What can we learn from past UV observations ?

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with special thanks to the instrument teams that provided the data

Key questions

- How does the Sun vary in the UV ?
- How unusual was the solar spectral variability during the last cycle ?

A debate unabated : Harder et al. GRL 2009 — Haigh et al., Nature 2010 — Deland & Cebula JASTP 2012 — Lockwood JGR 2011 — Lean & Deland J.Clim. 2012, ...

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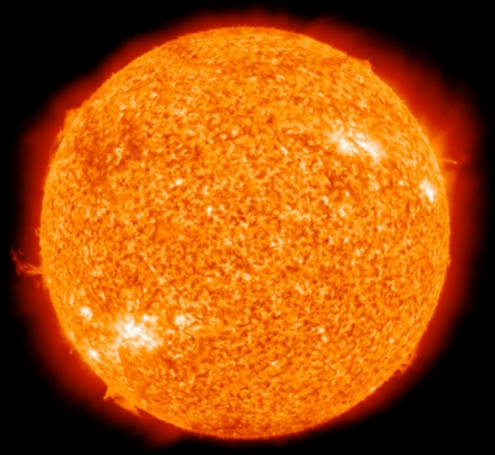
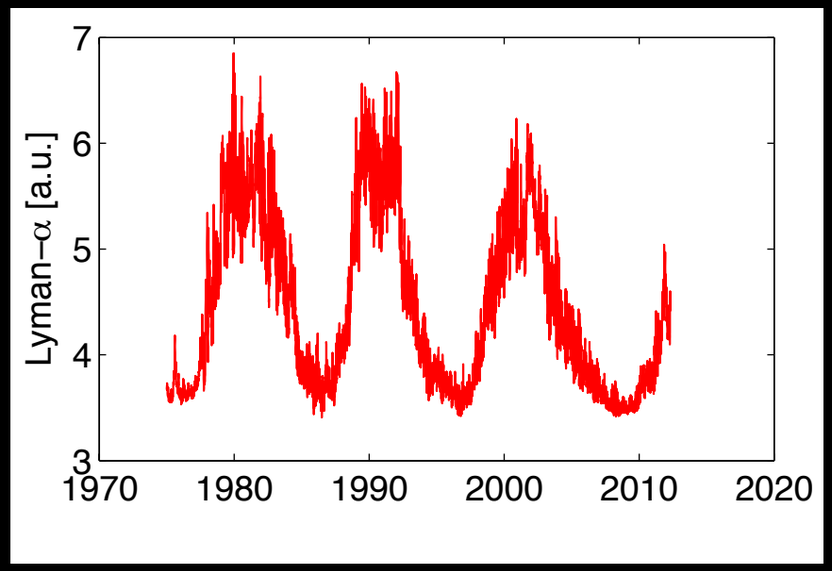
Various approaches





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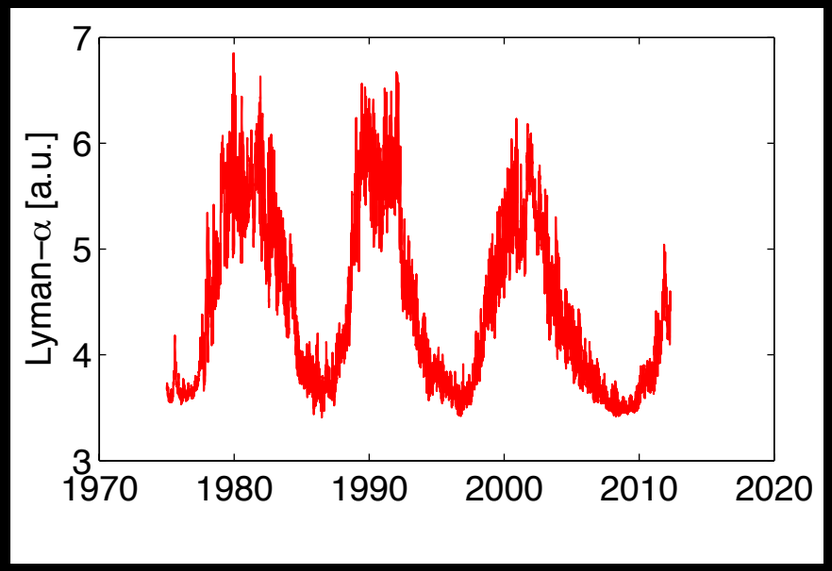

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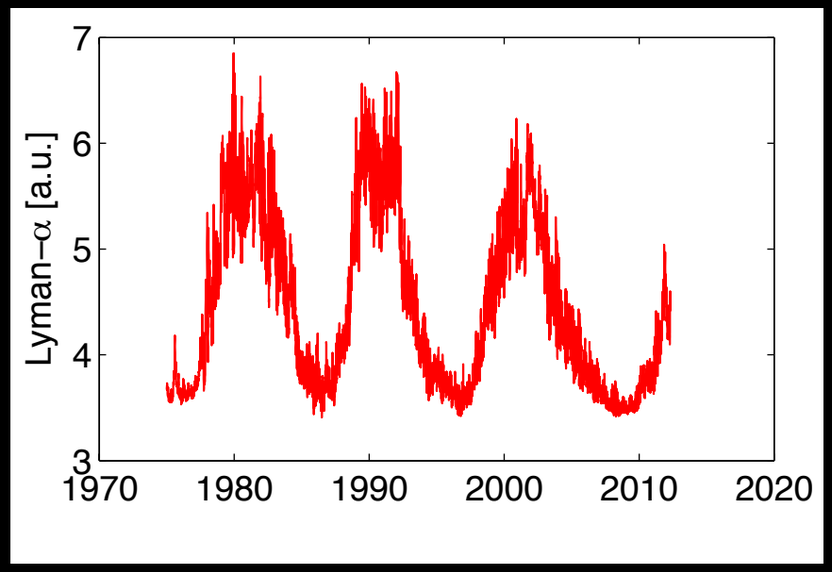

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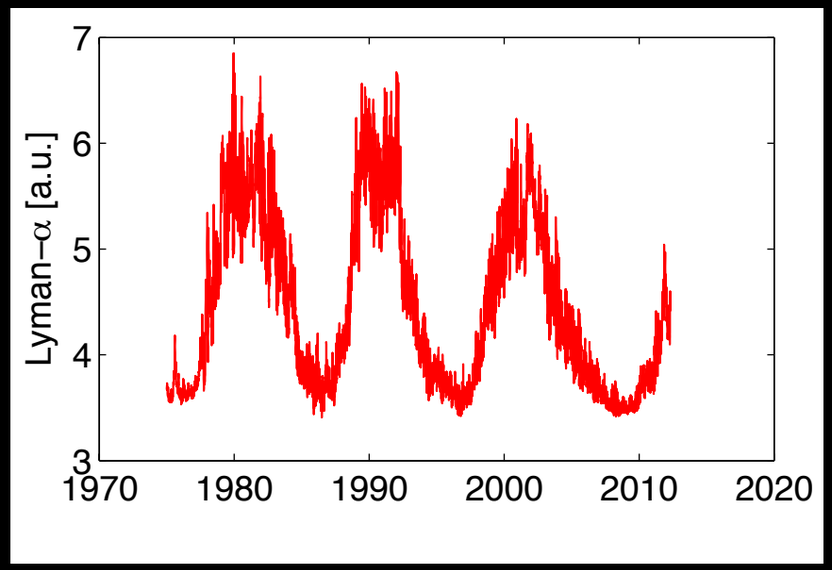
observations



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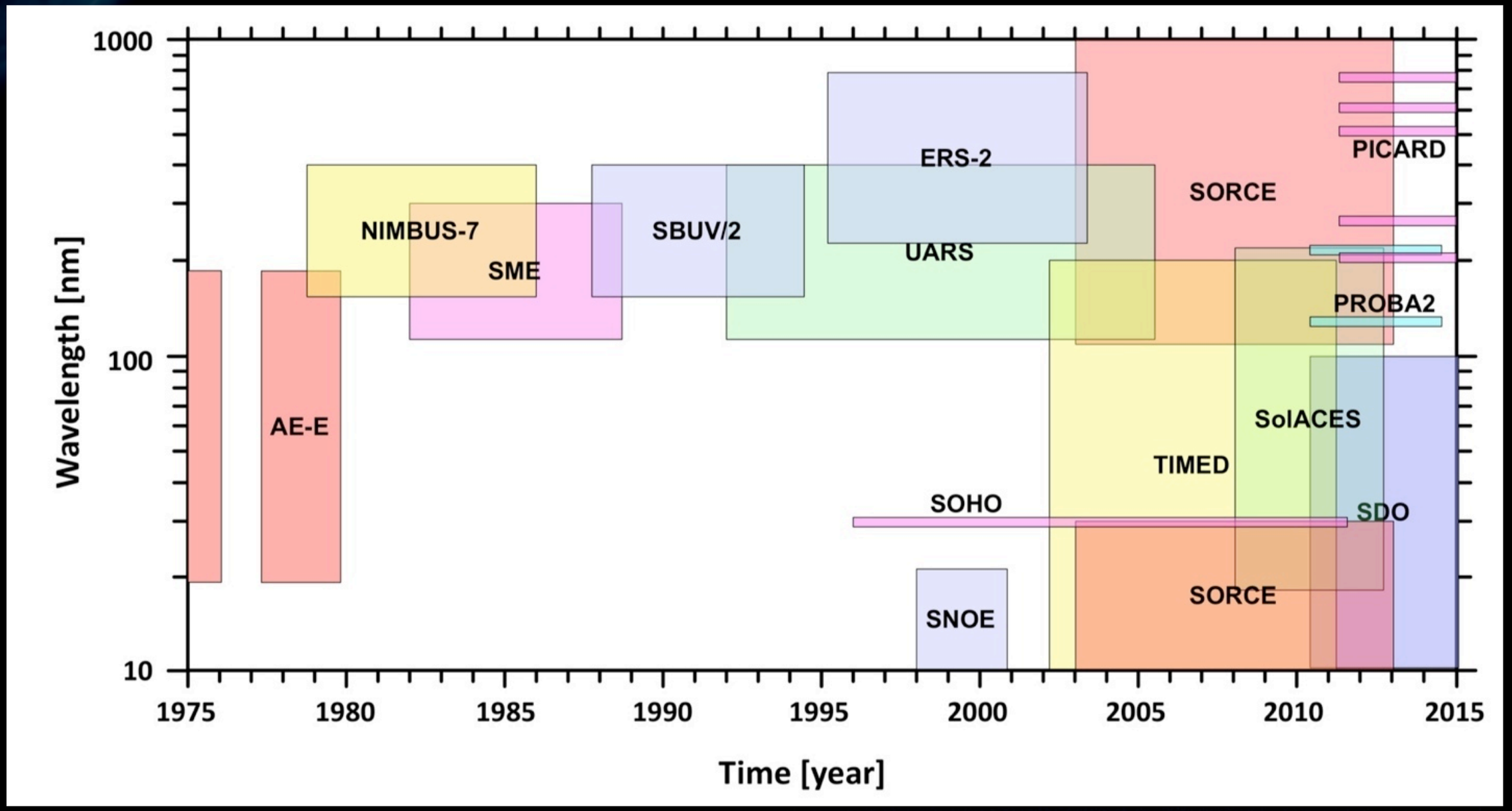

