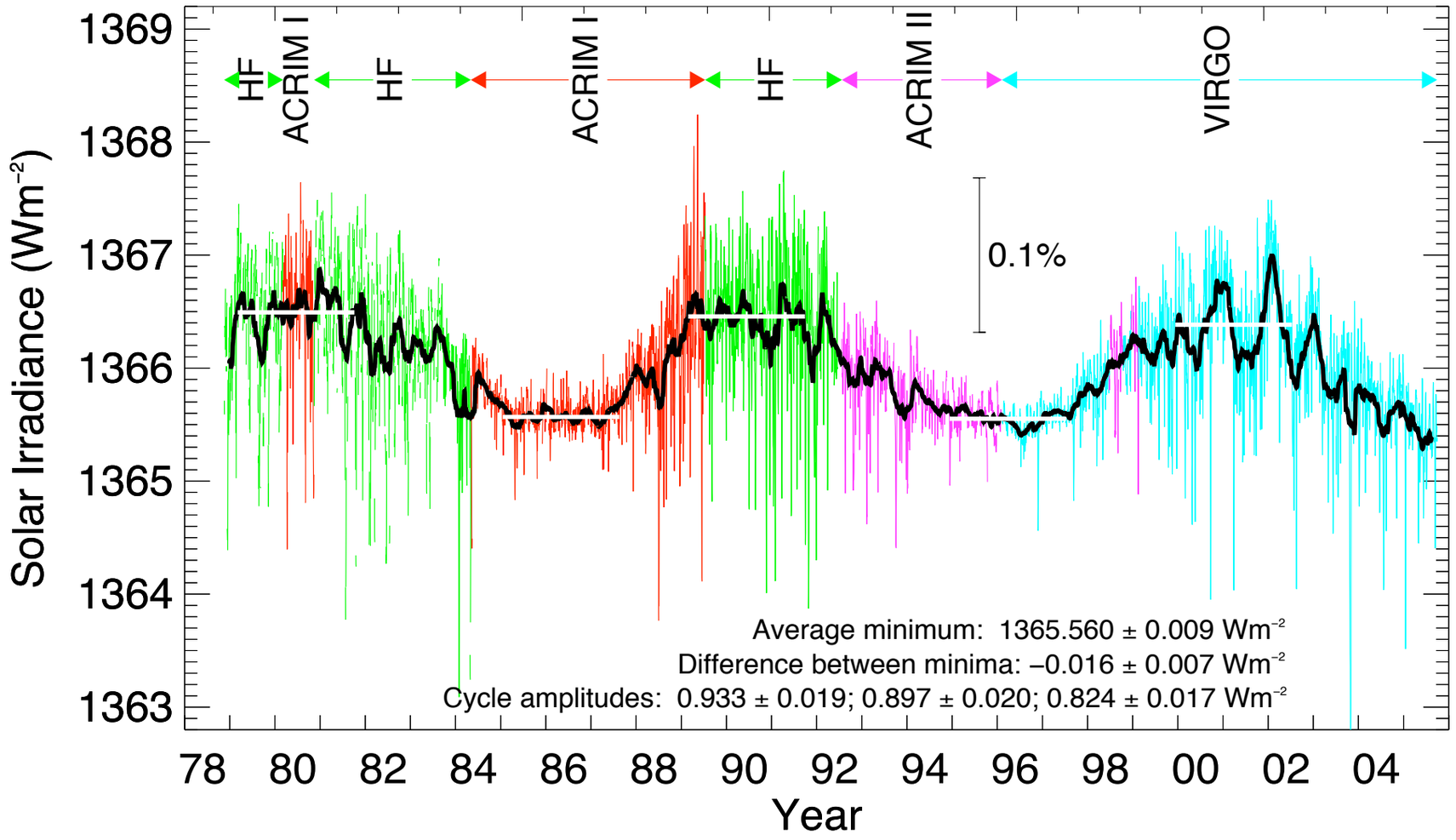
Can the Total Solar Irradiance be reconstructed from solar activity proxies ?



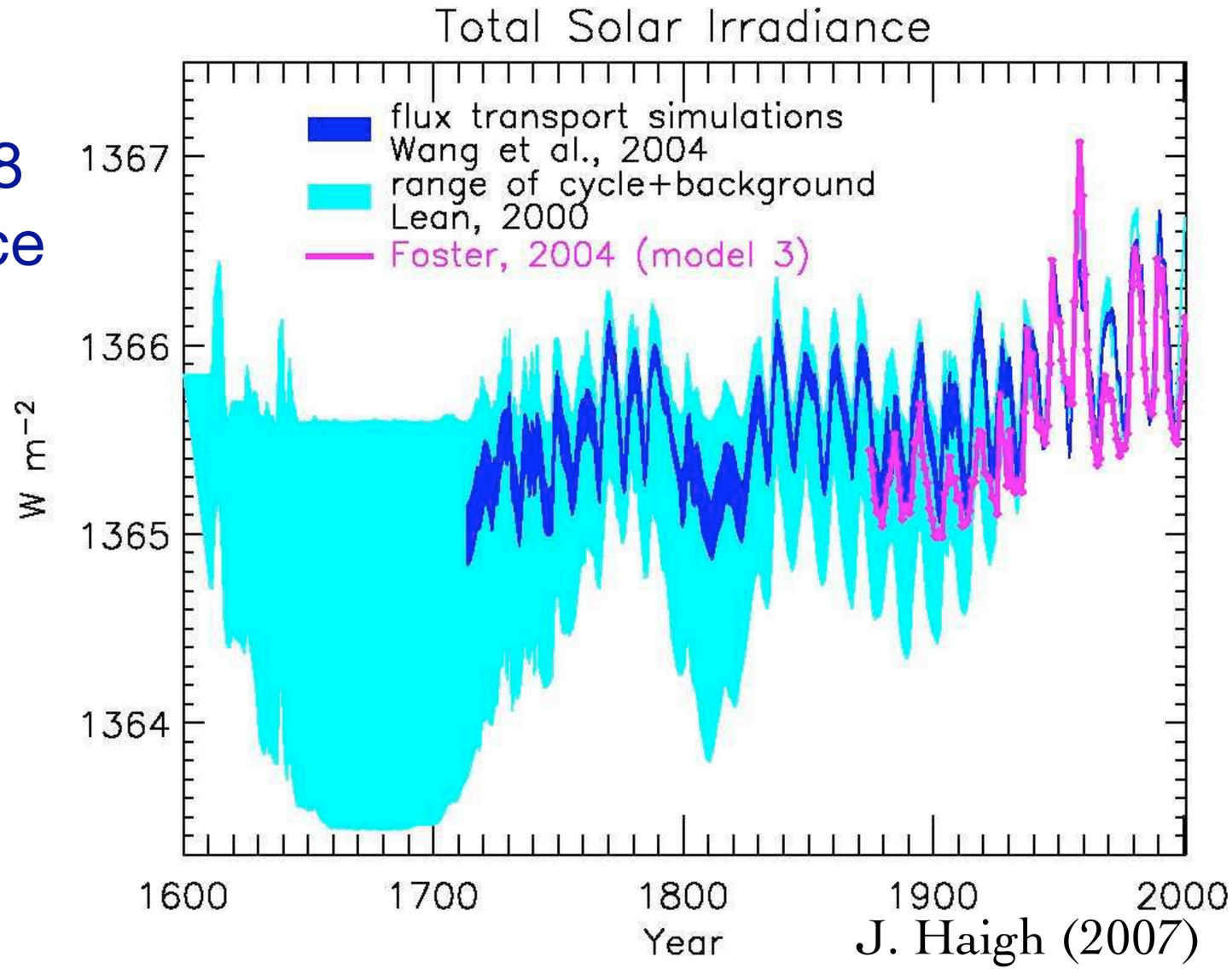
C. Fröhlich & J. Lean (2006)

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

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

Why reconstruct the TSI ?

