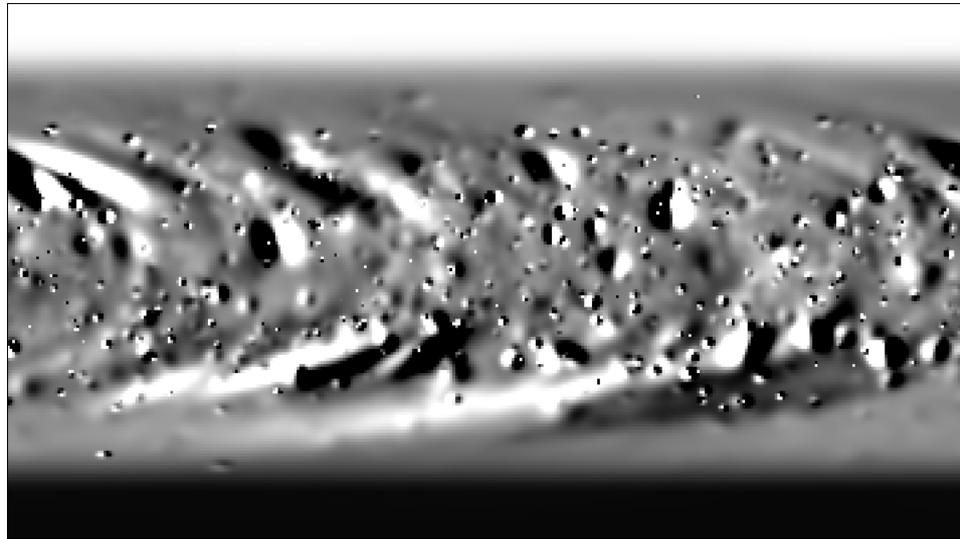


Reconstructing solar irradiance since 1700 from simulated magnetograms



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- Total solar irradiance (**TSI**) is an important input to climate models.
- Before 1978, TSI can only be retrieved through **reconstructions** from proxies.
- Solar variability is driven by **magnetic features**.
- The longest direct proxies of the surface magnetism are **sunspot number records**.

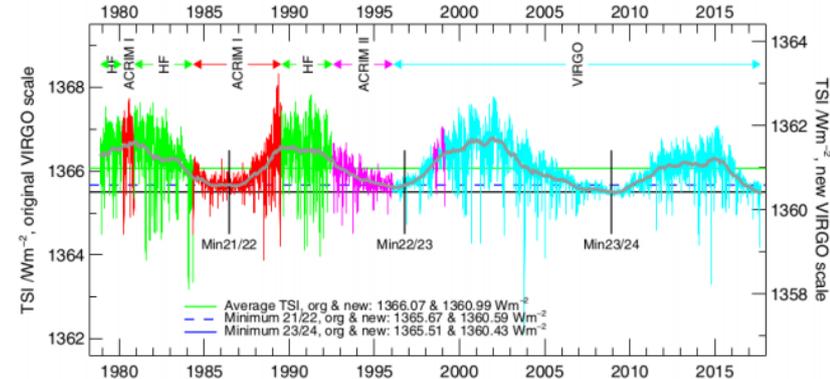
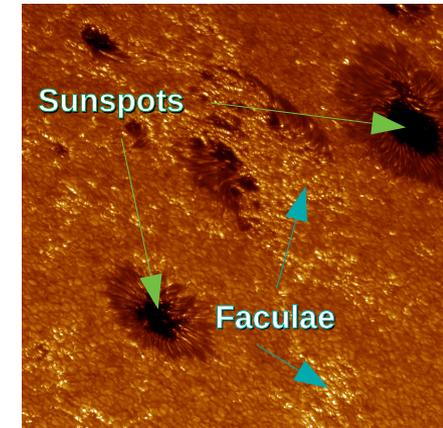


Figure is courtesy of the VIRGO team (From: <https://www.pmodwrc.ch>)



