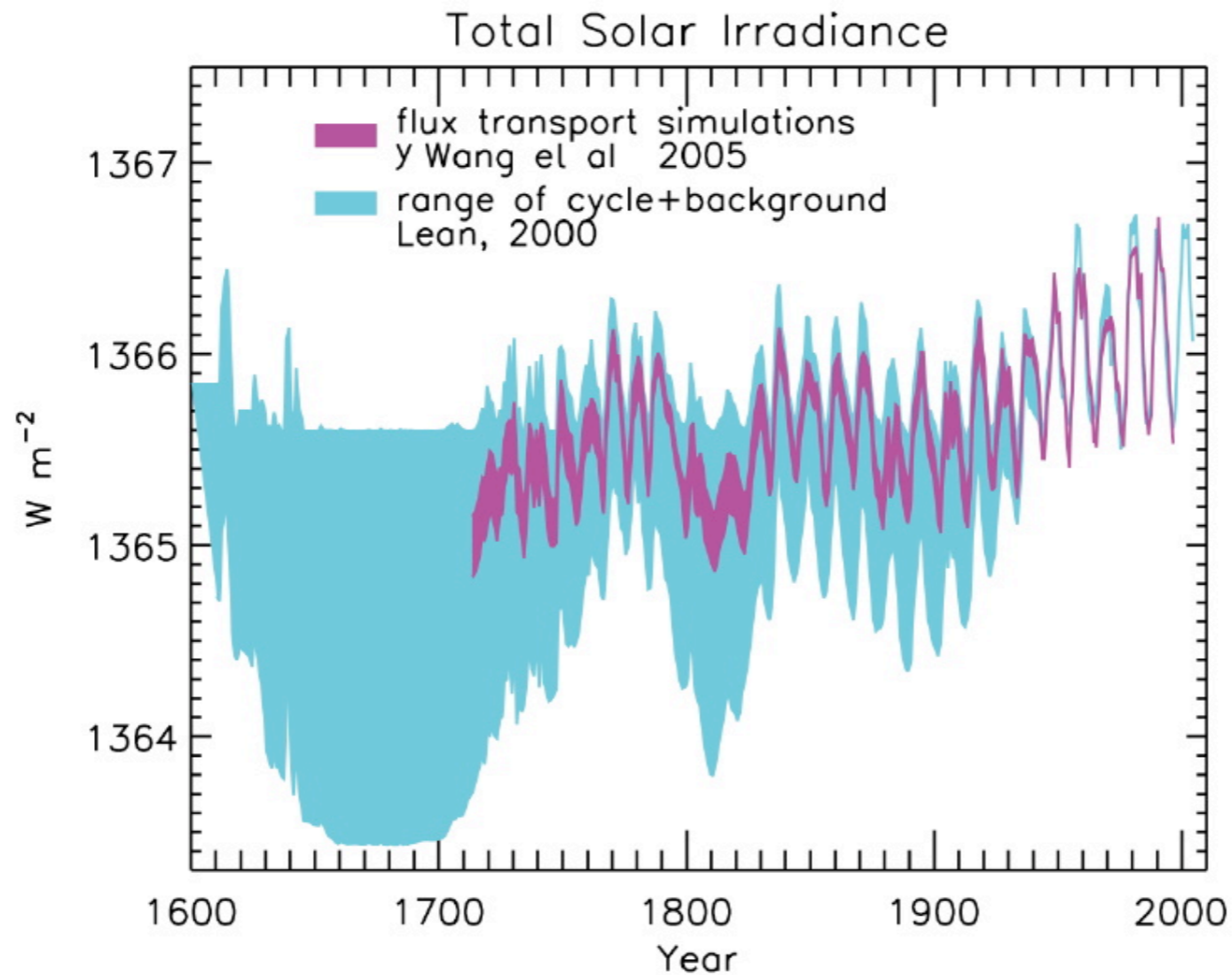
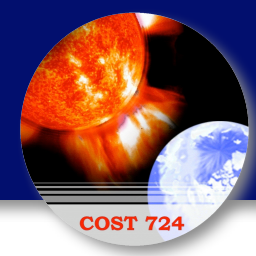


Can the Total Solar Irradiance be reconstructed from solar activity proxies ?



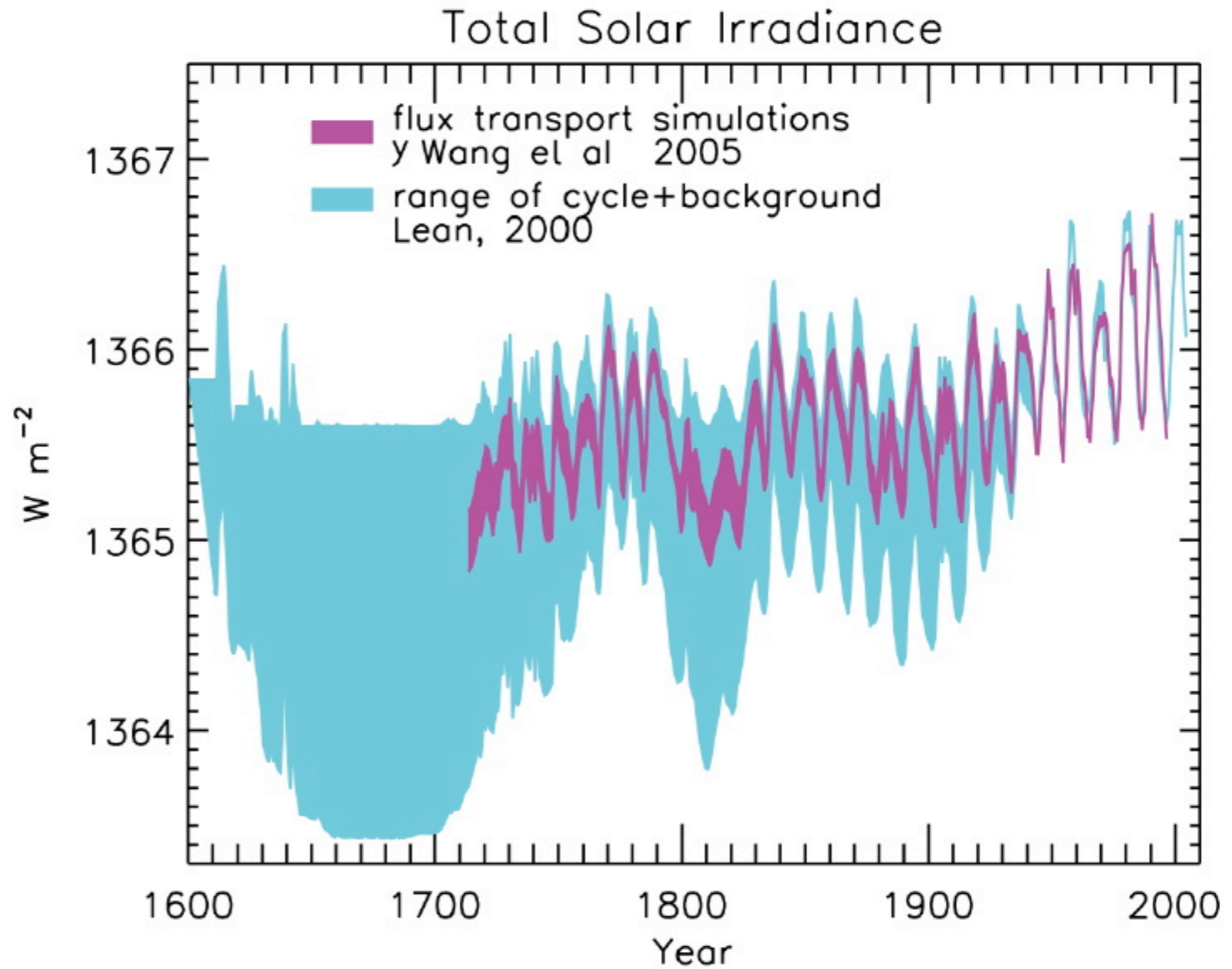
T. Dudok de Wit¹, M. Kretzschmar¹, J. Liliensten², P.-O. Amblard³,
S. Moussaoui⁴, J. Aboudarham⁵, F. Auchère⁶