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



J. Haigh (2007)

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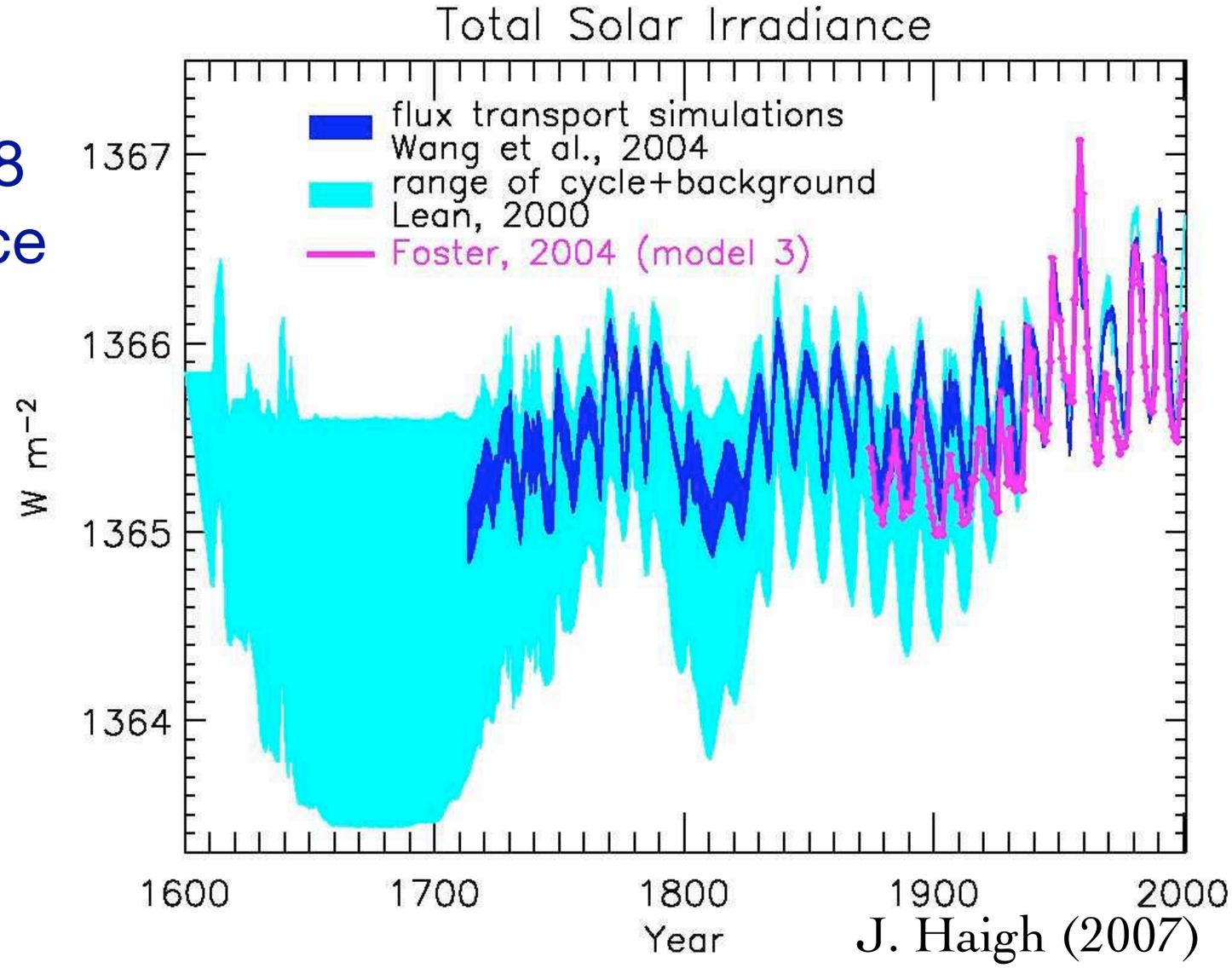


Such reconstruction are needed to

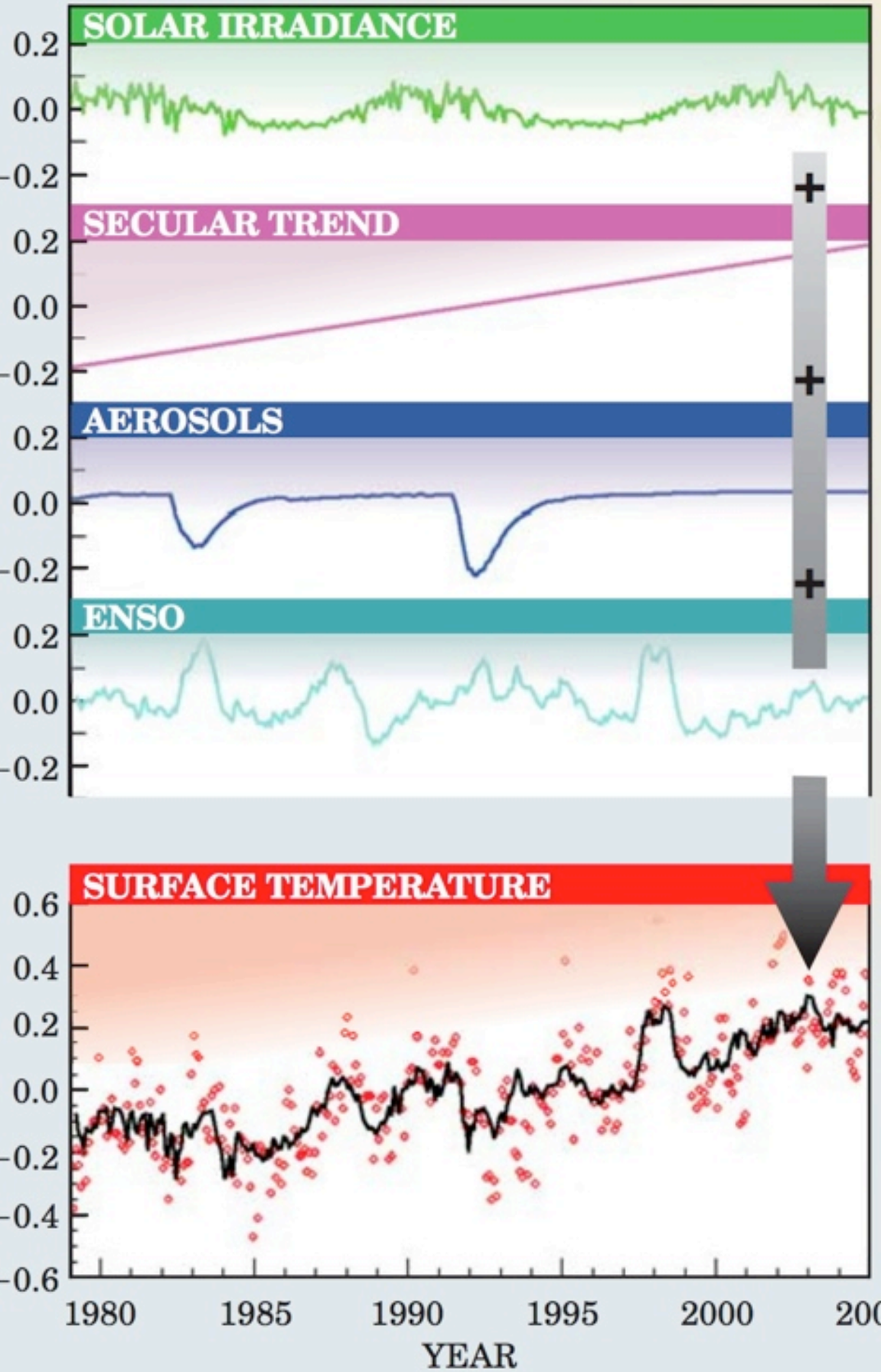
- assess solar effects on past climate changes
- understand what causes the weak variability of the TSI

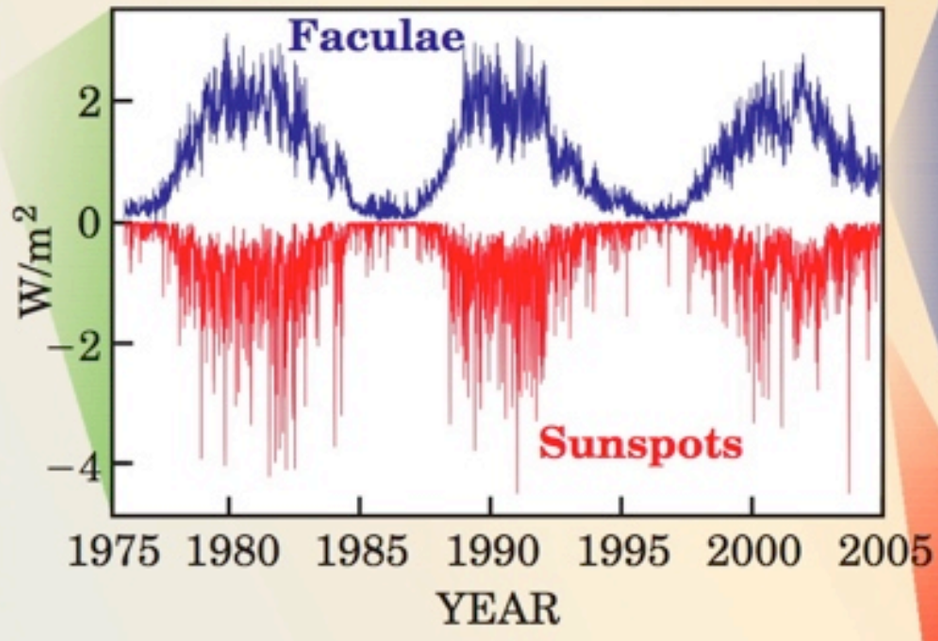
How to reconstruct the TSI

- Most reconstructions of the TSI use solar activity indices: sunspot number, MgII index, ...

- short-time reconstructions (days) have been quite successful so far...

- ...but the (presumably important) role of the solar magnetic field is hard to include





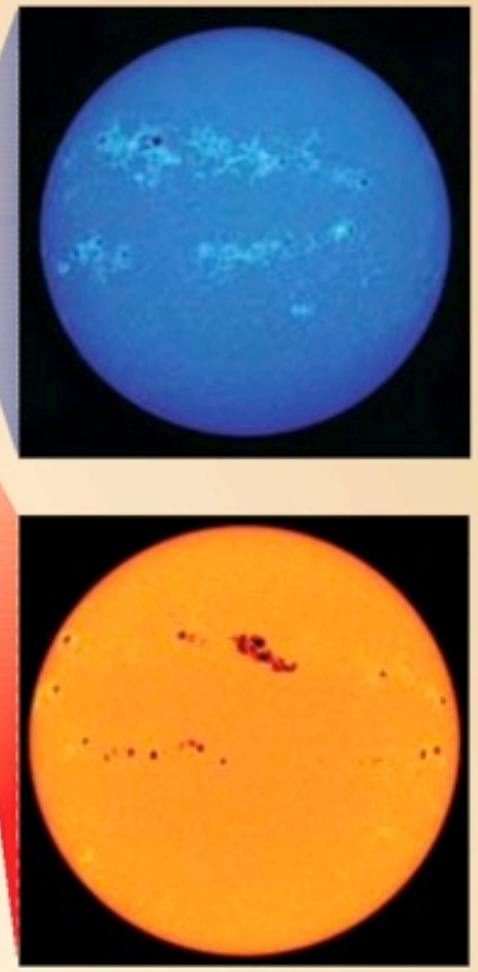


Figure 3. The variation in Earth's monthly mean global surface temperature is shown in the bottom panel by the red symbols. A statistical multiple regression model, shown by the black line, reproduces significant temperature variance by combining variations in solar irradiance (top panel); a secular trend, possibly anthropogenic (second panel); volcanic aerosols (third panel); and a measure of the El Niño Southern Oscillation (fourth panel). ENSO and volcanoes cause changes of 0.2–0.3 K on time scales of months, whereas solar irradiance is associated with a 0.1-K decadal cycle. The irradiance cycle arises from the competing effects of sunspots and bright areas called faculae; the two features are evident in the solar images on the right and produce the effects on daily irradiance shown above.

