STCE seminar: Irradiance

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Solar irradiance

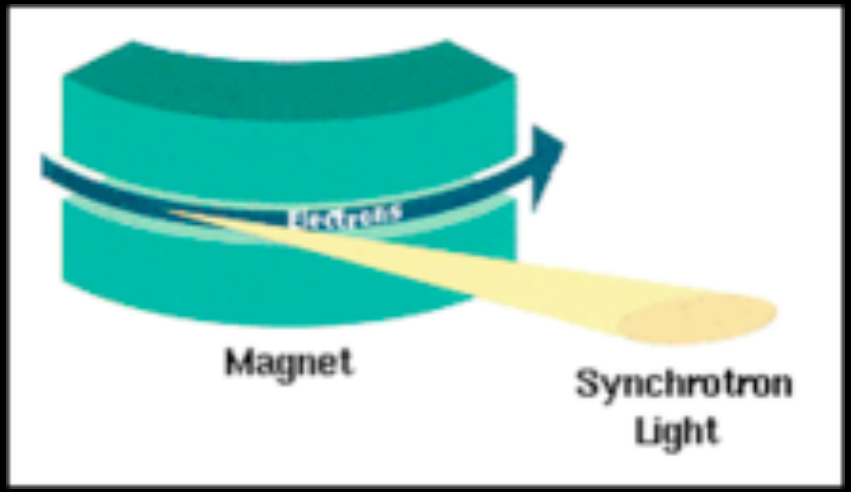
Definition: power per unit area received from the Sun in the form of electromagnetic radiation at 1 AU

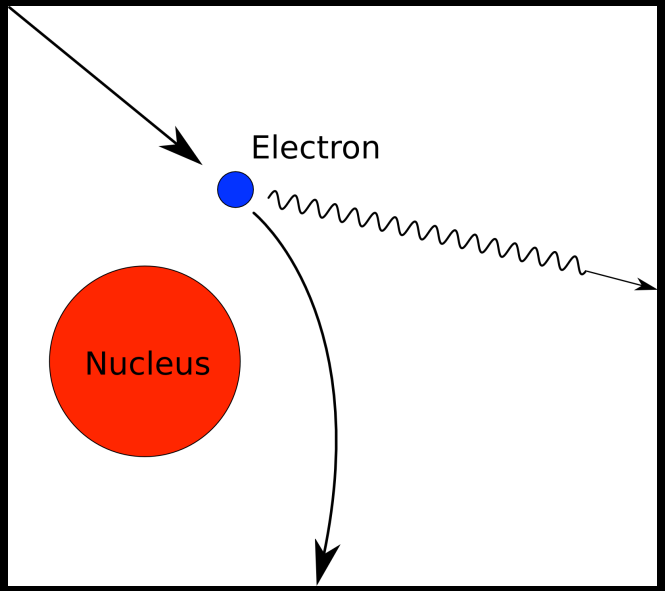
- Total Solar Irradiance (TSI), i.e. the "solar constant"
- Spectral solar irradiance (SSI), i.e. the solar spectrum

- One of the main diagnosis tool to get quantitative information about the Sun
- Multiple impacts on Earth

Origin of photons

- Two ways to produce photons:
  - Accelerate/decelerate a charge
  - Transitions between two energy levels in an atom





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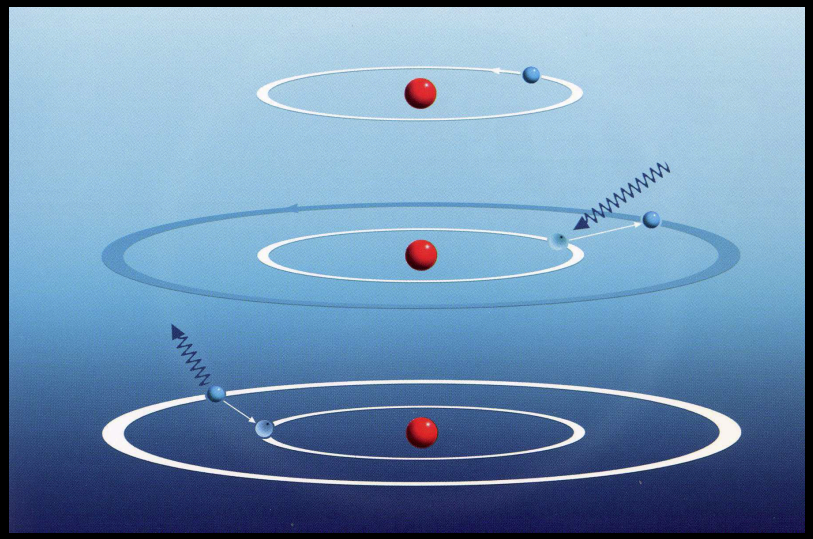
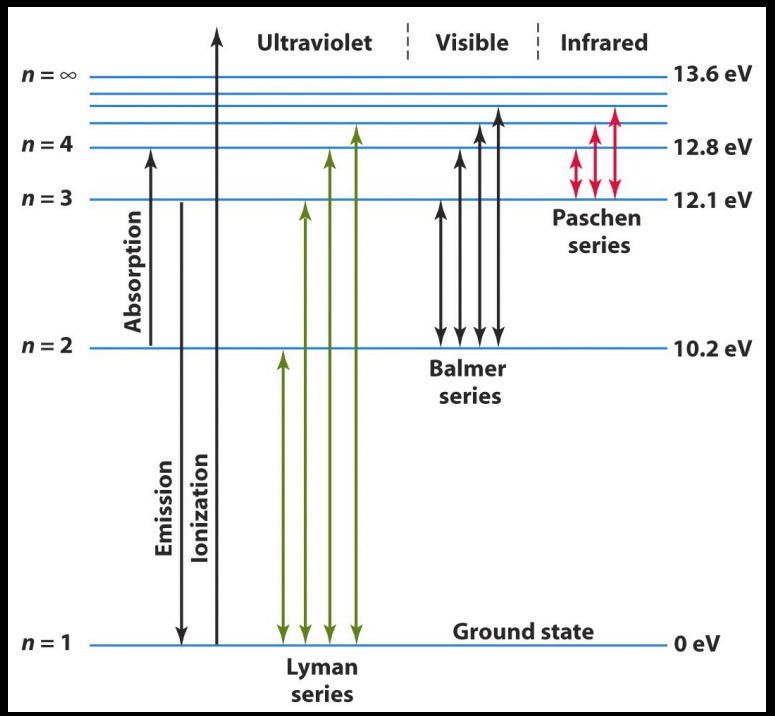
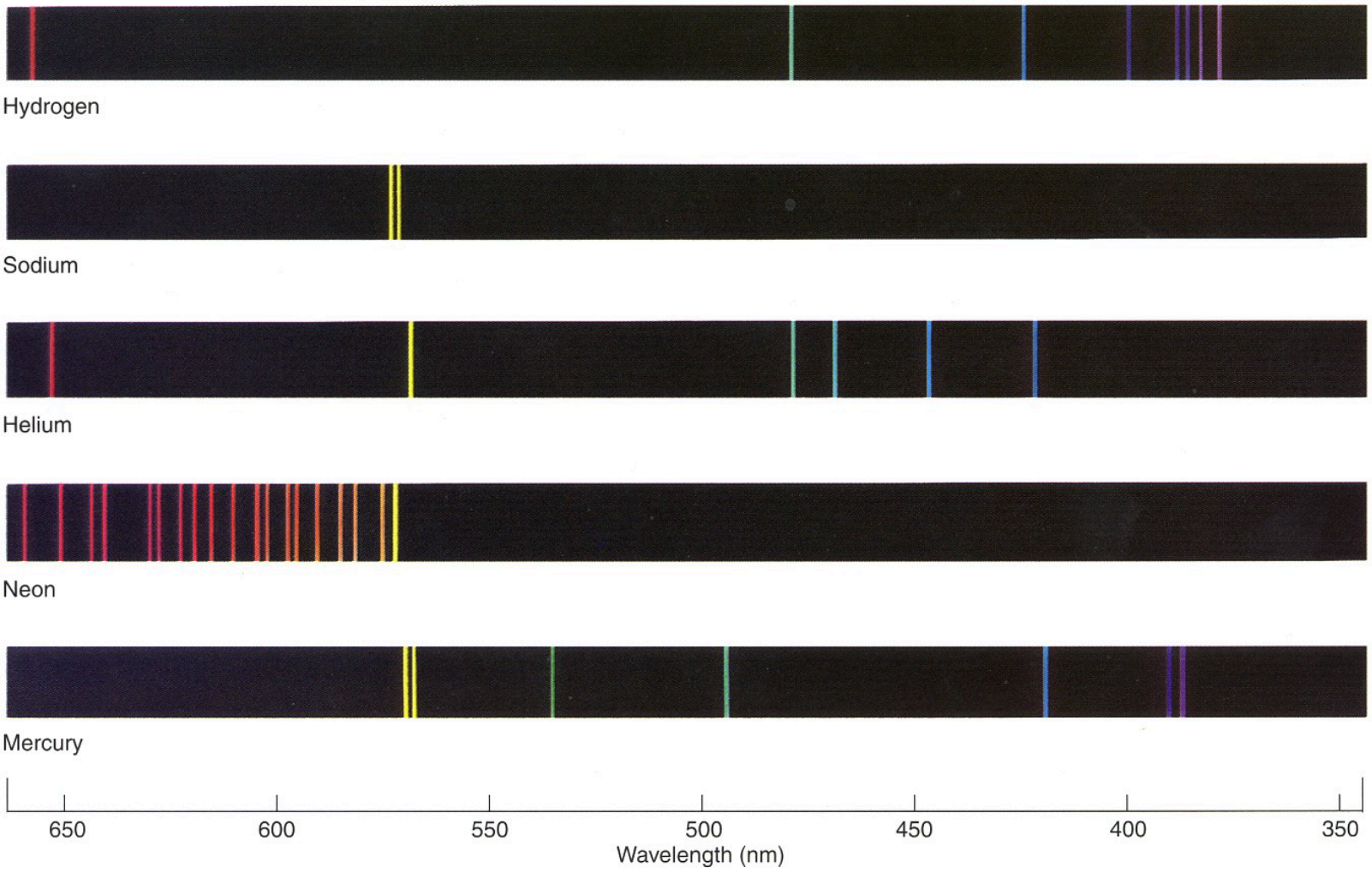


