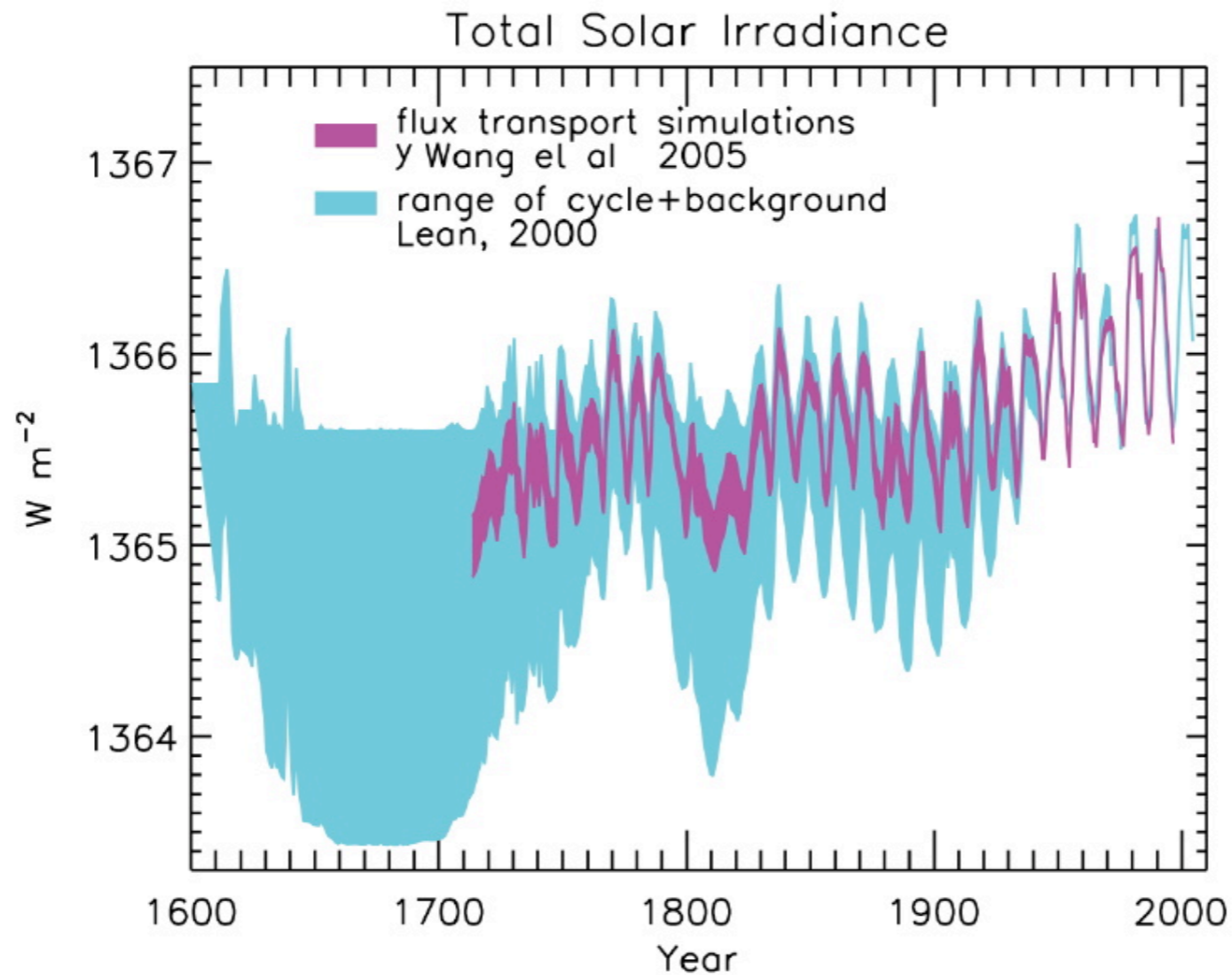
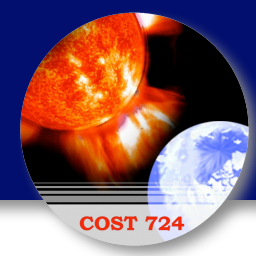


# Can the Total Solar Irradiance be reconstructed from solar activity proxies ?



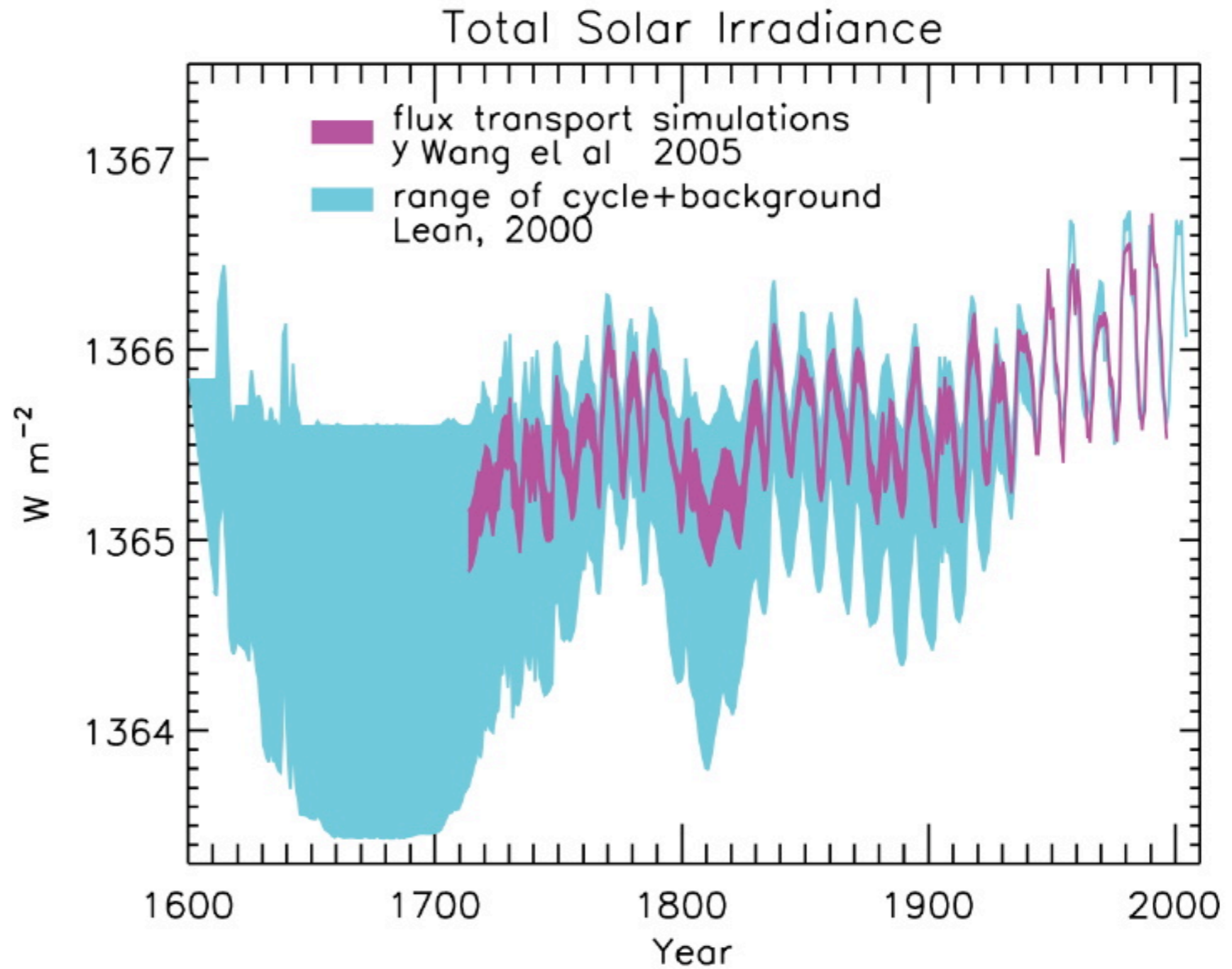
T. Dudok de Wit<sup>1</sup>, M. Kretzschmar<sup>1</sup>, J. Lilensten<sup>2</sup>, P.-O. Amblard<sup>3</sup>,  
S. Moussaoui<sup>4</sup>, J. Aboudarham<sup>5</sup>, F. Auchère<sup>6</sup>