J. Lean, Physics Today, 2005

There is a problem...

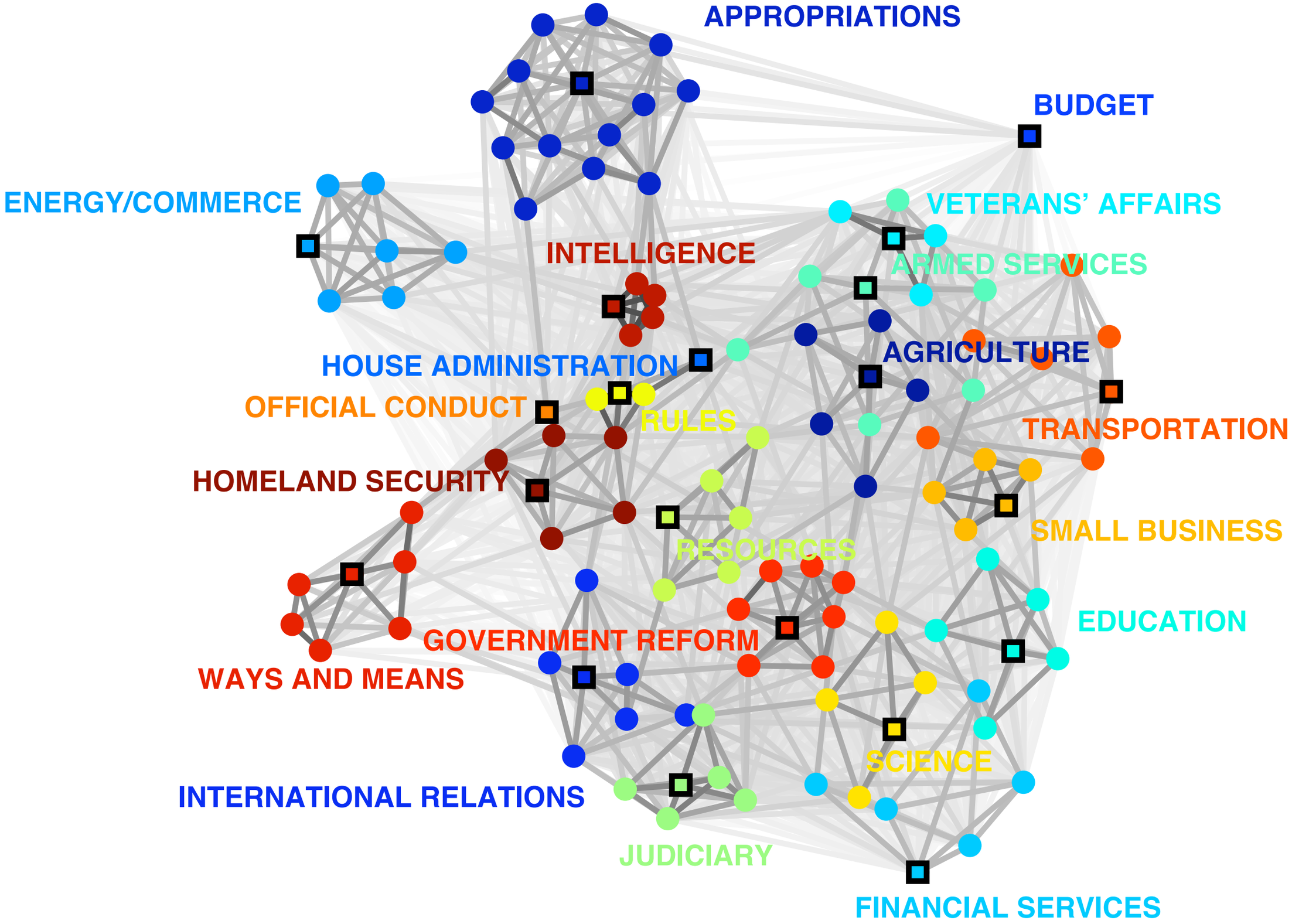
before determining **HOW** to reconstruct the TSI from proxies

we need to

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

and

and **WHICH** proxies are the best model inputs



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
  - earthquake dynamics
  - ...

- Networks can be studied within the frame of **statistical physics** (percolation, critical exponents, phase transitions, ...)

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Here we compare the TSI against 12 solar proxies, using daily measurements from 26 Nov 1978 till 30 Sep 2007

The data

The 12 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. **Mean magnetic field** of the Sun (Wilcox Obs.)
11. **OFI** : optical flare index (Ataç and Özgüç)
    —> intensity x duration of flares
12. **Coronal index** (Rybansky) —> total energy emitted by the solar corona in the FeXIV line at 530.3 nm

and

TSI : composite total solar irradiance (PMOD composite)

The method

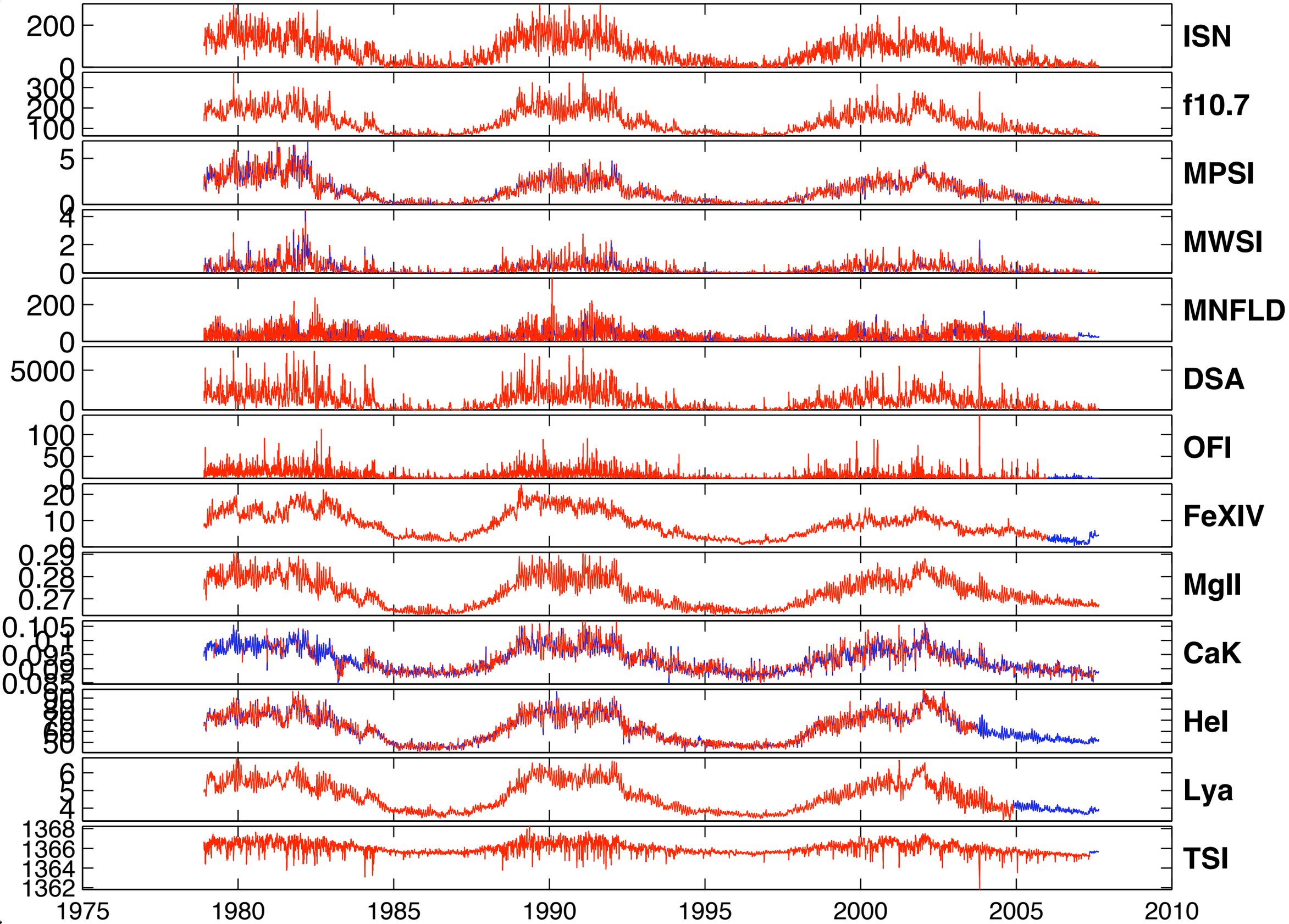
- Each proxy captures a different aspect of the solar activity
- Connections between proxies should reveal which mechanisms affect the TSI most
- We compute the **mutual information** $I(x,y)$ between each pair of proxies = amount of information that proxy x reveals about proxy y

