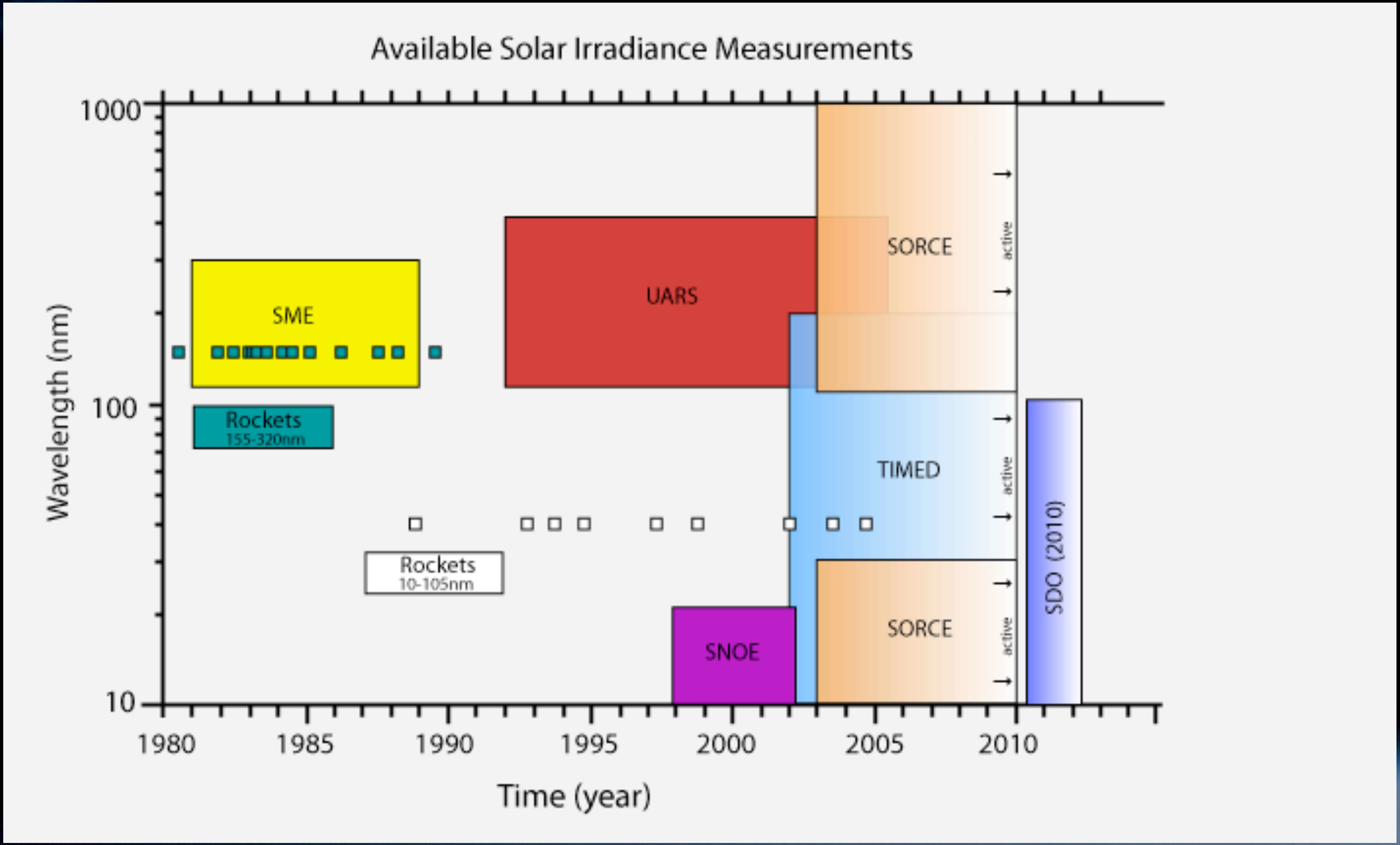
Use of PREMOS & LYRA for the reconstruction of the UV spectrum

T. Dudok de Wit, G. Cessateur, M. Kretzschmar, L. Vieira
(LPC2E, Orléans)
J. Lilensten
(LPG, Grenoble)

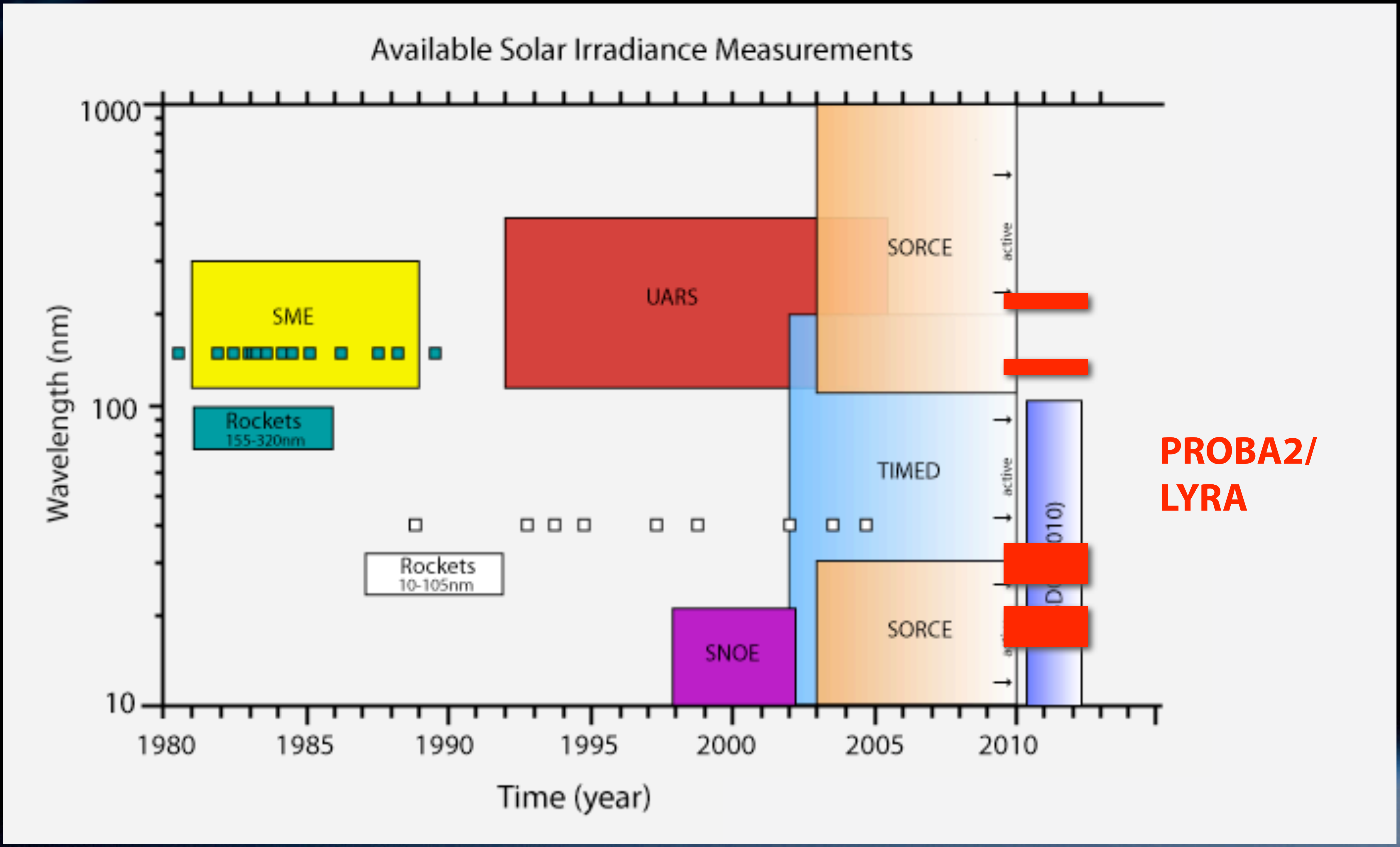
+ special thanks to the instrument teams (TIMED/SEE, SORCE/SIM, PROBA2/LYRA, ground-based instruments)