¹ LPCE, Orléans, ² LPG, Grenoble, ³ GIPSAlab, Grenoble, ⁴ IRCCYN, Nantes, ⁵
LESIA, Paris, ⁶ IAS, Orsay

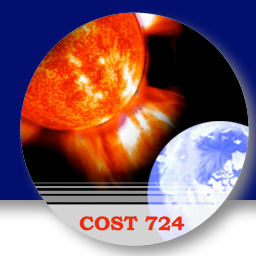


Why reconstruct the TSI ?

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

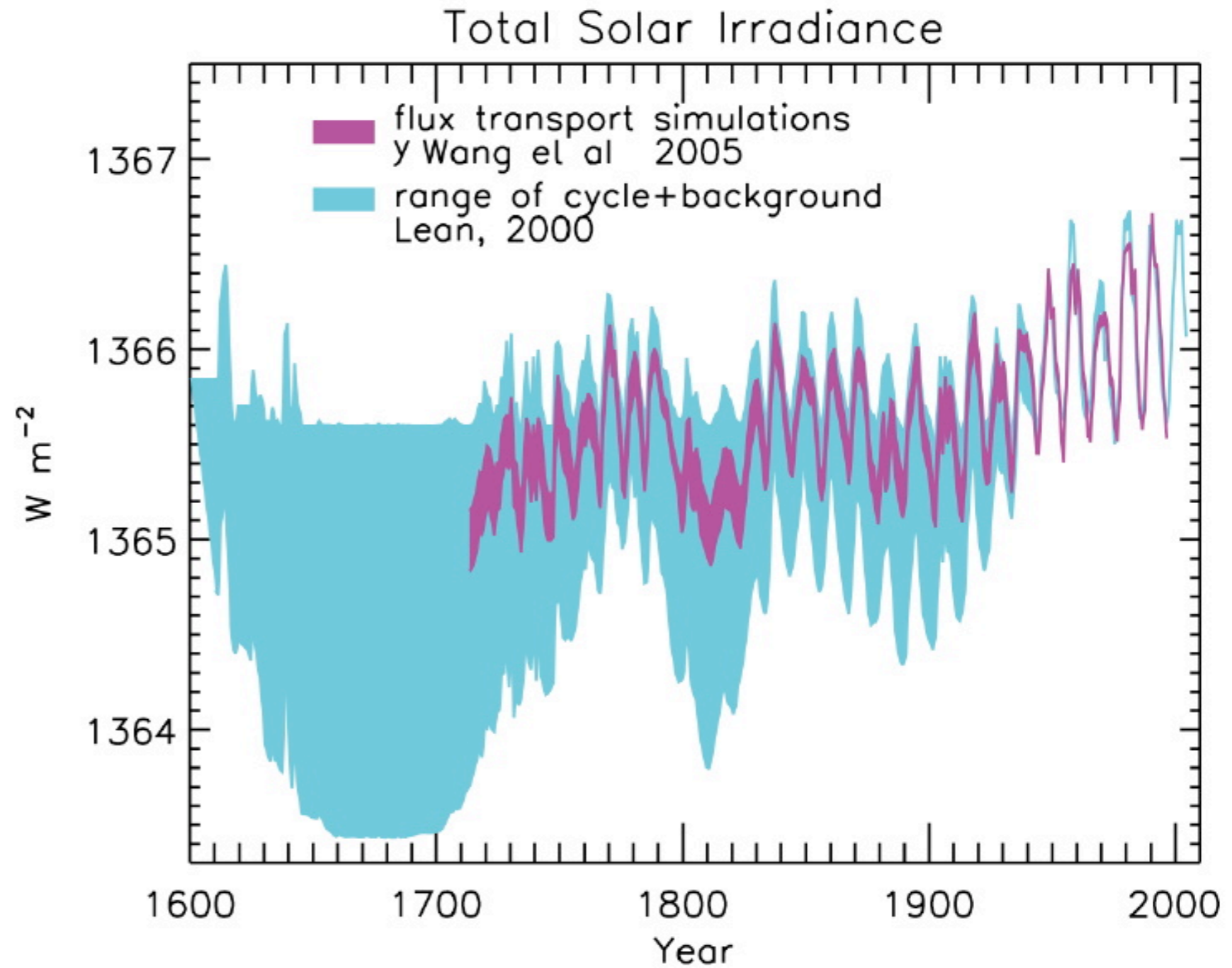


Lean & Haigh (2007)



Why reconstruct the TSI ?

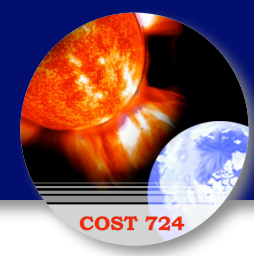
There have been many attempts to reconstruct pre-1978 values of Total Solar Irradiance (TSI) from proxy data



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...

