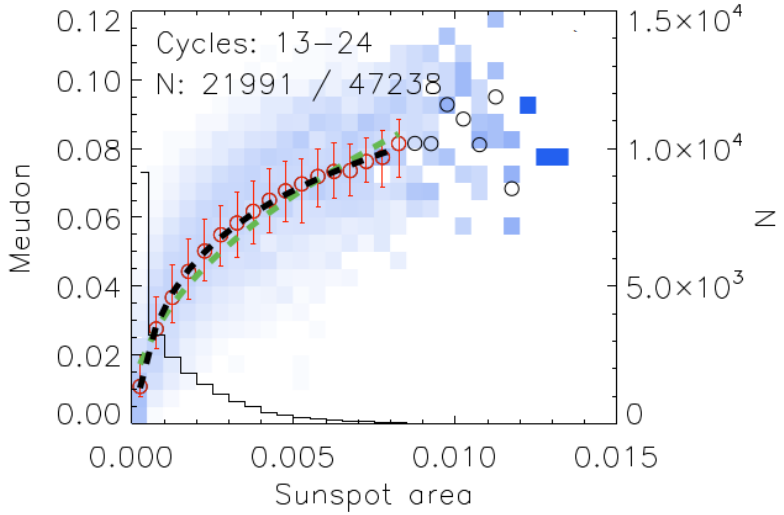
Chatzistergos et al., 2020b, A&A 639

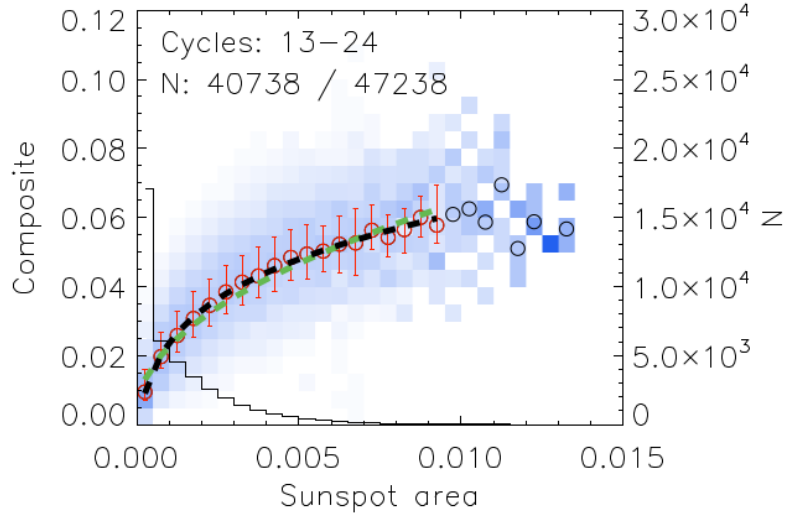
The data are available at https://www2.mps.mpg.de/projects/sun-climate/data.html