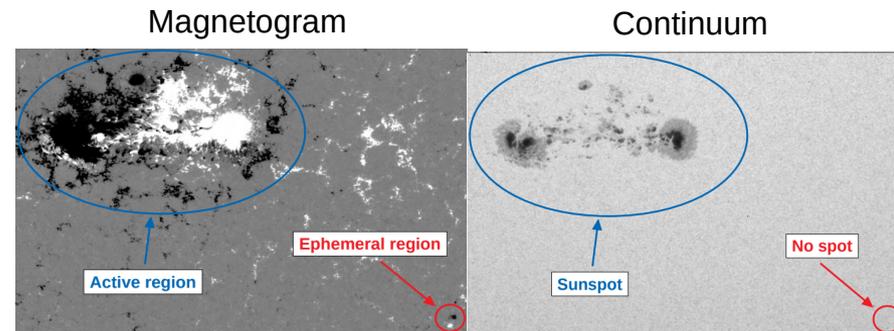
Credit to: Dan Kieselmann & Mats Löfdahl (Royal Swedish Academy of Science)
(From: <https://ttt.astro.su.se/news/20060913en.html>)

Ephemeral regions & SATIRE model

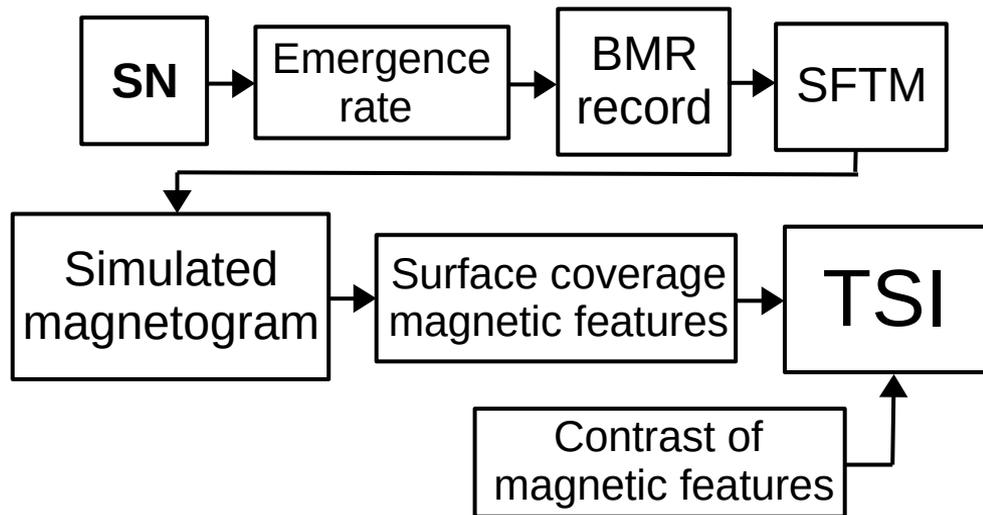
- **ERs** are short lived bipolar magnetic regions (**BMRs**) too small to feature sunspots.
- Important for secular TSI variation, but *missed by SN records!*

→ **Goal:** Reconstruct magnetic flux and TSI from Surface Flux Transport Model (**SFTM**)

- TSI is reconstructed by the **SATIRE** model.