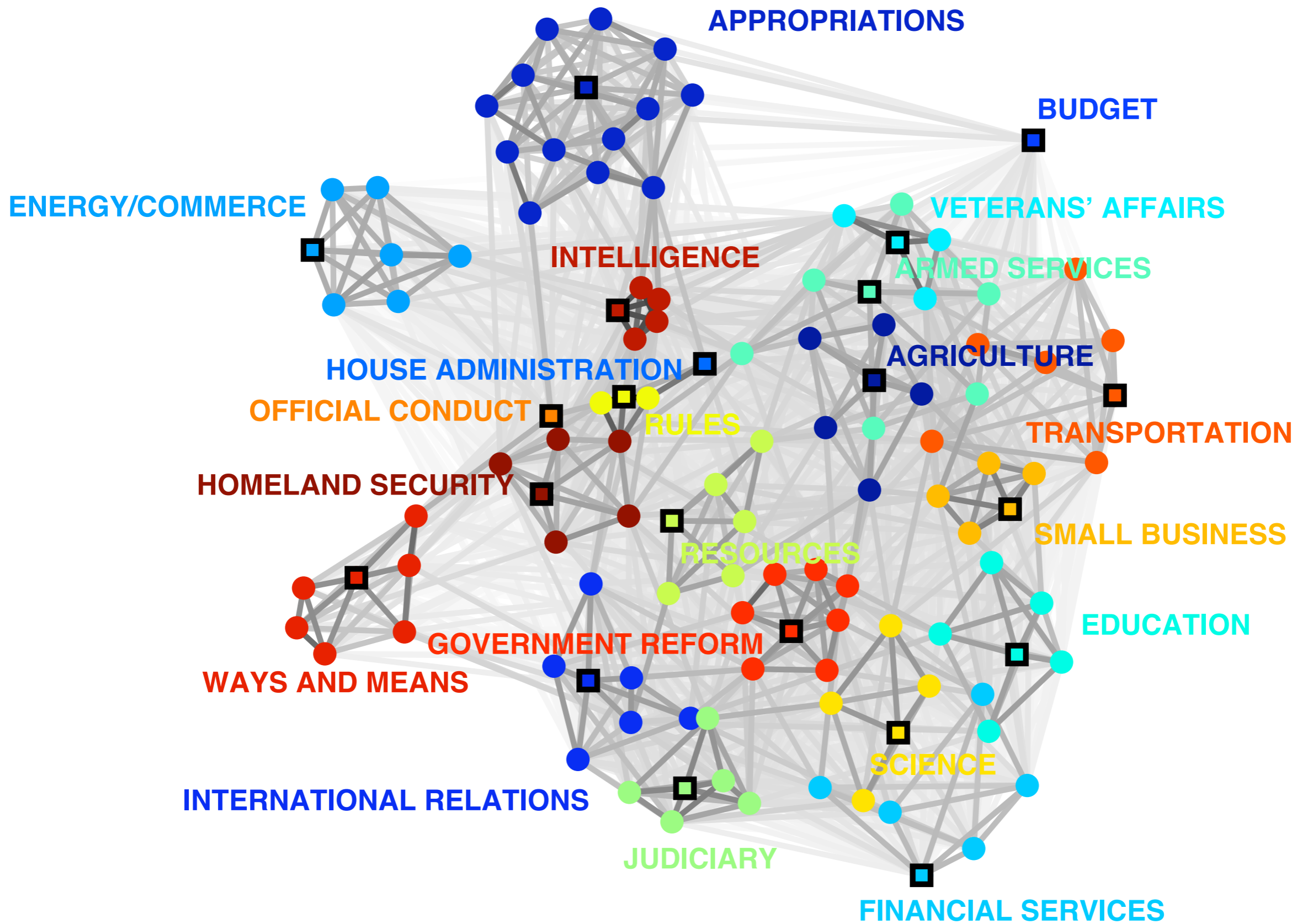
before determining **HOW** to reconstruct the TSI from proxies

we need to determine

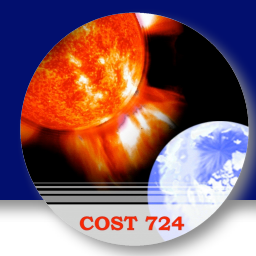
IF this reconstruction can be done at all

and

WHICH proxies are the regressors for the models

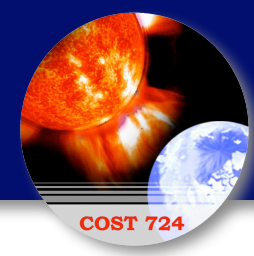


Community structure in the 108th U.S. house of representatives
 each dot represents a subcommittee
 (M. Porter et al., arxiv.org/physics/0602033)



Networks : studying interactions

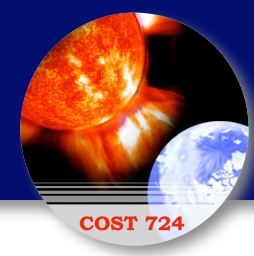
- Networks are important because **structure affects function**
- Examples
 - spread of disease in a population
 - robustness and stability of power grids
 - ...
- Networks are today studied within the frame of **statistical physics** (percolation, critical exponents, phase transitions, ...)



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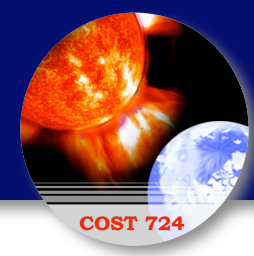
Here we compare the TSI against 14 solar proxies, using daily measurements from 26 Nov 1978 till 30 Sep 2007



The data

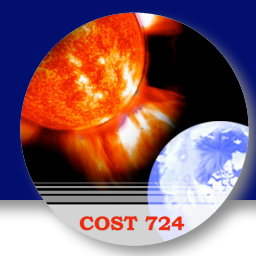
The 14 proxies for solar activity are:

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- α 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



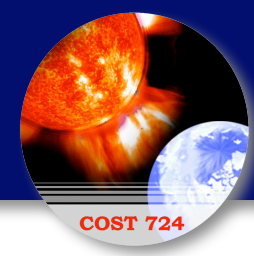
PMOD (Fröhlich & Lean)



ACRIM (Willson & Mordvinov)



SARR (Mekaoui & DeWitte)