Produce photons with an energy equal to the difference in electron energy levels



The elemental lines

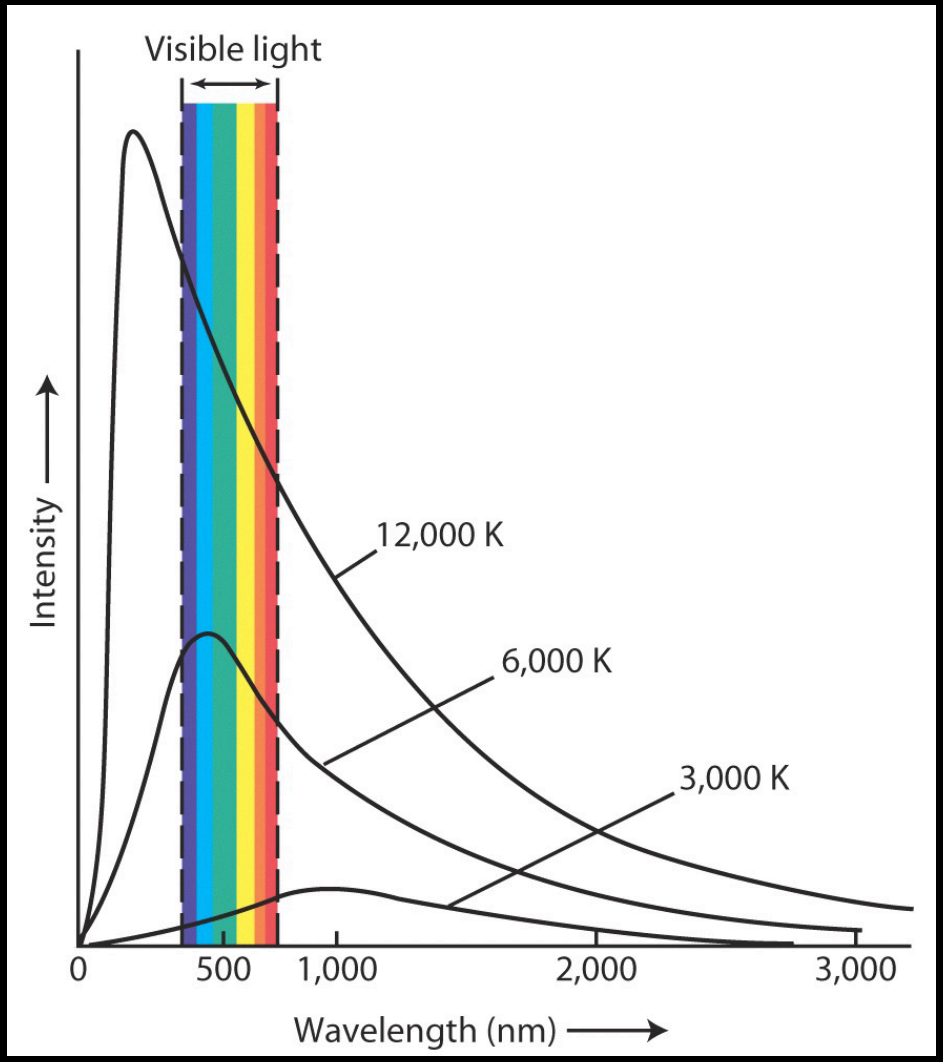


At the molecular level…

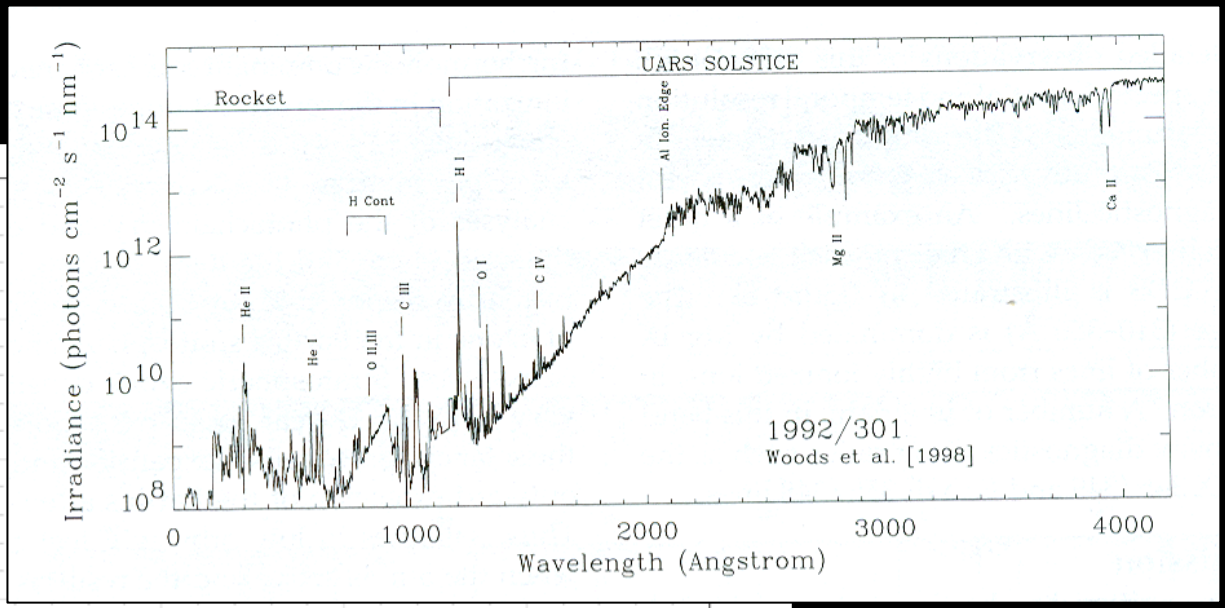
- Molecules have three types of energy levels - electronic, vibrational, and rotational
  - Transitions between electronic levels occur mainly in the ultraviolet
  - Transitions between vibrational levels - visible/ near IR
  - Transitions between rotational levels - far IR/mm wave region

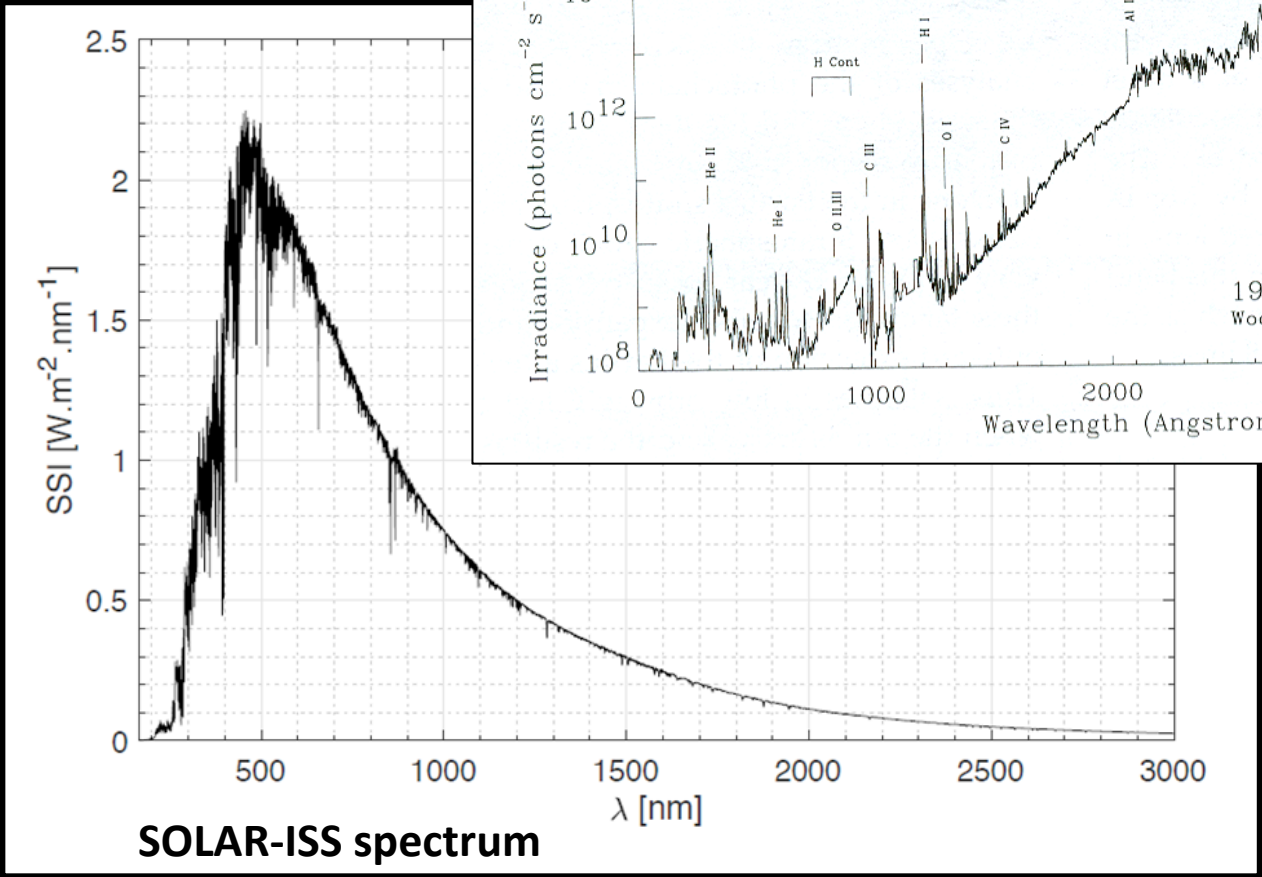
Thermal radiation

- Black-body = idealized object which absorbs all the EM radiation falling on it
- Its emission is solely determined by its temperature
- Stars roughly behave like black-bodies