<sup>1</sup> LPCE, Orléans, <sup>2</sup> LPG, Grenoble, <sup>3</sup> GIPSAIab, Grenoble, <sup>4</sup> IRCCYN, Nantes, <sup>5</sup>  
LESIA, Paris, <sup>6</sup> IAS, Orsay

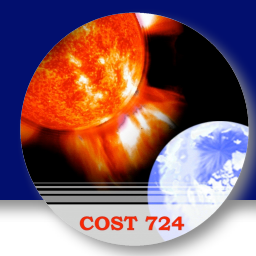


# Why reconstruct the TSI ?

There have been many attempts to reconstruct pre-1978 values of Total Solar Irradiance (TSI) from proxy data

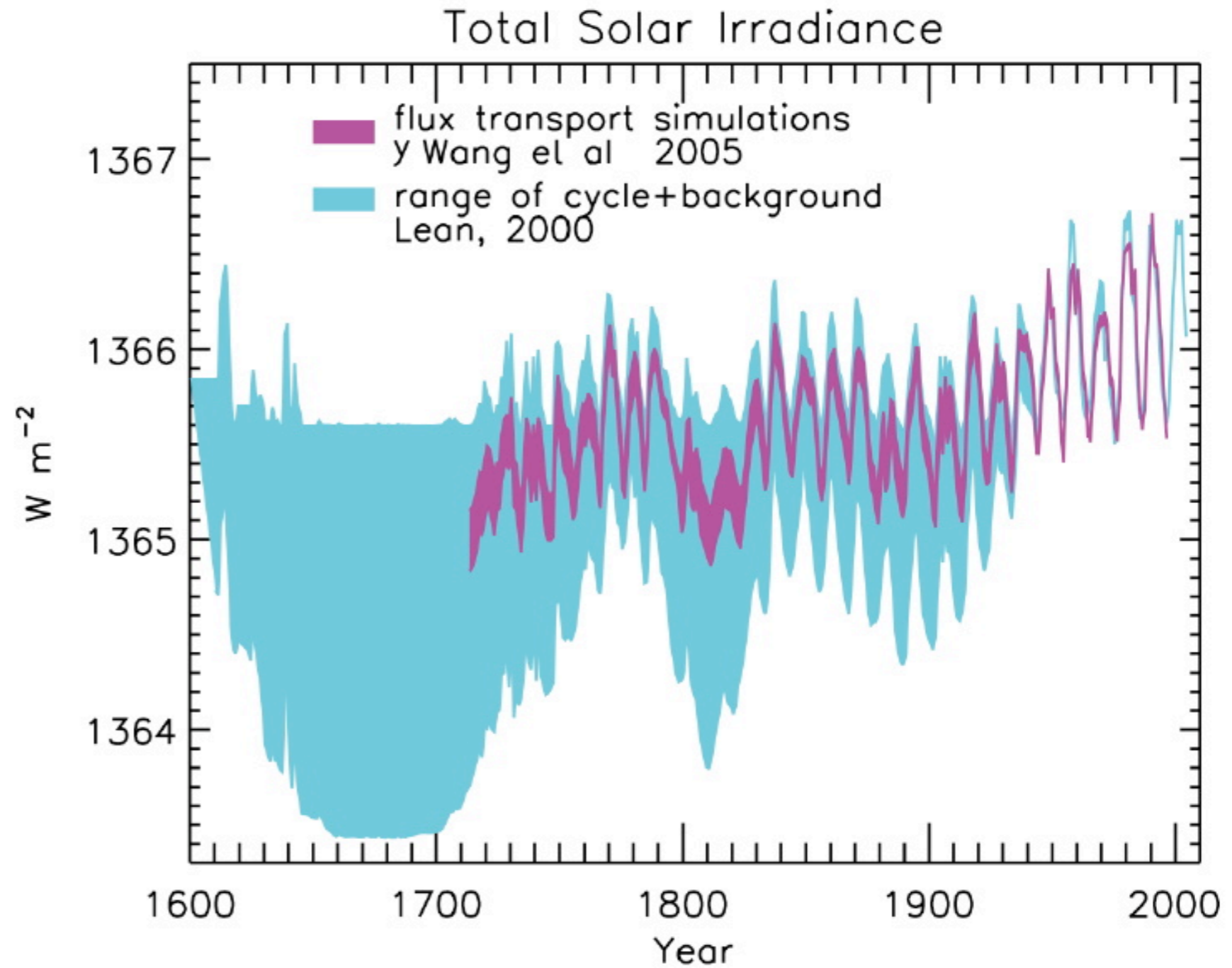


*Lean & Haigh (2007)*



# Why reconstruct the TSI ?

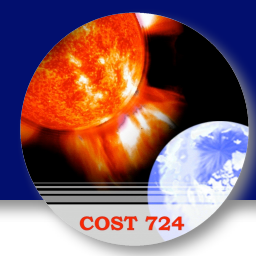
There have been many attempts to reconstruct pre-1978 values of Total Solar Irradiance (TSI) from proxy data



*Lean & Haigh (2007)*

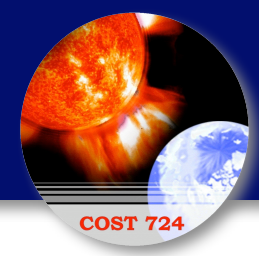
Such reconstruction are needed to

- assess the solar forcing on climate
- understand the causes of the variability of the TSI



# How to reconstruct the TSI

- Reconstructions of the TSI rely on
  - solar activity indices (sunspot number, ...)
  - geomagnetic indices (aa index, ...)
  - cosmogenic isotopes
  - solar dynamo models
- short-term reconstructions (days) have been quite successful so far...
- ...but long-term reconstructions (years) are much more difficult