Relation between plage and sunspot areas



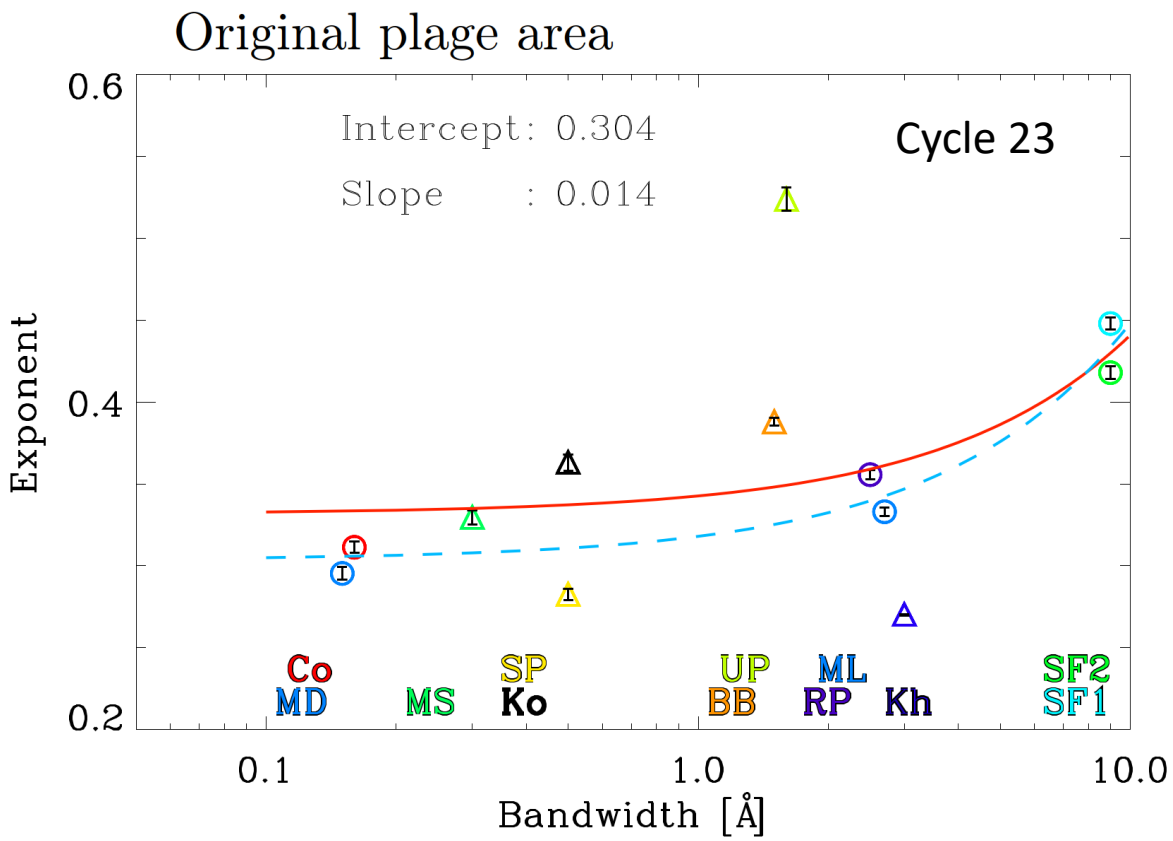


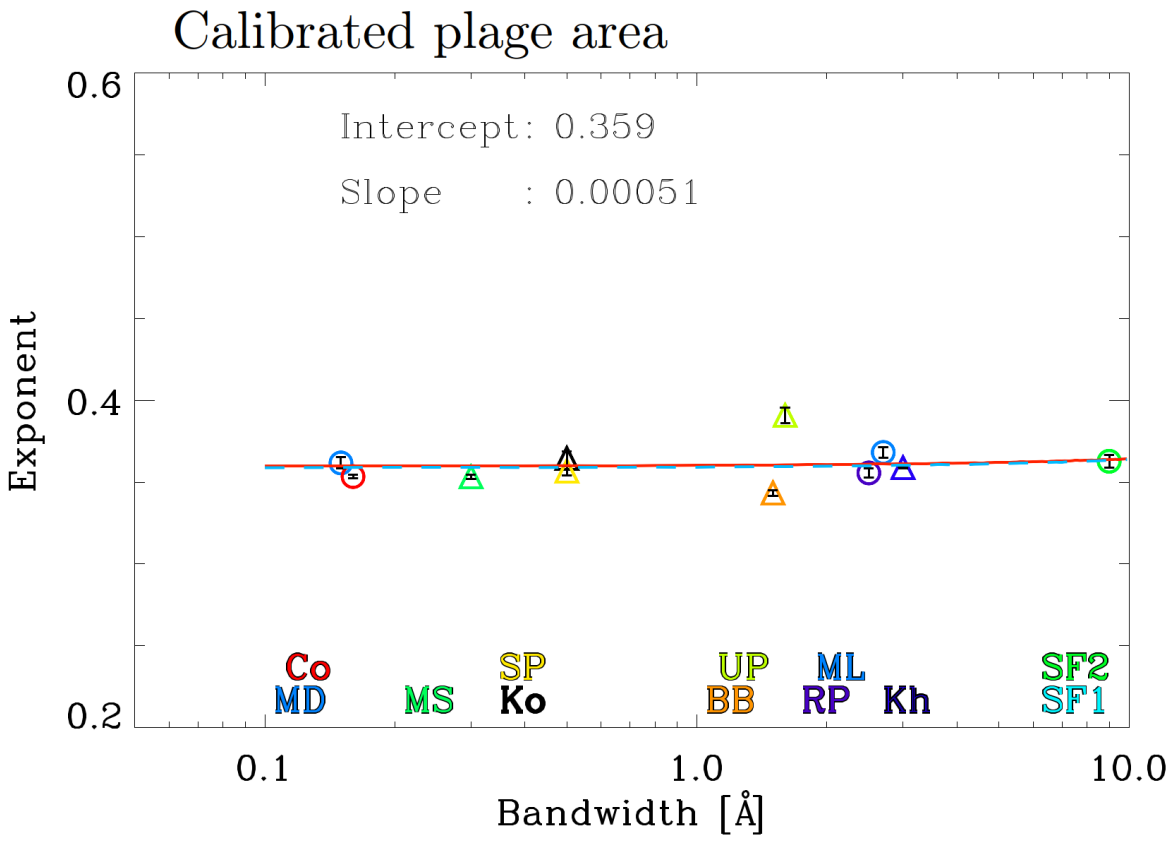




Chatzistergos et al., 2022, A&A

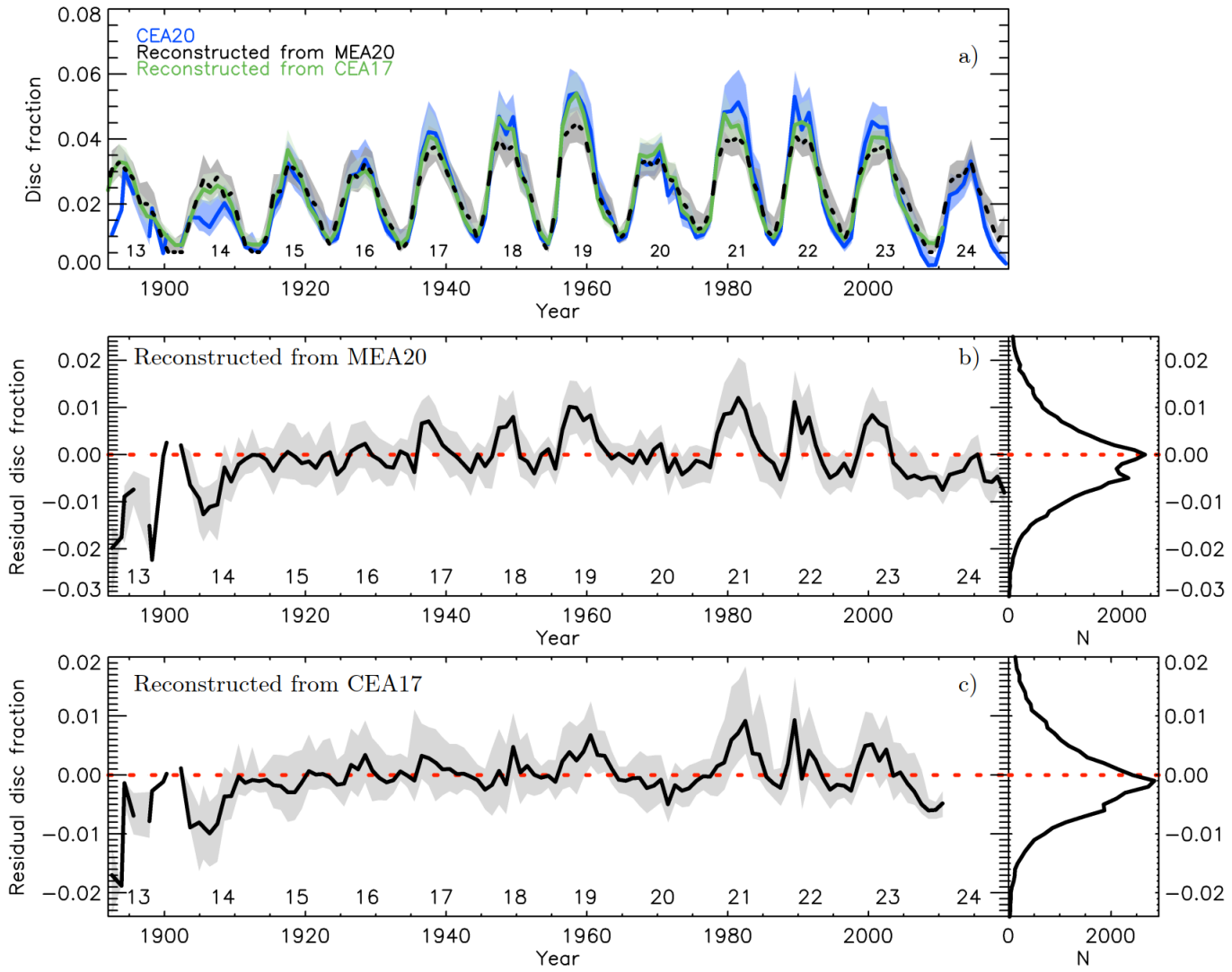
Dependence of relation on bandwidth





Chatzistergos et al., 2022, A&A