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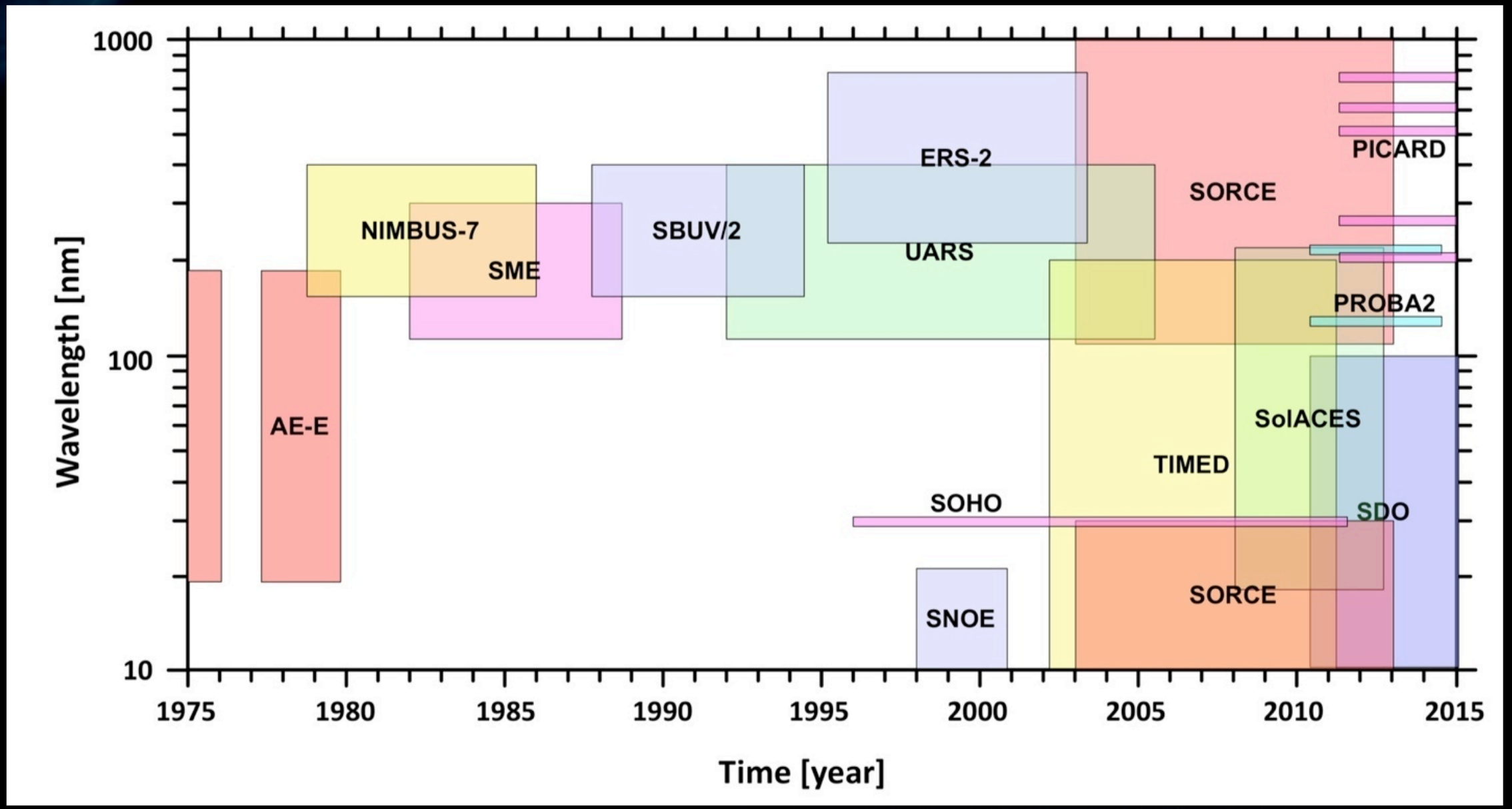

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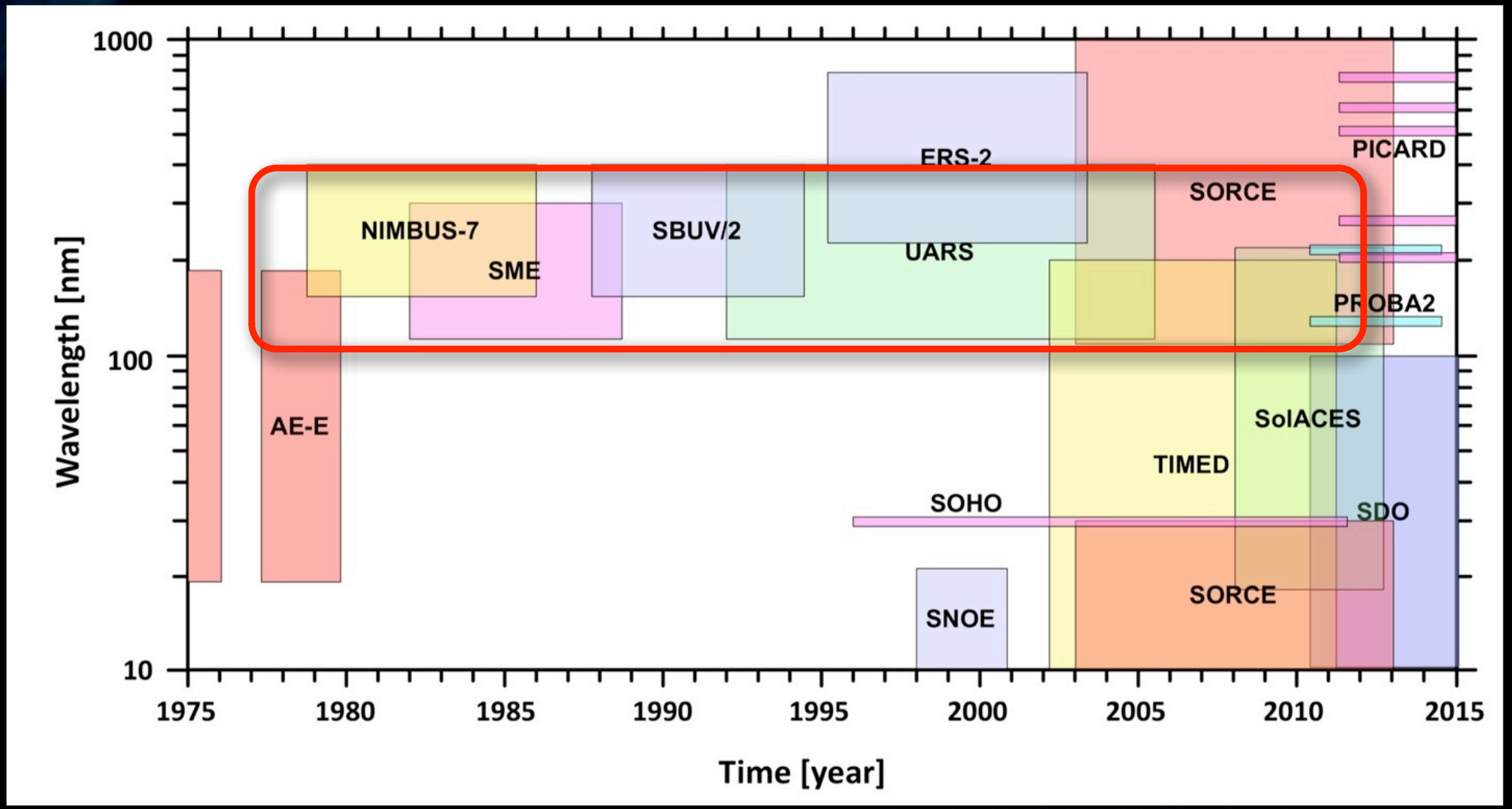
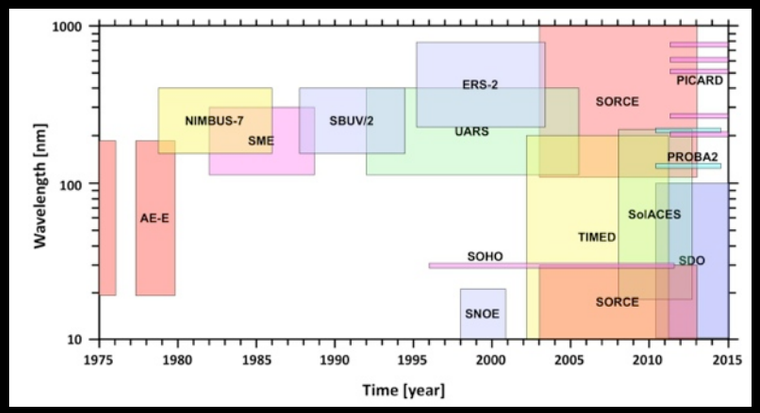


Problems : sparse observations, instruments (scientists) that disagree & suffer from degradation