Solar spectral irradiance measurements



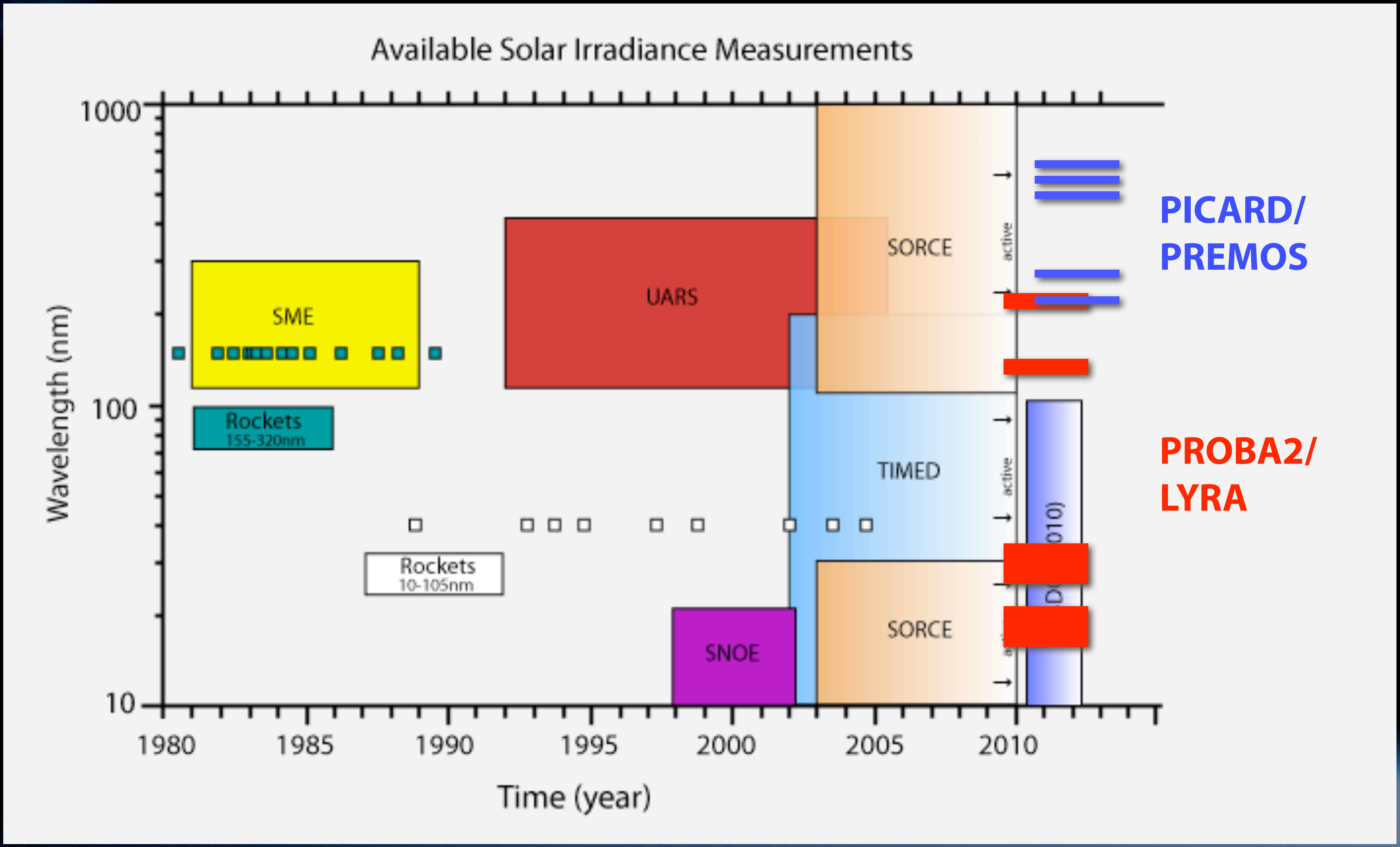
LASP, Boulder

Solar spectral irradiance measurements

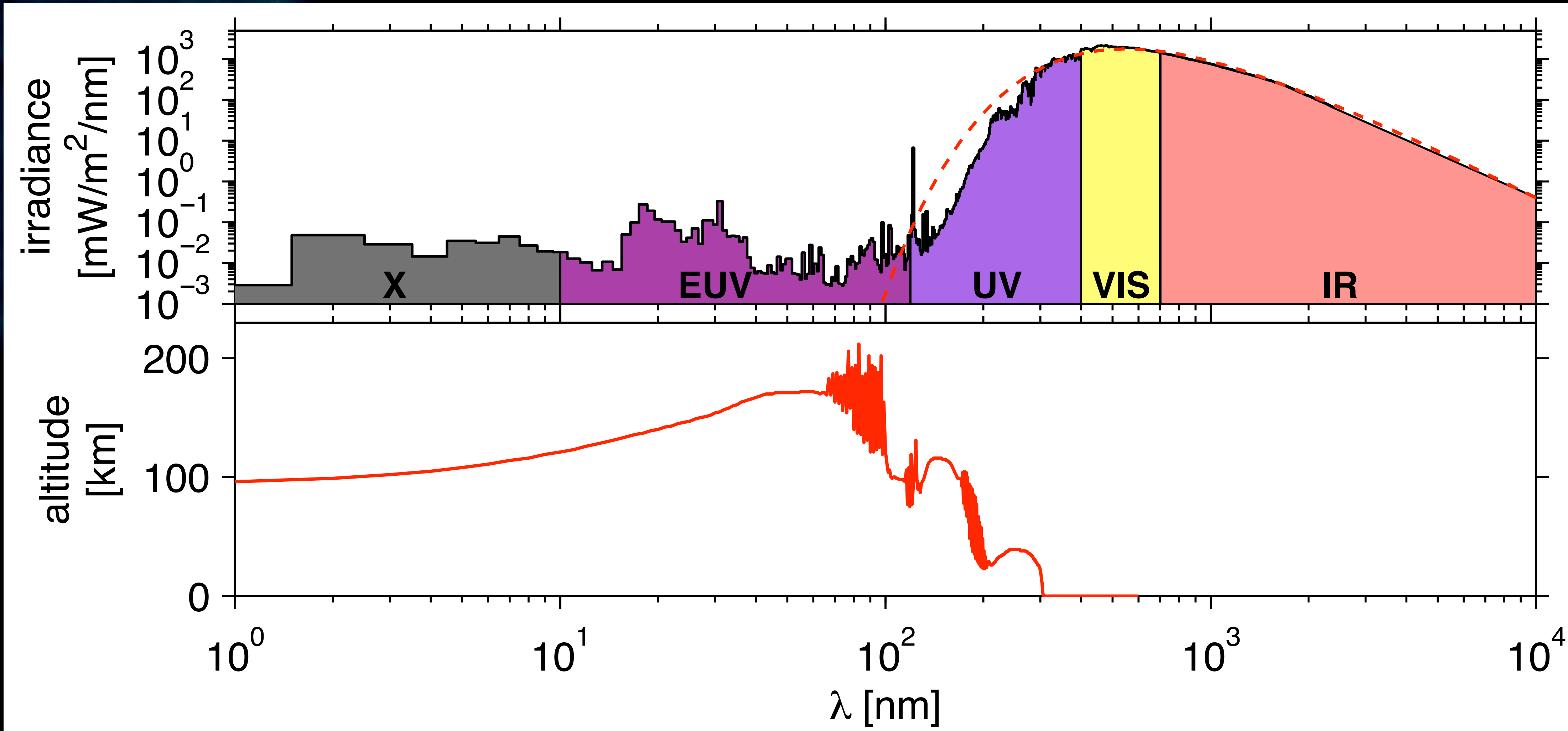


LASP, Boulder

Solar spectral irradiance measurements



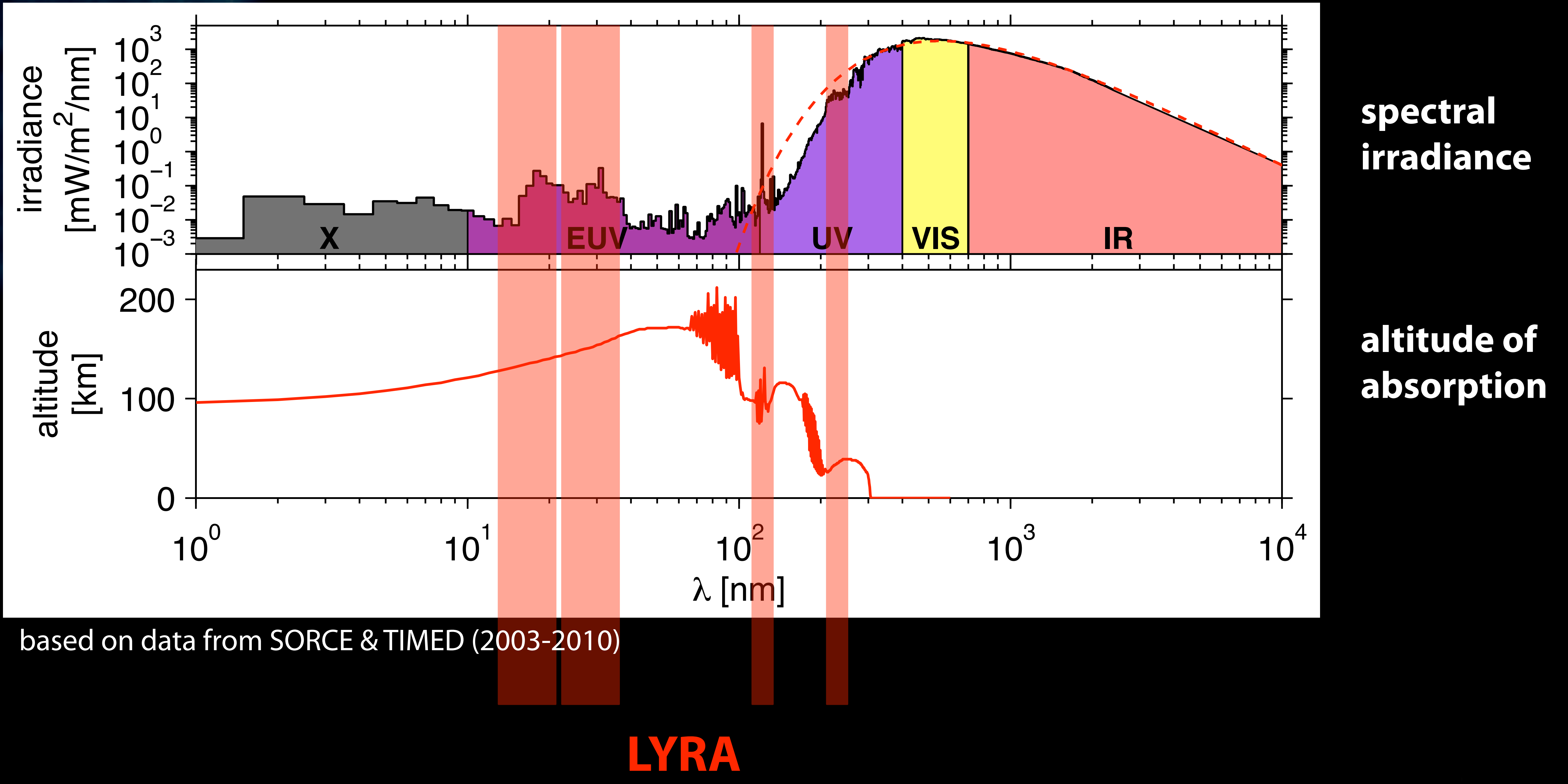
LASP, Boulder



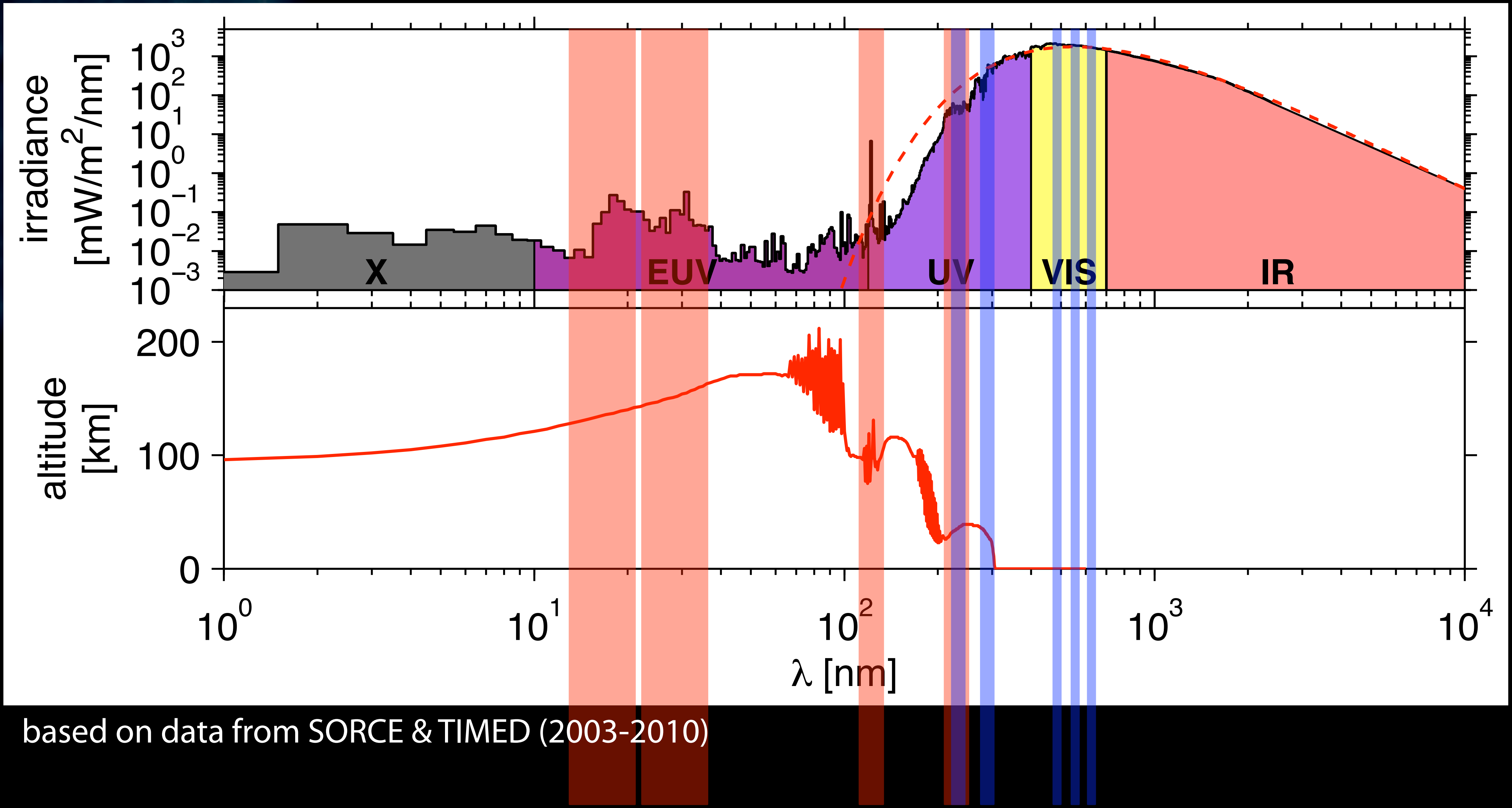
spectral irradiance

altitude of absorption

based on data from SORCE & TIMED (2003-2010)



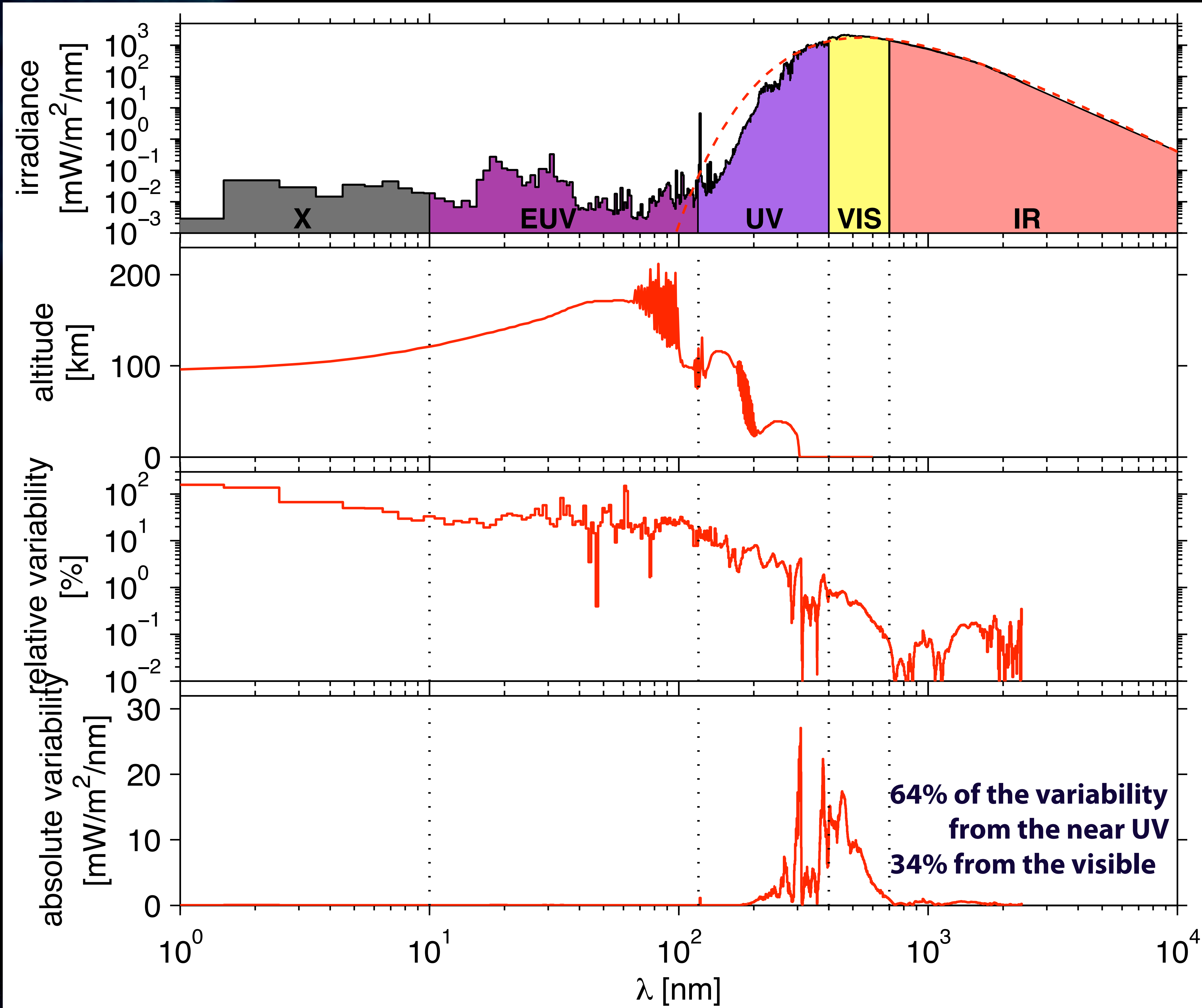
based on data from SORCE & TIMED (2003-2010)



based on data from SORCE & TIMED (2003-2010)

