Thermal signature in global MHD simulations of solar convection

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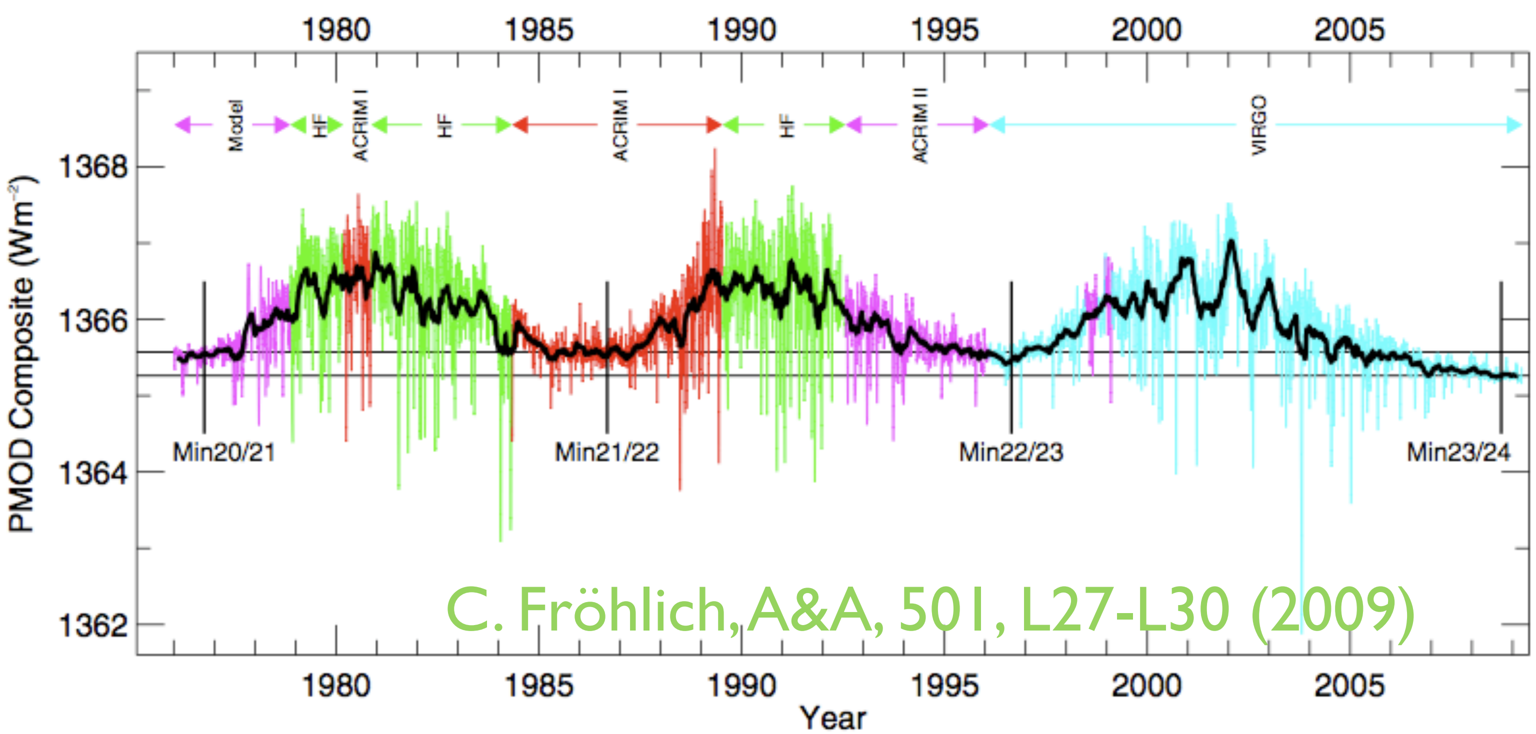
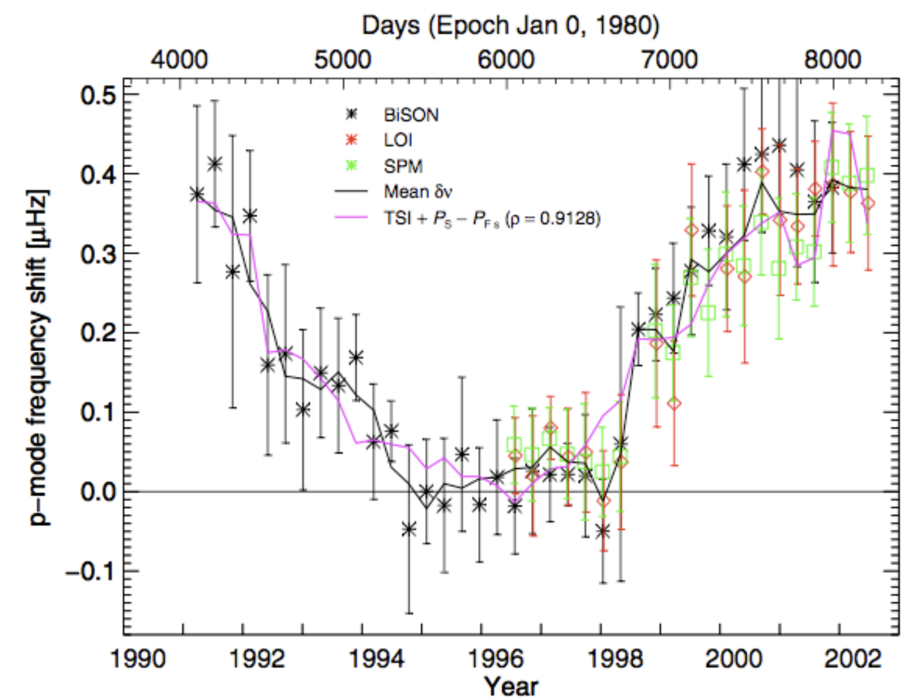
Total solar irradiance is the net flux of solar electromagnetic radiation measured by a satellite detector at 1AU; it varies on timescales of minutes, days, months.
What are the causes of long-term (decadal) TSI fluctuations?