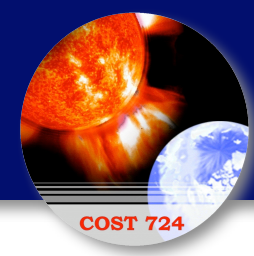
The method

- 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

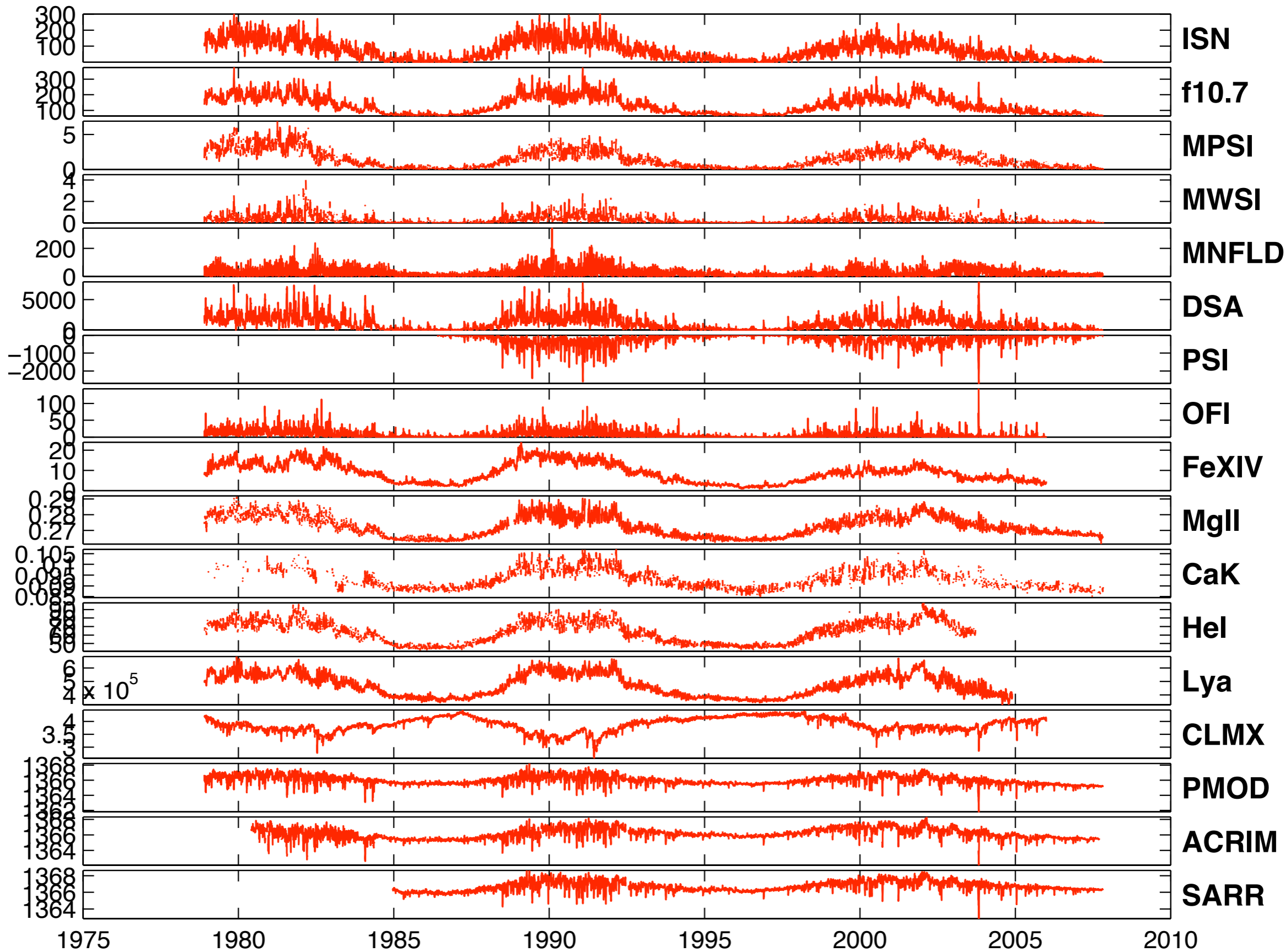
$$I(x, y) = H(x) - H(x|y)$$

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

$p(x)$ is the probability density



The data

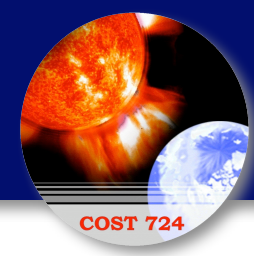




Different scales

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

Here, we focus on



Different scales

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Here, we focus on