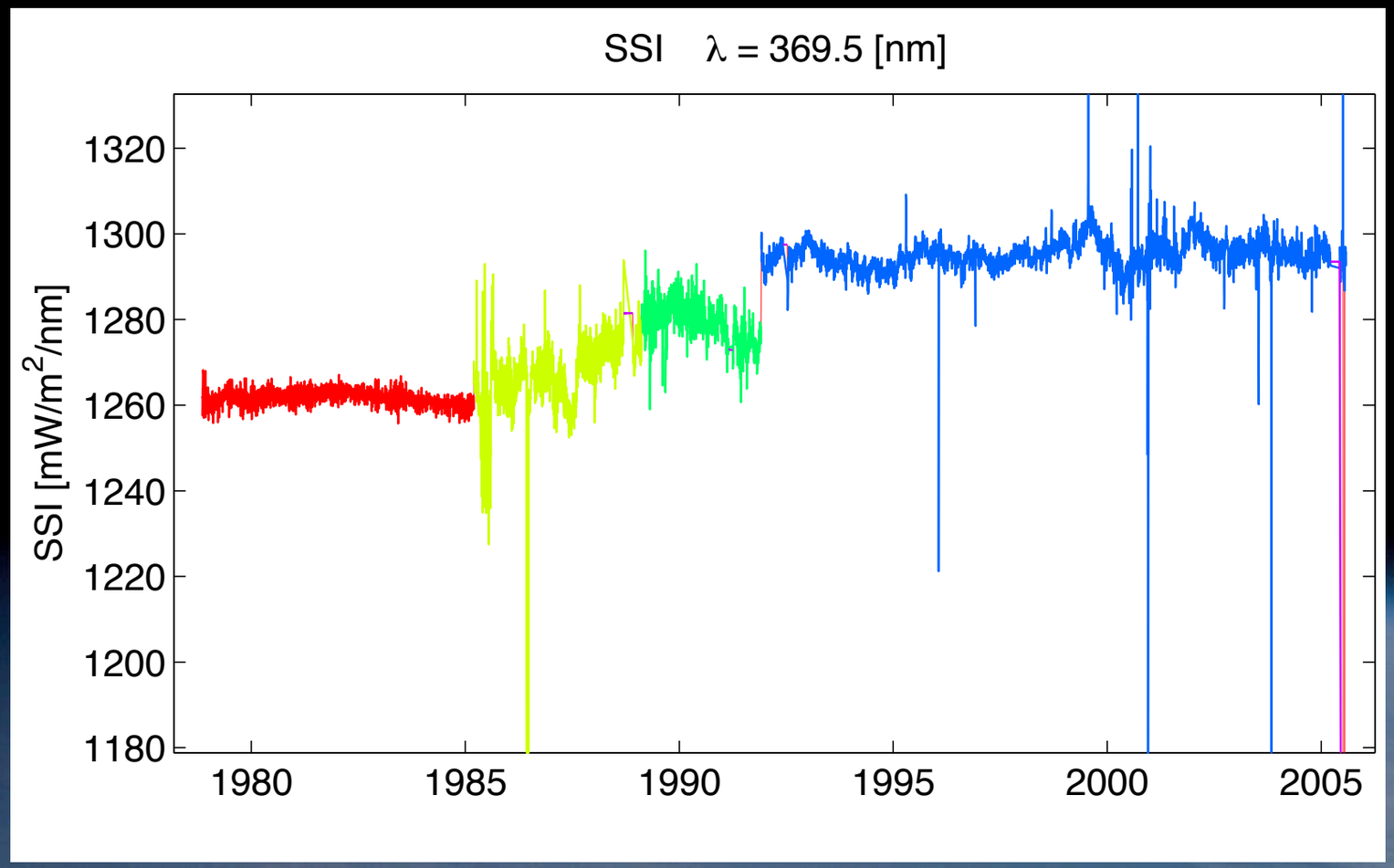
Raw data are pretty useless

- Deland & Cebula [JGR 2008] made a composite UV dataset out of these various records, from 120-400 nm



- But its interpretation is compromised by lots of instrumental artefacts

Example:
SSI at 369.5 nm



A general problem

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- How can we **stitch together** different records that
  - don’t agree in absolute value ?
  - have different noise characteristics ?
  - do not necessarily overlap in time ?
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- This is a **frequent problem**
  - fusion plasmas : merge observations from various diagnostics
  - climate proxies : build a single proxy out of many measurements
  - ...

My favourite motto

We use fantastic telescopes, the best physical models and the best computers. The weak link in this chain is interpreting our data using 100-year-old mathematics.

Dana McKenzie, New Scientist, 2004.

Our approach

- Go **Bayesian** ! A recent and highly productive field of research
- Instead of making (often questionable) averages, estimate the probability

$$\mathcal{P}(\Phi|O) = \frac{\mathcal{P}(O|\Phi) \cdot \mathcal{P}(\Phi)}{\mathcal{P}(O)}$$

Probability that the true flux is ϕ given a set of observations O

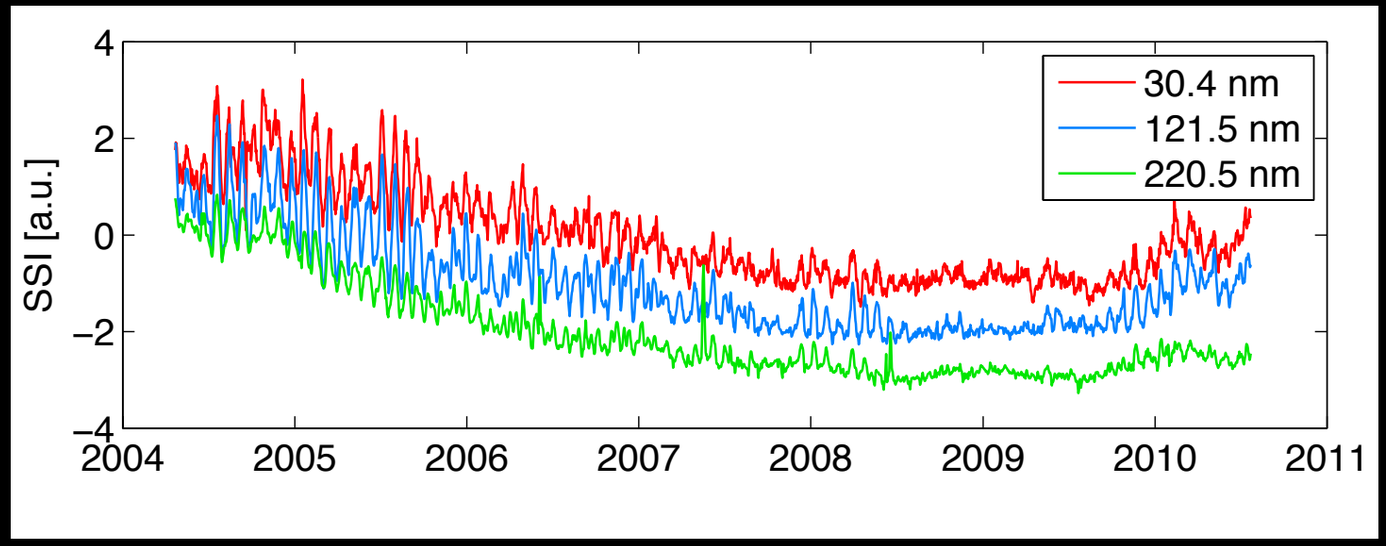
Our approach

- **Advantages**
  - a consistent method for extracting information from imperfect data
  - need to specify assumptions explicitly
- **Disadvantages**
  - can be computationally expensive
  - people tend to be scared by the word “Bayes”

Our assumptions

- **Redundancy**
  - the spectral irradiance at neighbouring wavelengths tends to evolve almost simultaneously in time.
  - the variability is driven by few degrees of freedom

    [Lean et al., JGR 1982; Amblard et al., A&A 2008]



- **Multiscale dynamics**
  - different time scales may not evolve in the same way (solar rotation, centre-to-limb effects, solar cycle, ...)

The method

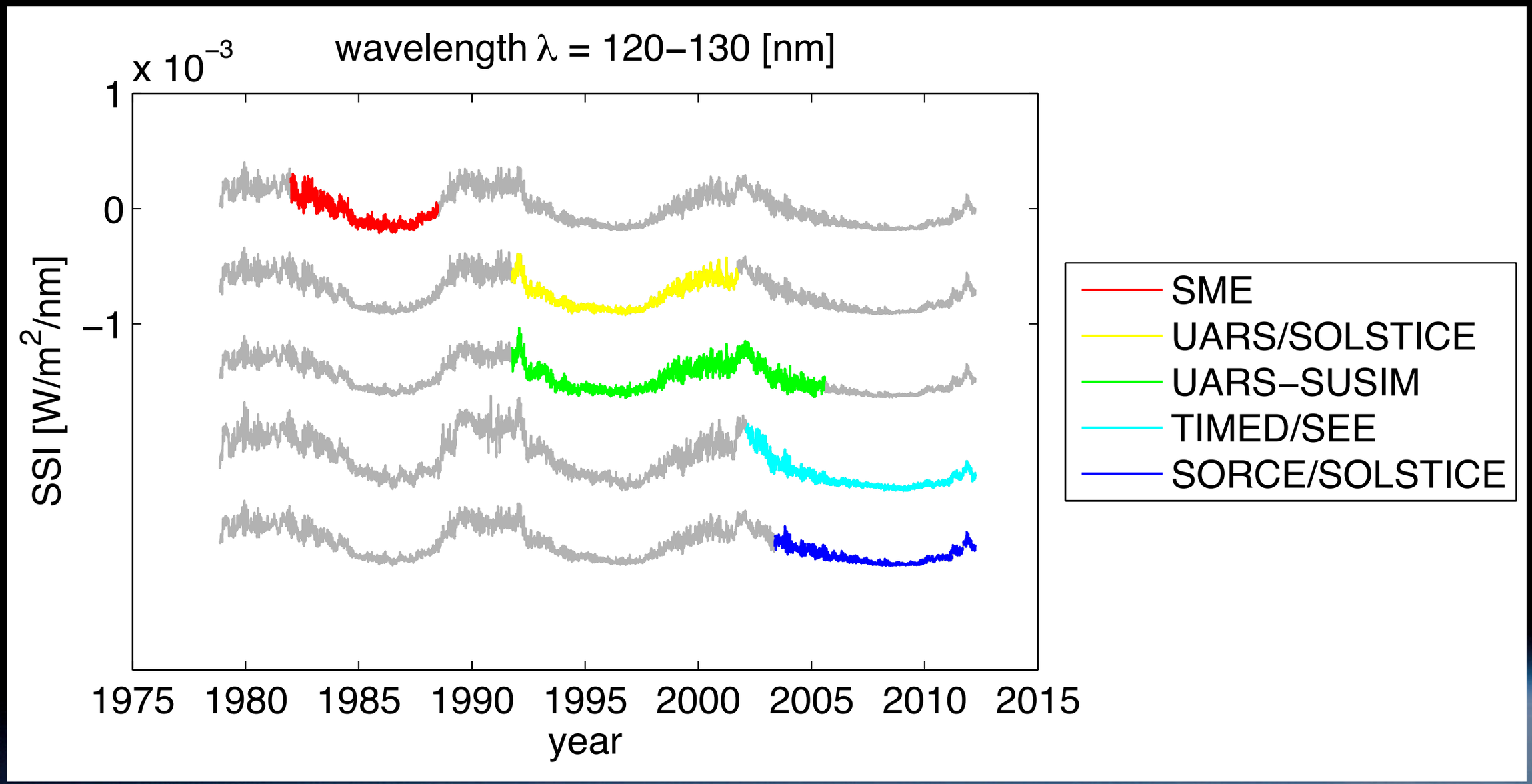
- **Each record is extrapolated in time** while assuming that its statistical properties with respect to all other records and wavelengths remain unchanged

- Period goes from 8 Nov 1978 - 31 Mar 2012

The numerical method is based on iterative Singular Value Decomposition [DdW, A&A 2011]. Validation is done by bootstrapping.