LYRA **PREMOS**

215 nm
266 nm
536 nm
607 nm
782 nm



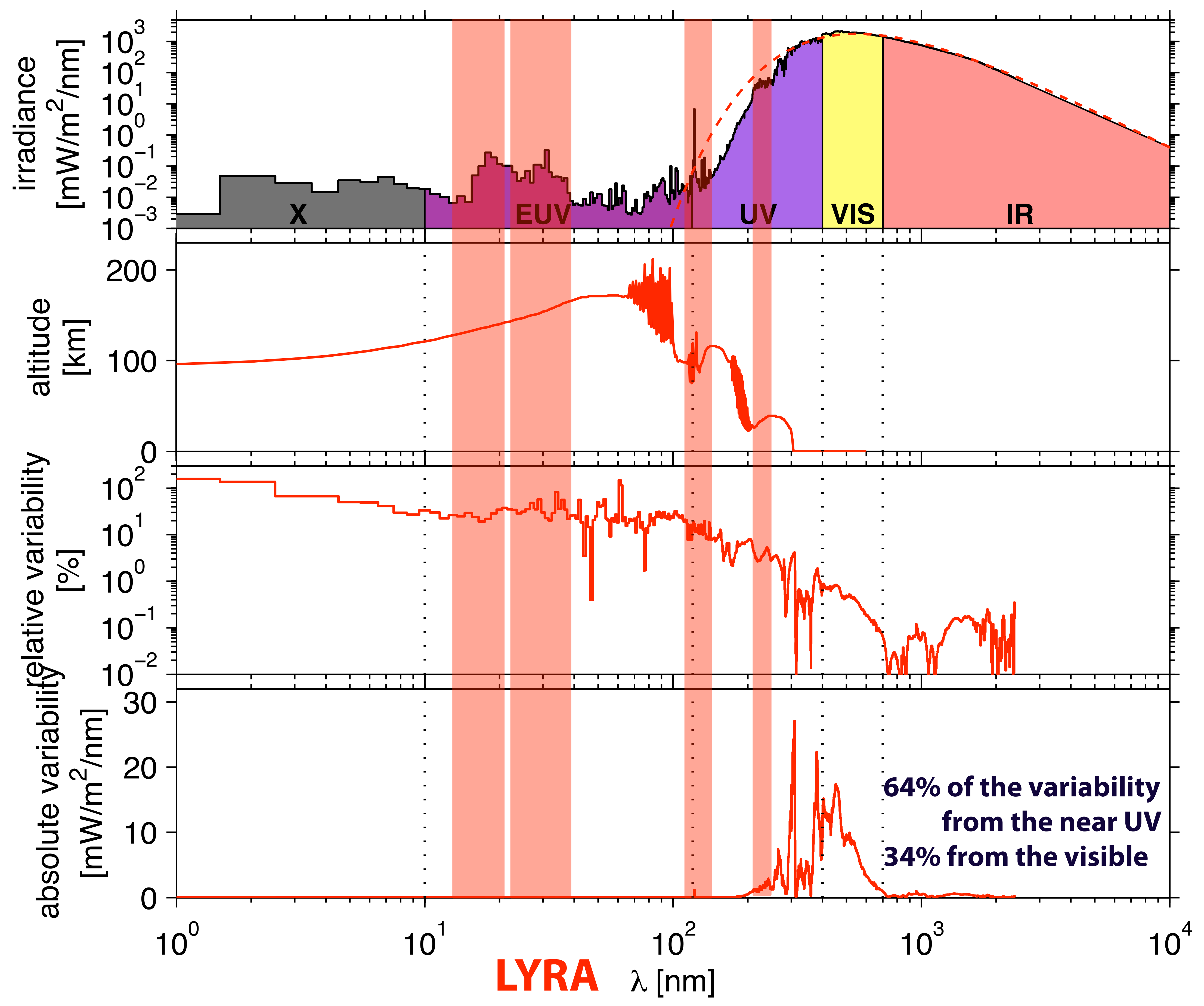
spectral irradiance

altitude of absorption

relative variability (solar cycle)

absolute variability (solar cycle)

based on data from SORCE & TIMED (2003-2010)



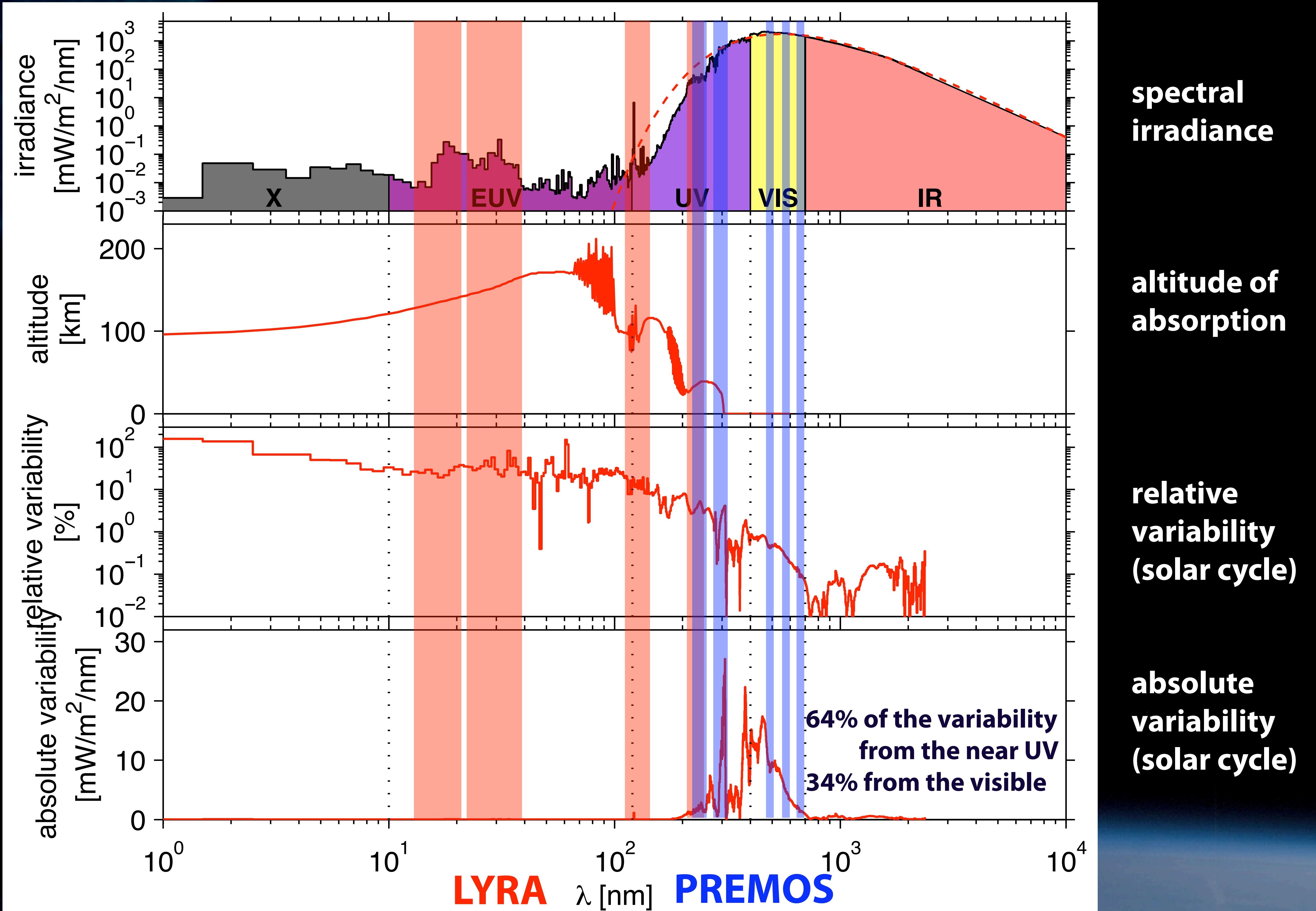
spectral irradiance

altitude of absorption

relative variability (solar cycle)

absolute variability (solar cycle)

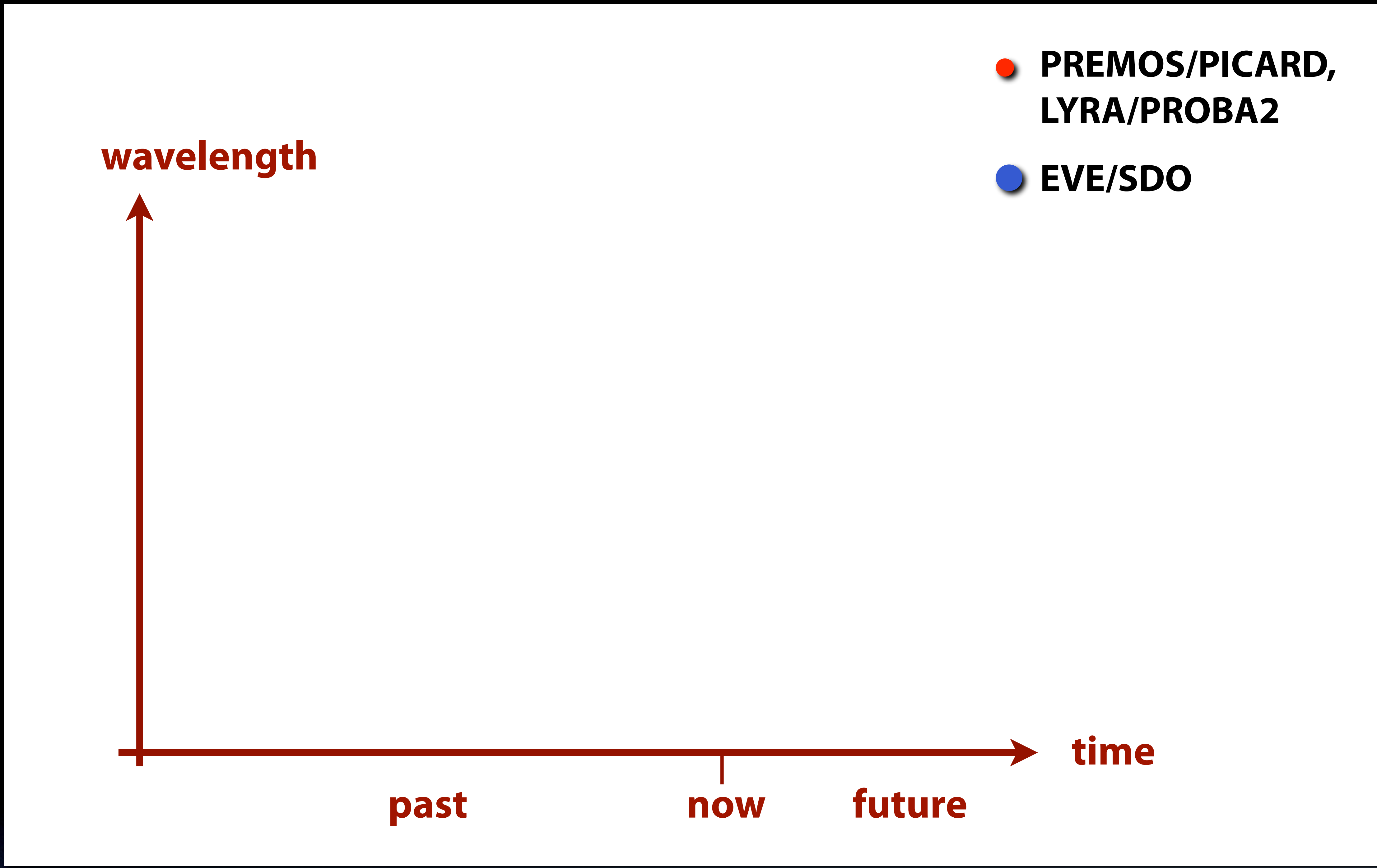
based on data from SORCE & TIMED (2003-2010)



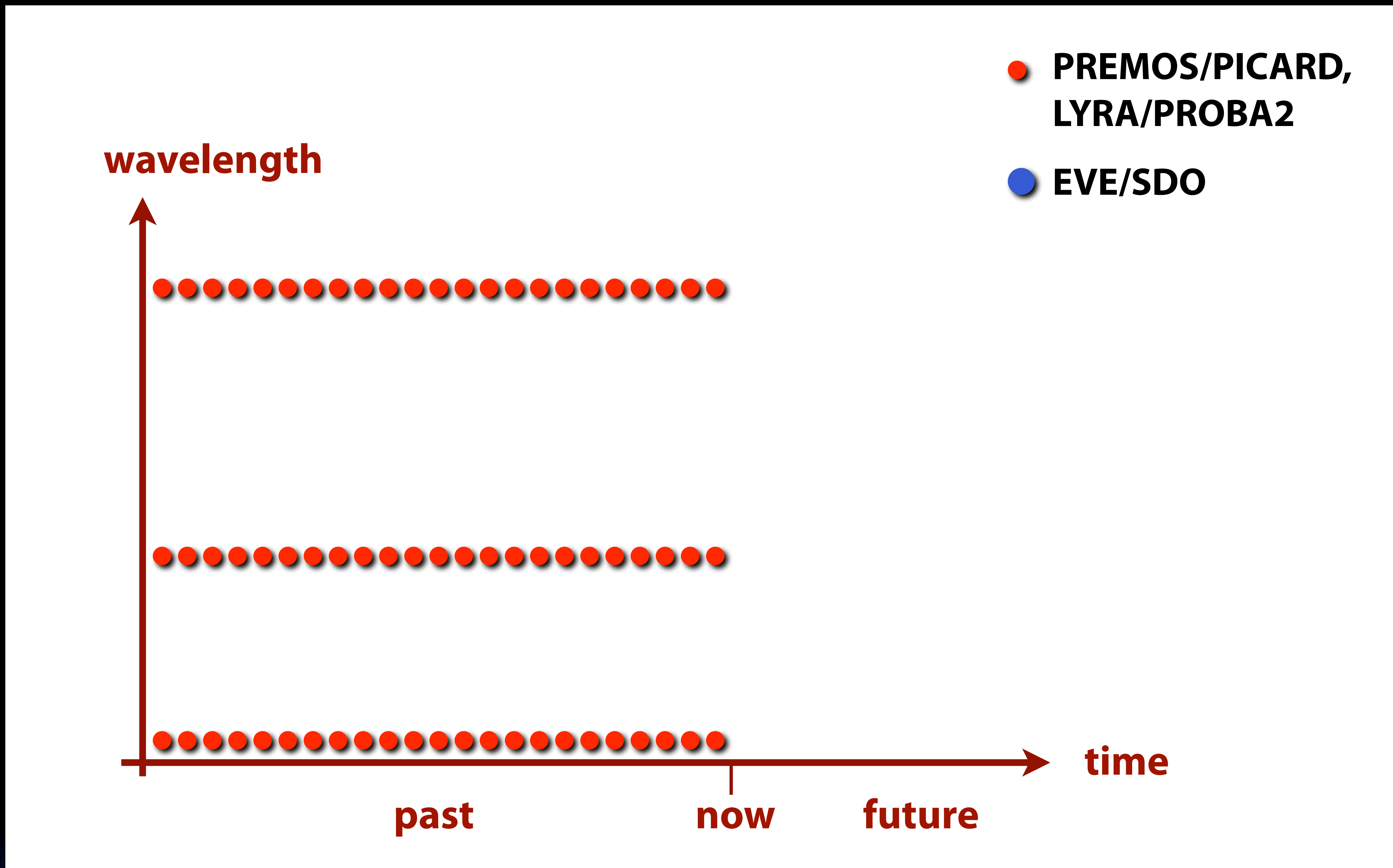
based on data from SORCE & TIMED (2003-2010)