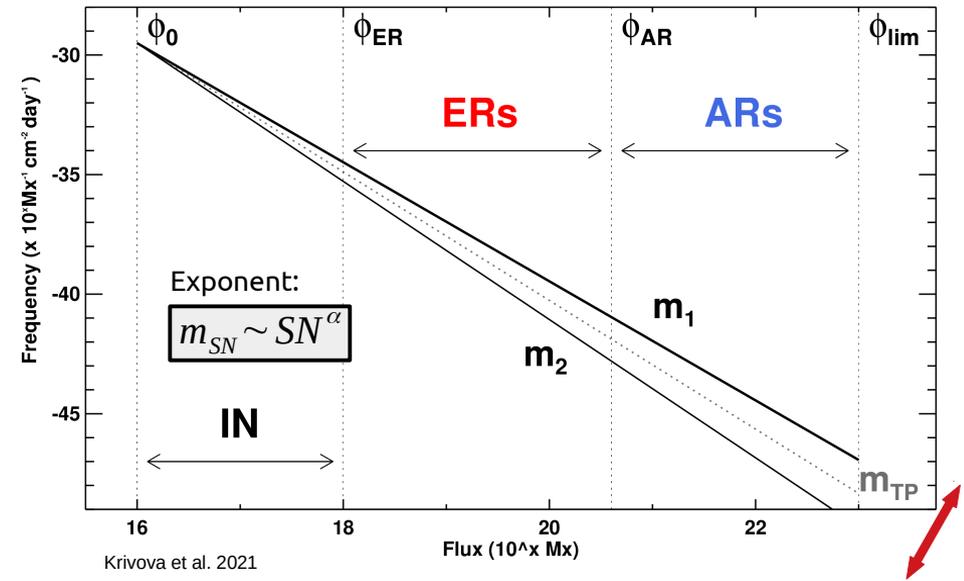


Adapted from www.helioviewer.org (SDO/HMI data)

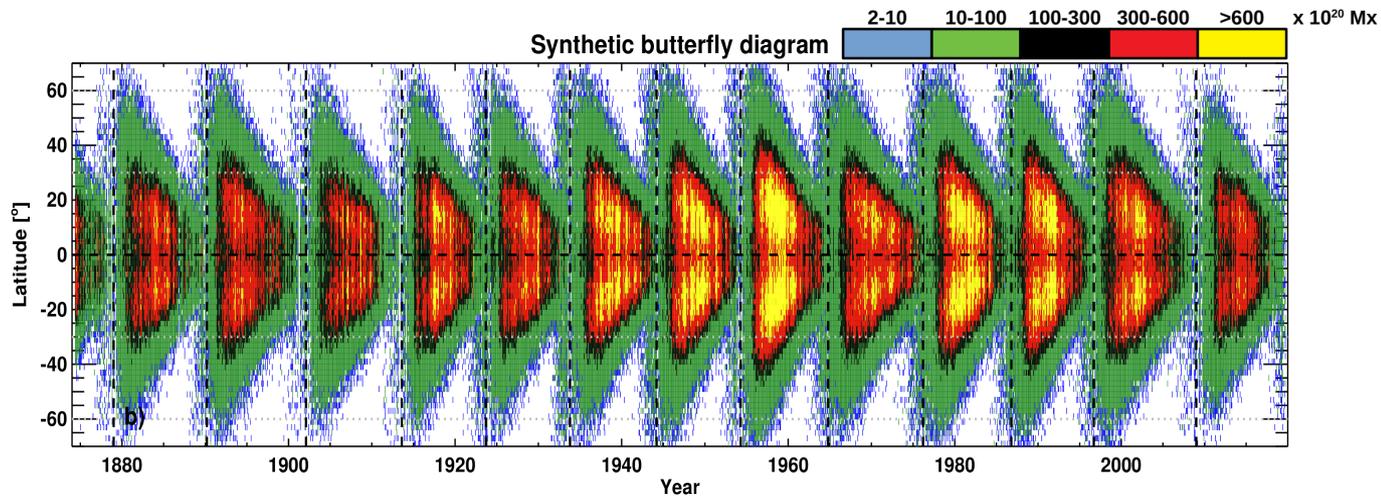