1.Pure surface effect

TSI variations solely due to surface coverage by sunspots, faculae, network and other magnetic structures

2.Global structural changes

A fraction of long-term TSI variations could be attributed to changes in the global thermal structure the Sun (large-scale circulations, radius deformation, etc..) modulated by cyclic magnetic activity.

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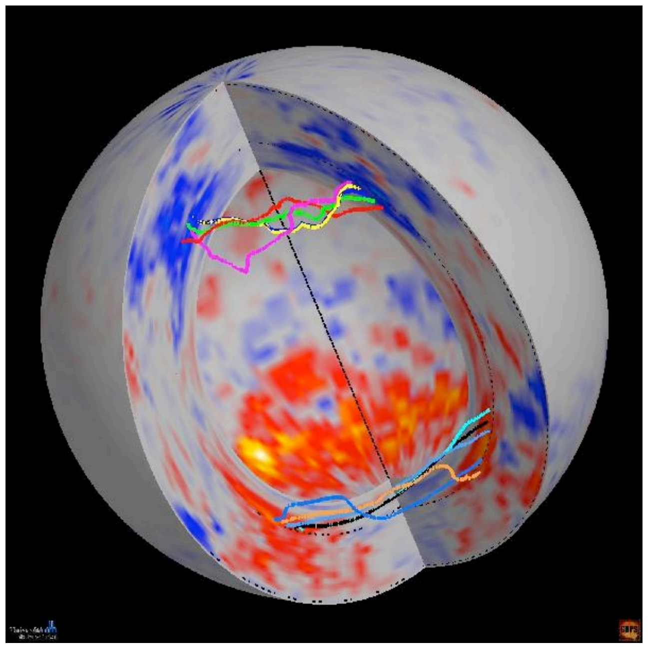
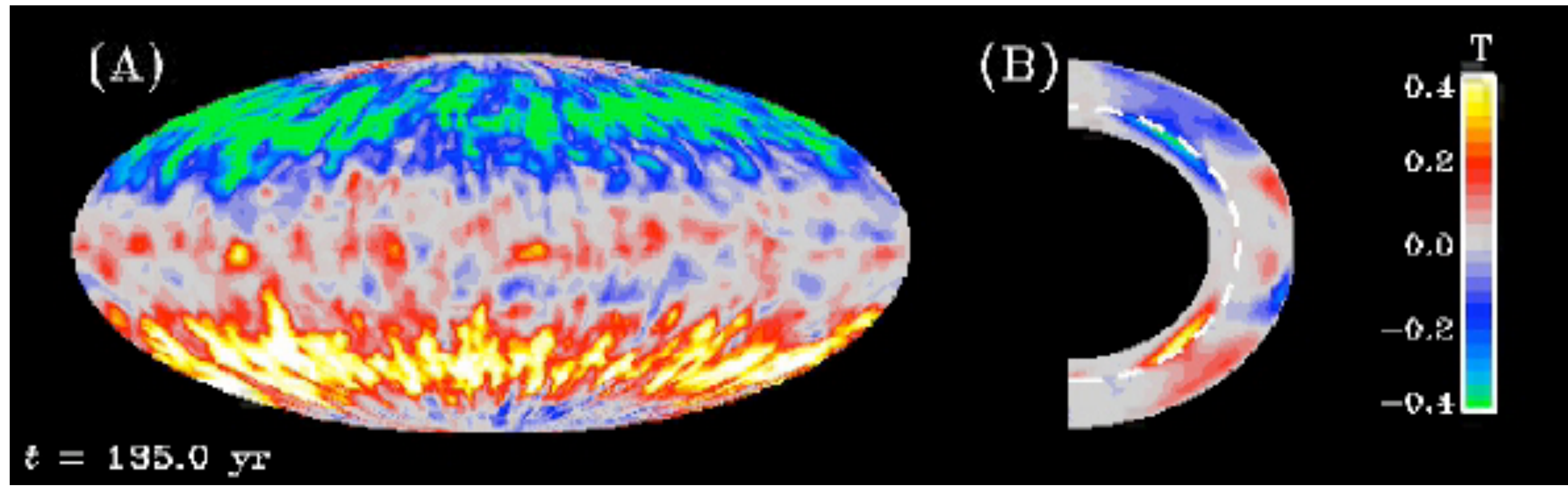
A step toward assessing the possibility of global structural changes impacting TSI variations: global MHD simulations that show a long-term cyclic trend in the thermodynamic structure