Our problem :
interpolate the spectral irradiance

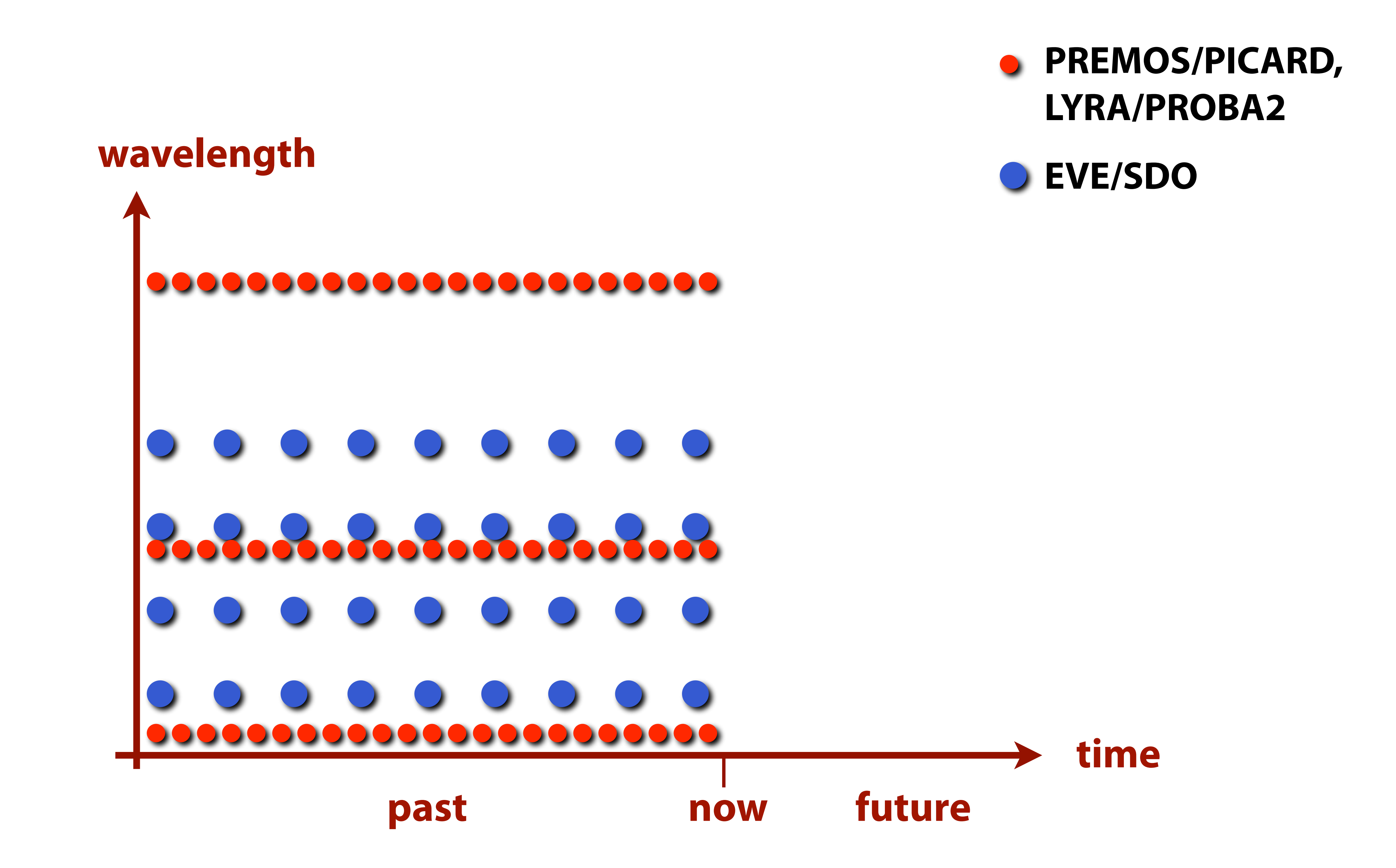
Our problem :
interpolate the spectral irradiance



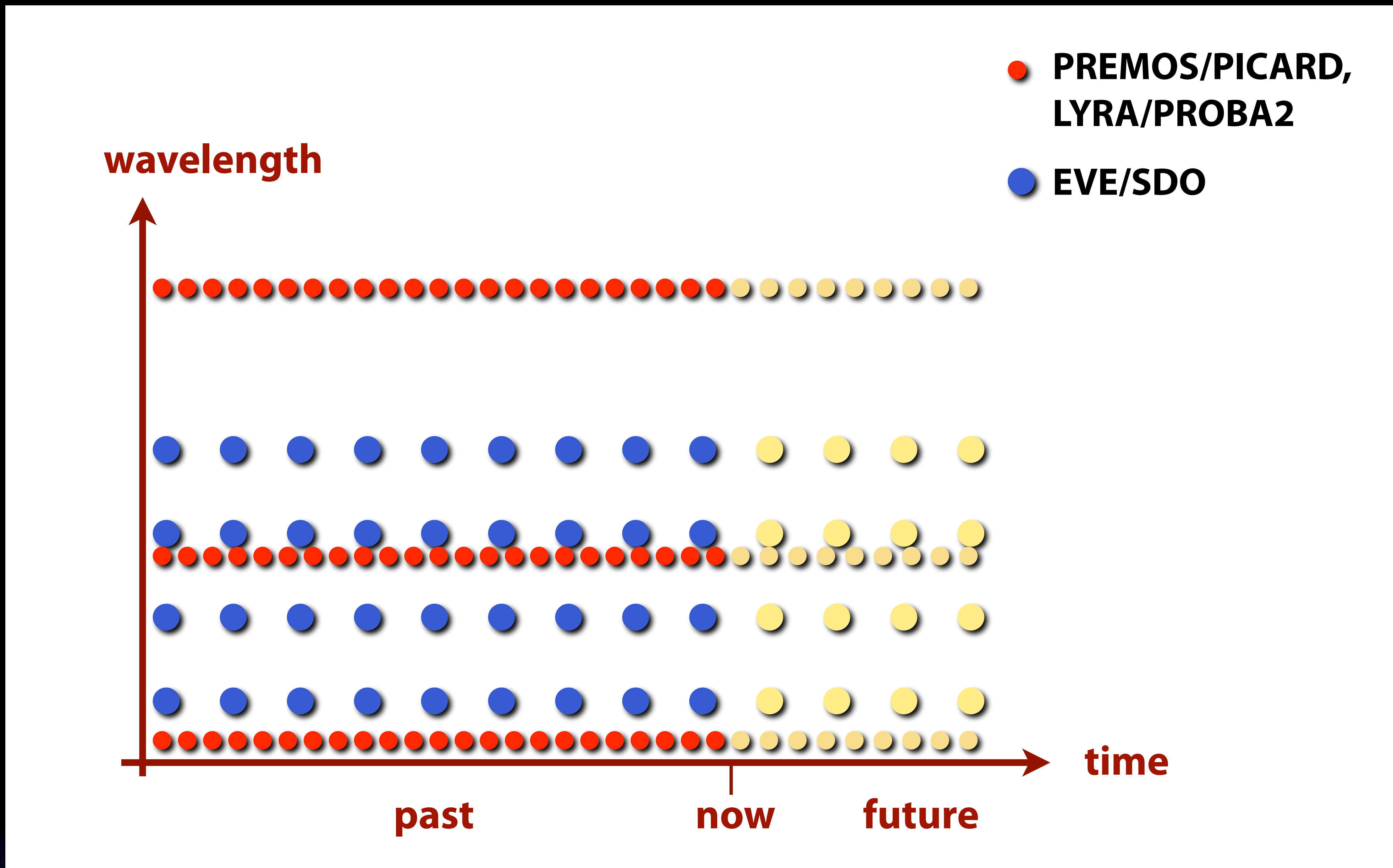
Our problem :
interpolate the spectral irradiance



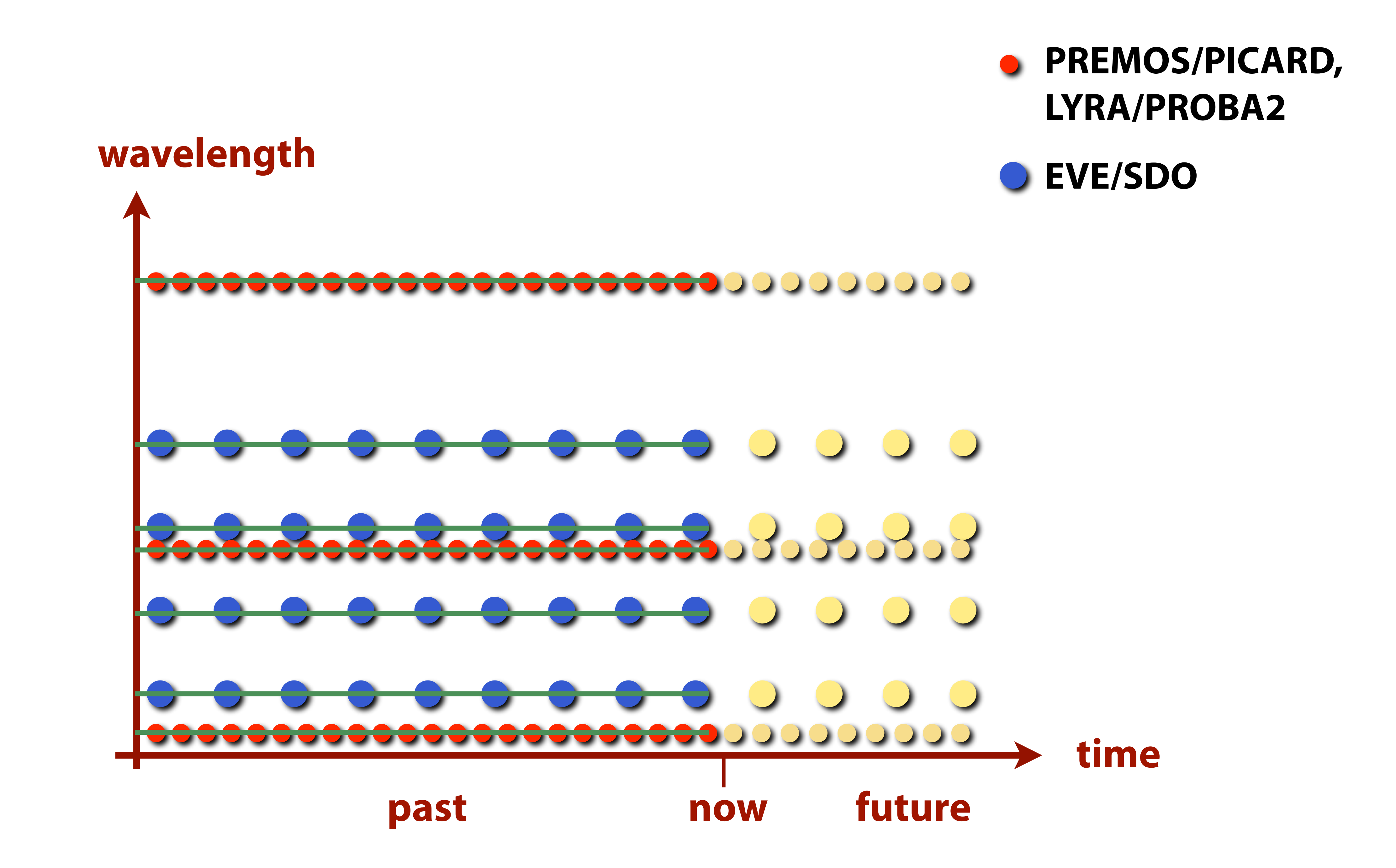
Our problem :
interpolate the spectral irradiance