# There is a problem...

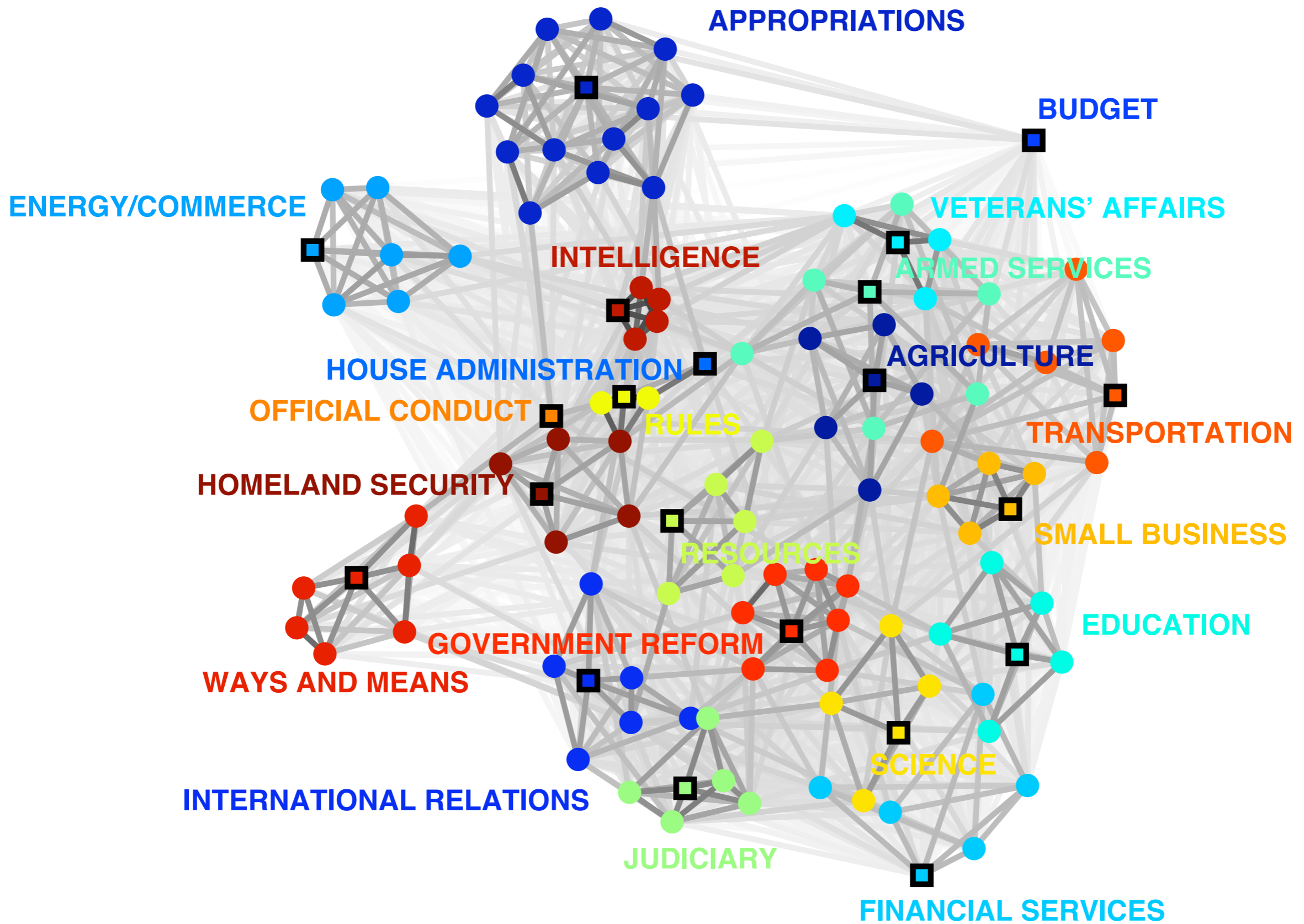
before determining **HOW** to reconstruct the TSI from proxies

*we need to determine*

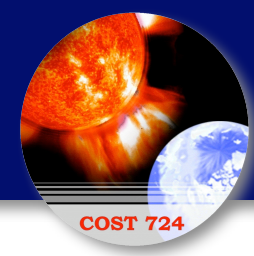
**IF** this reconstruction can be done at all

and

**WHICH** proxies are the regressors for the models

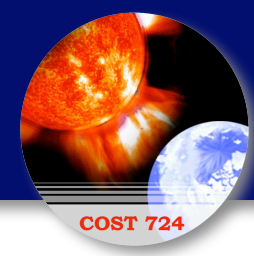


Community structure in the 108<sup>th</sup> U.S. house of representatives  
 each dot represents a subcommittee  
 (M. Porter et al., [arxiv.org/physics/0602033](http://arxiv.org/physics/0602033))



# Networks : studying interactions

- Networks are important because **structure affects function**
- Examples
  - spread of disease in a population
  - robustness and stability of power grids
  - ...
- Networks are today studied within the frame of **statistical physics** (percolation, critical exponents, phase transitions, ...)

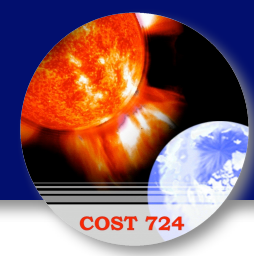


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**Here we compare the TSI against 14 solar proxies, using daily measurements from 26 Nov 1978 till 30 Sep 2007**

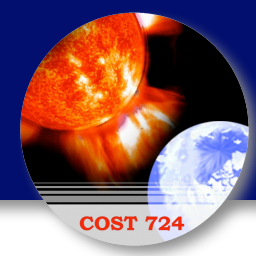




# The data

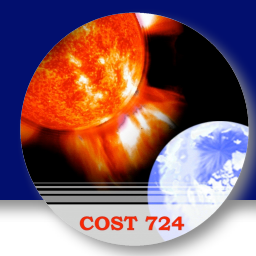
The 14 proxies for solar activity are:

1. **ISN** : international sunspot number (from SIDC)
2. **f10.7** : solar radio flux at 10.7 cm (Penticton Obs.)
3. **MgII index** : core to wing ratio of Mg II line (R. Viereck, NOAA)  
—> upper photosphere and chromosphere
4. **CaK index** : Ca K II equivalent width (Kitt Peak Obs.)  
—> plages and faculae
5. **HeI index** : equivalent width of He I line (Kitt peak Obs.)  
—> plages and faculae
6. **Lya index** : composite Lyman- $\alpha$  irradiance (T. Woods, LASP)  
—> upper photosphere up to corona



# The data

7. **MPSI** : magnetic plage strength index (Mt. Wilson Obs.)  
—> contribution from regions with  $10 < |B| < 100$  G
8. **MWSI** : Mount Wilson sunspot index (Mt. Wilson Obs.)  
—> contribution from regions with  $|B| > 100$  G
9. **DSA** : daily sunspot area (Greenwich Obs.)
10. **PSI** : photometric sunspot index (San Fernando Obs.)
11. **Mean magnetic field** of the Sun (Wilcox Obs.)
12. **OFI** : optical flare index (Ataç and Özgüç)  
—> intensity x duration of flares
13. **Coronal index** (Rybansky) —> total energy emitted by the solar corona in the FeXIV line at 530.3 nm
14. **CLMX** : neutron flux at Climax —> cosmic rays



# The TSI data

and also 3 TSI composites from



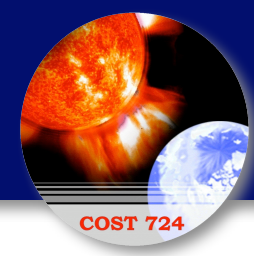
PMOD (Fröhlich & Lean)



ACRIM (Willson & Mordvinov)



SARR (Mekaoui & DeWitte)



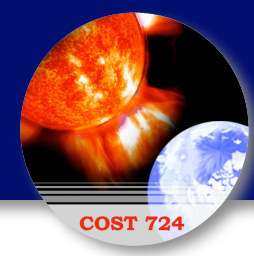
# The method

- Each proxy captures a different aspect of the solar variability
- Connections between proxies should reveal which mechanisms affect the TSI
- We compute the **mutual information**  $I(x, y)$  between each pair of proxies = amount of information that proxy  $x$  reveals about proxy  $y$