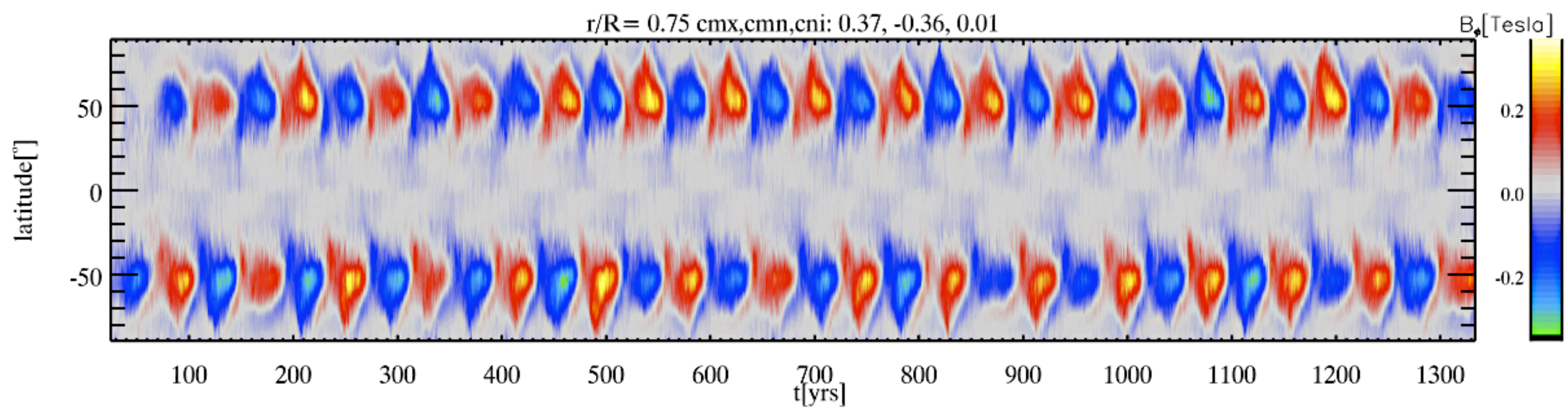


Credit: Nicolas Lawson



Credit: Patrice Beaudoin

http://www.astro.umontreal.ca/~paulchar/grps/page_accueil.html



The system is solved using a MHD generalization of EULAG, itself based on the NFT scheme MPDATA; *higher-order truncation terms effectively provide a self-similar subgrid model that handles dissipation.* (ILES).

Smolarkiewicz et Charbonneau 2013, *J Comput Phys*, 236 (2012) 608-623.
EULAG Web Page: http://www.mmm.ucar.edu/eulag/

$$\frac{d\mathbf{u}}{dt} = -\nabla\pi' - \mathbf{g}\frac{\Theta'}{\Theta_o} + 2\mathbf{u}\times\mathbf{\Omega} + \frac{1}{\mu\rho_o}\mathbf{B}\cdot\nabla\mathbf{B}\ ,$$

$$\frac{d\Theta'}{dt} = -\mathbf{u}\cdot\nabla\Theta_e + \frac{1}{\rho_o}\mathcal{H}(\Theta') - \alpha\Theta'\ ,$$

$$\frac{d\mathbf{B}}{dt} = \mathbf{B}\cdot\nabla\mathbf{u} - \mathbf{B}\nabla\cdot\mathbf{u}\ ,$$