short scale fluctuations

< 80 days

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

long scale fluctuations

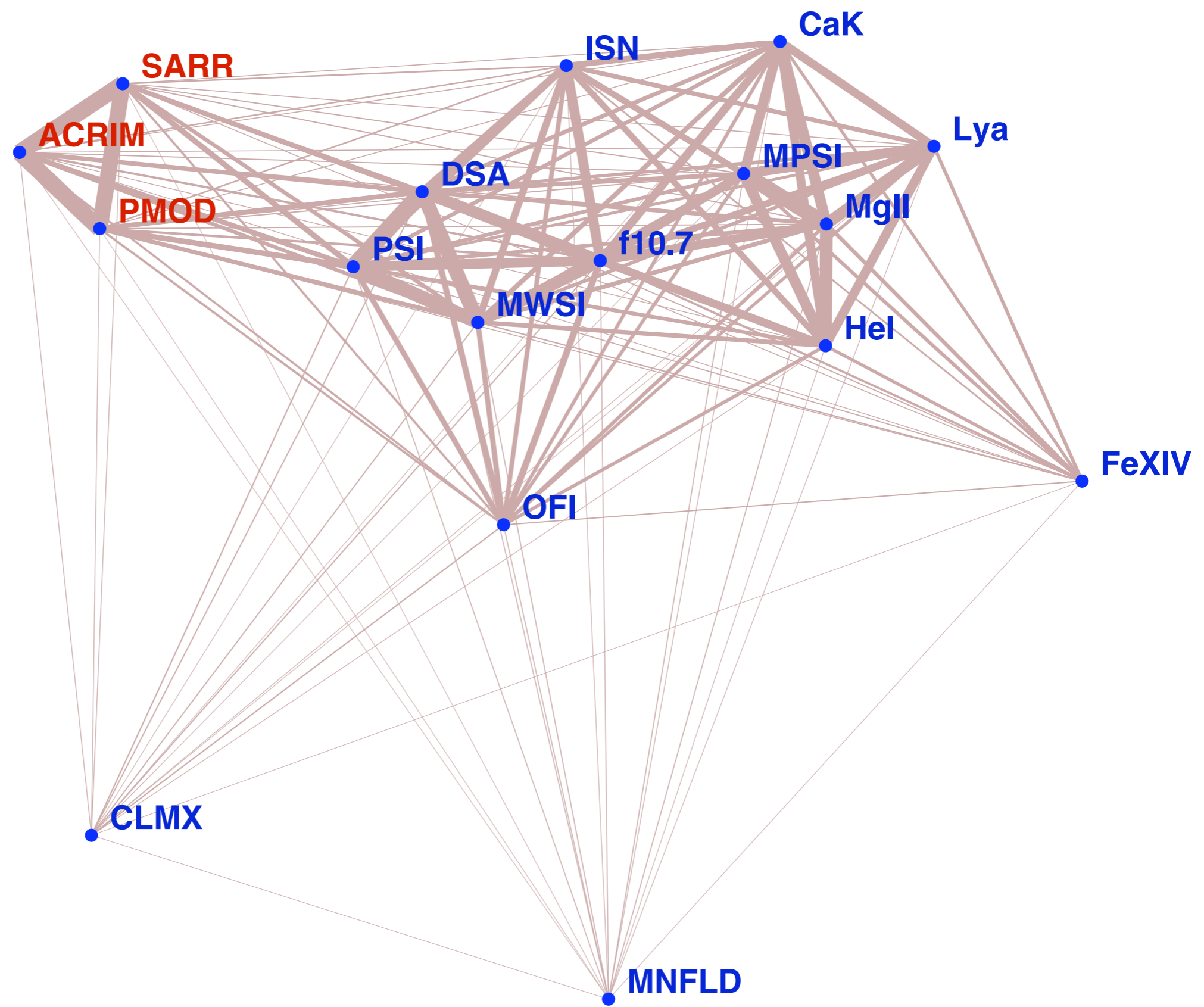
> 1 year

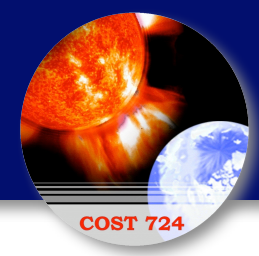
effect of solar magnetic
cycle + trend



Connections for **short** time scales

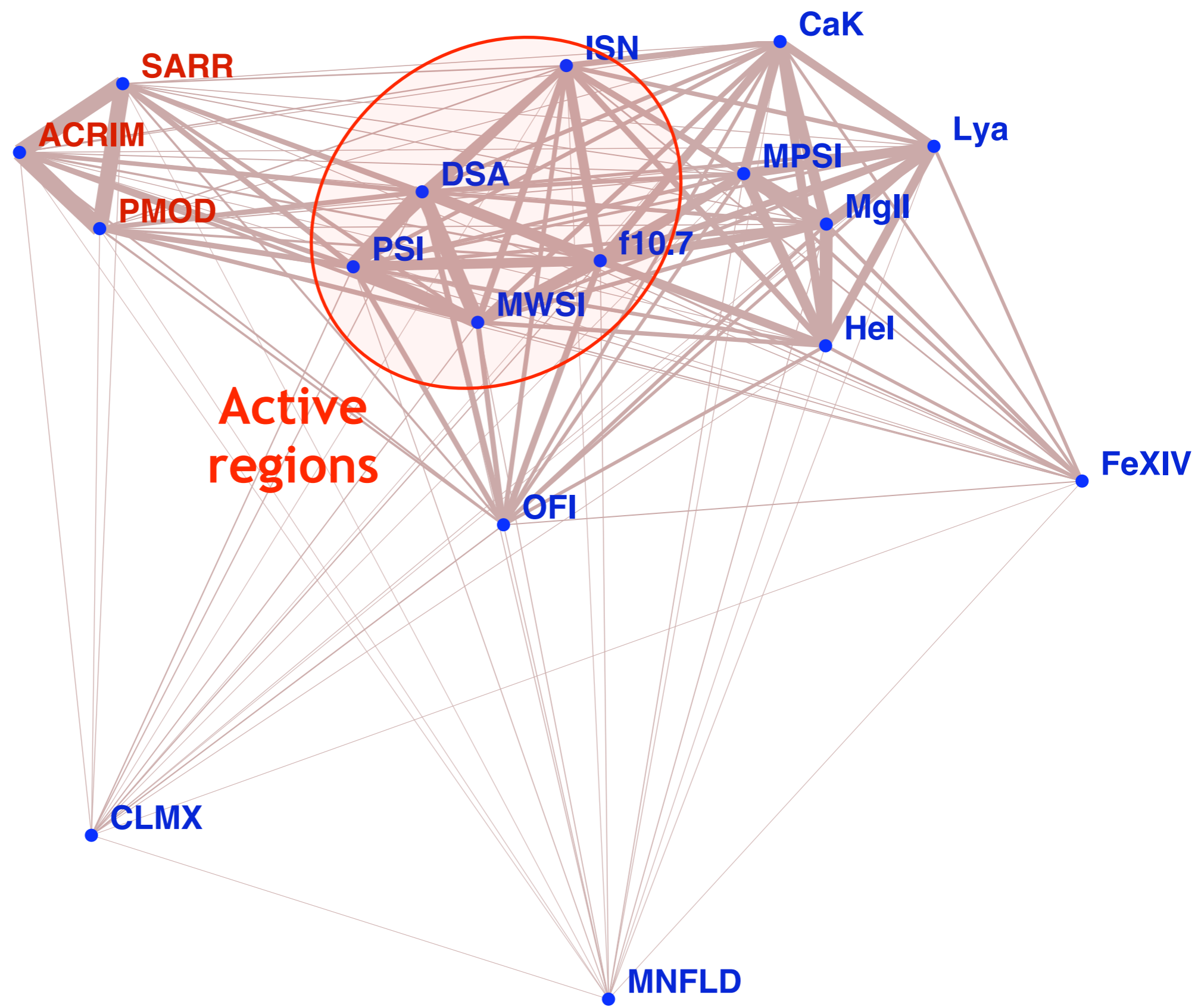
line thickness
reflects level of
mutual information





Connections for **short** time scales

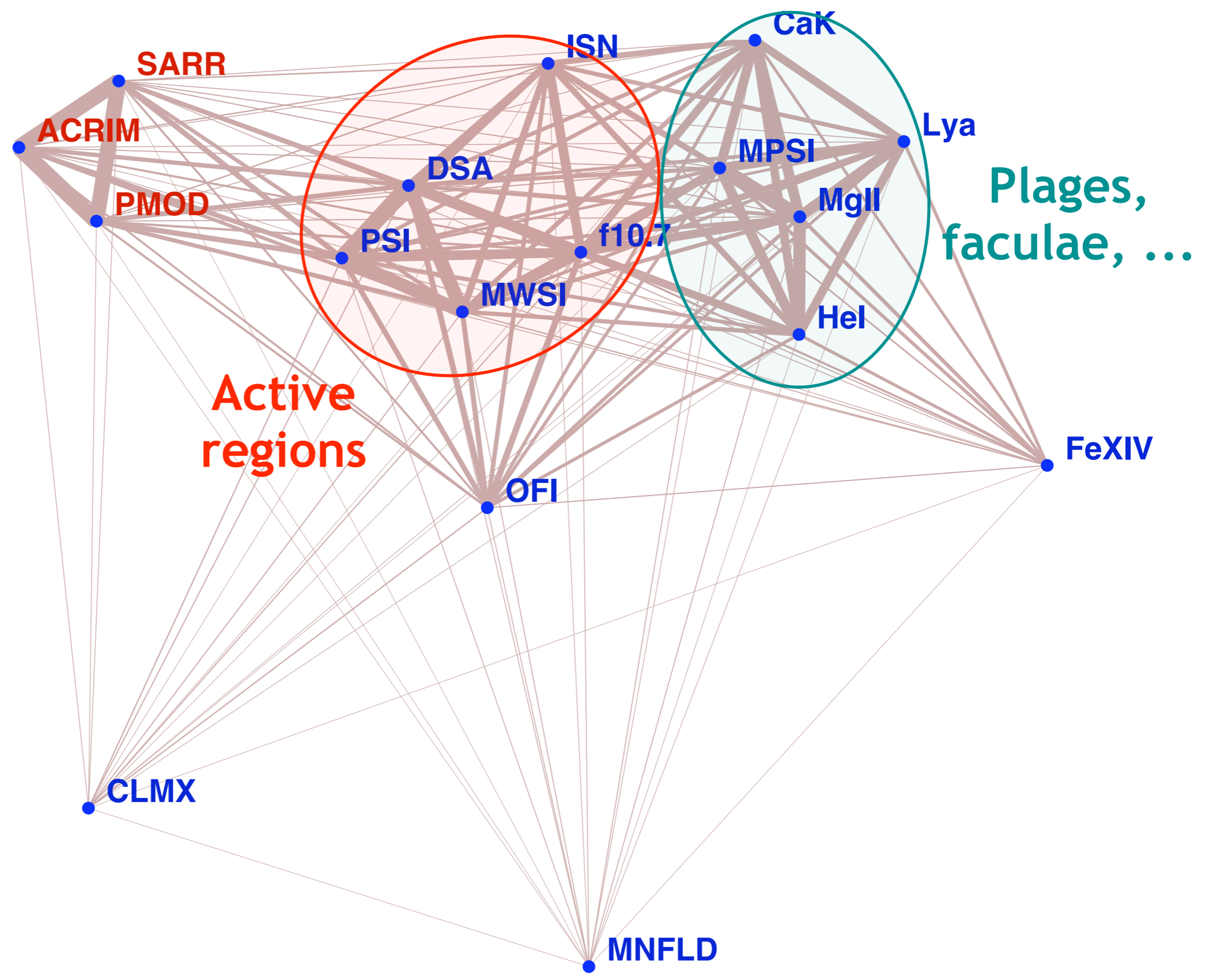
line thickness
reflects level of
mutual information