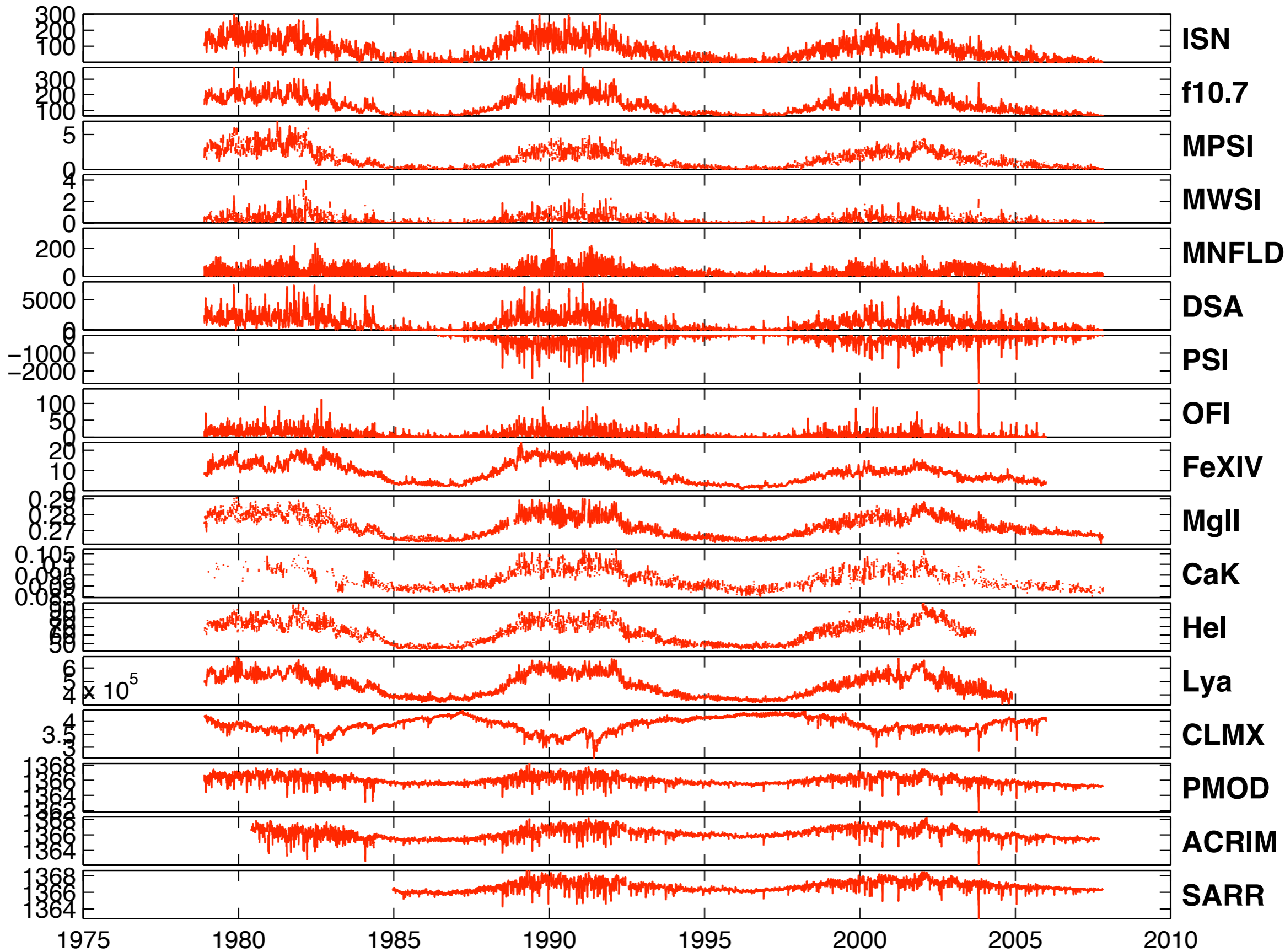
$$I(x, y) = H(x) - H(x|y)$$

$$H(x) = - \int p(x) \log p(x) dx \quad \text{is the Shannon entropy}$$

$p(x)$  is the probability density



# The data

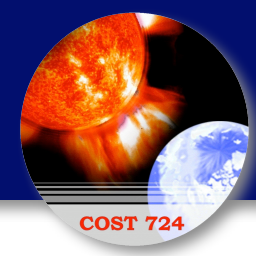




# Different scales

The analysis is done separately for different scales,  
using a wavelet ("à trous") decomposition

Here, we focus on



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Here, we focus on



## **short scale fluctuations**

< 80 days

effect of solar rotation,  
center-to-limb effects, ...