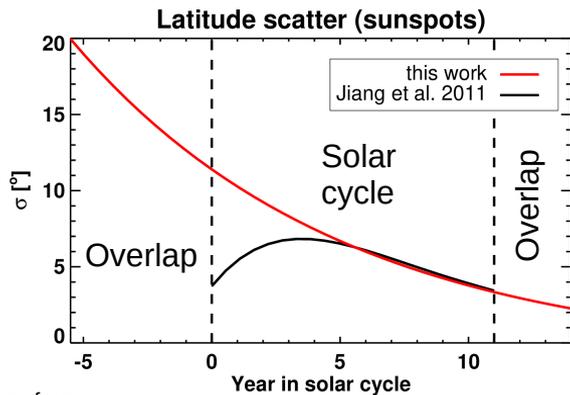
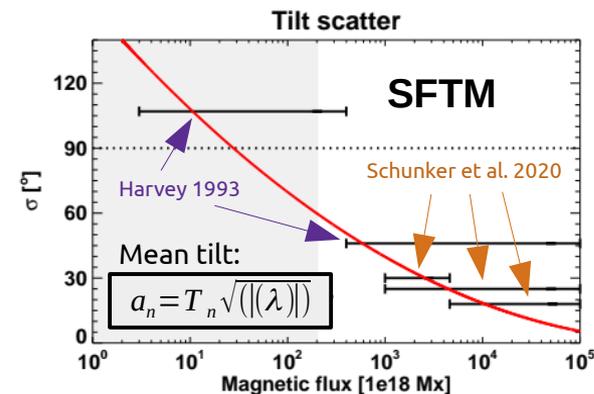
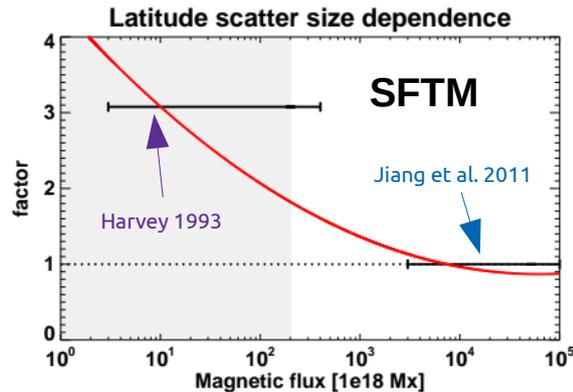
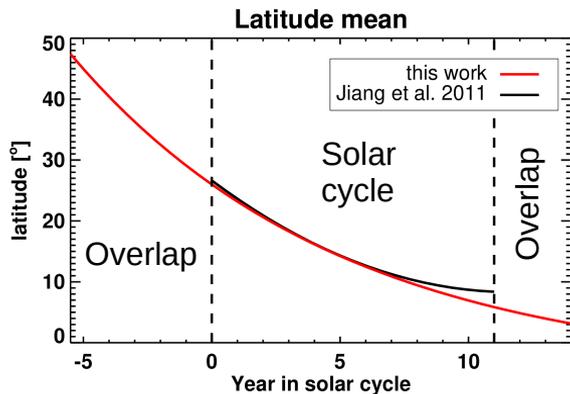