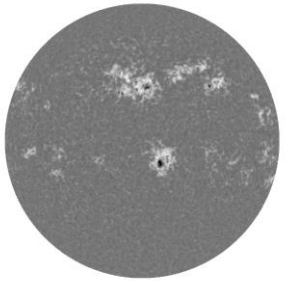
Reconstructing plage areas from sunspots



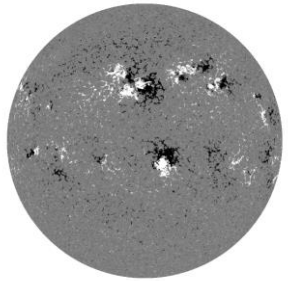
Chatzistergos et al., 2022, A&A

Ca II K as proxy to magnetic field

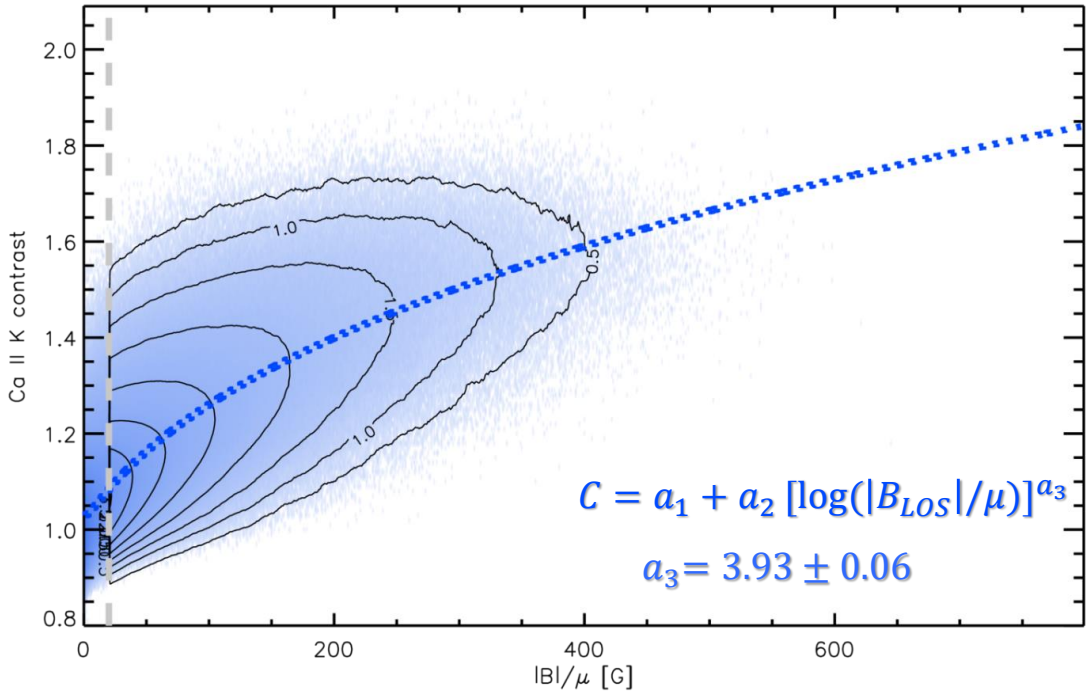
- Ca II K brightness is an excellent tracer of photospheric magnetic fields