## **long scale fluctuations**

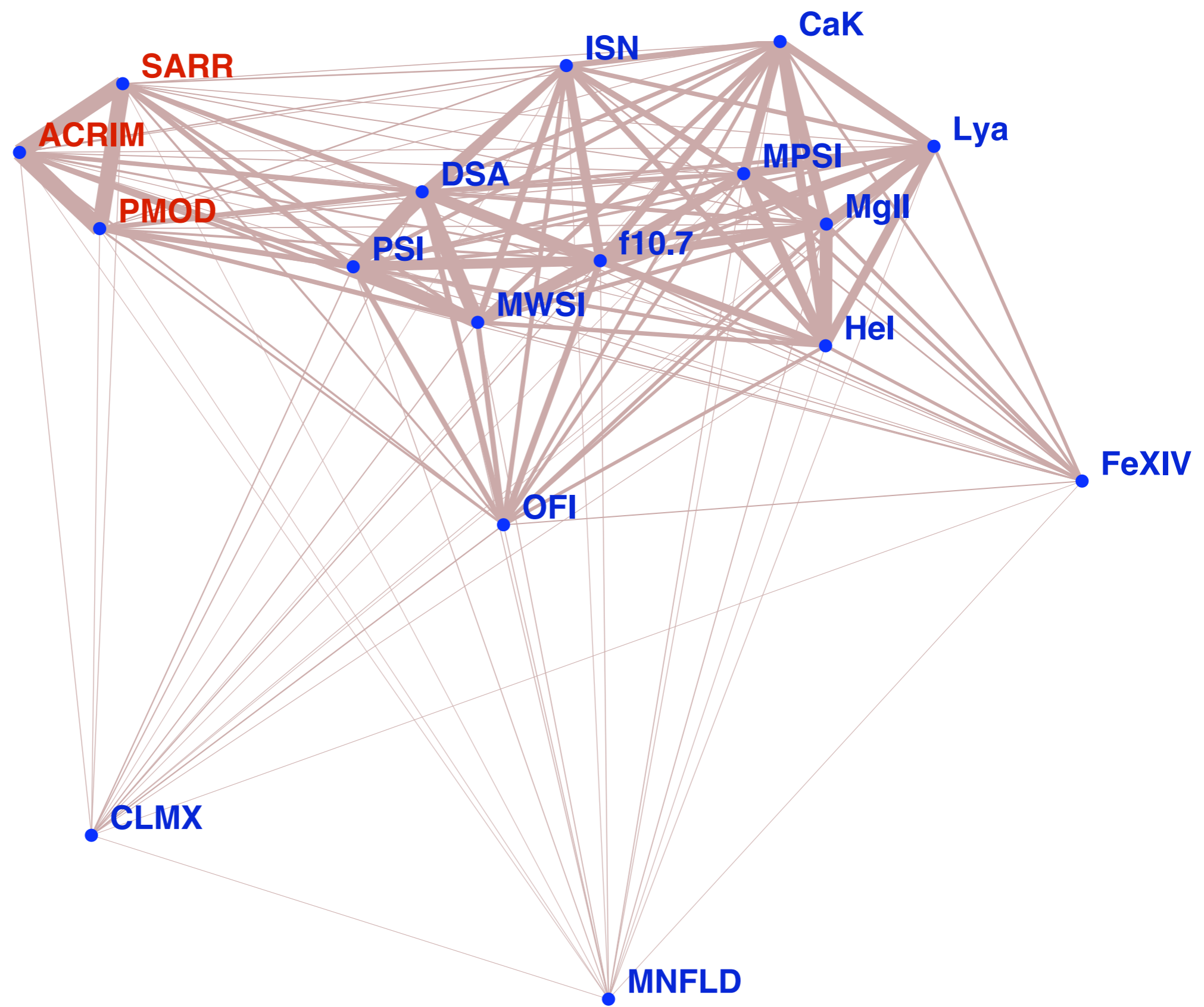
> 1 year

effect of solar magnetic  
cycle + trend

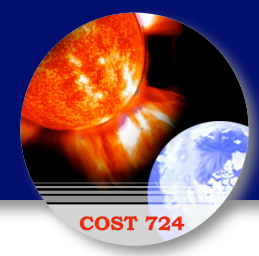


# Connections for **short** time scales

line thickness  
reflects level of  
mutual information

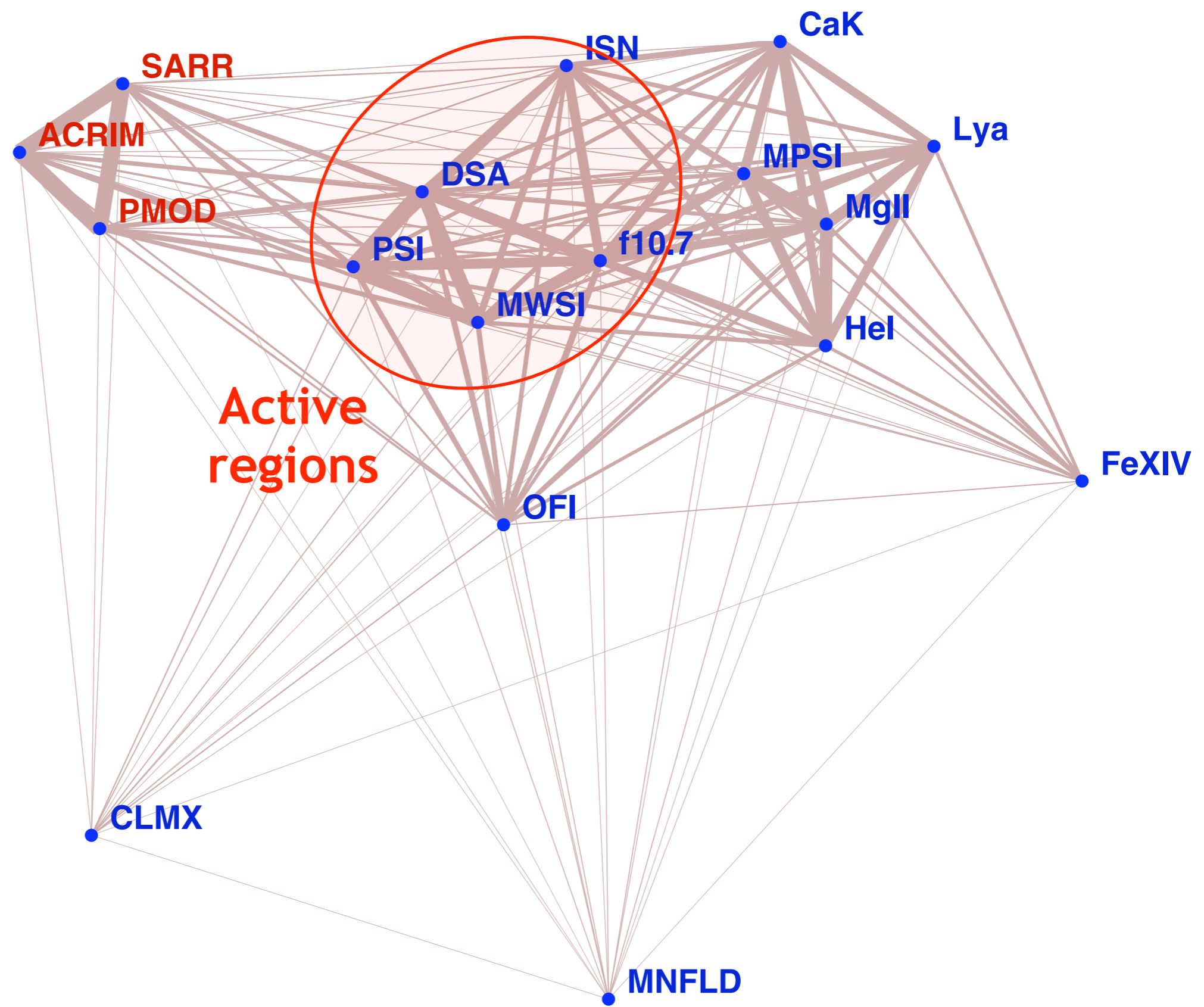


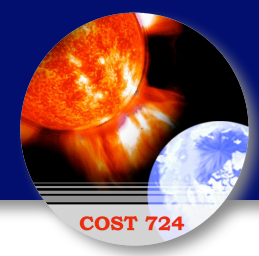




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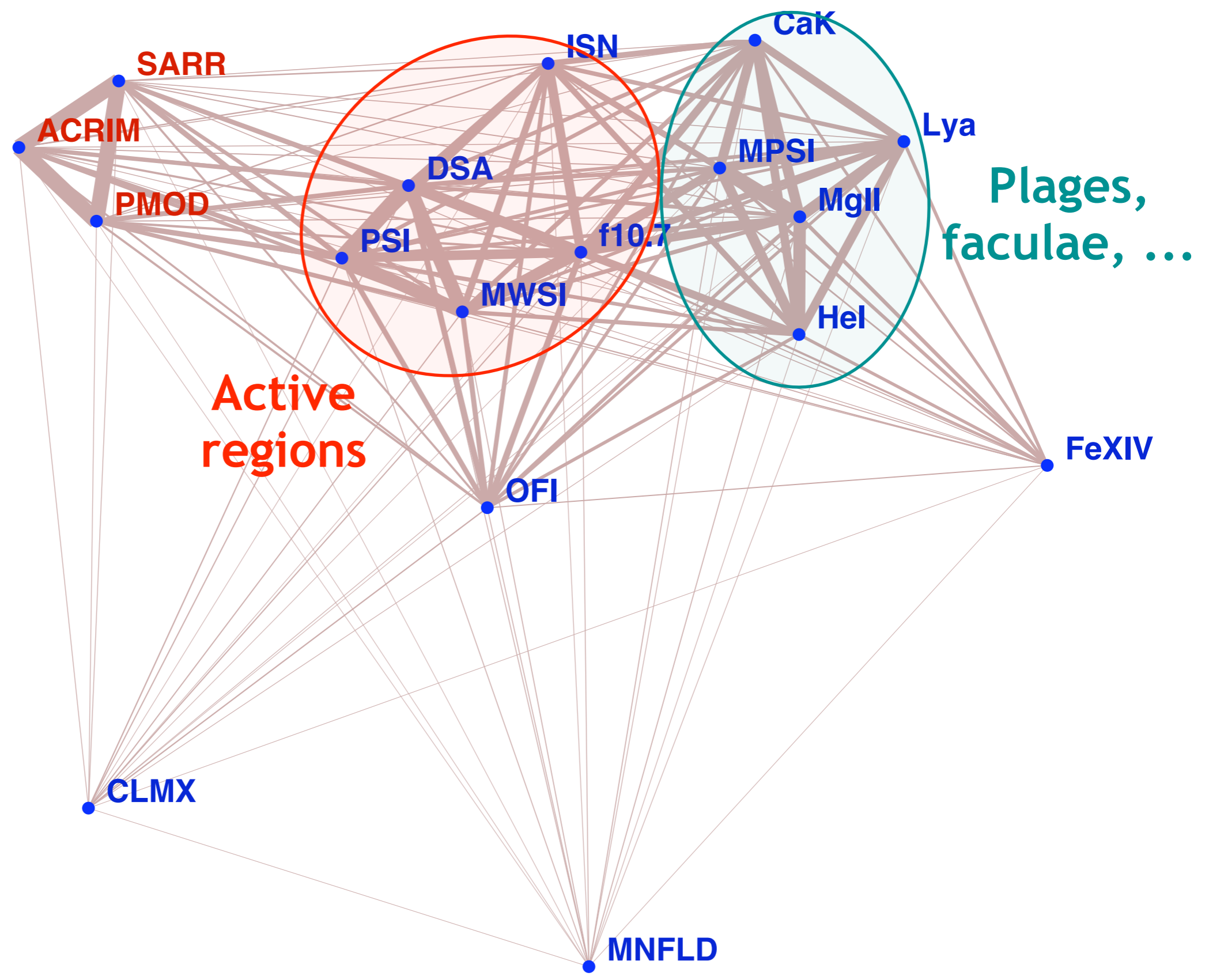
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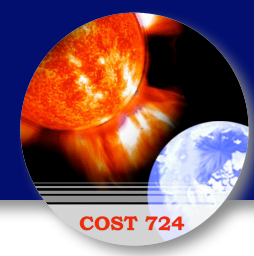