Solar spectrum

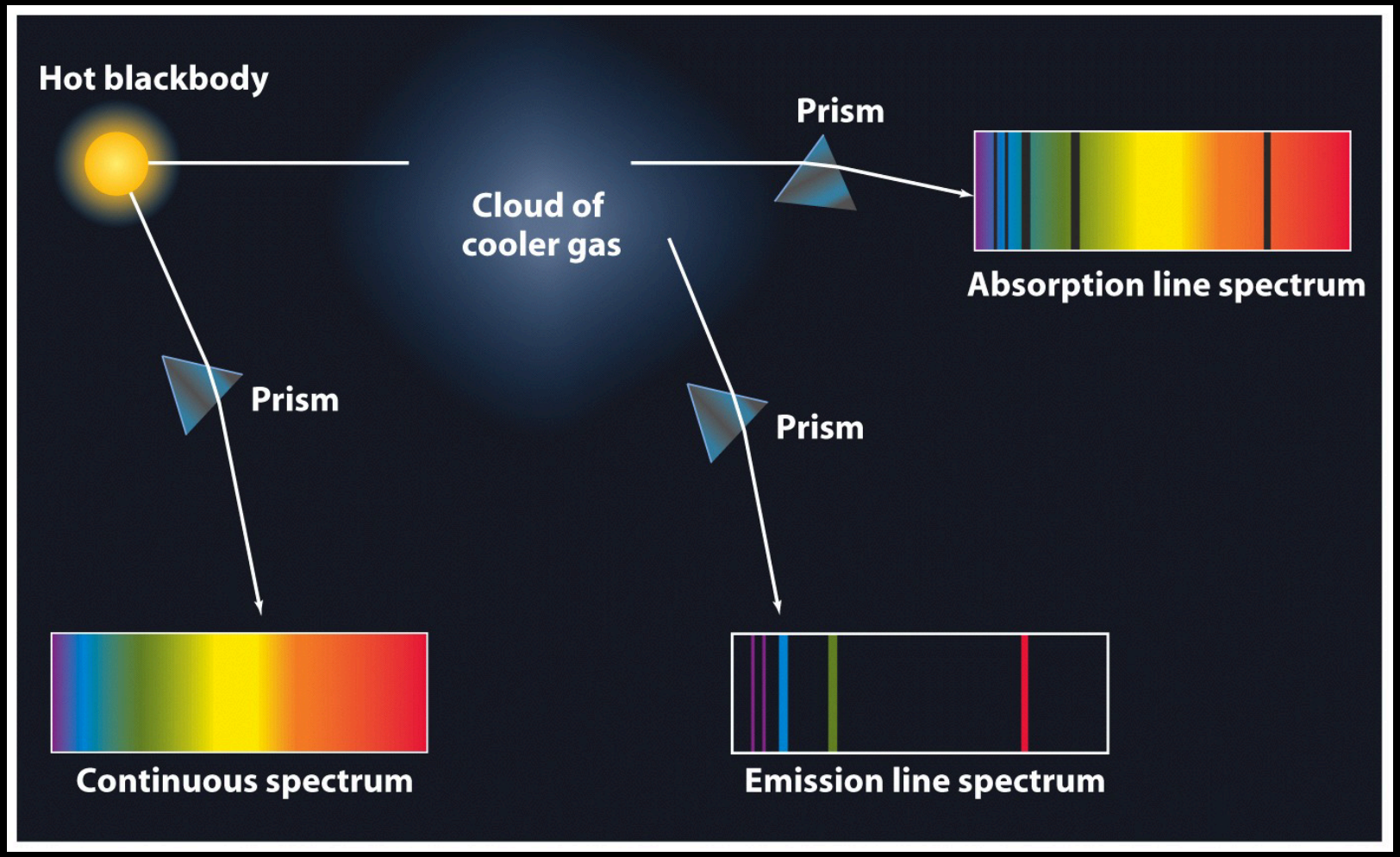




SOLAR-ISS spectrum

Black-body with T = 5762K + emission / absorption lines

Solar spectrum



Spectral line intensity in the solar corona (cfr. Seminar S. Shestov)

Under the hypothesis of

- Optically thin medium
- Ionization equilibrium
- Excitation by collision
- Radiative de-excitation

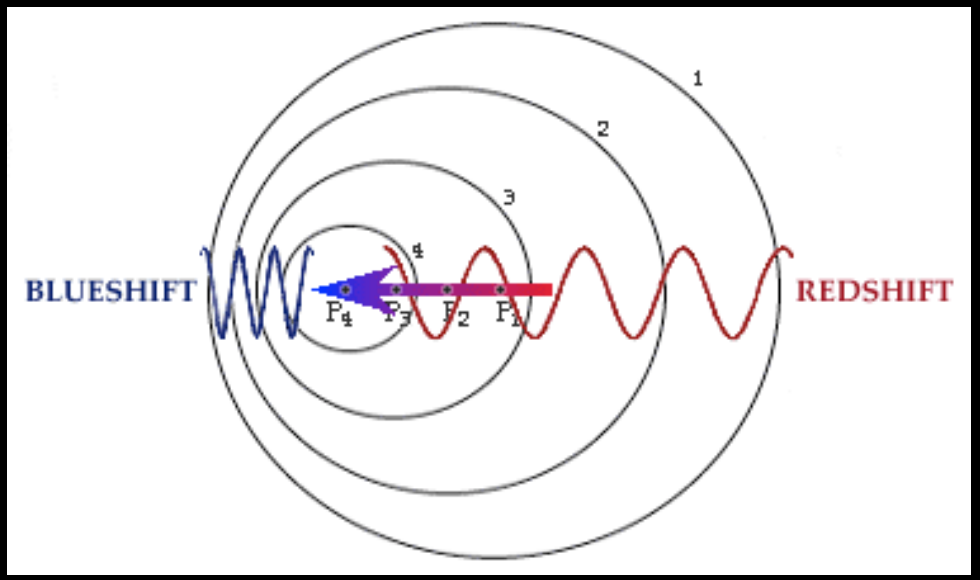
$$I_\lambda \approx A b_X f(T, N_e) A_{ji} N_H N_e$$

Using the intensity of spectral lines, or the ratios of some of them, we can get information about T, Ne

Doppler effect

Doppler effect = change of wavelength (and frequency) which occurs when the source of waves and the observer are in relative motion:

- When the source approaches, the wavelength decreases (blueshift)
- When the source and observer separate from each other, the wavelength increases (redshift).



Line broadening

- Natural broadening:
  Heisenberg principle
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Line broadening

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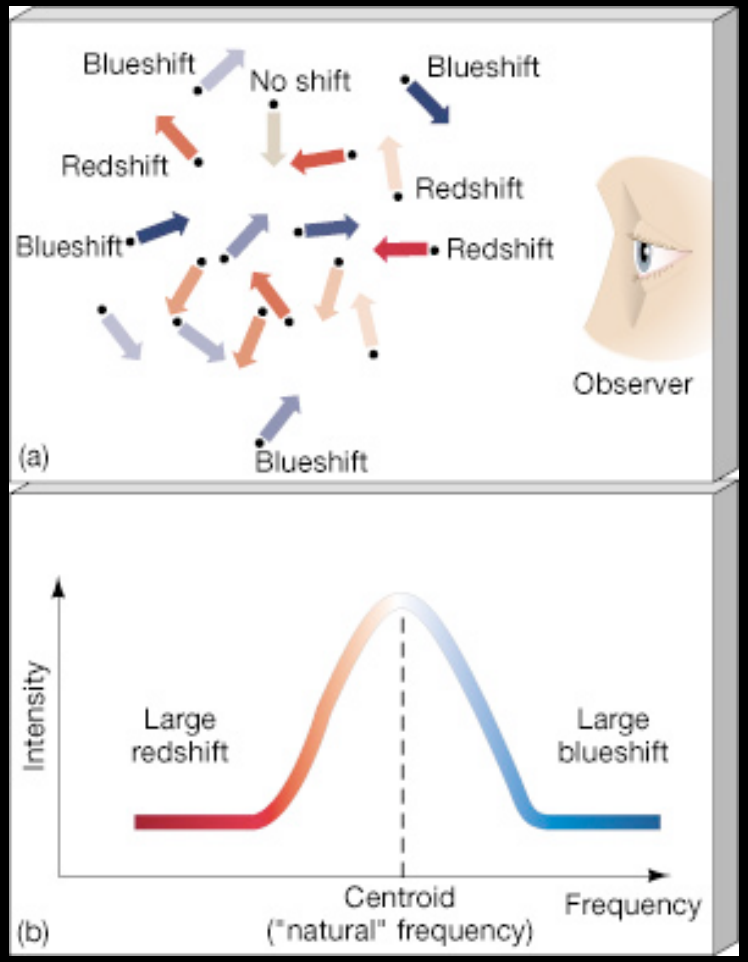
- Thermal Doppler broadening