Rome/PSPT
Ca II K

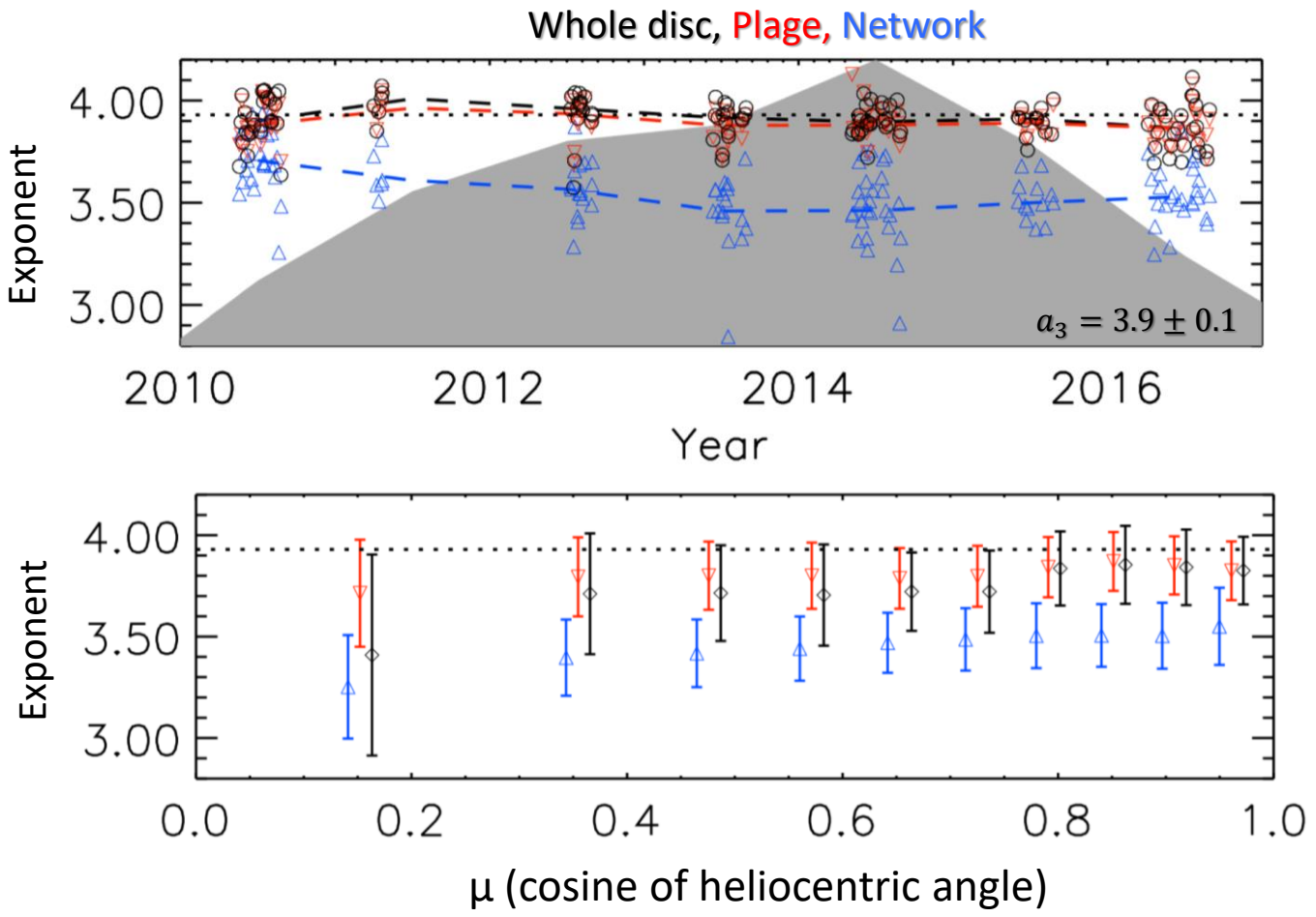


SDO/HMI
magnetogram



Chatzistergos et al., 2019d, 626

Fit parameters in time and position of solar disc



Constant parameters in time and positions on the disc

⬇

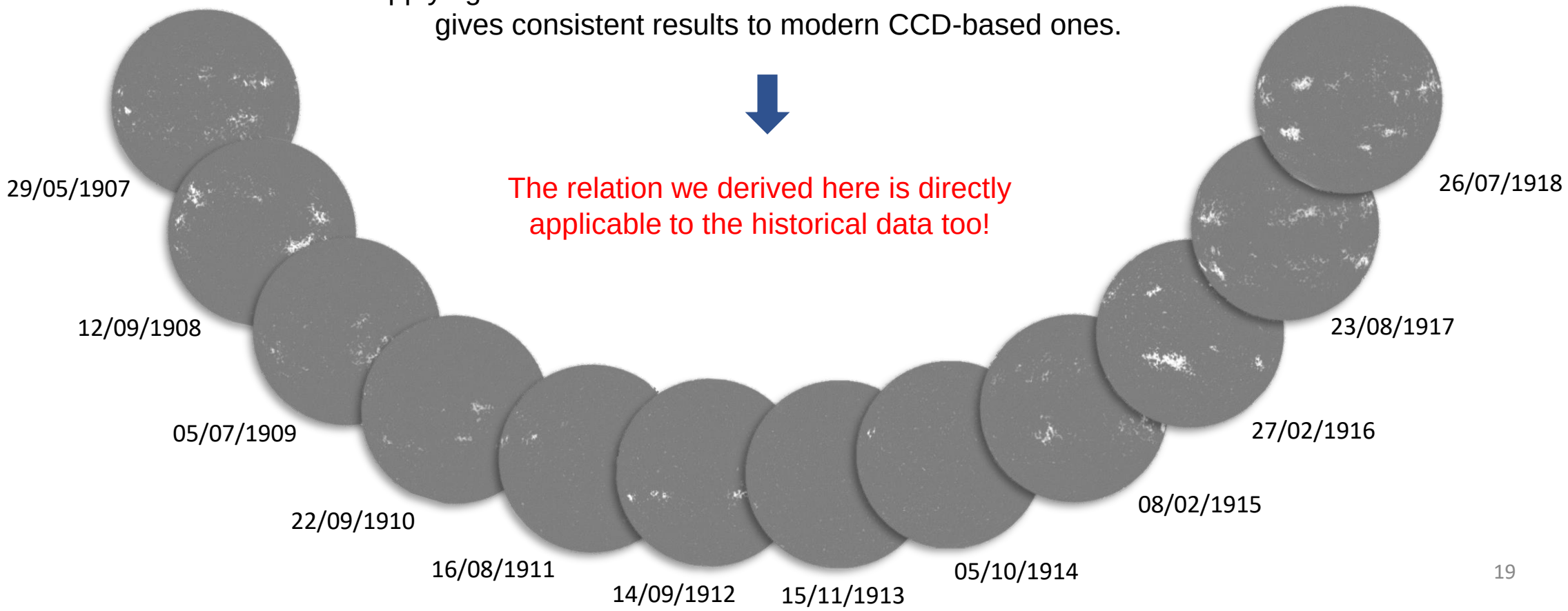
Only one parameter needed to reconstruct magnetograms from Ca II K

Chatzistergos et al., 2019d, 626

Reconstructing historical unsigned magnetograms

Applying our method to calibrate historical Ca II K observations gives consistent results to modern CCD-based ones.

The relation we derived here is directly applicable to the historical data too!