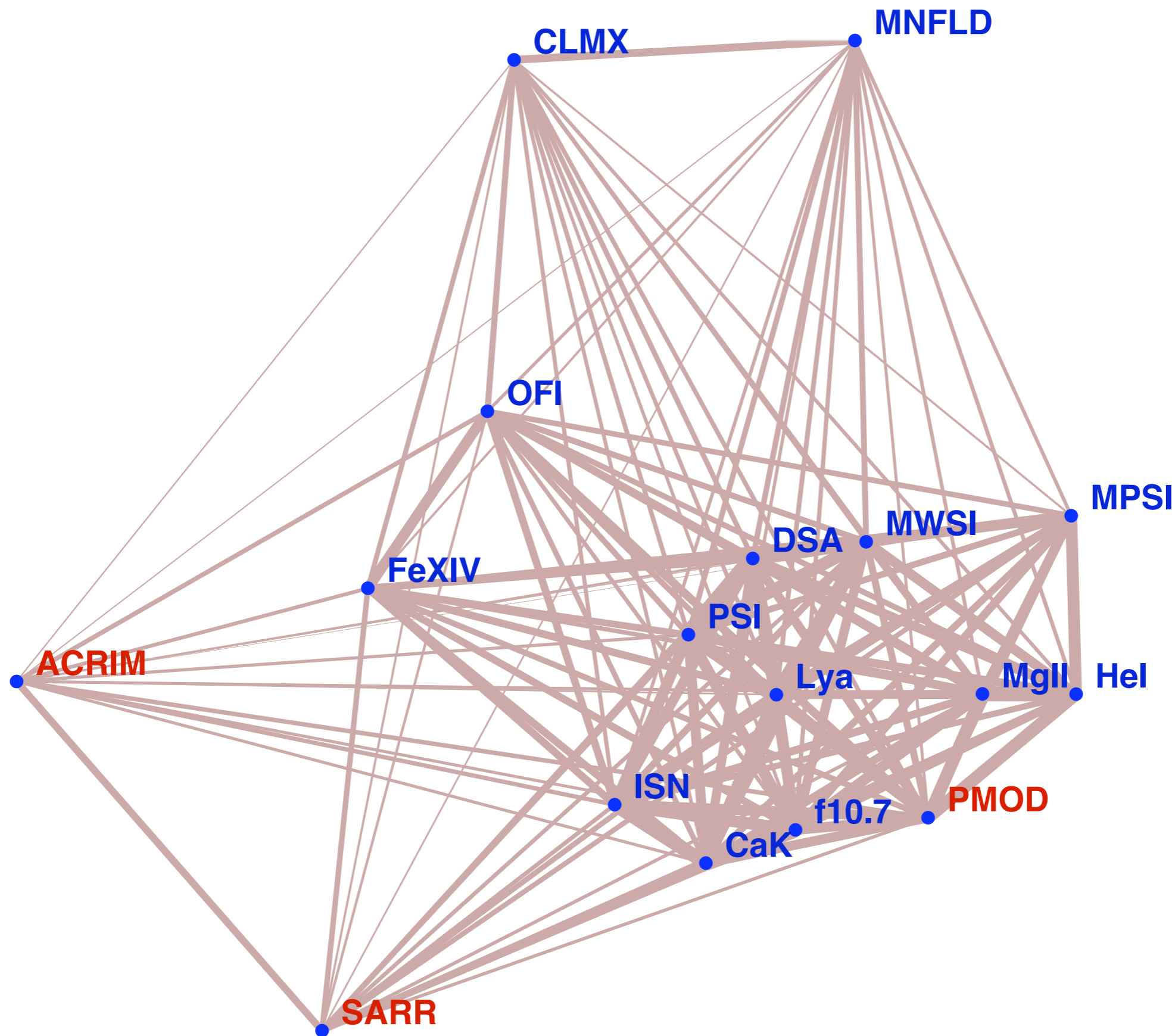
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# Connections for **long** time scales





# Conclusions (1/3)

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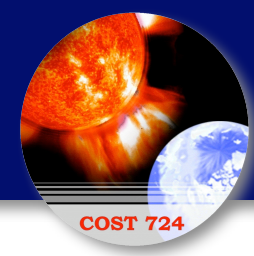
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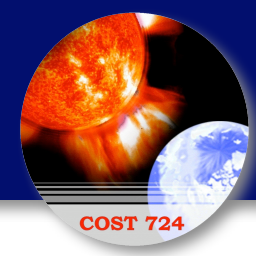