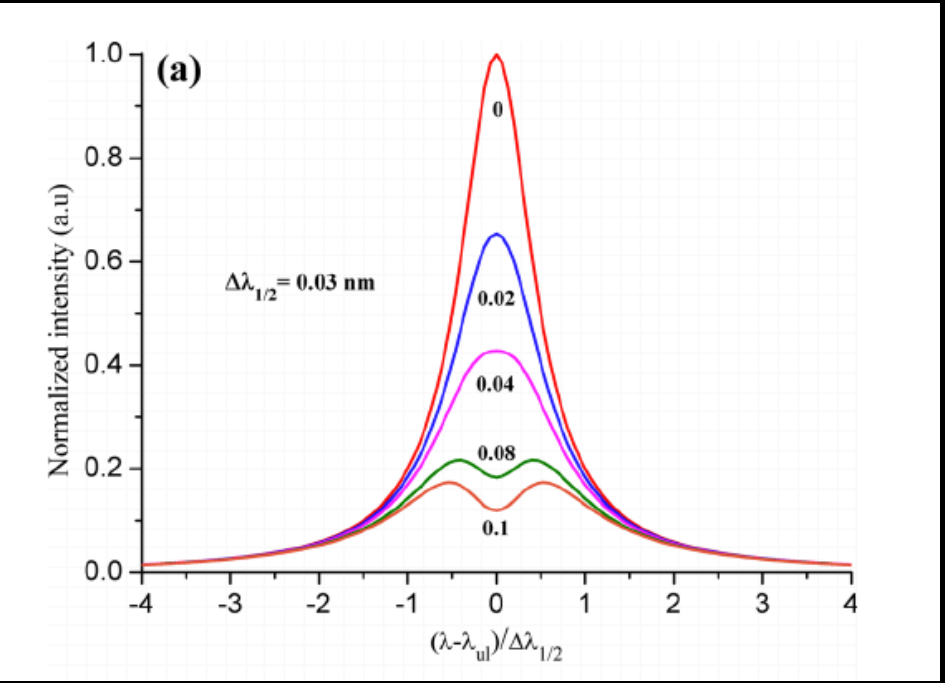


Line broadening

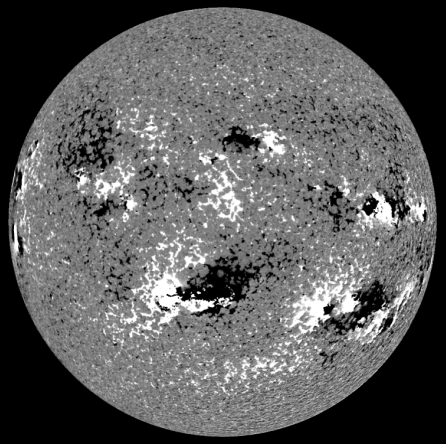
- Natural broadening: Heisenberg principle (very small effect)
- Thermal Doppler broadening
- Pressure broadening

Line broadening

- Natural broadening: Heisenberg principle (very small effect)
- Thermal Doppler broadening
- Pressure broadening
- Opacity broadening

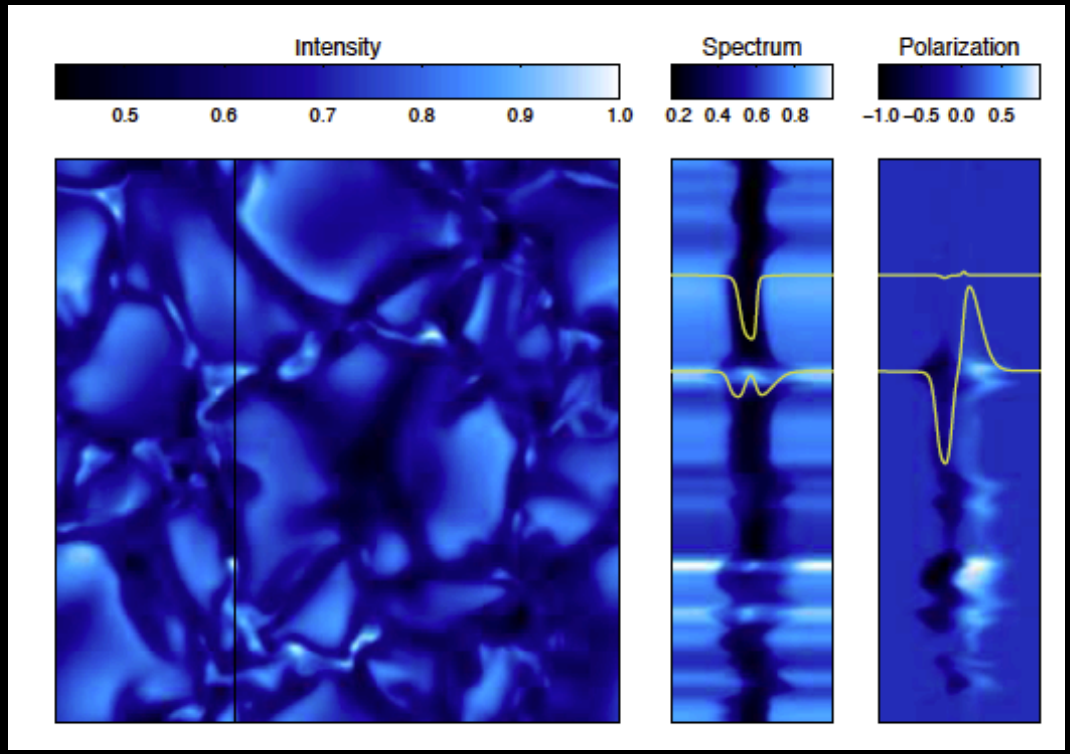


Zeeman Effect



Magnetic fields induce:

- a split of spectral lines
- a specific polarization pattern

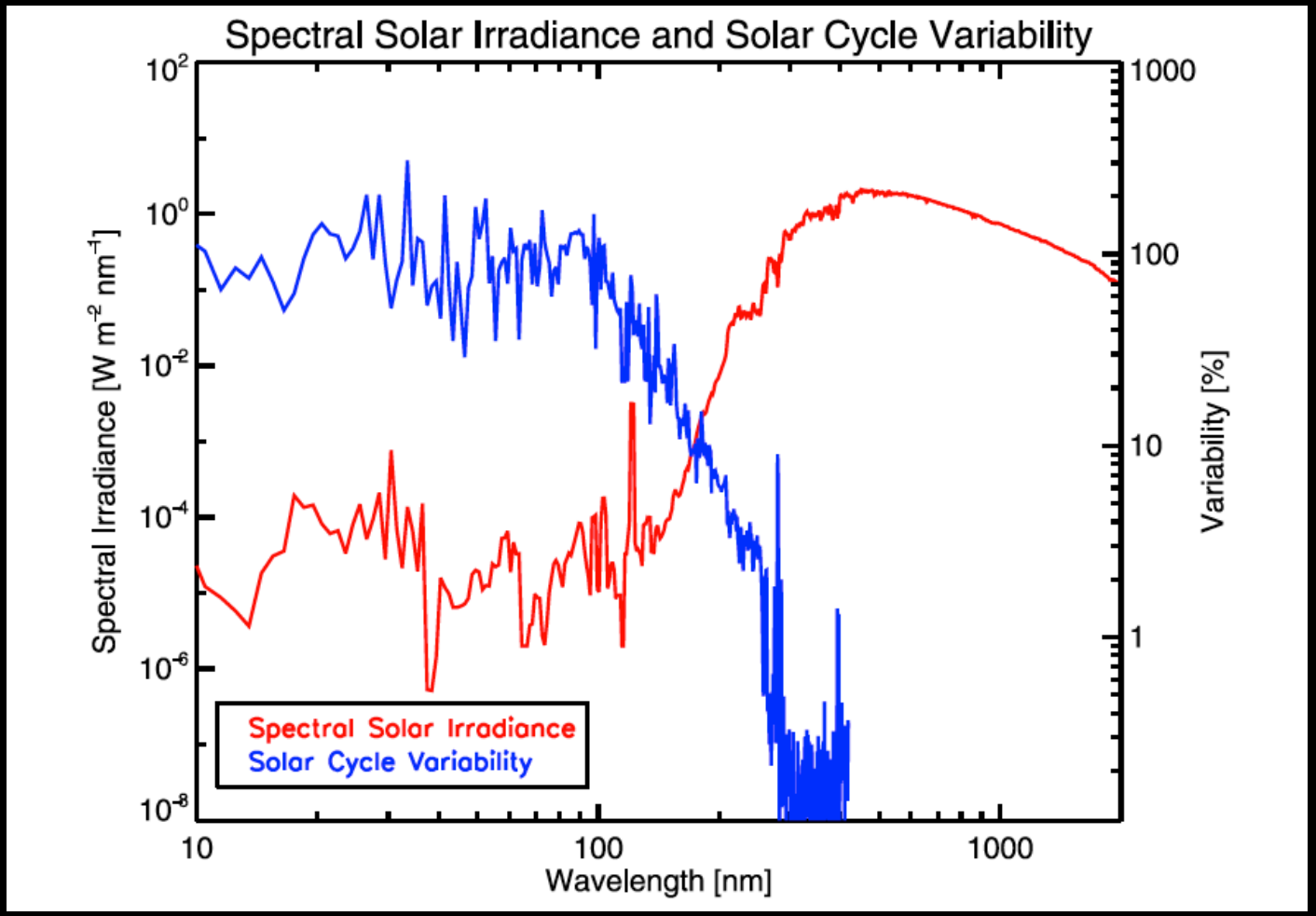


Solar irradiance and its impact on the Earth climate

- Total Solar Irradiance (TSI), i.e. the “solar constant”
  - Major contributor to the Earth’s energy budget