Spectral And Total Irradiance Reconstructions (SATIRE)

Krivova et al. 2003

$$S(t) = \int \left(\sum_{i,j} \right) d\lambda$$

Sunspots Faculae Quiet Sun

i, j pixels in the image

Intensity spectra (I) computed from corresponding model atmospheres (Unruh et al. 1999)

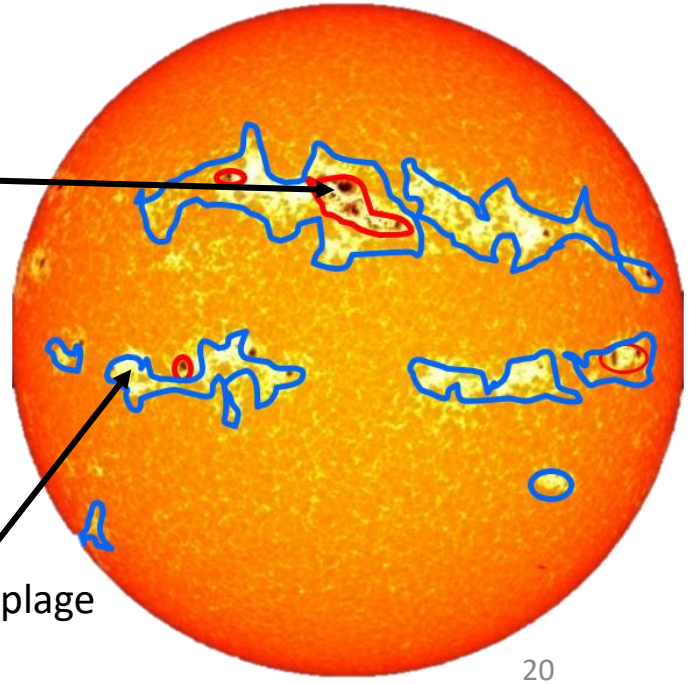
Filling factors (a)

Faculae: Reconstructed magnetograms from Ca II K (Chatzistergos et al. 2019)

Sunspots: Sunspot areas and positions database from RGO, Kislovodsk, and Pulkovo observatories (Mandal et al. 2020)

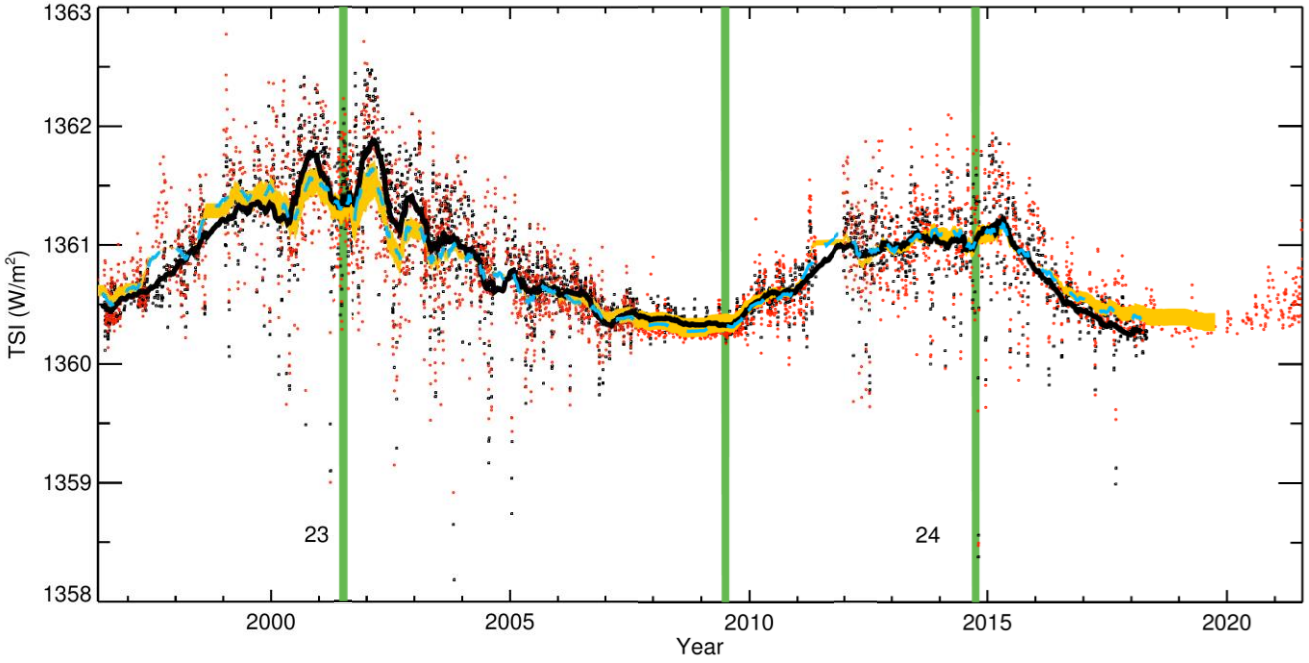
Only one free parameter: B_{sat} such that

$$a_f(i,j) = \begin{cases} \dfrac{|B|}{|B_{sat}|}, & |B| < |B_{sat}| \\ 1, & |B| \geq |B_{sat}| \end{cases}$$