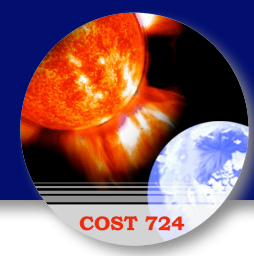




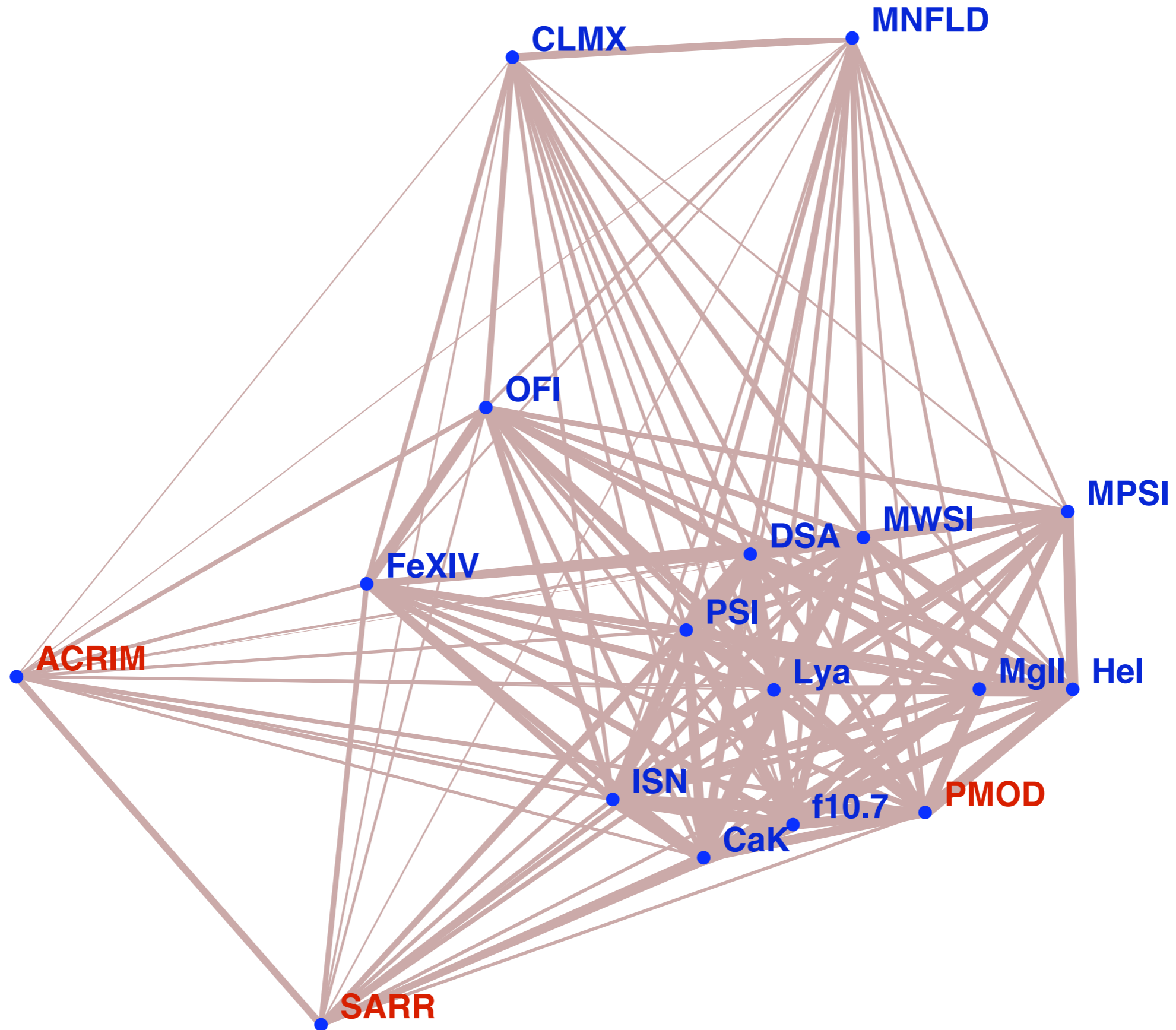
Connections for **short** time scales

line thickness
reflects level of
mutual information





Connections for **long** time scales





Conclusions (1/3)

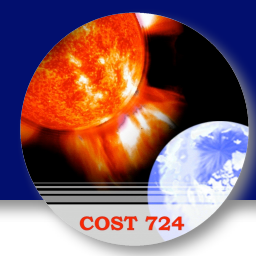
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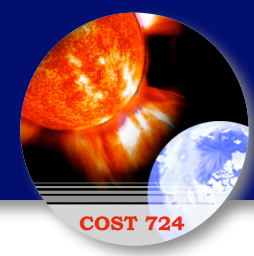
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Conclusions (1/3)

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- **long term dynamics** : mostly contribution from chromospheric regions (faculae, plages, ...)

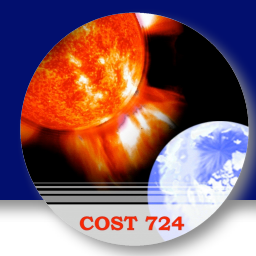


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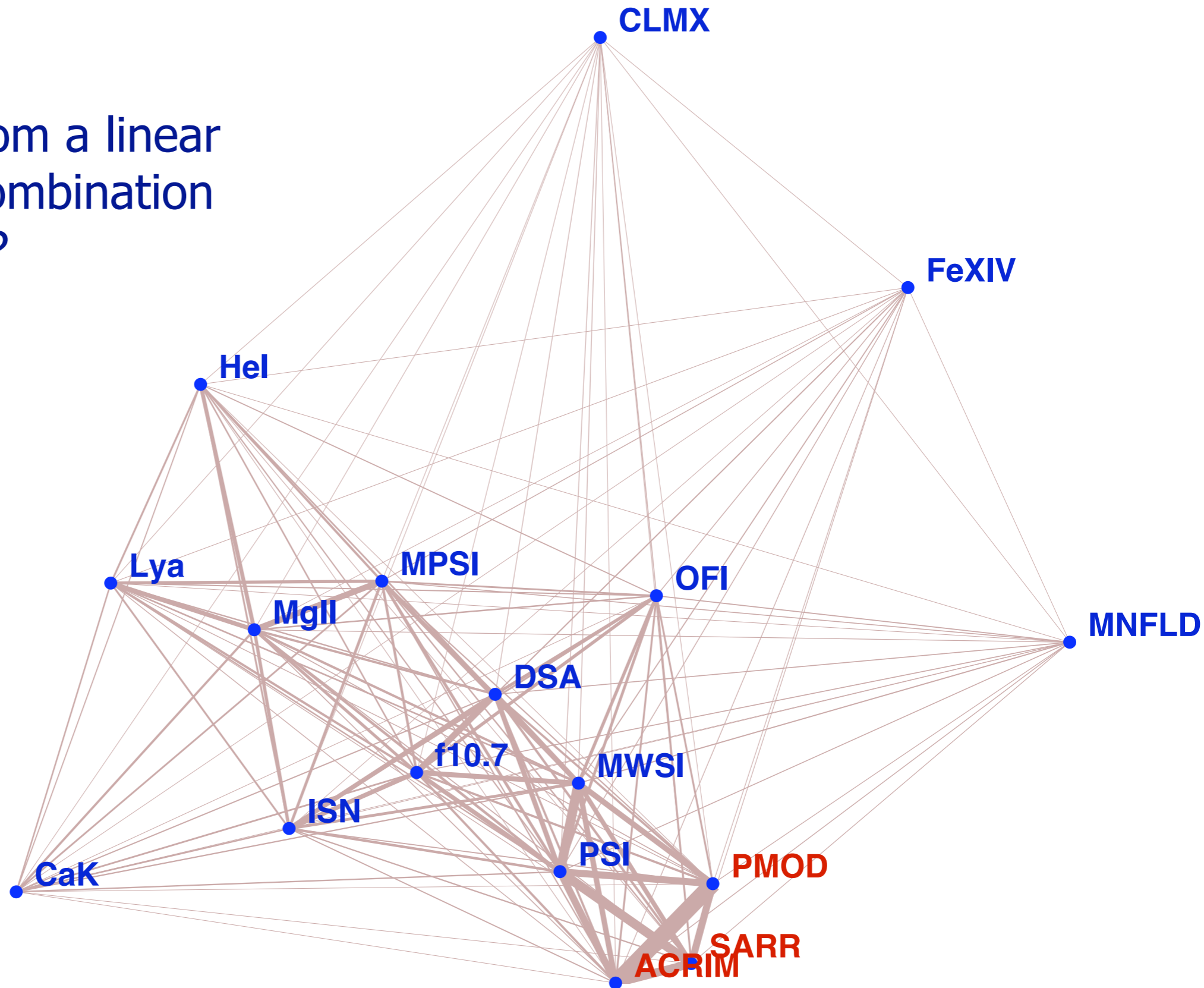
→ flares do also contribute to the variability, see next talk