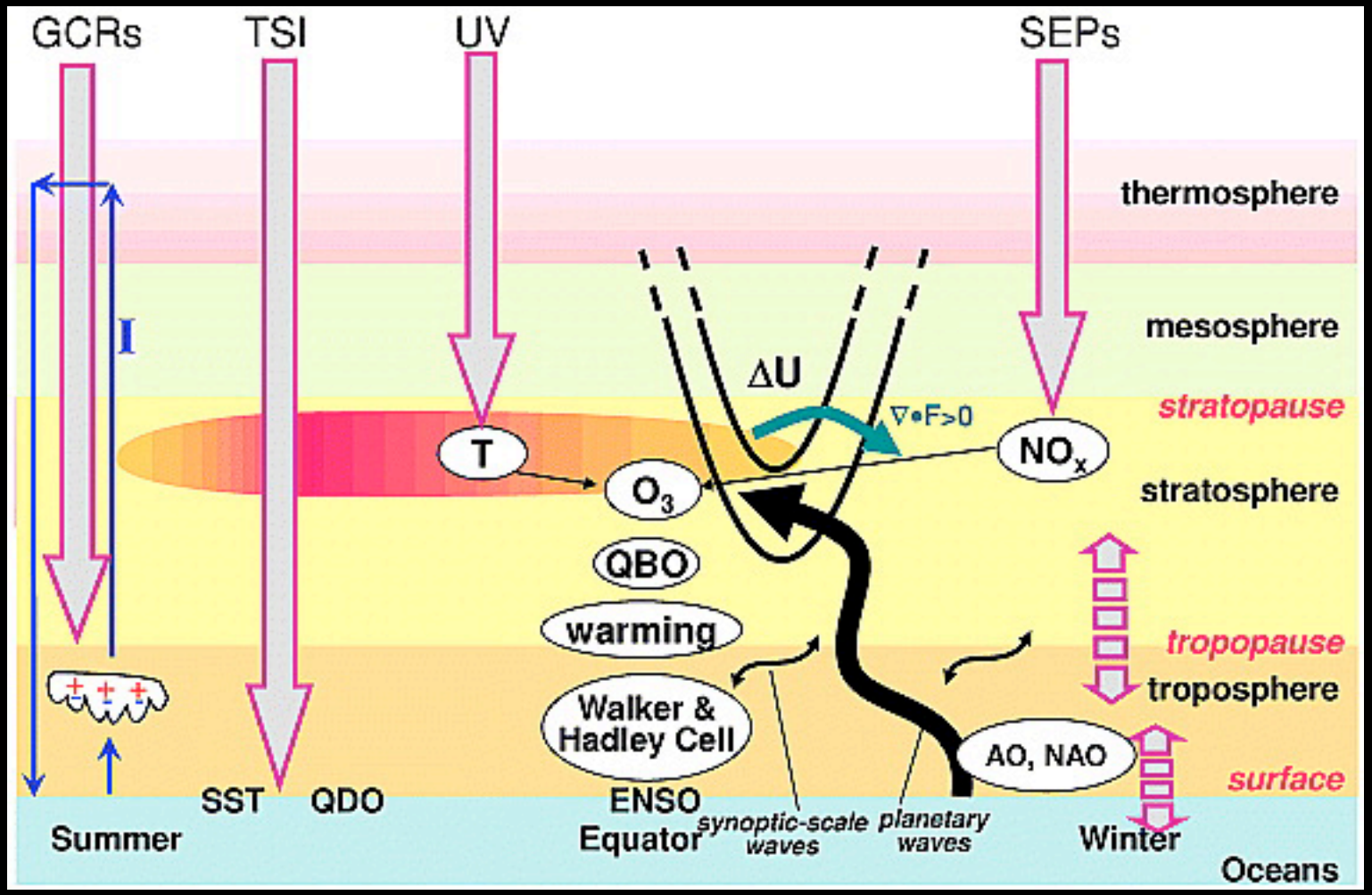
- Spectral solar irradiance (SSI), i.e. the solar spectrum
  - Visible and IR have an impact on the temperature at Earth
  - UV participates to the Ozone production
  - EUV and SXR are at the origin of the ionization processes in the high Earth atmosphere that result in the creation of the ionosphere

Variability



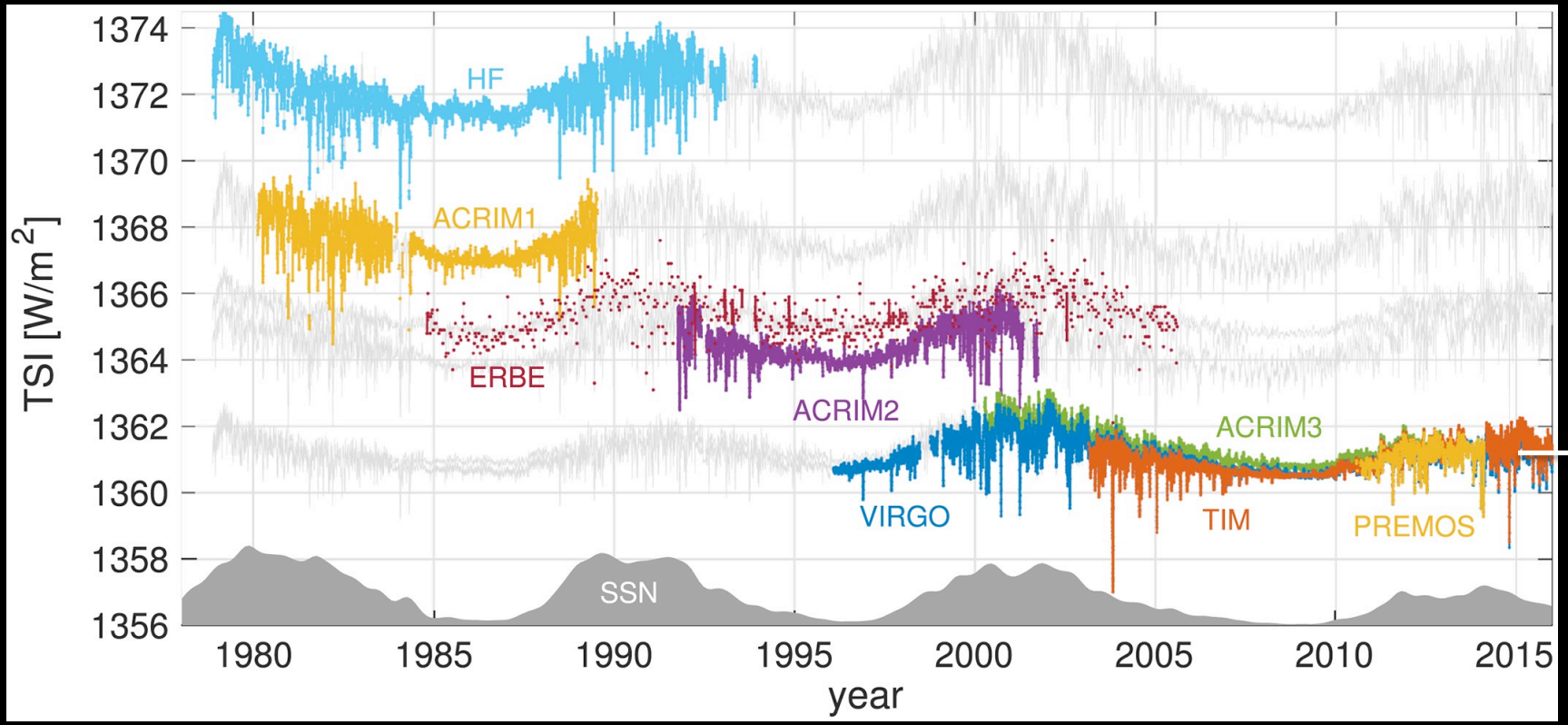
Domingo et al., 2009

Impact on climate



Gray et al. 2010

History of TSI measurements

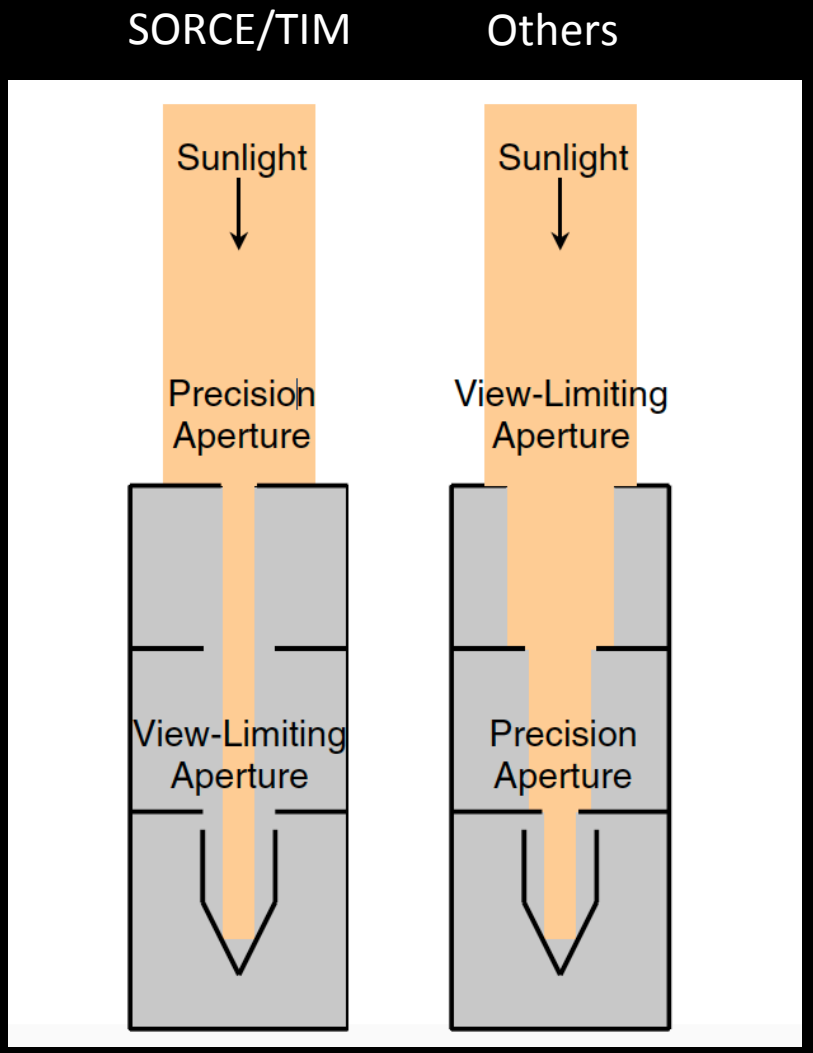


Dudok de Wit et al., 2017

Origin of the discrepancies

- Instrumental origin
- Lack of pre-launch calibration

Since VIRGO, all TSI instruments are calibrated to a common standard reference (the TSI radiometer Facility – TRF – at NIST)