SATIRE reconstruction with Rome/PSPT Ca II K

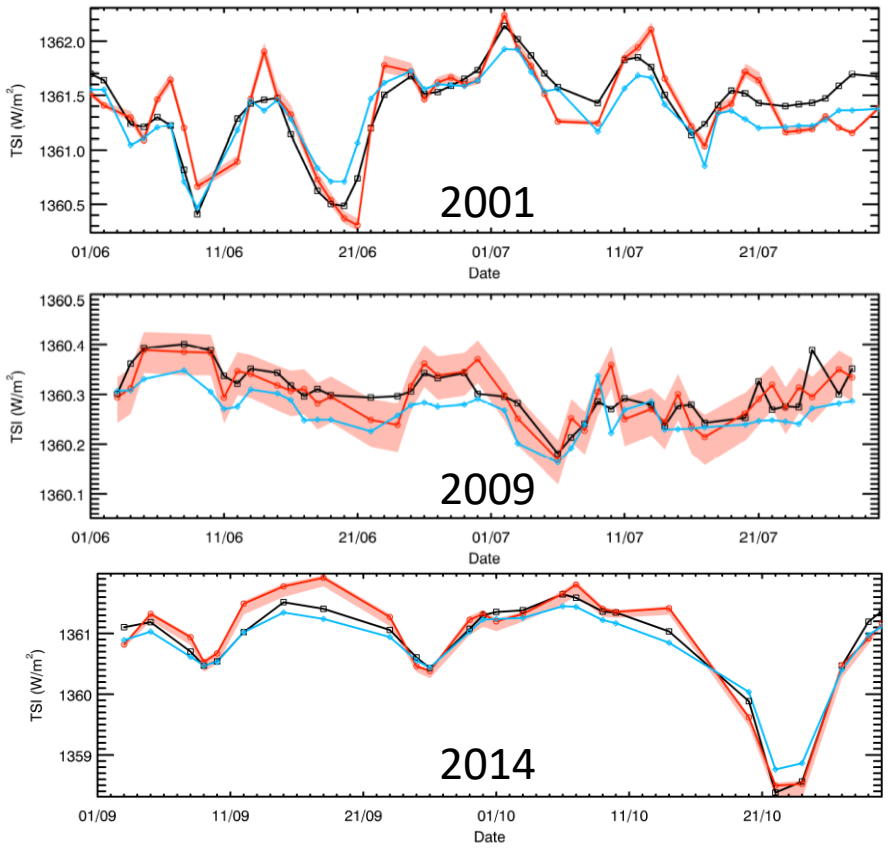
RMS=0.21Wm^{-2}, R=0.91



PMOD

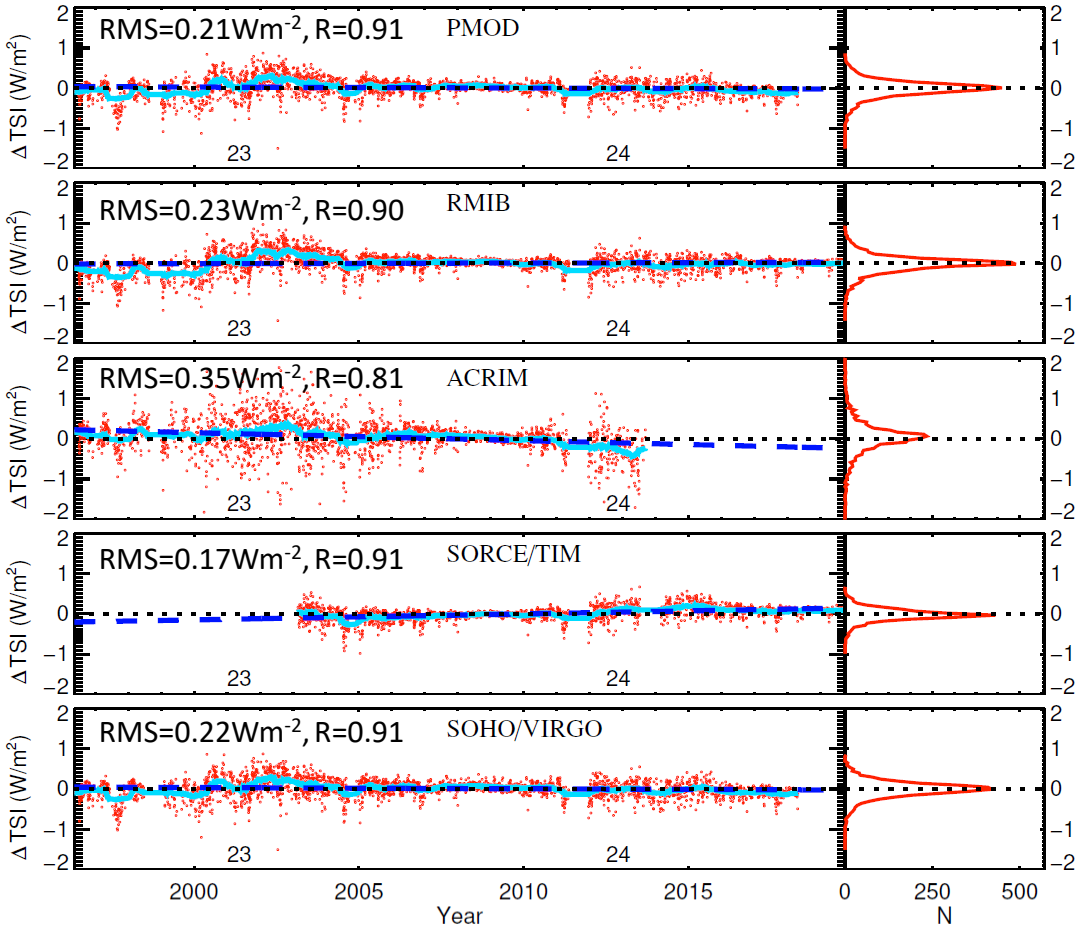
Ours (daily, 81-day running mean)