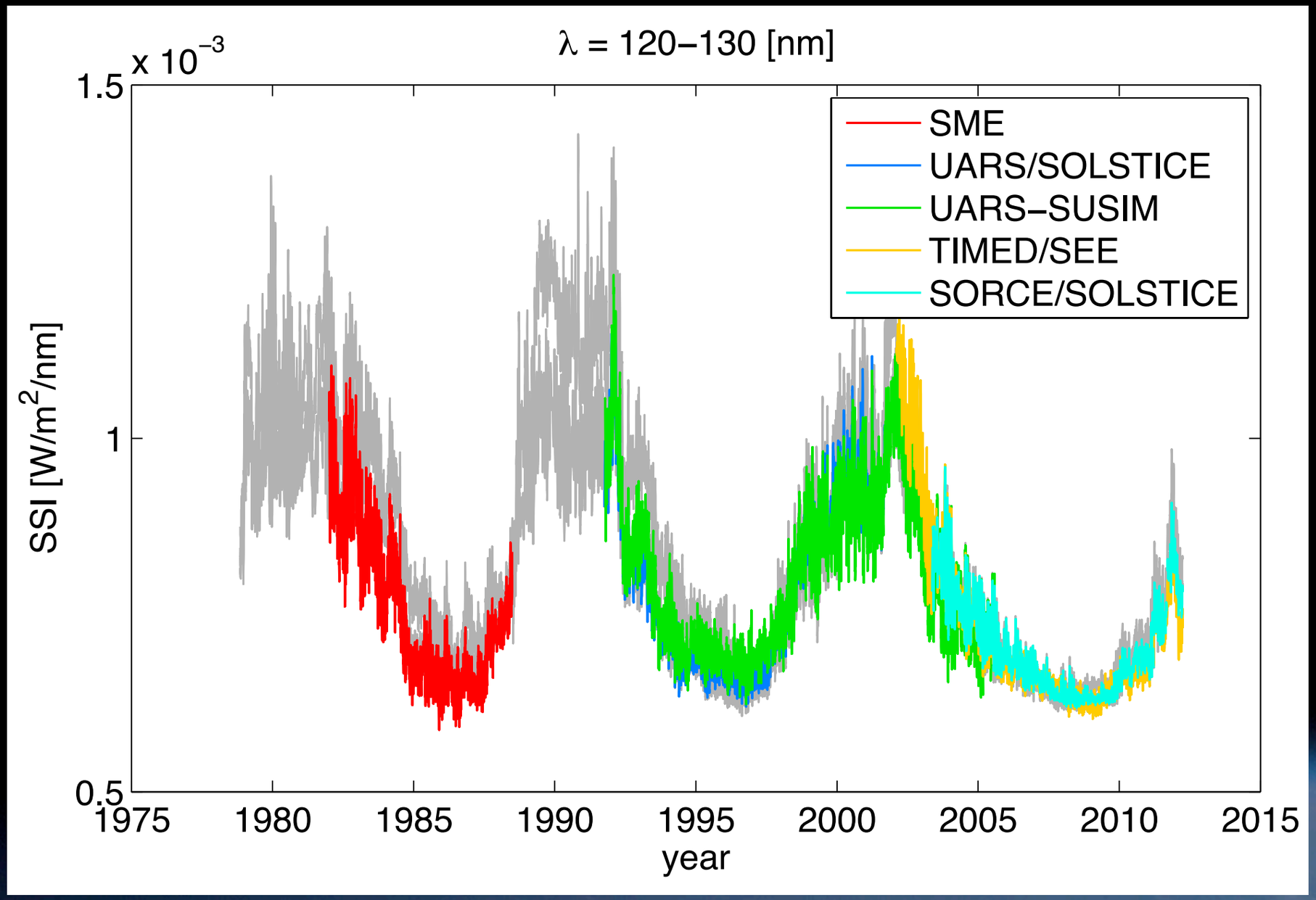
Results : Lyman-α line

- Example for the H I Lyman-α line



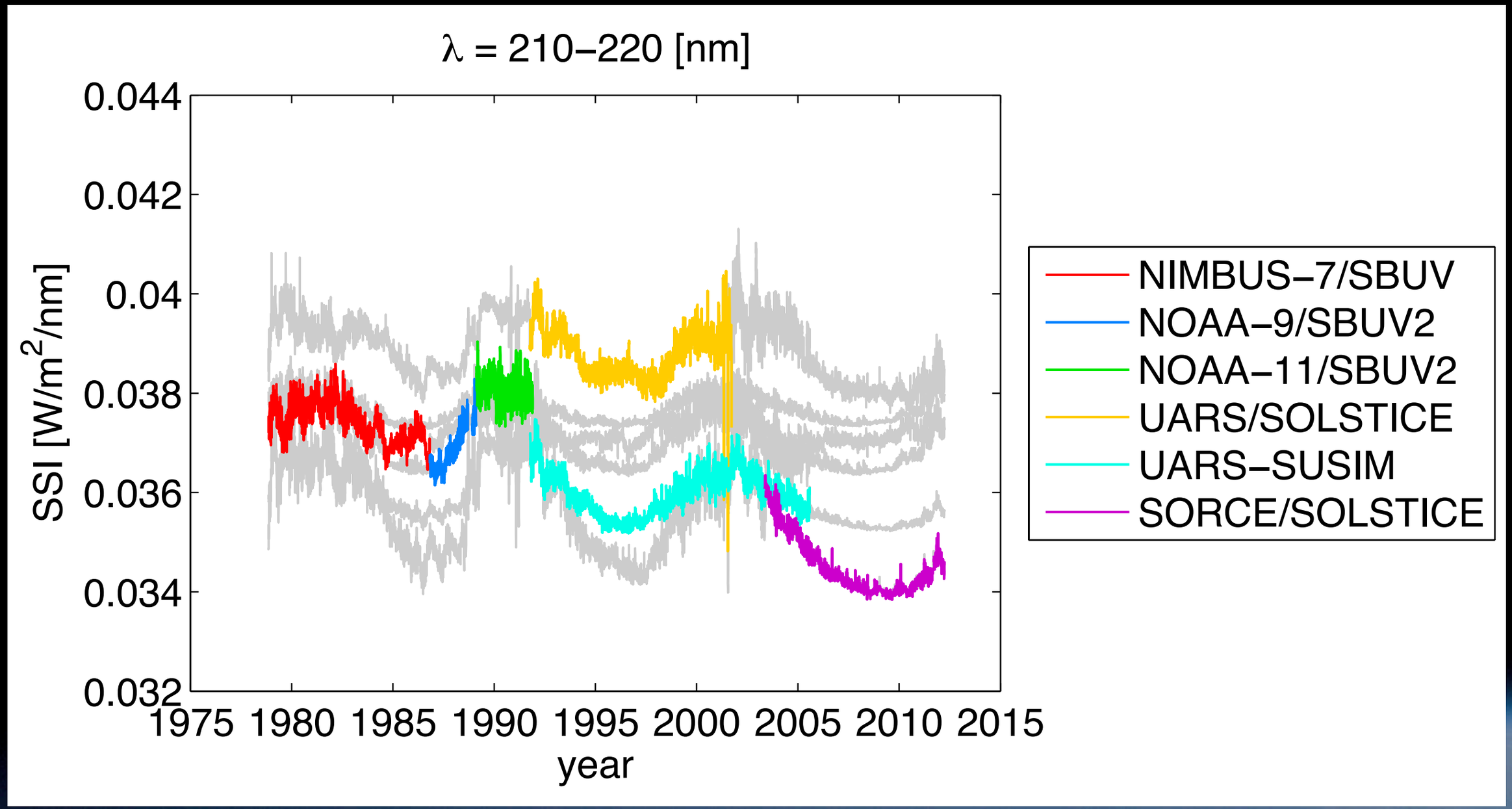
Results : Lyman-α line

- All records agree remarkably well for the H I Lyman-α line



Results: Herzberg band (210-220 nm)

- Agreement often is not so good



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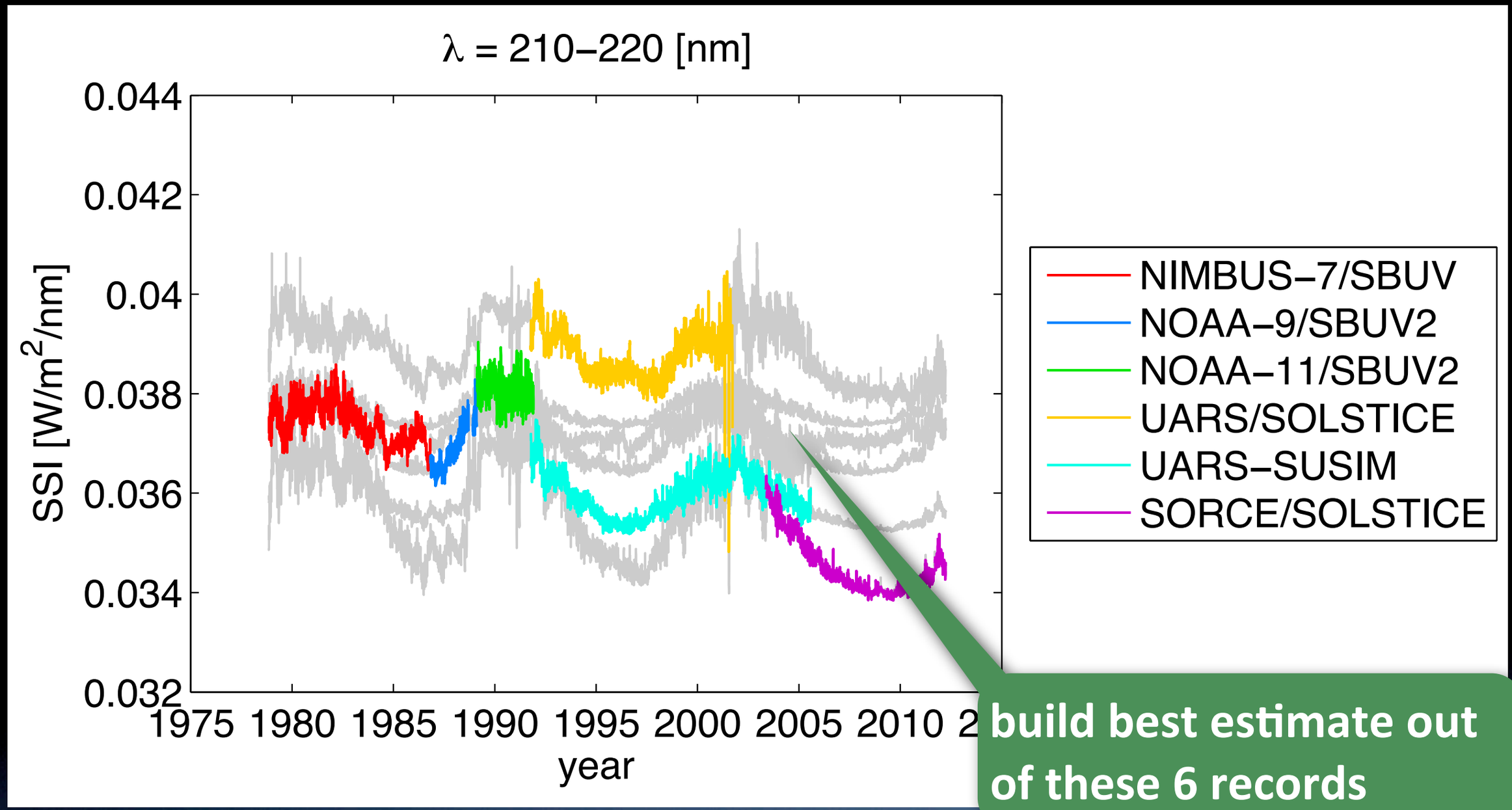

What's next ?