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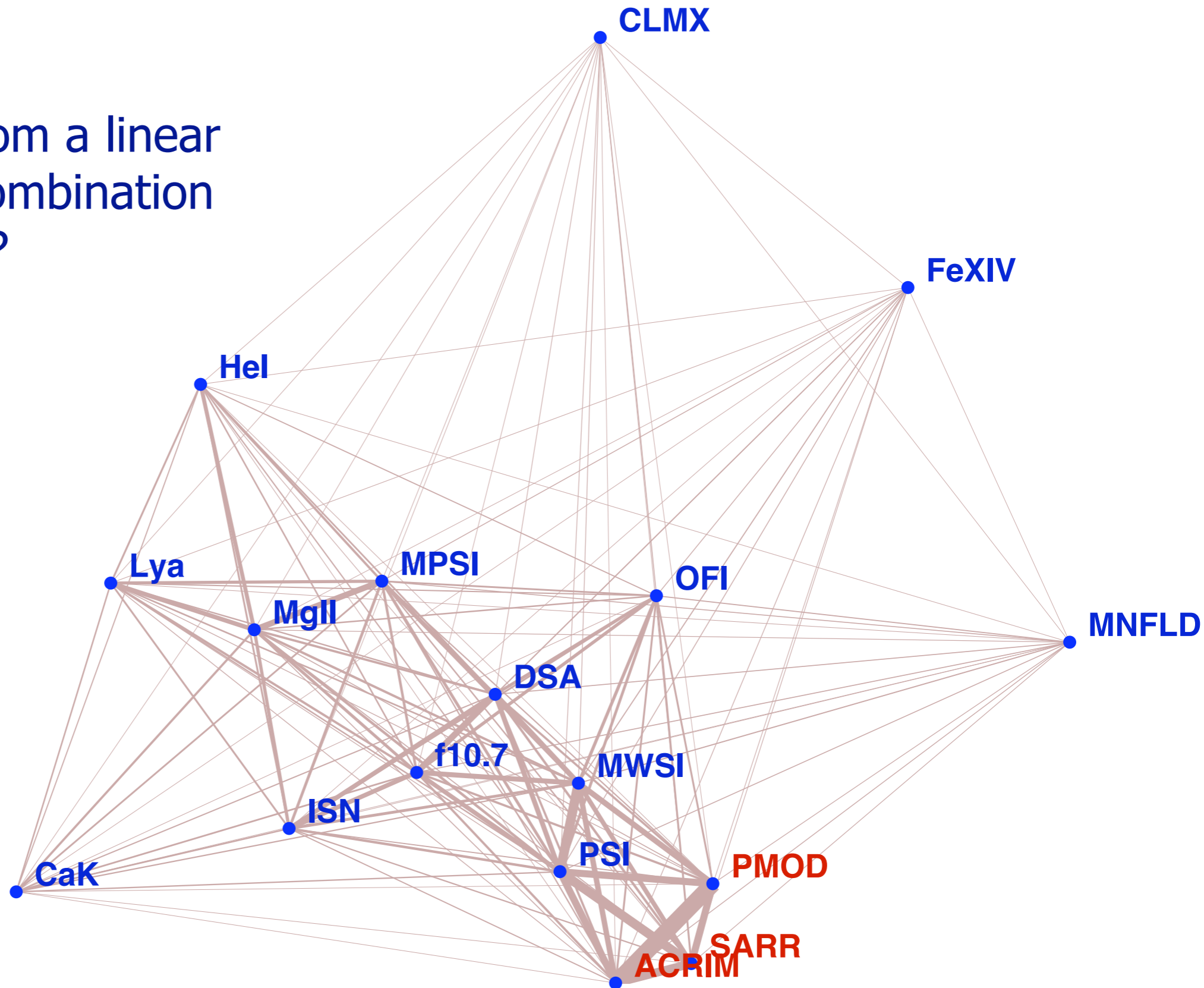
→ flares do also contribute to the variability, see next talk



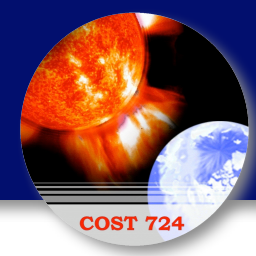
# Conclusions (2/3)

Can the TSI be reconstructed from a linear or a nonlinear combination of solar proxies ?

**Very unlikely**



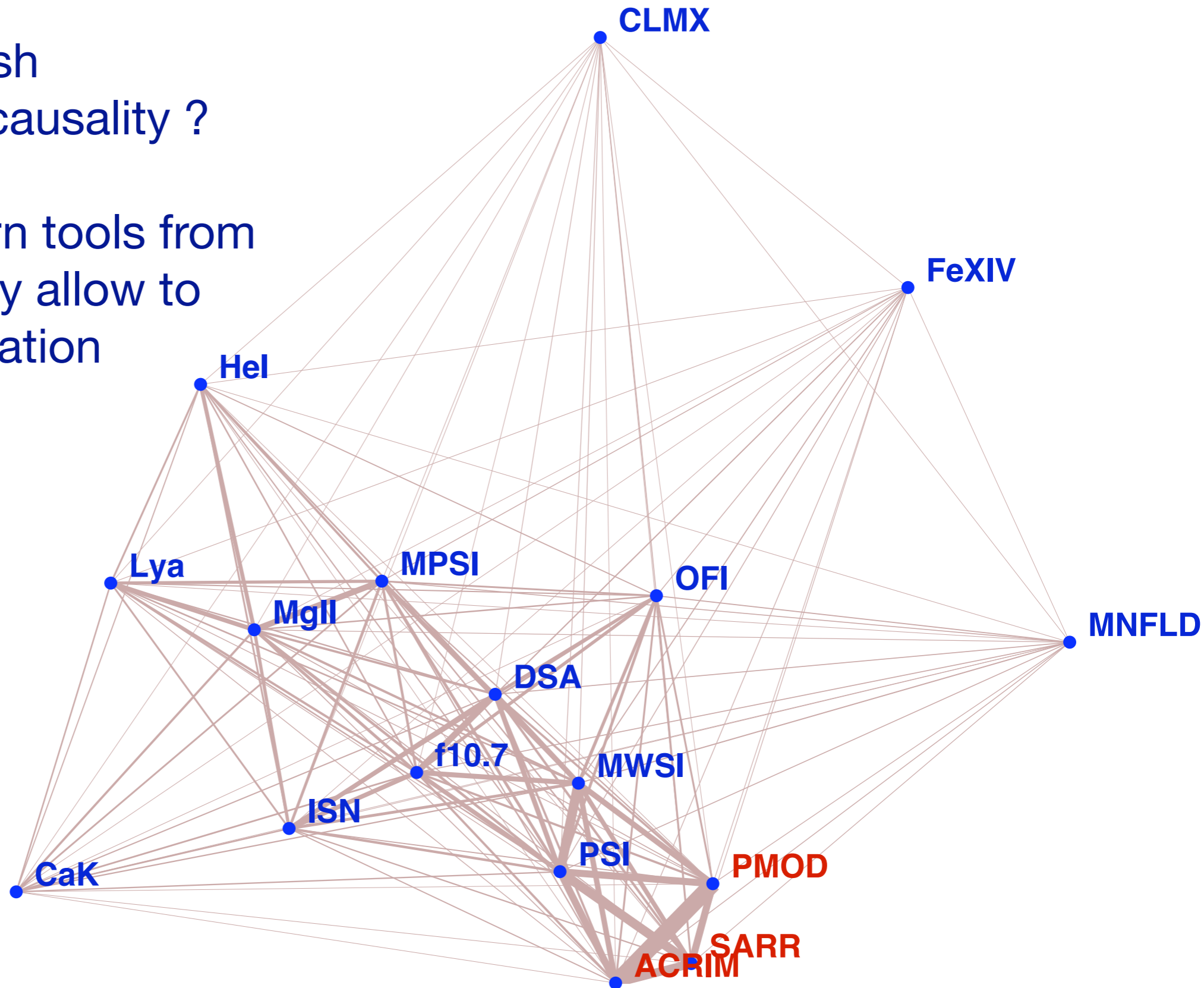


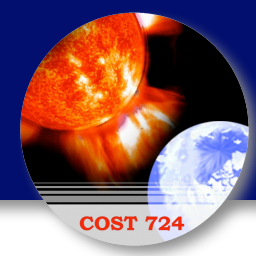


# Conclusions (3/3)

Can we distinguish correlation from causality ?

Possibly... modern tools from information theory allow to determine information transfer rates.