PMOD SATIRE-S Ours

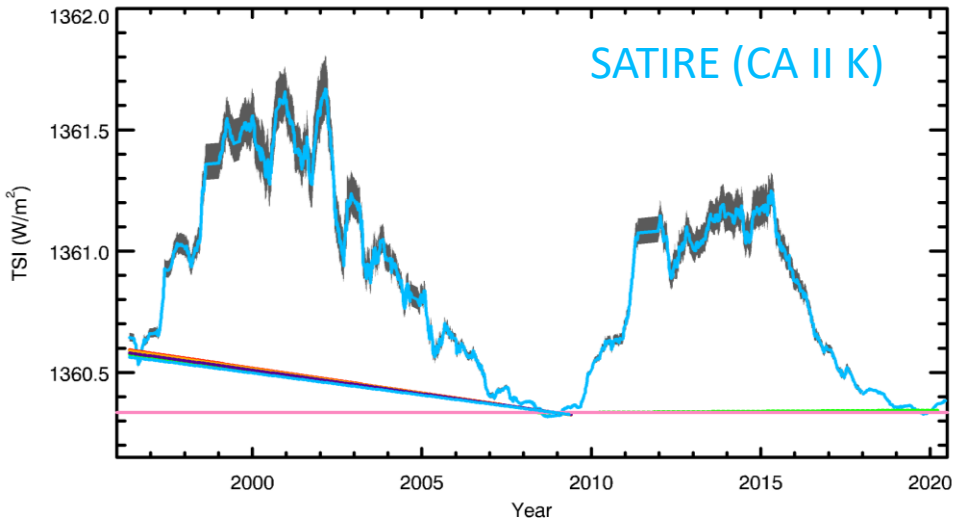


Chatzistergos et al. et al. 2021

Agreement to different TSI series



Chatzistergos et al. et al. 2021



Chatzistergos et al. 2021 ESSOAr

ACRIM
PMOD
RMIB
SORCE/TIM
SOHO/VIRGO
EMPIRE
NRLTSI
SATIRE-S

no-trend line

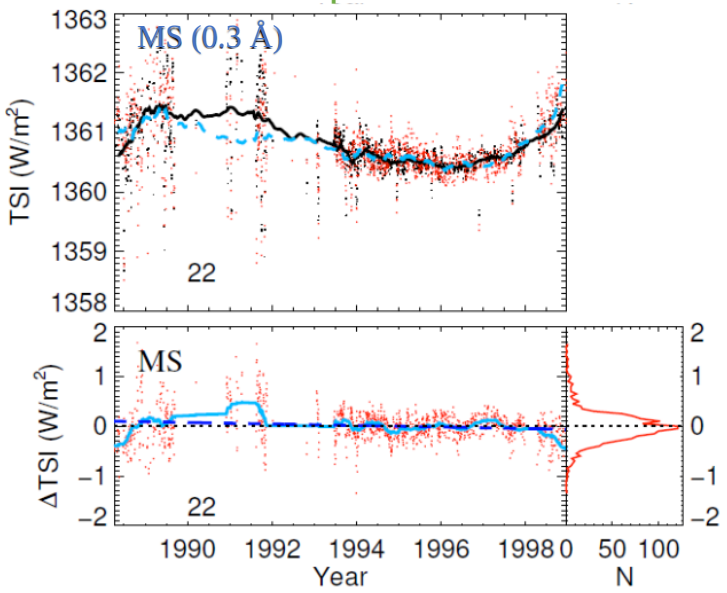
Reconstructions with diverse Ca II K archives

Archives with different

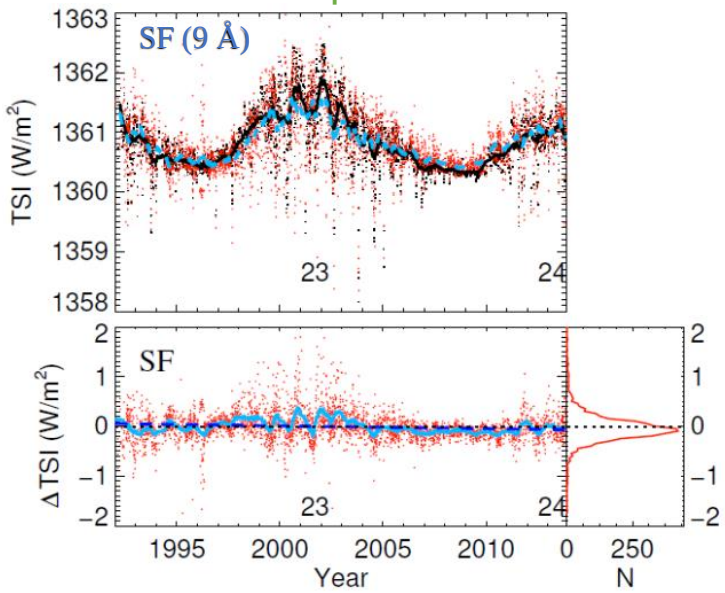
- Bandwidth (0.09 – 9 Å)
- Central wavelength
- Pixel scale (~0.7 – 5.5”/pixel)
- Cadence