- define the best spectral irradiance dataset, in a Bayesian sense, and test it against SSI models
- check the data for internal consistency

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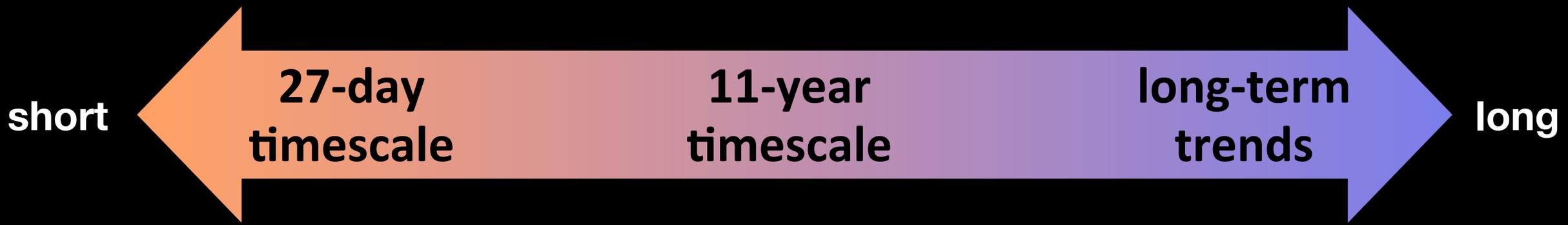
Are recent observations compatible with former ones, on solar cycle scales and beyond ?

The main idea

To be consistent, the observations should agree on several time scales



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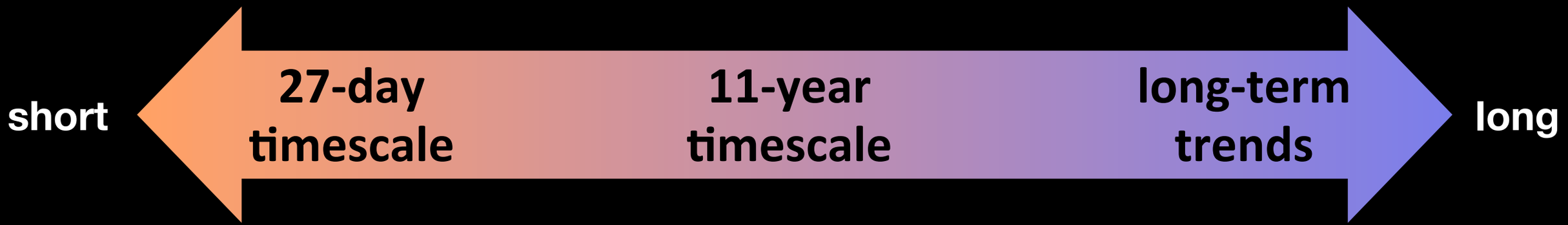

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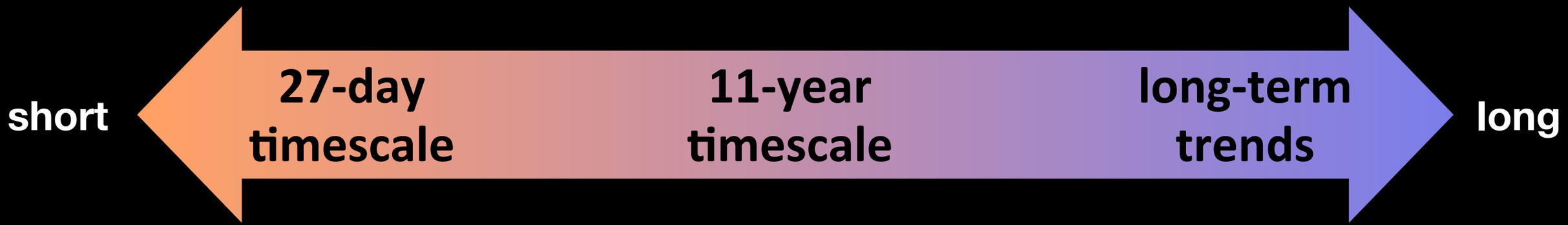

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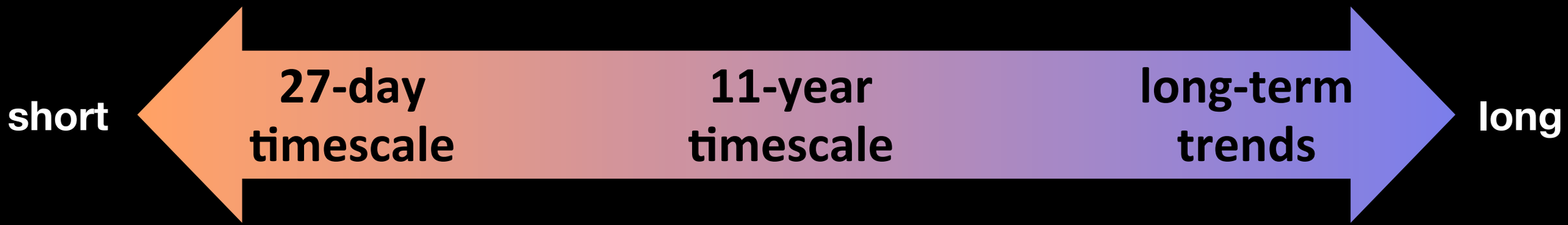


Not so interesting : all records agree (really ?)

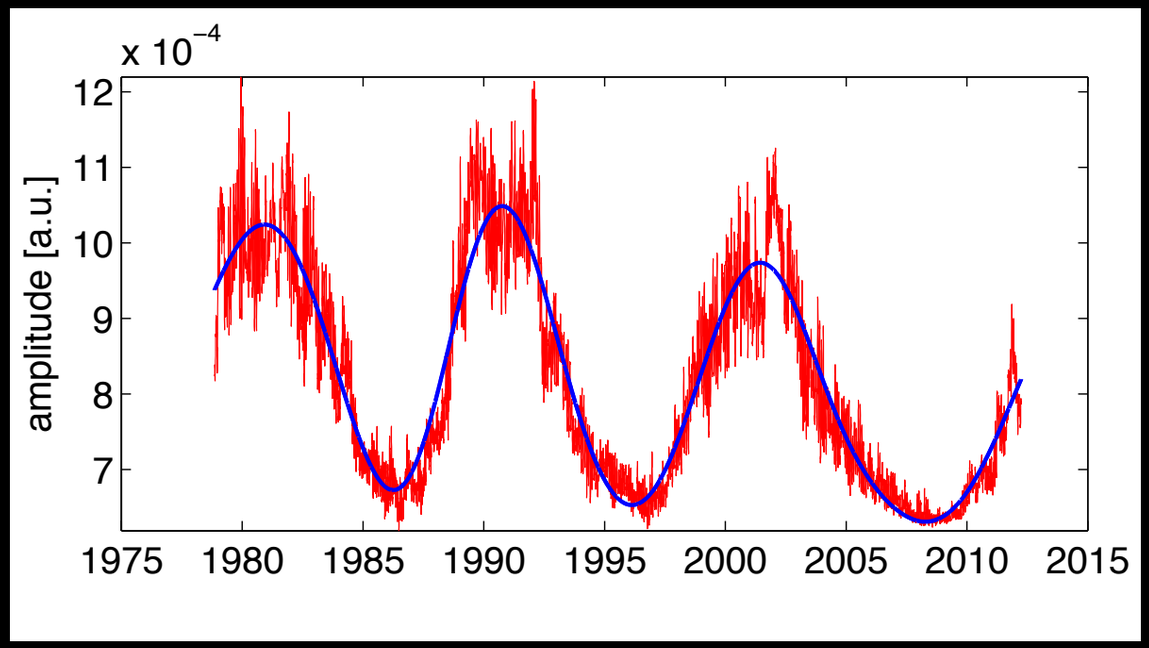
Interesting ! easy to check and any discrepancies are likely to be instrumental

Not interesting : very difficult to assess without independent means

The main idea

- Methodology

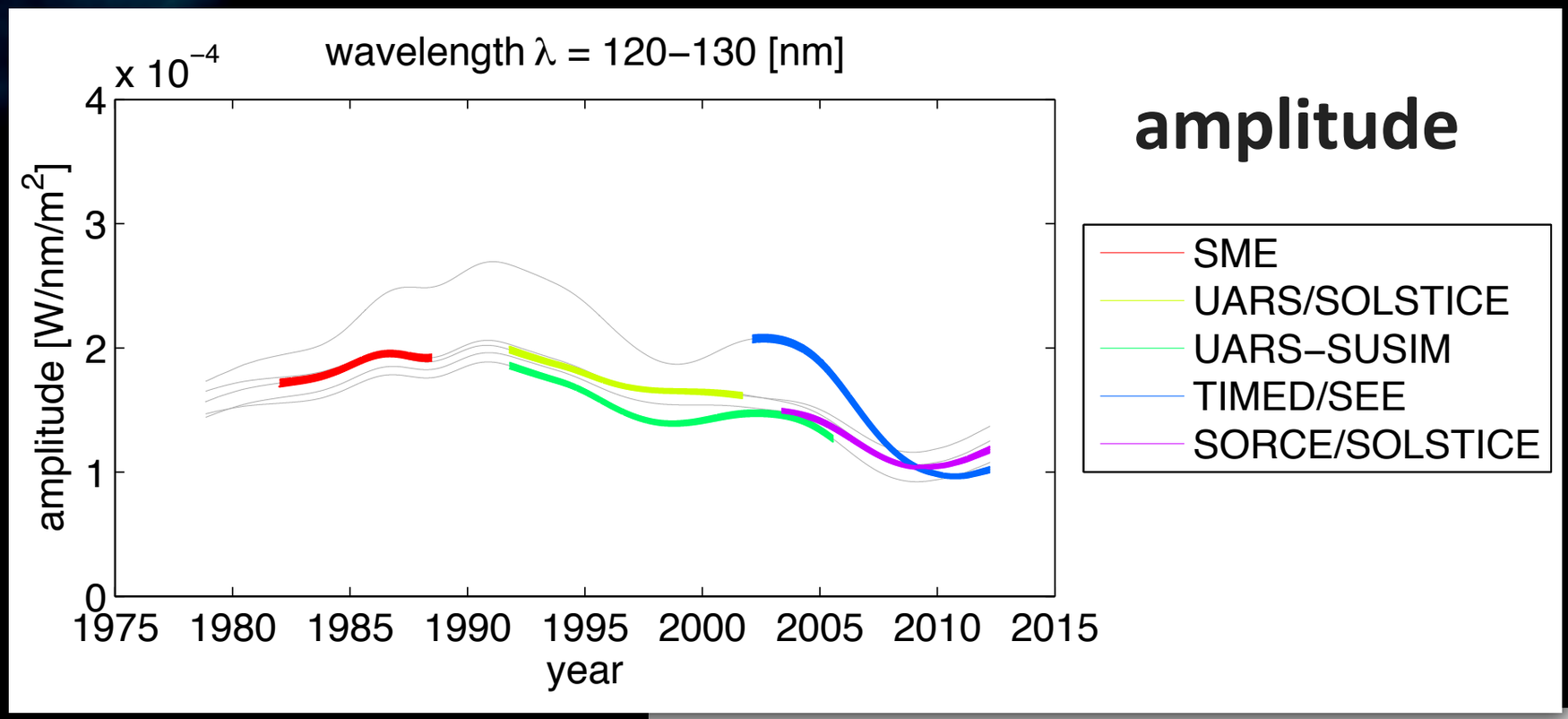
1. Fit an 11-year sine wave with a sliding Gaussian window