Perturbational form of entropy equation

$$\nabla\cdot\rho_o\mathbf{u} = 0\ ,$$

$$\nabla\cdot\mathbf{B} = 0\ .$$

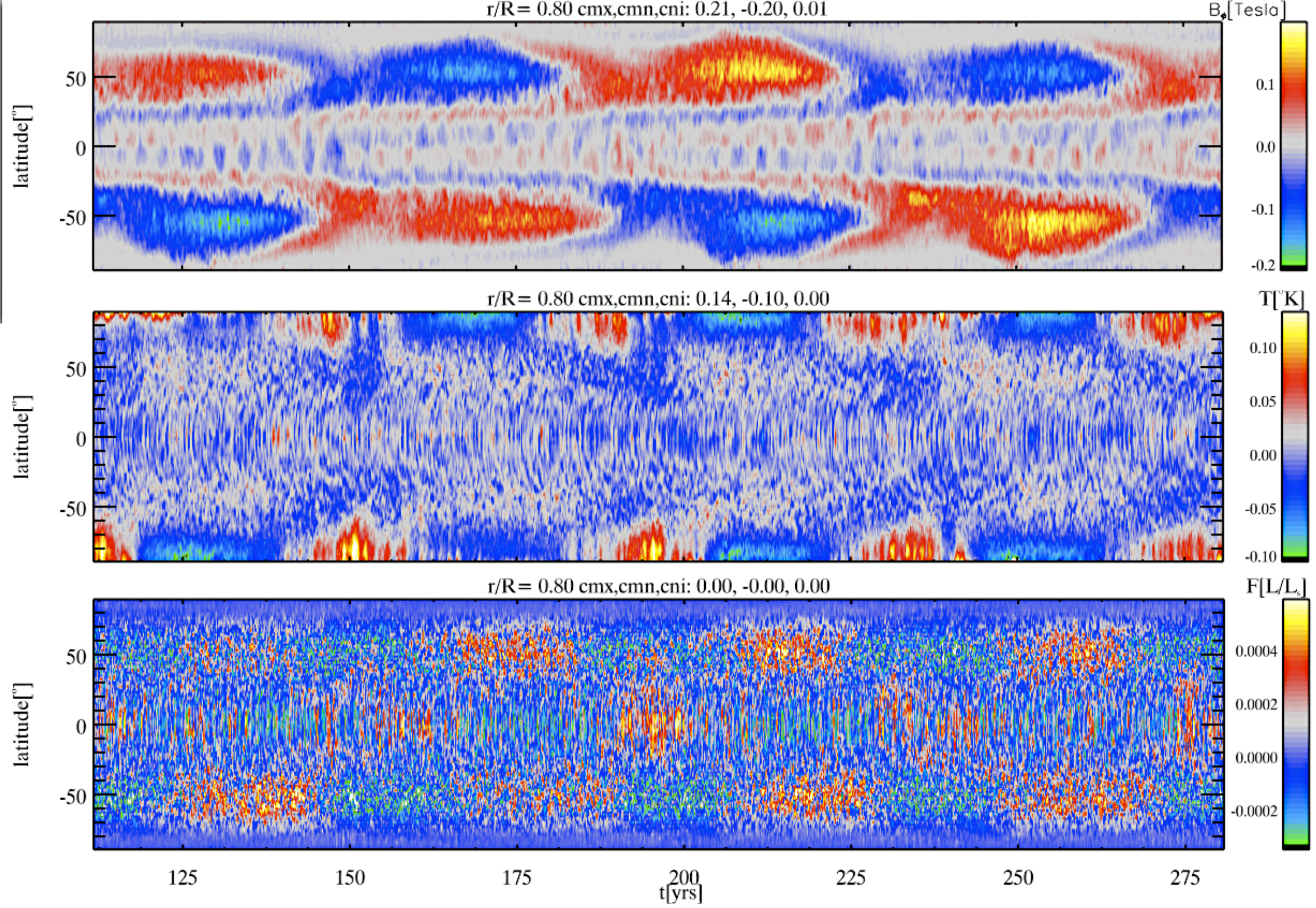
Anelastic classical MHD

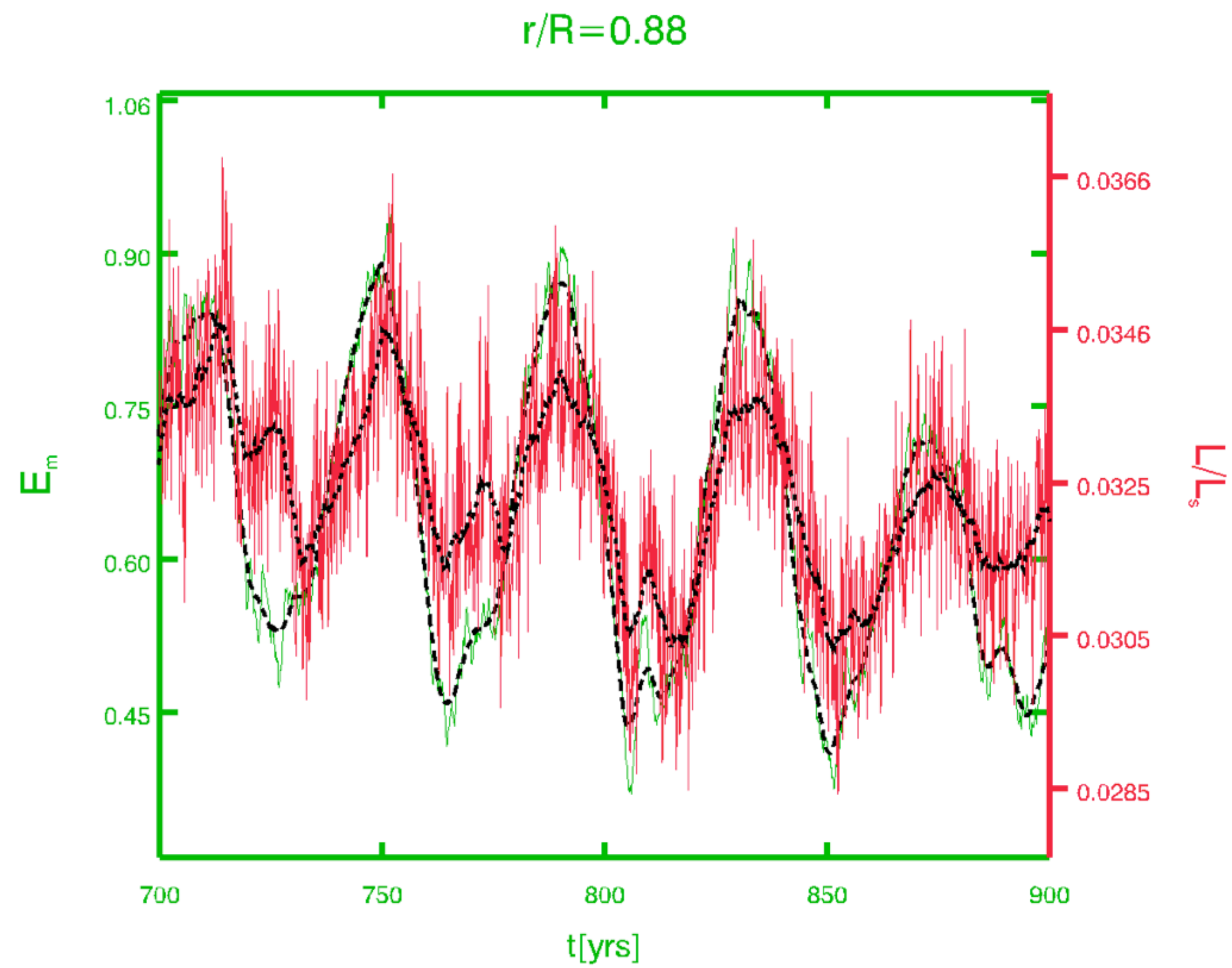
-128 x 64 x47.