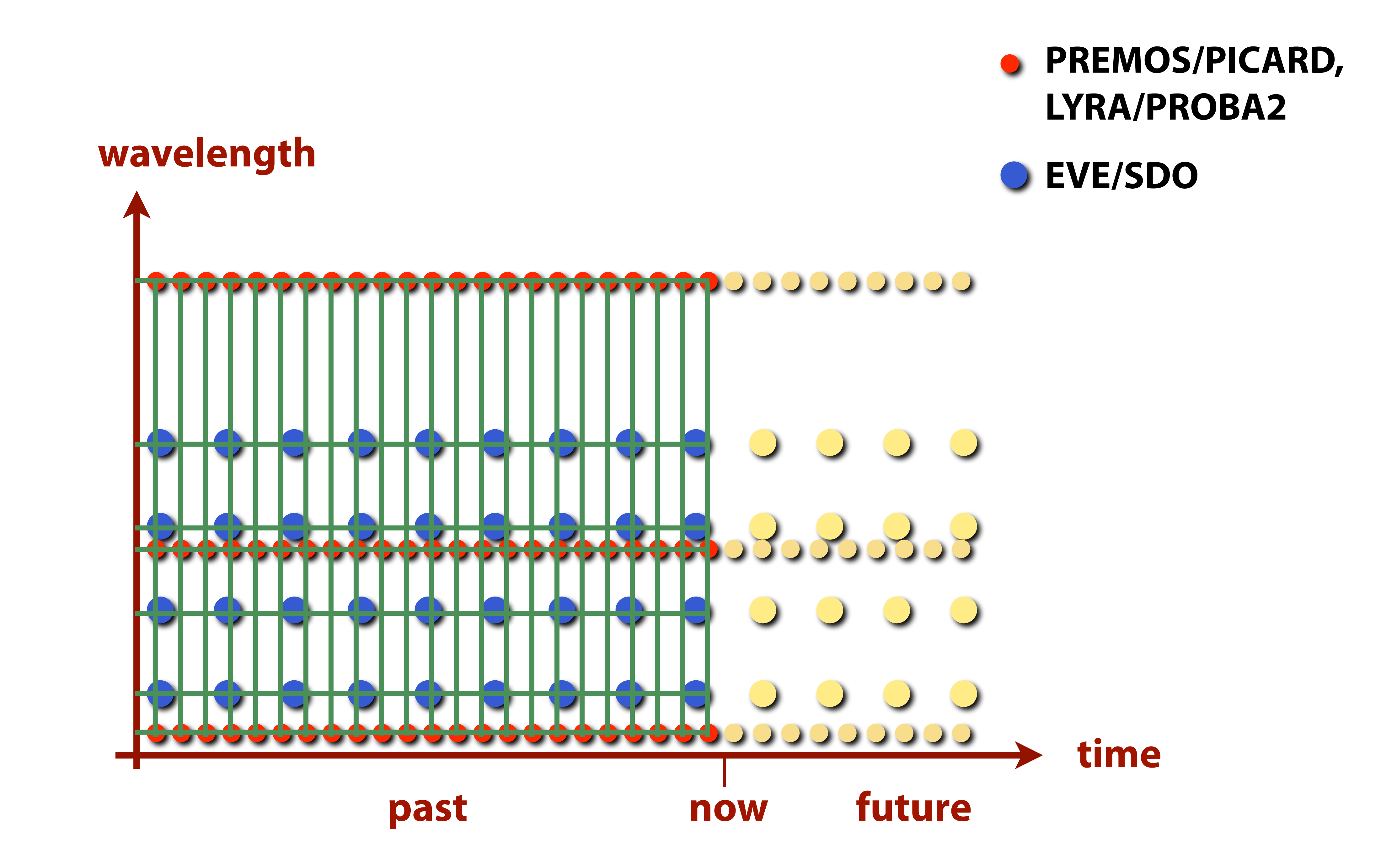
Our problem :
interpolate the spectral irradiance



Our problem :
interpolate the spectral irradiance



Our problem : interpolate the spectral irradiance



Interpolation is the problem...

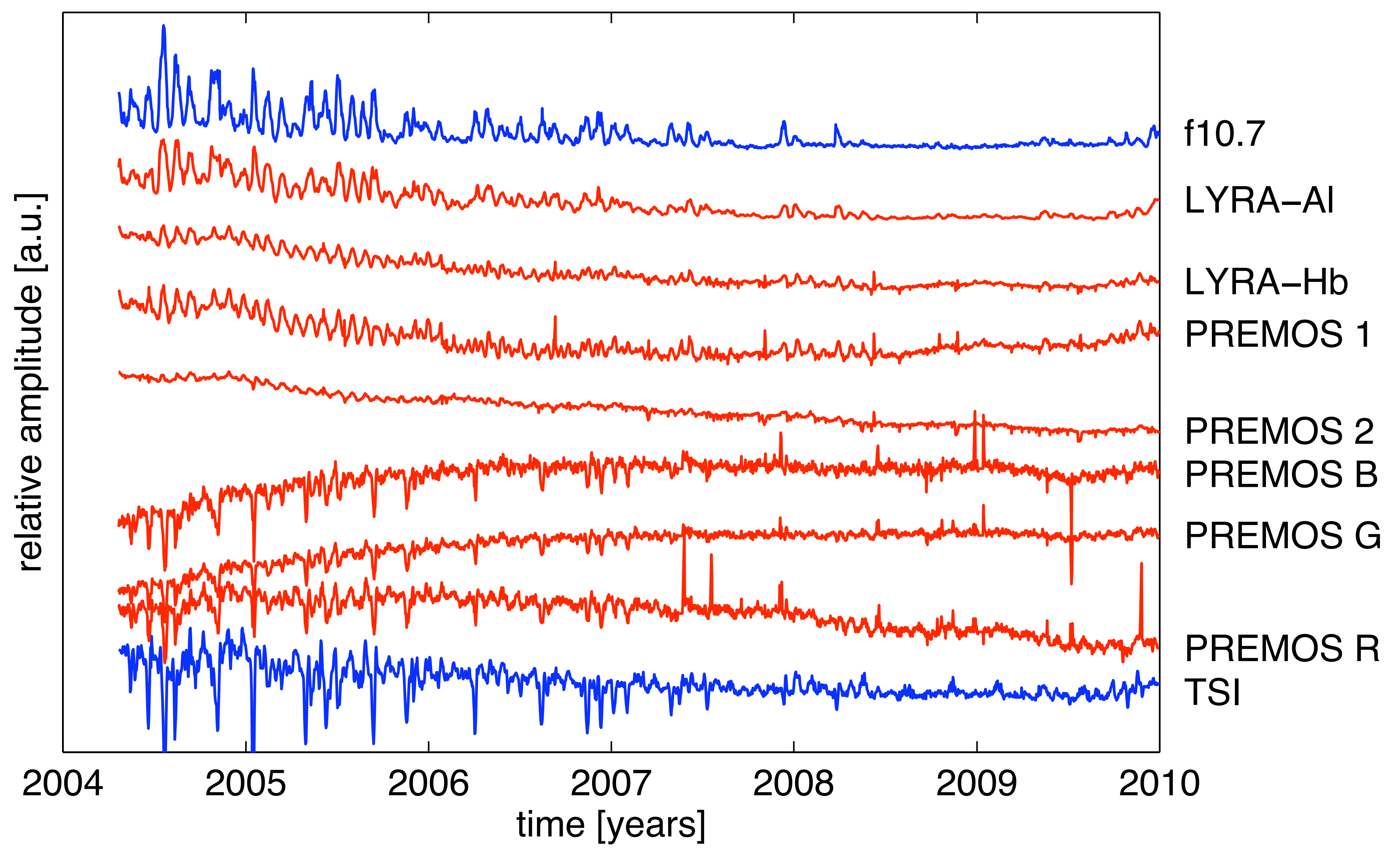
- **Forecasting** (extrapolation)
  - difficult except for salient features (→ talk by E. Quémerais)
- **Temporal interpolation**
  - difficult, since we still know very little about the spectral variability during flares (→ talks by J.-F. Hochedez and M. Kretzschmar)
- **Interpolation in wavelength**
  - very tricky at high resolution (< 0.1 nm) because of atomic lines
  - surprisingly easy otherwise

Outline

- Can we use channels from PREMOS & LYRA to reconstruct
  - the Total Solar Irradiance (TSI) ?
  - the solar spectral irradiance ?
- What does this tell us about the underlying physics ?
- Such reconstructions are required for space weather products (satellite drag...) and for upper atmospheric models

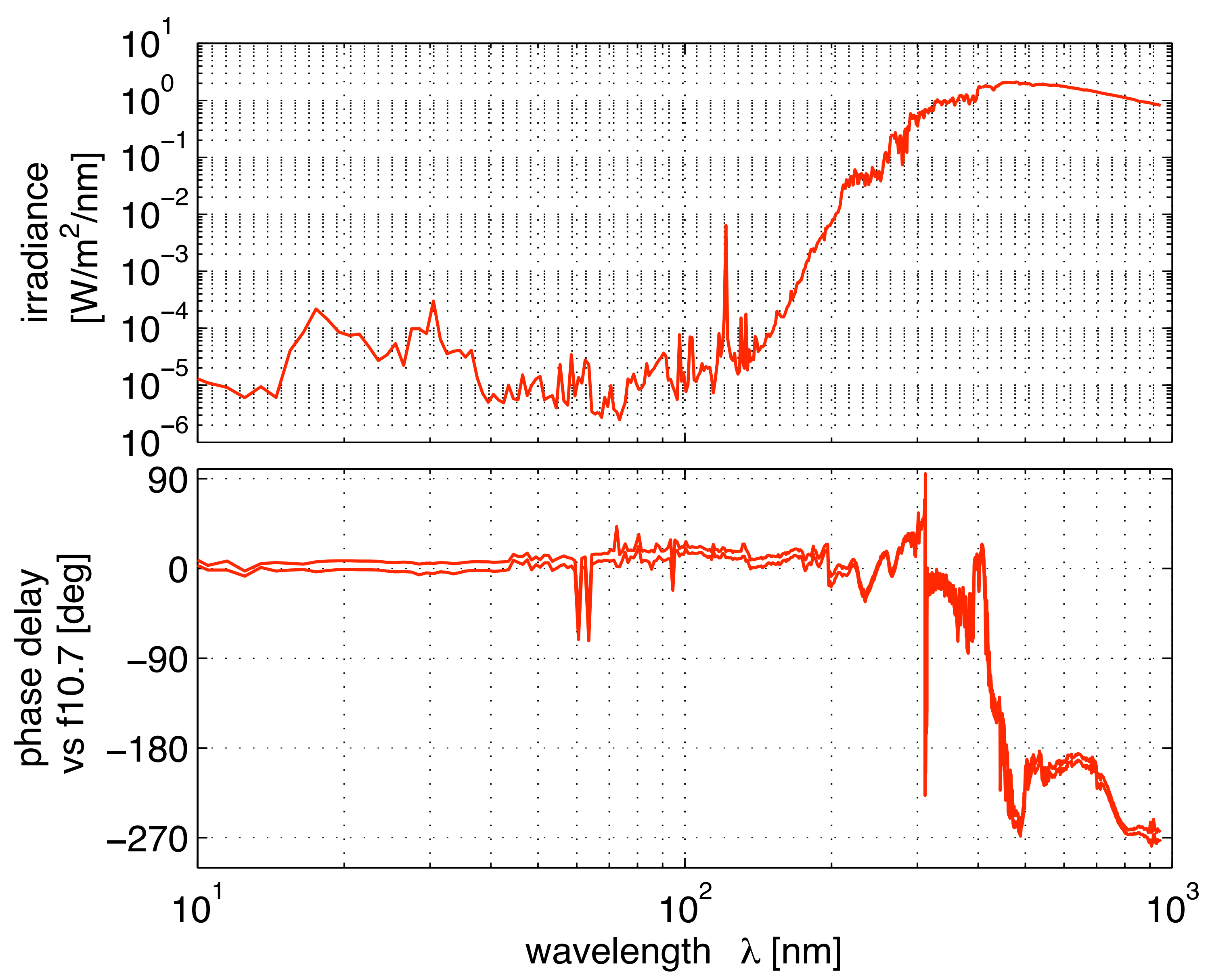
What PREMOS & LYRA could look like

- simulated daily outputs from PREMOS & LYRA
  (after data from SORCE/SIM, SORCE/SOLSTICE, TIMED/EGS & TIMED/XPS)