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

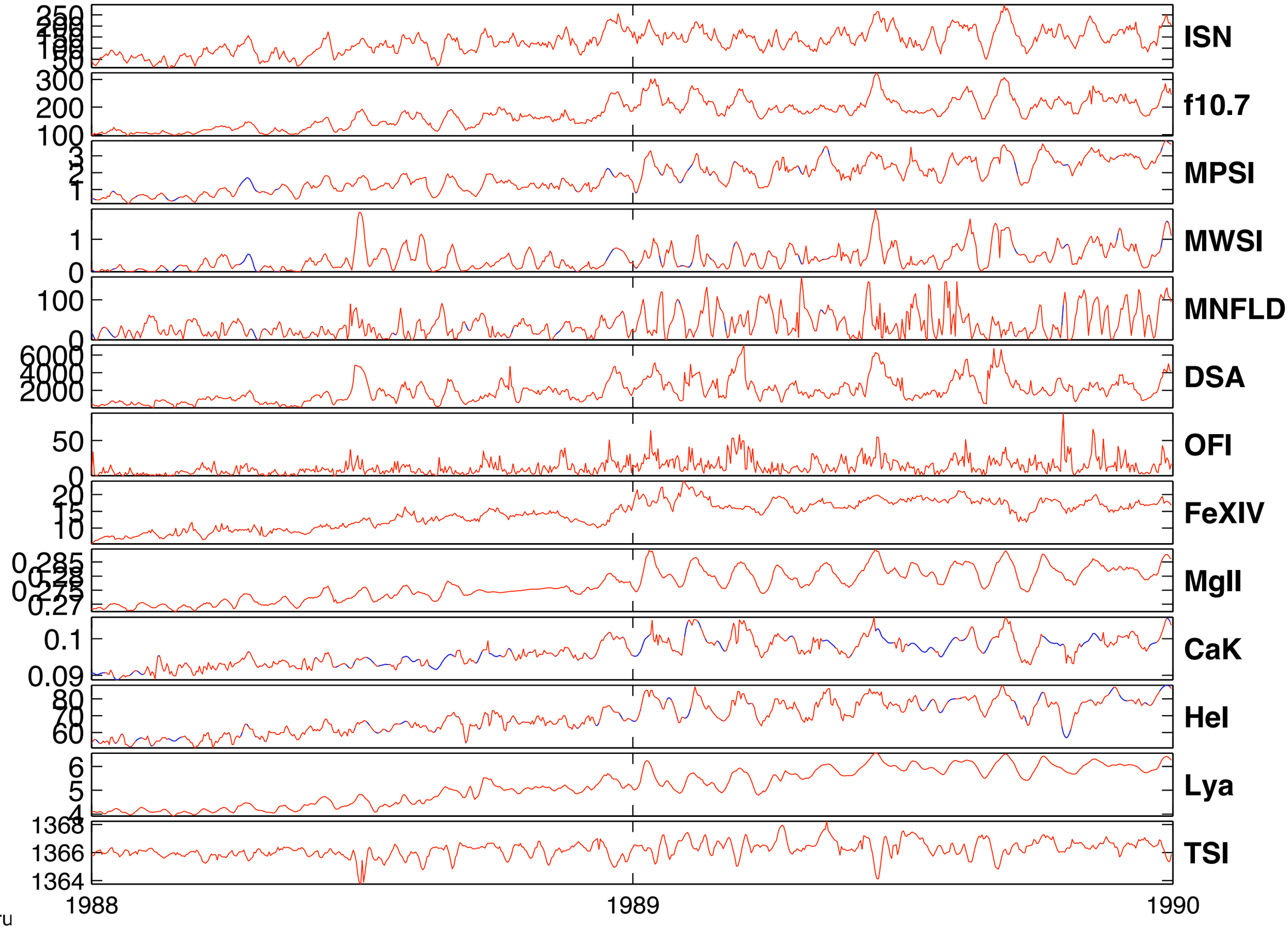
$$H(x) = -\int p(x)\log p(x)\, dx$$ is the entropy

$p(x)$ is the probability density

The data


ISN
f10.7
MPSI
MWSI
MNFLD
DSA
OFI
FeXIV
MgII
CaK
HeI
Lya
TSI
1975
1980
1985
1990
1995
2000
2005
2010

Excerpt


ISN
f10.7
MPSI
MWSI
MNFLD
DSA
OFI
FeXIV
MgII
CaK
HeI
Lya
TSI
1988
1989
1990

Different scales

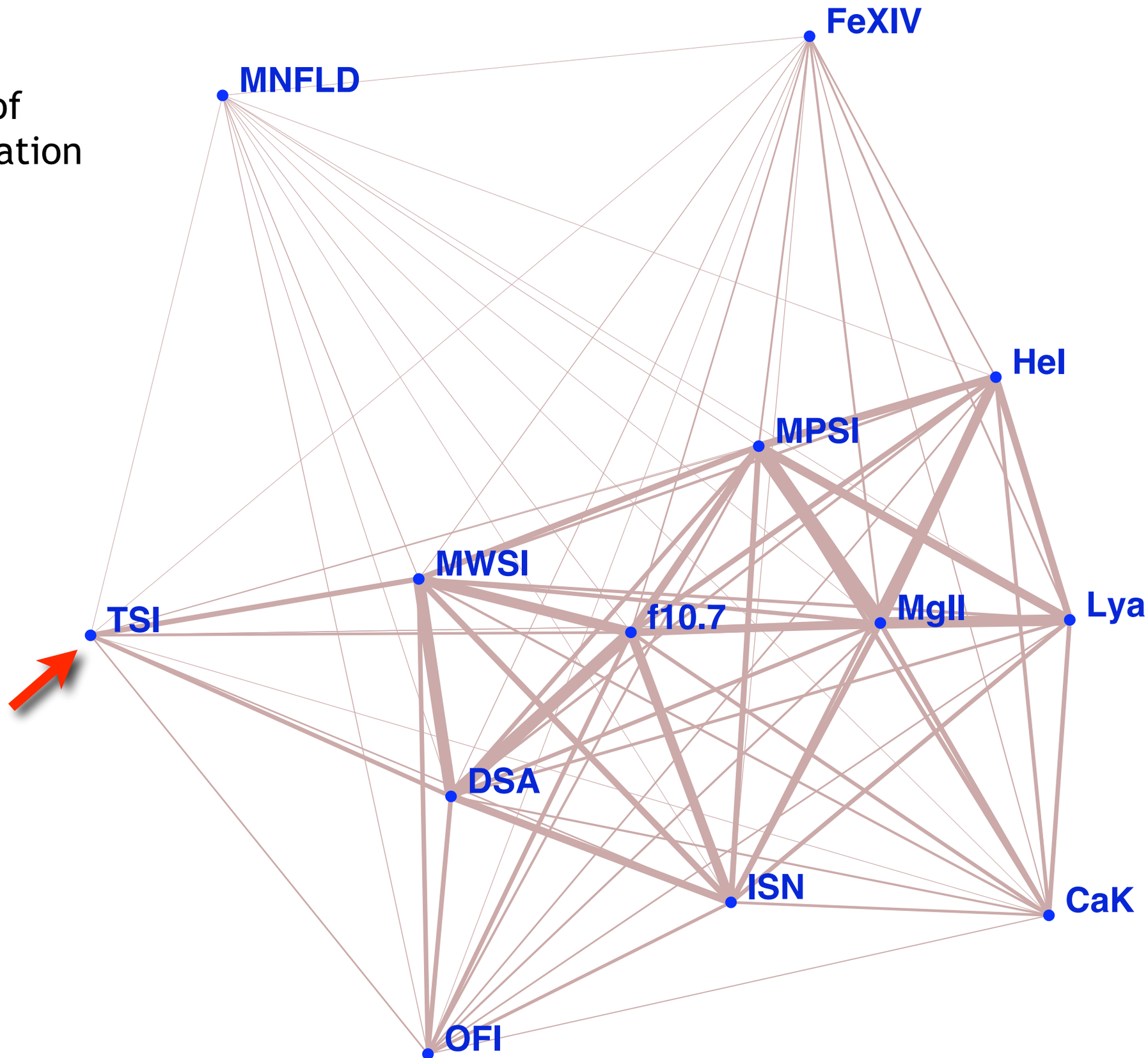
The analysis is done separately for

short scale fluctuations
< 80 days
effect of solar rotation,
center-to-limb effects, ...