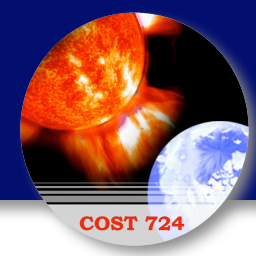


Conclusions (2/3)

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

Very unlikely

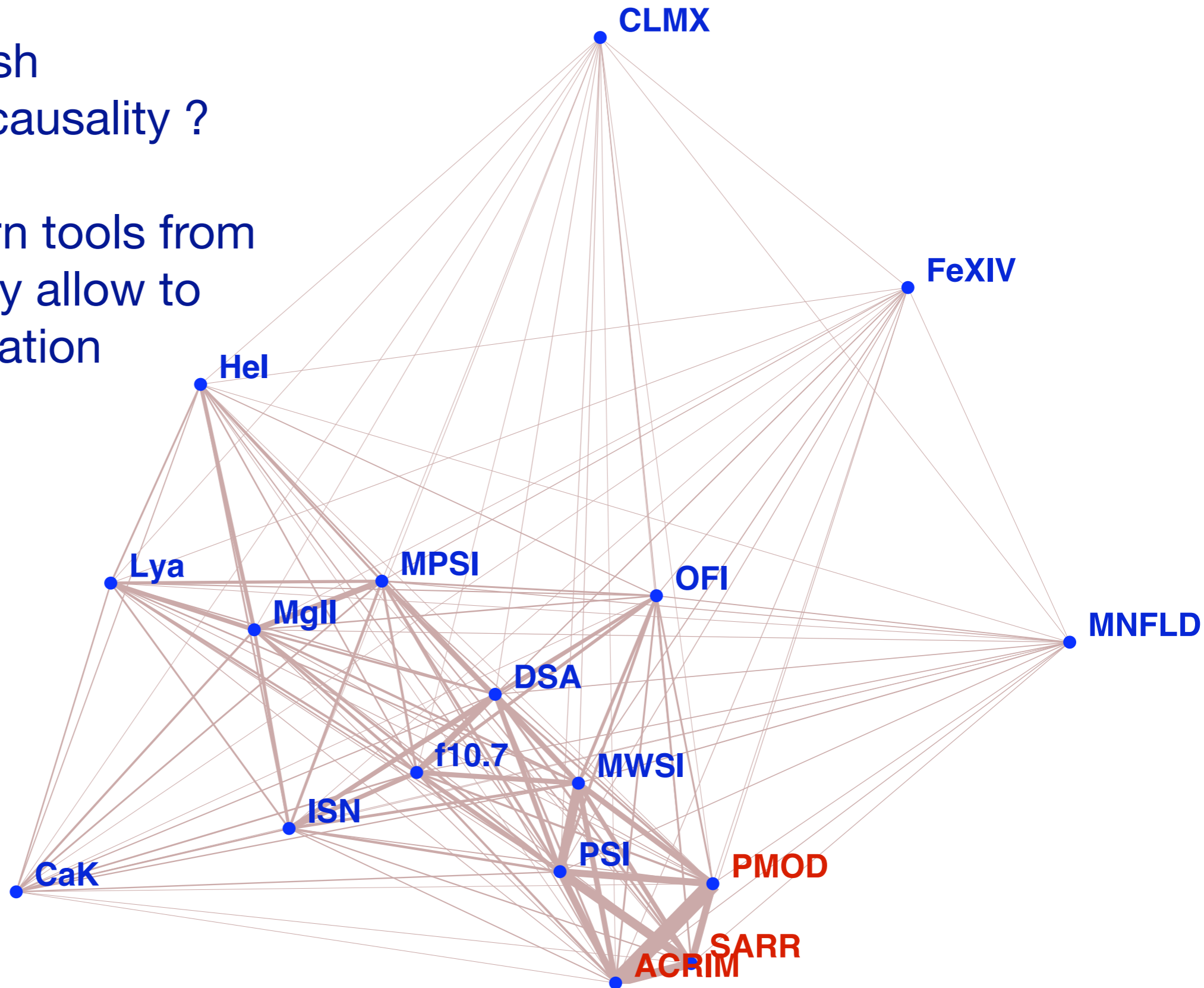


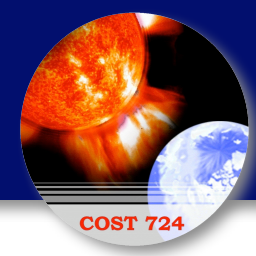


Conclusions (3/3)

Can we distinguish correlation from causality ?