Emergence rate

- Emergence of **all BMRs** described by a single **powerlaw size distribution**.
- Exponent **varies with SN** (ISNv2.0).
- **AR** more variable (factor **8**) than **ERs** (factor **2**) between minimum and maximum. (Harvey, 1993)

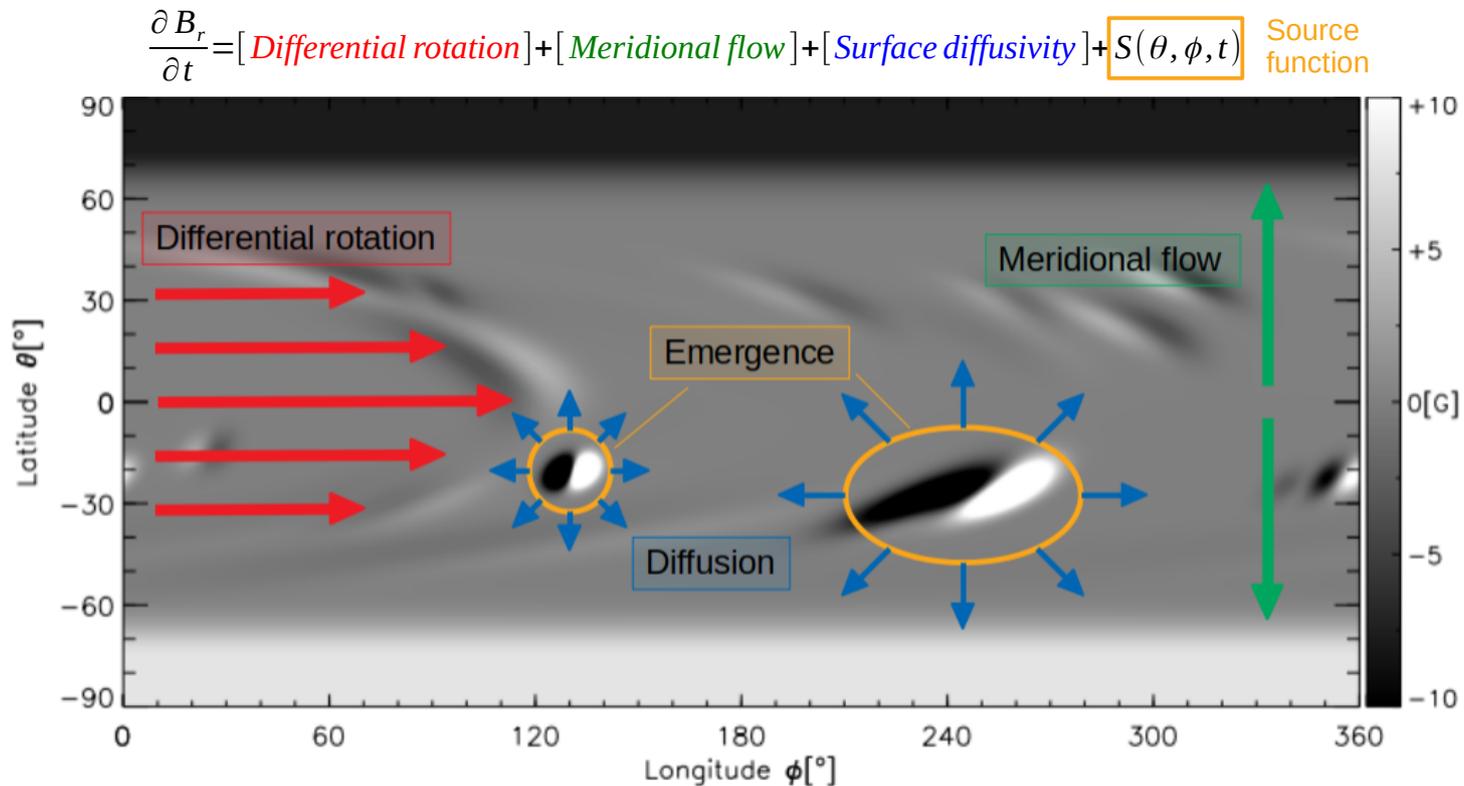


Latitude and tilt angle



All figures from
Hofer et al. 2023 (submitted)

- Magnetograms calculated by a **Surface Flux Transport Model**.



From magnetograms to TSI...

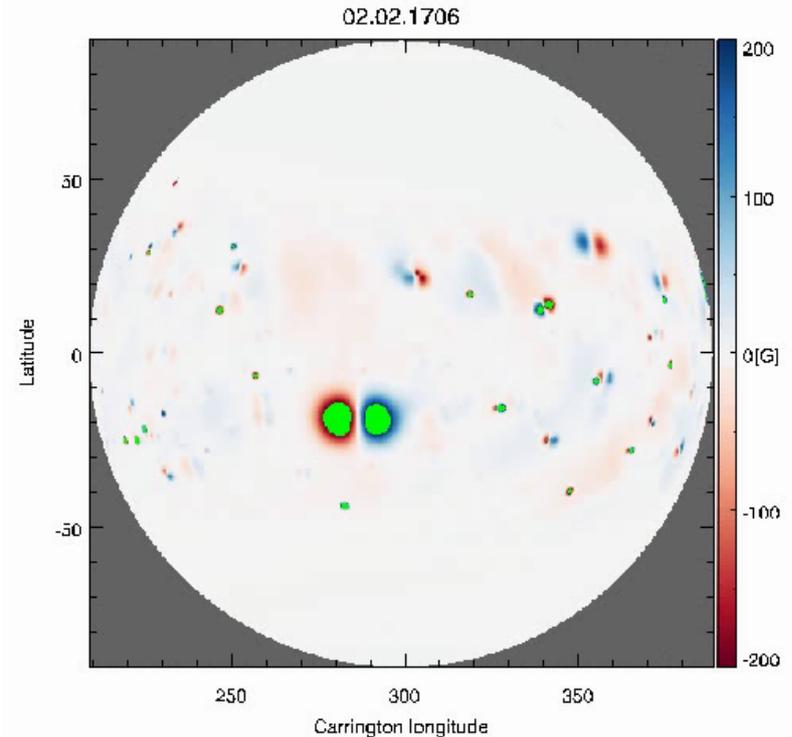
Magnetic features

- **Sunspots** above threshold.
(matching RGO/SOON sunspot areas)

$$B_{thr} = 200 \text{ G}$$

- Rest **faculae** and **quiet Sun**.
- Pixels may contain multiple features.