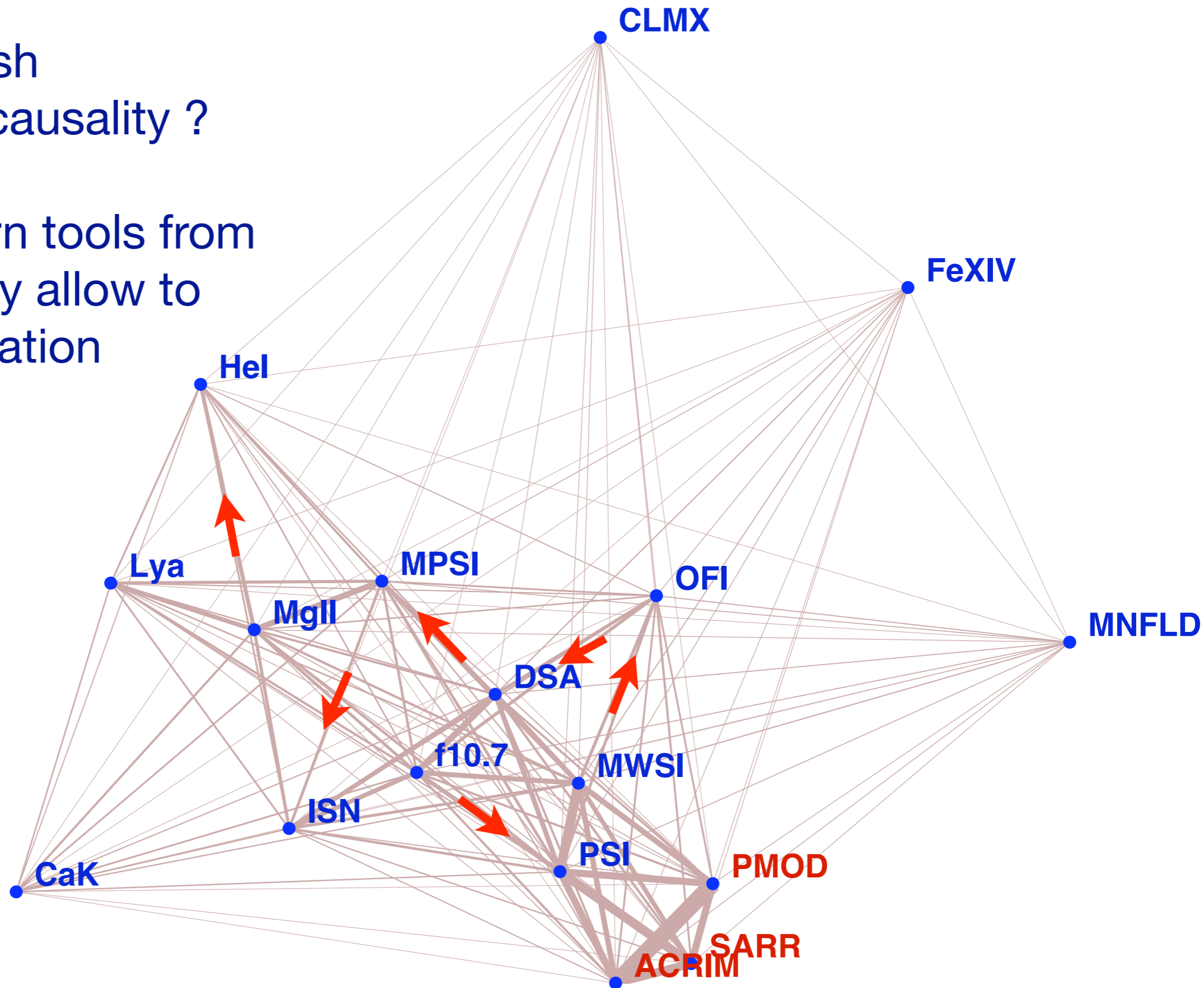




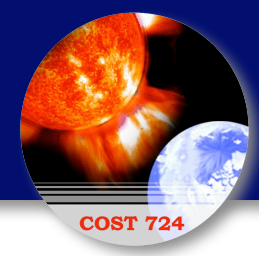
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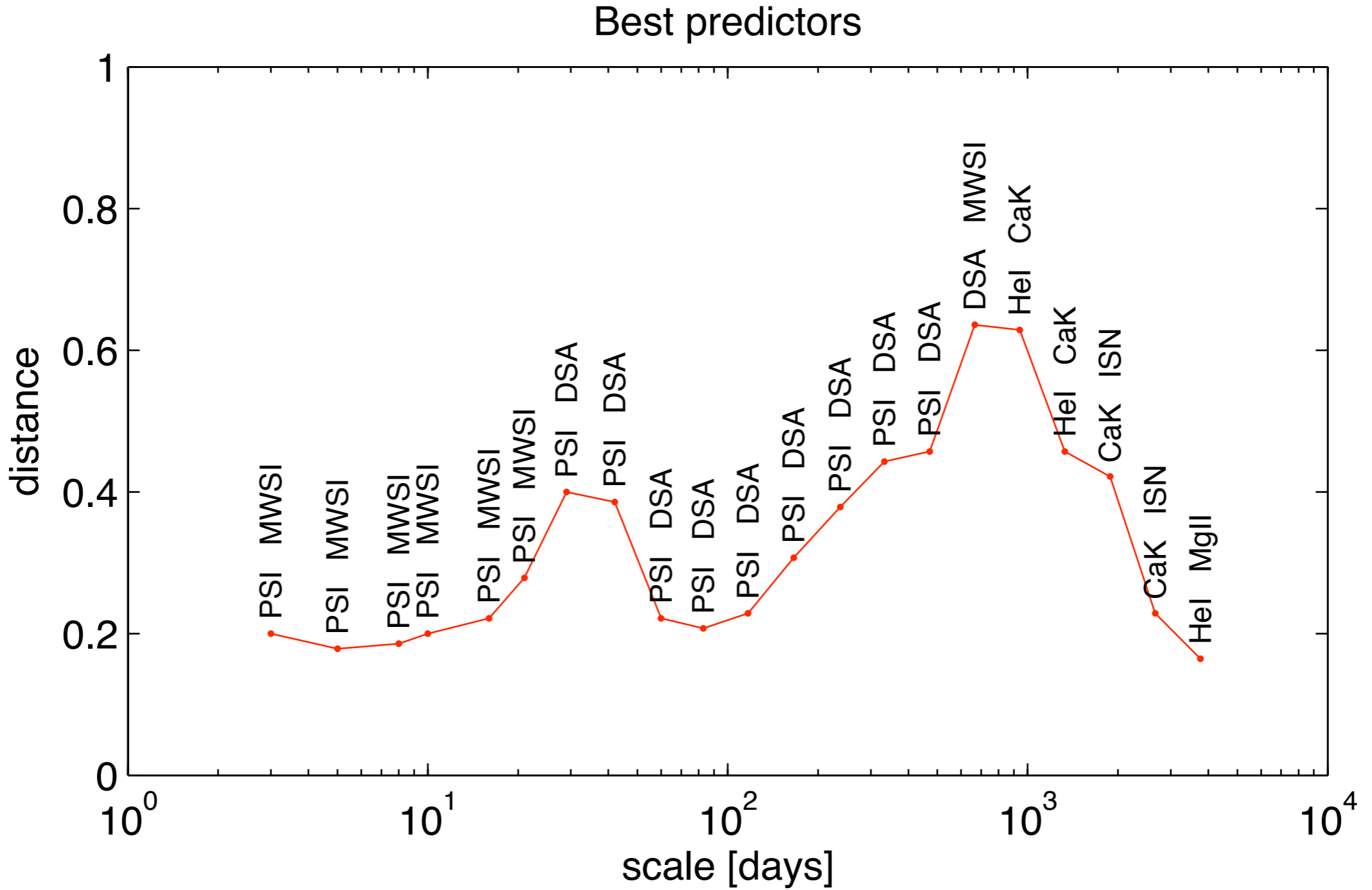
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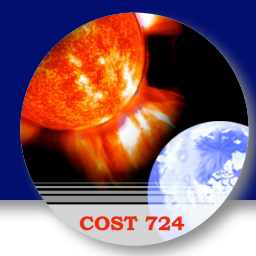






# What are the best predictors ?





# Multiscale decomposition