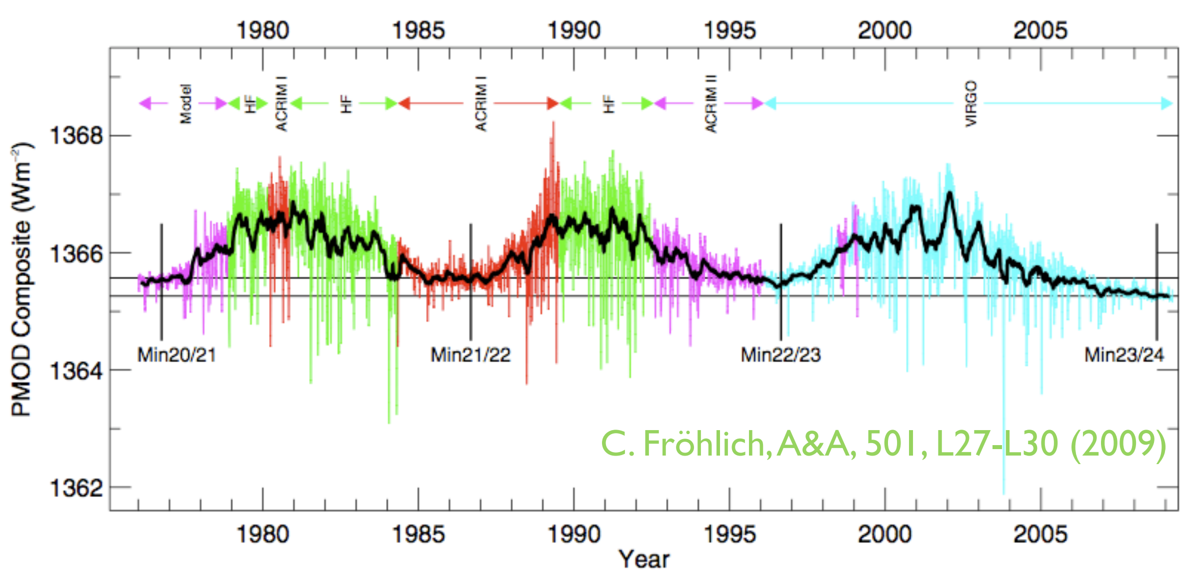
-Stress-free impenetrable bottom and top.