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

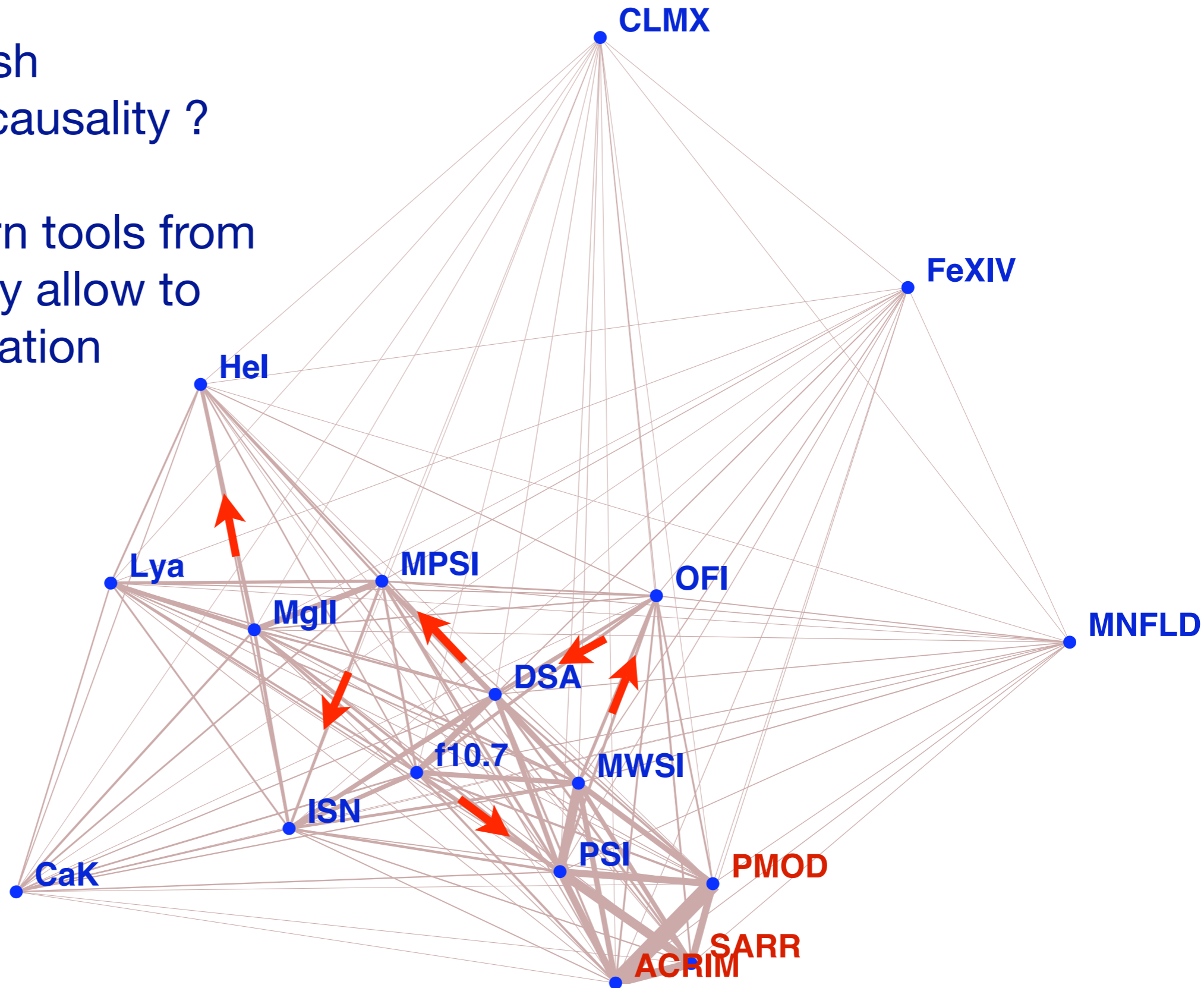




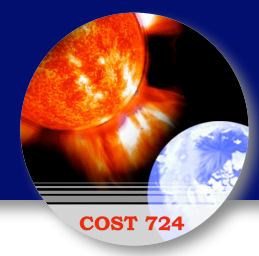
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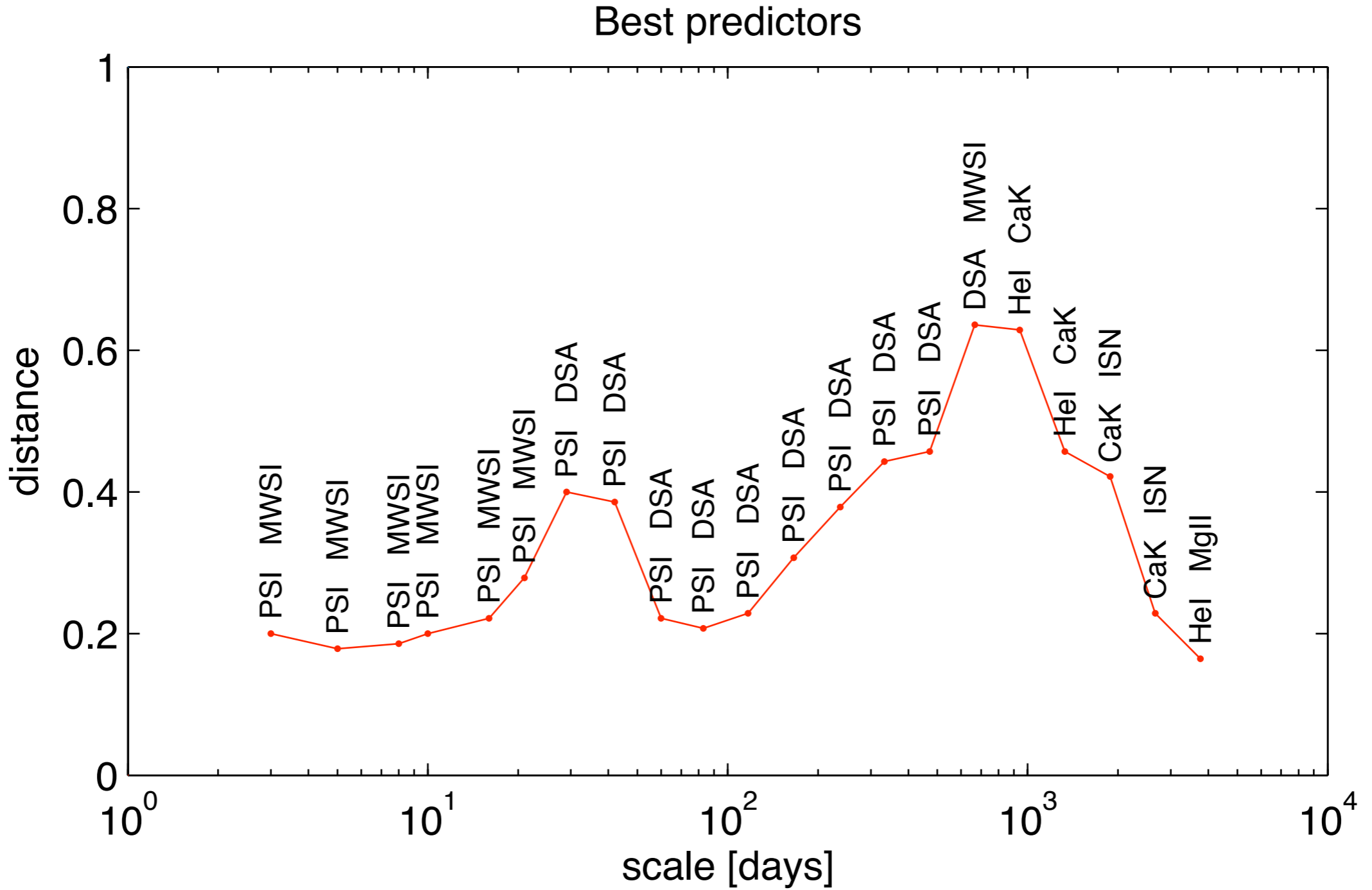
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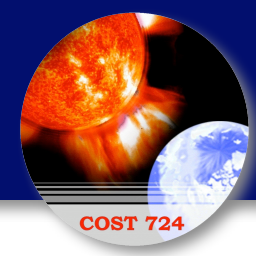






What are the best predictors ?





Multiscale decomposition