Long term evolution

- **Different trends** in the long term evolution (11 year scale) : visible and infrared bands are out of phase with solar cycle [Harder et al., 2009]



solar spectrum

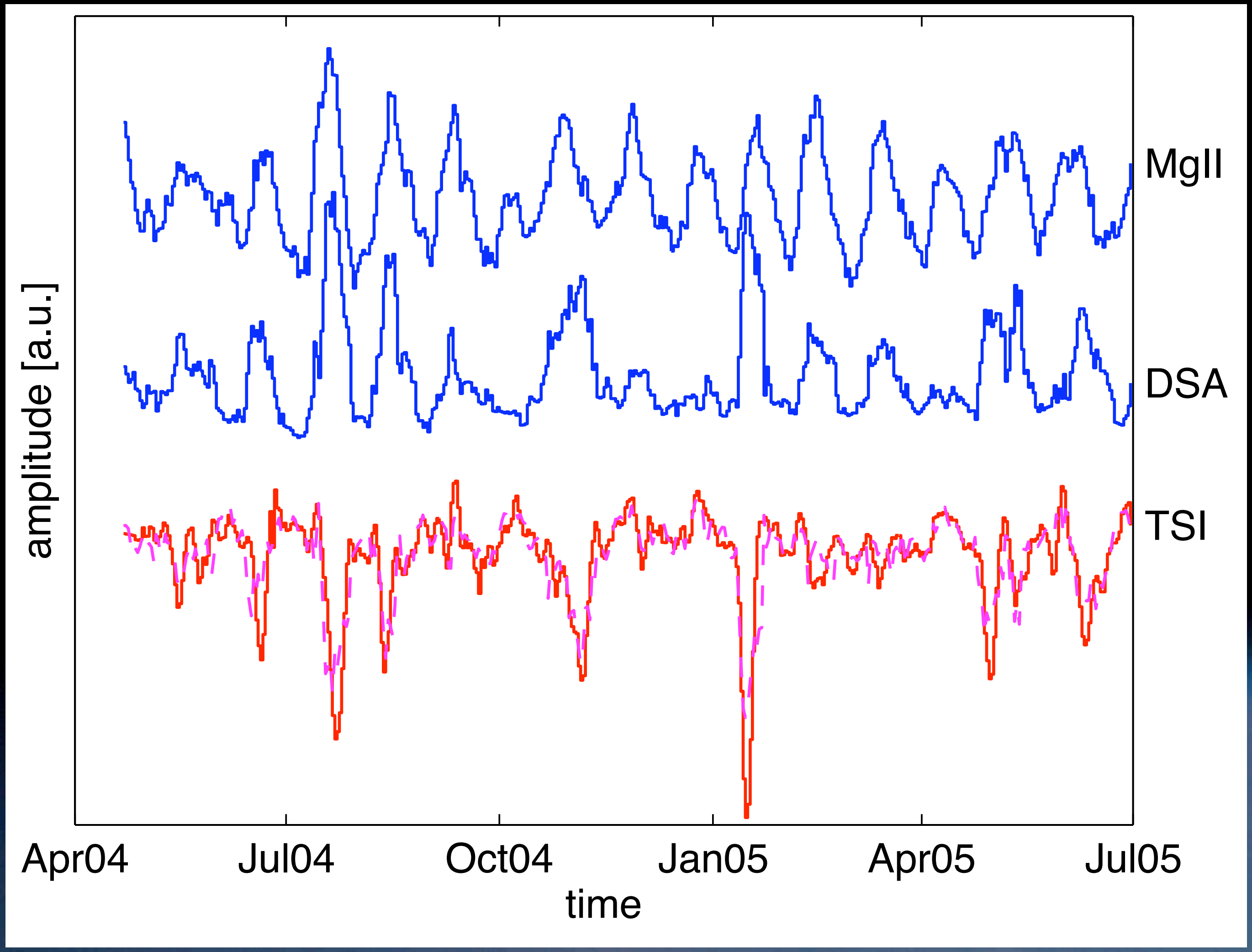
phase versus f10.7, for 11-year cycle

Can the TSI variability be reconstructed from a few bands / proxies ?

TSI variability

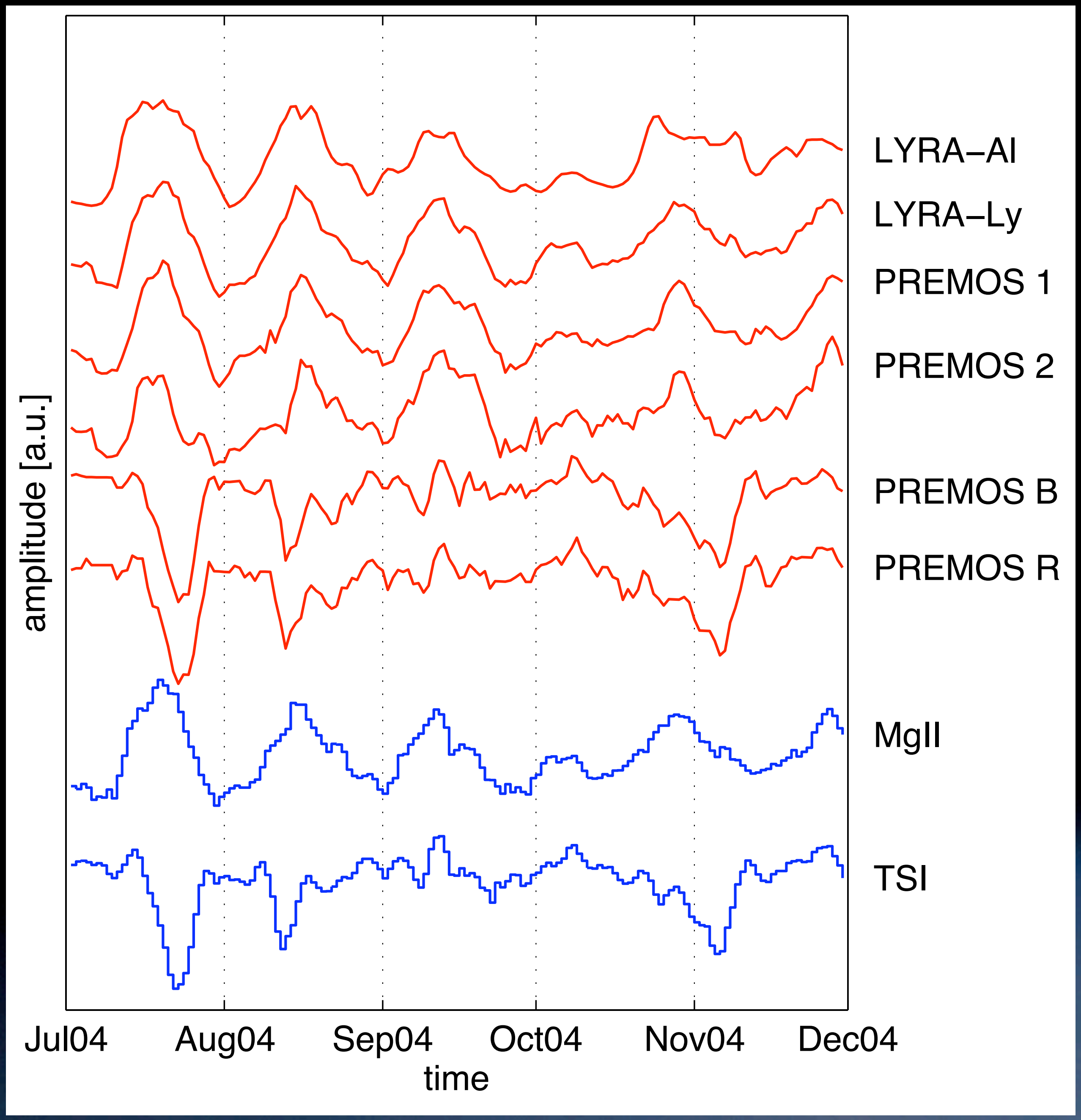
- Standard model for TSI variability

```
TSI = facular brightening - sunspot darkening
    = α Mg II index - β daily sunspot area
```



TSI varibility

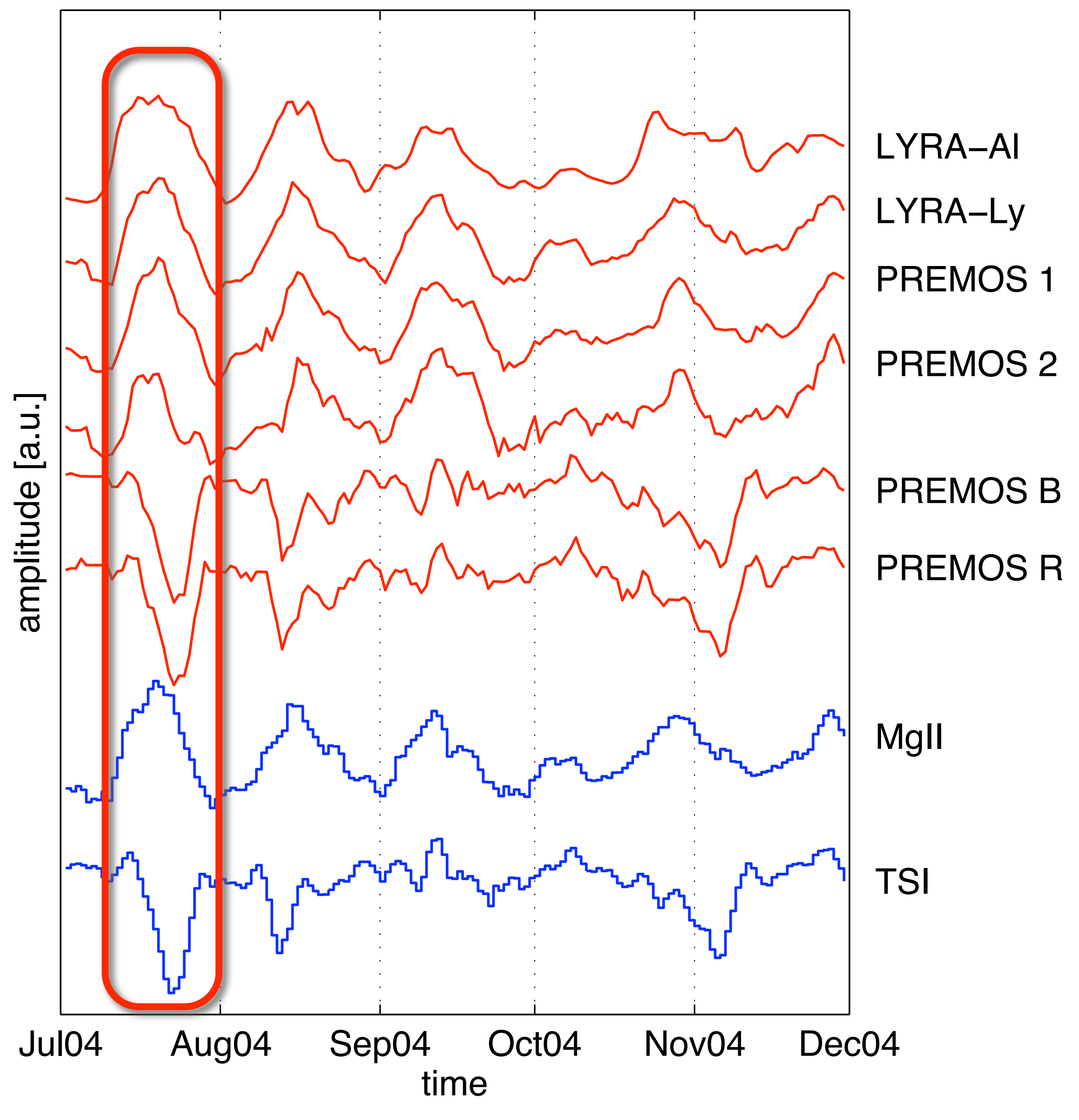
- But there are occasions where this simple model (chromospheric brightening - photospheric darkening) breaks down



Chromospheric & Photospheric emissions are sometimes in phase = active network dominates in TSI variability

TSI varibility

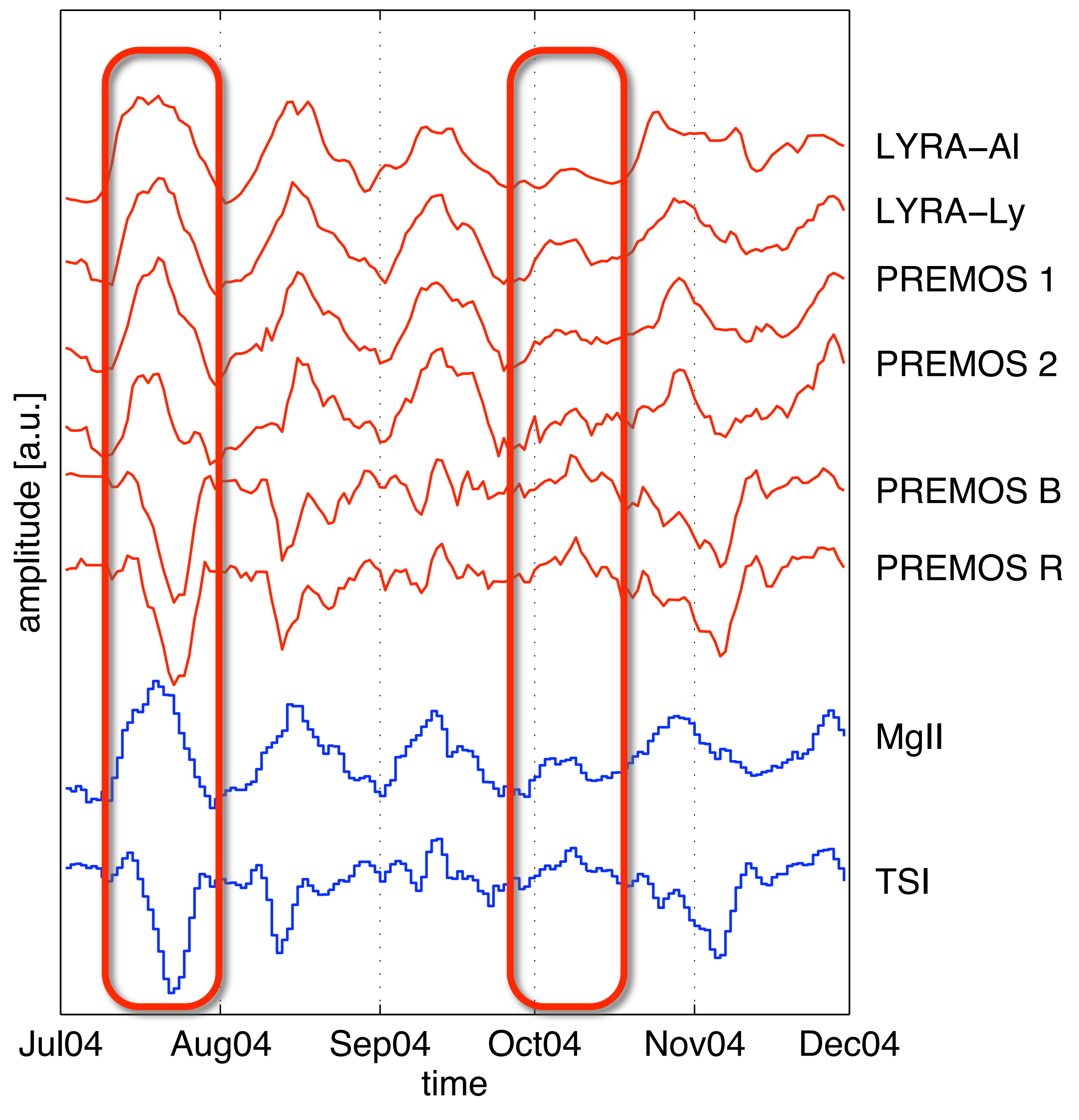
- But there are occasions where this simple model (chromospheric brightening - photospheric darkening) breaks down



Chromospheric & Photospheric emissions are sometimes in phase = active network dominates in TSI variability

TSI varibility

- But there are occasions where this simple model (chromospheric brightening - photospheric darkening) breaks down



Chromospheric & Photospheric emissions are sometimes in phase = active network dominates in TSI variability

Does the TSI vary in phase with solar activity ?