long scale fluctuations
> 80 days
effect of solar magnetic
cycle + trend

Connections for short time scales

line thickness
reflects level of
mutual information



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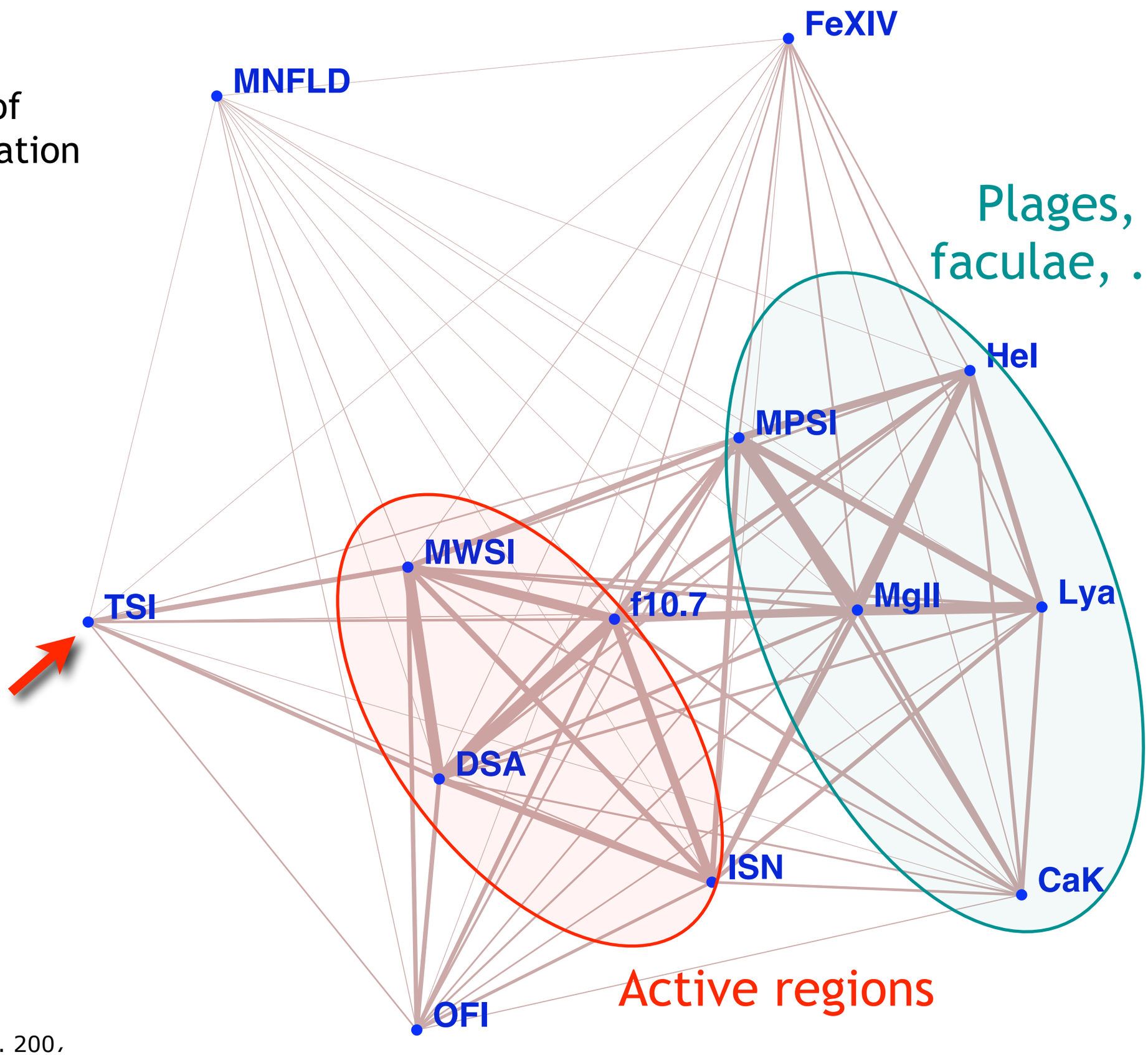
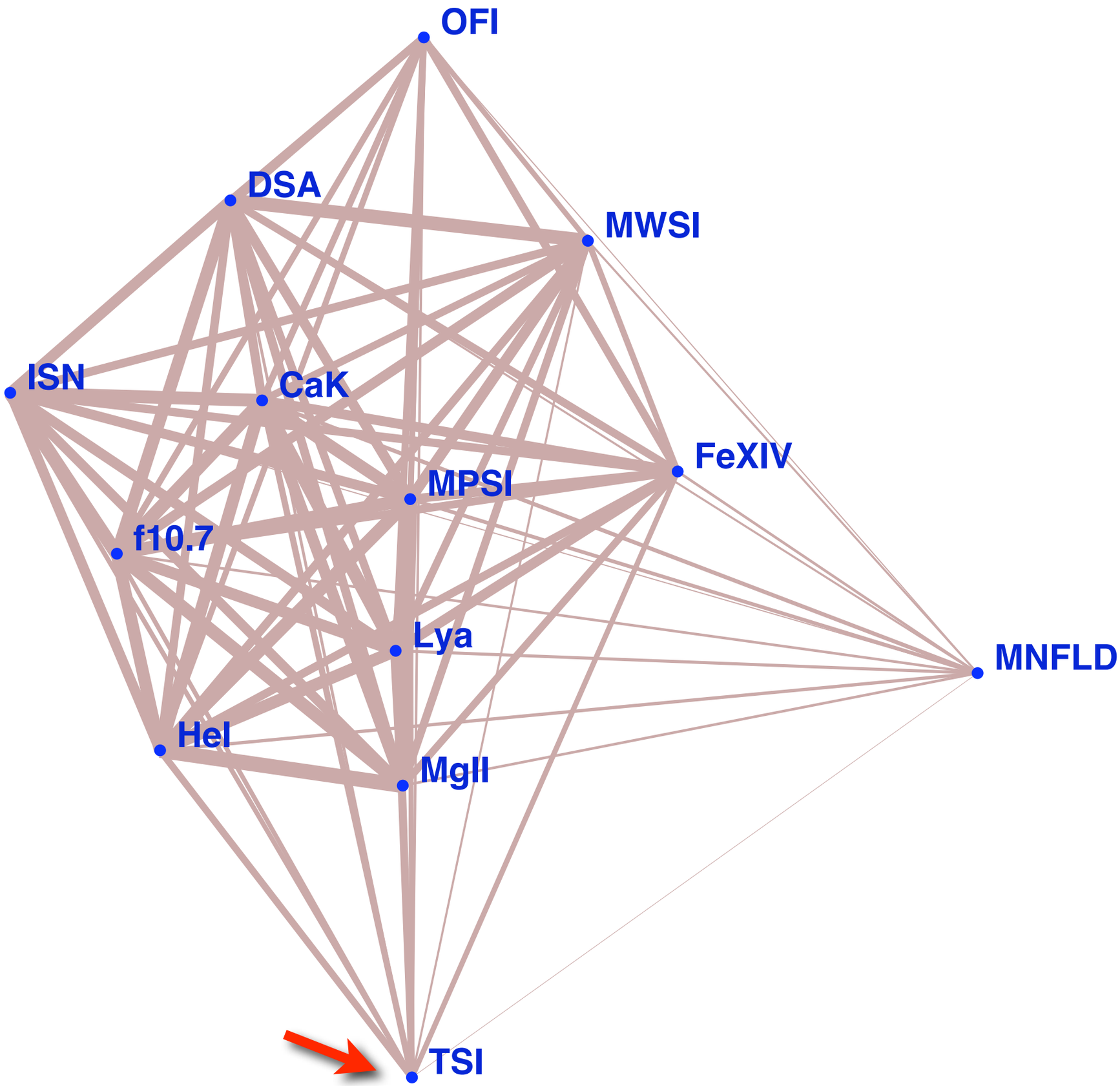
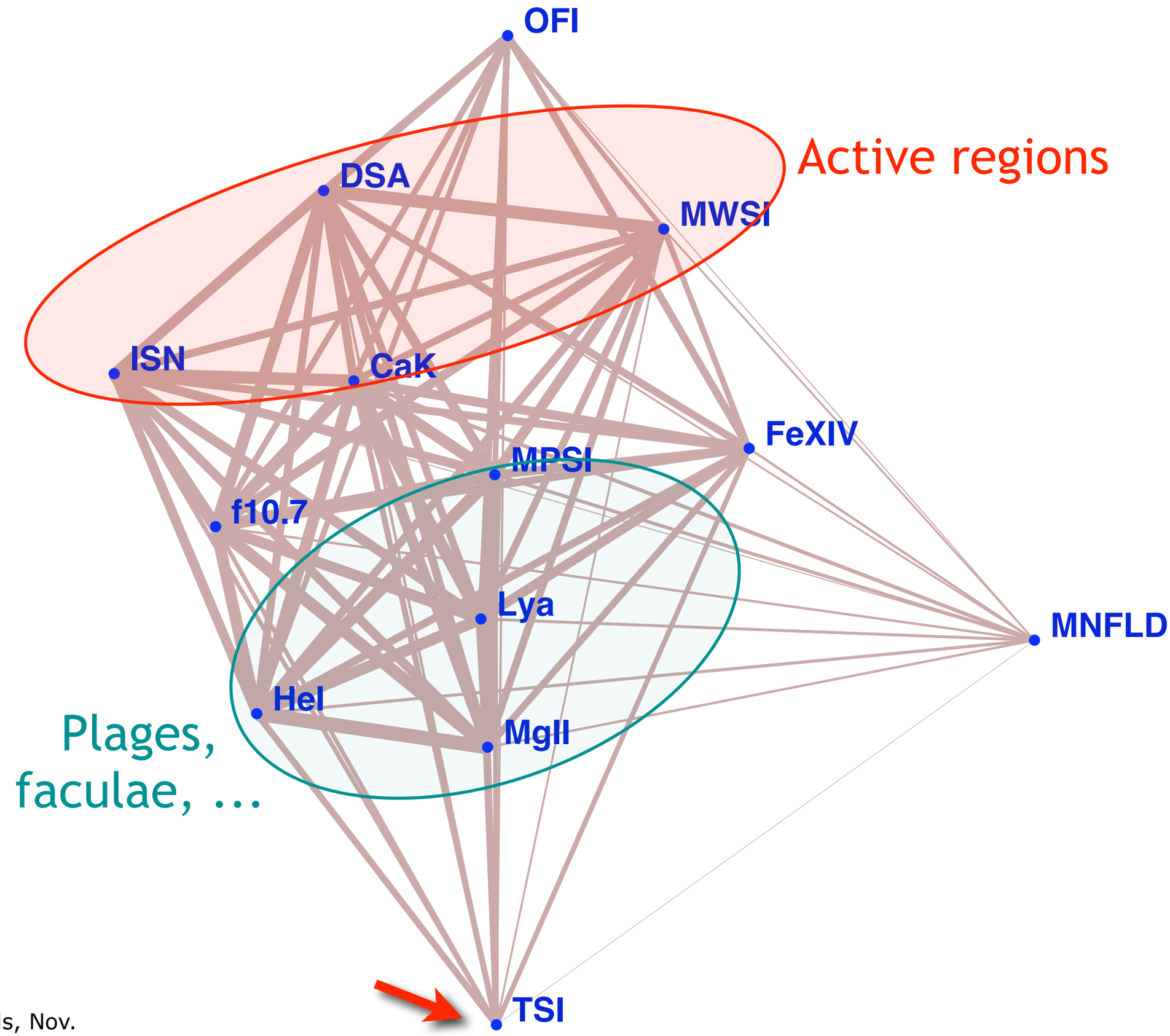


Connections for long time scales



Connections for long time scales



Conclusions (1/3)

Which mechanisms contribute to the variability of the TSI ?