→ **Brightness** from semi-empirical models, and depends on **distance from disk center!**



Magnetic flux

- **AMRs** (all regions) reproduce total magnetic flux measurement by **ground-based observatories**.
(no empirical parameter adjustment)
- **LMRs** 2 times **SMRs** at maximum, but similar at minimum.

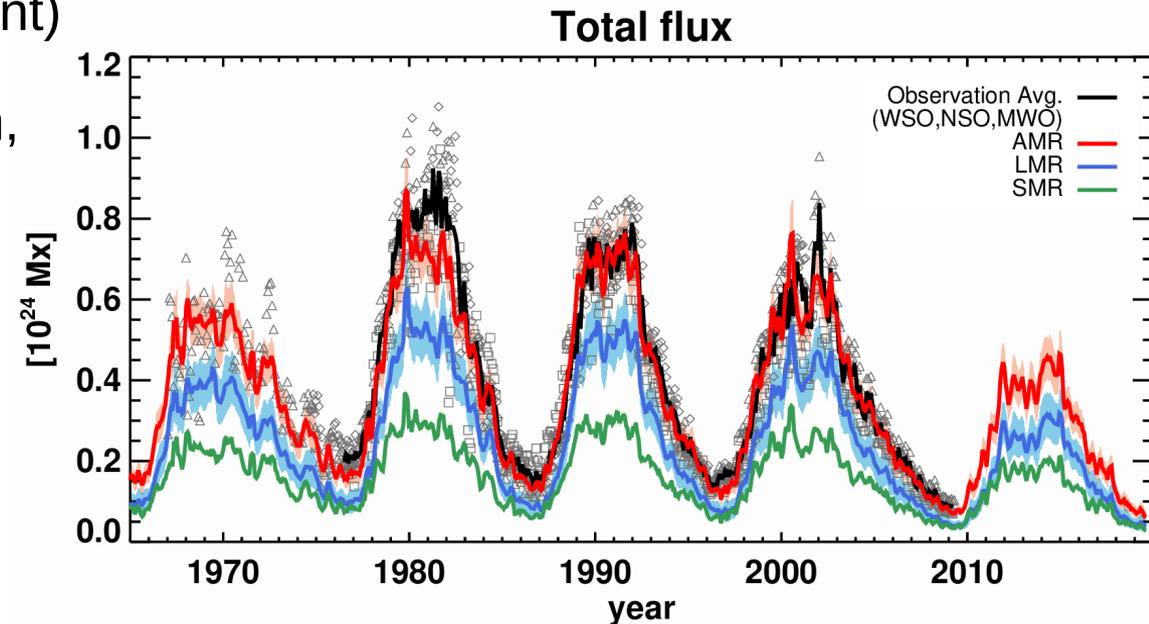
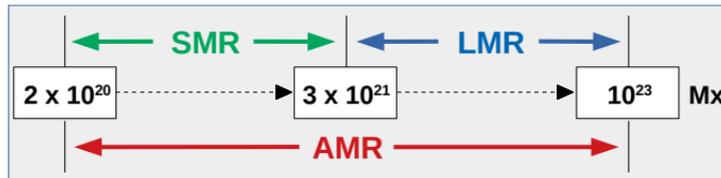
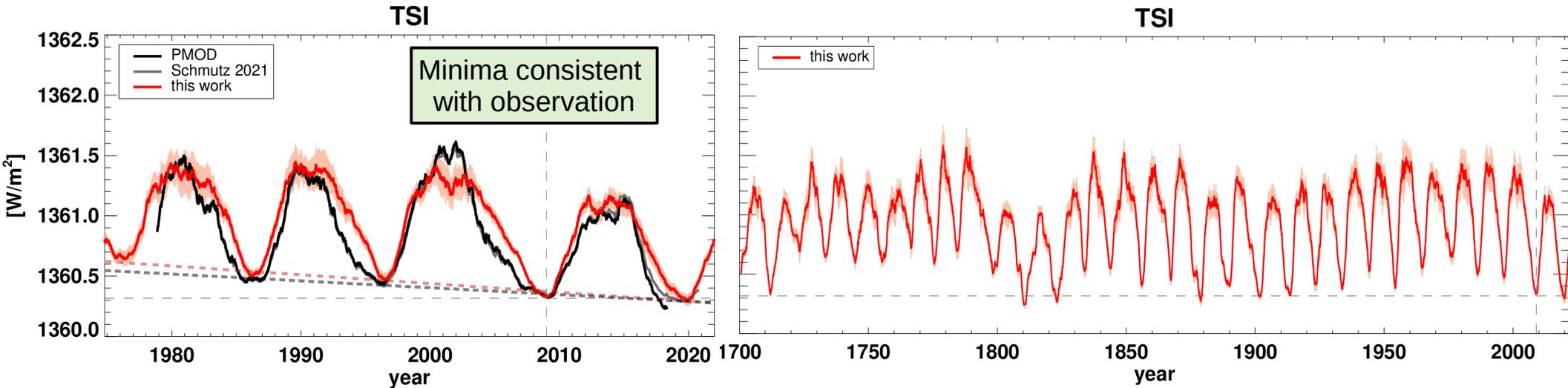