Kopp et al., 2012

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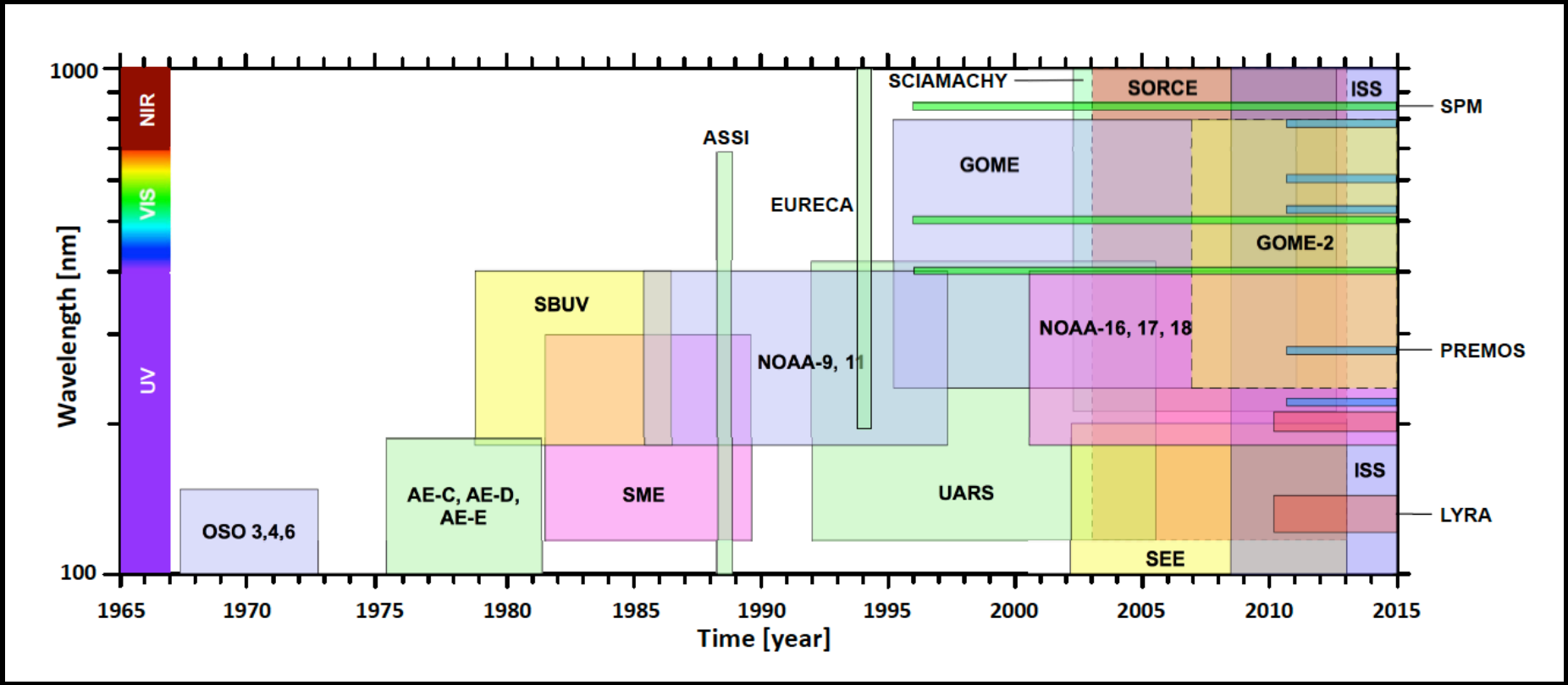
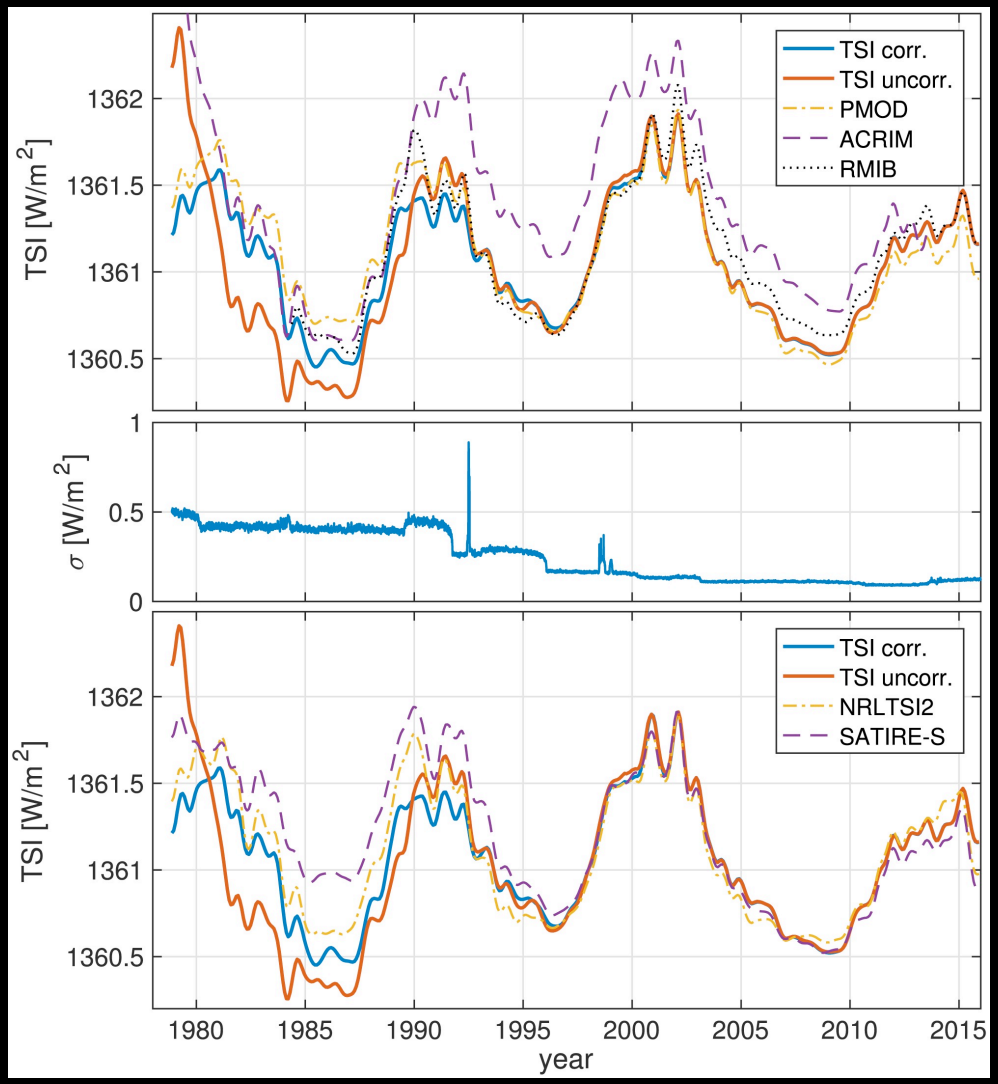


Ermolli et al. 2013

Main composites and models

- Historically 3 main TSI composites:
  - ACRIM (USA)
  - PMOD (Switzerland)
  - RMIB (Belgium)
- Main difference: the long-term trend
- Problem: based on specific instruments
- Recent attempts to conciliate them