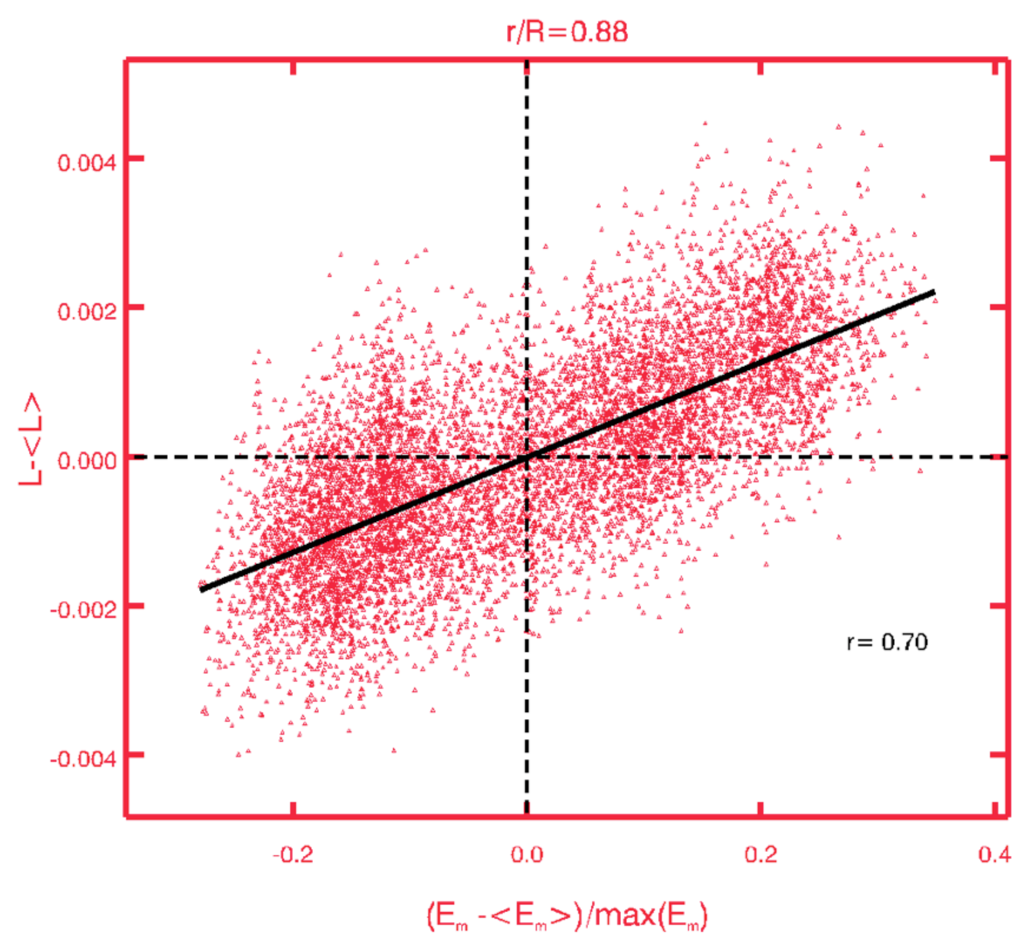
-Radial field bottom and top.

-Stable layer 0.62< r/R <0.71.
-Unstable layer 0.71<r/R<0.96.









1. Modulation of thermal structure and fluxes by the magnetic cycle which pervades the whole SCZ.

2. There is a positive correlation between peak convective flux and peak magnetic field strength

3. The amplitude of variations in convective luminosity's changes are 10% of the mean value in the bulk of the SCZ

4. Presence of a "short" cycle (~5 yrs).

Conclusions and remarks.

3D global MHD simulations of solar-like cycles have landed: Equatoward migration, polarity reversals, torsional oscillations, thermal signal that changes in phase with magnetic cycle.

ILES / use of a perturbational form of entropy equation (ambient state) yield solar-like cycles: dependence of the solution on dissipation is greatly reduced. Allows for dynamic equilibria that might have been unreachable on dissipative paths starting from $\Theta_e = \Theta_o$ and large-amplitude heating/cooling at lower/upper model boundaries.

Issues:

Convective luminosity in bulk SCZ: 10% of true solar luminosity. Perturbational form of entropy equation dictates the dissipative path to statistical stationary state.

Cyclic solution very sensitive to damping timescale of entropy perturbations.

What sets the length of the cycles? What control do we have over this aspect?