- According to these simple models, the TSI should be **in phase** with indices for solar activity (for time scales >> 27 days)

Is that really so ?

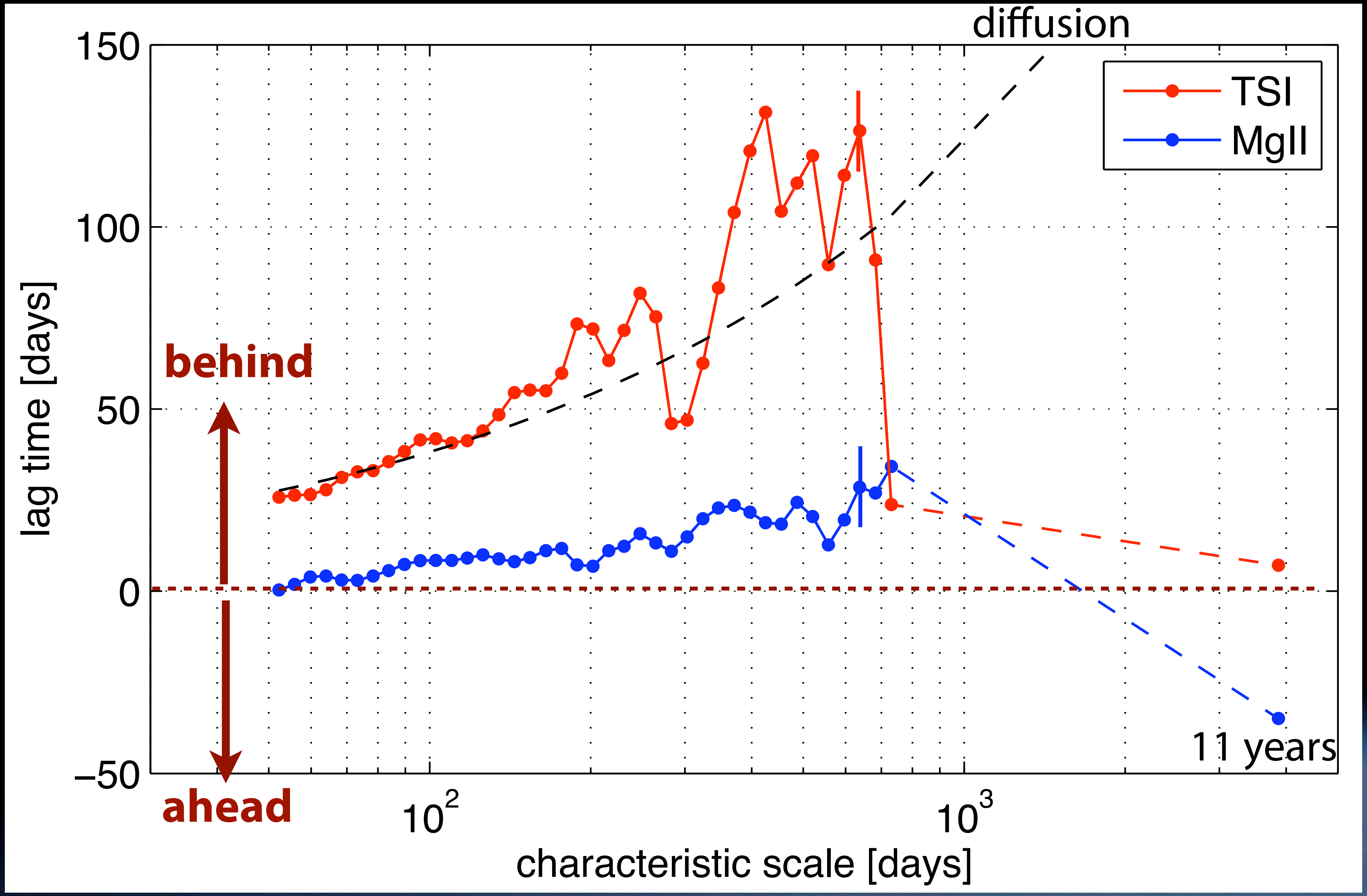
- We check this by computing the cross-phase ϕ between the TSI and other indices for solar activity

$$\phi = \angle \langle x(\omega) y^*(\omega) \rangle$$

We use continuous wavelets. Solar activity is expressed here by the DSA (Daily Sunspot Area) [Preminger & Walton, GRL, 2005].

The TSI does NOT vary in phase with solar activity

- Phase lag (in days) between the TSI and the MgII index, and the DSA, based on 31 years of data



The TSI lags much more behind the DSA than faculae do (MgII index)

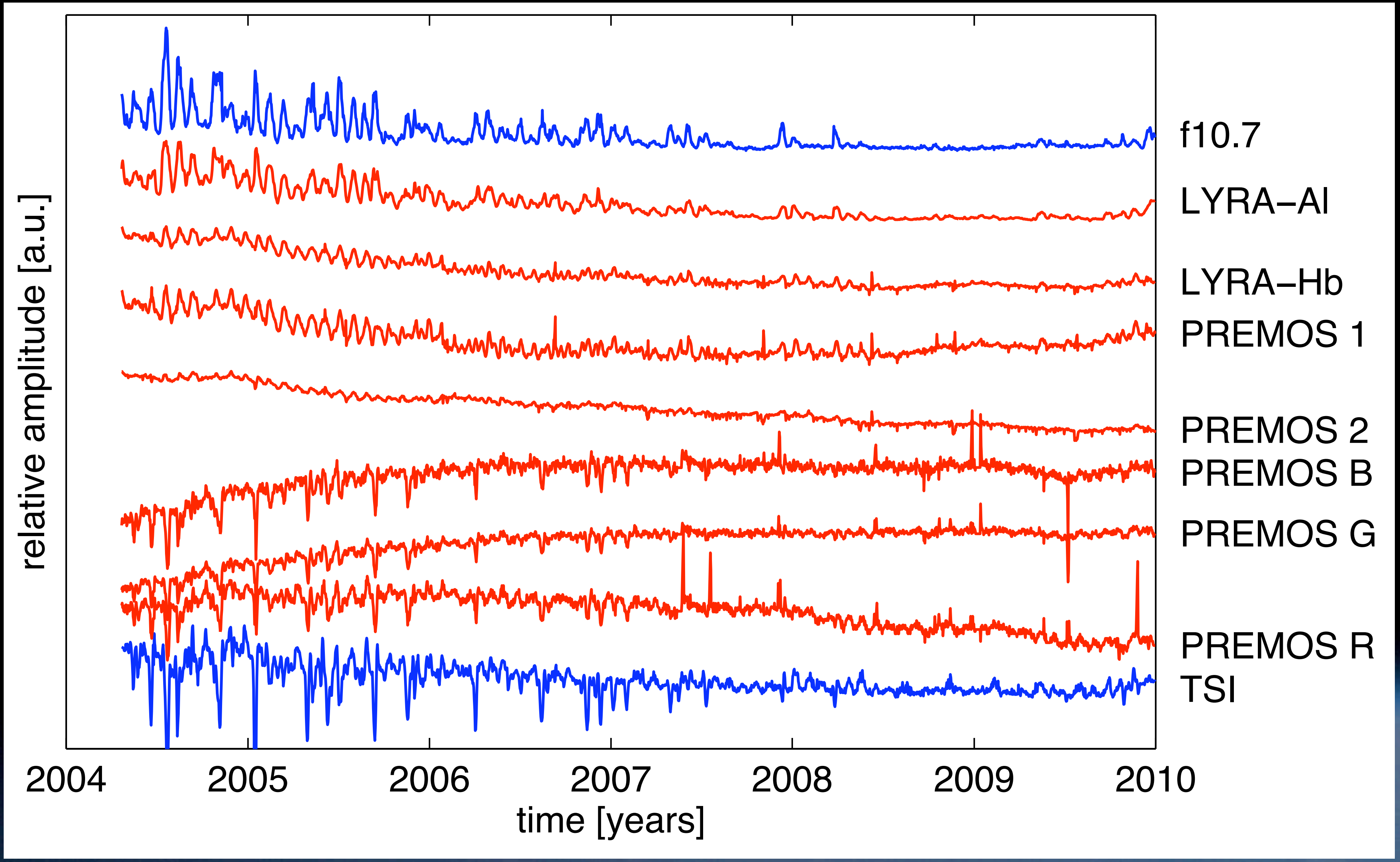
The TSI does not vary in phase with solar activity !

- This result suggests that **the excess of irradiance coming from plages and faculae continues to enhance the TSI after these regions have faded away**.
- This is compatible with a **diffusive decay of the magnetic field** at active regions *[Crouch et al., ApJ 2008]*.
- Unresolved magnetic structures do matter...

Can the spectral variability be reconstructed from a few bands ?

Spectral coherence

- The variabilty of the solar spectrum is **remarkably coherent** in spite of the complexity of the underlying processes



Spectral coherence

- Many authors claim that the solar EUV variability is made of **3 contributions** [Lean et al. 1982; Woods et al., 2000; Warren et al., 2001; Feldman et al., 2010; ...]
  - quiet Sun + coronal holes + active regions
- Amblard et al. [2008] showed, using a statistical approach, that these can be described by **3 elementary spectra** (≠ regions)
  - quiet Sun + hot corona + cool chromosphere

Spectral coherence

- Many authors claim that the solar EUV variability is made of **3 contributions** [Lean et al. 1982; Woods et al., 2000; Warren et al., 2001; Feldman et al., 2010; ...]
  - quiet Sun + coronal holes + active regions

- Amblard et al. [2008] showed, using a statistical approach, that these can be described by **3 elementary spectra** (≠ regions)
  - quiet Sun + hot corona + cool chromosphere

Can the full spectral variability (EUV-UV-visible) also be described that way ?

Spectral coherence

- Our approach is **empirical**
- It is based on the Singular Value Decomposition (SVD) + bayesian blind source separation

- We find that
  - > 60% of the variance can be described by a linear combination of only 3 contributions (elementary spectra)
  - instrumental noise sets in for > 3 contributions

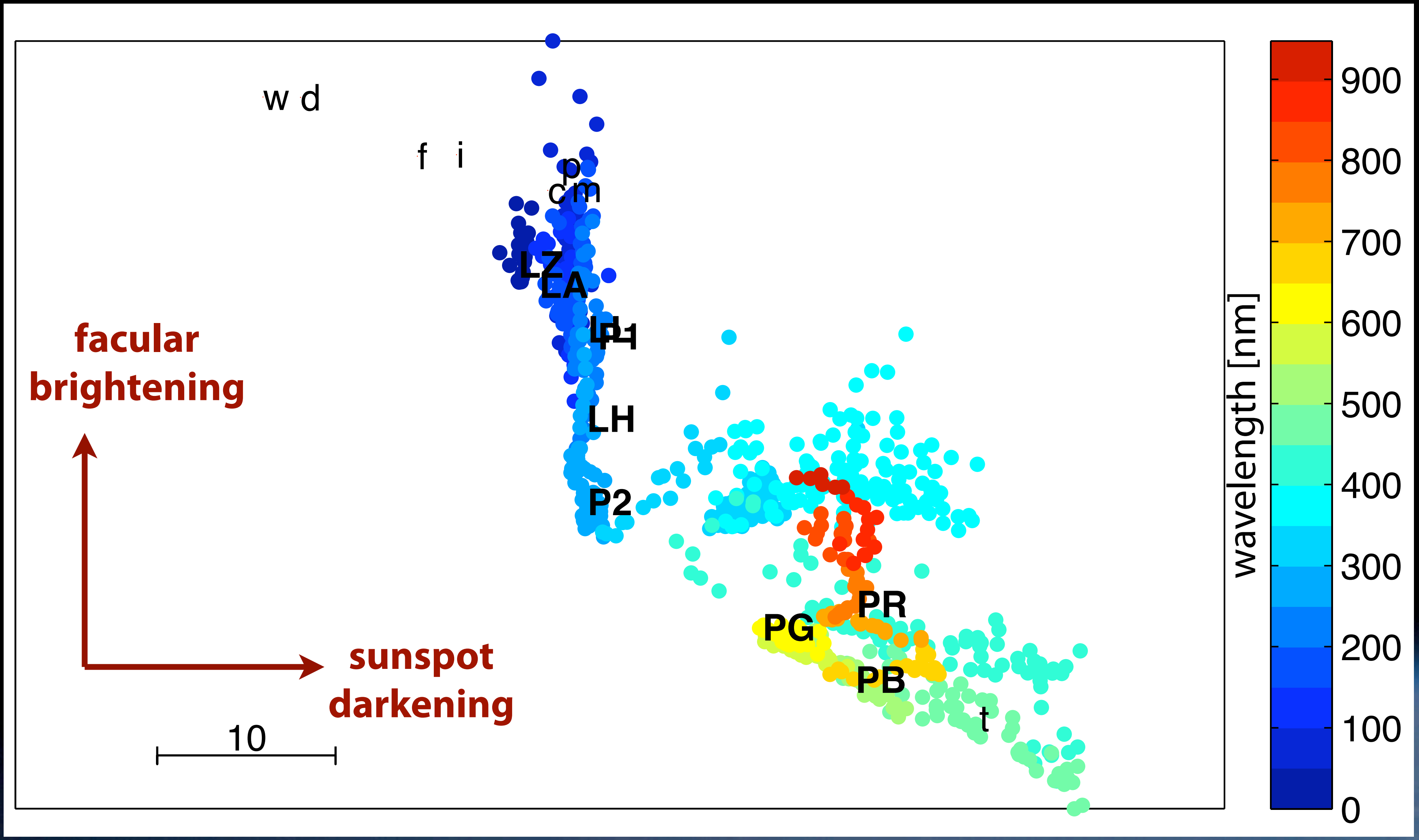
Spectral coherence

- Our approach is **empirical**
- It is based on the Singular Value Decomposition (SVD) + bayesian blind source separation
- We find that
  - > 60% of the variance can be described by a linear combination of only 3 contributions (elementary spectra)
  - instrumental noise sets in for > 3 contributions

The full spectral variability EUV-UV-VIS can be adequately described by 3 elementary spectra !