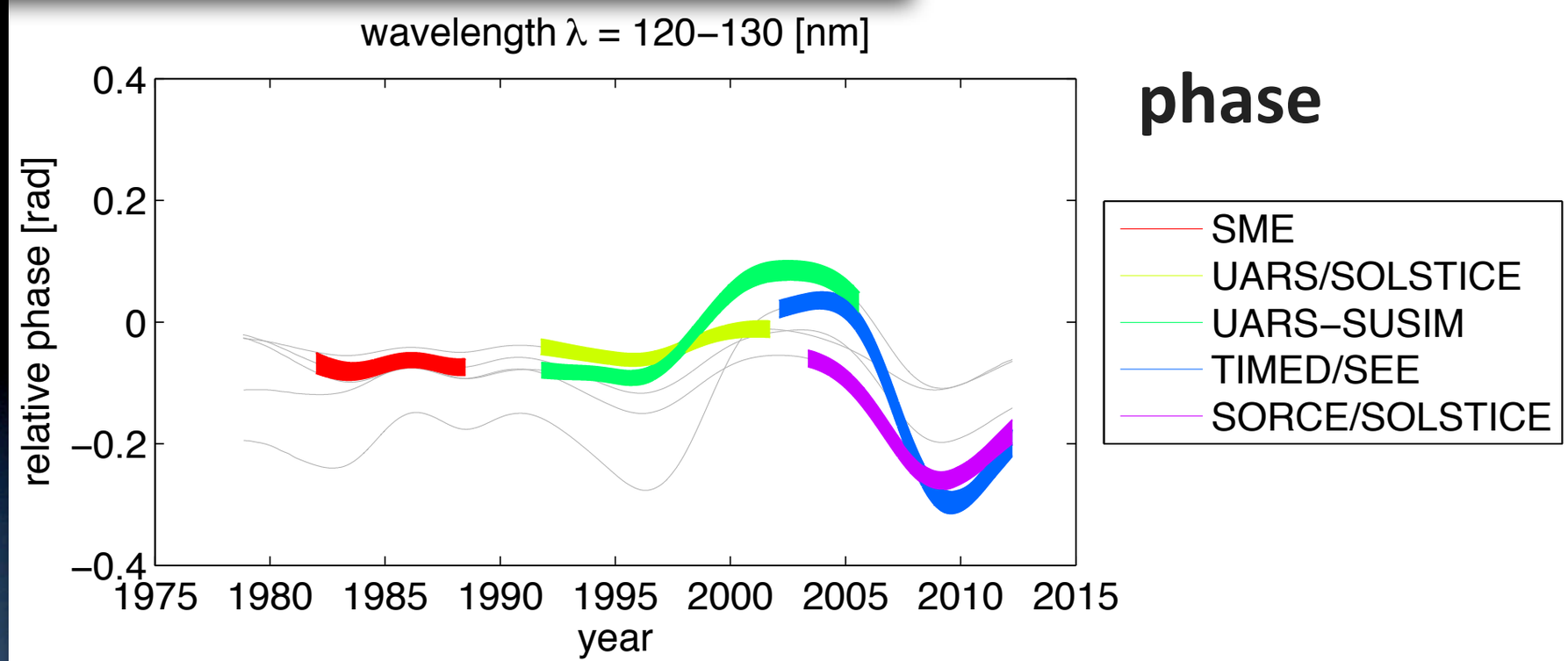


2. For each record determine the modulation **amplitude** and **phase** versus time

3. **Check** whether they agree for the same λ

Results : Lyman-α line





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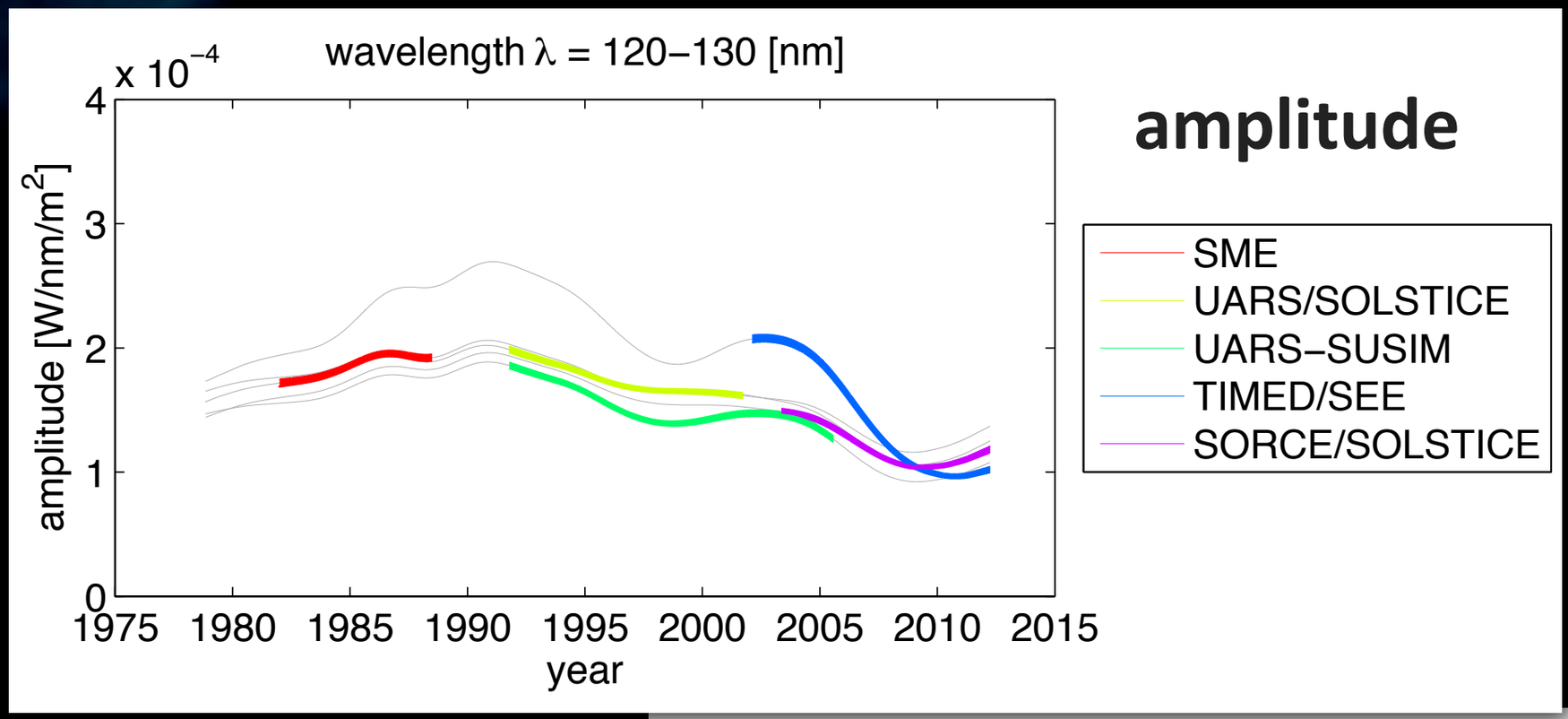
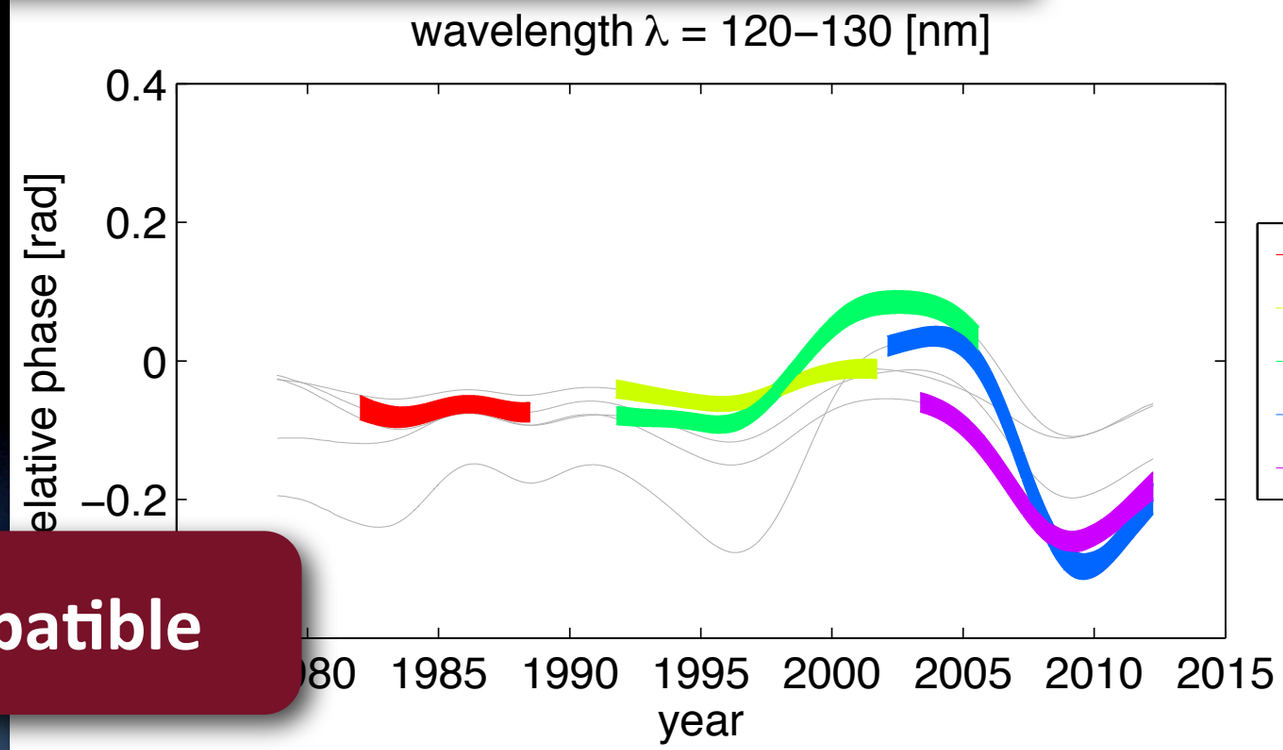