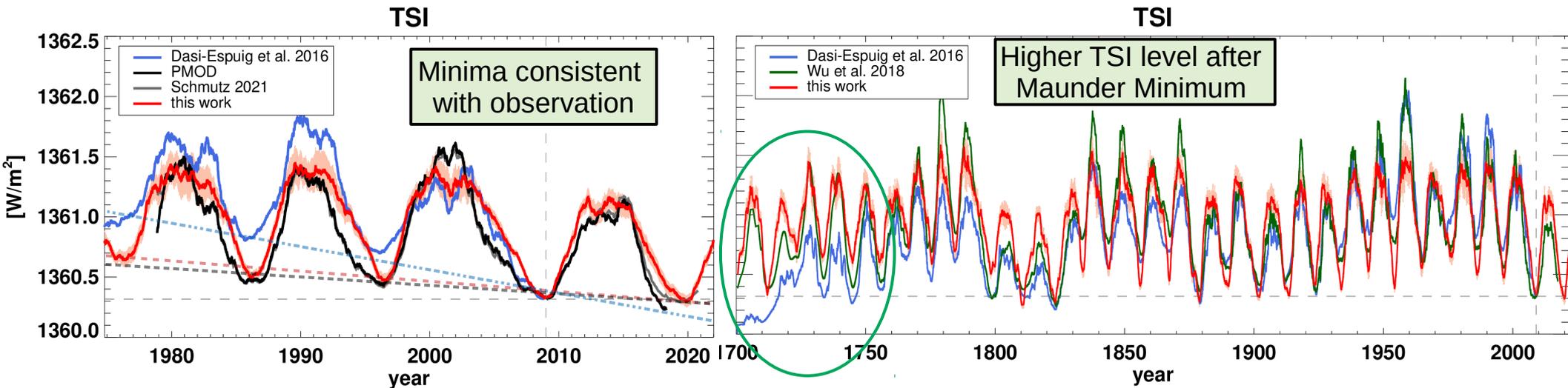
Figure adapted from Hofer et al. 2023 (submitted)

- **Reconstruction** reproduces minima and trend of **PMOD composite** (Fröhlich 2006).



TSI

- **Reconstruction** reproduces minima and trend of **PMOD composite** (Fröhlich 2006).
- Higher TSI level after Maunder Minimum compared to model with **only sunspot regions**, but similar to TSI from **cosmogenic isotopes**.



Conclusions

- Computed **total magnetic flux** reproduces observed flux well, while including smaller spotless regions ($2-30 \times 10^{20} M_x$).
- **TSI** reconstruction reproduces observed **minimum levels** better than model with only sunspot regions.
- Computed TSI in **good agreement with observations** (PMOD) .
- Due to flux emergence of smaller regions during minima, **smaller secular change** since Maunder Minimum compared to model with only SN.

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