- for **short** time scales : regions with **intense magnetic fields** because they describe the cooling effect of sunspots

- for **long** time scales : **”irradiance” proxies** which describe faculae and plages

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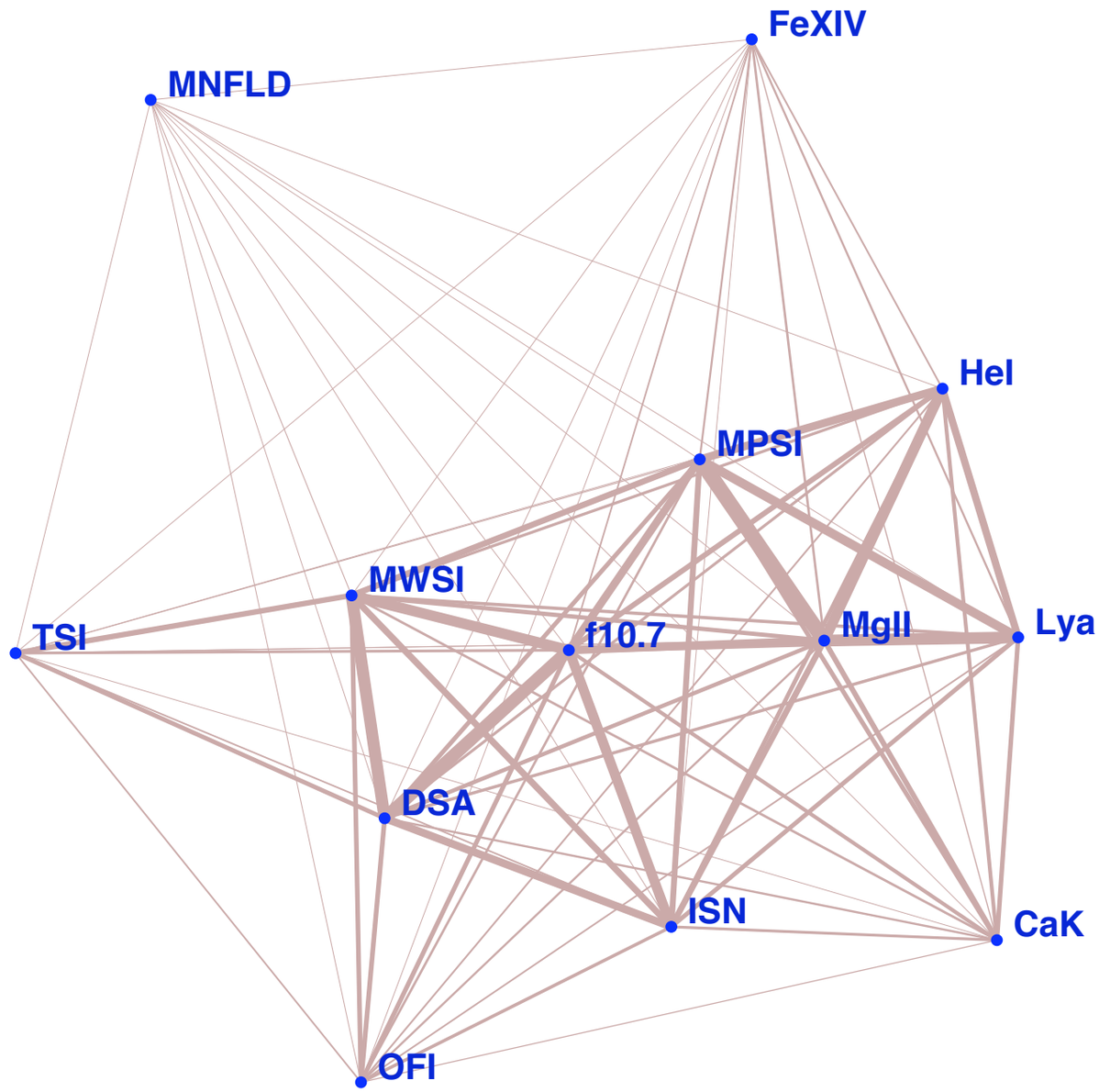
➜ the variability is dominated by the photosphere and the chromosphere

➜ flares do contribute to the variability *(poster by M. Kretzschmar)*

Conclusions (2/3)

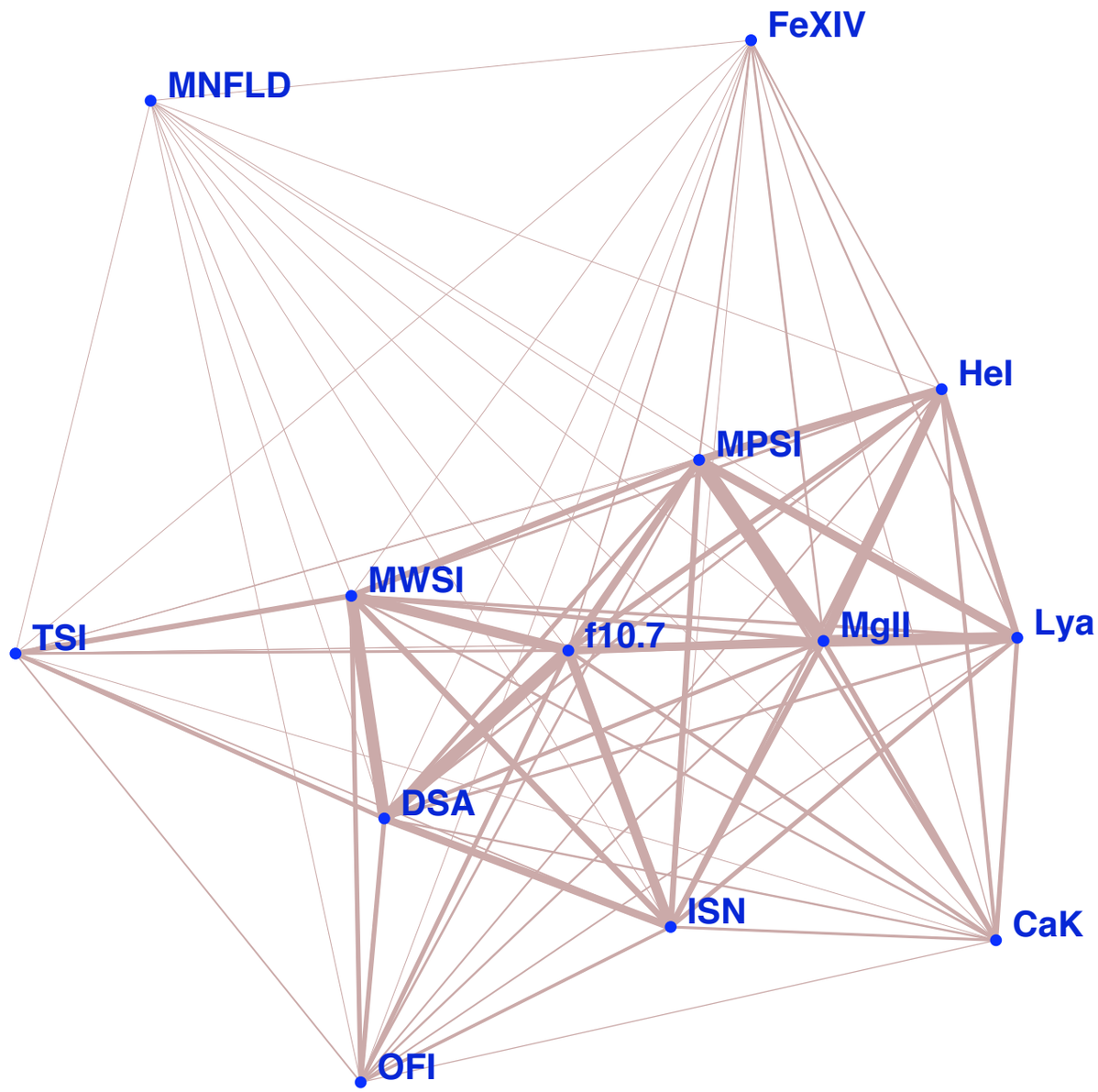
Can the TSI be reconstructed from a linear or a nonlinear combination of solar proxies ?



Conclusions (2/3)

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

Very unlikely.