PMOD

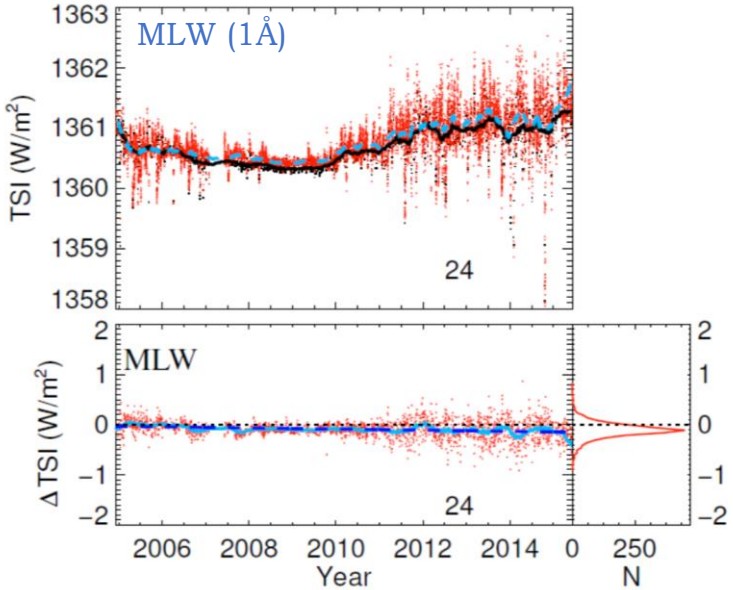
Mees
Centred at 3933.7Å
5.5”/pixel



San Fernando CFDT2
Centred at 3933.7Å
2.6”/pixel

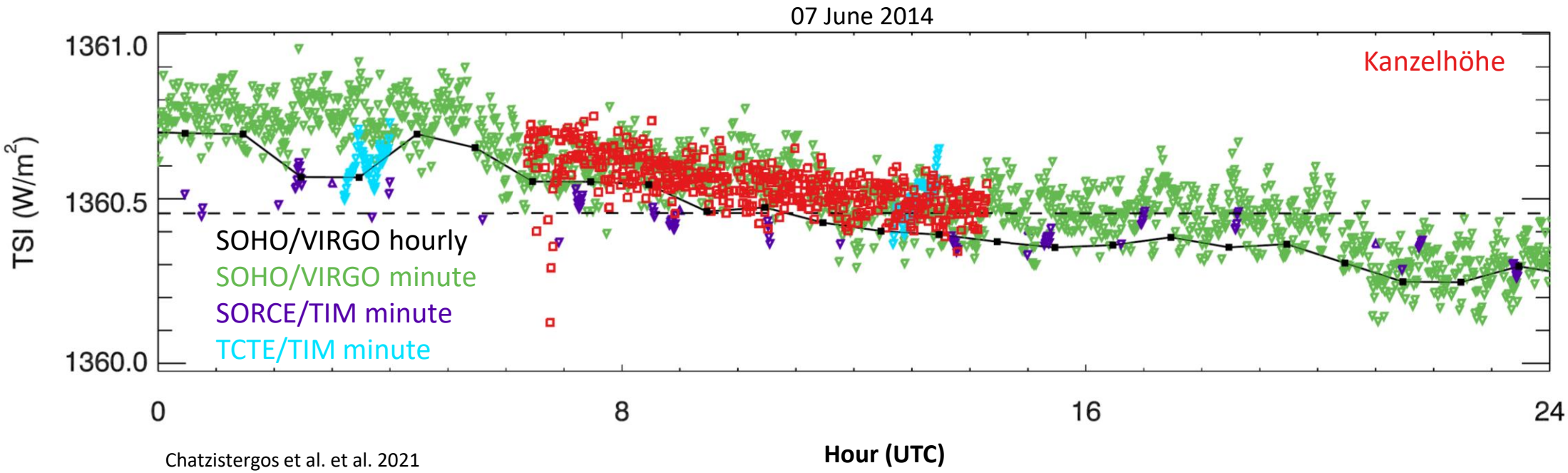


Mauna Loa PSPT
Centred at 3936.3Å
1.0”/pixel



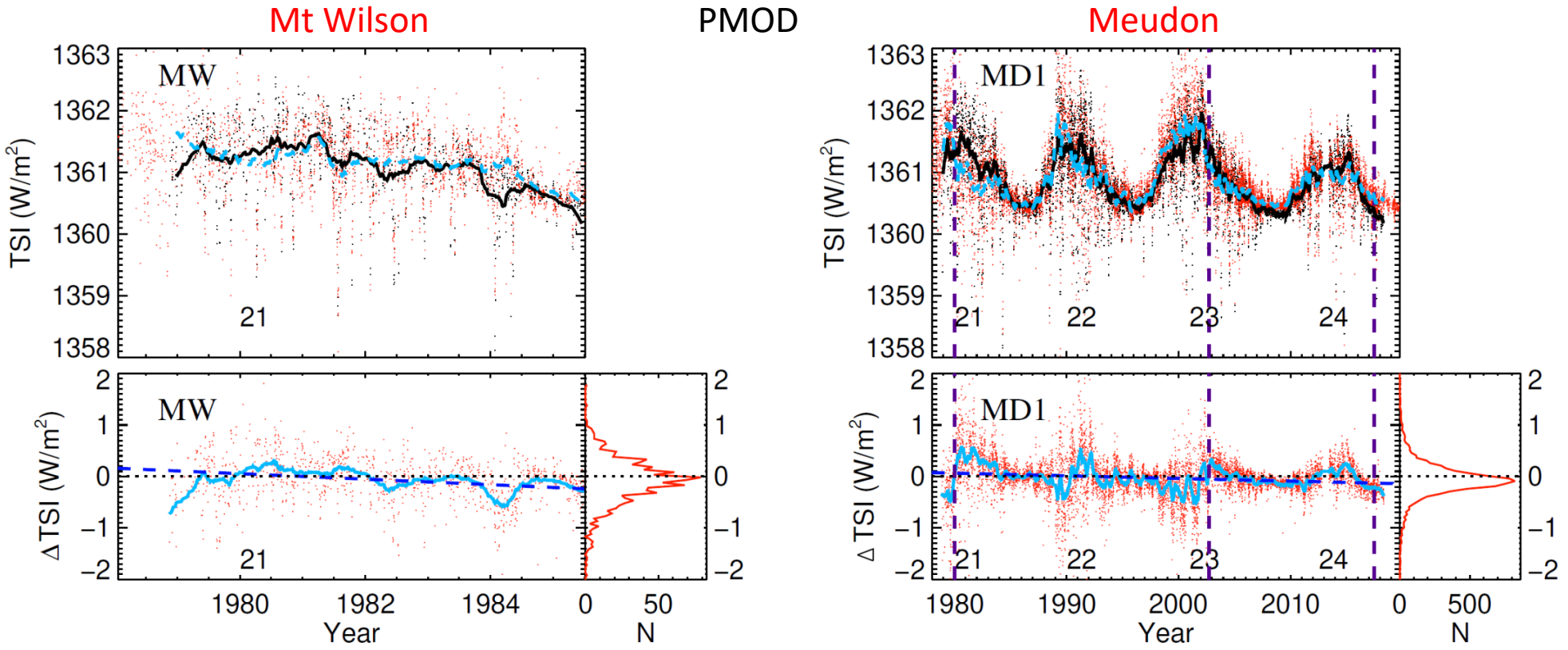
Chatzistergos et al. et al. 2021

Reconstructions with high-cadence data



Chatzistergos et al. et al. 2021

Results with photographic Ca II K data



Chatzistergos et al. et al. 2021

Summary

- Ca II K observations are an extremely valuable, but largely unexplored, resource for irradiance studies
- We performed a comprehensive analysis of Ca II K observations
  - Produced the first plage area composite from 38 archives
  - Scrutinised the relationship between plage and sunspot areas
  - Reassessed the relation between Ca II K brightness and magnetic field strength
  - Reconstructed TSI variations with SATIRE model
    - The reconstructions show excellent agreement with TSI composites
    - We acquire accurate reconstructions with quite diverse Ca II K archives including photographic ones