amplitude

- SME
- UARS/SOLSTICE
- UARS–SUSIM
- TIMED/SEE
- SORCE/SOLSTICE



phase

- SME
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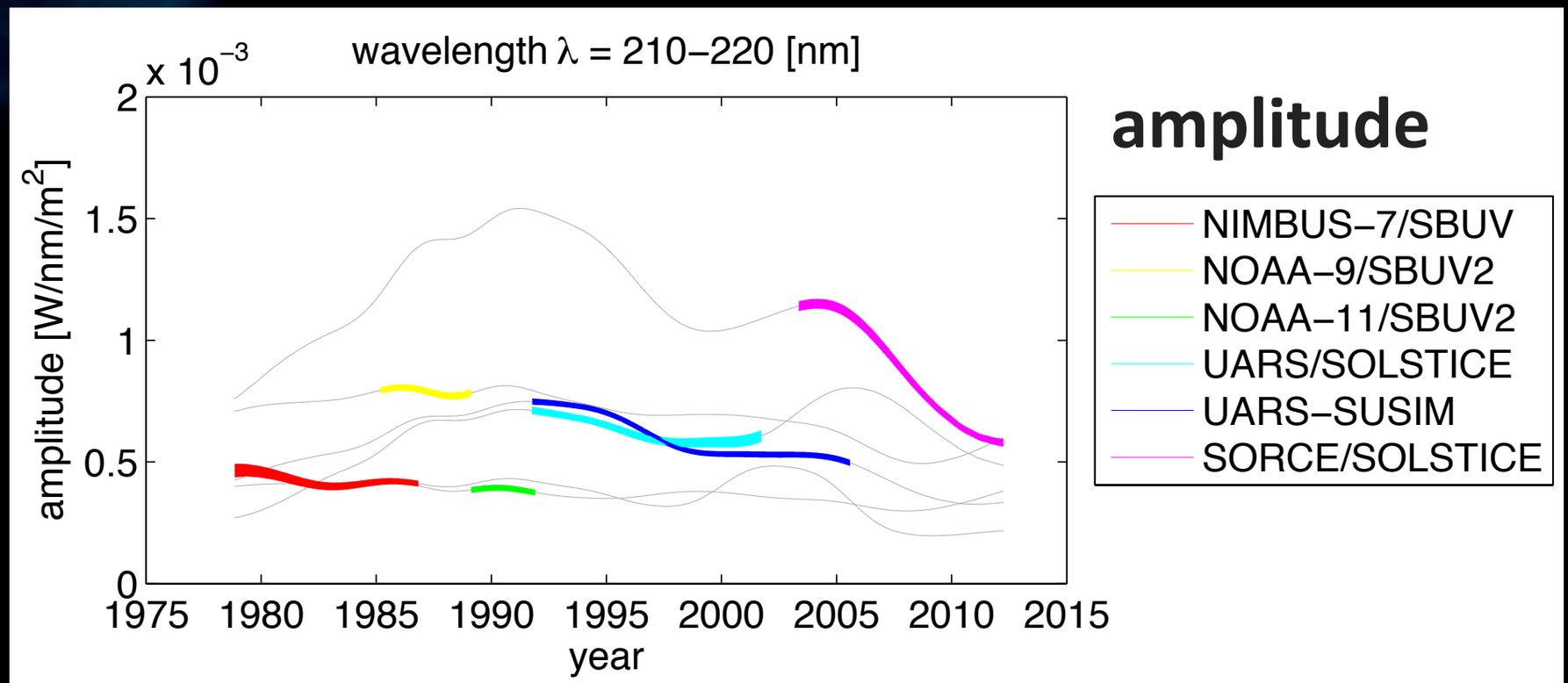
All results are compatible

Results : Herzberg band



amplitude

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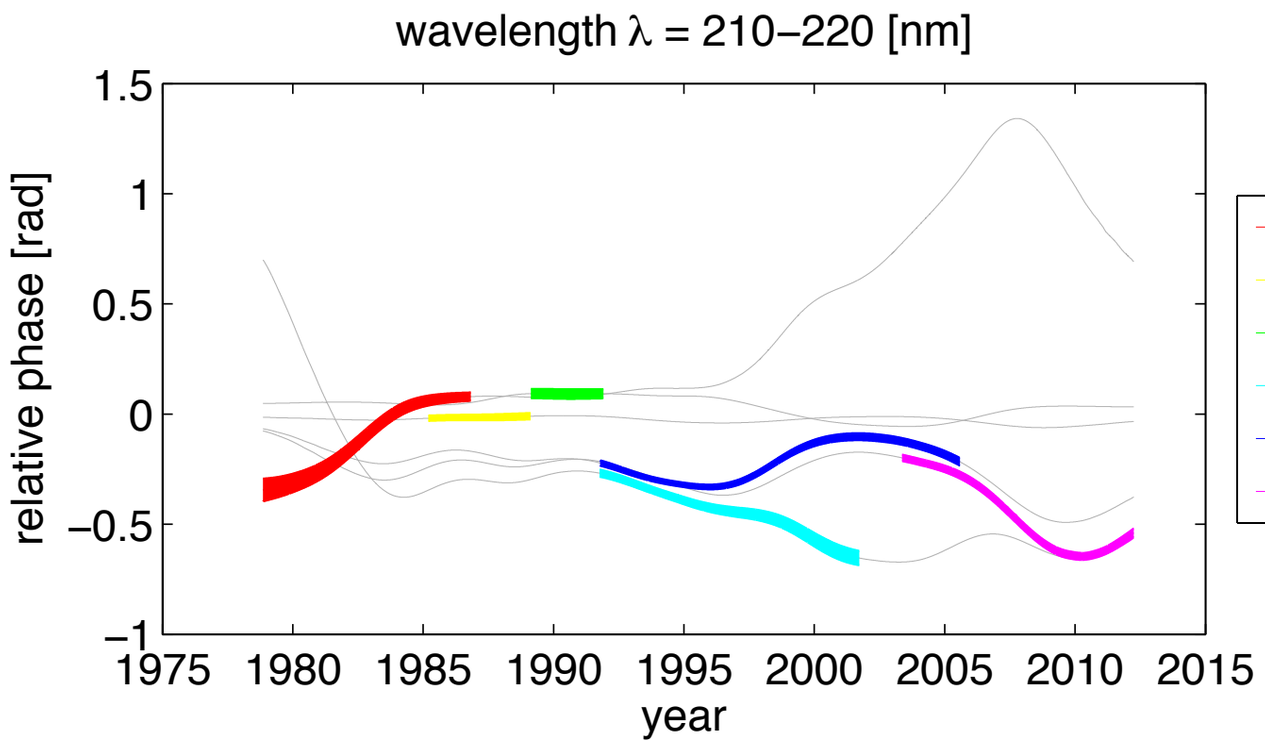
- SORCE/SOLSTICE



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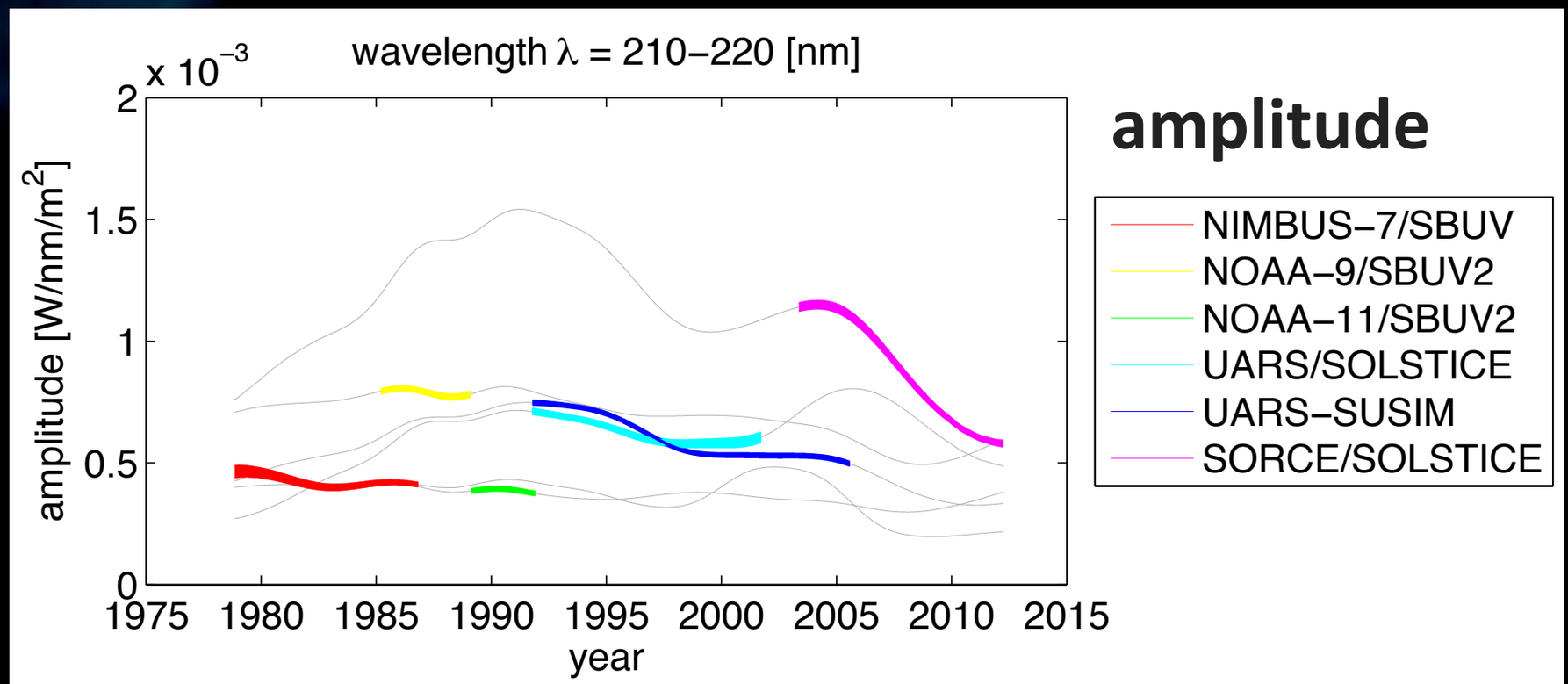