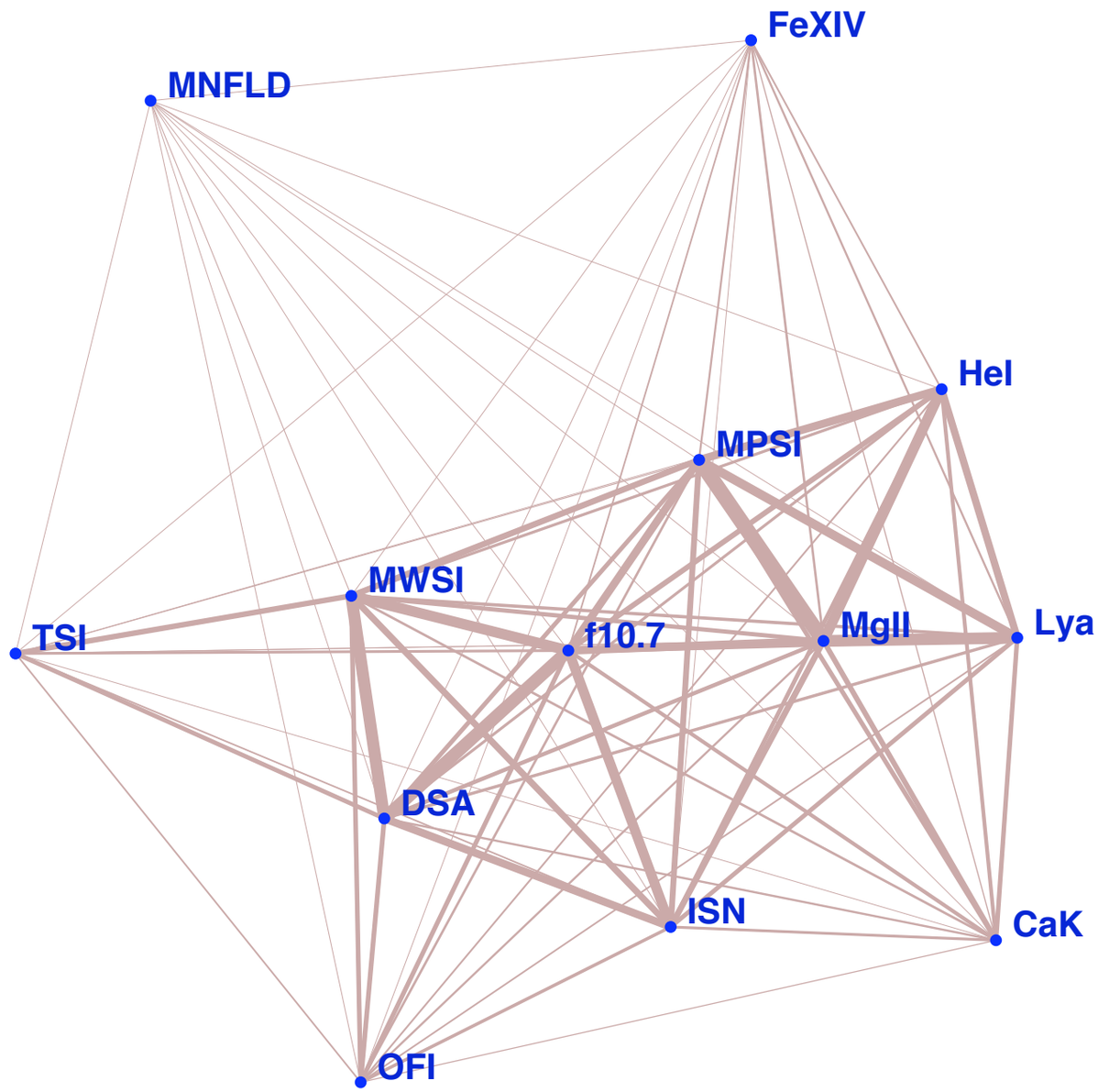


Conclusions (2/3)

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

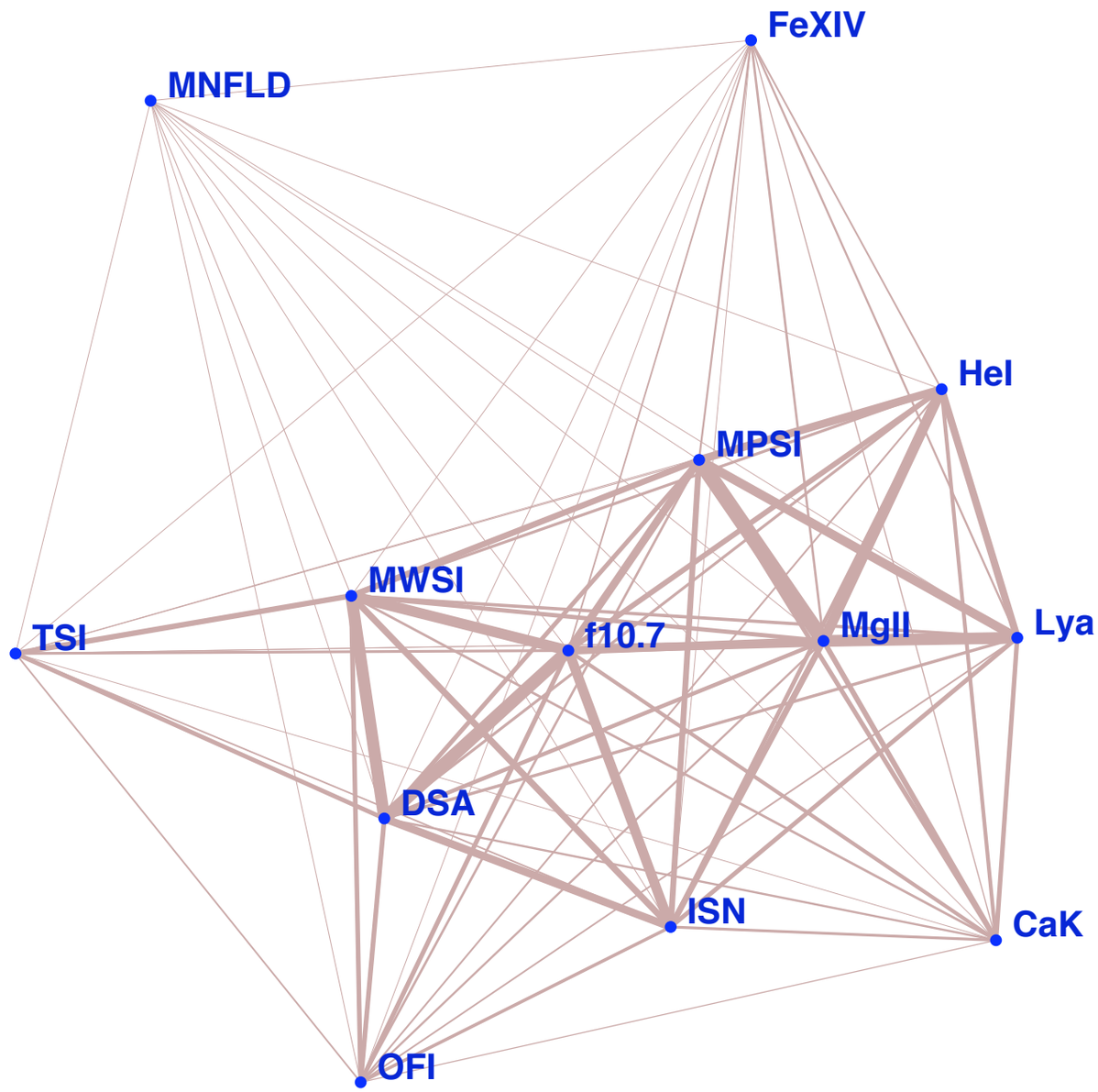
Very unlikely.

➔ archives are important for developing new proxies from historic data (photospheric sunspot index, facular index, ...)



Conclusions (3/3)

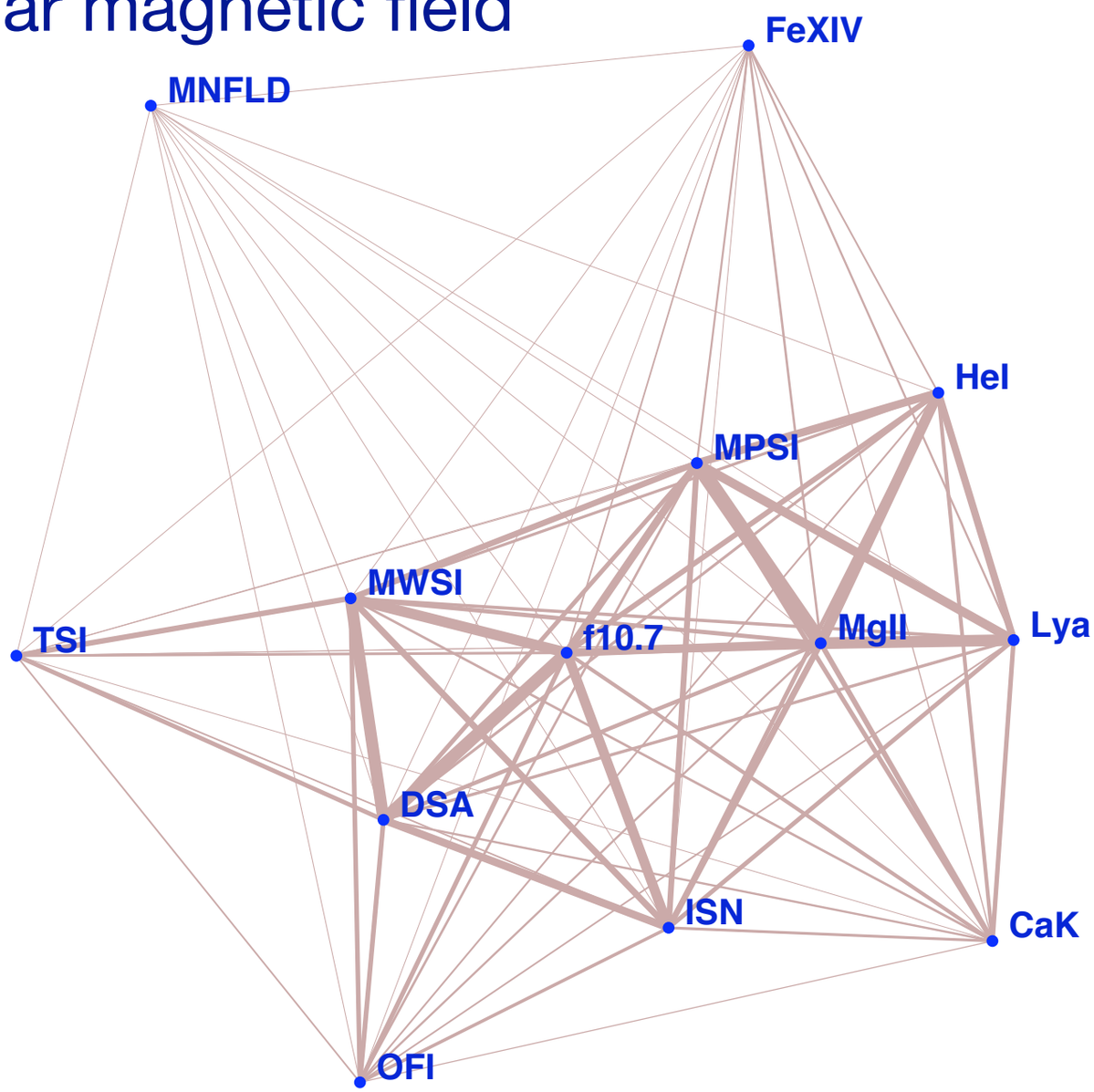
From what solar proxies can the TSI then be reconstructed ?