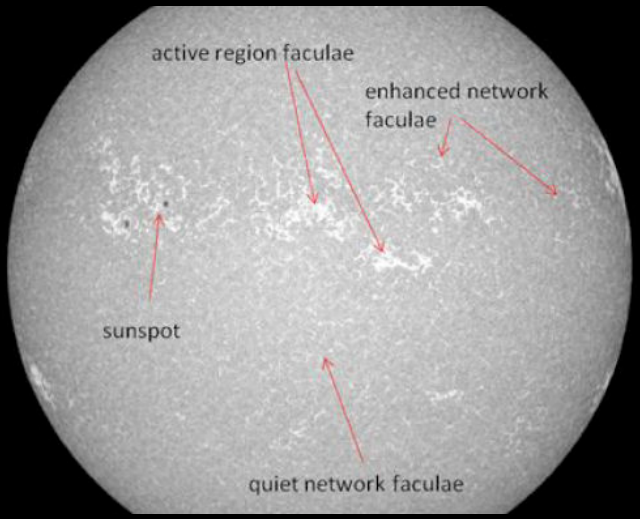


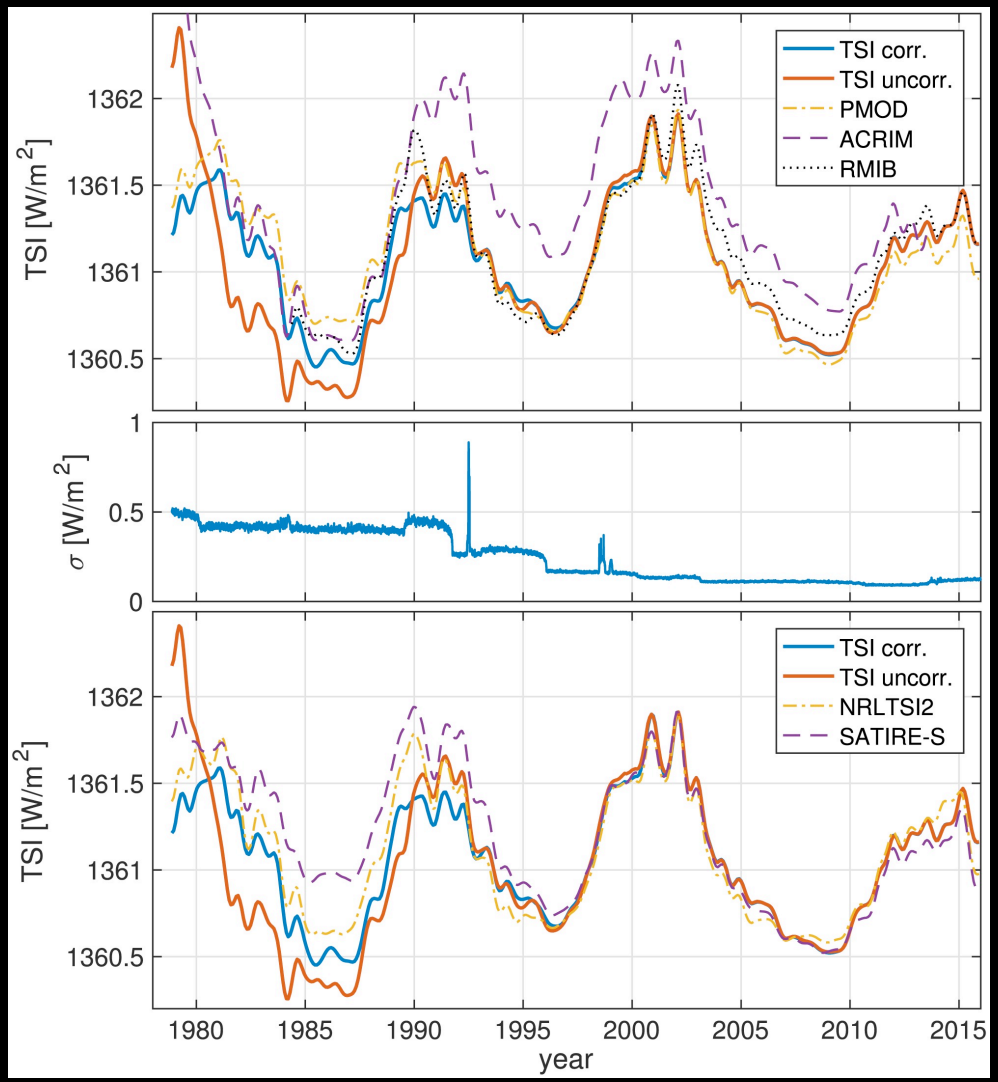
Dudok de Wit et al., 2017

Main composites and models

- Models are mainly based on the variations of the surface magnetic field
- Two families of models:
  - Proxy models
  - Physics-based

    e.g. SATIRE, COSI, SRPM, OAR



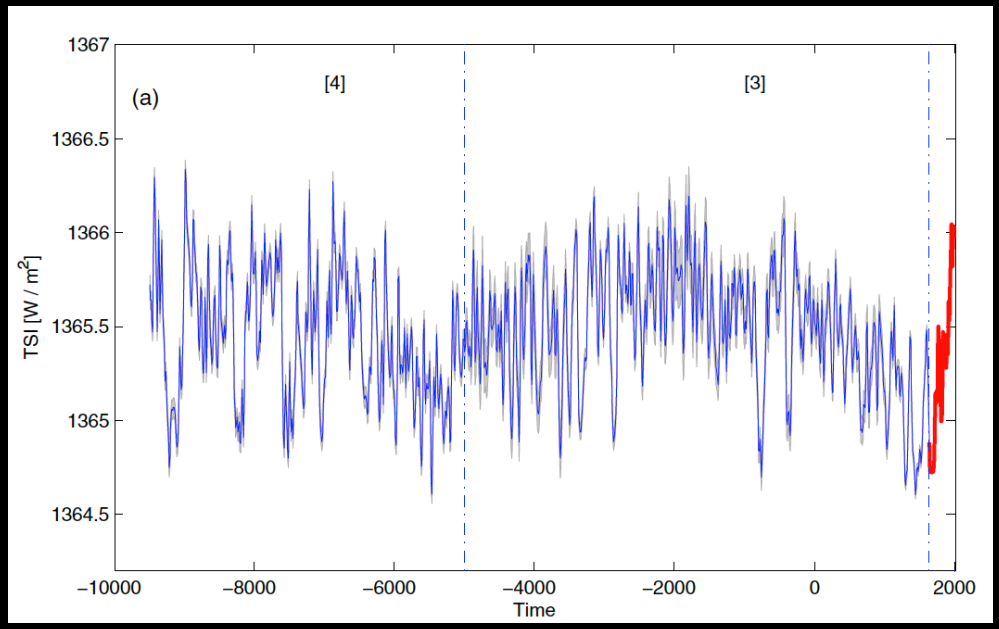


Dudok de Wit et al., 2017

Models over the long-term

- Attempts of reconstruction over the whole Holocene
- Need to rely on different magnetic field proxies over time.
- For example:
  - After 1974: Magnetograms/ continuum images
  - 1878-1974: Sunspot Area
  - 1700-1878: Sunspot Number
  - Before 1700: cosmogenic isotops

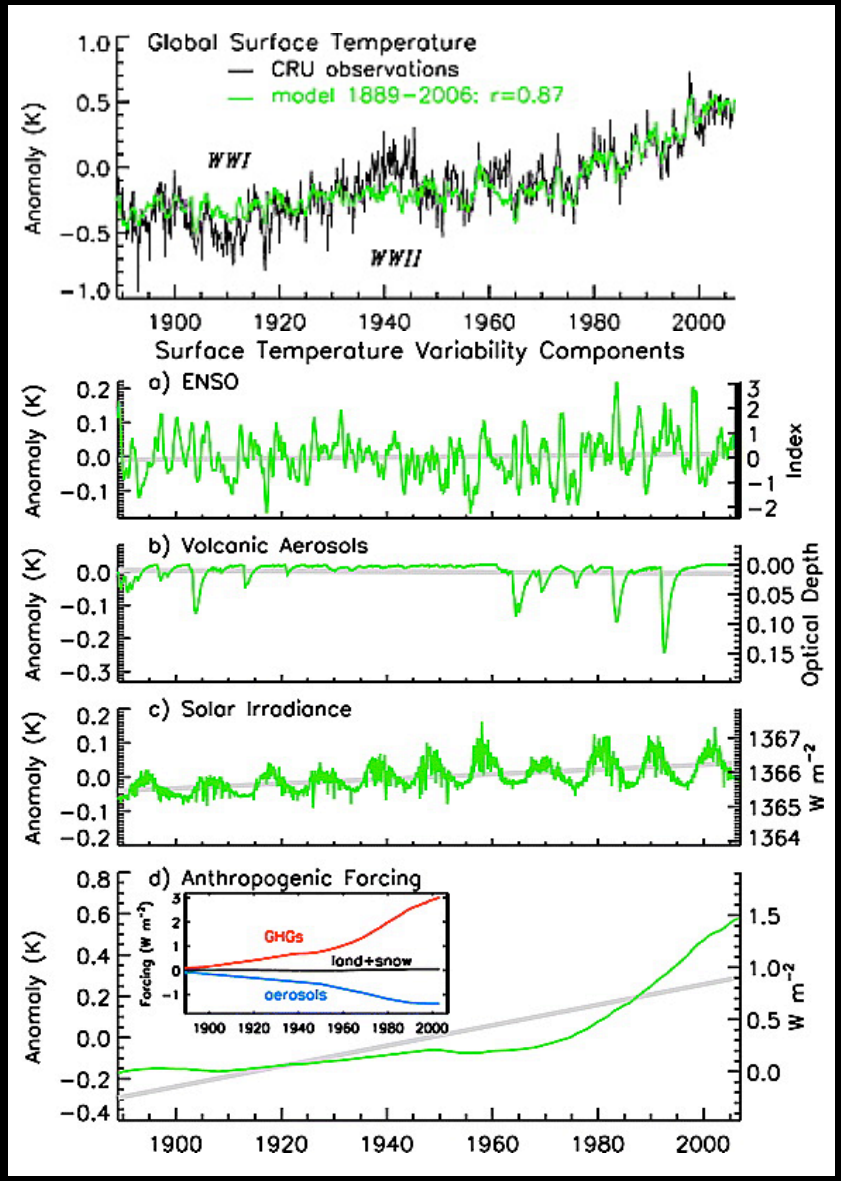
Recent attempts to use probabilistic approaches with multiple proxies: the SOLID project