Proximity map

- The closer two wavelengths are, the more similar their short-term (< 90 days) evolution is



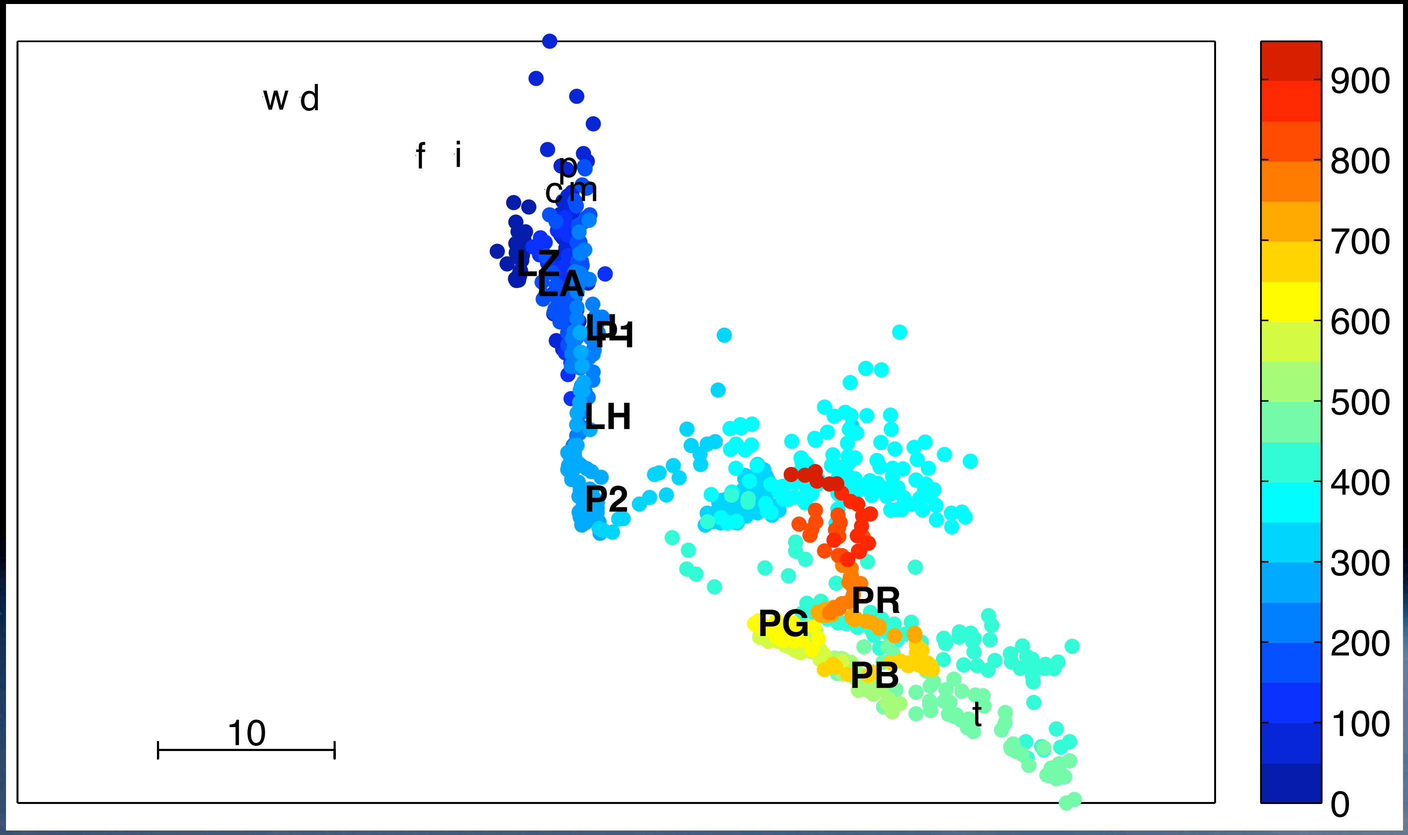
Legend

PB : PREMOS B
PG : PREMOS G
PR : PREMOS R
P1 : PREMOS 1
P2 : PREMOS 2
LH : LYRA Herzberg
LA : LYRA Al

t : TSI
f : f10.7
m : MgII
w : MWSI
d : DSA

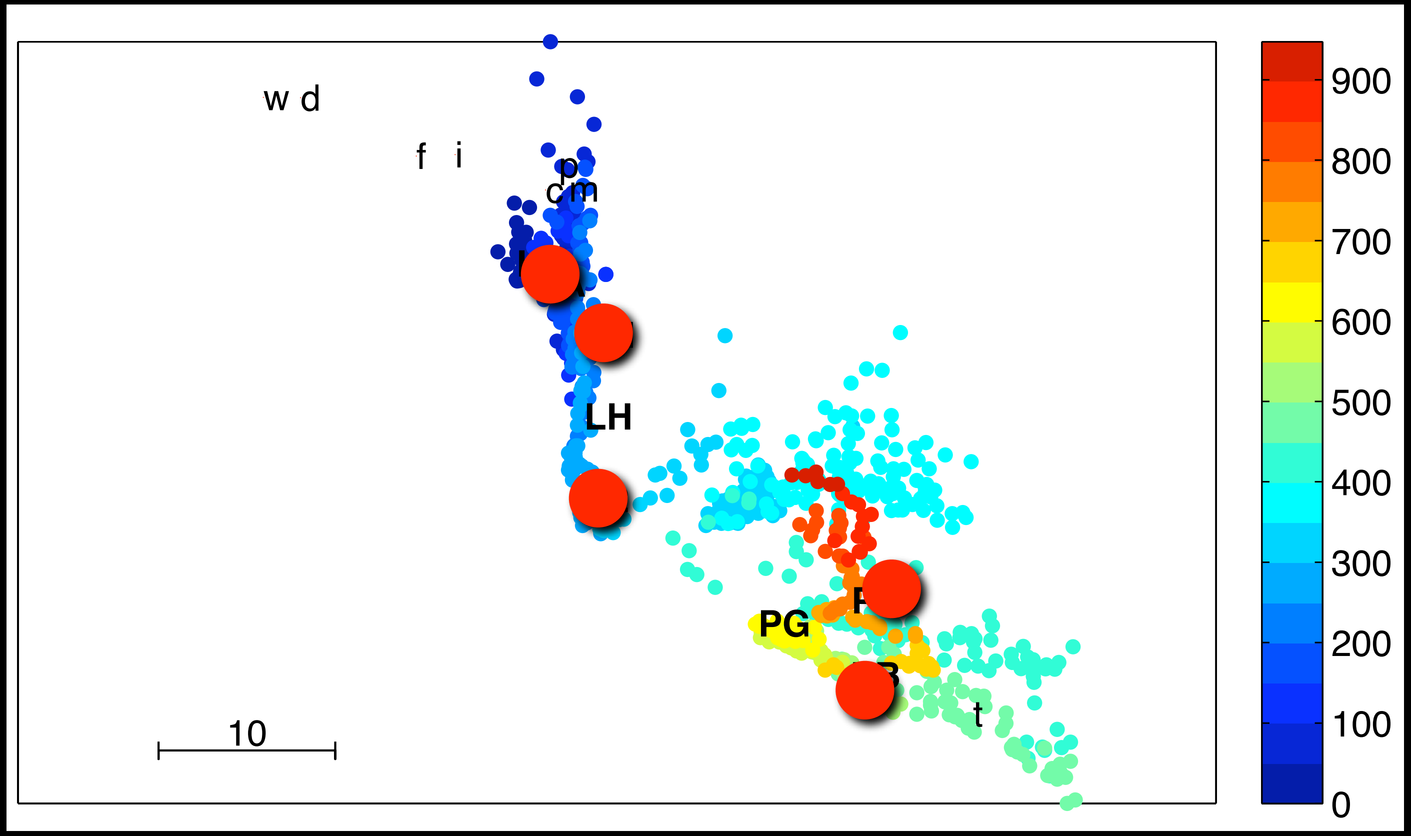
Interpretation

- The UV spectrum (< 300 nm) can be properly described by LYRA channels and PREMOS 215 + 266 nm channels
- Idem for visible part, with PREMOS visible channels
- The Near-UV (300 - 400 nm) is difficult to reconstruct. Unfortunately, this band has the highest absolute variability. Use SODISM ?
- The Near-IR (>900 nm) is also problematic.



Spectrum reconstruction

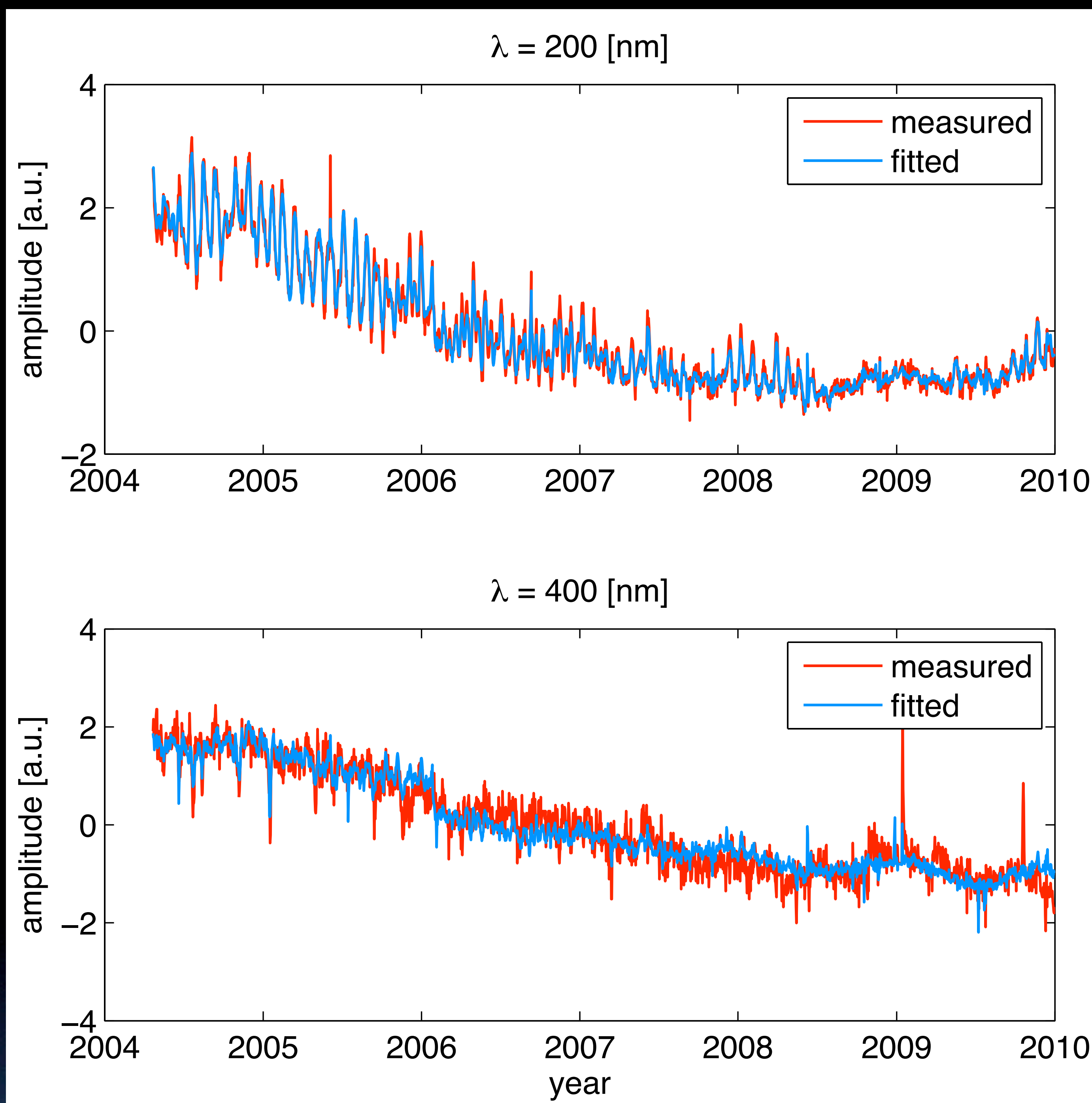
- Reconstruction by using most PREMOS channels + LYRA Al + LYRA Lyman-alpha



- In the following we reconstruct the spectrum using channels marked with ●

Examples

- 2 examples of reconstructed irradiance



Good reconstruction

λ = 200 [nm]
relative error < 15 %

Bad reconstruction

λ = 400 [nm]
relative error ~ 80 %

Conclusions

- The EUV-UV spectrum can be properly reconstructed using PREMOS & LYRA data
  - We shall soon provide online nowcasts of the EUV-UV spectrum (FP7 SOTERIA project)
- The reconstruction of the near-UV is much more challenging.
  - Instrumental errors from SORCE/SIM may be largely responsible for this.
- The combined use of PREMOS & LYRA will be particularly interesting for investigating the spectral variability during flares.

Reconstruction error