Conclusions (3/3)

From what solar proxies can the TSI then be reconstructed ?

The direction to go is a measurement of the spatial distribution of the (weak) solar magnetic field



Conclusions (3/3)

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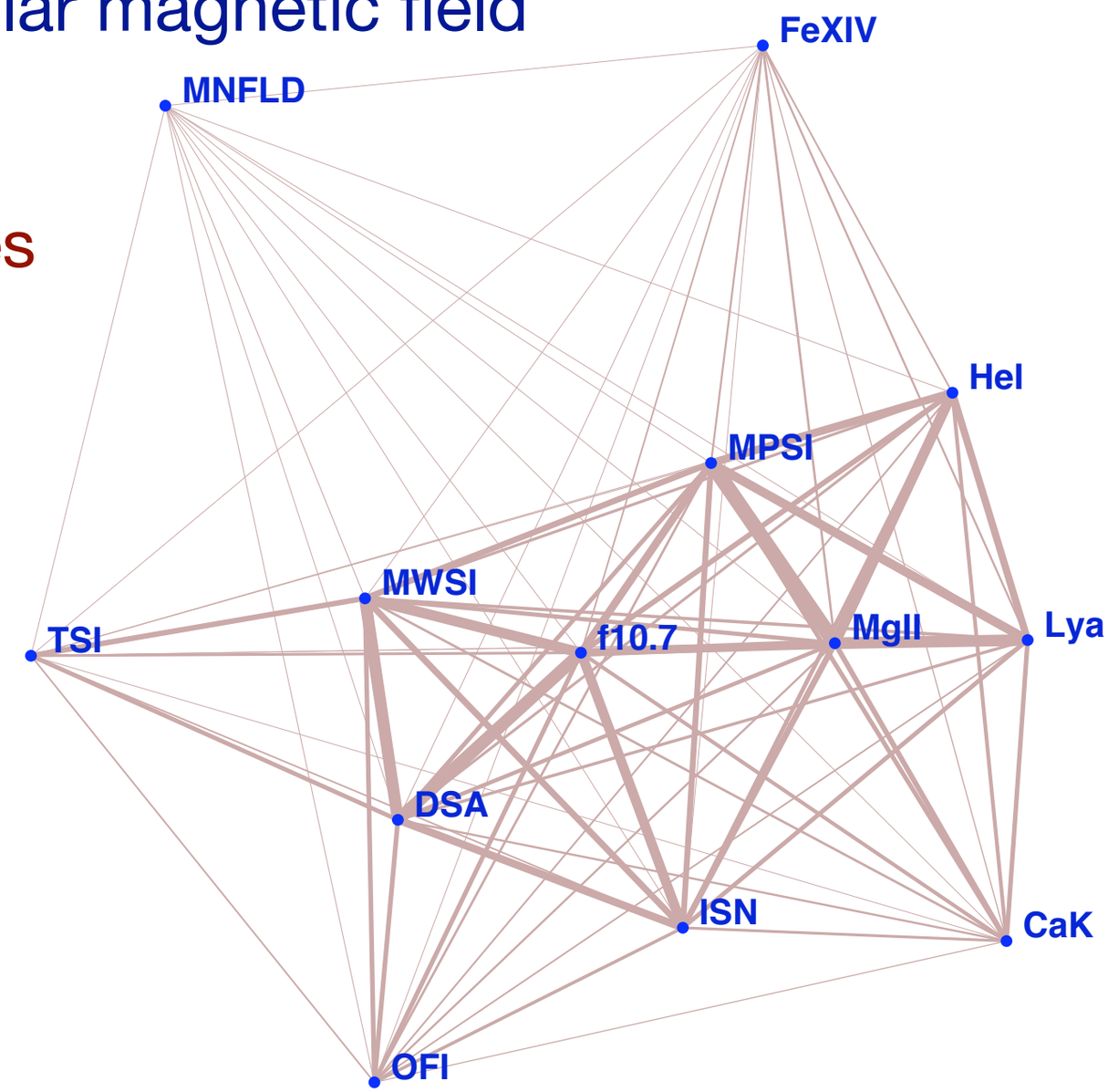
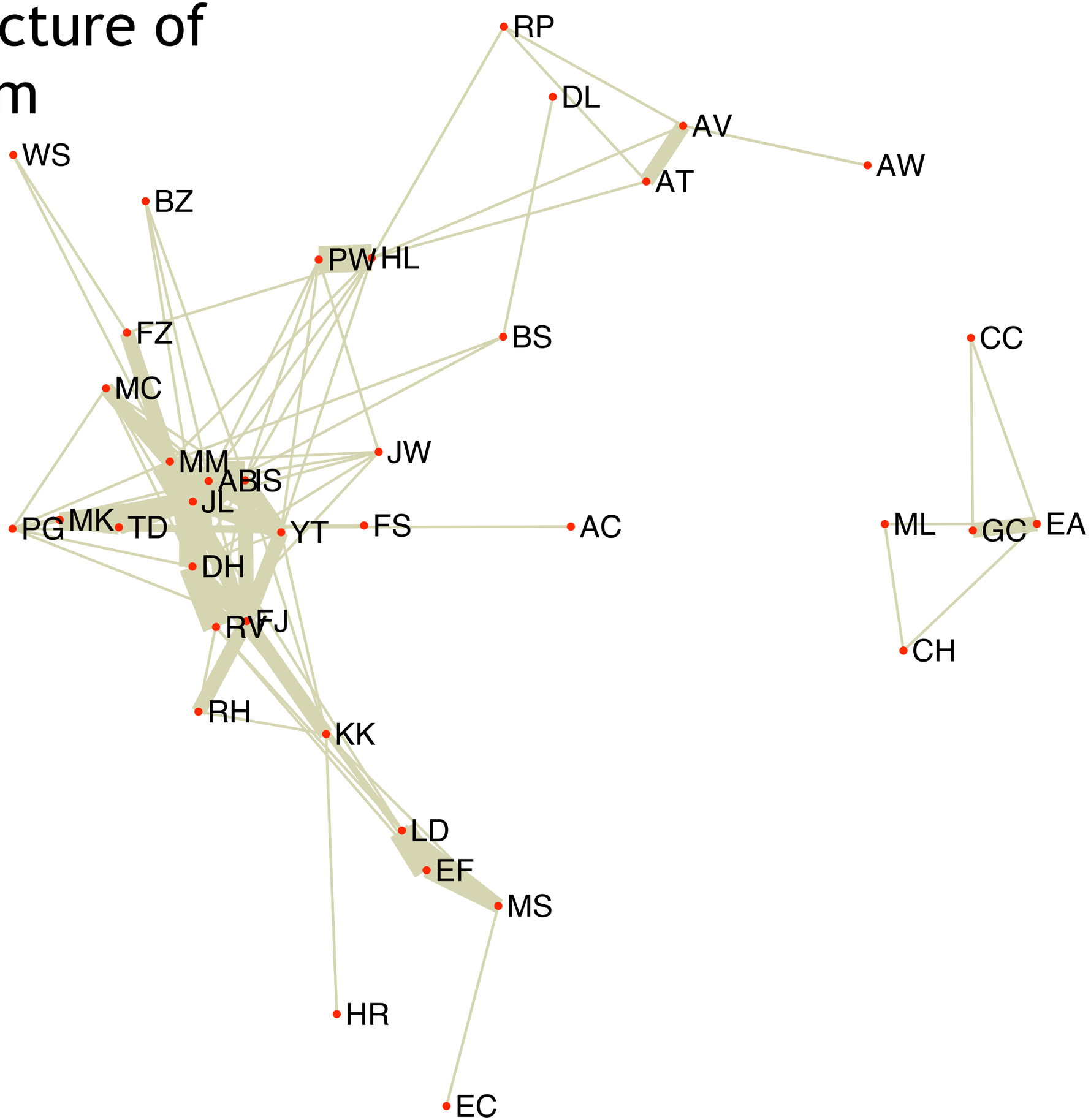
The direction to go is a measurement of the spatial distribution of the (weak) solar magnetic field

➔ include causality: in this coupled system, what causes what ?



Network structure of COST724 team



Data : lowpass