Vieira et al., 2011

Impact on climate

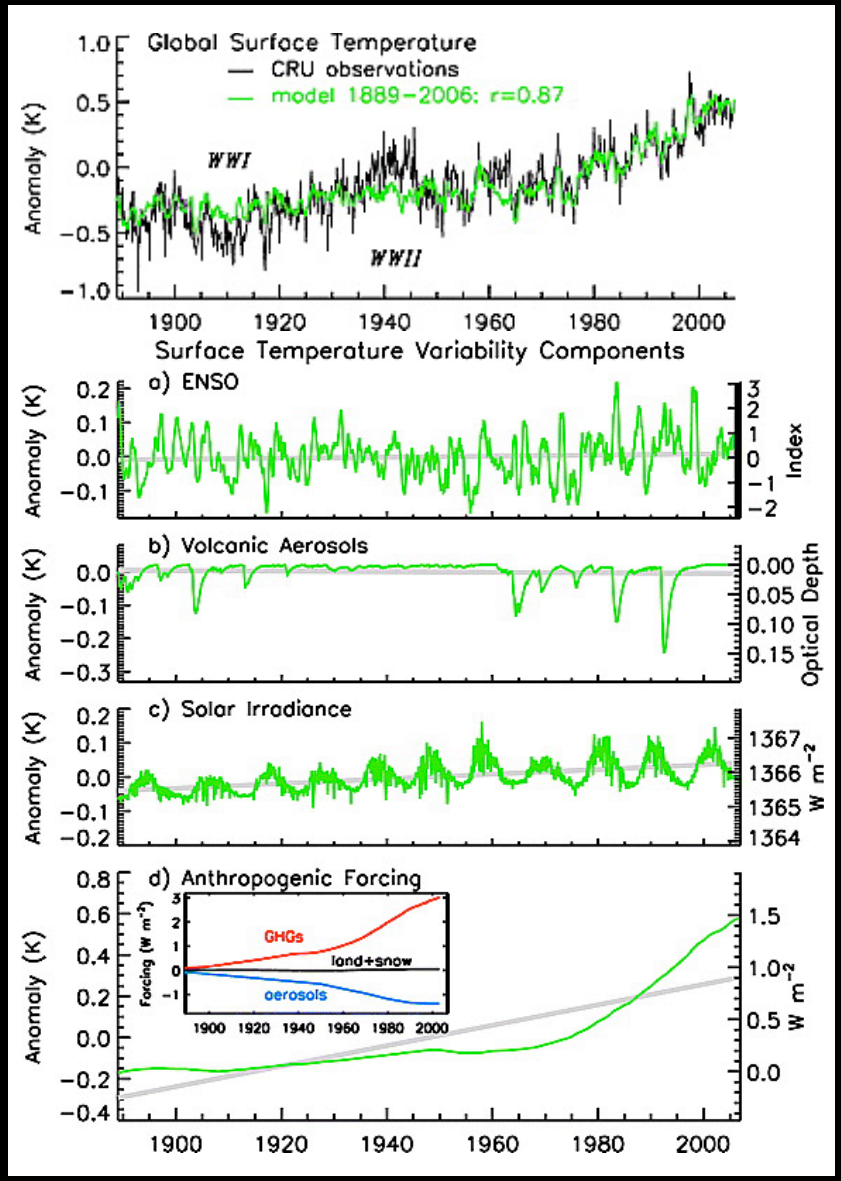
- Increase of the temperature at the Earth surface of ~1K over the century
- Max contribution of the solar irradiance: 0.07K before 1960
- Impossibility to reproduce the recent global warming using solar data only



Lean and Rind, 2008

Impact on climate

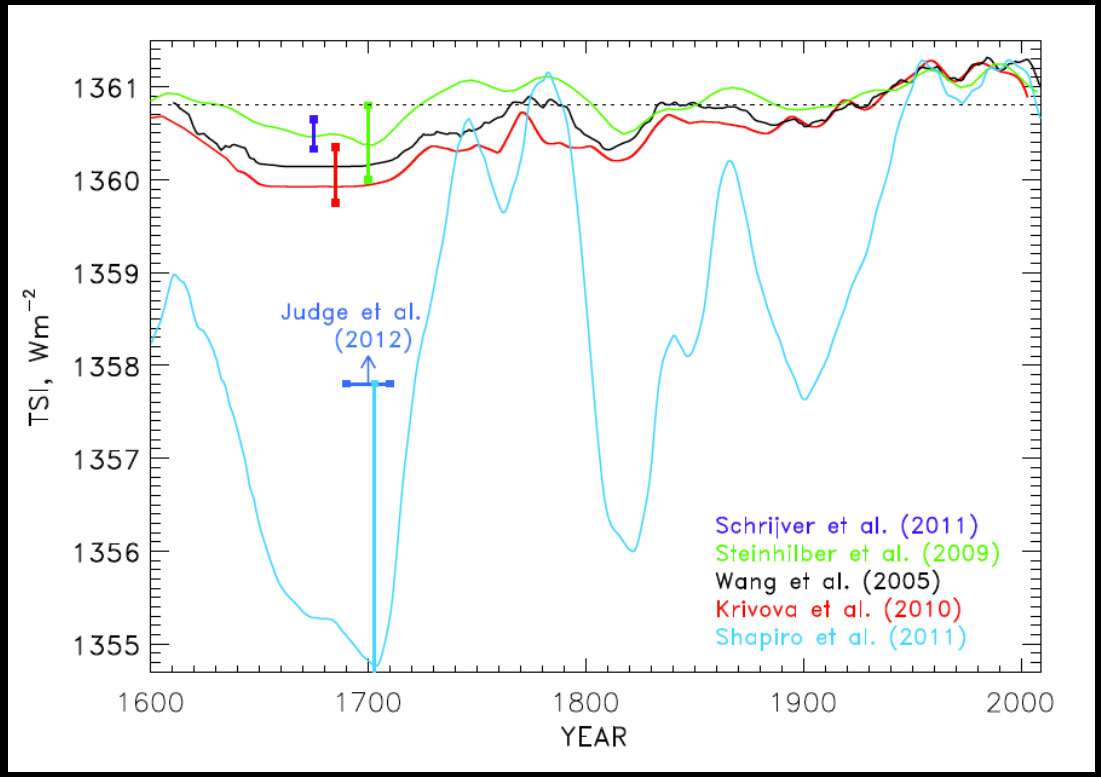
- At the solar cycle scale:
  - Local impacts a the ground level
  - Variations of up to 1.5K found in the stratosphere
  - Impacts on the cloudiness, winds, Ozone



Lean and Rind, 2008

Modeled trend since Maunder minimum

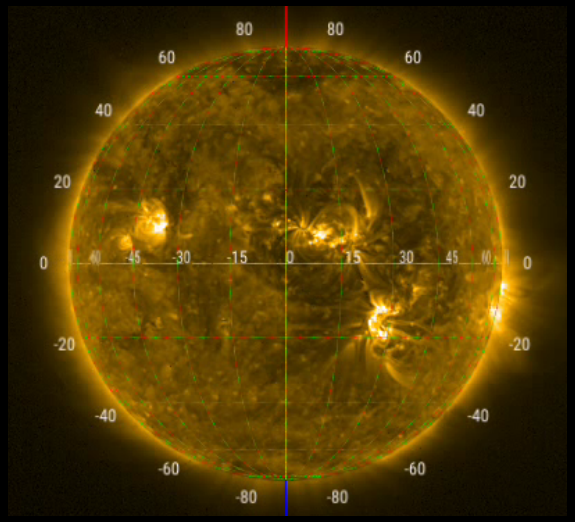
- Huge differences between the models (modeled increase between 0.8 and 3 Wm^{-2})
- Significantly impacts our estimation of the solar contribution to climate

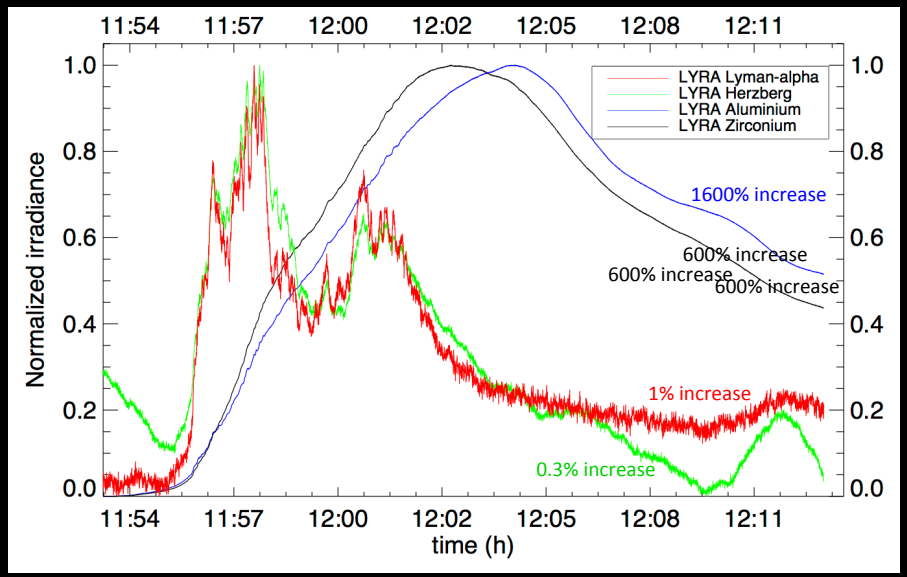


Solanki et al., 2013

And on the shortest terms?

- Spectral irradiance also significantly varies over the shortest term: flares
- Strong dependence on the wavelength:
  - Several orders of magnitude in the SRX-EUV
  - Max 0.1% in the visible





X9.3 flare of 6 September 2017 observed by SWAP and LYRA aboard PROBA2

To go further:
Solar Irradiance Variability and Climate, Solanki, Krivova and Haigh, 2013

Questions?