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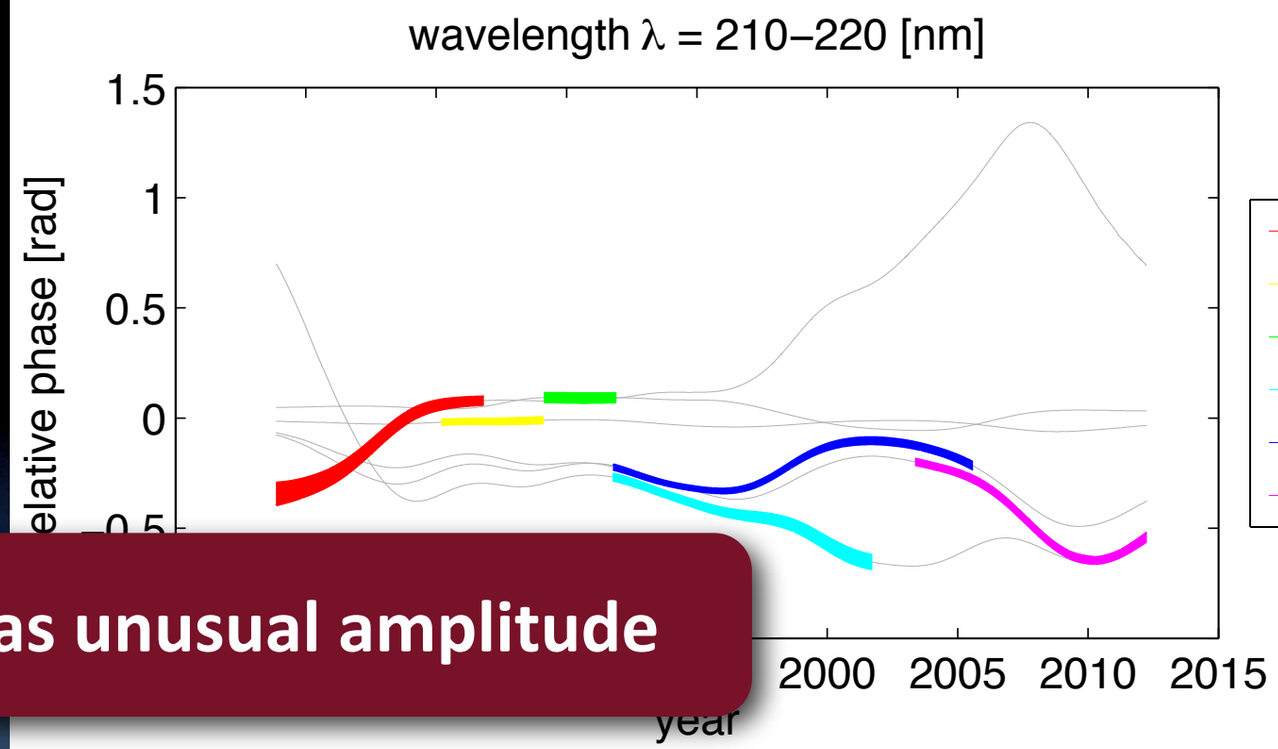

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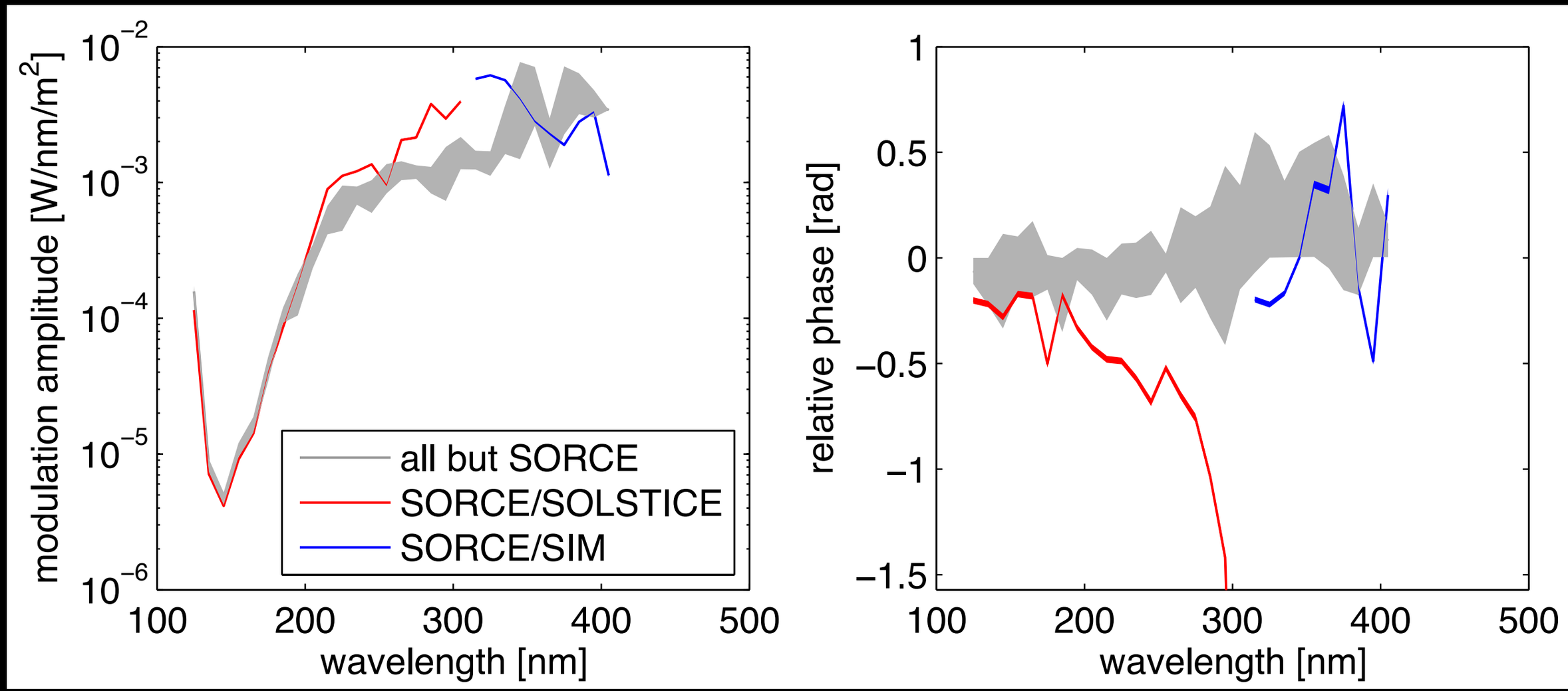
SORCE/SOLSTICE has unusual amplitude

To summarise : is there a problem with SORCE ?



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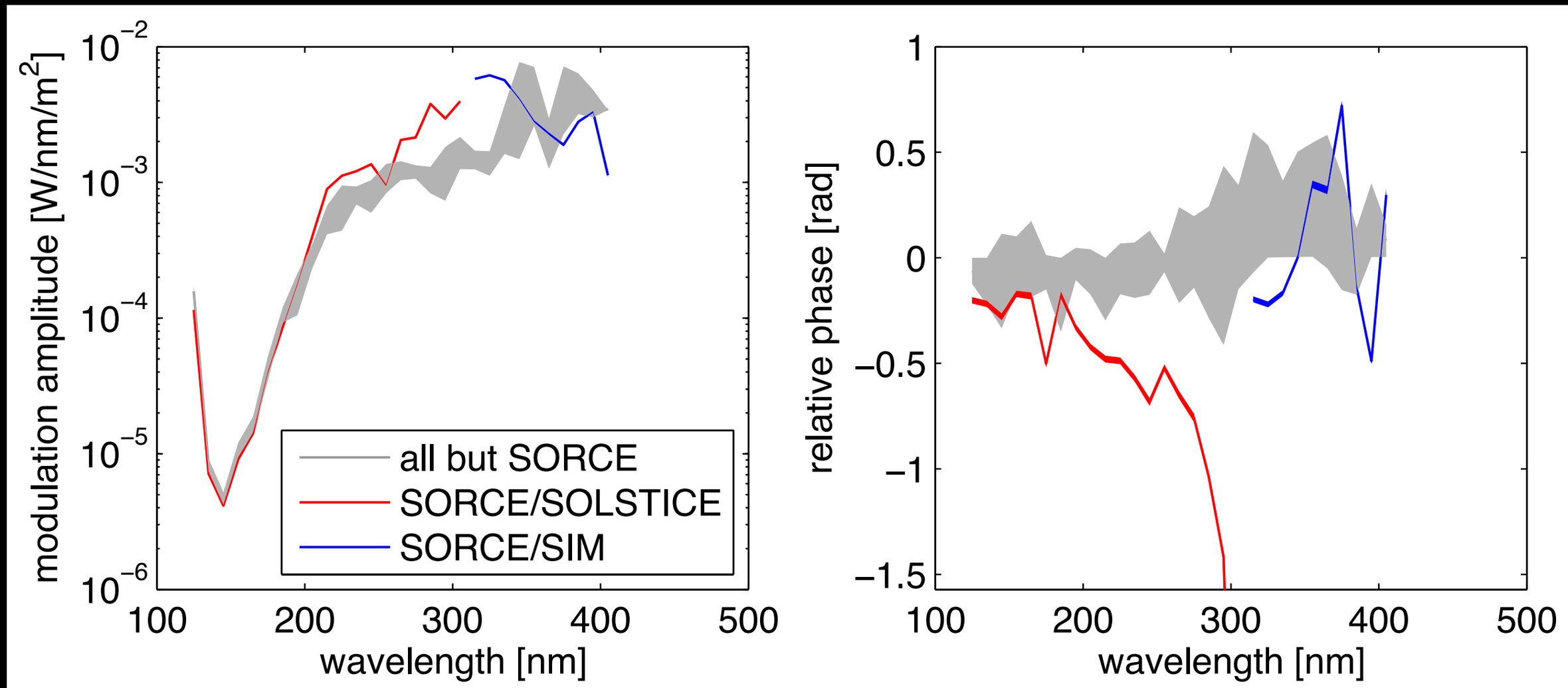

YES, especially for λ = 150-330 nm

Conclusions

- **Powerful framework** for stitching together observations from various instruments
  - This allows us to determine how unusual the last solar cycle is as compared to past (> 1978) UV observations
- **SORCE / SOLSTICE has an anomalous amplitude & phase**, which can be explained by an uncorrected trend